Minnesota Center for Environmental Advocacy

Clean Water Organizations' comments and first set of exhibits

CLEAN WATER ORGANIZATIONS'

Comments on the Proposed 2025 SDS General Permit and 2026 NPDES General Permit For Concentrated Animal Feeding Operations

September 3, 2024

Submitted by

Minnesota Center for Environmental Advocacy

CURE

Environmental Working Group

Friends of the Mississippi River

Food & Water Watch

Minnesota Division, Izaak Walton League of America

Will Dilg Chapter, Izaak Walton League of America

Minnesota Trout Unlimited

Hiawatha Trout Unlimited

Minnesota Well Owners Organization

Northern Waters Land Trust

Roots Return Heritage Farm LLC

Winona Clean Water Coalition

Joined by undersigned individual supporters

TABLE OF CONTENTS

Page

Page

INTRODUCTION

The undersigned Clean Water Organizations, along with the undersigned individual supporters, appreciate the opportunity to submit these comments on the Proposed 2025 State Disposal System ("SDS") General Permit and the Proposed 2026 National Pollutant Discharge Elimination System ("NPDES") General Permit for Concentrated Animal Feeding Operations ("Proposed Permits"). These permits regulate the largest feedlots in Minnesota, which account for approximately one-third of the manure produced in the state each year. This manure, when stored in massive lagoons or spread on fields as fertilizer, runs off into surface waters, leaches into groundwater, and volatilizes into the air, ultimately polluting Minnesota's waters with dangerous bacterial coliforms and nutrients, particularly nitrate. Largely because of pollution from cropland sources, Minnesota faces a nitrate pollution crisis. The drinking water of hundreds of thousands of Minnesotans has elevated levels of nitrate, which is linked not only to blue baby syndrome, but also to other serious health risks including cancers, pregnancy problems, and birth defects.

Minnesota law contains strict protections for its surface waters and particularly for its groundwater, which provides 75% of Minnesota's drinking water. But for decades, instead of implementing regulations that will ensure the state's waters are protected, Minnesota agencies have taken a largely voluntary approach to reducing nitrate pollution. This approach has proven to be woefully insufficient. Nitrate contamination has persisted and even increased in areas around the state, putting the health of people, animals, and aquatic ecosystems at risk. Even the Minnesota Pollution Control Agency ("MPCA") has recognized that the current approach is not enough to address the problem. Last year, the U.S. Environmental Protection Agency ("EPA") instructed MPCA to use all available tools to address the drinking water contamination crisis, including revisions to the NPDES permits for feedlots to reduce nitrate pollution over the long term.

In this context, MPCA has published the Proposed Permits, which include some important and common-sense steps toward addressing the nitrate pollution crisis in our state, particularly in the vulnerable groundwater areas like the karst region in southeastern Minnesota and the Central Sands region that have the greatest sensitivity to pollution. To protect Minnesota's health and environment, MPCA must implement all of its proposed revisions, including requiring additional restrictions on fall and winter manure spreading in vulnerable groundwater areas, incorporating manure within the 100-year floodplain, requiring manure recipients to abide by the provisions of the permittee's Manure Management Plan, requiring visual inspections of land application areas, and requiring sampling of discharges.

However, these steps are only incremental and are insufficient to fully address the problem. The Proposed Permits still allow practices that will cause nitrate pollution, and they fail to implement sufficient monitoring measures to ensure that the feedlots are eliminating discharges. To comply with the law and ensure permittees are not polluting, the Clean Water Organizations submit that MPCA must take the following additional steps to reverse the trends of increasing nitrate pollution around the state:

- Remove language stating that fall manure spreading Best Management Practices ("BMPs") in vulnerable groundwater areas are not required until 2028 and require these BMPs to be followed statewide.
- Require restrictions on winter spreading of solid manure in December, January, and February to be applied statewide.
- For land application areas, require (a) a visual monitoring plan that identifies locations where monitoring will occur, (b) monitoring of drain tile outlets, and (c) motion detecting cameras for downgradient field edges and sinkholes.
- For land application areas, require groundwater monitoring for fields within vulnerable groundwater areas.
- For production areas, require daily visual inspections of identified points where surface discharges are likely to occur and daily visual inspections of Liquid Manure Storage Areas ("LMSAs").
- For production areas, add a site-specific groundwater monitoring plan or a Subsurface Discharge Monitoring Plan.

- For land application areas and production areas, require permittees to identify sampling points with specificity and create regular plans for sampling, add further details about sampling protocols, and add sampling requirements for drain tile outlets.
- Require annual soil nitrate tests in accordance with University of Minnesota Extension Service ("Extension Service") guidelines for fall tests in western Minnesota and spring tests in south-central, southeastern, and east-central Minnesota.
- Require digestate from an anaerobic digester to be analyzed for nutrient content before application.
- Require permittees to follow the Runoff Risk Advisory Forecast recommendations before spreading manure.
- Require additional BMPs for emergency manure applications and define "unusual weather conditions" to include only extraordinary rain events.

With all of these changes, MPCA and the permitted feedlots would take an important and necessary step toward addressing the nitrate pollution crisis in our state.

I. Minnesota must take action to address its dangerous levels of nitrate pollution

A. Nitrate pollution is dangerous to people and aquatic life

The danger of nitrate pollution to human health has been recognized for decades. Some health effects from ingesting excess nitrate can occur within hours or days of short-term exposure. In 1962, a federal regulatory standard of 10 mg/L nitrate in drinking water[1] was set to address the problem of methemoglobinemia, also known as blue-baby syndrome. Blue-baby syndrome occurs when excess nitrate limits the ability of blood to carry oxygen, potentially leading to severe injury or death.[2] Infants and pregnant people are particularly at risk for this condition.[3]

Recent research, however, has demonstrated that long-term exposure to nitrate levels well below the 10 mg/L limit is also linked to serious health risks. Peer-reviewed medical research

[1] In 1991, this limit was also established as the Maximum Contaminant Level for nitrate under the Safe Drinking Water Act for public water systems, defined as systems that have at least 15 connections or serve at least 25 people for 60 days of the year. EPA, National Primary Drinking Water Regulations, https://www.epa.gov/ground-water-and-drinking-water/national-primary-drinking-water-regulations.
[2] MPCA, Statement of Need and Reasonableness, Proposed Feedlot Rules, at 13-14 (Dec. 1999) ("1999 Feedlot SONAR") (Ex. 1).
[3] *Id.*

demonstrates that exposure to nitrate at or above 3 mg/L—less than one-third of the health risk limit—is linked to a variety of cancers, birth defects, and pregnancy complications. Numerous human-based epidemiological studies now show that exposure to nitrate at levels below the health limit and as low as 3 to 5 mg/L leads to a statistically significant increase in the risk for colorectal cancer,[4] thyroid cancer,[5] ovarian cancer,[6] and pregnancy/birth complications.[7] In 2023, the EPA Integrated Risk Information System restarted a human health assessment of nitrate to determine if a lower federal maximum contaminant level for nitrate-N is needed based on other potential health effects, including cancers.[8] In a public comment submitted to the EPA to inform its human health assessment, a former EPA toxicologist raised alarms that the scientific basis for the 10 mg/L standard is deeply flawed and that it should be reduced to 2 to 5 mg/L to accurately capture exposure levels that present a risk to human health.[9]

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[4] Nadia Espejo-Herrera et al., *Colorectal cancer risk and nitrate exposure through drinking water and diet*, 139 Intl. J. of Cancer 334-346 (2016) (Ex. 2); Jorg Schullehner et al., *Nitrate in drinking water and colorectal cancer risk: A nationwide population-based cohort study*, 143 Intl. J. of Cancer, 73-79 (2018) (Ex. 3).

[5] Mary H. Ward et al., *Drinking Water Nitrate and Human Health: An Updated Review*, Intl. J. Envtl. Research and Public Health (2018) (Ex. 4).

[6] Maki Inoue-Choi et al., *Nitrate and nitrite ingestion and risk of ovarian cancer among postmenopausal women in Iowa*, 137 Intl. J. of Cancer, 173-182 (2015) (Ex. 5).

[7] Ward, *Drinking Water Nitrate and Human Health* (Ex. 4). MPCA recognized these dangers a decade ago in its Nitrogen in Minnesota Surface Waters report, where it acknowledged that "[s]tudies have suggested association with nitrate exposure and adverse reproductive outcomes, thyroid disruption, and cancer." MPCA, *Nitrogen in Minnesota Surface Waters: Conditions, trends, sources, and reduction*, page A2-7 (2013) ("Nitrogen in Surface Waters") (Ex. 6). The Minnesota Department of Agriculture ("MDA") also acknowledged these dangers when it proposed the Groundwater Protection Rule, stating: "Various epidemiological and animal studies have reported a wide range of negative health effects attributable to consumption of water with elevated nitrate-nitrogen including birth-defects, miscarriages, hypertension, stomach and gastro-intestinal cancer, and non-Hodgkin's lymphoma." MDA, Statement of Need and Reasonableness, Proposed Groundwater Protection Rules, at 63 (2018) ("2018 Groundwater Protection SONAR") (Ex. 7).

[8] David A. Belluck, Letter to EPA, Re: Response to US EPA on RFD Announcement, Docket Number: EPA-HQ-ORD-2017-0496 for nitrate/nitrite (Dec. 18, 2023) (Ex. 8).

[9] *Id.*

In addition to endangering humans, excessive nitrate levels are dangerous to aquatic life and animals that drink polluted water. Spontaneous abortions, stillbirths, and gastrointestinal disorders have occurred in livestock that consumed large quantities of nitrate-contaminated water.[10] Elevated nitrate levels in Minnesota's waterways also are devastating to aquatic habitats. High nitrate levels contribute to eutrophication, which stimulates excessive plant growth and depletes oxygen levels in the water, harming or killing fish and other aquatic life.[11]

Nitrate and ammonia, another form of nitrogen found in manure and fertilizer, also are directly toxic to fish and other aquatic life at high levels.[12] Invertebrates that form a critical part of the aquatic food chain are particularly vulnerable to nitrate and ammonia, and among vertebrates, the important game fish lake trout and rainbow trout are notably sensitive.[13] While Minnesota does not have a nitrate water quality standard for aquatic life (Class 2 waters), an analysis by MPCA proposed a chronic nitrate criterion of 5 mg/L for cold waters and 8 mg/L for other waters, as well as an acute standard of 60 mg/L for all Class 2 waters.[14] For ammonia, Minnesota has set an aquatic life water quality standard of 4.1 mg/L for cold waters and 10.1 mg/L for other waters, but MPCA has recommended adopting EPA's even stricter, temperature-dependent standards for total ammonia nitrogen.[15] Levels higher than these are established to be unsafe for aquatic life.

Exposure to nitrate and ammonia at toxic levels can lead to massive fish population die-offs, called "fish kills." In heavily agricultural areas, fish kill events have increased in intensity

[10] 1999 Feedlot SONAR, at 14 (Ex. 1).
[11] Nitrogen in Surface Waters, at 43 (Ex. 6).
[12] *Id.*
[13] MPCA, *Aquatic Life Water Quality Standards, Draft Technical Support Document for Nitrate,* at 5 (Oct. 2022), (Ex. 9); MPCA, *Aquatic Life Water Quality Standards Technical Support Document for Ammonia*, at 19 (July 2022) (Ex. 10).
[14] Aquatic Life Nitrate Standards, at 5 (Ex. 9).
[15] Aquatic Life Ammonia Standards, at 19 (Ex. 10).

and frequency: the Rush Creek fish kill in July 2022, where MPCA concluded contaminated runoff killed more than 2,500 fish, was the fourth major fish kill in the Winona County area since 2015.[16] Furthermore, fish are less sensitive to nitrate and ammonia than other aquatic life, which means that by the time a fish kill is discovered, numerous amphibians and invertebrates almost certainly have died already.

Unfortunately, the effects of nitrate pollution do not stop in Minnesota. Nitrate from Minnesota, which washes into the Mississippi River, is in part to blame for the hypoxic "dead zone" that forms every year in the Gulf of Mexico.[17] One study estimates that the 158 million pounds of nitrate that leave Minnesota annually via the Mississippi have caused nearly $2.4 billion in annual damages to fish stocks and habitat for more than 30 years.[18]

B. Minnesota's waters are already polluted with nitrates, and the pollution is worsening

The contamination of Minnesota's groundwater and surface waters with nitrate and other contaminants related to feedlot operations is a pervasive problem that has been well-documented for decades. Regular sampling of wells to detect nitrate began over 30 years ago, and the contamination trends have remained persistent or increased. Levels of ambient groundwater data from over 300 shallow wells in urban, agricultural, and undeveloped areas across the state sampled from 2013 to 2017 revealed that 49% of wells in agricultural areas exceeded the Maximum Contaminant Limit ("MCL") for nitrate.[19] In contrast, less than 1% of wells sampled in urban areas exceeded 10 mg/L of nitrate, and the highest nitrate level detected in undeveloped areas was under

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[16] MPCA, *Rush Creek fish kill response – Winona County,* at 2, 4 (April 2023) (Ex. 50).
[17] Nitrogen in Surface Waters, at 36, 46 (Ex. 6).
[18] *Id.* at 43.
[19] MPCA, *The Condition of Minnesota's Groundwater Quality: 2013-2017*, at 15 (July 2019) (Ex. 11).

3 mg/L.[20] An analysis of 117 wells in shallow aquifers monitored from 2005 – 2017 showed that 16% had significant increases in nitrate.[21] Furthermore, in surface waters, nitrate concentrations have increased between 20 and 60% in most major rivers in the state over the past 20 years.[22] More recent nitrate concentration trend data from 2010 to 2020 shows that nitrate levels in rivers across Minnesota either increased or showed no clear trend—none of the 38 sites studied by MPCA showed nitrate decreases in that time period.[23]

Between 1994 and 2016, 56 community water systems in Minnesota added nitrate removal systems, sealed a well, or removed a well from use to deal with increasing nitrate contamination in their drinking water sources, according to the Minnesota Department of Health ("MDH").[24] These public water system improvements are expensive and the costs are hard to bear for smaller rural cities and townships. For example, the city of Hastings had to spend $3.5 million on a new water treatment plant to lower nitrate levels.[25] The expenses to private well owners, who do not have the same regulatory protections as those on public water systems, are also extensive. Based on MDH estimates, installation and maintenance of a reverse osmosis treatment system costs approximately $2,600, while construction of a new well costs around $30,000.[26] Because of the

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[20] *Id.* Nitrate-N levels above 3 mg/L are considered to be caused by human activity rather than natural background levels. 2018 Groundwater Protection SONAR, at 20 (Ex. 7).
[21] MPCA, *Five-Year Progress Report on Minnesota's Nutrient Reduction Strategy,* at 31 (Aug. 2020) ("Five Year Progress Report") (Ex. 12).
[22] *Id.* at 25.
[23] *Id.* at 20.
[24] 2018 Groundwater Protection SONAR at 70 (Ex. 7).
[25] Envtl. Working Grp., *In Minnesota's Farm Country, Nitrate Pollution of Drinking Water Is Getting Worse* (March 2020) (Ex. 13).
[26] MDH, *Public Health Work Plan and Budget Overview: Nitrate in Southeast Minnesota Private Wells*, at 7 (Jan. 22, 2024) (Ex. 14).

difficulty and expense of remediating nitrate pollution in groundwater, preventing the pollution from entering water in the first place is critical.[27]

C. Certain areas of the state are particularly vulnerable to nitrate pollution

Although the overall trends across the state show persistent or increasing nitrate contamination, certain areas of the state are far more vulnerable to nitrate pollution than others. Soil and geologic conditions in portions of Minnesota provide easy pathways for pollution to make its way underground, making the aquifers that provide drinking water particularly vulnerable to pollution. Landscapes with coarse-textured soils, shallow depth to bedrock, or karst geology are defined by the MDA as vulnerable groundwater areas, because in those regions nitrate from the surface can easily and quickly move through the soil and into groundwater.[28]

In karst geology, a shallow layer of soil overlays fractured limestone carbonate bedrock, which allows water and contaminants from the surface to move rapidly into groundwater aquifers.[29] Water can move as much as miles per day and contaminants are not readily filtered out.[30] Minnesota officials have been aware of the karst region's vulnerability to groundwater contamination for decades, and as early as 1982, shallow wells in southeastern Minnesota were known to contain high nitrate levels.[31] In coarse textured (or sandy) soils and soils with a shallow depth to bedrock (within 5 feet), contaminants applied at the land surface also flush quickly

[27] MPCA et al., M*innesota Nutrient Reduction Strategy,* at 37 (Sept. 2014) (Ex. 15).
[28] MDA, Vul*nerable Groundwater Area Map*, https://www.mda.state.mn.us/chemicals/fertilizers/nutrient-mgmt/nitrogenplan/mitigation/wrpr/wrprpart1/vulnerableareamap. State agencies also have documented these vulnerabilities in resources like DNR's Pollution Sensitivity of Near-Surface Materials, https://files.dnr.state.mn.us/waters/groundwater_section/mapping/mha/hg02_report.pdf and Minnesota Regions Prone to Surface Karst Feature Development, https://files. dnr.state.mn.us/waters/groundwater_section/mapping/gw/gw01_report.pdf.
[29] Jeffrey St. Ores et al., *Groundwater Pollution Prevention in Southeast Minnesota's Karst Region*, 465 Univ. of Minn. Extension Bulletin, at 6 (1982) (Ex. 16).
[30] *Id.*
[31] Ores, *Groundwater Pollution Prevention*, at 3 (Ex. 16).

through the soil profile and into groundwater aquifers. Much of the vulnerable groundwater areas are located in southeastern Minnesota, where the landscape is largely karst geography, in the Central Sands region, which has coarse-textured soils.[32]

In vulnerable groundwater areas, state data demonstrate that residents on both public water systems and private wells have an increased risk of exposure to elevated nitrates and other agricultural pollutants that pose a human health risk. From 1995 to 2018, 115 community water systems had at least one nitrate test at or above 3 mg/L.[33] Furthermore, 72 of these community systems saw nitrate levels in their water supply increase in that time period, with an average of a 61% increase.[34] The community water systems with at least one test at or above 10 mg/L were concentrated in southeastern Minnesota, the Central Sands, and southwestern Minnesota, which has a large concentration of Concentrated Animal Feeding Operations ("CAFOs") and limited groundwater.[35] 1

Private well data in these vulnerable areas demonstrate this same pattern. From 2013 to 2019, the MDA Township Testing Program sampled approximately 32,000 private wells in 344 vulnerable townships[36] across 50 counties in Minnesota. Of those 344 townships, 143 had 10% or more of their wells test above the 10 mg/L nitrate standard, concentrated in southeastern, central, and southwestern Minnesota.[37] Statewide, 9.1% of the sampled wells in vulnerable townships exceeded the federal standard for nitrate.[38] In southeastern Minnesota the percentage was even

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[32] MDA, *Vulnerable Groundwater Area Map,* https://www.mda.state.mn.us/chemicals/fertilizers/nutrient-mgmt/nitrogenplan/mitigation/wrpr/wrprpart1/vulnerableareamap.
[33] Envtl. Working Grp., *Nitrate Pollution of Drinking Water Is Getting Worse* (Ex. 13).
[34] *Id.*
[35] *Id.*
[36] Townships were selected based on factors including soil types and geology as well as significant row crop production. MDA, *Township Testing Program Update* (May 2022) (Ex. 17).
[37] *Id.*
[38] *Id.*

higher: 12.1% of the wells tested exceeded the standard, which the EPA estimated meant that 9,218 residents with private wells in the karst region "were or still are at risk of consuming water at or above the maximum contaminant level (MCL) for nitrate."[39] In some townships within vulnerable counties in southeastern Minnesota, over 40% of the tested wells exceeded 10 mg/L nitrate.[40] A separate Volunteer Nitrate Monitoring Network in southeastern Minnesota reported that in 2022, nearly 70% of the 376 sampled wells had nitrate levels above 3 mg/L, and 8.2% were above 10 mg/L.[41]

D. Most of Minnesota's nitrate problem is caused by agriculture and, particularly, pollution from manure

That these highly polluted areas are largely rural and heavily farmed is no coincidence. Nitrogen is a nutrient that is critical for plant growth—when applied at reasonable rates. However, when operators apply nitrogen from either commercial fertilizer or manure used as fertilizer in amounts that exceed crop needs, at times when there are no crops to use it, or using risky application methods, it leads to water pollution. The nitrogen, if not used by plants, leaches into the groundwater in a water-soluble form (nitrate), runs off overland into surface waters, and volatizes and is released as atmospheric nitrogen and often re-deposited within the same watershed. Corn—which is the most widely grown crop in Minnesota in terms of total acreage—is a particularly "leaky" crop. Studies in Minnesota have shown that even when corn receives "near-optimum" rates of nitrogen fertilizer, it can still leach 15 to 40 pounds of nitrate per acre

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[39] EPA, Letter to Minnesota State Agencies Regarding Southeast Minnesota Petition, at 2 (Nov. 2023) (Ex. 18).
[40] MDA, *Winona County: Final Overview of Nitrate Levels in Private Wells (2016-2017)* at 2 (Updated Sept. 2019) (Ex. 19).
[41] MDA, *Southeast Minnesota Volunteer Monitoring Network* (Ex. 20).

each year.[42] When fertilizer is *applied* at higher rates or at inopportune times, losses are likely far greater.

Minnesota's state agencies acknowledge that row crop agriculture is the largest source of nitrogen pollution over time in Minnesota.[43] More than 70% of the nitrogen in Minnesota surface waters (measured as nitrate + nitrite) comes from cropland sources such as groundwater leachate below crop fields, tile drainage, and cropland runoff.[44] In intensively agricultural areas of the state, the nitrogen loads from cropland sources are even higher; such sources produce an estimated 89 – 95% of the load in the Minnesota, Missouri, and Cedar river watersheds, and the Lower Mississippi River basin.[45] Even as phosphorus pollution has decreased, nitrate concentrations have persisted and in some places increased across Minnesota during the past two decades.[46]

This nitrogen comes from both commercial fertilizer, which in 2013 accounted for approximately 75% of the nitrogen applied to fields in the state, and manure, which accounted for about 25%.[47] These two sources together account for 1.8 *billion* pounds of the nitrogen added to land in Minnesota in 2013, compared to 12 million pounds for lawn fertilizer and 9 million pounds for septic system drain fields.[48] And the amount of nitrogen applied to Minnesota lands has unquestionably grown in the last decade, as the number of animals on feedlots, corn acreage, and the amount of fertilizer sold continue to grow. Since 1991, the number of large feedlot operations in Minnesota has tripled, and fertilizer sales have increased by more than one-third.[49]

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[42] Univ. of Minn. Extension Service, *Nitrates in Minnesota Drainage Water* (Ex. 21).
[43] Five Year Progress Report, at 21 (Ex. 12).
[44] Nitrogen in Surface Waters, at 9 (Ex. 6).
[45] MPCA, *Water Pollutant: Nitrogen* (Ex. 22).
[46] Five Year Progress Report, at 21-22 (Ex. 12).
[47] Nitrogen in Surface Waters, at D1-5 (Ex. 6).
[48] *Id.*
[49] Envtl. Working Grp., *Nitrate Pollution Is Getting Worse* (Ex. 13).

The use of manure as fertilizer is particularly problematic for nitrate pollution because producers often overapply manure. This overapplication is a problem because applying nitrogen at rates higher than what crops need exponentially increases losses to the environment and is one of the most significant contributors to nitrate pollution statewide. Residual soil nitrate content spikes dramatically when nitrogen is applied at rates above the maximum return to nitrogen ("MRTN").[50] If Minnesota producers followed the MRTN on all applicable row crop areas (over 6 million acres statewide), statewide nitrate-N losses could be reduced by approximately 16%.[51] Several factors combine to make manure a contributor to overapplication.

First, manure is often treated as a waste product, applied not so much for its nutrients, but simply to dispose of it. As explained by the Extension Service, manure application timing may not be driven by crop needs but by instead storage limitations or the need to work around wet weather or other production processes.[52] Manure also may be overapplied at fields nearest the livestock operation to free up capacity in the manure pit without incurring the time and cost of transporting it further away.[53] Either of these practices likely will lead to higher nitrate loss than if the manure were applied at the times and in the places where it was needed for optimal crop growth.

Second, unlike commercial fertilizer, manure is uncertain and variable in its nutrient content, and the nitrogen in manure is not immediately available for plants to use for growth. In addition, much of the nitrogen content of manure may be lost during storage and application. This

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[50] MDA, *Root River Field to Stream Partnership* (Ex. 23). Even though the MRTN is intended to maximize producers' economic returns and not to minimize nitrate pollution, applying at this rate is still better than higher rates often applied by producers.
[51] Gary W. Feyereisen, et al., *Frontier: Eating the Metaphorical Elephant: Meeting Nitrogen Reduction Goals in the Upper Mississippi River Basin States*, 65(3) J. of Am. Society of Ag. & Biological Engineers 621-631, 623 (2022) (Ex. 51).
[52] Chryseis Modderman, *Manure is complicated: 5 reasons you need a manure management plan,* Minnesota Crop News (June 26, 2023) (Ex. 48).
[53] *Id.*

uncertainty about how much nitrogen is actually available after manure is applied encourages producers to apply at higher rates as insurance that they are meeting crop needs. In fact, the Extension Service recommends applying *more* nitrogen per acre when manure is used, as compared to commercial fertilizer, because the additional nitrogen is viewed as being needed to maximize crop yields. [54]

Finally, when producers apply both manure and commercial fertilizer to their crops, they often fail to adequately credit manure sources of nitrogen in their calculations, leading to overapplication of nitrogen.[55] Based on farmer interviews, the most common reason for the over-application of nitrogen is the combination of manure and commercial fertilizer and the failure to adequately account for nitrogen already in the soil.[56] In 2021, soil tests showed that more than 70% of tested fields should have taken a nitrate credit—including 28% that should have taken a credit of 155 pounds per acre, the full amount that the Extension Service recommends applying in some circumstances.[57] Confirming this propensity, MPCA has found that the average application rate of nitrogen is higher when manure is applied in combination with commercial fertilizer than when only non-manure sources alone are used.[58]

For all these reasons, nitrogen application rates often exceed crop needs when manure is used as a nitrogen source. This is supported by surveys of producers themselves. USDA survey

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[54] *Compare* Univ. of Minn. Extension Service, *Guidelines for manure application rates* (Ex. 24) (recommendation for corn after corn is a maximum of 195 pounds of plant available nitrogen per acre) to Univ. of Minn. Extension Service, *Fertilizing Corn in Minn.* (Ex. 25) (recommendation for corn after corn is a MRTN of 175 pounds of nitrogen per acre when the ratio of the nitrogen price to crop value is .10).
[55] 2018 Groundwater Protection SONAR, at 51 (Ex. 7).
[56] 1999 Feedlot SONAR, at 205 (Ex. 1).
[57] Brad Carlson, *Taking soil samples for nitrogen analysis could pay big this year*, Minnesota Crop News (March 30, 2022) (Ex 26).
[58] Five Year Progress Report, at 78 (Ex. 12).

data from 2012, for example, showed that nearly half of all surveyed producers who applied both manure and commercial fertilizer applied at rates of 200 pounds of nitrogen per acre or greater, compared to the recommended Extension Service rate of 155 pounds per acre.[59] In 2020, an Environmental Working Group ("EWG") investigation found that in 69 of Minnesota's 72 agricultural counties, nitrogen from manure and commercial fertilizer sources exceeded the recommended application rates from the Extension Service. In thirteen counties across the state, many of which fall within vulnerable groundwater areas, the EWG study found that nitrogen inputs from manure and commercial fertilizer exceeded the recommended rates by more than half.[60] In just one county, Martin County, more than 28 million pounds of nitrogen were applied from these sources than were needed by crops.[61]

Accordingly, although manure accounts for a much smaller percentage of nitrogen applied to fields overall than commercial fertilizer, its application can lead to significant pollution risks. Any plan to decrease the nitrate contamination levels in Minnesota's waters must adequately address manure management. Simply focusing on commercial fertilizer alone cannot resolve this multi-faceted problem.

E. Unsafe manure management practices also lead to coliform impairments

Beyond the widely documented nitrate contamination trends in public and private water supplies, there are also other microbial contaminants associated with manure that impact public health—further emphasizing the need for responsible manure management. Coliforms are a standard indicator of drinking water quality associated with acute gastrointestinal illness, and the

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[59] 2018 Groundwater Protection SONAR, at 55 (Ex. 7).

[60] Envtl. Working Grp., *Manure Overload: Manure Plus Fertilizer Overwhelms Minnesota's Land and Water* (May 28, 2020) (Ex. 27).

[61] *Id.*

MCL Goal under the Safe Drinking Water Act for these contaminants is set at zero.[62] Yet 243 Minnesota waters are listed as impaired for fecal coliform, and another 672 are listed as impaired for E. coli (one of the main fecal coliforms).[63]

One of the main sources of bacteria in surface waters—including coliforms—is runoff from feedlots and land application sites. MPCA has stated that one of the most effective ways to reduce coliforms in water is to ensure this runoff is controlled.[64] This is supported by a 2021 study in Northeastern Wisconsin that analyzed private well contamination data across a five-county region with vulnerable fractured bedrock and concentrated dairy CAFO production, similar to the karst region of Southeastern Minnesota. Of the 6,739 wells sampled for microbial contamination, 23% tested positive for total coliforms.[65] The primary risk factors for coliform detection were bedrock depth (which determines groundwater vulnerability) and distance to the nearest manure storage structure, with wells located within 48 meters of manure storage structures 87% more likely to have coliform detection than wells 4000 meters away.[66] The single risk factor most associated with an increase in coliform concentration levels was the distance to the nearest field with a nutrient management plan where commercial fertilizer and animal manure were land applied.[67] Practices that reduce manure runoff, accordingly, are critical to addressing not only nitrates but also dangerous bacteria.

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[62] EPA, *Revised Total Coliform Rule and Total Coliform Rule* (January 2017), https://19january2017snapshot.epa.gov/dwreginfo/revised-total-coliform-rule-and-total-coliform-rule_.html.

[63] MPCA, 2*024 Impaired Waters List*, https://www.pca.state.mn.us/air-water-land-climate/minnesotas-impaired-waters-list.

[64] MPCA, *Water Pollutant: Bacteria* (Ex. 29).

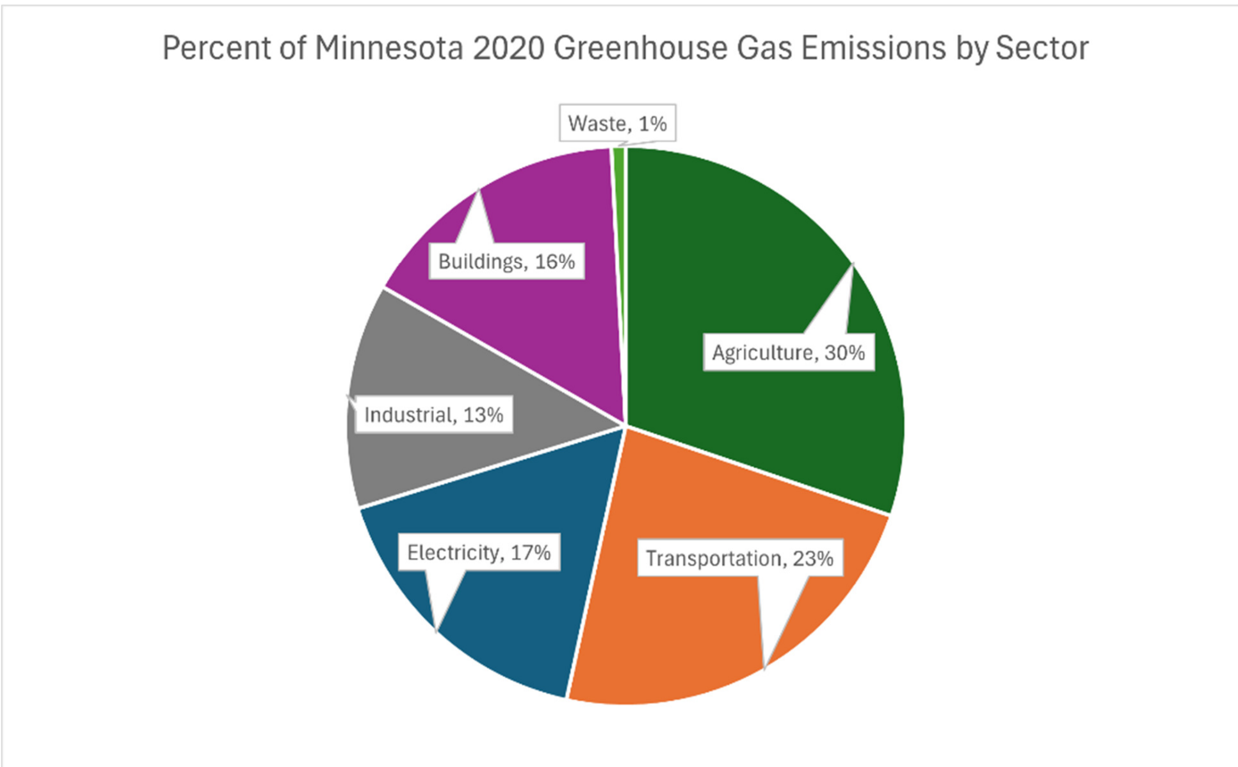
[65] Mark A. Borchardt et al., *Sources and Risk Factor for Nitrate and Microbial Contamination of Private Household Wells in the Fractured Dolomite Aquifer of Northeastern Wisconsin*, Environmental Health Perspectives 129(6), at 3-4 (June 2021) (Ex. 28).

[66] *Id.* at 26.

[67] *Id.* at 23-24.

F. Manure management practices that pollute water also contribute to climate change

The same feedlot practices that lead to nitrate and coliform pollution of waters also contribute to climate change. Agriculture is the largest contributor to greenhouse gas emissions in the state. In 2020, this sector produced nearly 47 million tons of carbon-dioxide equivalent ("CO2e") greenhouse gas emissions, or 30% of the total 155 million tons of CO2e greenhouse emissions produced in Minnesota.[68]



[68] MPCA, *Greenhouse gas emissions data*, https://public.tableau.com/app/profile/mpca.data.services/viz/GHGemissioninventory/GHGsummarystory (last visited May 5, 2024). Note that this estimate excludes the -18 million tons of carbon sequestered by forest regrowth, which is usually subtracted from agriculture emissions in MPCA reporting.

Of these emissions, 57% come from crop agriculture, and 23% come from animal agriculture.[69] But because 67% of crops in the United States are grown for animal feed, these statistics undercount the emissions ultimately attributable to animal agriculture.[70]

Emissions from animal agriculture are from two primary greenhouse gases: Nitrous oxide and methane. These are potent greenhouse gases that heat the atmosphere up to 30 and 273 times more rapidly, respectively, than carbon dioxide over a 100-year time frame.[71] Methane is produced from animal agriculture through enteric fermentation (animal belching during the natural digestive process) and the decomposition of manure stored in uncovered lagoons. Nitrous oxide is a byproduct of animal excrement—both manure and urine—as well as a byproduct of commercial fertilizer use, much of which is used to grow animal feed. Excess nitrogen in soil and surface waters can lead to denitrification, another source of nitrous oxide emissions. Proper handling of manure and use of the same manure management practices that reduce water pollution will also, as an additional benefit, decrease these climate change causing emissions.

G. Minnesota's efforts to control nitrate pollution have not been successful

Despite the fact that the causes and dangers of nitrate pollution have long been known—along with the associated dangers of bacterial coliforms and greenhouse gas emissions—Minnesota state agencies have not taken effective steps to control this pollution. For thirty years, Minnesota has spent hundreds of millions of dollars to address nitrate pollution, but groundwater and surface waters across the state continue to show persistent levels of contamination and even increases in nitrate loads and concentrations.[72] The state's Clean Water Fund alone has directed at

[69] *Id.*
[70] Vicky Bond, *The Animal Feed Industry's Impact on the Planet*, Independent Media Institute (Jan. 29, 2024) (Ex. 30).
[71] EPA, *Understanding Global Warming Potentials* (Jan. 12, 2016) (Ex. 31).
[72] Jeff Hargarten and Jennifer Bjorhus, *Nitrate contamination of Minnesota waters shows little sign of going away, despite years of effort*, Star Tribune (Nov. 28, 2023) (Ex. 32).

least $148 million to the nitrate problem since 2010, according to a Star Tribune analysis, and millions more in federal and state funding have paid for efforts that include nitrate research, programs and training to encourage farmers to make voluntary changes to practices, and nitrate filtration systems for several cities.[73] The response from state agencies has included a combination of regulatory and voluntary conservation programs, with an emphasis on voluntary incentives. These voluntary incentives, encouraged by technical and financial assistance from governmental programs, have not achieved the necessary reductions in nitrate pollution.[74] Despite the development of the updated Nitrogen Fertilizer Management Plan, the Groundwater Protection Rule, and the Nutrient Reduction Strategy over the past decade, there have not been significant decreases in nitrate levels in surface waters or groundwater.

MPCA has repeatedly acknowledged that its current regulations and voluntary BMPs are insufficient to protect groundwater from pollution.[75] MPCA's own progress report on nutrient management practices in 2020 admitted that none of the nutrient management practices adopted during the past decade were "expected to yield measurable nutrient reductions to surface waters at a large scale."[76] MPCA's website acknowledged that refinements in fertilizer rates and application timing could reduce nitrate loads by roughly 13% statewide, but "additional and more costly practices will be needed to make further reductions."[77] As the agency has stated, "statewide

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[73] *Id.*
[74] Kurt Stephenson et. al, *Confronting our Agricultural Nonpoint Source Control Policy Problem*, Journal of the Am. Water Resources Assn. (June 2022) (Ex 33) (explaining that programs to reduce agricultural non-point source pollution that depend on voluntary adoption, with technical and financial assistance from federal and state programs, have not been successful in reducing pollution loads).
[75] MPCA, *Groundwater quality* (Ex. 34).
[76] Five Year Progress Report, at 53 (Ex. 12).
[77] MPCA, *Nitrogen* (Ex. 22).

reductions of more than 30% are not realistic with current practices."[78] Only with significant regulatory changes—and enforcement of those changes—will Minnesota make progress on the nitrate pollution problem.

H. EPA has instructed Minnesota to make changes to address nitrate pollution

Not only are changes to address Minnesota's nitrate pollution compelled by the facts—the federal EPA has instructed MPCA to take actions to address this problem. In April 2023, MCEA led a coalition of 11 national, regional, and local organizations in submitting a petition that asked the EPA to use its powers under the Safe Drinking Water Act to address the "imminent and substantial endangerment to human health" posed by groundwater nitrate contamination in Minnesota's karst region.[79]

On November 3, 2023, the EPA responded with a letter to the MPCA, MDA, and MDH regarding the state's nitrate pollution in the karst region, stating "there is an evident need for further actions to safeguard public health."[80] The EPA directed state agencies to take immediate action to safeguard public health in the region, and to "hold sources of nitrate accountable using all available tools to reduce the amount of nitrate they release to ground water."[81] Specifically, the EPA recognized that more protective NPDES and SDS permits for large feedlots in the state would be a "long-term solution to achieve reductions in nitrate concentrations in drinking water supplies."[82] EPA called for Minnesota to consider adopting monitoring requirements in its permits related to subsurface discharges from manure, litter, and process wastewater storage, as well as discharges from land application. It also encouraged the state to consider modifications to its nutrient

[78] *Id.*
[79] MCEA et al., *Petition to EPA for Emergency Action Pursuant to the Safe Drinking Water Act*, (April 24, 2023) (Ex. 35).
[80] EPA, Letter to Minnesota State Agencies (Ex. 18).
[81] *Id.* at 4.
[82] *Id.*

management standards in karst areas with regard to land application of manure.[83] The agency stated that it would continue to closely monitor the situation and "consider exercising our independent emergency and enforcement authorities."[84] In response to EPA's letter, MPCA—which had previously stated it did not intend to make significant changes to the NPDES permit for feedlots—issued the Proposed Permits and requested comments.

II. MPCA has the authority and the duty to change the Proposed Permits to comply with state and federal law

MPCA has the authority and the duty under Minnesota and federal law to protect the state's groundwater and surface waters from manure-related pollution. Minnesota and federal statutes set up stringent protections for waters and significant requirements for permits that protect those waters. The current feedlot permits do not meet those requirements, as evidenced by the long-standing, wide-spread, and persistent nitrate pollution of surface waters and groundwater, shown by the state's own data. Accordingly, MPCA must revise the Proposed Permits to impose conditions that will address nitrate and other pollution both from feedlots and land application areas.

State and federal law contain critical and stringent protections for the state's surface waters and groundwater.[85] MPCA, as the agency designated under state law to implement and enforce protections for Minnesota's waters, has the duty to enforce these protections.[86] Under state law, MPCA must protect "waters of the state," which include both surface waters and groundwater.[87]

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[83] *Id.*
[84] *Id.* at 5.
[85] Minn. Stat. § 115.03, subd. 1(a)(1).
[86] As a delegated authority, MPCA acts for the EPA to implement the federal CWA permitting program in Minnesota. The MPCA was first delegated the authority to operate the NPDES program in lieu of the federal government in 1974. *See* 39 Fed. Reg. 2606 (July 16, 1974).
[87] Minn. Stat. § 115.01, subd. 22.

The agency's duties include adopting and enforcing rules, permits, and orders "in order to prevent, control or abate water pollution."[88] Specifically, MPCA must issue permits that:

- Require discontinuance of the discharge of wastes[89] into any waters of the state "resulting in pollution in excess of the applicable pollution standard."[90]

- Prohibit the discharge of any wastes into the waters of the state, or to deposit wastes "where the same is likely to get into any waters of the state" in violation of Minnesota's applicable laws, rules, or permits.[91]

- Require adoption of remedial measures "to prevent, control or abate any discharge or deposit of … wastes by any person."[92]

- Require establishment of systems of recordkeeping, sampling, monitoring, and reporting by dischargers for provision of information to the agency.[93]

- Include additional limits if technology-based standards are not adequate to maintain water quality standards, "notwithstanding any other provision of this chapter, and with respect to the pollution of waters of the state, chapter 116."[94]

- Establish standards, rules, and permit conditions consistent with and not less stringent than the requirements of the federal Clean Water Act and its implementing regulations.[95]

Pursuant to this authority, MPCA refined its water protection objectives and requirements for itself and dischargers through rules. For surface waters, Minnesota law requires MPCA to "protect and maintain surface waters in a condition which allows for the maintenance of all existing beneficial uses," such as drinking, recreating, or supporting aquatic life.[96] MPCA must ensure waters meet numeric standards for certain pollutants, but also "narrative" standards that ensure the

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[88] Minn. Stat. § 115.03, subd. 1(a)(5).
[89] Although certain components of land-applied manure may be used by plants, where manure, nutrients, or other pollutants escape their intended use and are instead discharged into waters of the state those pollutants are properly characterized as "other wastes" which as defined includes "agricultural waste" and "biological materials." Minn. Stat. § 115.01, subd. 9.
[90] Minn. Stat. § 115.03, subd. 1(a)(5)(i).
[91] *Id.* subd. 1(a)(5)(ii).
[92] *Id.* subd. 1(a)(5)(iv).
[93] *Id.* subd. 1(a)(5)(vii).
[94] *Id.* subd. 1(a)(5)(viii).
[95] *Id.* subd. 5.
[96] Minn. R. 7050.0150, subp. 1.

designated uses of the water are maintained.[97] This includes narrative standards that prohibit the degradation or impairment of aquatic life in Class 2 waters, i.e., those protected for aquatic life and recreation (a classification that applies to nearly every waterbody in the state).[98] Even without a numeric standard for nitrate in surface waters,[99] therefore, MPCA must still ensure that nitrates do not reach levels in surface waters that would harm aquatic life or prevent the use of the waters for swimming, fishing, and boating. In addition, under MPCA's rules, permits must include conditions necessary to ensure against "nuisance conditions" from either point or nonpoint sources, including aquatic habitat degradation or excessive growth of aquatic plants.[100]

For groundwater, Minnesota law imposes an antidegradation standard—meaning that MPCA must ensure that wastes are controlled "to the maximum practicable extent" to ensure against degradation of the groundwater.[101] Pollutants may not be discharged to the unsaturated zone (the zone between the land surface and the water table) if they "may actually or potentially preclude or limit the use of the underground waters as a potable water supply."[102] Under this rule, land disposal of "acceptable organic wastes" or the use of "fertilizers for agricultural crops or products" is only allowed "provided that such practices do not pose a significant pollutant

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[97] Minn. R. 7050.0150, subp. 1.
[98] Minn. R. 7050.150; 7050.0150, subp. 3; MPCA, *Class 2: Aquatic life and recreation beneficial uses*, https://www.pca.state.mn.us/business-with-us/class-2-aquatic-life-and-recreation-beneficial-uses.
[99] The Minnesota Legislature directed MPCA in 2010 to develop aquatic life standards for nitrogen and nitrate. Despite the production of technical support documents that support the imposition of a 5 mg/L standard for coldwater bodies of water and 8 mg/L for other waterbodies, MPCA has not yet implemented any numeric standard for nitrate. Aquatic Life Nitrate Standards, at 1, 7 (Ex. 9).
[100] Minn. R. 7053.0205, subp. 2.
[101] Minn. R. 7060.0500.
[102] Minn. R. 7060.0600, subp. 2.

hazard."[103] Accordingly, MPCA is required to ensure that *all* groundwater pollution—including nitrate pollution—is prevented as much as possible.

These requirements apply to the Proposed Permits. Accordingly, MPCA must ensure that the Proposed Permits (1) stop current discharges and prohibit new discharges of wastes that would violate pollution standards or other laws, (2) include limits needed to maintain water quality standards (even if this conflicts with other provisions of law), (3) include reporting and monitoring requirements needed to ensure permit conditions are being followed, (4) include provisions to prevent both production areas and land applied fields from causing nuisance conditions for aquatic life, and (5) include provisions to protect groundwater from any degradation and to prevent any discharges of wastes that might limit the use of groundwater for drinking water.

In addition to these general charges, MPCA has specific duties regarding the issuance of NPDES permits. Under federal law, MPCA must ensure that the Proposed NPDES Permit complies with the Clean Water Act ("CWA").[104] As a delegated authority, MPCA must establish permit conditions at least as stringent as the CWA, notwithstanding any provisions of state law to the contrary.[105] This means the Proposed NPDES Permit must contain requirements at least as stringent as the federal implementing regulations for NPDES permits for feedlots.[106] Minnesota law can and does impose requirements additional to and more stringent than the floor established in the CWA.[107]

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[103] *Id.,* subp. 5.
[104] *See* 39 Fed. Reg. 2606 (July 16, 1974).
[105] Minn. Stat. § 115.03, subd. 5.
[106] 33 U.S.C. § 1311(b)(1)(C); 33 U.S.C. § 1313(e)(3)(A); 40 C.F.R. § 123.25; *Am. Paper Inst. v. EPA*, 996 F.2d 346, 349 (D.C. Cir. 1993); Minn. R. 7020.0505, subp. 5 (feedlot permits required to include all applicable requirements of the Code of Federal Regulations, title 70, part 122).
[107] For example, Minnesota statutes define "waters of the state" much more broadly than the federal "waters of the United States," and Minnesota law prohibits point source discharge to this much

Under state law, NPDES permits must include all conditions necessary for the permittee to comply with all Minnesota and federal statutes and rules, including water quality standards.[108] The permits must contain "any conditions that the agency determines to be necessary to protect human health and the environment."[109] If numeric effluent limits are not feasible in a permit, MPCA must include BMPs as permit conditions to achieve compliance with state and federal laws and with effluent limitations, standards, and prohibitions.[110] NPDES permits must also include monitoring and reporting requirements "to ensure compliance with permit limitations."[111] The Proposed Permits, therefore, must comply with all of these requirements as well—ensuring compliance with laws and water quality standards through BMPs, and requiring monitoring and reporting to ensure permit limitations are being met.

MPCA is also obligated to include conditions in the Proposed Permits consistent with the state feedlot rules. With regard to land application of manure, the feedlot rules include provisions that (among other things):

- Prohibit the land application of manure in a manner that will "result in a discharge to the waters of the state during the application process."[112]
- Prohibit the land application of manure in a manner that will "cause pollution of waters of the state due to manure-contaminated runoff."[113]
- Require that land applied manure be limited so that available nitrogen sources do not exceed expected crop nitrogen needs.[114]

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larger group of water bodies without a NPDES permit. Minn. Stat. §115.01, subd. 22 (defining "waters of the state"); Minn. R. 7001.1030, subp. 1 (prohibiting point source discharge to any "water of the state" absent a NPDES permit).

108 Minn. R. 7020.0505; Minn. R. 7001.0150, subp. 2; Minn. R. 7001.1080, subp. 1 and 2.

109 Minn. R. 7001.0150, subp. 2.

110 Minn. R. 7001.1080, subp. 3.

111 Minn. R. 7001.1080, subp. 5.

112 Minn. R. 7020.2225, subp. 1(A)(1).

113 *Id.*, subp. 1(A)(2).

114 *Id.*, subp. 3.

- Require that producers consider *all* sources of nitrogen—including commercial fertilizer, soil organic matter, irrigation water, legumes grown during previous years, biosolids, process wastewater, and manure applied for the current year and previous years—and take appropriate credits for how much they are adding to their fields.[115]

The Proposed Permits, therefore, must impose conditions and limitations on land application of manure that will ensure all of these provisions are met.

Overall, Minnesota and federal law provide MPCA with broad authority and tools to ensure that the Proposed Permits effectively address the nitrate pollution crisis in Minnesota. State and federal law not only mandate the protection of groundwater and surface waters, but also compel MPCA to issue permits that will prohibit discharges of waste, protect water quality, and place conditions on land application of manure to prevent pollution. MPCA also must impose monitoring and reporting requirements that will ensure the Proposed Permits are not merely meaningless paper promises, but actually fulfilled by permittees. MPCA is required to use its authority to implement NPDES and SDS feedlot permits that comply with these laws.

III. MPCA's Proposed Permits include important and necessary changes, but MPCA must make further changes to comply with state and federal law and address nitrate pollution

MPCA has now issued Proposed Permits that include important changes that would, if adopted and enforced, constitute a meaningful step toward addressing nitrate pollution.[116] The explicit direction of the EPA, Minnesota's laws protecting groundwater and surface waters, and MPCA's duties to issue permits that comply with Minnesota and federal law all compel MPCA to implement these changes as a first step. Each of these changes is supported by law and science, and each must be included in the Proposed Permits. These changes, however, do not go far enough

[115] *Id.*, subp. 3(C).

[116] The Proposed NPDES Permit and the Proposed SDS Permit are very similar but not entirely identical. All references to section numbers in this comment are to sections in the Proposed NPDES Permit. The Clean Water Organizations intend that all of their proposed changes should be made to both Proposed Permits.

to address the widespread and persistent nitrate pollution crisis, particularly in vulnerable areas of the state. Accordingly, MPCA must make additional changes that will strengthen the Proposed Permits to comply with state and federal law and to effectively address nitrate pollution.

To bring the Proposed Permits into compliance with state and federal law, MPCA must do the following: (1) implement and strengthen the restrictions on fall and winter spreading in vulnerable groundwater areas; (2) implement the provision requiring incorporation of manure within the 100-year floodplain; (3) implement the provision requiring recipients of transferred manure to follow permit requirements; (4) at land application areas, strengthen visual inspection requirements and add groundwater monitoring requirements in vulnerable drinking water areas; (5) at production areas, strengthen visual inspection requirements and add groundwater monitoring requirements; (6) for both production areas and land application areas, impose further sampling requirements and provide additional information to permittees about how to conduct sampling; (7) require pre-plant soil testing for nitrate in accordance with Extension Service recommendations; (8) require nutrient testing before any application of digestate; (9) require producers to use the Runoff Risk Advisory Forecast; and (10) impose additional restrictions on emergency manure applications.

A. MPCA must add protections for vulnerable groundwater areas to the Proposed Permits

1. The Proposed Permits' restrictions on fall and winter spreading in vulnerable areas must be included in the permits

The Proposed Permits include several new requirements for land application in fields in "vulnerable groundwater areas," with coarse textured soils, shallow bedrock, or karst geology, or in highly vulnerable drinking water supply management areas. In such areas, permittees applying manure must:

- For October and November application, use additional BMPs for application, including applying to a growing perennial or row crop, planting a cover crop prior to or within 14 days of application, or rotating perennial crops at least 2 years during any 5-year period and the soil is below 50 degrees at the start of application (§13.6). These restrictions do not apply until 2028.

- For December, January, and February, do not apply solid manure if the ground is frozen or snow-covered (§§ 13.8, 13.9).

Notably, these changes constitute only an incremental addition to the previous NPDES permit's restrictions on fall and winter application—the previous permit already included statewide requirements for certain BMPs for application in early October, prohibited the spread of liquid manure in winter conditions in most months, and limited the spread of solid manure in winter conditions.

These changes, intended to target nitrate pollution where the problem is worst, are strongly supported by science. Applying manure in the fall greatly increases the risk of nitrogen loss—in fact, the Extension Service states that any nitrate left in the soil in the fall "is usually lost during the spring before the next year's crop can take it up."[117] For this reason, the Extension Service does not even recommend taking a nitrogen credit for late season nitrate; according to their recommendations, producers should simply assume that *all nitrate from the fall has been lost* over the winter and spring unless it has been a particularly dry year.[118] In vulnerable groundwater areas, fall application becomes even more risky, and BMPs to help address this problem are absolutely critical.

The new permit provisions will help address this problem. Cover crops, which take up leftover nitrogen in the soil at a time when fields are generally fallow, are a "well-established" way

[117] Carlson, *Taking soil samples for nitrogen analysis could pay big this year* (Ex 26).
[118] *Id.* This is contrary to the feedlot rules, which require producers to take credit for *all* sources of nitrogen, but the recommendation is nevertheless telling with regard to how much nitrogen the Extension Service expects to remain in the soil. *See* Minn. R. 7020.2225, subp. 3(A)(1).

to reduce nitrate loss.[119] Rotating annual crops with perennials decreases leaching losses because perennial grasses have greater root biomass that extends deeper into the soil, taking up nutrients from deeper within the soil.[120] One study on nitrate reduction strategies showed that planting cover crops such as rye can reduce nitrogen loads by approximately 40%, while diversified crop rotations can reduce nitrogen loads by approximately 50%.[121] A three-year study in Lamberton, Minnesota compared drain tile nitrate losses after conversion of alfalfa pasture to corn-soybean and continuous corn rotations and found that perennial pasture reduced nitrogen loads by 18 to 80%.[122] Another study from the University of Minnesota showed that one year of planting wheatgrass decreased soil nitrate-N concentrates by 77%.[123]

As for land application in winter conditions, when the ground is frozen or snow-covered, manure applied to the surface cannot seep into the ground, creating a significant risk of runoff and consequent loss of nitrate.[124] In an average year in Minnesota, nearly half of the total surface runoff volume occurs when the soil is frozen.[125] In addition, when the manure remains above the frozen ground, on the surface, there is a longer opportunity for volatilization—in which ammonium-nitrogen on the surface is turned into ammonia gas.[126] Ultimately, most of this gas turns back into

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[119] Univ. of Minn. Extension Service, *Cover Crops* (Ex. 36).

[120] Evelyn C. Reilly et al., *Reductions in soil water nitrate beneath a perennial grain crop compared to an annual crop rotation on sandy soil*, Frontiers in Sustainable Food Systems (Sept. 2022) (Ex. 37).

[121] Laura Christianson et al., *Financial comparison of seven nitrate reduction strategies for Midwestern agricultural drainage*, 2-3 Water Resources and Economics 30-56 (2013) (Ex. 38).

[122] David Huggins et al., *Subsurface drain losses of water and nitrate following conversion of perennials to row crops*, 93 Agronomy Journal 477-486 (May 2001) (Ex. 39).

[123] Reilly, *Reductions in soil nitrate* (Ex. 37).

[124] Melissa Wilson, *Manure applied on frozen soil or snow—what will happen to my nitrogen?* Minnesota Crop News, (Jan. 1, 2024) (Ex. 40).

[125] Five Year Progress Report (Ex. 12).

[126] Wilson, *Manure applied on frozen soil or snow* (Ex. 40). While freezing temperatures slow down volatilization, research suggests that the process does not stop entirely. In addition, freezing

ammonium and is redeposited on the ground, generally in the same watershed—meaning that it remains a local pollution hazard.[127] Because of the high likelihood of nitrogen loss, the Extension Service advises producers not to apply manure to frozen soils.[128]

Because of the effectiveness of these practices and the severity of the problem in the state's vulnerable areas, Minnesota law requires—at a minimum—that these incremental additions to manure application restrictions be added to the Proposed Permits. As shown by the data, nitrate pollution from agricultural sources in the karst and Central Sands areas has caused widespread violations of Minnesota's water quality standards. In addition, studies show that elevated levels of nitrate in groundwater and surface waters in these vulnerable areas increase risks to human health and hurt aquatic life and ecosystems, even where water quality standards may not be violated. MPCA, accordingly, must impose additional conditions, including BMPs, to ensure compliance with water quality standards and "to protect human health and the environment."[129] Moreover, the feedlot rules specifically prohibit the land application of manure in a manner that will cause pollution of the waters of the state due to manure-contaminated runoff, and applying manure in the fall without cover crops or in winter conditions greatly increases the likelihood of runoff.[130] These changes, accordingly, are both reasonable and necessary under Minnesota law, and they should be made to the Proposed Permits.

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and thawing cycles mean that there will be at least some time for volatilization to occur but make it difficult to determine how much nitrogen has been lost. *Id.*

[127] Christopher S. Jones et al., *Livestock manure driving stream nitrate*, 48 Ambio 1143, 1148 (Dec. 2018) (Ex. 41).

[128] Univ. of Minn. Extension Service, *Reducing Water Quality Issues from Manure* (2020) (Ex. 42).

[129] Minn. Stat. § 115.03, subds. 1(a)(5)(i), 1(a)(5)(ii); Minn. R. 7001.0150, subp. 2; Minn. R. 7020.0505.

[130] Minn. R. 7020.2225, subp. 1(A)(2).

2. The fall and winter restrictions should not be delayed and should be extended statewide

Because the changes are supported by science and the law, MPCA should do more than simply make these changes as proposed. First, there is no reason to postpone the October and November changes to 2028, which is nearly two years into the permit cycle. Nitrate pollution is a crisis *now*, and improvements in groundwater quality will not be immediate, even after changes are implemented. Because of that lag time, it is even more important to take action as quickly as possible. Producers still will have ample time to plan for these changes, which were announced in June 2024. The SDS Permit will not go into effect until May 2025 and the NPDES Permit will not go into effect until January 2026. In addition, because producers' permits expire five or ten years after they are obtained, some producers will not have to reapply for a new permit until well after the initial permit date. Producers know now—more than a year before October 2025, the very earliest anyone would have to comply with the new requirements—of these provisions and can make plans to comply with them.

Second, while it is most critical to apply these provisions in vulnerable groundwater areas, nitrate pollution is a statewide crisis, and applying these BMPs statewide would help reduce elevated nitrate levels across the state. In particular, spreading manure in winter conditions, on frozen ground or snow-covered soil, should be prohibited across the state. Applying manure to frozen or snow-covered ground, when there is assuredly no crop to use it, and when there is a significant risk that it will run off, should not be allowed anywhere in Minnesota. Accordingly, MPCA should not only make the changes included in the Proposed Permits but remove the delay for the fall application requirements and require both the new fall and winter application restrictions across the state.

B. MPCA must include the Proposed Permits' new provision requiring incorporation of manure within the 100-year floodplain in the final permits

The Proposed Permits also require manure to be injected or immediately incorporated if it is applied within the 100-year floodplain (§ 15.4). This is a reasonable requirement—applying manure within a floodplain is self-evidently riskier than applying it outside the floodplain. Not only does the floodplain flood more frequently, but even in ordinary conditions the lower, closer-to-water position of a floodplain means its soils are more likely to be saturated, and the surface is more likely to have water flowing over it. Injecting or incorporating manure into the soil of the floodplain will reduce this increased risk of runoff.[131] Again, Minnesota law requires the addition of this provision: MPCA is required to impose BMPs in the Proposed Permits to ensure compliance with water quality standards and to protect human health, and the feedlot rules prohibit applying manure in a manner that will create runoff that will pollute the waters of the state.[132] This reasonable provision must be included in the final permits.

C. MPCA must require recipients of transferred manure to follow all requirements of the Proposed Permits

The Proposed Permits also include new requirements for transferred manure, including that the permittee must not transfer manure to a recipient who will improperly apply manure during winter conditions (§ 9.3), the permittee must provide the transferee with a summary of requirements that the recipient must follow (§ 9.4), the recipient must comply with all requirements of the permittee's manure management plan ("MMP") (§ 10.2), and the recipient must provide information about its land application to the permittee, who must report this information annually (§§ 24.7, 25.2). In essence, these provisions level the playing field, ensuring that no matter who

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[131] Univ. of Minn. Extension Service, *Reduce water quality issues from manure* (Ex. 42).

[132] Minn. Stat. § 115.03, subds. 1(a)(5)(i), 1(a)(5)(ii); Minn. R. 7001.0150, subp. 2; Minn. R. 7020.0505, Minn. R. 7020.2225, subp. 1(A)(2).

uses the manure from the permitted feedlot, that user must follow the requirements of the MMP relating to land application in order to protect water quality. These provisions are absolutely necessary to the Proposed Permits, as they fill a significant loophole. Requiring the permittee to follow carefully crafted provisions intended to prevent nitrate pollution but then not applying these same requirements to transferred manure would significantly undermine the effectiveness of the Proposed Permits and their impacts on pollution.

State and federal law compel the inclusion of these provisions in the Proposed Permits. Minnesota's feedlot rules explicitly require recipients of transferred manure to comply with the MMP of the seller.[133] But more than that: MPCA is required to include in every permit conditions that are needed to ensure compliance with state and federal laws and rules, and to include conditions the agency determines to be necessary to protect human health and the environment.[134] This includes—among others—conditions that will ensure water quality standards are met, including Minnesota's antidegradation standard for groundwater;[135] no wastes are being discharged into the waters of the state or deposited where they are likely to get into the waters of the state;[136] manure is not being applied in a way that would result in a discharge during the application process or that would cause pollution through manure contaminated runoff;[137] and manure application is limited to not exceed expected crop nitrogen needs.[138] The provisions of the Proposed Permits relating to the land application of manure and permittees' MMPs are crafted specifically to meet these requirements. As explained by MPCA when it adopted the feedlot rules:

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[133] Minn. R. 7020.2225, subp. 1(D).
[134] Minn. R. 7001.0150, subp. 2; Minn. R. 7001.1080, subp. 1.
[135] Minn. R. 7060.0500.
[136] Minn. Stat. § 115.03, sub. 1(a)(5)(ii).
[137] Minn. R. 7020.2225, subp. 1(A)(1) and (2).
[138] *Id.*, subp. 3.

> Given the complexities associated with manure management, it is extremely difficult to apply manure in an environmentally and agronomically-sound manner without some forethought, calculations and planning prior to applying the manure. A manure management plan is a fundamental tool used by producers to provide assurance that manure is applied at proper rates, times and locations. Combined with accurate records, the manure management plan also provides additional assurance that a particular facility is impacting the environment.[139]

If following the provisions of the Proposed Permits and the MMP is necessary for permittees to comply with Minnesota law, it is also necessary for recipients of transferred manure. Manure applied in the winter, in vulnerable groundwater areas, or within a floodplain does not become less risky to water quality simply because it is sold to another user before it is applied.

Statements at public hearings on the Proposed Permits have indicated that some producers are concerned that they will not be able to sell their manure if recipients are required to follow the requirements of their MMPs. This does not, however, constitute a reason for MPCA to not follow the requirements of state and federal law, which compel MPCA to issue permits that will protect water quality. In any case, there is no evidence that this in fact will happen. Manure is considerably less expensive than commercial fertilizer, so there will continue to be a market for it. Nor will it be overly burdensome for recipients to comply with the incremental, common-sense protections for water quality that are included in the MMPs, particularly compared to the burdens imposed on communities and well owners whose drinking water is contaminated by nitrate pollution. MPCA has already posted tools for permittees who intend to sell manure explaining the requirements for permittees and recipients, which will make compliance easier. In order to make progress on the nitrate pollution crisis in Minnesota, MPCA must include these provisions in the final permits.

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[139] 1999 Feedlot Rules SONAR, at 209 (Ex. 1).

D. MPCA must add further monitoring provisions to the Proposed Permits for both production areas and land application areas

Though the Proposed Permits' new provisions for visual inspections of land application areas and sampling of discharges are a welcome step forward, to ensure permittees are complying with permit provisions, MPCA must strengthen monitoring provisions both for land application areas and production areas.

Under both state and federal law, MPCA must include effective monitoring provisions in permits to ensure that permittees are complying with permit provisions and applicable laws. Under federal regulations, NPDES permits must include provisions that "assure compliance with [the] permit limitations" by specifying what monitoring is required, including monitoring of pollutants, volume of effluent, and other measurements.[140] Under Minnesota law, MPCA must include monitoring provisions in its permits that will generate data adequate to "ensure compliance with permit limitations."[141] If a discharge is occurring, the permit must specify the "[r]equired monitoring including type, intervals, and frequency sufficient to yield data which are representative of the monitored activity."[142] A NPDES permit for a CAFO that does not include monitoring provisions sufficient to ensure compliance with its terms—particularly for the kinds of difficult-to-observe issues that contribute to water pollution—does not meet the requirements of

[140] 40 C.F.R. §§ 122.44(i)(1)(i)–(iii); 122.48(b).
[141] Minn. R. 7001.1080, subp. 5; *see also* Minn. Stat. § 115.03, subd. 1(a)(5)(i).
[142] 40 C.F.R. §§ 122.44(i)(1)(i)–(iii); 122.48(b).

the law.[143] Such a permit would be of little practical use, and as explained by multiple courts, the CWA "demands regulation in fact, not only in principle."[144]

Here, the Proposed Permits are considered "zero discharge" permits—they generally prohibit discharges of manure or contaminated water from the production areas to channels that convey fluids to groundwater (§ 26.2) or to surface waters except when an overflow discharge results from a 25-year, 24-hour rainfall event (§§ 26.4, 26.5). For land application areas, the Proposed Permits prohibit land applying manure in a way that will result in a discharge to waters of the state during the application process or "exceed the hydraulic loading capacity of the land application site based on soil conditions" (§ 11.4). The NPDES Permit also prohibits discharges from land application areas to waters of the United States, except where the discharge qualifies as an "agricultural stormwater discharge" (§ 26.3), and the SDS Permit prohibits discharging from land application areas to waters of the state unless the discharge is caused by a precipitation event and the facility otherwise complies with permit requirements (SDS Permit § 26.4). But these prohibitions are toothless without monitoring provisions. Someone, either visually or using technology, must be inspecting the production areas and land application areas to ensure that there are no discharges in violation of the permits.

However, the Proposed Permits require only limited monitoring. The Proposed Permits retain current requirements for occasional visual inspections of LMSAs (§§ 17.4, 21.2) and weekly visual inspections of production area components (§ 20.2), and they add new requirements for

143 *Food & Water Watch v. Env't Prot. Agency,* 20 F.4th 506, 515 (9th Cir. 2021) ("Our case law confirms that NPDES permits must contain monitoring provisions sufficient to ensure compliance with the terms of a permit."); *Nat. Res. Def. Council v. Env't Prot. Agency*, 808 F.3d 556, 565, 583 (2d Cir. 2015) ("Generally, an NPDES permit is unlawful if a permittee is not required to effectively monitor its permit compliance." (internal citation omitted)).

144 *Food & Water Watch*, 20 F.4th at 515 (citing *Waterkeeper Alliance, Inc. v. Env't Prot. Agency*, 399 F.3d 486, 507 (2d Cir. 2005)).

visual inspections of the land application areas (§ 14.3) and sampling requirements for known discharges (§ 28.3). These provisions do not adequately ensure that permittees are not, in fact, discharging pollutants to surface waters and groundwater. MPCA must add more specificity to the proposed monitoring provisions and include additional monitoring provisions to ensure that sufficient data are collected to be representative of the monitored activity. In production areas, MPCA should require a regular and specific plan for sampling of discharges, daily visual inspections, and a groundwater monitoring plan. At land application sites, MPCA should add further requirements to strengthen the required visual inspections and groundwater monitoring requirements in vulnerable groundwater areas. Finally, for both production areas and land application areas, MPCA must add more specificity to the sampling provisions to ensure permittees have sufficient information about how to handle samples and that MPCA obtains sufficient information about whether permittees are causing violations of water quality standards.

1. The Proposed Permits' new land application monitoring requirements are a crucial step forward, but the additions do not go far enough

For land application areas, the Proposed Permits add helpful monitoring requirements, but these are not enough to ensure that permittees are truly complying with permit provisions. The permits are purportedly "zero discharge" permits, but it is well-established that most of the nitrate load to Minnesota's waters comes from cropland sources. Clearly, discharges are occurring from land application fields, and permittees must be required to take further action—including creating a comprehensive visual inspection plan and adding subsurface monitoring to high-risk fields—to ensure they are not violating the provisions of their permits and state and federal laws.

a. The new visual inspection provisions are a welcome step forward for the Proposed Permits

The Proposed Permits have added requirements for visual inspections of land application fields at all downgradient field edges; sensitive features including tile intakes, sinkholes, and wells;

ditches; and other features that could convey manure to waters (§ 14.3). These inspections must take place at least once on each day of manure application, at the end of each day of application, and after any significant rainfall within 14 days after application unless the manure is injected or incorporated (§ 14.3). Any discharge must be responded to and reported to the State Duty Officer and the MPCA (§§ 14.3, 27.2, 27.3). These requirements are not overly burdensome; they do not require investing in expensive equipment or even expending a significant amount of time. Instead, they are common-sense provisions that take the first, necessary step toward adding monitoring provisions that will ensure compliance with the Proposed Permit's prohibition on dry-weather discharges and Minnesota's rules protecting groundwater. Producers cannot know whether they are violating their permits if they do not—at an absolute minimum—look to see if manure is visibly running off of their fields during or immediately after application, or after a significant rainfall. State and federal law require MPCA to include *at least* these monitoring provisions in the Proposed Permits.

b. The new visual inspection provisions should be strengthened to improve their effectiveness

To make these visual inspections more effective and actually ensure compliance with the Proposed Permits, MPCA should require permittees to generate a detailed visual monitoring plan. The plan should identify all locations where monitoring will occur, including subsurface drain tile outlets if they exist, and all sensitive features that require buffers or setbacks as outlined in Section 15 of the Proposed Permit. These sensitive features should all be monitored to ensure that conservation practices such as buffers, setbacks, or compliance alternatives function as intended. Permittees should use the digital Nutrient Management Tool that MPCA plans to integrate into the final Permits to generate the visual monitoring plan, since that tool will locate sensitive features on all fields where manure is land applied. The monitoring plan should describe the methodology that will be used to determine representative monitoring locations. It also should be integrated into the public notice for permit coverage, so it is available for public review and comment. In addition, those monitored points of discharge must include subsurface drain tile outlets in addition to tile intakes. This aligns with the EPA's recommendation that the Proposed NPDES Permit should require the identification of any subsurface drain tile on all land application fields as well as requiring "observation of subsurface drain tile outlets prior to, during, and following land application of manure or process wastewater for volume/rate of flow and color, turbidity, foam, and odor to identify any discharges that may violate effluent limitations.[145] Further, for the areas with the highest risk of discharges at the surface—downgradient edges of fields or sinkholes, for example—the monitoring plan could include cheap and durable motion sensor cameras that could to detect discharges during applications and for 14 days thereafter.

c. Groundwater monitoring provisions for land application fields in vulnerable groundwater areas must be added to the Proposed Permits

To ensure compliance with the Proposed Permits, in addition to visual inspections, MPCA should require groundwater monitoring on fields with the highest risk of nitrate loss to groundwater from overapplication of nitrogen sources.[146] Subsurface monitoring of this kind is the only way to ensure that unauthorized discharges to groundwater, which would not be discovered by a visual inspection, are not occurring in violation of the Proposed Permits.

MPCA has already determined that fields in the new vulnerable groundwater areas are those most at risk of discharging nitrate and other pollutants to groundwater because of their soil and geologic conditions. And state agency data and producer surveys demonstrate that producers

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[145] EPA, Letter to MPCA re: Pre-Public Notice Draft Feedlot NPDES General Permit (MNG440000), Enclosure A p. 1 (May 9, 2024) (Ex. 43).
[146] For more details on effective monitoring tools for land application areas, see the comments of Food and Water Watch.

who land apply manure in addition to commercial fertilizer are likely to exceed recommended nitrogen application rates. Based on this combination of risk factors, land application fields that fall entirely within the mapped vulnerable groundwater areas should require subsurface monitoring in addition to visual inspections. To identify fields where there is a high risk of nitrate loss to groundwater and additional monitoring practices are required to comply with the Permit terms, MPCA should incorporate risk assessment tools like the USDA Web Soil Survey maps for coarse textured soils, shallow bedrock, and Manure and Food-Processing Waste limitations into the statewide definition of vulnerable groundwater areas, as well as the Minnesota Department of Natural Resources maps on Groundwater Sensitivity to Pollution.[147] MPCA should also incorporate these tools into the anticipated digital Nutrient Management Tool that feedlot operators will be required to use to generate MMPs under the Proposed Permit.

Along with a plan for visual inspections, permittees should be required create a plan for appropriate subsurface monitoring of their fields within their MMP, which would use soil probes, soil moisture probes, or lysimeters to monitor water quality within high-risk fields. These technologies would effectively monitor whether land application practices "exceed the hydraulic loading capacity of the land application site based on soil conditions," as required by the Proposed Permit and Minnesota feedlot rules (§ 11.4). Soil moisture probes and lysimeters require uniform installation across a field to generate representative data,[148] so a field-wide system must be used. Generally, one sample should be taken for every 20 acres, and the monitoring should occur during

[147] Both the USDA Web Soil Survey and the Minnesota DNR Groundwater Sensitivity maps are incorporated into the definition of vulnerable groundwater areas by the Minnesota Department of Agriculture under the Groundwater Protection Rule.
[148] Kevin Kuehner et al., *Examination of Soil Water Nitrate-N Concentrations from Common Land Covers and Cropping Systems in Southeast Minnesota Karst*, MDA (Oct. 2020) (Ex. 44).

land application or irrigation of fields where manure has been land applied.[149] If a discharge is discovered at a land application area and it is clear that there has not been an appropriate agronomic utilization of nutrients, the producer must be required to have a professional engineer or hydrogeologist review the MMP.[150] Results of the assessment would then be uploaded to the new digital Manure Management Tool and any deficiencies would have to be addressed by the permittee to ensure no additional discharges occurred. Subsurface monitoring at select fields in vulnerable groundwater areas would have the added benefit of generating representative data on the effectiveness of the newly required BMPs for these high-risk areas in the Proposed Permit. With this combination of comprehensive visual inspections and subsurface monitoring in the places where it is most needed, MPCA can ensure that permittees are actually following the requirements of the Proposed Permits and not discharging from land application areas.

2. The Proposed Permits fail to require sufficient monitoring of discharges from production areas

For production areas, the Proposed Permits only require occasional visual inspections, which are inherently unequipped to capture the myriad of ways in which CAFOs discharge from production areas. MPCA must alter the Proposed Permits to include monitoring requirements that capture these illegal discharges and other discharges that may violate the state's water quality standards. This includes requiring more frequent visual inspections and groundwater monitoring, potentially through a Subsurface Discharge Monitoring Plan.

a. MPCA must require more frequent visual monitoring to ensure production areas are not discharging to surface waters

Although the Proposed Permits generally prohibit discharges to surface waters, the monitoring provisions in the permits fail to impose a monitoring regime that is robust enough to

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[149] *See* Food & Water Watch comment on the Proposed Permit, David J. Erickson expert report.
[150] EPA, *Proposed 2024 Permit for CAFOs in Idaho*, Section IV.E.1 (June 2024) (Ex. 45).

detect such discharges. The Proposed Permits do not contain adequate monitoring requirements to identify if, and when, a facility is discharging at times other than when it is conditionally authorized to do so during a 25-year, 24-hour rainfall event. Under the current permit terms, an unauthorized discharge could occur for days or weeks before even a visual inspection is required (§20.1-21.2). To promptly capture and report unauthorized discharges, daily visual inspections of production areas should be required.

Daily visual inspections are particularly important with regard to LMSAs. The Proposed Permits require visual inspections of the LMSAs and their components weekly or after a 25-year, 24-hour storm event (§ 21.2). However, the Proposed Permits also require that the permittee notify MPCA within 24 hours of encroachment of the liquid manure into the freeboard of the LMSA (§ 17.5). MPCA must alter the inspection schedule in section 21.2 to require a daily visual inspection of the liquid level and freeboard marker in each LMSA to ensure that adequate freeboard is maintained. In order for a permittee to notify the MPCA "within 24 hours of encroachment" and list "the date when the freeboard encroachment began" under section 17.5, MPCA must require permittees to conduct daily, not weekly, visual inspections of the liquid level and freeboard marker in each LMSA.

b. MPCA must add groundwater monitoring provisions to ensure compliance with water quality standards

i. Visual inspections are insufficient for production areas, particularly when the approved liners are designed to leak

The Proposed Permits also prohibit discharges to groundwater (§ 26.2) to comply with Minnesota's strict protections for groundwater.[151] However, the Proposed Permits not only fail to

[151] *See* Minn. Rs. 7060.0400-.0600. MPCA must also monitor discharges to groundwater that are the equivalent of a "functional discharge" to surface waters. Particularly in areas like the karst region, there is no question that the groundwater and surface waters are intimately connected and

require any groundwater monitoring whatsoever at the production area, they in fact *allow* discharges to groundwater at significant levels through the design standards for LMSAs. Despite this, the Proposed Permits contain no way to ensure that production areas comply with the permit's zero-discharge requirement.

MPCA cannot avoid the need for groundwater monitoring by asserting that the Proposed Permits will prevent any discharges to groundwater, as the permits allow significant discharges to groundwater through the allowable designs for LMSA and manure stockpile liners. The Proposed Permits require permittees to construct manure storage areas in compliance with Minnesota's feedlot rules (§ 4.4). Under the feedlot rules, LSMAs, if not concrete lined, may be designed and constructed to "achieve a maximum theoretical seepage rate of not more than 1/56 inch per day."[152] However, this design standard allows a discharge from the LMSA of approximately 500 gallons per acre per day.[153] MPCA did not calculate how many millions of gallons of discharge it was authorizing from the hundreds of CAFOs covered under the general permits. Similarly, the Proposed Permits require the liner of a permanent manure stockpile to be built in compliance with Minnesota's feedlot rules (§ 6.2). The rules require the stockpile site liner to be constructed of soils or other liner materials that achieve hydraulic conductivity of 1 x 10^{-7} cm/sec or less.[154] Again,

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that discharges to groundwater enter surface water. Nitrate has an extremely low partitioning coefficient, which enables nitrate to migrate quickly through groundwater and travel long distances that can and do reach surface water. Nitrate plumes in groundwater have a high likelihood of impacting surface water.

[152] Minn. R. 7020.2100, subp. 3(C)(1).

[153] Natural Resources Conservation Service, *Agricultural Waste Management Field Handbook, Agricultural Waste Management System Component Design*, Appendix D, 10D-3 (2009) ("Waste Management Field Handbook") (Ex. 46) ("If regulations or other considerations require that unit seepage be less than 500 gallons per acre per day (1/56 inch per day), synthetic liners such as high-density polyethylene (HDPE), linear low-density polyethylene (LLDPE), ethylene propylene diene monomer (EPDM), or geosynthetic clay liners (GCL), concrete liners, or aboveground storage tanks may be more feasible and economical and should be considered.").

[154] Minn. R. 7020.2125.

this design standard allows a discharge. National Resources Conservation Service's Animal Waste Management Handbook, Section 10D states that, under conservative estimates, a permeability of 1 x 10^{-6} cm/sec will seep 9,240 gallons per day.[155] Using the same calculations, if a liner has a permeability of 1 x 10^{-7} cm/sec, it will still leak 924 gallons of manure-laden water per day *by design*. MPCA failed to explain how these standards and leakage rates ensure compliance with the "no discharge" permitting requirements. And those are only the discharges that are expected when liners are performing as designed. Over time, liners may fail, with earthen liners particularly vulnerable to increased leakage rates that degrade water quality.[156] This makes groundwater monitoring particularly important.

Notably, visual inspection requirements of lagoons (§ 20.1-21.2) are ineffective in lieu of monitoring because an inspector cannot visually see a leak below the opaque, manure-laden process wastewater. As a result, these inspections cannot in most cases determine if a lagoon is leaking or seeping to a degree that exceeds the permits' effluent limitations. LMSAs operate dynamically, with differing inputs (e.g., manure, precipitation, process wastewater) and outputs (e.g., land application, manure transfer, evaporation) of varying quantities and timing throughout the crop year. Requiring permittees to monitor LMSAs through only visual inspections means only the most catastrophic leaks will be detected, as measuring lagoon seepage and leakage through observation of a freeboard measuring stick is imprecise given the dynamic nature of LMSAs. With the substantial groundwater contamination problems plaguing Minnesota, especially the Southeastern portion of the state, a mere visual accounting of the integrity of large LMSAs is contrary to the goals of the Proposed Permits and Minnesota law.

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[155] Waste Management Field Handbook at 10D-2 (Ex. 46).
[156] MPCA, *Best Management Practices and Data Needs for Groundwater Protection*, at 16 (2019) (Ex. 47).

Moreover, construction requirements do not substitute for leak detection monitoring. The routine cleaning of manure solids results in excavation, erosion, and liner damage over the life of the lagoon. As a result, a lagoon that meets the permits' requirements when constructed may fail the requirements after the first and subsequent cleanings. Permittees cannot know if there is an impact to groundwater through construction mistakes or erosion without routine monitoring.

Thus, MPCA must require groundwater monitoring as a requirement of the permits. Indeed, as the Ninth Circuit Court of Appeals recently found in a challenge to a similar general feedlot permit in Idaho, "[w]ithout a requirement that CAFOs monitor waste containment structures for underground discharges, there is no way to ensure that production areas comply with the Permit's zero-discharge requirements."[157]

ii. MPCA has several options for adding groundwater monitoring at production areas to the Proposed Permits

While producers may claim that groundwater monitoring is overly burdensome, several options exist for groundwater monitoring, or at a minimum, a Subsurface Discharge Monitoring Plan for the production areas to be added to the Proposed Permits.

Groundwater monitoring is a simple and well-established process that does not require new or innovative technologies, and it is the only method to definitively determine whether a subsurface discharge complies with the state's groundwater quality standards. In fact, groundwater monitoring is a condition of numerous other state discharge permits.[158] Groundwater monitoring can be accomplished with low-cost lysimeters, a series of up and downgradient groundwater monitoring

[157] *Food & Water Watch*, 20 F.4th at 517.
[158] *See* MPCA, *Discharge Monitoring Reports*, https://www.pca.state.mn.us/business-with-us/discharge-monitoring-reports (last visited Aug. 29, 2024).

wells, or a designed leak detection sump system. Well drilling, sampling and analysis protocols are well documented in EPA regulations.[159]

To determine the most appropriate form of monitoring for a particular site, MPCA should require a Subsurface Discharge Monitoring Plan ("SDMP") as part of a permittee's MMP, included in the permittee's notice of issuance of permit and subject to public review and comment. An SDMP (a) identifies the structures and locations to be monitored, (b) establishes a routine periodic inspection schedule adequate to identify leaks, damage, and other issues that could cause a subsurface discharge, (c) identifies criteria or protocols that will be used to determine whether a subsurface discharge has occurred, and (d) establishes site-specific protocols for monitoring subsurface discharges.[160] SDMPs are particularly necessary where, as here, the Proposed Permits do not require routine inspections of the integrity of the liners used in production areas. Requiring SDMPs will ensure that liner materials retain their structural integrity and prevent all discharges, while also ensuring that permittees are not burdened with a "one size fits all" groundwater monitoring plan that might impose more monitoring than their feedlot truly needs.

To start, MPCA could follow the specific language EPA used in its latest draft NPDES General Permit Modification for CAFOs in Idaho to require SDMPs unless each wastewater or manure storage structure is "constructed of concrete or steel, or with a double-layer synthetic liner with leak detection, and is properly operated and maintained in accordance [with the Permit's structural evaluation requirement]."[161] MPCA should include language ensuring that monitoring plans are tailored to individual facilities, similar to how MMPs are facility specific. Since the approved manure storage structures are *designed to leak*, monitoring plans must be targeted at the

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[159] 40 C.F.R. §§ 257.91–.95.
[160] EPA, *Proposed 2024 Permit for CAFOs in Idaho*, Section IV.D (Ex. 45).
[161] EPA, *Proposed 2024 Permit for CAFOs in Idaho*, Section III.A.2.a.iii (Ex. 45).

characteristics of the underlying hydrogeology receiving that continuous seepage. These site-specific plans must be designed by a professional engineer or geologist with experience in monitoring methodology, systems, and analytical requirements. Further, MPCA should require that groundwater monitoring systems be progressively more rigorous depending on the type of waste impoundment liner used. Earthen liners should require a full groundwater monitoring plan,[162] while synthetic liners could require an abbreviated monitoring scenario, and a double synthetic liner with leak detection or a sump and pump design would not require a groundwater monitoring system at all *if* the operation and maintenance standards outlined in Minnesota Rule 7020.2100 subpart 6 are met.

Notably, monitoring through these kinds of tools, even through monitoring wells, is immensely cheaper and less time consuming than remediation of impacts to groundwater and drinking water aquifers. Remediation involves the physical removal of the manure-saturated soils under the waste lagoons and compost areas, treatment or removal of contaminated soil in the vadose zone, active treatment of groundwater, or treatment of drinking water for communities and private well owners. Such remediation can cost tens to hundreds of millions of dollars. Proper permitting, monitoring, and management vastly reduce these costs by minimizing impacts to soil and groundwater. Thus, MPCA must alter the Proposed Permits to require effective monitoring at production areas and land application areas.

[162] For a full groundwater monitoring plan, wells should be placed upgradient and downgradient of the lagoon or area to be monitored, and sampling should be conducted quarterly or semiannually to establish seasonal fluctuation in groundwater quality or quantity, to collect representative data, and to establish statistically significant background data. Data analysis requires statistical evaluation of the data to determine if upgradient water quality is different than downgradient water quality. A statistically significant delta between these two data sets establishes that the monitored area is contributing pollutants to groundwater.

3. The Proposed Permits' new discharge sampling requirements are a step forward, but the provisions do not go far enough

In addition to monitoring for the existence of discharges, the Proposed Permits must include provisions that will determine whether the discharge is causing a violation of water quality standards or other state or federal laws—including requirements to sample the content of discharges and waters contaminated by the discharge. MPCA is obligated by Minnesota Rules to include monitoring requirements in the Proposed Permits that include (1) a measurement of the volume of effluent discharged from each outfall and (2) any other measurements needed to determine compliance with a permit condition.[163] Accordingly, the Proposed Permits must contain monitoring requirements that will measure the volume of effluent being discharged as well as measurements that will determine whether the discharge is leading to violations of water quality standards. In addition, the Proposed Permits require compliance with all state and federal water quality standards, including the groundwater antidegradation standard and the narrative standards for Class 2 waters. The permits must, therefore, contain provisions that would determine whether discharges are causing violations of these standards. This can only be done by requiring routine water sampling. Though the Proposed Permits do now require some water sampling, they do not go far enough to ensure compliance with state and federal law.

a. The new water sampling provisions are a welcome addition to the Proposed Permits

The Proposed Permits now require that the permittee monitor discharges by collecting a sample of the discharge and a sample of the water the discharge is entering and have those samples analyzed by a certified lab (§ 28.3). If conditions make sampling unsafe—as in flood conditions or severe weather—the permittee may delay sampling until the conditions have passed (§ 28.3).

[163] Minn. R. 7001.1080, subp. 5.

These provisions are required by MPCA's obligations under state and federal law to include appropriate monitoring provisions to ensure permit compliance. As with the visual inspection of the land application areas, obtaining several samples of discharges is the absolute minimum that should be required of permittees. Without samples, MPCA cannot determine whether water quality standards are being exceeded, violating state and federal law as well as the permit provisions. Sampling requirements must be included in the Proposed Permits.

b. Further instructions for sampling and additional sampling requirements must be added to the Proposed Permits

While the addition of water sampling is a step forward, the Proposed Permit provides little guidance for how, when, and where to obtain samples, and it does not go far enough in imposing conditions that will actually determine whether water quality standards are being violated. The Proposed Permits should be revised to remedy these deficiencies, and in particular to require sampling of drain tile outlets, as recommended by the EPA.

First, the Proposed Permits provide little guidance for permittees who may not know how to correctly obtain a discharge or water sample. Though the Proposed Permits point to Minnesota Rule 7053.0155, this rule does not provide any practical information about how to obtain the samples. Nor do the Proposed Permits explain where, how, or when to send such samples, other than to a "certified lab." Additional details—either in the permit itself or a linked document—likely would increase compliance with this new provision of the Proposed Permits. MPCA could point to established water sampling protocols, such as Section 3 of EPA's Industrial Stormwater Monitoring and Sampling Guide[164] or the EPA Region 4 Surface Water Sampling procedures.[165]

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[164] EPA, *Industrial Stormwater Monitoring and Sampling Guide, 832-B-09-003* (April 2021), https://www.epa.gov/sites/default/files/2015-11/documents/msgp_monitoring_guide.pdf.

[165] EPA, *Region 4 Surface Water Sampling Procedures, LSASDPROC-201-R6* (April 2023), https://www.epa.gov/sites/default/files/2017-07/documents/surface_water_sampling201_af.r4.pdf.

Alternatively, it could draft its own details. Either way, MPCA should provide more information about how to sample, including how large the sample should be, what kind of container is appropriate, how to handle the samples after obtaining them, and information for labs where the samples could be sent. The protocol should specify instances where instruments that require experienced operators—such as the automatic flow proportionate sampling devices for stream water grab samples—are necessary. Samples should be analyzed in accordance with approved EPA methods (as set forth in 40 C.F.R. Part 136) for, at a minimum, total Kjeldahl nitrogen, nitrate nitrogen, nitrite nitrogen, total phosphorus, E. coli, fecal coliform, and five-day biochemical oxygen demand. Producers should be required to identify the sampling points with a map, latitude and longitude, or a narrative description that provides enough information for a reviewer to pinpoint the location. Including more specific instructions would likely encourage more compliance with the sampling requirements, as permittees will have more information about how to effectively comply.

Second, the sampling requirements are not clear regarding when samples must be taken. As written, Section 28 could be read to require sampling only of a discharge that is detected and reported to the State Duty Officer. But to actually obtain representative data sufficient to characterize the monitored activity and determine whether it causes or contributes to a violation of state water quality standards, producers must do more. Instead, MPCA should impose a regular schedule of required sampling at both land application sites and production areas, including samples of dry-weather discharges into tile outlets, ditches, or alternative locations that provide representative data.[166] For land application areas, this should include samples taken before land application, to provide baseline data, and samples taken within 14 days of land application, to

[166] *See* EPA, *Proposed 2024 Permit for CAFOs in Idaho* (Ex. 45).

determine whether changes have occurred. For production areas, producers should be required to take samples to obtain baseline data and then set a regular schedule for sampling of authorized and unauthorized discharges. These requirements for both land application and production areas could be built into the MMP, and specifically into MPCA's new online tool, which could help producers identify appropriate places for sampling.

In its comments on the Proposed Permits, EPA recommended to MPCA that it include sampling requirements for drain tile outlets, but MPCA asserted that such a requirement would be too difficult to implement.[167] However, tile drainage is one of the most significant ways that nitrate gets into Minnesota's waters, making the tile outlets one of the most important sources to monitor and sample. To meet its obligations to include monitoring provisions sufficient to ensure that permit provisions are being met, MPCA must revise this section to include more information regarding sampling protocol and a regular schedule for sampling at discharge points.

Overall, adding effective monitoring and sampling provisions is one of the most significant changes MPCA can make to the Proposed Permits. As other courts have recently determined, and the EPA has recognized in the proposed Idaho CAFO General Permit, permits without effective monitoring provisions cannot address the problem of water pollution from feedlots. These changes are absolutely critical to addressing Minnesota's nitrate contamination crisis.

E. MPCA must add provisions requiring pre-plant soil testing for nitrate to the Proposed Permits

To comply with state and federal law and address water quality issues, MPCA should not only implement its proposed changes to the Proposed Permits and make revisions to strengthen those changes, MPCA should also make several additional changes to the permits that will help

[167] MPCA, Letter to EPA re: Pre-Public Notice Draft Feedlot NPDES General Permit (MNG440000) (June 18, 2024) (Ex. 49).

address nitrate pollution. First, in addition to requiring water sampling, the Proposed Permits must include requirements for pre-plant soil nitrate testing. No spring soil testing for nitrate currently is required by the Proposed Permits, although they require soil phosphorus testing every four years (§ 11.5). Adding requirements for nitrate pre-plant testing will ensure that producers are appropriately taking credit for nutrients already in the soil before they add even more nitrogen.

Under Minnesota's land application rules and the provisions of the Proposed Permits (§ 12.3), manure must not be applied at rates that "exceed expected crop nitrogen needs for nonlegume crops and expected nitrogen removal for legumes."[168] In determining whether sufficient nitrogen has been applied, producers must consider *all* nitrogen sources, including not only fertilizer and manure applied that particular year, but also manure applied in previous years, soil organic matter, and legumes grown during previous years.[169] However, it is well-established that producers often fail to properly credit all sources of nitrogen, particularly for previously planted legumes and previously applied manure.[170] Requiring a pre-plant soil nitrate test would ensure that producers who may not properly account for all nitrogen sources actually need additional applications of nitrogen.

Recognizing that pre-plant nitrogen tests can be a tool to ensure nitrogen is not overapplied, the feedlot rules require MMPs to include plans for soil nitrate testing in accordance with Extension Service recommendations.[171] Even though the Proposed Permits do not require soil

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[168] Minn. R. 7020.2225, subp. 3(A).
[169] *Id.* subp. 3(A)(1).
[170] MDA, *Minnesota Nitrogen Fertilizer Management Plan*, 63, 136-37 (Mar. 2015) (explaining survey data shows the need to improve crediting for nitrogen sources including previous years' legumes and manure, that proper manure crediting is one of the greatest opportunities for advancement in nutrient management, and that lack of proper manure crediting is a statewide issue).
[171] Minn. R. 7020.2225, subp. 4(D)(12).

nitrate tests, the Extension Service does recommend soil nitrogen tests in the fall in western Minnesota and in the spring in south-central, southeastern, and east-central Minnesota.[172] The recommendations also explain that appropriate credits based on the soil nitrate concentration determined by the test can be up to 155 pounds of nitrogen per acre—the entire amount of nitrogen that should be applied in some situations under Extension Service recommendations.[173] This could, in some cases, prevent significant overapplication of nitrogen to fields where more nutrients are not needed—which is helpful both for the environment and producers' bottom lines. Accordingly, to comply with the feedlot rules, MPCA must add requirements for annual pre-plant soil nitrate tests that follow the Extension Service recommendations.

F. MPCA must add a provision requiring nutrient testing before any application of digestate

The Proposed Permits currently require permittees to analyze manure for its nutrient content annually and following any changes that may significantly affect its nutrient content (§ 8.2). This provision should be revised to explicitly require that any digestate from an anaerobic digester be sampled and analyzed for nutrient content before application. Manure that enters a digester and the digestate that exits it will have significantly different properties and nutrient content, particularly if different waste streams are combined. Digestate has significantly higher concentrations of nutrients than manure, with higher proportions of plant-available forms of

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172 Univ. of Minn. Extension Service, *Fertilizing Corn in Minnesota* (Ex. 25). The Extension Service recommendations say the pre-plant nitrate test should not be used in the spring when manure or commercial nitrogen has been applied the previous fall or in the spring before the sample was taken. *Id*. However, for western Minnesota, this simply means that the nitrate test should be taken in the fall before any manure or commercial fertilizer is applied. For the areas of Minnesota where a spring pre-plant nitrate test is recommended, the sample should be taken before any nitrogen is applied.

173 *Id.*

nitrogen.[174] This higher concentration could easily lead to overapplication of nitrogen when digestate is applied. In addition, digestate may have a different composition each time it is applied, depending on the particular inputs that were combined to produce it. Accordingly, production of digestate should be considered a "change[ ] to conditions that may significantly affect the nutrient content," (§ 8.2) and any application of digestate should be tested for its content before application. Stating this clearly in the Proposed Permits will help reduce the risk of inadvertent nutrient overapplication.

G. MPCA must add a provision requiring producers to use the Runoff Risk Advisory Forecast before land applying manure

The Proposed Permits require manure to be injected or immediately incorporated into soil if the National Weather Service predicts that there is a more than 50 percent chance of rainfall over 0.5 inches within 24 hours of the application period (§ 13.3). This is not a new requirement, and it is reasonable considering the higher risk of runoff in rainy conditions. However, MPCA should further decrease the risk of manure runoff by also requiring permittees to use the MDA's Runoff Risk Advisory Forecast ("RRAF"), a tool specifically created by MDA to help producers determine the best time to apply manure.[175]

The RRAF was created specifically to help reduce manure nutrient runoff.[176] Rainfall during or immediately after manure application is a significant source of runoff—in one study, more than half of the runoff from fields was caused by one or two rain events each year.[177] The RRAF is more accurate in predicting a runoff risk than a weather report, as it considers not only

[174] *See* MDA, *Manure Digesters*, https://www.mda.state.mn.us/environment-sustainability/manure-digesters.
[175] MDA, *Runoff Risk Advisory Forecast*, https://www.mda.state.mn.us/protecting/cleanwaterfund/toolstechnology/runoffrisk.
[176] *Id.*
[177] MDA, *Root River Field to Stream Partnership* (Ex. 23).

upcoming rainfall, but also soil moisture content, temperatures, snow melt, and other factors.[178] It is more precise than a weather report as well—the RRAF uses this information to assign a specific runoff risk to each 2 square kilometer area of the state: No Runoff Expected, Low, Moderate, or Severe. Producers can sign up to receive texts on their phones for their fields, making the system extremely user-friendly. However, relatively few producers have signed up to use the tool, despite its usefulness.

To reduce the risk of runoff—at times when the state's own model has determined risk of runoff is high—MPCA should add provisions to the Proposed Permits that require permittees to (1) sign up for the RRAF, (2) reconsider applying manure in fields where the risk is "moderate," and (3) refrain entirely from applying manure in fields where the risk is "severe." Again, MPCA has the authority to add such a provision to the permit. Spreading manure at a time when the state's own tool determines that the risk of runoff is "severe" violates the feedlot rules' requirement that manure not be applied in a way that will create runoff that will pollute the waters of the state.[179] In addition, prohibiting application of manure when runoff risk is "severe" is a reasonable BMP to impose in order to ensure permittees comply with water quality standards. To help address nitrate pollution, MPCA should add these provisions to the Proposed Permits instead of relying solely on weather forecasts.

H. MPCA must add a provision imposing additional restrictions on emergency manure applications

The Proposed Permits allow emergency manure applications (1) when application would ordinarily be prohibited because of forecast rain (§ 13.3), (2) without the otherwise-required implementation of the fall BMPs, even in vulnerable groundwater areas (§§ 13.5, 13.6), and (3) of

[178] *Id.*
[179] Minn. R. 7020.2225, subp. 1(A)(2).

liquid manure in winter conditions when certain BMPs are followed (§ 13.7). Situations that constitute an emergency under the Proposed Permits include "unusual weather conditions, unavoidable equipment failure, or other circumstances that could not have been avoided with proper planning and management." (§ 31.20.) Under these circumstances, producers are allowed to apply manure in ways that MPCA has explicitly determined are too dangerous to water quality to otherwise be allowed.

MPCA should implement more restrictions on these emergency applications. As EPA recommended, MPCA should provide further clarification of the extremely vague phrase "unusual weather conditions," [180]which permittees could interpret as meaning nearly anything, even one instance of unusually heavy rain. Instead, this should be defined as a truly extraordinary and unexpected amount of rainfall. As EPA also recommended, MPCA should provide more options for managing manure than only storage—for example, treatment—before allowing emergency application.[181] In addition, even in an emergency application, certain of the fall BMPs still could be used, including using a nitrogen stabilizing agent or requiring cover crops after the application. MPCA could also require the BMPs for winter application of liquid manure to be followed for any emergency application of manure (§ 13.7).

In response to EPA, MPCA asserted that further restrictions on emergency application are unnecessary because producers must notify MPCA within 24 hours of encroachment of the freeboard in an LMSA, which allows MPCA and the producer to explore options other than an emergency application.[182] There are several problems with this response. Nothing prohibits a

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[180] EPA, Letter to MPCA re: Pre-Public Notice Draft Feedlot NPDES General Permit, at 5 (Ex. 43).
[181] *Id.*
[182] MPCA, Letter to EPA re: Pre-Public Notice Draft Feedlot NPDES General Permit, at 7 (Ex. 49).

permittee from conducting an emergency application within that 24-hour period before contacting MPCA—in fact, the responsibility of the permittee to maintain the freeboard might suggest to permittees they should conduct the application immediately (§17.5). Alternatively, the producer might have considered the application to be an "emergency" without encroachment of the manure into the freeboard, or the application could be of solid manure, not from an LMSA at all. Nor does this response explain why MPCA could not require any fall BMPs feasible under the particular conditions, or why the winter emergency limitations do not apply to other emergency applications. If MPCA is indeed relying on permittees to discuss an emergency application with MPCA in advance, MPCA should simply prohibit all emergency applications until the permittee has contacted MPCA to discuss options for the application. But the Proposed Permits do not have such a provision.

Under the Proposed Permits, a determination that an emergency application of manure is needed—which permittees have considerable freedom to determine on their own—allows producers to engage in a number of practices that MPCA has explicitly determined pose an unacceptable risk to water quality. MPCA has the authority and duty to place further limitations on these risky practices to ensure that such applications are used only when necessary and are conducted in the manner that poses the least threat to water quality.

IV. MPCA must consider the positive climate impacts of the changes to the Proposed Permits

In addition to considering the effects of the Proposed Permits on nitrate pollution, MPCA must assess the climate implications of issuing the Proposed Permits, even though the permits are not directed at controlling air emissions. The Minnesota Legislature has prioritized greenhouse gas emission reductions, setting a goal to reduce all emissions to net zero by 2050.[183] This goal is informed by the state's 2022 Climate Action Framework, which establishes a goal of reducing annual greenhouse gas emissions and increasing the amount of carbon sequestered from the "working lands" economic sector, which includes agriculture, by 25% by 2035.[184] The Framework's key initiatives for achieving this goal include promoting soil health and best manure management practices, and supporting end markets for the cover and perennial crops that increase carbon storage and decrease use of nitrogen fertilizer.[185] Accordingly, MPCA is also required to use its authority to implement Proposed Permits that will move Minnesota toward the accomplishment of these goals.

The same changes in the Proposed Permits that will have positive water quality impacts will also mitigate greenhouse gas emissions and, in some cases, even act as a carbon sink. Changes that limit the amount of excess nitrogen in soil and water will also reduce denitrification, which creates nitrous oxide emissions. The proposed fall BMPs, limits on winter spreading, the requirement that manure recipients follow MMPs, and requirements for visual inspections to minimize overapplication and runoff will all have climate impacts as well as water quality impacts. In addition, certain BMPs—including the requirements to use cover crops and perennial crops—even act as carbon sinks.

A literature review conducted by the MPCA estimated that cover crop use could avoid an average of 1.19 CO_2e metric tons of emissions per hectare per year.[186] This review also estimated

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[183] Minn. Stat. § 216H.02.
[184] *Minnesota's Climate Action Framework*, at 33, https://climate.state.mn.us/sites/climate-action/files/Climate%20Action%20Framework.pdf.
[185] *Id* at 36-38.
[186] MPCA, *Greenhouse gas reduction potential of agricultural best management practices (revised edition)*, at 91 (Sept. 2022), https://www.pca.state.mn.us/sites/default/files/p-gen4-21.pdf.

that cover crops could sequester an additional 0.42 metric tons of carbon per hectare per year.[187] Lengthening annual crop rotation by adding two or more years of perennial grasses or alfalfa could avoid 41,000 CO2e tons of emissions annually, per 100,000 acres, with most of the emission reductions coming from carbon sequestration in soil.[188] Published studies of the carbon sequestration potential of perennial or alfalfa crop rotations suggest that these practices could sequester 0.32 to 0.46 metric tons of carbon per hectare per year.[189] Accordingly, the potential for greenhouse gas reductions from the agricultural sector—the state's largest contributor to climate-change causing emissions—provides another reason for MPCA to implement its proposed changes and the further changes proposed by the Clean Water Organizations to limit excess nitrogen in soil and water.

CONCLUSION

MPCA's Proposed Permits make helpful steps forward on the nitrate pollution problem, as well as reductions of greenhouse gas emissions, but the Clean Water Organizations respectfully submit that they do not go far enough to make sufficient progress on this widespread, persistent, and dangerous problem. To comply with state and federal law and to protect Minnesota's surface waters and groundwaters, MPCA must include all of its proposed changes to the Proposed Permits, including the following:

Permit Section	**Provision**	**Summary of Change Proposed by MPCA**
9.3	Prohibitions on manure transfer	• Permittee must not transfer manure to recipient who will improperly apply liquid or solid manure to vulnerable groundwater areas during winter conditions in December, January, February, or March.
9.4	Summary of requirements	• Permittee must provide a Manure Transfer Tracking form to the recipient at time of transfer.

[187] *Id.* at 93.
[188] *Id* at 121-22.
[189] *Id* at 123.

10.2	MMP development	• All manure recipients must comply with the requirements of the MMP.
13.6	Vulnerable Groundwater Restrictions: Fall Spreading	• For October and November land applications of manure, use additional BMPs starting in 2028.
13.8, 13.9	Vulnerable Groundwater Restrictions: Winter Spreading	• For December, January, and February, application of solid manure is prohibited in winter conditions.
14.3	Land application area visual inspections	• All fields that receive manure must be visually inspected for evidence of manure discharge at downgradient field edges and other potential discharge locations, at least once for each day of application, at the end of each day of application, and as soon as possible after a rainfall of 0.5 inch within 14 days of application, unless manure is injected or incorporated.
15.4	Incorporation in 100-year floodplain	• Manure must be injected or immediately incorporated within the 100-year floodplain.
24.7	Records of manure application	• Permittee must maintain records of manure application activities, including when manure ownership is transferred, within the Nutrient Management Tool.
28.3	Sampling of discharges	• Permittee must ensure that all discharges, including authorized discharges, do not cause or contribute to non-attainment of applicable state water quality standards and must take samples of discharges.

In addition, MPCA should include the following additional changes in the Proposed Permits:

Permit Section	**Provision**	**Summary of Change Proposed by Clean Water Organizations**
8.2	Manure nutrient testing	• Add requirement that any digestate from an anaerobic digester be sampled and analyzed for nutrient content before testing.
11.5	Soil testing	• Add requirement for annual nitrate soil tests in accordance with Extension Service guidelines for fall tests in western Minnesota and spring tests in south-central, southeastern, and east-central Minnesota.

13.3	Prohibition on spreading when rain forecast	• Add requirements to follow the Runoff Risk Advisory Forecast. • Permittee must reconsider applying manure in fields when risk is "moderate." • Permittee cannot apply manure in fields when risk is "severe."
13.5, 13.6, 13.7	Emergency manure applications	• Require permittees to consider treatment of manure before spreading. • Require permittees to follow fall BMPs where possible in an emergency application. • Require permittees to follow BMPs for an emergency application of manure in winter conditions for any emergency application. • Alternatively, prohibit emergency manure applications until the permittee has contacted MPCA to discuss options for the application.
13.6	Oct./Nov. vulnerable groundwater area restrictions	• Remove language stating that vulnerable groundwater area restrictions are not required until 2028. • Require these BMPs statewide.
13.8, 13.9	Dec./Jan./Feb. winter conditions restrictions	• Require these restrictions on spreading in winter conditions statewide.
14.3	Visual inspections of land application areas	• Require visual monitoring plan that identifies locations where monitoring will occur and all sensitive features. • Require monitoring of subsurface drain tile outlets. • Add requirements for motion sensor cameras for high-risk areas in vulnerable groundwater areas, including downgradient field edges and sinkholes during application and for 14 days thereafter.
14.4	Groundwater monitoring at land application areas	• Add requirements for soil probes and soil moisture probes or lysimeters in fields that lie entirely within vulnerable groundwater areas. • If discharge discovered, professional engineer or hydrogeologist must review MMP and permittee must address deficiencies.
20.2	Visual inspections of production areas	• Require daily inspections of production areas.

21.2	Inspections of LMSAs	• Add site-specific groundwater monitoring plan, based on liner used at LMSA and manure stockpile or Subsurface Discharge Monitoring Plan. • Require regular groundwater monitoring in accordance with plan.
28.3	Sampling requirements for discharges	• Add further details about sampling by referring to established water sampling protocols or adding more information about how and where to sample and handling and testing of samples. • Require permittees to identify sampling points with specificity. • Add regular schedule of required sampling at land application areas, including samples of dry weather discharges into tile outlets and ditches, taken before land application and within 14 days of land application. • Add sampling requirements for drain tile outlets. • Add regular schedule of required sampling at production areas.
31.20	Definition of emergency manure application	• Further define "unusual weather conditions" to ensure only excessive rain events qualify.

/s/Joy R. Anderson
Joy R. Anderson
Minnesota Center for Environmental Advocacy
1919 University Avenue West, Ste. 515
Saint Paul, Minnesota 55104
(651) 223-5969

/s/Carly Griffith
Carly Griffith Ph.D.
Minnesota Center for Environmental Advocacy
1919 University Avenue West, Ste. 515
Saint Paul, Minnesota 55104
(651) 223-5969

On behalf of the Clean Water Organizations

Minnesota Center for Environmental Advocacy,
CURE
Environmental Working Group
Friends of the Mississippi River
Food & Water Watch
Minnesota Division, Izaak Walton League of America
Will Dilg Chapter, Izaak Walton League of America
Minnesota Trout Unlimited
Hiawatha Trout Unlimited
Minnesota Well Owners Organization
Northern Waters Land Trust

Roots Return Heritage Farm LLC
Winona Clean Water Coalition

And the undersigned individual supporters:

Name	Address	City	State	Zip
Janet Ackerman	15781 Hayes Trl	Apple Valley	MN	55124
Mair Allen	2829 17th Ave S	Minneapolis	MN	55407
Andrew Anderson	133 3rd Ave SW Apt 201	Hutchinson	MN	55350
Angela Anderson	1121 4th St N Apt 1	Stillwater	MN	55082
Janet Anderson	317 Locust St	Saint Peter	MN	56082
Lynn Anderson	15621 Goshawk St	Tamarack	MN	55787
Craig Andresen	2013 Walnut Ave	Saint Paul	MN	55112
Lori Andresen	3025 E Superior St	Duluth	MN	55812
Christine Andrews	94 Crocus Pl	Saint Paul	MN	55102
DyAnn Andybur	4119 Mcculloch St	Duluth	MN	55804
Christine Austin	606 N Saluki Dr	Marion	IL	62959
Sharon Bachman	13000 Sylvan Ave	Lindstrom	MN	55045
Ellen Barr	2735 138th Ave NW	Andover	MN	55304
Vedavathi Bellamkonda-Athmaram	350 Nathan Ln N Unit 542	Plymouth	MN	55441
Bonny Bellville	737 Forest Hills Dr SW	Rochester	MN	55902
Glenn Biegon	1071 Charles Ave	Saint Paul	MN	55104
Gerald Blaisdell	4216 Manorwoods Dr NW	Rochester	MN	55901
Jon Blumenthal	5941 Grimes Ave S	Edina	MN	55424
Joanna Bobbitt	3327 21st Ave S	Minneapolis	MN	55407
Lawrence Bogolub	1424 Lincoln Ave	Saint Paul	MN	55105
Julia Bohnen	8881 Irving Ave S	Minneapolis	MN	55431
Dean Borgeson	36030 Bonnie Lakes Rd	Crosslake	MN	56442
Diana Brainard	4544 Sunset View Dr	Duluth	MN	55803
Gretchen Bratvold	3444 Edmund Blvd	Minneapolis	MN	55406
Naomi Brim	1800 Washington Ave S Apt 412	Minneapolis	MN	55454
Cynthia Brockway	1664 Nebraska Ave E	Saint Paul	MN	55106
David Brockway	6301 Maloney Ave	Hopkins	MN	55343
Kelsey Brodt	1013 120th Ln NW	Minneapolis	MN	55448
Meredith Bruster	421 Dayton Ave Apt 2	Saint Paul	MN	55102
Elizabeth Burr	2025 Fairmount Ave	Saint Paul	MN	55105
Garrett Butler	PO Box 64	Medford	MN	55049
Liz Campbell	605 N 64th St	Seattle	WA	98103
Rick Canning	548 S Randall Rd	Aurora	IL	60506
David Carlson	5818 County Road 2	Fort Ripley	MN	56449
Susan Chambers	700 Agency Trl Unit 202	Mankato	MN	56001
JL Charrier	1910 Heritage Dr	Wayzata	MN	55391
Steven Chesney	8172 Zenith Ct N	Minneapolis	MN	55443
Jeff Christopherson	2382 Bourne Ave	Saint Paul	MN	55108
James Clapp	24613 N Melissa Dr	Detroit Lakes	MN	56501
sharon coombs	3400 Owasso St	Saint Paul	MN	55126
Lori Cox	14525 County Road 40	Carver	MN	55315
Amy Crane	4909 Hodgson Connection	Shoreview	MN	55126
Dennis Cuchna	2108 Irvine Pl	Alexandria	MN	56308
Cathy Curtis	1714 Whitetail Run	Buffalo	MN	55313

Name	Address	City	State	Zip
Suzanne Damberg	415 Vadnais Lake Dr	Saint Paul	MN	55127
Matthew Davis	15274 Sunset Hill Dr	Detroit Lakes	MN	56501
Tina Decker	2253 Clark Ct	Saint Paul	MN	55122
Lobsang Dhondup	2680 Oxford St N	Saint Paul	MN	55113
Christy Dolph	3323 Benjamin St NE	Minneapolis	MN	55418
Patrick Doss-Smith	210 N 3rd Ave	Albert Lea	MN	56007
Kim Dupre	17835 Norell Ave N	Marine On Saint Croix	MN	55047
Valerie Eastland	13570 Hershey Ct	Saint Paul	MN	55124
Kaye Eiken	25783 Cedar Rd	Peterson	MN	55962
Stephanie Emerich	1393 Schletti St	Saint Paul	MN	55117
John Enblom	14755 113th St S	Hastings	MN	55033
Barbara Erickson	104 W 36th St	Minneapolis	MN	55408
Cheryl Ethen	1225 Karth Lake Dr	Arden Hills	MN	55112
William Faber	7427 Cottonwood Rd	Cushing	MN	56443
Mary Faulkner	4921 Girard Ave S	Minneapolis	MN	55419
Alan Felix	4141 Connelly Cir NE	Bemidji	MN	56601
dwight fellman	7909 Victoria Curv	Minneapolis	MN	55426
John Finazzo	1070 N Shore Dr W	Mound	MN	55364
Simona Fischer	3220 33rd Ave S	Minneapolis	MN	55406
Richard Fish	5345 37th Ave S	Minneapolis	MN	55417
Elizabeth Fleck	4253 40th Ave S	Minneapolis	MN	55406
Steven Foldes	2700 Glenhurst Ave	Minneapolis	MN	55416
Michael Forbes	9611 Foxcroft Rd NW	Bemidji	MN	56601
Joyce Frohn	425 Congress Ave	Oshkosh	WI	54901
Greta Gaard	3034 41st Ave S	Minneapolis	MN	55406
Mary Gallagher	5509 Costa Garraf Rd NW	Albuquerque	NM	87120
Jane Gfrerer	7520 Cahill Rd Apt 323A	Edina	MN	55439
Mark Giese	1520 Bryn Mawr Ave	Mount Pleasant	WI	53403
Anne Marie Gillen	3999 Clover Ave	Saint Paul	MN	55127
Yazmin Gonzalez	9627 Maple St	Bellflower	CA	90706
River Gordon	4320 45th Ave S	Minneapolis	MN	55406
Jesse Gore	2411 Chapel Ave	Nashville	TN	37206
Susan Gray	5120 Logan Ave S	Minneapolis	MN	55419
Taran Green	4343 Zane Ave N	Crystal	MN	55422
Peter Gunther	5628 N Spaulding Ave	Chicago	IL	60659
Roger Hagedorn	521 2nd St SE	Minneapolis	MN	55414
Diane Haines	8868 Hidden Oaks Dr	Eden Prairie	MN	55344
Cherie Hales	511 E King St	Winona	MN	55987
Sue Halligan	5350 Nolan Pkwy	Oak Park Heights	MN	55082
Verlaine Halvorsen	3510 the Mall	Minnetonka	MN	55345
Carolyn Ham	1672 Hartford Ave	Saint Paul	MN	55116
Eric Hammang	1896 Barclay St	Saint Paul	MN	55109
John Harrington	30726 Ivywood Trl	Stacy	MN	55079
Kenneth Harris	5099 157th St N	Hugo	MN	55038

Name	Address	City	State	Zip
Paul Harris	704 20th Ave S	Moorhead	MN	56560
Sharon Hattenberger	16100 Panola Dr	Lindstrom	MN	55045
Jon Hayenga	421 2nd St NW	Stewartville	MN	55976
Monta Hayner	63 Arthur Ave SE	Minneapolis	MN	55414
Jim Head	15307 Northgate Blvd Apt 201	Oak Park	MI	48237
Linda Headley	121 SE 276th St	Cross City	FL	32628
Susan Heath	2552 Mount Vernon St SE	Albany	OR	97322
Susan Hedin	650 Main St N Apt 405	Stillwater	MN	55082
Nathan Hetrick	1279 Westlake Ave	Lakewood	OH	44107
Cynthia Hill	161 Amherst St	Saint Paul	MN	55105
Susan Hix	11341 300th Ave NW	Princeton	MN	55371
Barbara Hoch	391 Whiting Ave	Dedham	MA	02026
Philip Holtegaard	305 Maple Dr	Lanesboro	MN	55949
Sarah Horner	3125 43rd Ave S	Minneapolis	MN	55406
Virginia Huber	1516 W 61st St	Minneapolis	MN	55419
Maxine Hughes	1259 Maxine Cir E	Shakopee	MN	55379
jason husby	3531 N 3rd St	Minneapolis	MN	55412
Susan Imker	309 Elizabeth St SW	Isanti	MN	55040
Daniel Iverson	4640 N Arm Dr	Mound	MN	55364
Dana Jackson	814 Everett St N	Stillwater	MN	55082
John James	740 Carla Ln	Saint Paul	MN	55109
Annette Jewell-Ceder	4950 170th Ln NE	Andover	MN	55304
John Joadwine	2010 Ohm Ave	Eau Claire	WI	54701
Julie Johnson	31764 Wiscoy Ridge Rd	Winona	MN	55987
Kyle Johnson	7 Barton Ave SE Apt 3	Minneapolis	MN	55414
MATTHEW JOHNSON	705 McKnight Rd N Apt 302	Saint Paul	MN	55119
Steve Jorgenson	36901 Xenon St NW	Princeton	MN	55371
Sana Joseph	4678 Blaine Ave	Inver Grove Heights	MN	55076
Shawn Kakuk	4340 Clearwater Rd Apt 106	Saint Cloud	MN	56301
Tracey Katsouros	1322 Harwich Dr	Waldorf	MD	20601
Sophia Keller	851 SW 127th St	Seattle	WA	98146
Theresa kelly	49540 Nautical Dr	Chesterfield	MI	48047
Loni Kemp	14083 County 23	Canton	MN	55922
Vernita Kennen	2665 Victoria St N Unit 415	Roseville	MN	55113
Andrew Kistler	25260 Chase Dr	North Olmsted	OH	44070
Robert Klein	1520 Oakcrest Ct	Appleton	WI	54914
Aaron Klemz	1359 Hillcrest Dr NE	Minneapolis	MN	55432
Dag Knudsen	70985 277th Ave	Lake City	MN	55041
Eugene Kremer	3938 Cannon Ball Lake Rd	Duluth	MN	55803
Martha Krikava	9696 101st St N	Stillwater	MN	55082
Jennifer Krinke	99 Milton St N Apt 3	Saint Paul	MN	55104
Diane Kroll	9680 234th Ln NE	Stacy	MN	55079
jane kroon	17820 28th Ave N	Minneapolis	MN	55447
Suzanne Kruger	60 Huckleberry Ln	Harpers Ferry	WV	25425

Name	Address	City	State	Zip
Thomas Kunkel	40211 120th St	Waseca	MN	56093
Janelle Kuznia	26775 Grand Ave	Elko New Market	MN	55020
Laura Lambert	2708 Gerald Ave	Saint Paul	MN	55109
Phedra Larson	826 Wall St	North Mankato	MN	56003
Anna Larsson	801 Washington Ave N Apt 109	Minneapolis	MN	55401
Susan Lasoff	1235 Yale Pl Apt 407	Minneapolis	MN	55403
Karen Leno	460 1st Ave SE	Harmony	MN	55939
James Leon	373 Runge Ln	Saint Paul	MN	55118
Lee Lewis	4100 Edmund Blvd	Minneapolis	MN	55406
Robynne Limoges	701 Southwaite Ct	Redwood Falls	MN	56283
Kristin Lindner	28935 127th St NW	Zimmerman	MN	55398
Christopher Loch	2410 Garfield Ave	Minneapolis	MN	55405
Elene Loecher	4300 W River Pkwy	Minneapolis	MN	55406
alice madden	3316 Columbus Ave	Minneapolis	MN	55407
Michael Madigan	2366 Hidden Lake Cv	Saint Paul	MN	55125
Thomas Mahoney	3121 SE 19th Pl	Cape Coral	FL	33904
Craig Maki	311 E Redwood St	Marshall	MN	56258
Kathleen Malecki	2709 Pearson Pkwy	Minneapolis	MN	55444
Barry Maloney	5511 Pompano Dr	Minnetonka	MN	55343
mary jane manion	4325 Cooke St	Duluth	MN	55804
Gina Marano	9013 13th Ave S	Bloomington	MN	55425
Laurence Margolis	3916 Avondale St	Minnetonka	MN	55345
Maureen McCarter	1931 17th St S	Saint Cloud	MN	56301
Harriet McCleary	2440 Stevens Ave Apt 2	Minneapolis	MN	55404
Judith McCormick	311 Pleasant Ave Apt 202	Saint Paul	MN	55102
Mary McGilligan	814 5th Ave	Two Harbors	MN	55616
Robert McKlveen	5261 Lochloy Dr	Edina	MN	55436
Molly McMullen	916 Ashland Ave Apt 12	Saint Paul	MN	55104
Nicholas McNeely	35225 Whitetail Ave	Bayfield	WI	54814
Joan Meierotto	13900 44th St S	Afton	MN	55001
Juventino Meza	318 Washburn Ave N	Minneapolis	MN	55405
Mary Miller	3804 Cedar Lake Pl	Minneapolis	MN	55416
Scott Mills	9 N Yukon Dr	Ely	MN	55731
Donald Mitchell	798 HI Park Ave	Red Wing	MN	55066
T Mo	3310 69th St E	South Saint Paul	MN	55076
Margot Monson	22 Ludlow Ave	Saint Paul	MN	55108
WENDY MORICAL	3942 Enchanted Ln	Mound	MN	55364
Steven Morley	574 Shryer Ave W	Saint Paul	MN	55113
jackie Mortenson	7325 63rd Ave N	Minneapolis	MN	55428
Kathryn Mosher	4316 Clemson Cir # B	Eagan	MN	55122
Paul Moss	1849 Whitaker St	White Bear Lake	MN	55110
Terrence Nayes	9133 Preserve Blvd	Eden Prairie	MN	55347
Bonnie Nelson	4105 30th Ave S	Minneapolis	MN	55406
Robert Nesheim	1705 W Highway 61 # 729	Grand Marais	MN	55604

Name	Address	City	State	Zip
Richard Nethercut	14083 County 23	Canton	MN	55922
Debi Niebuhr	571 E Howard St	Winona	MN	55987
kimberly nieman	4550 Orchid Cir	Minneapolis	MN	55446
Randall Nies	4525 Nicollet Ave Apt 4	Minneapolis	MN	55419
Carley Nipp	8994 Lone Oak Ln	Chisago City	MN	55013
Eric Norgaarden	5019 Campbell Ave	White Bear Lake	MN	55110
Carrie Noring	7200 Kentucky Ave N	Minneapolis	MN	55428
Dawn Nothwehr	722 Center St W Apt 315	Rochester	MN	55902
Cheryl Olseth	601 Carlson Pkwy Ste 1050	Minnetonka	MN	55305
Michael Overend	1087 Isackson Rd	Two Harbors	MN	55616
Ron P	524 S Euclid Ave	Ontario	CA	91762
Lynda Pauling	5812 Olene Ave N	Stillwater	MN	55082
John Pegg	4300 W River Pkwy Apt 371	Minneapolis	MN	55406
Constance Pepin	4031 Zenith Ave S	Minneapolis	MN	55410
Candice Pierce	5192 Lavaque Junction Rd	Hermantown	MN	55811
Peter Pierce	1928 E Superior St Apt 12	Duluth	MN	55812
Meryl Pinque	615 Odlin Rd	Bangor	ME	04401
Robin Pinsof	FORT SHERIDAN Rd	Highland Park	IL	60035
Nora Plesofsky	1235 Yale Pl Apt 409	Minneapolis	MN	55403
Raphael Ponce	20 RUE DE NAPLES	Toulouse	MH	31500
Christine Popowski	2630 Pleasant Ave Apt 101	Minneapolis	MN	55408
Betsey Porter	10040 Penn Ave S Apt 11	Minneapolis	MN	55431
Charlotte Quiggle	10789 Hollister Ave NW	Maple Lake	MN	55358
Ian Radtke-Rosen	22300 Penn Ave	Lakeville	MN	55044
Gyles Randall	2642 8th St NE	Waseca	MN	56093
Lynn Reeser	3320 Court Ave	Vernon	FL	32462
Anne Reich	751 Pine Cone Trl	Marine On Saint Croix	MN	55047
Karen Renaud	1975 Collin St	Mora	MN	55051
James Reynolds	4455 W 7th St	Winona	MN	55987
Lynn Rice	225 Prairie Rd	Monticello	MN	55362
Sue Rich	153 Winifred St W	Saint Paul	MN	55107
Annick Richardson	420 Lewiston Rd	Dayton	OH	45429
Paul Richtman	2854 Nightingale Ct	Stillwater	MN	55082
Cheryl Ritenbaugh	4917 Oliver Ave S	Minneapolis	MN	55419
Jean Ross	3624 Bryant Ave S	Minneapolis	MN	55409
Maisie Rossi	10 Glade St	Excelsior	MN	55331
Juliann Rule	35002 115th Ave	Avon	MN	56310
Scott Russell	5124 Thomas Ave S	Minneapolis	MN	55410
Trevor Russell	3519 32nd Ave S	Minneapolis	MN	55406
Ann Sandritter	3 Ashwood Mall Apt B	Old Bridge	NJ	08857
Judy Sausen	530 1st Ave Apt 5	Two Harbors	MN	55616
Jennifer Schally	1104 Creekside Cir	Stillwater	MN	55082
Robert Scheierl	1109 NE 5th Ave	Grand Rapids	MN	55744
Terrance Schrammen	859 McKnight Rd N	Saint Paul	MN	55119

Name	Address	City	State	Zip
Craig Schroeder	19524 Rosemary Ct	Paynesville	MN	56362
Jon Schroeder	8407 Penn Ave S	Bloomington	MN	55431
Jane Schuler	695 Sherwood Ave	Saint Paul	MN	55106
Maribeth Schulke	4207 Fiedler Ave NW	Maple Lake	MN	55358
Cherry Schwartz	100 Shady Ave	Owatonna	MN	55060
Caroline Sévilla	4 Allée Marc Chagall	Boling	TX	77420
Lansing Shepard	5289 Pleasant Ct W	Saint Paul	MN	55110
Adaline Shinkle	4708 Eastwood Cir	Minnetonka	MN	55345
Joanne Sieck	5877 River Ridge Ct NE	Rochester	MN	55906
Kurt Simer	3201 E 24th St	Minneapolis	MN	55406
Kent Simon	4733 Isabel Ave	Minneapolis	MN	55406
Ginger Sisco	8308 40th Ave N	New Hope	MN	55427
Julie Skelton	40900 Bemis Rd	Van Buren Twp	MI	48111
Kay Slama	5380 132nd Ave NE	Spicer	MN	56288
Carrie Slater Duffy	38 Harrison Ave S	Hopkins	MN	55343
Nancy Elizabeth Slocum	31005 County 7 Blvd	Welch	MN	55089
Gregory Solberg	1645 Millwood Ave	Saint Paul	MN	55113
Lindsay Sovil	1197 Kawishiwi Trl	Ely	MN	55731
Kelley Stanage	31775 Hwy 76	Houston	MN	55943
Greg Stawinoga	1247 E 168th Pl	South Holland	IL	60473
William Steele	21950 County Road 445	Bovey	MN	55709
Heidi Steinert-Bresilge	703 Esta Dr	Plano	IL	60545
DeeAnn Stenlund	2687 Matilda St	Saint Paul	MN	55113
Ron Sternal	2712 Glenhurst Ave	Minneapolis	MN	55416
Cleone Stewart	41265 500th St	Perham	MN	56573
Leland Stoe	13826 Eveleth Ct	Apple Valley	MN	55124
Patricia Thomas	6219 E Superior St	Duluth	MN	55804
Mary Thompson	1370 White Lake Dr	Duluth	MN	55803
Steven Timmer	5348 Oaklawn Ave	Edina	MN	55424
Anne Tisel	2940 Autumn Woods Dr	Chaska	MN	55318
Elizabeth Tisel	100 2nd St SE Apt 503	Minneapolis	MN	55414
Lyndon Torstenson	4138 41st Ave S	Minneapolis	MN	55406
Sheila Tran	1766 Serpentine Dr	Saint Paul	MN	55122
Clara Ueland	1902 Homestead Trl	Long Lake	MN	55356
Jennifer Valentine	313 1st Ave	Massapequa Park	NY	11762
Tracy van der Leeuw	128 Saint Albans St N	Saint Paul	MN	55104
Caroline van Schaik	40002 Wolf Hill Dr	La Crescent	MN	55947
Mary Ann VandeVusse	13960 Kentucky Ave	Savage	MN	55378
Mike Vant	495 Mackubin Cir	Shoreview	MN	55126
Martha Vennes	1015 2nd St NE Apt 214	Hopkins	MN	55343
John Viacrucis	3002 17th St S Apt 206	Moorhead	MN	56560
Barb Viker	3929 Everest Ln N	Minneapolis	MN	55446
Karl Vohs	428 2nd St NW	Faribault	MN	55021
Nicholas Vorpahl	1525 Sherburne Ave	Saint Paul	MN	55104

Name	Address	City	State	Zip
Wallace Wadd	2530 Queensport Rd	Woodbury	MN	55125
Donald Waskosky	310 River Park Dr	Mankato	MN	56001
Carol Weber	5223 Silver Maple Cir	Hopkins	MN	55343
David Wee	1920 S 1st St Apt 406	Minneapolis	MN	55454
Alice West	315 1st Ave E Apt 11	Grand Marais	MN	55604
Rebecca Wiinanen	19150 Easton Rd	Wayzata	MN	55391
Mary Lou Wilm	2919 45th Ave S	Minneapolis	MN	55406
Katharine Winston	4634 France Ave S	Edina	MN	55410
Larry Wolf	2425 County Road C2 W	Roseville	MN	55113
Bruce Wood	190 Albany St	Cambridge	MA	02139
Daryl Wood	1804 Cameron Ave	La Crosse	WI	54601
John Wozniak	7070 153rd St W Apt 105	Saint Paul	MN	55124
Bryan Wyberg	2458 Farrington Cir	Saint Paul	MN	55113
Stephen Yahn	1467 Thomas Ln	Saint Paul	MN	55122
Jenna Yeakle	623 N 39th Ave W	Duluth	MN	55807
Don A. Zatroch	2366 17th Ave NW	Saint Paul	MN	55112
Nick Zeller	19521 P And M Dr	Rollingstone	MN	55969
David Zentner	2116 Columbus Ave	Duluth	MN	55803

Index of exhibits to Clean Water Organizations' September 3, 2024 Comments

Exhibit 1 - MPCA Feedlot Rules SONAR.pdf

Exhibit 2 - Espejo-Herrera et al. (2016).pdf

Exhibit 3 - Schullehner et al. (2018).pdf

Exhibit 4 - Ward et al. (2018).pdf

Exhibit 5 - Inoue-Choi et al. (2015).pdf

Exhibit 6 - MPCA Nitrogen in Surface Waters.pdf

Exhibit 7 - MDA Groundwater Protection Rule SONAR.pdf

Exhibit 8 - Belluck Letter to EPA.pdf

Exhibit 9 - MPCA Aquatic Life Nitrate Standards.pdf

Exhibit 10 - MPCA Aquatic Life Ammonia Standards.pdf

Exhibit 11 - MPCA Condition of MN Groundwater Quality.pdf

Exhibit 12 - MPCA Five Year Progress Report.pdf

Exhibit 13 - EWG Nitrate Pollution in Minnesota.pdf

Exhibit 14 - MDH Public Health Work Plan 2024.pdf

Exhibit 15 - MPCA MN Nutrient Reduction Strategy.pdf

Exhibit 16 - Ores et al. (1982).pdf

Exhibit 17 - MDA Township Testing Update.pdf

Exhibit 18 - EPA Letter to Minnesota Agencies_November 2023.pdf

Exhibit 19 - MDA, Winona County Final Overiew of Nitrate Levels.pdf

Exhibit 20 - MDA Southeast Volunteer Nitrate Monitoring.pdf

Exhibit 21 - U M Ext Nitrates in Minn Drainage Water.pdf

Exhibit 22 - MPCA Water Pollutant Nitrogen.pdf

Exhibit 23 - MDA Root River Field to Stream.pdf

Exhibit 24 - U M Ext Guidelines for Manure Application Rates.pdf

Exhibit 25 - U M Ext Fertilizing Corn in MN.pdf

Exhibit 26 - Carlson Taking Soil Samples for Nitrogen.pdf

Index of exhibits to Clean Water Organizations' September 3, 2024 Comments

Exhibit 27 - EWG Manure Overload.pdf

Exhibit 28 - Borchardt Sources and Risk Factors for Nitrate.pdf

Exhibit 29 - MPCA Bacteria.pdf

Exhibit 30 - Bond Animal Feed Industry Impact on the Planet.pdf

Exhibit 31 - EPA Understanding Global Warming Potentials.pdf

Exhibit 32 - Hargarten Star Tribune.pdf

Exhibit 33 - Stephenson Confronting Our Ag Nonpoint Source.pdf

Exhibit 34 - MPCA Groundwater Quality.pdf

Exhibit 35 - MCEA, Petition to EPA under SWDA.pdf

Exhibit 36 - U M Ext Cover Crops.pdf

Exhibit 37 - Reilly Reductions in Soil Water Nitrate Beneath a Perennial Grain Crop.pdf

Exhibit 38 - Christianson Financial comparison of seven nitrate reduction strategies.pdf

Exhibit 39 - Huggins Subsurface drain losses of water and nitrate.pdf

Exhibit 40 - Wilson Manure applied on frozen soil.pdf

Exhibit 41 - Jones 2019 Livestock manure driving stream nitrate.pdf

Exhibit 42 - U M Ext Reducing Water Quality Issues.pdf

Exhibit 43 - EPA Letter to MPCA CAFO Draft Permit 2024.pdf

Exhibit 44 - Kuehner Examination of Soil Water Nitrate.pdf

Exhibit 45 - EPA 2024 Proposed Idaho CAFO Permit.pdf

Exhibit 46 - NRCS Waste Mgmt Field Handbook Chapter 10 Appendix D.pdf

Exhibit 47 - MPCA BMPs and Data Needs for Groundwater Protection.pdf

Exhibit 48 - Modderman Manure is Complicated.pdf

Exhibit 49 - MPCA Letter to EPA re Draft Feedlot Permit.pdf

Exhibit 50 - MPCA Rush Creek fish kill response.pdf

Exhibit 51 - Feyereisen Frontier Metaphorical Elephant.pdf

TABLE OF CONTENTS

Page

Page

Page

STATE OF MINNESOTA
POLLUTION CONTROL AGENCY
POLICY AND PLANNING DIVISION

In the Matter of Proposed
Amendments to Minnesota Rules
Relating to Animal Feedlots,
Storage, Transportation, and
Utilization of Animal Manure

STATEMENT OF NEED
AND REASONABLENESS

Minn. R. pt. 7001.0020
Minn. R. pt. 7002.0210 to 7002.0280
Minn. R. ch. 7020

December 8, 1999

I. INTRODUCTION

The Minnesota Pollution Control Agency (MPCA or agency) is proposing to revise the existing rules governing issuance procedures for permits regulating animal feedlots and manure storage areas, Minn. R. pt. 7001.0020, related permit fees, Minn. R. pt. 7002.0210 to 7002.0280, and related permit requirements and technical standards associated with pollution prevention, Minn. R. ch. 7020. The application of manure to land is also governed primarily by Minn. R. ch. 7020. The Minnesota Administrative Procedures Act requires a statement of need and reasonableness (SONAR) justifying and explaining the need for revisions to the existing rule. This document fulfills that requirement.

The feedlot rules contain a set of requirements and standards that are intended to control the discharge of pollutants from feedlots to the environment. The rules apply to all aspects of livestock production including the location, design, construction, operation and management of feedlots and manure handling facilities. Swine and dairy confinement facilities, pasture and winter-grazing operations, poultry facilities, and composting sites are examples of livestock production operations and manure processing facilities that are subject to these rules.

Minn. R. ch. 7020 has not been revised since 1978. Many changes have occurred since 1978 that create the need to revise the feedlot rules. Livestock production techniques and practices have changed dramatically. There have been new discoveries and understandings regarding agriculture and the environment. The MPCA and its partner counties have also acquired a lot of experience administering the animal feedlot regulatory program. Finally, regulatory strategies have evolved and these strategies require rule changes to implement. The rule revision process is an opportunity to respond to these changes and seek public input to the proposed changes. Parts of the rule currently ineffective are deleted or revised; and new parts are developed for areas previously not addressed. Therefore, the revision should benefit the public, the environment, and the regulated community.

The rule revision development processes began in early 1995. The rule development process included a substantial effort to involve concerned parties, which is discussed in more detail under Additional Notice, Section VI, of this SONAR.

In the more than twenty years since Minn. R. ch. 7020 was last revised, much has changed in the agricultural industry. In response to these changes, the agency began an effort to re-design this program in 1995. After evaluating the existing rules, administrative processes, and status of environmental impact from animal feedlots and manure storage areas, revised goals were identified. The agency's goals for revising the rules are to:

- Focus on animal feedlots, manure storage areas and pastures that have the greatest potential for environmental impact;
- Expand the role of delegated counties in the feedlot program;
- Increase agency and delegated-county staff field presence; and
- Achieve the desired environmental outcomes with existing agency and county resources.

Further discussion of these goals and how they influenced this rulemaking is included in the Reasonableness as a Whole and in the Reasonableness by part discussions.

The Office of the Legislative Auditor recently conducted an extensive evaluation of the current MPCA animal feedlot regulatory program. The findings are in the report called, "Animal Feedlot Regulation: A Program Evaluation Report (January 1999)." See Exhibit G-1. This Report guided the agency in the development of the proposed rules. Among the comments made in the Report were the need for: better oversight of permitted and unpermitted animal feedlots, manure storage areas and pastures; better oversight and coordination with delegated counties; and a "need to develop a better strategy to correct water pollution hazards." Exhibit G-1, page 81.

There are five major sections in the proposed rules: 1) permit fees; 2) registration program; 3) permit program; 4) delegated county program; and 5) standards for discharge, design, construction, operation and closure. Permit fees are discussed in this SONAR under parts 7002.0210 to 7002.0280; the registration program is discussed under part 7020.0350; the permit program is discussed under parts 7020.0400 to 7020.0535; the delegated county program is discussed under parts 7020.1600; and the technical standards are discussed under parts 7020.2000 to 7020.2225.

The agency is proposing that the owner of an animal feedlot, manure storage area, or pasture be required to apply for a permit if, for example, the owner's facility:

- Is required by federal regulations to be covered under a NPDES permit;
- Is a pollution hazard; or
- Has been required to implement mitigation measures or alternative designs/operations during an environmental review process.

The agency is also proposing a streamlined permit process for owners with animal feedlots and manure storage areas with more than 300 and fewer than 1,000 animal units and that meet specific eligibility criteria. This streamlined permit is called a construction short-form permit and the corresponding permit conditions are specified under parts 7020.0405 to 7020.0535. The need for and reasonableness of the rules proposed in these parts are discussed in this document.

This statement of need and reasonableness can be made available in other formats, including Braille, large print and audio tape. If you are interested in obtaining this SONAR in another format, please call TTY: (651) 282-5332 or 1-800-657-3864.

II. MPCA'S STATUTORY AUTHORITY

The MPCA's statutory authority to develop and adopt the proposed rules is set forth in a number of statutes, including Minn. Stat. ch. 115 and 116, and federal regulations. For example, Minn. Stat. § 115.03, subd. 1, paragraphs (e)(1), (2), (3), (4) and (7), (f) and (g) which provides the MPCA with the powers and duties to:

> (e) To adopt, issue, reissue, modify, deny, or revoke, enter into or enforce reasonable orders, permits, variances, standards, rules, schedules of compliance, and stipulation agreements, under such conditions as it may prescribe, in order to prevent, control or abate water pollution, or for the installation or operation of disposal systems or parts thereof, or for other equipment and facilities;
>
> > (1) Requiring the discontinuance of the discharge of sewage, industrial waste or other wastes into any waters of the state resulting in pollution in excess of the applicable pollution standard established under this chapter;
> > (2) Prohibiting or directing the abatement of any discharge of sewage, industrial waste, or other wastes, into any waters of the state or the deposit thereof or the discharge into any municipal disposal system where the same is likely to get into any waters of the state in violation of this chapter and, with respect to the pollution of waters of the state, chapter 116, or standards or rules promulgated or permits issued pursuant thereto, and specifying the schedule of compliance within which such prohibition or abatement must be accomplished;
> > (3) Prohibiting the storage of any liquid or solid substance or other pollutant in a manner which does not reasonably assure proper retention against entry into any waters of the state that would be likely to pollute any waters of the state;
> > (4) Requiring the construction, installation, maintenance, and operation by any person of any disposal system or any part thereof, or other equipment and facilities, or the reconstruction, alteration, or enlargement of its existing disposal system or any part thereof, or the adoption of other remedial measures to prevent, control or abate any discharge or deposit of sewage, industrial waste or other wastes by any person; . . .
> > (7) Requiring the owner or operator of any disposal system or any point source to establish and maintain such records, make such reports, install, use, and maintain such monitoring equipment or methods, including where

> appropriate biological monitoring methods, sample such effluents in accordance with such methods, at such locations, at such intervals, and in such a manner as the agency shall prescribe, and providing such other information as the agency may reasonably require; . . .
>
> (f) To require to be submitted and to approve plans and specifications for disposal systems or point sources, or any part thereof and to inspect the construction thereof for compliance with the approved plans and specifications thereof;
>
> (g) To prescribe and alter rules, not inconsistent with law, for the conduct of the agency and other matters within the scope of the powers granted to and imposed upon it by this chapter and, with respect to pollution of waters of the state, in chapter 116, provided that every rule affecting any other department or agency of the state or any person other than a member or employee of the agency shall be filed with the secretary of state;

Additional authority is set forth in Minn. stat. § 115.03, subd. 5, which provides:

> Agency authority; National Pollutant Discharge Elimination System. Notwithstanding any other provisions prescribed in or pursuant to this chapter and, with respect to the pollution of waters of the state, in chapter 116, or otherwise, the agency shall have the authority to perform any and all acts minimally necessary including, but not limited to, the establishment and application of standards, procedures, rules, orders, variances, stipulation agreements, schedules of compliance, and permit conditions, consistent with and, therefore not less stringent than the provisions of the Federal Water Pollution Control Act, as amended, applicable to the participation by the state of Minnesota in the National Pollutant Discharge Elimination System (NPDES); provided that this provision shall not be construed as a limitation on any powers or duties otherwise residing with the agency pursuant to any provision of law.

Additional authority is set forth in Minn. stat. § 116.07, subd. 2 and 4. For example, subdivision 2 provides for management of manure when it is not used as a fertilizer and persons operating feedlots and dealing with manure may be required to meet other rules established by the agency that address air quality and hazardous waste issues. Subdivision 4 also addresses air quality issues and other matters related to feedlots. For example, subdivision 4, second paragraph, provides for general rulemaking authority and reads, in part, as follows:

> Pursuant and subject to the provisions of chapter 14, and the provisions hereof, the pollution control agency may adopt, amend, and rescind rules and standards having the force of law relating to any purpose within the provisions of Laws 1969, chapter 1046, for the collection, transportation, storage, processing, and disposal of solid waste and the prevention, abatement, or control of water, air, and land pollution which may be related thereto, and the deposit in or on land of any other material that may tend to cause pollution . . . Without limitation, rules or standards may relate to collection, transportation, processing, disposal, equipment, location, procedures, methods, systems or techniques or to any other matter

> relevant to the prevention, abatement or control of water, air and land pollution which may be advised through the control of collection, transportation, processing, and disposal of solid waste and sewage sludge, and the deposit in or on land of any other material that may tend to cause pollution . . .

Additional authority is set forth in Minn. stat. § 116.07, subd. 4d, paragraph (a), which provides:

> The agency may collect permit fees in amounts not greater than those necessary to cover the reasonable costs of reviewing and acting upon applications for agency permits and implementing and enforcing the conditions of the permits pursuant to agency rules. Permit fees shall not include the cost of litigation. The agency shall adopt rules under section 16A.1285 establishing a system for charging permit fees collected under this subdivision. The fee schedule must reflect reasonable and routine permitting, implementation, and enforcement costs. The agency may impose an additional enforcement fee to be collected for a period of up to two years to cover the reasonable costs of implementing and enforcing the conditions of a permit under the rules of the agency. Any money collected under this paragraph shall be deposited in the special revenue account.

Additional authority is set forth in Minn. stat. § 116.07, subd. 7, as amended, which provides:

> Subd. 7. Counties; processing of applications for animal lot permits. Any Minnesota county board may, by resolution, with approval of the pollution control agency, assume responsibility for processing applications for permits required by the pollution control agency under this section for livestock feedlots, poultry lots or other animal lots. The responsibility for permit application processing, if assumed by a county, may be delegated by the county board to any appropriate county officer or employee.
>
> (a) For the purposes of this subdivision, the term "processing" includes:
>
> (1) the distribution to applicants of forms provided by the pollution control agency;
>
> (2) the receipt and examination of completed application forms, and the certification, in writing, to the pollution control agency either that the animal lot facility for which a permit is sought by an applicant will comply with applicable rules and standards, or, if the facility will not comply, the respects in which a variance would be required for the issuance of a permit; and
>
> (3) rendering to applicants, upon request, assistance necessary for the proper completion of an application.
>
> (b) For the purposes of this subdivision, the term "processing" may include, at the option of the county board, issuing, denying, modifying, imposing conditions upon, or revoking permits pursuant to the provisions of this section or rules promulgated pursuant to it, subject to review, suspension, and reversal by the pollution control agency. The pollution control agency shall, after written

notification, have 15 days to review, suspend, modify, or reverse the issuance of the permit. After this period, the action of the county board is final, subject to appeal as provided in chapter 14.
(c) For the purpose of administration of rules adopted under this subdivision, the commissioner and the agency may provide exceptions for cases where the owner of a feedlot has specific written plans to close the feedlot within five years. These exceptions include waiving requirements for major capital improvements.
(d) For purposes of this subdivision, a discharge caused by an extraordinary natural event such as a precipitation event of greater magnitude than the 25-year, 24-hour event, tornado, or flood in excess of the 100-year flood is not a "direct discharge of pollutants."
(e) In adopting and enforcing rules under this subdivision, the commissioner shall cooperate closely with other governmental agencies.
(f) The pollution control agency shall work with the Minnesota extension service, the department of agriculture, the board of water and soil resources, producer groups, local units of government, as well as with appropriate federal agencies such as the Natural Resources Conservation Service and the Farm Service Agency, to notify and educate producers of rules under this subdivision at the time the rules are being developed and adopted and at least every two years thereafter.
(g) The pollution control agency shall adopt rules governing the issuance and denial of permits for livestock feedlots, poultry lots or other animal lots pursuant to this section. A feedlot permit is not required for livestock feedlots with more than ten but less than 50 animal units; provided they are not in shoreland areas. These rules apply both to permits issued by counties and to permits issued by the pollution control agency directly.
(h) The pollution control agency shall exercise supervising authority with respect to the processing of animal lot permit applications by a county.
(i) Any new rules or amendments to existing rules proposed under the authority granted in this subdivision or to implement new fees on animal feedlots, must be submitted to the members of legislative policy and finance committees with jurisdiction over agriculture and the environment prior to final adoption. The rules must not become effective until 90 days after the proposed rules are submitted to the members.
(j) Until new rules are adopted that provide for plans for manure storage structures, any plans for a liquid manure storage structure must be prepared or approved by a registered professional engineer or a United States Department of Agriculture, Natural Resources Conservation Service employee.
(k) A county may adopt by ordinance standards for animal feedlots that are more stringent than standards in pollution control agency rules.
(l) After January 1, 2001, a county that has not accepted delegation of the feedlot permit program must hold a public meeting prior to the agency issuing a feedlot permit for a feedlot facility with 300 or more animal units, unless another public meeting has been held with regard to the feedlot facility to be permitted.

Minnesota statutes also provide additional permit authority and is set forth in Minn. stat. § 116.07, subd. 7c, (1998), which reads in part:

> Subd. 7c. NPDES permitting requirements.
> (a) The agency must issue National Pollutant Discharge Elimination System permits for feedlots with 1,000 animal units or more based on the following schedule:
> (1) for applications received after April 22, 1998, a permit for a newly constructed or expanded animal feedlot with 2,000 or more animal units must be issued as an individual permit;
> (2) for applications received after January 1, 1999, a permit for a newly constructed or expanded animal feedlot with between 1,000 and 2,000 animal units that is identified as a priority by the commissioner, using criteria established under paragraph (e), must be issued as an individual permit; and
> (3) after January 1, 2001, all existing feedlots with 1,000 or more animal units must be issued an individual or general National Pollutant Discharge Elimination System permit.
> (b) . . .
> (e) By January 1, 1999, the commissioner, in consultation with the feedlot and manure management advisory committee, created under 17.136, and other interested parties must develop criteria for determining whether an individual National Pollutant Discharge Elimination System permit is required under paragraph (a), clause (2), for an animal feedlot with between 1,000 and 2,000 animal units. The criteria must be based on proximity to waters of the state, facility design, and other site-specific environmental factors.
> (f) By January 1, 2000, the commissioner, in consultation with the feedlot and manure management advisory committee, created under section 17.136, and other interested parties must develop criteria for determining whether an individual National Pollutant Discharge Elimination System permit is required for an existing animal feedlot, under paragraph (a), clause (3). The criteria must be based on violations and other compliance problems at the facility.

Additional authority to adopt these rules is set forth in other sections of Minn. Stat. ch. 115 and 116, including Minn. stat. § 115.03, subd. 1(a) and 1(b); 115.04; 115.06, subd. 3; 115.07; 116.07, subd. 4a; 116.07, subd. 4d; 116.07, subd. 7a; 116.081; and 116.091. The agency is also the delegated Minnesota state agency to implement and administer the Clean Water Act's NPDES program. Under that delegation, the agency has duties, obligations and authorities under Title 40 Code of Federal Regulations (CFR) part 122, including part 122.23, for the permitting of NPDES-covered sites and facilities and under 40 CFR 412, related to effluent limitation regulations and standards for the specified feedlot categories.

Under the above-cited statutes, the agency has the necessary statutory authority to adopt the proposed rule.

III. NEED FOR THE RULES

Minn. Stat. ch. 14 requires the agency to make an affirmative presentation of facts establishing the need for its proposed rules or amendments. In general terms, this means that the agency must set forth reasons for its proposal, and the reasons must not be arbitrary or capricious. The term, need, is used to mean a problem exists that requires administrative attention. The need for a revision of feedlot rules is discussed in three parts: contaminants associated with manure; specific needs supporting revisions of the existing rules; and discussions contained in the reasonableness for individual parts of the proposed rules.

A. Overview of Livestock and Poultry Operations in Minnesota

An estimated 40,000 animal feedlot, manure storage and pasture facilities exist in Minnesota with over 10 animal units, and thousands of these feedlots are located in shoreland areas. Minnesota's ranking among other states for livestock related production is listed Table 1.

Table 1. Minnesota's National Ranking for Livestock Related Production.

Type of Production (1997)	**Rank Nationally**
Turkeys raised	2nd
Hogs marketed	3rd
Milk production/# of milk cows	5th
Red meet production	6th
Eggs produced	9th

Source - Minnesota Agricultural Statistics (1998). See Exhibit A-16.

Livestock at these facilities produce the amount of waste, which is produced by roughly 60 million people. It is important to prevent the contaminants in manure from moving from the animal holding areas, manure storage areas, and manure application areas into surface and ground water supplies. The Minnesota Pollution Control Agency has the responsibility to regulate the collection, transportation, storage, processing, and disposal of animal manure for the prevention and abatement of water, air, and land pollution. Therefore, the MPCA needs to establish rules to prevent manure from becoming a pollutant and causing unwanted environmental effects.

In manure, the constituents most impacting water quality include phosphorus, nitrogen, biological oxygen demand, and disease causing organisms (pathogens). Other contaminants may include trace metals and hormones. Human health and the environment are put at risk from these water quality impact factors. The problems caused by contaminants or the results of contaminants in the environment have different pathways of entry and source areas. Various types of gaseous compounds emanating from manure are an additional human health and environmental concern.

B. Overview of Minnesota Water Quality Assessments

Watershed projects conducted through the Minnesota Clean Water Partnership Program have diagnosed water quality problems in 37 project sites throughout the state. Sixteen projects identified feedlots as significant contributors of nonpoint source contamination to lakes and streams. While the statewide effects of contaminants from manure have not been completely separated from other nonpoint sources of pollution, it is clear that surface water quality is being impacted from agricultural sources in general, which includes discharges and runoff from feedlots and manure application sites.

Rivers and lakes are described, under the federal and state clean water programs, based on their ability to meet water quality standards. An impaired water body is one that pollutant levels exceed safe levels for the particular pollutant. Thus, the waterbody no longer fully supports its designated uses. These designations may include uses as water supply, recreation, wildlife, industrial consumption, and aesthetics.

In an assessment of nonpoint source pollution throughout the state, the MPCA concluded the following in the Minnesota Nonpoint Source Management Program – 1994 report about some of the impacts experienced by water bodies in this state. See Exhibit A-17.

Of the 12,241 river miles assessed by monitoring data:

- Nonpoint sources of pollution were reported to contribute to the degradation of 63 percent of the assessed river miles;
- 90 percent of the surveyed river miles were significantly impacted (either impaired or threatened of impairment) by agricultural sources including irrigated and non-irrigated cropland, pastures, feedlots, animal holding/management areas and agri-chemicals;
- About 37 percent of the impaired river miles had heavy algae and weed growth problems resulting in low oxygen levels;
- Elevated bacteria were identified in half to two-thirds of the impaired river miles; and
- All parts of the state have threatened and impaired stream conditions.

Of the 2.1 million lake acres assessed by monitoring data:

- Nonpoint sources of pollution were reported to contribute to the degradation of 43 percent of the assessed lake acres;
- 64 percent of the surveyed lake acres were significantly impacted (either impaired or threatened of impairment) by agricultural sources including irrigated and non-irrigated cropland, pastures, feedlots, animal holding/management areas and agri-chemicals;
- About 90 percent of the impaired lakes had heavy algae blooms and weed growth resulting in low oxygen levels;
- Elevated bacteria were identified as problems in nearly half of the impaired lakes; and
- All parts of the state have threatened and impaired lake conditions, but the southern half of the state has a much higher percentage of impaired and threatened lakes than the northern half of the state. For example, the Minnesota River basin in southern Minnesota

> has nearly 40 percent of the lakes impaired and an additional seven percent threatened to become impaired, largely from agricultural sources. Whereas, the Lake Superior Basin in northern Minnesota has about five percent of the lakes impaired and another 12 percent threatened to become impaired, with a lower percentage affected by agriculture.

Manure is only one of several nitrogen sources that can lead to elevated nitrate in ground water. The volume of manure generated, the widespread application of manure, and the close proximity of feedlots to rural wells make manure a potential risk to human health and the environment. The agency needs to develop a program for animal feedlot and manure management that reduces this risk.

According to "Nitrogen in Minnesota Groundwater", the 10 mg/l drinking water standard was exceeded in 1.2 percent of the 1,678 community water supply wells with measured and reported nitrate-N concentrations. See Exhibit A-2. Nitrate concentrations were elevated above background, one milligram per liter (mg/l), in another 20 percent of the wells. The percentage of private domestic wells with nitrate exceeding the drinking water standard is unknown, but is estimated from available data sets described in the "Nitrogen in Minnesota Ground Water" study to be roughly seven percent. See Exhibit A-2. Assuming seven percent of an estimated 450,000 private wells exceed the drinking water standard and an average of 3.3 people per home, then the population exposed to nitrate above drinking water standards is about 104,000. Several hundred thousand additional people are exposed to nitrate-N elevated above background, but which is still below the 10 mg/l drinking water standard. The report found that the largest source of impact was from agricultural sources. See Exhibit A-2. Thus, the need for the agency to update feedlot rules, which are more than 20 years old and are insufficient to protect the water resources of Minnesota.

The discussion that follows will focus on the main factors impacting water in Minnesota. Improper management of manure can cause impacts; poor locations for facilities; over application of manure; or improper design and construction of manure or the facilities used to store manure. A set of standards to address these activities is needed for consistency in requirements asked of feedlot owners and for protection of the environment.

C. Overview of the Primary Contaminants Associated With Manure

Phosphorus

Phosphorus is the limiting nutrient affecting weed and algae growth in most of Minnesota's lakes and streams. One pound of phosphorus will produce roughly 500 pounds of weeds or algae growth in a lake. Decomposition of weeds and algae causes a decrease in dissolved oxygen levels; thereby, affecting the entire aquatic ecosystem. Water impaired by algae, weed growth, and game-fish reductions can affect the beneficial recreational uses including swimming, water-skiing, and fishing. Water impaired by excess algae and weed growth cannot support the game fish that are valued by sport fishermen and are seen as less valuable for recreational uses also including swimming and waterskiing. Non-water contact recreational enjoyment, such as canoeing, boating, and sailing, can be greatly reduced by severe algae growth. Thus, the agency, as the responsible state entity for water quality, must give considerations to feedlot rules that reduce this sector as a large contributor to phosphorus loading to lakes and streams.

In addition to the detrimental effects caused by phosphorus on the ecosystem and human quality of life, human health can also be affected from very high levels of phosphorus. Blue-green algae are commonly found in lakes enriched with phosphorus. Large numbers of decomposing blue-green algae can cause toxicity problems. Swimmers contacting water impacted by blue-green algae will typically experience skin rashes. The cause of the skin rashes is typically unknown to the swimmer and therefore goes unreported. Aerosols from the toxic blue-green algae can cause upper respiratory effects. Humans or animals drinking water with toxic blue-green algae can also have toxic health effects. The number of people affected by blue-green algae in Minnesota is unknown. An animal that has ingested toxins from an algae bloom can show symptoms for nausea and skin irritation to severe circulatory, nervous and digestive disorders. Obviously, the need for proper manure management and animal feedlot location, design and construction is important to the economics of agriculture as it is to human health and the environment.

Phosphorus typically does not leach through soils in large quantities. However, high soil phosphorus levels can lead to phosphorus movement to ground water. The ground water once contaminated with phosphorus may serve as a conduit to surface water.

Phosphorus from animal manure can be a significant pollutant when runoff that contains manure is allowed to enter surface water. Manure-contaminated runoff most often occurs from outdoor animal holding areas and manure application sites, but can also occur from stockpile runoff or intentional pumping, piping or dumping of manure into waters. Table 2 shows typical phosphorus concentrations from various sources.

Table 2. Comparison of Phosphorus Concentration in Waters, Sewage and Manure.

Source	Phosphorus (mg/l)
Lake Water (clear)	0.02
Lake Water (green due to algae)	0.2
Municipal Sewage (treated)	1 - 4
Municipal Sewage (untreated)	8
Cattle Feedlot Runoff	85
Cattle or Hog Manure	100 to 2500

See Exhibit A-3.

Watersheds in northern Minnesota, where there is less agricultural activity, have average phosphorus loads of 0.13 to 0.21 pounds per acre per year. Whereas, watersheds in southern Minnesota have phosphorus loads of 0.84 mg/l (Heiskary and Wilson, 1994). See Exhibit A-3. In a review of the literature, a highly significant relationship shows that the greater the rate of manure applied the more phosphorus found in the runoff. See Exhibit L-2. Other studies show that when soils have higher soil phosphorus levels, the dissolved phosphorus in runoff from those soils will be higher compared to soils with lower soil phosphorus levels. See Exhibit L-5. Thus, it is necessary to establish management controls to eliminate direct manure runoff into water bodies and reduce excess phosphorus application to fields.

Relatively small amounts of manure can have detrimental effects on surface water quality. Modeling of a watershed with two lakes in LeSeuer County indicated that by improving the three worst feedlots, phosphorus loading reductions of 30 to 40 percent could be achieved. A lake restoration project in Redwood County focused on improving three feedlots, which contributed an estimated 62 percent of the annual phosphorus loading to the lake. Very detailed lake and stream monitoring data has shown dramatic water quality improvements associated with the feedlot changes and a marked improvement in the algae blooms in this lake. See Exhibit A-4.

The reversibility of phosphorus loading into Minnesota's lakes is quite variable and is dependent upon the type and size of watershed and lake and stream. Water quality was greatly improved during a period of three years in the shallow lake in Redwood County described above. However, when phosphorus attached to sediment settles to the bottom of many lakes, these nutrients can be recycled for decades or centuries and continually create eutrophication and dissolved oxygen problems. See Exhibit A-4.

The transport of phosphorus to waters from manure sources can be greatly reduced by containing runoff from outdoor animal holding areas; injecting or immediately incorporating manure when applying to land; avoiding excess manure application to soils high in phosphorus, especially where runoff to surface waters is likely; siting manure stockpiles properly; and preventing the intentional piping, pumping or dumping into water bodies. Thus, the agency finds a need to establish minimum requirements to reduce impacts from manure sources and to ensure a consistent program exists to protect the environment across Minnesota and to ensure management flexibility by the feedlot owner be retained.

Nitrogen

Elemental nitrogen is found in the air we breathe. However, nitrogen-based compounds often have negative impacts on human health and the environment. The improper management of manure may result in surface water and ground water impacts from the introduction of nitrogen compounds that could deplete oxygen needed by fish or plants or by changing forms that impact human health. The discussion that follows explains how nitrogen compounds have the potential for negative impacts on human health and the environment and the need for a regulatory approach that establishes minimum standards for proper management of manure. It is necessary to site, design, construct and operate feedlots in a manner to reduce or eliminate risks to human health and the environment from the manure produced at these facilities and used elsewhere.

The nitrogen in manure is mostly in the forms of organic nitrogen and ammonium. Ammonia easily volatilizes into the atmosphere when the manure is land applied or disturbed in any manner. Ammonia can contribute to odors and can be transported long distances before being re-deposited during precipitation events. Under the presence of oxygen, most of the nitrogen in manure will eventually convert to the nitrate form of nitrogen. This conversion to nitrate typically will occur when ammonium (active form of ammonia, which is a gas) moves into soil below a feedlot, manure storage area or land application site, or when diluted in surface waters. Varying amounts of nitrate and ammonium from manure will be converted to nitrogen gas and consequently be lost from the water. The remaining nitrogen can present environmental problems in either the ammonium or nitrate forms.

The feedlot rules are needed to manage manure in such a way as to prevent negative impacts from ammonium and nitrates. The following discussion explains why and how proper management of manure reduces the potential impacts associated with these nitrogen compounds.

Runoff to surface waters from areas of manure accumulation can cause ammonia concentrations to be high enough to be toxic to fish and other aquatic organisms. As the ammonia converts to nitrate, oxygen will be consumed, also affecting aquatic life. Ammonium concentrations in Minnesota lakes and streams are often less than 0.1 mg/l and rarely exceed 1 mg/l. See Exhibit A-5. Typical ammonium concentrations in manure range from 300 to 2000 mg/l.

Ammonium is the form of nitrogen that presents the greatest environmental risk associated with surface runoff from outdoor animal holding areas and excessive surface application of manure to fields. Ammonium is very mobile in most soil types due to its solubility in water and thus, ease of movement. Ammonium can also leach through poorly lined liquid manure storage systems into ground water, where it will typically convert to the nitrate form of nitrogen. Nitrate can have negative health impacts on humans and animals. Elevated ground-water ammonium concentrations have been found below a poorly-lined manure storage facilities.

Problems from ammonium can be minimized by containing open lot runoff; immediately incorporating manure into the soil when applying to land; and using a well-constructed liner for liquid manure storage systems. It is necessary that the agency provide the minimum standards for these activities in rule to provide the feedlot owner a good understanding of what the agency believes are needed to protect human health and the environment. It is needed to provide such consistency as often capital outlays are required by the feedlot owner and without this knowledge up front, the feedlot owner will be unable to make wise business decisions.

Most of the nitrate in Minnesota waters originates from cropland production, feedlots and septic systems. Studies completed by the agency and the Minnesota Department of Health in 1991 confirm this statement. See Exhibit A-8. Nitrate is of greatest concern when it leaches to ground water and enters drinking water supplies. Over 70 percent of Minnesota's population obtain their drinking water from ground water supplies, either private or public wells. High levels of nitrate in drinking water supplies can cause methemoglobinemia (blue baby syndrome) in human infants. It is for this reason that a drinking water standard of 10 mg/l has been set for nitrate.

Infants less than three months of age are most susceptible to methemoglobinemia, although individual adults may display increased susceptibility due to various factors. This condition occurs when nitrate is reduced to nitrite in the stomach or oral cavity. Nitrite is absorbed in the bloodstream and converts hemoglobin to methemoglobin. Methemoglobin interferes with oxygen transport; therefore, decreasing the amount of oxygen available to the person. Afflicted infants develop a bluish to lavender color around the lips and extremities. Other symptoms are those related to oxygen deprivation, including breathing difficulties, central nervous system defects, cardiac disrythmias and circulatory failure. Death sometimes results.

Between 1945 and 1972, approximately 2000 cases of infant methemoglobinemia were reported in world literature. However, it often goes unreported or may be misdiagnosed. See Exhibit A-6. In Minnesota, no registry is maintained for methemoglobinemia cases. However, a study of the problem was conducted in the 1940's. Between 1947 and 1949, 146 cases of methemoglobinemia were documented in Minnesota, including 16 deaths. None of the cases resulted when the suspected drinking water source had less than 30 milligrams per liter (mg/l) nitrate-nitrogen. At least three documented cases of methemoglobinemia have been reported in the Midwest during the past two decades, with one fatality. See Exhibit A-6.

In addition to human health concerns, it must be noted that nitrates at high levels will also have detrimental impacts on livestock. Spontaneous abortions, stillborn piglets, and gastrointestinal disorders are also found in livestock having consumed large quantities of nitrate-contaminated water. See Exhibit A-6. Thus, a need exists to establish standards that protect the economic investment by feedlot owners.

Nitrate-contaminated ground water also causes loss of property value and results in large expenditures in water treatment systems. Nitrate entering Minnesota streams affects water quality in our oceans. Much of Minnesota ultimately drains into the Mississippi River. The Gulf of Mexico, which receives water from the Mississippi, has experienced an increasing problem from algae growth. A condition known as hypoxia has developed on over 7,000 square miles of the Gulf of Mexico. In this zone, dissolved oxygen has decreased to levels, which do not support shellfish and much other aquatic life. Minnesota contributes some of the nutrients that cause the hypoxia problem. See Exhibits A-1 and A-7.

Livestock and poultry in Minnesota produce an estimated 269,000 tons of nitrogen annually. This number is calculated based on the Department of Agriculture statistics on the number of animals, types of animals, and the nitrogen contained in each animal type's manure. Feedlots can contribute to ground water nitrate problems primarily when manure from feedlots is applied to cultivated lands, or when manure seeps through improperly constructed or maintained liquid manure storage systems. Other feedlot-related contributions to ground-water nitrate can include abandoned open lots or infiltration of runoff near stockpile sites and open lots.

Manure is applied to approximately 3 million acres of cropland in Minnesota and supplies roughly 15 percent of crop nitrogen needs throughout the state. It has been well established through research that excessive nitrogen rates, applied as manure or inorganic fertilizer, will result in nitrate leaching and potential movement to ground water. See Exhibit A-8. The fraction of nitrate from over-applied manure that will move to ground water depends on the soil physical, chemical and biological characteristics and the conditions present between the soil and the water table.

Several investigations in Minnesota have provided information about nitrate concentrations moving in soil water below the rooting zone in cropland. Other investigators have measured nitrate concentrations in shallow aquifers on the down-gradient edges of cropped fields. The studies show that nitrate-nitrogen concentrations leaching below the rooting zone of row crop production fields in Minnesota typically exceed 10 mg/l, even with best management practices implemented, and often are two to four times the 10 mg/l drinking water standard. See Exhibit A-9.

While it is difficult to keep ground water nitrate levels below 10 mg/l when growing row crops, no matter what the fertilizer source, the additional nitrogen applied above crop fertilizer needs increases the potential for elevated nitrate movement to ground water. Based on numerous studies conducted by the Minnesota Department of Agriculture examining nutrient budgets on over 64,000 corn acres, livestock producers have been typically applying 40 to 70 pounds per acre of excess nitrogen in the forms of commercial fertilizer and manure. See Exhibit A-10. The over-application of the manure itself was not the principle cause of the excessive nitrogen rates. The lack of taking the full nitrogen credit from manure and legumes and, therefore, not reducing subsequent commercial fertilizer application is the primary reason for over-application. See Exhibit A-10.

Nitrate leaching to ground water and tile line water from fields subjected to manure application can be reduced by taking full credit for the nitrogen in manure and from legumes grown during the previous year. Understanding nitrogen credits will also reduce phosphorus loading to ground water and other water bodies. The agency proposes to establish minimum standards for manure application and nitrogen management in the proposed rules. These standards are needed to ensure that proper nitrogen credits and application rates are incorporated into feedlot operations and are based on the current industry knowledge.

Soil and ground water monitoring studies conducted throughout the country have determined effects on ground water from earthen manure storage basins that were constructed without a minimum two-foot thick clay-liner or a synthetic liner material equivalent to this standard. Results from 42 such monitored basins reported in the literature show that most of these sites have some evidence of elevated nitrogen in ground water or soil water resulting from the manure storage systems. See Exhibit A-11. The degree of reported ground water contamination varies widely, ranging from very slight elevations in nitrate and/or ammonium concentrations to some sites with total nitrogen concentrations over 100 mg/l above background levels. No ground water contamination or only slight evidence of degradation was reported at about half of the monitored facilities, with the other half showing total nitrogen concentrations at least 10 mg/l above background. It is necessary to establish design and construction standards for liquid manure storage basins to protect ground water from impacts from seepage through the liner.

Biological Oxygen Demand

Microorganisms flourish on the increased food supply provided by organic matter in manure. This increase in microorganisms depletes the oxygen levels in receiving waters faster than it can be replaced. The depletion of oxygen can cause fish kills or alter the species of fish and other aquatic life. Animal manure and feedlot runoff sources have relatively high concentrations of oxygen-depleting substances. Typical oxygen-depleting properties of various substances are listed in Table 3:

Table 3. Comparison of Oxygen-Depleting Properties of Waters, Sewage and Manure.

Source	Oxygen Demand (mg/l)
Stream water	2
Municipal sewage (treated)	25
Municipal sewage (untreated)	250
Cattle feedlot runoff	1000
Milkhouse wastes	1,500
Cattle or hog manure	50,000

See Exhibit L-2.

Recently, collected manure-contaminated runoff from a field that received a heavy application of manures contained 2200 mg/l of biological oxygen demand (BOD). As this liquid flowed into a ditch, the concentration was 1800 mg/l BOD. Runoff from an adjacent field that did not receive manure had 5 mg/l BOD. At a different site, manure-contaminated runoff from a hay field had 360 mg/l BOD, whereas runoff from an adjacent hay field with no manure applied had 1.6 mg/l BOD. See Exhibit L-2. It is necessary to establish some minimum controls to protect the environment from runoff of manure directly or from fields where manure has been excessively applied.

The impact of BOD-contaminated runoff from manure can be prevented by containing runoff from outdoor animal holding areas; immediately incorporating manure when land spreading near surface waters; and preventing intentional piping, pumping and dumping of manure. To ensure that these measures are utilized across the state, minimum standards are needed in the feedlot rules.

Pathogens

Bacteria, viruses, protozoa, fungi, rickettsiae and helmintus can be transmitted from animal waste to humans. Over 32 potential diseases can be transmitted by animal manure, mostly through ingestion of manure-contaminated surface or ground water. See Exhibit L-2. Both humans and livestock can potentially be impacted from manure-associated pathogens. Most of the pathogenic organisms associated with animal waste can enter another animal only by ingestion; however, hookworm and larvae can enter through the skin.

Transmission of water-borne diseases from animal manure to humans is not common. Even though large numbers of animals have existed for years in Minnesota, there have been no known major water-borne disease outbreaks as a result of animal waste contamination in the state. Yet, reporting of waterborne disease outbreaks is voluntary in the United States, and it is likely that waterborne diseases are under-recognized and under-reported.

Cryptosporidium, a protozoa commonly found in human and animal waste, has been responsible for numerous diseases outbreaks in the United States. In 1993, this organism caused the largest disease outbreak in U.S. history, resulting in 403,000 Milwaukee, Wisconsin, residents contracting watery diarrhea. Nearly 100 people died from this outbreak. See Exhibit L-2. Three to four other cryptosporidium outbreaks in municipal water supply systems have occurred in areas where livestock manure was a potential source of the problem. Cryptosporidium is very difficult to detect and very difficult to remove in water treatment systems.

Giardia is another parasite in animal manure that can be transmitted to manure. Giardia is now more easily detected in treated or public water supply systems. Several bacteria species found in manure can cause diarrhea in humans. Many other diseases can be transmitted from bacteria in manure, including septicemia, toxemia, meningitis, kidney infection, jaundice, Johne's disease and others. Bacteria can live from days to hundreds of days in the soil and water environment.

The occurrence of pathogens in the soil and water environment is rarely measured directly. Their presence is typically indicated by the measurement of indicator organisms such as coliform bacteria. The presence of fecal coliform does not necessarily imply that pathogens are also present; however, it does indicate that animal or human fecal contamination is present in the water. Fecal coliform organisms in feedlot and manure application site runoff typically number several million per 100 milliliters (ml) of sample. A small amount of manure contaminated runoff can result in exceedances of bacteria water standards, which are 200 MPN per 100 ml for most lakes and streams in Minnesota. The term, MPN, means most probable number and is a statistical means of reflecting the presence of bacteria. Elevated bacteria counts are a common reason for impaired surface waters in Minnesota. See Exhibit A-1. Most bacterial contaminants are not highly persistent and if placed in the sunlight will die fairly rapidly. See Exhibit L-2.

The number of people drinking water with pathogens originating from livestock manure is unknown. The most susceptible water supplies include all farm wells constructed prior to about 1974, wells in the uppermost aquifers in karst areas, and municipalities that rely on surface water for some or all of their drinking water. Swimmers and other water contact recreationalists also can be exposed to pathogen consumption. It is necessary to establish design, construction, and operational standards to protect surface water from the direct discharge of manure or manure-contaminated runoff. The minimum standards are needed in rule to ensure that all Minnesotans are afforded the same level of protection.

A very comprehensive and recent review of the effects of animal agriculture on water quality is included in the "Generic environmental Impact Statement on Animal Agriculture: A summary of the literature related to the effects of Animal Agriculture on Water Resources," and abbreviated "GEIS." See Exhibit A-1. The summary statements based on the literature review support the information previously presented in this document. For example, some of the conclusions presented in the Executive Summary are listed below. See Exhibit A-1, pages G-1 to G-13.

- "Livestock waste can contribute significantly to phosphorus loads in surface waters (seven to 65 percent of total loads);"
- "Feedlot runoff contains extremely large loads of nutrients and oxygen demanding substances, and if not properly collected and prevented from entering surface waters, this runoff can severely degrade surface water quality;"
- "Fecal bacteria in surface waters from lands receiving fresh manure applications can be a significant proportion (over 80 percent) of the fecal bacteria carried in surface waters" and
- "Nutrient losses in runoff from manured or fertilized fields are typically much greater than losses from unmanured or unfertilized plots."

Gaseous Compounds

Reduced sulfur, ammonia, and many other gasses are emitted from manure and can potentially affect human health. The sensitivity of people to these gases varies greatly. It is important to recognize the distinction between odor intensity and gas concentration. Odor intensity is a measure of detection sensed by the nose. Gas concentration is the actual concentration of the gas in the air. Studies estimate that between 80 and 200 gases are produced from decomposing livestock manure. See Exhibit A-12. A broad range of compounds has been identified in livestock manure, including volatile organic acids, alcohols, aldehydes, amines, fixed gases, carbonyls, esters, sulfides, disulfides, mercaptans, and nitrogen hetrocycles. The nose in very low concentrations (hydrogen sulfide) can detect some of these gases and others cannot be detected even at very high concentrations (methane). Gases are transmitted via air currents and can travel several miles or several feet, depending on the specific conditions.

Studies have established that there is a dose/response relationship for gases such as ammonia and hydrogen sulfide on human health (i.e., a particular concentration of gas for a particular amount of time will elicit a certain human response). These relationships are often not related to odor intensity. The dose/response relationship to most of the gases given off during manure decomposition has not been well documented or researched.

Feedlot odors may alter a person's mood. However, it is unclear if the mood altering impact is a psychological or physiological response to odor. Recent monitoring of hydrogen sulfide near Minnesota swine operations has occasionally shown levels that exceed health standards. Nausea, headaches, eye irritation, throat and respiratory irritation may result from short-term exposure to elevated levels of hydrogen sulfide. Short-term exposure is not believed to have any lasting health effects. Short-term exposure is defined as less than 8 consecutive hours over a 24-hour period at the health standard. See Exhibit A-12.

Other possible health problems associated with manure odors and gases include vomiting, shallow breathing, modified olfactory function, coughing, sleep disturbances and loss of appetite. Workers at the livestock facility or neighbors near the facility may be exposed to the feedlot gases and potential health risks. However, there is little documented information available concerning the health effects on either workers or neighbors.

A very comprehensive and recent review of the effects of animal agriculture on air quality is included in the GEIS. Some of the conclusions listed in the Executive Summary are included below. See Exhibit A-1, pages H-1 to H-2.

- "Animal agriculture can be a source of numerous airborne contaminants, including gases, odor, dust, microbes, and insects."
- "The rate of generation of these gases, organisms, and particulates varies with time, species, housing, manure handling system, feed type, and management system used, thus making prediction of contaminant presence and concentrations extremely difficult."
- "The environment and health effects of these ambient air contaminants on people, animals and the environment surrounding animal production sites is only beginning to be investigated. In some areas some or all of the emission contaminants have created environmental or health concerns, but long term impacts on ecological systems and people are not known."

The need clearly exists to establish standards for the design, construction, and operations of animal feedlots and manure storage areas such that the negative impacts of gases generated at these facilities are minimized, particularly past the property line of a facility. It is also necessary to provide feedlot owners information on when and how specific standards will be applied (i.e., hydrogen sulfide).

D. Specific Needs Supporting Amendments to the Existing Rules.

The MPCA is required by statute to protect the state's environment from pollution, including pollution from animal feedlots. The Legislative Auditor's Report of 1999 provides a summary of many of the potential concerns associated with animal manure. See Exhibit G-1.

Minn. R. ch. 7020, under the current language, establishes the process for reviewing and issuing interim permits and Certificates of Compliance for the agency and delegated counties. Minn. R. ch. 7020 was last revised in 1978. The Legislative Auditor's Report of 1999 points out some of the weaknesses of the current rule. See Exhibit G-1. In part, these weaknesses include:

- "MPCA's current rules on the responsibilities of delegated counties are vague;"
- "current rules do not directly address siting feedlot issues such as whether new construction or expansion should be allowed in environmentally sensitive locations;" and
- "without adequate rules, many of the regulatory restrictions placed on feedlots appear in certificates of compliance where their enforceability may be in doubt."

The proposed rules are intended to address these and many other identified deficiencies in the feedlot rules and program.

The agency has identified the three high priority areas where feedlots pose significant water quality challenges. The technical standards in the proposed feedlot rules primarily focus on these challenges. The three priority challenges are:

- Improper manure management for nutrients and over application of manure;
- Manure runoff from open-lot feedlots; and
- Improper siting, design, and construction of new and expanding facilities.

The other portions of the revised rules provide the administrative support to meet the technical standards.

Nutrients in the manure from Minnesota's livestock and poultry could supply about one-quarter of the nutrients needed for the state's crop production. Many large and small-operation livestock producers don't take enough credit for these manure-related nutrients in their nutrient planning efforts. Because of this, producers often apply excess commercial fertilizer to cropland that has already received manure nutrients. This over-application can cause nutrients to leach to ground water or be washed off to nearby lakes, streams and rivers.

Many open-lot feedlots have mild-to-severe problems with runoff of manure into surface waters. There is an environmental need to address these chronic problems. The environmental problems due to improper manure management or storage have not been solved by traditional regulatory methods, especially for the smaller existing open-lot facilities.

These older, smaller facilities are frequently greater sources of pollution from runoff than newer, larger facilities, where animals are kept inside. Installation of pollution-abatement can be very expensive for smaller operations; costing up to $100,000 for some operations with limited options. On the other hand, some operations may only experience the cost of moving a fence and re-seeding a buffer area along a stream or wetland ($3,000 per site depending on the length of fence). The agency anticipates, however, that the majority of smaller operations will spend $36,000 per site to comply with the requirements of the proposed rules. See the discussion of the estimated costs in the Section V of this SONAR.

To provide some financial relief, the proposed rules allow the owner of a small animal feedlot or manure storage area (fewer than 300 animal units) until 2009 to come into complete compliance with the effluent limitations. The agency is proposing this extended compliance schedule under part 7020.2003 as a tool for owners to address the problem of runoff from small feedlots, and the related cost to comply with the standards. In the past, permits were not issued because the problem could not be fully solved by the owners within the 10-month period for an interim permit, and governmental permitting systems would be quickly overwhelmed by the prospect of issuing 8,000 individual permits. Interim permits often required an extension to complete the project.

The three primary goals of the amendments to the feedlot rules are to:

- Make progress in the short-term by owners making the quick and low cost changes as soon as possible even though full compliance is not achieved;

- Provide more time for owners to completely fix problems than previously allowed so funding can be acquired and the changes do not interrupt facility operations; and
- Establish an interim and ultimately an end date for existing pollution problems to be resolved so that compliance is finally achieved.

Those facilities that are eligible for the extended compliance schedule and are proposing an expansion will be required to come into complete compliance with the effluent limitations prior to stocking the expanded site with livestock. The agency staff estimates that the majority of the feedlots eligible for the extended compliance schedule will take advantage of this relief mechanism.

The proposed rules do require the owner to achieve compliance with the standards in steps. A partial solution, which is intended to reduce the runoff by 50 percent, must be implemented by October 1, 2003. This first step can be accomplished through the installation of clean water diversions and buffer zones, which are relatively inexpensive pollution abatement methods (see the discussion of the estimated costs in the Section V of this SONAR). The second, and final, step is to bring the animal feedlot or manure storage area into compliance with the effluent limitations by October 1, 2009. This may be accomplished through the installation of a settling basins and adequately sized filter strip, and additional water diversions or the installation of a manure storage area (also see the discussion of the estimated costs in the Section V of this SONAR).

We can avert pollution problems in the future by ensuring that new and expanding facilities are built to specifications that prevent pollution problems in the first place. The proposed rules codify the requirements that the agency has inserted in individual permits in recent years. By putting these requirements in rule, owners will have an easier time identifying the minimum requirements for construction prior to submitting a permit application. This will save the owner, counties, and the agency time and money, and will better protect the environment. Besides specifying pollution controls in the siting, design and construction of new facilities, the MPCA also offers technical assistance to help farmers meet those specifications.

In addition to addressing the high priority environmental problems presented by feedlots, the goals of the proposed rules and the redesigned feedlot program are to:

- Focus on animal feedlots and manure storage areas that have a greater impact on water quality;
- Expand the role of delegated counties in feedlot regulation;
- Increase agency and delegated county field presence; and
- Make the feedlot program compatible with existing agency and county resources.

These goals are more specifically addressed in the statement of reasonableness.

IV. STATEMENT OF REASONABLENESS

Minn. Stat. ch. 14 requires the MPCA to explain the facts establishing the reasonableness of the proposed rules. "Reasonableness" means that there is a rational basis for the MPCA's proposed action. The reasonableness of the proposed rules is explained in this section. Section IV is broken into two parts: the reasonableness as a whole and the reasonableness of individual rule parts.

A. Reasonableness of the Proposed Rules as a Whole

The reasonableness portion of this SONAR provides the discussion and background on why and how certain provisions of the proposed rules were established. Specific requirements are not found under this part of the discussion but rather under part B. This Reasonableness of the Rules as a Whole deals with the mandatory requirements established by the Administrative Procedures Act in completing the SONAR. Minn. Stat. § 14.131 requires the agency to address the following issues.

1. **Describe the classes of persons who probably will be affected by the proposed rule, including classes that will bear the costs of the proposed rule and classes that will benefit from the proposed rule.**

The classes of persons most likely be affected by this rule include owners and operators of animal feedlots; persons involved in the storage, transportation, disposal and utilization of manure; those interested in management of domesticated animals or related facilities; delegated counties, counties interested in applying for delegation to implement a feedlot program; and those interested in Minnesota water quality.

Technical requirements impact more than just the owners and operators of animal feedlots, manure storage areas, and pastures. These requirements may also apply to those persons who haul and apply the manure as well as the owners of the land to which the manure is applied. The agency is proposing technical requirements under parts 7020.2000 to 7020.2225. The cost implications of these proposed requirements are discussed in the Consideration of Economic Factors under Section V of this SONAR.

Agency staff anticipates all parties in the state will be benefit from the implementation of these proposed rule revisions. The goals of the proposed rules are to establish a more efficient regulatory process; a closer county/state working relationship; and on-going guidance and support to animal feedlot, manure storage, and pasture owners, operators and technicians for the purpose of improving or protecting water quality in the state.

2. **Estimate the probable costs to the MPCA and other agencies of implementing and enforcing the proposed rule and any anticipated effect of the rule on state revenues.**

This discussion is located under the Consideration of Economic Factors, in Section V of this SONAR.

3. Discuss whether there are less costly or less intrusive methods of achieving the purpose of the proposed rule.

In developing the proposed rules, one of the focal points for agency staff was to develop a new permitting program that would, minimize costs to the state, delegated counties, and persons to which the rules apply. This goal had to be balanced with the need to address the requirement by the Legislature to issue National Pollutant Discharge Elimination System (NPDES) permits to animal feedlots with 1,000 or more animal units by the year 2004; the need to improve the environmental performance of a large number of small animal feedlots and manure storage areas (those with fewer than 300 animal units); and the need to provide ample opportunity for public input into the process of regulating animal feedlots and manure storage areas.

The agency is proposing several provisions intended to reduce the cost of compliance with the feedlot rules. The agency is proposing that animal feedlots or manure storage areas with fewer than 300 animal units are not required to apply for a permit unless that facility does not request the extended compliance schedule and has been determined to be a pollution hazard. The construction short-form permit is proposed as a method to make permitting for construction or expansion of facilities with 300 to 999 animal units more streamlined and less intrusive. In addition, the agency plans to establish general permits for those that are required to get a NPDES permit but are part of a group having similar regulatory issues. Thus, the agency will take advantage of a streamlined permitting process.

Experience with the existing regulatory program has shown staff that working with delegated counties also makes the permitting process less intrusive. Persons required to have permits are allowed to work closer to home with people more familiar with local concerns. The proposed rules expand delegated counties' ability to issue permits from facilities with fewer than 300 animal units to 999 animal units.

The guiding principal for the proposed permitting systems is to require the owner to apply for a permit only if the permit is required by federal regulations, or the permit will provide tangible benefits that cannot otherwise be achieved. For these reasons, the proposed rules require the owners of those facilities that:

- Meet the definition of concentrated animal feeding operation (CAFO) to apply for National Pollutant Discharge Elimination System (NPDES) permit;
- Are being constructed or expanded that have greatest the potential to be objectionable to local residents (construction or expansion of a facility that will hold 300 to 999 animal units after construction) to apply for a construction short-form permit; and
- The commissioner or county feedlot pollution control officer has determined that either the animal feedlot or manure storage area is a pollution hazard and must apply for an interim permit.

Facilities in the first group are required to obtain a permit under the federal regulations (40 CFR 122.23), and the agency has been delegated this permitting authority. Therefore, a permit is required by federal regulation and the agency is authorized to receive and process a permit application.

The second group of facilities is the new or expanding facilities. As discussed below, the construction of these facilities can be adequately regulated through rule. However, regulating construction at these facilities by rule eliminates an important opportunity for people interested in a facility to review the facility plans; to raise concerns; and to request from the agency a hearing on that facility. Animal feedlots and manure storage areas with 300 or more animal units are likely facilities to draw the most frequent criticism from local residents. The opportunity for local residents to consider the potential impacts of the construction or expansion of these facilities was an opportunity that the agency believed was worth preserving. Therefore, the notification establishes a route by which local governments or residents may raise concerns through local ordinances or perhaps the request for an Environmental Assessment Worksheet.

The agency considered requiring construction short-form permits for those animal feedlots or manure storage areas with 50 to 299 animal units. This was rejected for the following reasons:

- The state has an estimated 32,000 animal feedlots. The workload to issue permits for this group would shift staff resources away from the more valuable task of feedlot in-the-field oversight;
- The proposed rule establishes construction standards and notification requirements that would be required in the vast majority of construction permits issued to this group. Therefore, anyone interested in the requirements for construction of a facility of this size can see them at any time, especially prior to construction of the facility. An interested person would be able to request a copy from the project proposer. The small portion of owners that would propose to construct a facility different than allowed under the proposed rule will be required to obtain a state disposal system (SDS) permit. The SDS permit would require a public notice and comment period;
- The proposed rules still require agency, or county feedlot pollution control officer and local government notification of any construction including that at animal feedlots or manure storage areas with fewer than 300 animal units.

The agency did identify two factors that would support requiring animal feedlots and manure storage areas with fewer than 300 animal units to apply for a construction short-form permit. These factors are:

- Any animal feedlot or manure storage area has the potential to be objectionable to local residents and, if the proposed rules required the owner to apply for a permit, local residents would have one more opportunity to object to the construction or expansion of the facility. However, these facilities are more generally viewed as the small operators and have not drawn the criticism of the larger operations. The proposed rules do require the owner to notify all local governing bodies.
- Some county feedlot pollution control officers (CFOs) like the idea of requiring a construction permit for the construction or expansion of any animal feedlot or manure storage area with 50 or more animal units. The participation of delegated counties in the

> proposed animal feedlot program is critical to the success of the program. Thus, the agency sees the opinions of the CFOs as very important. The agency believes that the primary argument for issuing permits to this small size facility is opportunity it provides for contact between the owner and the CFO. Since the proposed rule requires notification of the CFO prior to construction, the agency believes that opportunity for contact and discussion is preserved.

After considering the arguments for and against the construction short-form permit, the agency concluded that the additional cost of requiring construction short-form permits from animal feedlots and manure storage areas with fewer than 300 animal units was not justified. Thus, the agency did not include this requirement in the proposed rule.

The third group of facilities is the group that has been identified as those with existing or potential pollution hazards that must be corrected. A facility in this group is required to apply for a permit to give the agency or delegated county the opportunity to match a particular environmental problem with the appropriate fix. The fix to the environmental problem could also be accomplished through an enforcement action. However, the interim permit provides a mechanism for the agency or delegated county to get the environmental problem addressed in a much shorter period of time than could be achieved through the agency or county attorney pursuing an enforcement action. The cost (financial and administrative) to the agency or delegated county and the owner would be also much lower using interim permits than the cost of an enforcement action. The agency will, however, retain the ability to use enforcement actions instead of an interim permit depending on the particular situation.

Using the above-stated guiding principle of requiring an individual permit in limited and justified situations, the agency believes that the cost to owners, delegated counties and the agency to regulate all animal feedlots and manure storage areas in Minnesota has been minimized and the rules as proposed are reasonable.

4. **Describe any alternative methods of achieving the purpose of the proposed rule that the MPCA seriously considered and the reasons why they were rejected in favor of the proposed rule.**

As stated in the statement of need, the most efficient means to regulate a group of facilities is through individual permits for those that are unique, and cannot be regulated as a group, and general permits or permit-by-rule for the vast majority of facilities that have similar characteristics.

The agency considered requiring each owner having an animal feedlot or manure storage area to apply for a permit. However, the administrative cost to issue an estimated 40,000 permits does not provide a reasonable payback in terms of enforceability of the requirements.

The agency also consider no permits for any animal feedlot or manure storage area other than those required to obtain a permit under federal regulations. While the enforceability of requirements found in rule is the same as that of permits conditions, the opportunity for meaningful review and comment on the part of interested parties to a project are significantly reduced under such a program. The proposed rules require construction short-form permits for facilities that will have 300 or more animal units after construction for this reason. The agency believes that facilities under this size are those to which there will be the least objections. The proposed permitting system makes the best use of staff resources because permits are required for each facility only when the permit will meet a specific goal or accomplish a needed activity. No permit is required for any facility for which no justification exists.

5. **Estimate the probable costs of complying with the proposed rule.**

The probable costs of complying with the proposed rules are discussed in the Consideration of Economic Factors under Section V of this SONAR.

6. **Provide an assessment of any differences between the proposed rule and existing federal regulations and a specific analysis of the need for and reasonableness of each difference.**

The proposed rule has been developed with great consideration of federal regulations governing animal feeding operations (AFO) and concentrated animal feeding operations (CAFO) and all provisions proposed in this rule are intended to meet or exceed the federal regulations. The proposed rule is also consistent with many of the performance expectations for AFOs identified in the joint Environmental Protection Agency (EPA) and United States Department of Agriculture's (USDA) Unified National AFO Strategy (Strategy). See Exhibit G-2. Many provisions of the proposed rule also place AFO owners in a position to develop and implement a Comprehensive Nutrient Management Plan (CNMP), as the National Strategy suggests. However, the proposed rules, which establish criteria for the development of a manure management plan, allow more flexibility regarding who prepares the manure management plan and its content. These rule provisions include manure storage and handling requirements, land application of manure requirements, record keeping and other utilization options such as composting manure.

While there are several differences between the proposed rule and the existing federal regulations, many of these differences also exist today under the current state feedlot program. This Section, first, provides a brief description of the relevant federal regulations. Second, the Section provides a discussion of the general differences between the federal regulations and the proposed state regulations. Finally, a more detailed discussion of the following specific differences is provided:

- Definition of CAFO;
- Animal unit values;
- Federal effluent limitations versus state discharge standards;
- Case-by-case designation as a CAFO versus pollution hazard; and
- State technical standards for design, construction and operation

The Clean Water Act (CWA) establishes requirements for the discharge of pollutants from point sources. See Exhibit P-1. The federal regulations governing animal feeding operations are established in 40 CFR 122.23 and 40 CFR 122, Appendix B. See Exhibit A-14. Within the federal system, any discharge of animal manure or process wastewaters from CAFOs is prohibited, except in accordance with a National Pollutant Disposal Elimination System (NPDES) permit. In addition, when chronic or catastrophic storm events cause a discharge from a facility designed, constructed and operated to hold the manure, process wastewater and runoff from a 25-year, 24-hour storm event and under the current EPA effluent guidelines for CAFOs, permitted discharges do not violate the CWA.

In addition, the owner of a CAFO is required to obtain an NPDES permit, if the owner's facility is included in one of the following categories:

- AFOs having more than the number of animals listed in 40 CFR 122 Appendix B(a) including facilities with more than 1,000 animal units (a description of how to calculate animal units is provided in Appendix B to 40 CFR 122);
- AFOs having more than the number of animals listed in 40 CFR 122 Appendix B(b) including facilities with more than 300 animal units that may or do discharge by one of the methods covered by the regulations at 40 CFR 122, Appendix B(6); or
- AFOs designated by the permitting authority as a CAFO on a case-by-case basis.

The agency is given and charged with powers and duties that include the adoption of rules to prevent, control or abate water pollution. The existing rules pertaining to animal feedlots, manure storage areas and pastures, which have been in effect for the past 20 years, are established and implemented under these powers and duties. The proposed rule can be divided into four main sections: a registration program; a permit program; a delegated county program; and technical standards. Within these four main sections, the agency estimates that rule regulates an estimated 40,000 facilities in the state compared to the estimated 840 facilities (approximately 800 facilities having over 1000 animal units and 40 facilities having under 1000 animal units) in the state that are subject to the CAFO permitting regulations at the federal level. The proposed rule regulates these 40,000 facilities, which are comprised of CAFOs, AFOs, manure storage areas and pastures; whereas, the federal regulations regulate only CAFOs. The existing agency rules currently cover the estimated 40,000 facilities in Minnesota and the proposed rules intend to regulate the facilities under a different approach, which includes less administrative burden and clearer performance measures.

The proposed rule establishes regulations for any person involved in the storage, transportation, disposal or utilization of animal manure, process wastewaters or process generated wastewaters. The agency's justification for the need and reasonableness of regulating this comprehensive list of operations and persons is the wide range of potential pollutants associated with these operations and high value Minnesotans place on the natural resources of the state. The basic purpose of the federal regulations is to create a minimum program addressing larger feedlot operations in the country that have, or pose a significant potential to have, a discrete discharge to surface waters. There is no way a one-size-fits-all national regulatory framework is expected to provide adequate environmental protection for the myriad of different feedlot situations existing in a diverse number of individual states. More details of this justification are given in sections of this SONAR dealing with specific need and reasonableness issues.

The registration and permitting programs within this proposed rule are designed to work directly with the technical standards for design, construction and operation. The state program proposes two distinctly different types of permits, operational permits (NPDES and State Disposal System) and non-operational permits (construction short form and the interim corrective action), whereas the federal regulations rely solely on NPDES operational permits. Since the agency is proposing non-operational permits for most facilities under 1000 animal units, the proposed rule provides a registration system and technical standards to require regular contact with the regulatory agency or county and to place ongoing operational requirements on facilities.

The following is a more detailed discussion on the specific differences between the federal regulations and the proposed state rule.

Definition of CAFO

There are a few differences in how Minn. R. ch. 7020 classifies those facilities that are CAFOs and, therefore, those facilities that are required to apply for and obtain an NPDES permit. First, the federal regulations basically define a CAFO as having *more than* 1000 animal units or *more than* 300 animal units and meeting at least one of two discharge criteria. The proposed rule requires all facilities having 1000 *or more* animal units to comply with the same discharge standards and permit application requirements as CAFOs. The rule also establishes an animal unit threshold at 300 animal units *or more*, to distinguish facilities for purposes of the permitting program and technical standards. This difference results in approximately 20 facilities (MPCA Agwaste database, November 18, 1999) that are currently permitted for exactly 1000 animal units and are considered CAFOs under the state program.

The difference in the universe of facilities permitted under the federal programs is due, in part, to Minnesota statutes. Minn. Stat. § 116.07, subd. 7c(a), requires the agency to issue NPDES permits for feedlot with 1000 animal units or more based on a specified schedule. The existing feedlot rules, Minn. R. pt. 7020.1600, subp. 2, item A, uses the "less than 1000 animal units" language, Minn. R. pt. 7020.1600, subp. 2, item B, uses "less than 300 animal units" and Minn. R. pt. 7020.1600, subp. 3, uses "smaller than 300 animal units" language, all of which are consistent with the proposed rule language. The provisions under 40 CFR 412.10 of the federal regulations also establish the subcategories of feedlots subject to applicable effluent standards. This federal provision establishes an equivalent capacity of "as large or larger than" 1000 animal units. Additionally, Minn. R. pt. 4410.4300, subp. 29, item A, deals with mandatory Environmental Assessment Worksheet (EAW) categories for animal feedlots and also uses the "1000 animal units or more" language. Finally, many counties, townships and cities in Minnesota currently have local ordinances that regulate animal feedlots and the ordinances use language consistent with the existing rules. Thus, the inclusion of facilities at exactly 1000 animal units under the proposed feedlot rules and different from the federal program is reasonable because it does not cause a significant shift in local government programs; impacts a relatively small number of facilities in the state, which most already consider their facilities to be subject to federal regulations; and the program has operated under this regulatory structure since at least 1979, when the rules were last revised.

Another potential difference exists because the proposed rule includes manure storage areas (where no animals exist) in the definition of CAFO. The federal regulations do not specifically include manure storage areas where no animals exist in the definition of CAFO. However, the EPA Guidance Manual and Example NPDES Permit for CAFOs, review Draft, August 6, 1999, describes in section 2.1 what an AFO is. See Exhibit P-2. The guidance states that "EPA defines the AFO to include the confinement area and the storage and handling areas necessary to support the operation (e.g., waste storage areas)." Therefore, the inclusion of manure storage areas having the capacity of 1000 animal units or more in the definition of CAFO is reasonable because a storage are capable of storing manure from 1000 animal units or more is a facility that is necessary to support an animal feeding operation.

The agency does not intend that a CAFO obtain two separate permits for the two distinct parts of the operation. The agency does intend, as does EPA, that one permit would cover the entire operation even if the parts are not adjacent. Furthermore, the agency intends that a manure storage area capable of storing manure from the equivalent of volume 1000 animal units or more from several non-CAFOs be defined as a CAFO. This is reasonable because the facility presents a comparable environmental risk as an animal holding area for 1000 or more animal units, given the presence of a comparable volume of manure. Such a facility would typically be a commercial manure management facility, and not only presents risks from the actual storage facility, but also from the loading of vehicles for transport to land application sites and unloading of manure from the original animal feedlot. Therefore, it is reasonable to treat these facilities similarly to the facility managing 1000 animal units of livestock.

An issue receiving considerable comment during this rulemaking is in federal regulations, 40 CFR 122 Appendix B, which reads in part as: "Provided, however, that no AFO is a CAFO as defined above if such AFO discharges only in the event of a 25-year, 24-hour storm event." Federal regulations require CAFOs to apply for an NPDES permit and Minnesota statute requires the agency to issue NPDES permits to the owners of all facilities having 1000 animal units or more. EPA's August 6, 1999, draft guidance document describes in section 2.3.6 that "Most AFOs with more than 1000 animal units probably have discharged in the past or have a reasonable likelihood to discharge in the future, at less than a 25-year, 24-hour storm event, and therefore are required to apply for and obtain a (NPDES) permit." See Exhibit P-2. This Section of the guidance document also provides that "Facilities that believe that they do not discharge should apply for an NPDES permit and provide documentation of no discharge with the permit application." The proposed rules provide for permit coverage under either scenario. If the facility meets the CAFO criteria, the facility will be issued a joint NPDES/SDS permit; if the facility does not meet the CAFO criteria but has 1000 animal units or more, the facility will be issued an SDS permit. It is reasonable to regulate both types of facilities similarly due to the risks associated with confining 1000 animal units in one area, whether the facility is a CAFO under federal regulations or not. The managing of livestock or poultry in numbers great enough to reach the 1000 animal unit have additional concerns regarding their construction, design and operation of whether that facility is subject to federal regulations because of the CWA issues regarding point source discharges. It is reasonable to use the permitting process to account for these risks.

A significant factor in determining the potential to discharge under the federal program is the consideration of stockpiling and the land application sites. EPA's draft guidance addresses this factor in two sections of the guidance document. See Exhibit P-2. Section 2.1 states that "discharges of CAFO wastes from land application areas can qualify as point source discharges in certain circumstances… Accordingly, CAFO permits should address land application of wastes from CAFOs." Section 2.3.2 states that "a poultry operation that conducts improper land application activities or stacks waste in this manner (in areas exposed to rainfall or adjacent to a watercourse) and that otherwise meets the CAFO definition …, is a CAFO and subject to the NPDES program." An EPA memorandum dated September 27, 1999, also addresses this issue by reiterating the guidance sections above and also stating that "More specifically, discharges of manure and wastewater from land application areas should be viewed as discharges from the CAFO itself, even though, as the draft guidance notes, the definition of an AFO describes the area of confined animals and does not mention land application areas." See Exhibit P-2. The agency's position on this issue is again, that any facility having 1000 animal units or more may be a CAFO under the federal program, which the agency is delegated to implement, because these is the potential to discharge where manure is produced, stored or land applied. This position is reasonable because it is consistent with the excerpts from EPA above, it provides a more consistent and certain position for facility owners, and owners have the opportunity to demonstrate that they are not a CAFO.

All facilities having 1000 animal units or more must apply for an NPDES permit under the proposed rule. If a facility in this category demonstrates through the permit application process or is determined through a process or guidance established by the federal government that it does not meet the definition of CAFO and thus, does not need an NPDES permit, the proposed rule requires that the facility apply for an SDS operating permit. The requirement for an SDS permit is reasonable because it establishes a similar set of standards for all facilities having 1000 or more animal units.

<u>Animal Unit Values</u>

Federal regulations provide criteria in 40 CFR 122, Appendix B for determining if an AFO is a CAFO. These criteria are based, in part, on: the number of animals in a category that are housed at a facility (nine animal categories are listed); or by the total number of animal units housed at a facility (animal unit multiplication factors are given for five animal types). The proposed rule part 7020.0300, subp. 5, includes animal unit multiplication factors for thirteen animal categories. Of these, five have state multiplication factors that are different than the corresponding federal categories or multiplication factors. In general, the proposed animal unit values in the proposed rule are intended to provide clarity and fill gaps in the federal animal-unit multiplication factors.

First, the animal-unit multiplication factor for mature dairy cattle (whether milked or dry cows) is given by federal regulations as 1.4. Federal regulations also have animal number thresholds set at 700 mature dairy cattle (within the group of 1000 animal unit facilities) and at 200 mature dairy cattle (within the group of 300 animal unit facilities). The state multiplication factor is set at 1.4 under the existing rules and is proposed to be separated into two factors, one for mature dairy cattle over 1000 pounds which will remain at 1.4 and one for mature dairy cattle under 1000 pounds which is proposed as 1.0 animal units. The reader is advised to read the explanation found in the specific reasonableness for part 7020.0300, subp. 5, items A and B, for a more detailed explanation on the determination of the state multiplication factor. The agency has selected a separate multiplication factor for a mature dairy cow over 1000 pounds and for a mature dairy cow weighing less than 1000 pounds. The agency believes specifying two separate factors for dairy cows is reasonable because those breeds tending to mature at lighter weights have been shown to produce less manure and therefore, the risk to human health and the environment would not be equivalent from 1000 animal units. Additionally, the separation of dairy cows based on mature weights allows agency and delegated counties to reconcile differing approaches to this issue. County concerns regarding the management aspects need to be heard as they are critical to the success of the proposed feedlot program as explained in this SONAR under part 7020.1600.

Another difference exists in the dairy cattle category. This difference is the agency's proposed addition of a second dairy cattle multiplication factor (part 7020.0300, subp. 5, item A, subitem (2) providing a lower weight criteria of 1000 pounds for the 1.4 factor, that may be viewed as being less restrictive than federal regulations for dairy cattle. As described in this SONAR for this definition, the agency has been provided with data that identify a significantly lower manure production rate for the Jersey cow breed compared to other milking breeds. See Exhibit P-5. The need and reasonableness of these proposed changes is discussed in more detail in this SONAR for part 7020.0300, subp. 5, item A.

Second, the animal-unit multiplication factor for slaughter steer and feeder cattle in the proposed rule includes heifers. This difference from the federal regulations is reasonable because it retains the heifer language that exists in the current state rule and clarifies a very common animal type. Minnesota feedlot owners raising heifers will not be under a different category of permit needed due to a change in animal units managed simply due to a rule change. The inclusion of heifers is consistent with the amount of manure generated by them and the other cattle types included in the category.

Third, the animal-unit multiplication factors for swine in the state program includes a value for swine under 55 pounds, which is not included in the federal regulations. Again, this difference from the federal regulations is reasonable because it retains language that exists in the current state rule and clarifies a very common animal type.

Fourth, federal regulations do not include a specific multiplication factor for poultry. However, the animal unit multiplication factors for chickens in the proposed rule are consistent with the factor one would obtain by interpreting the animal number categories in federal regulations (e.g., 1000 animal units divided by 100,000 broiler chickens equals 0.01). The existing state rule has been implemented to consider all chickens, regardless of size, as 0.01, which is both more restrictive and less restrictive than the federal regulations. The existing state value is more restrictive by including small chickens or pullets as 0.01 animal units that are not addressed by the federal regulations and are less restrictive for facilities with a liquid manure system that have a (interpreted) multiplication factor of 0.033. The proposed rule eliminates this less restrictive factor and provides a more reasonable factor of 0.003 for the smaller chickens by adding a weight threshold of 3 pounds. The reasonableness of this threshold is discussed in this sonar under part 7020.0300, subp. 5, item F. Providing a threshold any higher than 3 pounds creates too great a potential inconsistent interpretation of the rule. For example, if the threshold were set at five pounds and a facility has 100,000 broiler chickens that weigh up to five pounds each, the facility would be considered CAFO under the federal regulations while having only 300 calculated animal units under the state program and providing an argument that the facility is not a CAFO under the state program. Such a difference would create a risk to owners of poultry operations for being out of compliance with federal regulations. The agency believes that it is unreasonable to put feedlot owners at such a risk. Again, the provision is reasonable because the state program meets or exceeds the federal program, reduces risk to the feedlot owner, and fills the needed gaps to allow the agency and delegated counties to address manure produced at facilities of all sizes.

Finally, similar to the discussion above for chickens, federal regulations do not include a specific multiplication factor for turkeys. However, the animal-unit multiplication factors for turkeys in the proposed rule are consistent with the factor one would obtain by interpreting the animal number categories in federal regulations (e.g., 1000 animal units divided by 55,000 turkeys equals 0.018). The existing state rule has been implemented to consider all turkeys, regardless of size, as 0.018 animal units. The proposed rule retains this factor for the adult turkeys and adds a more reasonable factor of 0.005 for the smaller brooder turkeys (by adding a weight threshold of 5 pounds). The reasonableness of this threshold is discussed in this sonar under part 7020.0300, subp. 5, item G. These differences are, therefore, reasonable because the state program meets or exceeds the federal program and fills the needed gaps to allow the agency and delegated counties to address manure produced at facilities of all sizes.

Federal Effluent Limitations and State Discharge Standards

There are several differences between the federal discharge standards or effluent limitations and the proposed state discharge standards. The federal regulations require all CAFOs to meet the "no-discharge" standard (40 CFR 412.13), except that CAFOs discharging when chronic or catastrophic events cause an overflow from a NPDES-permitted facility designed, constructed, and operated to contain all process waste waters plus the runoff from the 25-year, 24-hour storm event do not violate the CWA. The state standards propose a three-tier approach for which the need and reasonableness is described in this SONAR under part 7020.2003. The three-tier state standards require that CAFOs and facilities with 1000 or more animal units must meet the federal regulations described above; that other facilities under 1000 animal units must comply with the effluent limitations in Minn. R. pt. 7050.0215; and that eligible open-lot facilities under 300 animal units must comply with Minn. R. pt. 7050.0215 through an extended schedule with interim improvements required by October 2003 and final measures completed by October 2009.

In all cases, the agency may require a facility to meet an effluent limitation more stringent than specified above to address such issues as total maximum daily loading (TMDL) requirements for a particular waterbody.

The federal regulations allow NPDES permits to address ground water only when a discharge of pollutants to surface waters can be proven to be via ground water. See Exhibit A-15. Under the existing and proposed state permitting programs, when issuing an NPDES permit, the agency will issue the owner a combination NPDES and State Disposal System (SDS) permit in the same document. It is needed and reasonable for the state to address both surface- and ground-water quality standards in a single permit for CAFOs so that comprehensive protection of state water resources occurs.

The referenced effluent limitations under Minn. R. pt. 7050.0215 requires owners not subject to the no-discharge standard under the federal regulations (40 CFR 412) to meet a 5-day biochemical oxygen demand (BOD) limit of 25 milligrams per liter (based on the arithmetic mean of all samples taken with a calendar month). If the facility also discharges to or affects a lake or reservoir the nutrient control requirements in Minn. R. pt. 7050.0211, subp. 1 also apply. However, federal regulations define facilities between 300 and 1000 animal units as CAFOs if they discharge by one of two methods including directly or through a man-made conveyance. Again, the state standards also regulate discharges to ground water for this group of facilities. If a non-CAFO between 300 and 1000 animal units can demonstrate compliance with Minn. R. pt. 7050.0215, then the facility may comply with the effluent limitations in accordance with Minn. R. pt. 7050.0215.

The third tier of the state discharge standards provides a compliance schedule for open-lot feedlots having fewer than 300 animal units. This provision of the rule has been designed to require the smaller open-lot feedlots (under 300 animal units) to comply with the same effluent limitation standard as the non-CAFO 300 to 1000 animal unit facilities, although this group is given an extended time period to achieve compliance. In part, the agency selected the October 1, 2009, final compliance date to be consistent with the joint EPA/USDA Strategy that identifies the year 2009 as the desired date for all AFOs to have developed and implemented a CNMP. See Exhibit G-2. It is reasonable for the state rules to address these smaller, high-risk facilities, even if federal rules do not cover these facilities. As stated before, federal regulations are primarily intended to focus on larger facilities but that does not mean that it is not reasonable for states to address additional risks associated with smaller facilities that may also impact both surface and ground water.

<u>Designation as a CAFO and designation as a pollution hazard</u>

Federal regulations provide for designation of any sized AFO as a CAFO on a case-by-case basis if the facility is a significant contributor of pollution (40 CFR 122.23(c)). Under the definition of CAFO, the agency has incorporated by reference the case-by-case designation process under 40 CFR 122.23 into the proposed rules. Similarly, the commissioner or delegated county feedlot officer may designate a non-CAFO facility as a pollution hazard if the facility meets one of two criteria (part 7020.0300, subp. 19a). Item B of the pollution hazard definition is very similar to the case-by-case designation criteria identified in federal regulations. However, the most significant differences are:

- The agency has removed the consideration of "other relevant factors" in the definition of pollution hazard to better distinguish the federal criteria from the state criteria;
- The agency's pollution hazard definition may also address pollution to ground water;
- County feedlot officers may use the pollution hazard definition to address problems; and
- The agency would not have the resources to address under an NPDES case-by-case designation process.

This is reasonable because the agency does not intend to issue require NPDES permits to all facilities with pollution hazards.

When implementing the case-by-case designation process and the pollution hazard process the agency intends to follow consistent procedures. In fact, the agency has a policy on implementing the federal case-by-case designation process for AFOs. See Exhibit P-3. This process is consistent with the federal process, and therefore, no differences exist in how the agency or EPA will designate a CAFO on a case-by-case basis.

Furthermore, the agency anticipates that when an animal feedlot, manure storage area, or pasture has been determined to be a significant pollution source, the agency will attempt to seek the owner's cooperation in obtaining a timely resolution and elimination of the pollution problem. This process may include issuance of an interim permit, a tool most frequently used by the agency or delegated county, if the matter can be resolved within a short time period. The process could also include the use of other tools such as notice of violation or other enforcement tools, such as an administrative penalty order. In any case, a variety of tools are available, including the NPDES permit if the facility is designated a CAFO. The differences in these processes are reasonable because the EPA and the agency have the same basic goal to eliminate the discharge as soon as possible. The agency's experience has been that most pollution problems at the smaller facilities can be corrected in a relatively short time frame. Often, the problems can be corrected faster than the agency could process and issue an NPDES permit. The process described above is reasonable because it significantly reduces the administrative resources needed to correct the problem by agency or delegated county issuance of an interim permit instead of an NPDES permit and allows ground water pollution hazards to be addressed under the state feedlot program.

<u>State Technical Standards for Design, Construction and Operation</u>

Parts 7020.2000 to 7020.2225 of the proposed rule establish standards for discharge, design, construction, operation and closure of animal feedlots, manure storage areas and pastures (technical standards). A subtle difference in the technical standards and federal regulations is that the federal regulations provide the effluent limitations with little direction on how to achieve compliance and the state proposes to establish technical standards to clarify its expectations of facility owners to achieve compliance.

However, many of these, or similar, specific technical requirement have been placed directly into NPDES permits issued by the agency for about the past six years. A second difference is in the state's overt protection of ground-water discharges through several of the specific technical standards including: discharge standards, part 7020.2003; location restrictions, part 7020.2005; closure, part 7020.2025; liquid manure storage areas (MSA), part 7020.2100; unpermitted MSAs, part 7020.2110; poultry barn floors, part 7020.2120; stockpiling, part 7020.2125; composting, part 7020.2150; and land application of manure, part 7020.2225. Again, the federal regulations do not address ground-water discharges and it is reasonable that the state rules provide a comprehensive protection framework, particularly, when it is understood that nearly 70 percent of Minnesota's population obtains its drinking water from ground water sources.

7. **Conformance to the requirements under Minn. stat. § 16A.1285 relating to review of the proposed rules by the Commissioner of Finance.**

As required by Minn. Stat. § 16A.1285, the Commissioner of Finance has reviewed the charges proposed in this rule. See Exhibit F-3. The Commissioner of Finance's comments and recommendations are attached. See Exhibit F-4. For additional discussion on this topic see the Consideration of Economic Factors, Section V of this SONAR.

8. **Describe how the agency, in developing the proposed rules, considered and implemented the legislative policy under Minn. Stat. § 14.002, which requires state agencies, whenever feasible, to develop rules and regulatory programs that emphasize superior achievement in meeting the agency's regulatory objectives and maximum flexibility for the regulated party and the agency in meeting those goals.**

The agency focused on providing maximum flexibility for the regulated parties in three main topic areas as follows:

Providing opportunity for implementing construction and operation methods that differ from those required in the specific rule parts

During the FMMAC meetings held from May to October 1999, the poultry industry representatives raised concern regarding proposed rule language that specified one construction method for soil-lined poultry barn floors. They raised the issue that a construction method or material other than what is stated in the rules could provide the same level of environmental protection. Since the agency is concerned about the environmental protection outcomes rather than establishing one construction method, the agency responded to this concern by providing construction option for concrete-lined, asphalt-lined or PVC-lined floors under part 7020.2120. It is reasonable to allow a facility owner options for meeting an environmental outcome to incorporate the final design option that matches the facility business plan.

Since the concept that the agency's environmental protection goals can be achieved through methods that are different than the construction or operation methods outlined under parts 7020.2000 to 7020.2225, the agency proposes to allow alternative methods as they are approved through the SDS permitting process. Since methods other than those specified in the rules must be evaluated to determine that they will achieve at least the same level of environmental protection as the rules, the agency is allowing these alternative methods to occur under the SDS permit process. See part 7020.0405, subp. 1, item B, subitem (3). The SDS permit process provides an extensive site-specific review and a public notice and comment period for the proposed permit. This process allows alternative methods other than those stated under the rules to address pollution issues and reach state pollution goals and opens the door to possible new technologies in the future without jeopardizing the established level of protection for the environment.

Custom fitting annual goals for delegated county programs

Currently, 51 counties have received delegation under Minn. R. pt. 7020.1600 for the processing of interim permits and certificates of compliance. Each of these counties is unique in the number of livestock operations and the types and number of environmentally-sensitive areas that are contained within its jurisdiction and the number of staff hired to manage the local program. These and other related characteristics determine what procedures and goals are achievable and effective for each delegated county.

Therefore, the agency wanted to design the county delegation program with the flexibility for counties to determine how best to use their resources and establish their own inspection and other programmatic goals to help the agency meet the state environmental goals for animal facilities. For this reason, the agency did not specify numeric annual inspection, permitting, registration, and complaint response or owner assistance goals. Instead, the agency is proposing to use a delegation agreement. The delegation agreement will allow the agency and county to establish annual goals through negotiation that are based on available resources and the work needed to achieve an effective program. The agency believes that it is reasonable to allow a county to evaluate its needs and resources when establishing a program to meet the environmental outcomes specified in the proposed rules. Under this management scheme, a county will not be required to expend more resources than appropriate to achieve the environmental results or that are beyond its capabilities.

Establishing steps for achieving compliance with water quality discharge standards for smaller open-lot feedlots

One of the greatest existing threats to Minnesota's waters is runoff from open lots at small animal feedlots. The current rules require that all animal feedlots and manure storage areas comply with the water quality discharge standards of Minn. R. pt. 7050.0215. Attaining this standard is out-of-reach for many of these facilities due to the cost to comply with the standard and the short period of time allowed, under the current Interim permit, to correct the runoff problem.

The agency have added flexibility into the proposed rules by establishing a stepped approach for achieving compliance with the water quality standards at open lots under Minn. R. pt. 7050.0215 for the owners of these small animal feedlots (fewer than 300 animal units). See part 7020.2003, subp. 4, for proposed eligibility requirements. The agency proposes to allow these facility owners until October 1, 2009 to come into compliance with Minn. R. pt. 7050.0215 for the open lot portion of the facility. However, these owners must install and operate a system of clean water diversions (diversion to keep uncontaminated runoff from running across an open lot and becoming contaminated prior to entering waters of the state) prior to October 1, 2003. The intent of requiring owners to install the diversions is to achieve a reduction in the quantity of pollutants entering waters of the state by at least 50 percent by October 1, 2003. A 50 percent reduction in runoff will have a measurable impact on the water quality of Minnesota. The proposed rules allow the owners time to arrange financing, and potentially a subsidy, for the installation of the manure storage area and/or runoff filtering area before complying with the water quality discharge standards under Minn. R. pt. 7050.0215 for the open lots.

9. Describe the agency's effort to provide additional notification to persons or classes of persons who may be affected by the proposed rule.

The agency's efforts to provide additional notification to persons or classes of persons who may be affected by the proposed rule are discussed in the Additional Notice Section VI of this SONAR.

B. Reasonableness of the Rules Related to the Goals of the Feedlot Program Plan

The proposed rule is intended to address ground-water and surface-water quality protection issues resulting from animal feedlots, manure storage areas, and pastures. The proposed rule consists of essentially four parts that deal with the following: registration, permitting in general, county feedlot programs and technical standards (standards for discharge, design, construction, operation and closure). Each of these parts is required to achieve the goals established for the proposed rules. Air emissions from animal feedlots and manure storage areas are considered to the extent directed by the Governor in his legislation veto letter to Speaker Sviggum dated May 25, 1999. See Exhibit G-4.

The MPCA's broad goals for revising the rules at this time include the need to:

- Focus on animal feedlots, manure storage areas and pastures that have a greater impact on water quality;
- Expand the role of delegated counties in feedlot regulation;
- Increase agency and delegated county field presence;
- Achievable with existing agency and county resources.

Focus on facilities that have a higher impact on water quality

Not all animal feedlots, manure storage areas, and pastures have the same water quality impact or the potential for water quality impact. As a group, small open lots with runoff present one of the greatest threats to water quality in Minnesota. It is estimated that 8,000 to 12,000 of the 40,000 or so feedlots in the state have fewer than 300 animal units and significant runoff from an open lot. This runoff pollutes innumerable rivers, lakes and streams that result in waters that cannot support life other than vegetation and some rough fish.

Large animal feedlots and manure storage areas with more than 1,000 animal units individually present the greatest potential for significant water quality impact in the event of a significant failure such as failure of a liquid manure storage area. For this reason alone, it is necessary to closely monitor these facilities.

In addition to focusing the agency's attention on the two previously mentioned groups, the proposed rules address technical issues that confront all animal feedlots, manure storage areas, and pastures including the establishment of clear:

- Statewide expectations for manure storage, handling and land application or utilization;
- Design and construction requirements;
- Operation requirements; and
- Manure and nutrient management requirements.

The agency is charged with the responsibility to protect human health and the environment for Minnesota. Therefore, it is reasonable to focus the agency's resources on those feedlots presenting the greatest potential for impact.

Expand the roles and responsibilities of delegated counties in feedlot regulation

The agency recognizes the vital role that delegated counties have played in effectively regulating animal feedlots, manure storage areas, and pastures in the past and the even more important role these counties will play in the future. The method of regulating feedlots under the proposed rules would undergo a dramatic realignment of resources from staff dedicated to issuing permits to staff in the field interacting with owners. This shift has been termed as a movement to field presence. Field presence is best described as communication between the owner and agency and/or delegated county staff at the facility. This communication will include a continuum that ranges from educating owners of the requirements of the rule and suggesting ways in which to achieve environmental performance at the facility to inspections and enforcement action for violations of the rule requirements. The proposed rules include provisions intended to increase the field presence by increasing the number of delegated counties. The number of delegated counties should increase under the proposed rules by addressing the concerns that the agency has heard as reasons for counties not to seek delegation. The proposed rule would:

- Increase the number of feedlots for which delegated counties can issue permits;
- Clarify the roles and duties of the delegated counties and the Agency; and
- Increase county share of administrative responsibility of the feedlot program.

It is reasonable to provide delegated counties more responsibility for implementing the feedlot program because they know the local geologic conditions and environmentally-sensitive areas that could be negatively impacted by feedlots. Additionally, the increased permitting authority to counties allows them to coordinate local land use issues more effectively and efficiently. It is also reasonable to spend the agency's resources by meeting with facility owners at the site rather than issuing permits from an office as it allows for site specific conditions and management options to be incorporated in the owners methods to achieve an environmental outcome. Each feedlot is unique with specific factors that must be addressed in efforts to protect the environment.

Increase agency and delegated county field presence

As stated above, the proposed rules represent a dramatic shift in the allocation of staff toward an emphasis on field presence. This strategy is based on the belief that the greatest environmental gains can be realized through education and compliance verification. This is best accomplished through direct contact between the agency and county staff and livestock producers. Given the desire to achieve this field presence without significantly increasing the number of staff working on feedlots, it is necessary to devise a program that allows the reallocation of the existing staff. Changes in the proposed rules regarding permit procedures and the universe of facilities to be permitted are reasonable as they allow this reallocation of staff by significantly reducing or eliminating the need for permits by providing clear rule technical requirements.

Clear technical requirements allow the agency to adopt a regulatory system that is not entirely dependent on permits to effectively regulate a large number of facilities. Most regulated groups can be divided into two groups: one that has relatively few members that have unique characteristics or concerns; and the second, much larger group, whose members are very similar with the same or similar characteristics and concerns. The most efficient means to regulate a large number of similar facilities is through clear rules. Rules and permits carry the same legal weight with regard to enforcing conditions to which a facility is subject. The animal feedlots, manure storage areas, and pastures in Minnesota all have similar issues, or at least a very small number of different issues, with regard to manure storage area construction, and manure management. For this reason, the proposed rules contain clear detailed technical requirements for the following:

- Locating animal feedlots and manure storage areas;
- Transportation of manure;
- Livestock access to water;
- Milkhouse waste;
- Animal feedlot and manure storage area closure;
- Non-certified/unpermitted manure storage areas;
- Poultry barns floors;
- Manure stockpiling;
- Manure composting; and
- Land application of manure.

By including these parts in the proposed rules and making them broadly applicable, the need to issue permits to each feedlot is significantly reduced and the time required to draft any individual permit is significantly reduced because these requirements (if deemed adequate by the agency) can be referenced in the draft permit instead of negotiated individually with the owner. This is a reasonable outcome of the rules as the window of opportunity for expanding or entering the livestock or poultry market can be very small and administrative delays can have serious economic impacts.

The proposed rules do not require permits for facilities, with fewer than 1,000 animal units that are in compliance with the proposed technical standards; are not constructing or expanding; and are not determined to be a pollution hazard. A pollution hazard, under the proposed rules, can only be determined by a site inspection by the agency or delegated county. Thus, a feedlot owner will not face expenditures not related to a real environmental need. The proposed rules also do not require owners to apply for a construction permit if the facility will have fewer than 300 animal units; if the facility is in compliance with the technical standards; and if the facility owner will construct and operate the facility or expansion in compliance with these standards. Potentially lost in a system of regulation not dependent on permits for each facility is the opportunity for public notification and input on a specific project. The proposed rules address this potential problem by publishing in the rules the technical conditions that would be included in an individual permit if one were to be issued, and by requiring notification in a local paper for any construction project that will increase the capacity of the facility and local government notification for construction or expansion of animal feedlots or manure storage areas with 500 or more animal units. The latter notification is intended to address and clarify the notification requirements under Minn. Stat. § 116.07, subd. 7a.

Because the need to issue permits has been significantly reduced by including clear technical standards in the rule, the staff resources that were previously dedicated to the permitting activity can be reallocated, in the future, to activities that increases the field presence. The proposed regulatory system will produce superior environmental performance (improved water quality) with a lower administrative burden and the fewer staff than would be required achieve similar environmental results under the existing permitting system. The agency believes that is prudent public policy and a reasonable use of resources to match desired environmental outcomes and the potential risks associated with a facility to the administrative requirements.

Achievable with existing agency and county resources

A goal of the proposed rule revisions has been to achieve superior environmental results with the existing state and county staff resources. The program plan is largely based on the goal of increased field presence. See Exhibit I-4. That is what staffing level would it take to visit and inspect each of the approximately 40,000 animal feedlots and manure storage areas in Minnesota within 10 years of the effective date of the rule. The program plan also includes the estimated staffing level to effectively oversee the county feedlot programs; issue NPDES, SDS, construction short-form and interim permits; provide training to feedlot and manure storage area owners and county feedlot pollution control officers; review manure management plans, and all of the other requirements of the proposed rules. Currently, the feedlot program at the agency has approximately 22 full-time equivalent (FTE) staff. So far, the needs versus available resources to implement the program with existing agency staff levels has not been met as evident by the estimated 38 FTE required estimated in the program plan. Therefore, the agency believes a strategy is needed to achieve the goals and that this strategy must accompany the rule process.

As stated above, the proposed rule consists of essentially four parts that deal with the following: registration, technical standards (Standards for Discharge, Design, Construction, Operation and Closure), county feedlot programs, and permitting in general. These parts are the overall foundation of the strategy to achieve the stated goals.

Also as stated above, the proposed rules are intended to increase the field presence of the agency and delegated counties staff. To improve the effectiveness of the field presence, the proposed rules require the owner of each animal feedlot, manure storage area, and pasture to register each of these facilities with the agency. The purpose of this registration is to gather enough information to allow the agency and delegated counties to identify each facility and to prioritize the site visits. Site visits would be prioritized based on the highest potential to impact water quality will be visited first. The agency believes that the information collected in the Level 2 inventories compiled by some counties will provide sufficient information to facilitate this prioritization. This means that those facilities that are closest to water bodies may be a higher priority than those that are great distances from water. Those that are located in areas susceptible to sinkhole development may be a higher priority than those that are not. The program plan includes some of the criteria upon which an inspection list may be prioritized. Exhibit I-4. See the Statement of Reasonableness for part 7020.0400 for more discussion of the need for and reasonableness of the proposed registration requirements.

Among the options available to the agency for regulating animal feedlots, manure storage areas, and pastures, in the past, the agency elected to use permits. Permits were required when construction was proposed at an animal feedlot or manure storage area. In addition to the permit, the facility that applied for the permit might be inspected at some point before, during, or after the construction was completed. Inspections and outreach have not been a significant part of the strategy for regulating animal feedlots, manure storage areas, and pastures.

The permitting requirements of the proposed rules are smaller in scope than previous rules, but they form a very significant shift in the strategy for regulating animal feedlots, manure storage areas, and pastures. In addition to the proposed rule revisions, the agency has undertaken the task of redesigning the feedlot program at the agency in an attempt to optimize (from an environmental outcome standpoint) the use of staff resources. The general direction of the redesign has been to emphasis work to be done in the field and to de-emphasize paper reviews to determine if an environmental goal will be achieved. The lack of a significant field presence is one of the areas in which the agency and the feedlot program were criticized in the Legislative Auditor's report. See Exhibit G-1. The program redesign, which is a work in progress, has been documented in the form of a program plan for all agency activities related to animal feedlots and manure storage areas. See Exhibit I-4, Program Plan. The program plan is intended to guide the implementation of the proposed rules and addresses the following activities:

- NPDES permitting;
- Non-NPDES permitting;
- Animal feedlot and manure storage area inspection plans and priorities;
- Education and outreach;
- County feedlot program oversight;

- Manure management plan review;
- Construction plan review; and
- Measurement of affect of the proposed rules on the environment (i.e., is the environment improved as a result of the rule and program plan).

As stated above, the impetus for the preparation of this plan was to make the best use of the agency and delegated staff to achieve the best possible environmental outcome. The agency believes that the best environmental outcome will be achieved through an increased field presence. The program plan reflects the emphasis on field presence and the de-emphasis on paper review that can often be the central point of a regulatory system based on issuing permits. Field presence means that staff spends a significant amount of their time in the field instead of behind a desk. This notion, that field presence will be effective, is based on the agency's belief that most facility owners will make every attempt to comply with rules and laws if they are aware of the rule or law and; and if they believe that the rule or law is based on sound reasoning. The proposed rules, as a whole, are intended to allow the agency and delegated counties to shift staff resources from doing paper reviews to doing inspections, education and outreach activities. The proposed rule is intended to allow and encourage the agency and delegated to shift their strategies for regulating animal feedlots and manure storage areas from one of reviewing paper work to one of actually looking at and addressing the issues at the animal feedlots and manure storage areas.

The four main portions of the proposed rule: registration, permitting, county feedlot programs and technical standards are all intended and designed to work together to achieve the best possible environmental outcome. The proposed technical standards, parts 7020.2000 to 7020.2225, establish the minimum location, construction, and operational requirements needed to minimize the environmental impact of these operations. One of the reasons for including the technical standards in the proposed rule is to reduce or eliminate the need to use permitting as the regulatory tool for a large number of animal feedlots and manure storage areas. The proposed rules include clearly stated technical standards that are broadly applicable. By including clear technical standards and making them broadly applicable, individual permits are not needed to impose legally enforceable location, construction, and operating conditions on any facility. These technical standards also reduce the amount of time needed to draft and issue permits for those facilities that still need one.

The proposed rules emphasize the important role that delegated counties play in the regulation of animal feedlots and manure storage areas. The well-run county feedlot programs are part of the model used to develop the program plan and the proposed rules. In these counties, the county feedlot pollution control officer spends a large portion of his/her time at an animal feedlot or manure storage area talking with the owner and affecting the environmental performance of that facility through education. For this reason, it is reasonable and wise to build on the county program that is already in place. The proposed rules are intended to do that and address the deficiencies identified in the Legislative auditor's report. Emulating the well-run county programs will place more agency staff in the field and will result in measurable environmental improvement.

The proposed permitting system is also intended address confusion that exists relative to in the federal NPDES permitting requirements. As discussed in further detail under the Statement of Reasonableness for part 7020.0405, subp. 1, item B, subitem 1, there is some confusion about the applicability of the NPDES permitting requirement for facilities that do not discharge but may have the potential to discharge. The confusion seems to be about the use of the term "potential." Does the fact that manure is present and open to precipitation mean that the facility has the potential to discharge? The proposed rules are intended to address this confusion by requiring the owners of those facilities with more than 999 animal units that can demonstrate that the facility does not meet the definition of CAFO to apply for a SDS permit. It is the intent of the agency to issue a permit that contains the same requirements as would be required in a NPDES permit. This is consistent with Minn. Stat. § 116.07, subd. 7c, that requires the agency to issue NPDES permits to owners of those animal feedlots with 1,000 or more animal units.

Consistent with the current rules, the agency will issue one permit that addresses NPDES and SDS permittees. Thus, facilities issued an NPDES permit will be covered under the same permit as an SDS facility. The National Pollutant Discharge Elimination System permits are intended to address and only have the authority to address discharges to surface water. As stated in Section II of this Statement of Need and Reasonableness, Minnesota statutes provide the agency with the authority to adopt rules and issue permits to for the purpose of preventing pollution of waters of the state of which ground water is a part. The State Disposal System permit addresses potential discharges to ground water, while the NPDES permit would only address surface water discharges. Since discharges from animal feedlots, manure storage areas, and poorly operated pastures have in the past and have the potential to discharged in the future to surface water and ground water, it is reasonable to require owners that are subject to the requirement to obtain a NPDES permit and an SDS permit. Combining these permits into a single permit is allowed under Minn. R. pt. 7001.1010. In order to minimize the administrative burden of apply for and obtaining a permit, it is reasonable to combine the NPDES and SDS permits into a single permit.

Finally, the proposed permitting system takes advantage of the technical standards by reducing the number of permits. Individual permits will be issued where there is a tangible benefit for issuance of the permit, and, where the agency has an obligation to issue such an NPDES permit.

The proposed rules will allow small animal feedlots, manure storage areas (fewer than 300 animal units), and pastures to construct and operate within the constraints of the technical standards without applying for a permit from the agency or the delegated county. Animal feedlots, manure storage areas, and pasture with more than 300 animal units that propose to locate, construct, and operate in accordance with the proposed technical standards will be able to do so under a streamlined permitting system called construction short-form permits. Animal feedlots, manure storage areas, and pastures with fewer than 1,000 animal units will not be required to apply for an operating permit if the facility is constructed and operated in accordance with the proposed technical standards. The agency believes this is reasonable because the standards that would be drafted into individual permits will now be codified in rule. The administrative burden to review for anything other than construction is not warranted and not obtainable with current agency staffing levels.

One of the greatest threats to Minnesota's waters is runoff from open lots at small animal feedlots. See the Statement of Need for further discussion of runoff from open lots. The current rules require that all animal feedlots and manure storage areas comply with the standards of Minn. R. pt. 7050.0215. Attaining this standard is out-of-reach for many of these facilities due to the cost to comply with the standard and the short period of time allowed, under the current Interim permit, to correct the runoff problem. For this reason, owners of these facilities have chosen to do whatever is necessary to avoid contact with the agency to avoid be forced to decide whether to quit operation or fix the problem at a cost that may yet force them out of operation. For this same reason, the agency and delegated counties have not made great efforts to locate these facilities and force that decision. The proposed rules will allow owners of these small animal feedlots (fewer than 300 animal units) until October 1, 2009, to come into compliance with Minn. R. pt. 7050.0215. However, these facilities will also have to commit to and install and operate a system of clean water diversions (diversion to keep uncontaminated runoff from running across an open lot and becoming contaminated prior to entering waters of the state) prior to October 1, 2003. The intent of requiring owners to install the diversions is to achieve a reduction in the quantity of pollutants entering waters of the state by at least 50 percent by October 1, 2003. This in-and-of-itself will have a measurable impact on the water quality of Minnesota.

The proposed rules will then allow the owners time to arrange financing, and potentially a subsidy, for the installation of the manure storage area and/or runoff filtering area needed to comply with Minn. R. pt. 7050.0215. As an alternative to completely fixing the runoff problem, some owners may then decide to cease operating. For further discussion of the cost to install and operate these diversion systems, manure storage areas, and filtering areas, see Section V, of this Statement of Need and Reasonableness, Consideration of Economic Factors. The proposed rules for this group of owners will only be effective if the owners know, and understand what is needed and why it is needed and if there is a credible threat that those who choose to take advantage of the deferred enforcement of the standards of 7050.0215 and do not take the appropriate actions to come into compliance with the standards will be caught and punished. The credible threat can only be demonstrated through a strong "field presence" by the agency and delegated counties.

The proposed system reduces or foregoes completely much of the review that has taken place prior to construction at an animal feedlot or manure storage area. The proposed system allows the agency to dedicate many more staff to being in the field. If owners discover that the proposed rules require less initial oversight and less oversight after a project is complete, the proposed regulatory system will fail. The environmental performance of animal feedlots and manure storage areas will only improve if the agency and delegated counties make a credible effort to place staff in the field to oversee these facilities and ensure that the facilities are located constructed and operated in accordance with the proposed rules. The potential environmental gains that proposed system would allow will not be realized without a strong "field presence."

Under the proposed system, the agency will do less up front review of plans and specs and will do more inspections of construction sites. The agency will issue fewer construction permits and do more education and outreach through personal visits to more animal feedlots and manure storage areas. Under the proposed rules, owners will be required to apply for a permit less frequently but will be more responsible for locating, constructing and operating in accordance with the proposed rules.

As stated in Section IV, item A, subitems 3 and 4, Reasonableness of the Rules, Reasonableness as a Whole, the proposed rules establish an new permitting system for animal feedlots and manure storage areas. Parts 7020.0350 to 7020.1600 establish the proposed registration and permitting system and county feedlot program requirements. The intent of the proposed system is to allow the agency and delegated counties to refocus staff time on issues that will result in the greatest environmental gains. Parts 7020.0400 to 7020.0535 establish the proposed permitting system; a permitting system that places more emphasis on an owner's ability to comply with technical requirements and less emphasis on agency staff issuing permits unless there is a tangible gain to be had by going through the permitting process and issuing that permit. The proposed system is a new way for the agency to regulate these facilities. In many ways, the proposed system is about owners accepting responsibility for the environmental performance of their facility and the agency accepting that these owners will do what is needed if they know and understand what is needed and why it is needed.

C. Reasonableness of the Specific Proposed Rule Parts

This section addresses the reasonableness of specific parts of the proposed rules.

Chapter 7001 Agency Permit Procedures

7001.0020 Scope

This part of the existing Minn. R. ch. 7001 sets forth the requirements applicable to permits and certifications issued by the agency. The existing rule requires permits and certifications to comply with parts 7001.0010 to 7001.0210, except as otherwise specifically provided. The proposed modification to item F of this part is needed to address permitting related modifications to the agency's rules governing animal feedlots, manure storage areas and pastures under Minn. R. ch. 7020.

Item F. The proposed revisions to item F are intended to clarify which parts of Minn. R. ch. 7001 apply to permits issued to animal feedlots, manure storage areas and pastures, and which do not. The current rule states that parts 7001.0040 to 7001.0070 do not apply to an agency permit required for the construction and operation of a feedlot; and part 7001.0100, subparts 4 and 5, and part 7001.0110 do not apply to interim permits. Minn. R. pt. 7001.0020, item F, establishes permit related requirements as summarized in Table 4.

Table 4. Summary of Permit Requirements in Referenced in Part 7001.0020, Item F.

Part No.	Part Heading	Summary of Requirements
7001.0040	Application deadlines	This part establishes the deadline requirements for submitting applications for permits, permit modifications, and permit reissuance.
7001.0050	Written application	This part establishes the requirements for permit application content.
7001.0060	Signatures	This part establishes the requirements for which persons must sign a permit application
7001.0070	Certifications	This part establishes the certification requirements for permit applications with regard to completeness and truthfulness of the information submitted in the application.

The proposed rules state that Minn. R. part 7001.0020, item F, applies to construction short-form permits as well as interim permits as stated in the current rule and described above. As discussed in more detail in the Statement of Reasonableness for part 7020.0405, the proposed construction short-form permit is quite similar to the interim A permits that are issued under the current Minn. R. ch. 7020, in that they allow construction at animal feedlots and manure storage areas. For this reason, it is reasonable to exclude construction short-form permits from part 7001.0100, subparts 4 and 5, and part 7001.0110, as interim permits currently are.

The proposed rules delete the exemption to parts 7001.0060 and 7001.0070 for permits for animal feedlots and manure storage areas. Therefore, under the proposed rules, owners are required to comply with the same signature and certification requirements as all other permits issued under Minn. R. ch. 7001. The signature requirements identify the person that must sign a permit application. The trend in the industry in the recent past has been toward larger animal feedlots with ownership agreements resembling large corporations more than the stereotypical family farm. Since the owner is ultimately responsible for the facility's compliance with all requirements and the ownership structures are as complex as that of large corporations, it is reasonable for the proposed rules to have the same signature requirements as other facilities permitted under Minn. R. ch. 7001. For these same reasons, it is reasonable to require the same certifications as other facilities permitted under Minn. R. ch. 7001.

The current rule states that the requirements under Minn. R. pt. 7001.0020, item F, only apply to animal feedlots. The proposed rules state that these requirements also apply to manure storage areas and pastures that are subject to the permitting requirements. Since manure storage areas and poorly operated pastures potentially have the same pollution problems as animal feedlots (runoff and ground water contamination) and the proposed rule intends to permit manure storage areas where no livestock exist and all problem sites, it is reasonable to establish the same requirements for these operations as animal feedlots.

The proposed amendments to this provision states that part 7001.0050, part 7001.0100, subparts 4 and 5, and part 7001.0110 does not apply to construction short-form permits issued under the proposed revisions to Minn. R. ch. 7020. The permit application content provision (part 7001.0050) is added to the exempted parts of Minn. R. ch. 7001, applicable to construction short form and interim permits because these requirements are incorporated into part 7020.0505 of the proposed rule. This proposed amendment also exempts construction short-form permits from the public notice and public comment provisions. Interim permits are already exempt form these provisions. Construction short-form permits are intended for new or expanding facilities and to replace Interim-A permits and certificates of compliance, which are exempt from these provisions. Interim-A and Interim-B permits and certificates of compliance currently issued by the agency or delegated county for under 1000 animal unit facilities including new construction and expansion projects, or for pollution hazards, do not include requirements for public notice and comment. All applicable requirements of a construction short-form permit are included in the proposed rule. Therefore, all interested parties will have this opportunity for input under this rule making activity and permit requirements are available for review. The agency holds the right to revoke a construction short-form permit. Therefore, if an interested party feels that the s construction short-form permit does not adequately regulate any feedlot with this type of permit, the agency can then take the appropriate actions to address these concerns including requiring the feedlot owner to obtain a different permit. For these reasons, the proposed amendments are reasonable.

The proposed amendments to Minn. R. pt. 7001.0020, item F, are needed to provide consistency between the permitting provisions of this part and the proposed revisions to Minn. R. ch. 7020. The SONAR for part 7020.0405 describes the need and reasonableness of providing appropriate incentives for feedlot owners to apply for a construction short-form permit, one of which is a streamlined permitting process. By exempting these parts from the construction short-form permitting process the streamlined nature of the permit is preserved. Conversely, state disposal system (SDS) permits will be required to meet the requirements of these parts because SDS permits will be issued to feedlots that are not eligible for a construction short-form permits. This is reasonable because these feedlots will be doing something different than the proposed technical standards allow and/or will be large feedlots and manure storage areas (non-CAFOs with 1,000 or more animal units). These types of feedlot specific factors require feedlot specific compliance requirements and schedules to be incorporated into the SDS permit. This provision is reasonable because it provides interested parties the opportunity to review and comment on SDS permits for these different cases.

Chapter 7002 Permit Fees

The agency proposes changes to the water quality fees rules, Minnesota Rules parts 7002.0210 to 7002.0310. The changes are being proposed to: 1) reflect agency organizational changes; 2) clarify the existing requirement that National Pollutant Discharge Elimination System (NPDES) permits that regulate animal feedlots, manure storage areas or pastures will be charged the fees already established under Minn. R. ch. 7002; 3) add the requirement that State Disposal System (SDS) permits that regulate animal feedlots, manure storage areas or pastures with a capacity of 1,000 or more animal units will be charged the fees already established under Minn.

R. ch. 7002; and 4) clarify that no fees will be assessed for construction short form permits and interim permits.

The proposed changes do not change the fee amounts that are already established under Minn. R. ch. 7002. The MPCA is currently charging fees for NPDES permits that regulate animal feedlots, manure storage areas or pastures. However, Minn. R. ch. 7002 uses a broad fee category called “Non-municipal permits, other non-municipal (any flow)” and the agency is proposing language that will clarify that NPDES permits that regulate animal feedlots, manure storage areas or pastures are included within this broad category. This is the fee category currently being used to determine fees for these permits. This rule change is reasonable because it more clearly states the fee requirements for NPDES permits; it clarifies current fee requirements and does not impose an increase in the fee amounts.

The MPCA also proposes to charge the fees under the “Non-municipal permits, other non-municipal (any flow)” category to State Disposal System (SDS) permits that regulate animal feedlots, manure storage areas or pastures with a capacity of 1,000 or more animal units. The MPCA currently does not charge fees for SDS permits that regulate livestock or manure storage facilities. However, the MPCA also seldom issues an SDS permit for one of these facilities. Currently under Minn. R. ch. 7020, “SDS permit” is not listed as a permit tool, but the SDS permit tool does currently exist under Minn. R. ch. 7001. In the agency’s proposed permit system, some facilities are required to have an SDS permit. See part 7020.0405.

One of the underlying foundation policies for the proposed permit system is that animal facilities with 1,000 or more animal units pose a significant potential environmental concerns because of the very large amounts of manure and/or process generated wastes that are produced or managed at these facilities. The MPCA is proposing to require an operating permit (a permit that is required for the life of the facility and addresses management and operational issues) for these facilities to address the significant potential environmental concerns.

Under the current MPCA animal feedlot regulatory program, NPDES permits are the only type of operating permits issued and fees are charged for these permits. Under the proposed rules, the MPCA may also issue an SDS operating permit. Since both the NPDES and SDS permits will be operating permits it is reasonable to charge the fees that are currently being charged for NPDES operating permits also for the SDS operating permits. Both the SDS and NPDES permits require the same amount of staff time and resources to process a permit application, develop permit requirements, and conduct inspections, technical assistance and enforcement actions needed to ensure compliance. An operating permit requires more resources than permits that just regulate a construction project because the permit must remain current with the facility. Staff must review and modify the permits whenever there is a significant change in operation, a pollution concern arises, a change in ownership occurs, or for renewal.

The MPCA is proposing to limit charging permit fees for SDS permits to the permits that regulate animal facilities with a capacity of 1,000 or more animal units. The agency has chosen this group of permittees for two reasons: 1) this category of facilities is proposed to be required to have operating permits, and 2) to prevent creating a financial incentive that will cause facility owners to seek the SDS permit rather than the NPDES permit proposed to be required.

As discussed earlier in this section, facilities with a 1,000 or more animal unit capacity are proposed to be required to have an operating permit. Most facilities with less than 1,000 animal units are only required to have permits for the duration of a construction project or pollution hazard correction project, usually no more than 24 months. The MPCA has introduced the SDS permit as an option to the NPDES operating permit currently issued. It is reasonable to require the fee that is currently required for NPDES permits to also be charged for the SDS permit that regulate facilities with 1,000 or more animal units because both the NPDES and SDS permit being issued for the 1,000 or more animal unit category will be operating permits that regulate facilities with similar site conditions and environmental impact issues.

In the proposed rules, the MPCA uses the definition of CAFO as it is stated in the federal regulations. See part 7020.0300, subp. 5a, for a discussion of the reasonableness of this definition. CAFOs are regulated by the federal requirements and must have a NPDES permit. Based on federal CAFO guidance documents, MPCA staff concluded that the 1,000 or more animal unit facilities are included in the CAFO definition. See Exhibit P-2 . Further support for proposing that facilities with 1,000 or more animal units are CAFOs comes from Minn. Stat. § 116.07, subd. 7c, which requires that all facilities in this animal unit category must have an NPDES permit. Staff concludes from this statute that the Legislature has clearly stated that facilities with 1,000 or more animal units are CAFOs.

Since facilities with 1,000 or more animal units are CAFOs under the proposed rules, they are required to have NPDES permits. However, the MPCA has received letters that challenge staff's interpretation of the CAFO definition. See Exhibit P-4. The foundational concern of the agency under the proposed rules is that these large facilities be required to have an operating permit. When the MPCA issues an NPDES permit, it issues a combined NPDES and SDS (NPDES/SDS) permit, which ensures that the permit meets both federal and state requirements. This practice is based in part on MPCA's position that even if the federal Clean Water Act NPDES program did not exist, a person would at least have to get the MPCA SDS permit to construct, operate and use the disposal system that has the potential to discharge to waters of the state. In response to the uncertainty of how the challenge to the CAFO definition will be resolved, the agency has included in the proposed rule under part 7020.0405, subp. 1, item B, subitem (1), that if a facility with 1,000 or more animal units is determined not to meet the CAFO definition then the facility is required to have an SDS operating permit.

Since the MPCA plans to issue NPDES permits to most facilities with 1,000 or more animal units, it is anticipated that issuing an SDS permit for a facility with 1,000 or more animal units will be rare. However, the agency staff is concerned that an administrative problem will result if a fee is charged for an NPDES permit and not charged for an SDS permit. If a fee is not charged for the SDS version of the operating permit for facilities with 1,000 animal units or more than the MPCA staff are concerned that the rules will have established a financial incentive for owners to pursue an SDS permit by challenging the NPDES permit requirement. A demonstration is a written notice from the director of the Environmental Protection Agency stating that the facility is not a CAFO or a finding from a legal proceeding. It is not the intent of MPCA staff to limit facility owner's ability to request a CAFO determination. However, staff wants to limit such requests to facilities that by characteristic of design, operation and management truly are in question of meeting the CAFO definition rather than establishing a method for avoiding fees. Having no fee for the SDS permit would result in a significant amount of MPCA staff resources being spent on non-CAFO determination requests (which may occur in lengthy court proceedings) and will take the staff away from their duties, such as permit issuance and derail the MPCA program procedures. Since having the same fees for both NPDES and SDS operating permits for this animal unit category is reasonable for the reasons stated in the paragraphs above, it is also reasonable to use the permit fees already established under Minn. R. ch. 7002 to prevent creating a financial incentive for challenging the rule definition and to prevent the resulting MPCA program inefficiencies.

The agency is also proposing to charge no fees for interim permits and construction short form permits. No fees are currently charged for interim permits. The construction short form permit is similar in design and is issued to the 300 to 999 animal unit facility category like the interim permit. It is reasonable to propose language that states there is no fees for the interim permit because the language does not change, but clarifies the current fee policy for this permit. It is reasonable to charge no fees for the construction short form permit because this permit is similar to the interim permit and the proposed rules will make the fees the same for these two permits.

<u>Permit Fees Background</u>

The MPCA charges application fees, annual fees and permit modification fees that are used to help defray the costs of developing and issuing permits, conducting inspections to evaluate compliance with permits and regulations, training and outreach programs to educate regulated parties and pursuing enforcement actions. The schedule of fees charged for permits regulating water quality concerns is established under parts 7002.0210 to 7002.0310. For animal feedlots, manure storage areas, and pastures, the agency currently charges permit fees for NPDES permits. These permits are categorized under the "Non-municipal permits. Other non-municipal (any flow)" category under part 7002.0310, subp. 2, item B, and are charged: an $85 application fee, and a $1,230 annual fee for an individual permit or a $260 annual fee for a general permit. If a permit must be modified before the expiration date, a modification fee that is 50 percent of the annual fee is charged as stated under part 7002.0270, item B. No permit fees are currently charged for SW-A permits, interim permits, or five-year permits.

Initially, the agency planned to change the fee structure for permits that regulate animal feedlots, manure storage areas, and pastures. The change in fee structure would permit the agency to increase the number of staff in district and subdistrict offices. The increased staff would permit the agency to increase inspections and field work, better coordinate with local government on feedlot issues, and to process the large number of NPDES permits as required under Minn. Stat. § 116.07, subd. 7c, in a timely manner. See Exhibit F-2, FY99 Legislative Budget Initiative--Animal Feedlot Fees, for a more complete discussion of the MPCA fee initiative. In response to the MPCA's efforts to increase the fees, the legislature passed 1999

Minnesota Session Law, chapter 231, section 2, subdivision 2, was passed and states that the agency shall not approve additional fees on animal feedlot operations until July 1, 2001.

Four laws are important to the proposed fee discussion:

- Minn. Stat. § 116.07, subd. 4d;
- 1999 Minnesota Session Laws chapter 231, section 2, subdivision 2;
- 1999 Minnesota Session Laws chapter 250, article I, section 49; and
- Minn. Stat. § 14.18, subd. 2. See Exhibit F-3.

Minn. Stat. § 166.07, subd. 4d, gives the MPCA the authority to adopt permit fee rules. However, this authority was clouded with the passing of 1999 Minnesota Session Laws chapters 231 and 250. These Laws are discussed further under annual fees, part 7002.0270 of this SONAR.

<u>7002.0210 Scope</u>

Subpart 1. The agency proposes to add part 7001.0020, item F, to the scope of the water quality permit fee rules, parts 7002.0210 to 7002.0310. This is needed to clarify that animal facility permits are included under these rules. The agency is currently charging fees under these parts to owners that are issued NPDES permits that regulate animal feedlots, manure storage areas or pastures. It is reasonable to make this change in scope to clarify that animal facility permits are addressed under these parts. Clearly stating how animal facility permits fit into the water quality permit fee rule parts will make it easier for agency staff to explain fee requirements and for permit holders to understand when they are required to pay fees.

<u>7002.0240 Payment of Fees</u>

The agency is proposing to revise this part by changing “the director of the Water Quality Division” to “MPCA Fiscal Services.” This is needed to reflect a change in the agency’s organization. In 1998, the MPCA underwent an agency-wide restructuring. This effort changed the agency from a pollution-media structure (air quality, water quality, hazardous waste and solid waste/ground water) to the current geographic structure, which is focused on state districts. As a result, the Water Quality Division no longer exists. The agency is proposing that the fee payments are made to the agency’s fiscal services office. This is reasonable because the fiscal services office is responsible for collecting and processing revenues and expenses.

<u>7002.0250 Application Fee</u>

The agency is proposing language under part 7002.0250 to excluding interim and construction short form permits issued under Minn. R. ch. 7020 from the application fees. This proposed language is part of the agency’s efforts to clarify when fees are to be charged for permits that regulate animal feedlots, manure storage areas, and pastures. The agency currently does not charge application, annual or modification fees for interim permits. The agency is not proposing to change this practice. Construction short form permits do not currently exist under Minn. R.

ch. 7020. The agency is proposing to add this permit tool and proposes to treat this new permit like the interim permit and not charge permit fees. Since the agency does not intend to charge fees for the construction short form permit, it is reasonable to state this under part 7002.0250 to clarify that no application fees will be charged. In addition, the MPCA needs to clarify that application fees for SDS permits that regulate facilities with 1,000 or more animal units will not be charged application fees until July 1, 2001. This is the same delay proposed for annual fees under part 7002.0270, item F. See that part for a further discussion on the reasonableness of this delay in charging fees.

7002.0270 Annual Fee

Item F. The agency is proposing to add item F to this subpart to identify when annual fees will be charged for permits that regulate animal feedlots, manure storage areas or pastures. A separate item is needed to address permits issued under Minn. R. ch. 7020 because some of the permits (interim and construction short form permits) are unique to the animal facility regulatory program and not used in other water quality programs and not addressed under the fee parts. The existing fee parts that address fees for water quality permits include fees for NPDES and SDS permits. The agency is proposing to charge fees to only a portion of the NPDES and SDS permits unlike other water quality programs, which assess fees to all permits issued in these categories. Therefore, the agency is proposing language that clearly identifies which permits will be assessed the fees and which permits will be exempt.

The agency is proposing the phrase, "a permittee or applicant for permits issued under Minn. R. ch. 7020 must pay fees as follows:" This language mirrors existing language under item E regarding fees for individual storm water permits. Part 7002.0270 states that "all persons required to obtain a permit . . . shall pay an annual fee for processing of the permit and enforcement . . ." The agency interprets the words "obtain a permit" to mean the submittal of a permit application. Therefore, the agency charges annual permit fees once a complete permit application has been submitted, which begins the sequence of staff work of application review and permit development that leads to permit issuance. The agency proposes to use the word "applicant" here to clarify that annual fees must be paid once a complete application has been submitted to the agency. It is reasonable to clearly describe the agency's procedures so that agency staff implement the rules consistently and persons submitting a permit application clearly understand that they will be required to pay annual fees before the permit is issued.

Subitem 1. The agency proposes to charge fees for NPDES permits that regulate animal feedlots, manure storage areas or pastures. This language states the agency's current practice. The agency currently includes these permits under the "Non-municipal permits, other Non-municipal (any flow)" in part 7002.0310, subp. 2, item B. These annual fees are $1,230 annual fee for an individual permit or a $260 annual fee for a general permit. This item is reasonable because it clarifies existing practice.

An excerpt from the 1999 Minnesota Session Laws chapter 231, section 2, subdivision 2, reads: "Until July 1, 2001, the agency shall not approve additional fees on animal feedlot operations." The NPDES fees discussed in this subitem are not new fees because the fee amounts already exist under part 7002.0310, the agency is charging these fees to these permits under the existing rules, and no fee increases are proposed.

Subitem 2. The agency proposes to charge fees for SDS permits that regulate animal feedlots, manure storage areas or pastures with 1,000 or more animal units. The agency does not currently routinely issue SDS permits to regulate animal feedlots, manure storage areas or pastures. The agency is proposing to change Minn. R. ch. 7020 to require SDS permits for many facilities. See part 7020.0405. The agency is proposing to charge fees only for SDS permits that regulate animal facilities with 1,000 or more animal units because these permits will be operating permits and have nearly the same requirements as the NPDES permits for facilities in this animal unit category. Most other facilities will be required to have permits for construction that adds animal units and to solve a pollution hazard under permits with a 24-month term instead of being required to have on-going operating permits.

The proposed fees for SDS permits are needed to treat all facilities in the 1,000 and more animal units category consistently by charging them all annual fees; and to eliminate any potential financial incentive for facility owners to seek an SDS instead of an NPDES permit. Federal regulations require concentrated animal feeding operation (CAFO) to have an NPDES permit. The definition for CAFO as proposed under part 7020.0300, subp. 5a, incorporates the federal definition, which the MPCA interprets to include facilities with 1,000 or more animal units. However, if a facility in this category is determined through a legal proceeding or any other future process established by the federal government to demonstrate that is does not meet the definition of CAFO, the facility would be issued an SDS operating permit. If no annual fees are charged for the SDS permits in the 1,000 or more animal unit category, the discrepancy in fees would create an incentive for owners to pursue SDS permits instead of NPDES permits. This would create an inefficient component in the permitting system that could bog down the permit issuance process with time spent on requests for determinations and exclusion from the NPDES permit requirement. It is reasonable to charge permits that regulate facilities with similar pollution potential concerns and that are required to have operating permits the same amount of permit fees. This issue is also discussed under the *Reasonableness as a Whole* section.

The 1999 Minnesota Session Laws chapter 231, section 2, subdivision 2, reads: “Until July 2, 2001, the agency shall not approve additional fees on animal feedlot operations.” The fees proposed under subitem (2) indicate that for the SDS permits regulating facilities with 1,000 or more animal units could be viewed as new fees. Therefore, the agency requested the Commissioner of Finance’s review as required under Minn. Stat. § 16A.1285. See Exhibit F-3. The agency is not proposing a new fee amount, but proposes to apply the fees to a new group of permits. The fee amounts for SDS permits already exist under part 7002.0310. The MPCA has not routinely been issuing SDS permits for the regulation of animal feedlots, manure storage areas or pastures. The SDS permit will be used differently under the proposed rules causing facility owners not required to have an SDS permit under the current rules to be required to have an SDS permit as a result of the rule changes. See part 7020.0405 for a proposed list of facility owners required to have an SDS permit. The agency proposes to extend the fees to SDS permits that regulate facilities with 1,000 or more animal units. Since the MPCA is prevented by this law to impose any additional fees on animal feedlot operations until July 2, 2001, the agency is proposing to begin charging the fees for SDS permits that regulate feedlots with 1,000 or more animal units after July 2, 2001.

The MPCA proposes to require animal feedlots, manure storage areas and pastures with 1,000 or more animal units to have an SDS operating permit if the facility is determined not to be a CAFO. However, the MPCA does not anticipate issuing many of these permits and therefore anticipates to collect very few annual fees from SDS operating permits. Based on federal guidance documents and staff conversations with U.S. EPA representatives, finding an animal feedlot, manure storage area or pasture with 1,000 or more animal units not to be a CAFO will be the rare exception. All other facilities in this category will regulated by an NPDES operating permit with the fees under subitem 1.

The 1999 Minnesota Session Laws chapter 250, Article I, section 49, reads:
"(a) notwithstanding any law to the contrary, an executive branch state agency may not impose a new fee or increase an existing fee unless the new fee or increase is approved by law."
Section 116(d) establishes the effective date for this requirement to be July 2, 2001. Minn. Stat. § 14.18, subd. 2, already requires new fees or fee increases to be approved by the Legislature. The statutes read:

> "A new fee or fee increase adopted by the MPCA is subject to legislative approval during the next biennial budge session following adoption. The commissioner must submit a report of fee adjustments to the legislature as a supplement to the biennial budget. Any new fee or fee increase remains in effect unless the legislature passes a bill disapproving the new fee or fee increase. A fee or fee increase disapproved by the legislature becomes null and void on July 1 following adjournment."

The MPCA plans to use the Legislative approval process required under Minn. stat. § 14.18, subd. 2, to fulfill the requirements under Minnesota Session Laws chapter 250. The Minn. stat. § 14.18 process allows the MPCA to adopt the rules before Legislative approve is acquired. Therefore, the agency is proposing the fee rules before seeking Legislative approval. Since the 2000 Legislative Session is not a budget session, the MPCA will present the fees proposed under this subitem to the required Legislative committees during the 2001 session for review and approval as required under Minn. stat. § 14.18. This review will occur before the effective date for the fees proposed under this subpart. If the Legislature does not approve the proposed fees under the Minn. stat. § 14.18 process, the fees will never be charged. Permit fees are calculated and collected based on the state fiscal year. The state fiscal year begins on July 1 and ends on June 30. For the fees for SDS permits that regulate 1,000 or more animal units, this means that the agency will begin charging application fees ($85 see part 7002.0250) for the SDS permits beginning July 2, 2001. However, the annual fees proposed under this subitem will not be billed until April 2002 and required to be paid by June 30, 2002, the end of the state fiscal year. Since the fee rules will already be adopted, the MPCA will have all the materials to present to the Legislature at the beginning of the session and anticipates that a decision will be made before the April 2002 mailing date for the fee invoices. Since the agency anticipates that few, if any, of these permits will be issued. It is anticipated that at the most, only a few SDS fees will be collected because it is anticipated that most, if not all, owners of facilities in this animal unit category will be required to have an NPDES permit and to pay the NPDES permit fees.

Subitem 3. The agency is proposing to state in this subitem that there are no annual fees for interim permits. This subitem states the agency's current practice. This proposed language is part of the agency's efforts to clarify when fees are to be charged for permits that regulate animal feedlots, manure storage areas, and pastures. The agency currently does not charge annual fees for interim permits. The agency is not proposing to change this practice. It is reasonable to clearly state that no annual fees will be charged for interim permits so that staff administer the fees correctly and permittees and permit applicants have a clear understanding of when fees must be paid.

Subitem 4. The agency is proposing to state in this subitem that there are no annual fees for construction short-form permits. The agency is proposing the construction short-form permit as a new permit tool for regulating animal feedlots, manure storage areas and pastures. Construction short-form permits are not currently issued for any water quality regulatory program and the permit will be unique to Minn. R. ch. 7020. The agency is not proposing to charge annual fees for this permit because the permit is similar in design to the interim permit. Like the interim permit, the construction short-form permit is issued for facilities with less than 1,000 animal units, expires after 24 months and does not address on-going facility operation. Even in the 1999 Legislative budget initiative seeking increased permit fees, the agency did not intend to charge these types of facilities permit fees due to the financial hardships currently being experienced by the industry. Due to the discussions that took place during the 1999 Legislative Session and the on-going situations in the farming community, annual fees are not being proposed to be increased and the agency's historical practice of charging permit fees for only operating permits is being proposed to be continued. Since operating permits are only being required for facilities with 1,000 animal units or more, in general, permit fees will only be charged to very large facilities. It is reasonable not to charge a fee for the construction short-form permit because this new permit is similar in design to the interim permit, it addresses facilities that are smaller than 1,000 animal units and it is not an operating permit. It is reasonable to clearly state that no annual fees will be charged for construction short form permits so that staff administer the fees correctly and permittees have a clear understanding of when fees must be paid.

7002.0280 Notification of Error

The agency is proposing to revise this part by changing "the director of the Water Quality Division" to "Minnesota Pollution Control Agency Fiscal Services." This is needed to reflect a change in the agency's organization. In 1998, the MPCA underwent an agency-wide restructuring. This effort changed the agency from a pollution-media structure (air quality, water quality, hazardous waste and solid waste/ground water) to the current geographic structure, which is focused on state districts. As a result, the Water Quality Division no longer exists. The agency is proposing that the fee payments are made to the agency's fiscal services office. This is reasonable because the fiscal services office is responsible for collecting and processing revenues and expenses.

Chapter 7020 Animal Feedlots, Storage, Transportation and Utilization of Animal Manure

7020.0100 Preamble

The proposed rules delete the preamble statement in the current rules. The current preamble is a statement of the goals of the current feedlot rules and contains no enforceable requirements. While it was standard practice to include a preamble in rules, this is not the current practice. The stated goal of "local units of government to provide adequate land use planning for residential and agricultural areas" in the current is incorporated into the proposed part 7020.0200. Additionally, the proposed part 7020.0505, subp. 4, items C and D, and part 7020.2000, subp., 4 and 5 create an enforceable requirement that an owner notify local residents and local government prior to submitting a permit application or constructing when a permit is not required. It is reasonable to delete this portion of the rule, which contained no enforceable requirements. The reasonableness of each of the proposed part 7020.0505, subp. 4, items C and D, and part 7020.2000, subp. 4 and 5 is discussed later in this Statement of Need and Reasonableness.

7020.0200 Scope

The proposed revisions to this part are intended to clarify the applicability of Minn. R. ch. 7020. Minn. R. ch. 7020 applies to owners of all animal feedlots, manure storage areas, pasture operations and all persons storing, processing, transporting and utilizing manure in Minnesota. This chapter applies broadly, not just to owners that are issued permits from the agency. The current rule excludes the county permitting process from this applicability statement, although the county programs are a critical component of the feedlot regulation in the state. It is reasonable to clarify and state as clearly as possible the broad applicability of this chapter to address pollution hazards and potential hazards related to animal manure.

This part has also been changed slightly from the existing rule that excludes "aquatic species." The proposed language "fish" as an alternative to "aquatic species." This change is reasonable because fish is the intended exclusion to the existing rule and the change provides clarification that species such as ducks (which frequently use water) are not part of the exclusion.

The last sentence of this provision states that this chapter does not preempt local units of government from adopting additional regulations related to manure from feedlots, manure storage areas and pastures. This provision is similar to the language in the existing rule under part 7020.0100 (Preamble) that states "the agency will look to local units of government to provide adequate land use planning for residential and agricultural areas." In proposing to repeal the existing language the agency heard concerns that local units of government may view this as the agency no longer taking the position of local units being responsible for land use issues related to animal feedlots. While this was unlikely, the proposed language is reasonable because it clarifies that this rule does not limit local governments to adopt or enforce additional requirements on animal feedlots.

7020.0205 Incorporation by Reference

This proposed all-new part establishes the incorporation of references used in part 7001.0020 and parts 7020.0200 to 7020.2225. Minn. Stat. § 14.07, subp. 4, requires that references to text publications and documents be incorporated into a rule, and the availability of the text identified for the reader. This part thus identifies for the reader that certain documents are used within the above-stated parts and where these documents are available. The need and reasonableness of individual items incorporated by reference is discussed in this SONAR under the specific rule part where it is used. Table 5 summarizes the rule parts where the documents that are incorporated by reference are used in the proposed rule or discussed in this section of this SONAR.

Table 5. Rule Parts Where Incorporated Documents are Used and/or Discussed.

Item Number and Title of Document	**Rule Parts Where Document is Used and/or Discussed**
Item A. ASTM D 1557, Test Methods for Moisture-Density Relations of Soils, 10 lb. Rammer.	Part 7020.2100, subp. 4, items G and K.
Item B. ASTM D 4318, Test Method for Liquid Limit and Plasticity Index of Soils	Part 7020.2100, subp. 4, items G and K; and part 7020.2120, subp. 3, item B(2).
Item C. ASTM D 422, Method for Particle Size Analysis of Soils	Part 7020.2100, subp. 4, items G and K; and part 7020.2120, subp. 3, item A(2)(a).
Item D. ASTM D 698, Test Methods for Moisture-Density Relations of Soils, 5.5 lb. Rammer.	Part 7020.2100, subp. 4, items G and K; and part 7020.2120, subp. 4, item B(4).
Item E. 40 CFR 412, Feedlot Point Source Category	Part 7020.0300, subp. 19b and 19c; and part 7020.2125, subp. 1, item A. Exhibit A-13
Item F. 40 CFR 122.23, Concentrated Animal Feeding Operations	Part 7020.0300, subp 5a; and part 7020.0405, subp 1, item A. Exhibit A-14
Item G. Minnesota DNR, Protected Waters and Wetland Maps	Part 7020.0300, subp 23; and through special protection area definition in part 7020.2015, subp. 3; and part 7020.2225. Exhibit P-8

Item Number and Title of Document	Rule Parts Where Document is Used and/or Discussed
Item H. USGS Quadrangle Maps	Part 7020.0300, subp 13a and subp. 23; and through special protection area definition in part 7020.2015, subp. 3; and part 7020.2225. Exhibit P-6
Item I. Minnesota NRCS, Waste Storage Pond-Code 425 or Waste Storage Facility-Code 313	Part 7020.2100; and part 7020.2110, subp. 2, item B. Exhibits M-9 and M-15
Item J. Feedlot Inventory Guidebook	Part 7020.0350. Exhibit I-1
Item K. USDA NRCS, Natural Range and Pasture Handbook, Chapter 5, Part 2(i)	Part 7020.2015, subp. 3. Exhibit T-3
Item L. USDA ARS, An Evaluation System to Rate Feedlot Pollution Potential	Part 7020.2003, subp. 4 to 6. Exhibit M-34
Item M. Minnesota NRCS, Prescribed Grazing-Code 528A	Part 7020.2015, subp. 3. Exhibit T-2
Item N. Minnesota NRCS, Heavy Use Area Protection-Code 561	Part 7020.2015, subp. 3. Exhibit T-1

7020.0250 Submittals and Records

Subpart 1, Accuracy of submittals. This proposed all-new part sets forth requirements for submittals and records that apply to persons that are subject to the requirements of chapter 7020. The proposed requirements of this part require any information submitted to the commissioner or the county feedlot pollution control officer to be accurate; if the information is inaccurate, corrected information must be submitted. Since the decisions made by the commissioner or county feedlot pollution control officer can have a significant environmental impact, it is reasonable to require that the information upon which that decision is base to be as accurate as possible.

Subpart 2. Record retention, access to records, and inspections. This subpart requires persons subject to the requirements of this rule to keep the required records for at least three years. Since the records that are required are an integral part of being able to determine if a person subject to these rules has complied with the rules, it is reasonable to require all records to be kept for some period of time.

Some pieces of information are critical and must be kept for longer than the three years required under this part. The proposed rule require a person to keep a record for at least six years for manure applied in special protection areas (part 7020.2225, subp. 5). Owners proposing construction projects such as liquid manure storage areas, would be required to submit the plans and specifications to the commissioner or county feedlot pollution control officer where they will be held for the life of the structure. Three years is a reasonable length of time to keep records for all but the most critical pieces of information.

The proposed requirements also require any person that is subject to the requirements of this chapter to allow the commissioner, county feedlot pollution control officer, or a designated representative to inspect any facility or records pertaining to the requirements of this chapter. As stated above, the decisions that are made by the commissioner or county feedlot pollution control officer need to be based on the most accurate information available. One important information gathering method is through facility and record inspection. For this reason, it is reasonable to require persons subject to the requirements of this chapter to grant access to facilities and records to the commissioner or county feedlot pollution control officer of authorized representative.

These provisions are also a restatement of the provisions of Minn. Stat. § 115.04.

7020.0300 Definitions

Subpart 1. Scope. This subpart establishes the meaning for terms ascribed in Minn. Stat. §§ 115.01 and 116.06, and Minn. R. pt. 7020.0300 when used in this chapter. When a term is defined in both statute and in this chapter, the definition given in statute is the authoritative meaning for the purposes of these parts. The proposed amendments modify this scope to reflect this approach and to correct the reference to the definitions section from Minn. Stat. § 115.07 to the correct reference Minn. Stat. § 115.01.

Subpart 1a. Above ground manure storage area. "Above ground manure storage area" is a term used in several locations in part 7020.2100 for describing a type of liquid manure storage area. Defining this term is needed to establish that the important factor with these manure storage areas is that the liner is above natural ground level. This definition is reasonable as it allows part 7020.2100 to simply state the storage type, much like the term "composite liner" is used.

Subpart 4. Animal Manure. "Animal manure" and "manure" are terms that apply not only to animal excreta, but also to any excreta that is combined with other substances at a feedlot site such as straw, sawdust, other forms of bedding, soil, and/or water. The definition of "animal manure" now includes the term "manure" as having the same meaning for the purposes of these parts. This addition allows use of the more commonly used term "manure" in the livestock industry compared to the more formal term "animal manure." The definition includes milkhouse wastes and other waste waters at an animal feedlot, manure storage area or pasture that contains any manure. Milkhouse wastes and other process generated waste waters are typically produced from cleaning and/or flushing procedures at livestock operations which mix with animal excreta and therefore present the same pollution threat as manure itself. Precipitation, including rainfall and snowmelt, has also been added to the definition to clarify that when mixed with excreta the precipitation and resulting runoff may contain substantial manure pollutants and create a significant environmental hazard. Therefore, it is reasonable to identify these liquids as animal manure and, for clarity, to include them as part of the definition of animal manure.

Subpart 5. Animal Unit. For purposes of administering applicable state and federal regulations related to animal feedlots, manure storage areas and pastures, the most common species of livestock are assigned an animal unit value which is based, in part, on the amount of manure each produces. The language and specific animal unit values proposed in this definition meet the requirements of animal unit values assigned in federal regulations under 40 CFR 122.23, appendix B. However, several additional animal unit values are listed to provided clarity and are needed to fill gaps in the federal animal unit criteria. These additions are reasonable, as states have the authority to have regulations which are more stringent than the federal regulations which are intended to address only the largest facilities and others having the most significant pollution problems. As discussed in this SONAR in the Reasonableness as a Whole and under part 7020.0405, the state of Minnesota has significant surface and ground water and soils resources which justify regulation of facilities not covered by the federal regulations which regulate only surface waters. Since the EPA is in the very early stages of seeking comments to redefine these values, aligning the animal unit values with federal regulations also provides the agency with better justification to change these values if and when the federal regulations change.

A common misconception regarding these animal unit values is that they are used to establish requirements for manure storage capacity and land application acres. While there are rules of thumb for storage capacity and acres needed for land application, the specific requirements vary greatly and are based on a range of site-specific features and management practices. This should not be confused with the requirements of item J of this subpart, that assigns an animal unit value to a facility that stores more manure than is produced at the facility. For determining manure storage capacity, for example, the agency uses manure and wastewater production data published in Midwest Planning Services, MWPS-18 to estimate the required storage capacity. See Exhibit F-1. The Natural Resources Conservation Services also has specific design standards for designing manure storage capacity that do not use animal unit data. Changes in livestock feeds, manure storage, handling and land application methods and the variability of manure nutrient content, eliminates the appropriateness of animal units as single criteria to use when determining requirements for storage and land application.

Animal unit values are important consideration for livestock producers because they may impact the cost of regulation. Certain animal unit thresholds impact the type of permit an owner is required to apply for and obtain and, therefore, may affect the fees or permit processing procedures to which the owner will be subject. For example, owners with 1,000 animal units or more, or is issued an NPDES or SDS permit will pay fees, while an owner with fewer than 1,000 animal units that is in compliance with the rules would not have to pay fees. Because of the regulatory and economic implications, it would be irresponsible to ignore these factors during the rule-making process and therefore, the proposed amendments establish new animal unit values to provide a consistent framework for the various animal species, one which can be used for both state and federal permitting requirements. In evaluating the existing animal unit framework the agency considered the adequacy of the existing definition for regulatory fairness, consistency with EPA criteria, and where available consistency with current industry data regarding animal weights and manure production characteristics. The following additions and changes are proposed based on that evaluation:

Item A. The dairy cattle animal unit language has been modified to read identical to the federal regulations. This change is reasonable because it does not change the meaning or outcome of animal unit assignments for this species. This change simply provides clarity. The second change to this item relates to the establishment of a new animal unit value of 1.0 for mature dairy cows under 1000 pounds, while maintaining that dairy cows over 1000 pounds are assigned a value of 1.4 each. The agency considered adding a specific value for jersey cows, but selected a weight-based criterion instead, because the weight-based criterion provides consistency with other parts of this definition of animal unit. This change is reasonable because it does not overburden dairy breeds such as jersey cows that have a mature weight of about 900 pounds and have been demonstrated to produce a significantly lower volume of manure than a 1400 pound dairy cow breed. Since it is the pollutants in the manure for which these rules are intended to regulated, it is reasonable to base an animal unit value on a demonstrated difference in manure volume. The selected value of 1.0 more accurately represents the per-animal manure and wastewater production rates of a jersey cow as compared to other species of mature dairy cow. Data to support this change was provided to the agency by the Minnesota Department of Agriculture, Dairy Development Specialists. See Exhibit P-5. This proposed change could be viewed as providing a less restrictive regulatory structure for jersey cows (and any other dairy cow breed weighting less than 1000 pounds at maturity) than EPA currently requires. The agency acknowledges that a difference exists, although, the agency believes that the intent of the EPA regulations is to establish thresholds based on the potential pollution hazard at a given facility. As described above, jersey cows have been demonstrated to produce a significantly lower volume of manure that other dairy breeds, therefore the agency believes this change is consistent with the intent of the federal regulations.

Item B. The addition of the term “feeder cattle” to this item is needed to create consistency with EPA values. It is reasonable because it allows the agency and delegated counties to administer a program, which does not conflict with federal requirements. This is also reasonable for owners of facilities who may otherwise not have been aware that they are listed in federal regulations. For example: an owner having feeder cattle weighing about 800 pounds could interpret the existing rule under (the same as item I in the proposed rule) as assigning a value of 0.8 animal unit per cattle, whereas federal regulations would assign these animals a value of 1.0. If not clarified, this could be problematic for owners having facilities at or near the 300 animal unit or 1000 animal unit permitting thresholds in federal regulations.

Item C. The changes to this item have not resulted in a change in animal unit assignments to swine, but the existing rule has simply been combined into one item for swine.

Item D. The animal unit value for horses was changed from 1.0 to 2.0. This is needed and reasonable to provide consistency with federal regulations. Administration of the current rule, which is less restrictive for horses than federal regulations has not caused any permitting related problems to date as only one horse facility in Minnesota is over the 1000 animal unit threshold that requires an NPDES permit. This facility would be over 1000 animal units with the value at 1.0 or 2.0.

Item E. The term "or lamb" was added to the language in this item. This is needed and reasonable to provide consistency with federal regulations.

Item F. Item F lists the assigned animal unit values for chickens. The proposed amendments involve two parts: first to provide consistency with federal regulations and second to fill the gap for chickens, which are not addressed by the federal regulations. Subitem 1 is language directly from the federal regulations. Subitem 2 establishes values for chickens not covered in subitem 2 into chicken over and under three pounds. Adding the 0.033 animal unit value for laying hens or broiler chickens (if the facility has a liquid manure system) is needed to meet the federal regulations. Subitem 2 maintains the value in the current rules of 0.01, but distinguishes this value from chickens weighing less than three pounds. Establishing a value for chickens over and under three pounds, provides a clear and consistent method of distinguishing between chicken pullets and adults and is reasonable because it fills a gap in the federal regulations which do not specifically address non-layer or broiler pullets. At the time of transfer from a brooder barn to a layer or broiler barn, as applicable, a chicken weighs less than three pounds, which is approximately one-half the weight of an adult layer or broiler chicken. Therefore, an animal unit value of 0.003 (or about 30 percent of the animal unit value for adult layer hens or broilers) is reasonable to assign to chickens under three pounds because it is consistent with the value that would be obtained by dividing the three pound maximum weight by 1000 pounds according to the method under item I of this subpart. These changes are needed and reasonable because they establish a consistent approach to federal regulations and the approach currently used for other livestock species within this chapter where a weight range is used to distinguish animal unit values.

Item G. Item G lists the assigned animal unit values for turkeys. The agency proposes to modify the existing language by establishing separate values for turkeys weighing more or less than five pounds. This change is needed and reasonable because, similar to the changes to the dairy cow unit values, brooder turkeys under about five pounds, produce less manure than the adult turkeys. This change is reasonable because it provides a clear and consistent method of distinguishing between turkey poults and adults, similar to other livestock species within this chapter where a weight range is used to distinguish animal unit values. The term turkey poults commonly applies to young turkeys that are less than four to six weeks in age, however, for the purposes of these parts, a poult turkey is one weighing less than five pounds. At the time of transfer of a poult from a brooder barn to a grower/finisher barn, a turkey poult weighs less than five pounds. Poults at this stage weigh approximately 12.5 to 25 percent of the weight of turkeys that are ready for market (light hens weigh approximately 18 pounds; heavy toms weigh approximately 40 pounds). Therefore, the assigned animal unit value of 0.005 (30 percent of the animal unit value for adult turkeys) is conservative and a reasonable value to assign to this category.

Item H. There has been no change to the animal unit value to ducks, which was previously listed as item E.

Item I. There has been no change to this provision, which was listed at the end of the animal units values in the current rule. The agency considered several additional animal unit values, which were not specifically included in the proposed rules because they could be determined though this provision which divides the average weight of the animal by 1000 pounds. Several examples (for the animal types the agency considered incorporating into the rule) of how this provision would be used by are provided below.

Example 1: One calf equates to 0.2 animal unit. An industry trend is for livestock producers to concentrate on one stage of the livestock maturity cycle. The 0.2 animal unit value is reasonable because it appropriately falls within the range of weight assigned to this animal type from 0 to 500 pounds. The 0.2 is lower than the midpoint of this range (0.0 to 0.7 animal units) because the calves typically spend a higher percentage of time below the midpoint weight than above, thus the assigned value represents an approximate weighted average.

Example 2: One beef cow with calf equates to 1.2 animal unit. The reasoning for this value is to more accurately assess the number of animal units at cow/calf operations. Cow/calf operations, also know as beef-grazing, or range operations, are operations where new-born calves are kept with the mother cows for several months until they are weaned and moved to a separate location. These types of operations are common in the pasture-grazing areas of northern Minnesota. The animal unit value 1.2 was obtained by adding the animal unit value of a slaughter steer of heifer (1.0 in item B) to the value assigned to a calf equal to 0.2.

Example 3: Dairy young stock equals 0.7 animal unit. Various regulatory levels (state, county and township) use values ranging from 0.5 to 1.0 animal units for young stock. The animal unit value of 0.7 animal unit represents the size (and therefore the manure production rate) of a dairy young stock animal as approximately one-half that of a mature dairy cow animal. The animal unit value of a mature dairy cow is 1.4, therefore, the animal unit value of a diary young stock is half of that value, or 0.7.

Example 4. One sow with litter less than 18 days old equals 0.4 animal unit. This is the same animal unit value assigned in the existing rule to any swine greater than 55 pounds, including any sow. The manure production rate of a sow and with piglets less than 18 days old is approximately the same as the sow prior to the delivery of the litter. The alternative to the proposed value is to assign each piglet an animal unit value of 0.05. Based on the manure production rate, the primary factor in assigning an animal unit value, an animal unit value of 0.05 for each piglet under 55 pounds would significantly over state the number of animal units. For these reasons, it is reasonable to assign a sow and litter less than 18 days old the same animal unit value as a mature sow with no litter. Since the piglets are moved to a separate facility at about 14 days of age; the 18 day criterion provides a reasonable margin of error to accommodate this practice. After the 18 day period or before 18 days if they are no longer with the sow, the piglets are assigned the value of 0.05 animal units per animal which is applicable to all swine under

55 pounds. Stating this a different way, the piglets must be both with the sow and be under 18 days of age, or they are assigned a value of 0.05 animal units.

Item J. Item J is needed to establish a method for assigning animal unit values to manure storage areas that store or process more manure than is produced at the animal feedlot. This provision is also needed for calculating comparable animal unit values for manure storage areas or manure processing facilities where livestock are not present. This addition is needed and reasonable because the animal unit values listed in items A to I apply only to the number of animals present and may not account for the entire volume of manure present at a feedlot or manure storage area. Since manure is the primary source of pollutants associated with livestock production, it is reasonable to establish a method for assigning animal unit numbers at facilities which only store or process manure and at facilities which store or process more manure than they generate.

Item J sets forth two options for determining the animal units assigned to the types of facilities described above. Subitem 1 applies when the type of livestock that produced the manure, and amount of manure present is known for all sources of the manure stored or processed at the facility. Under these circumstances, the animal units are calculated for a facility is equal to the number of animal units that produced the manure. For example, a manure storage area where no livestock are present and which receives 50 percent of the manure at a 1000 animal unit swine operation and 25 percent of the manure produced at a 1000 animal unit dairy facility, will be assigned 750 animal units. Subitem 2 applies when the type of livestock or amount of manure from each type of livestock is not know for all manure sources. This provision provides a clear and consistent method for assigning animal units at all facilities storing or processing manure that are not covered under subitem 1. The assigned value is based on the quantity of manure handled annually in pounds, divided by 4,000. This method is based on the most conservative estimate of animal units per pound of manure produced for all of the species discussed in items A to H. Annual manure production values are based on estimates in MWPS-18. See Exhibit F-1. The agency recognizes that this method may seldom be used, however, the proposed method is needed for those few owners without sufficient information to determine an animal unit number under subitem 1. The proposed method is a conservative method of estimating the number of animal unit, which produced a quantity of manure. It is reasonable to establish a conservative method to provide an incentive for owners to know the type of manure they are handling, thus providing the basis for better and more consistent manure land application practices and nutrient utilization.

Subpart. 5a. Concentrated animal feeding operation or CAFO. Certain types of feedlots and manure storage areas are regulated by EPA under 40 CFR 122.23. See Exhibit A-14. These feedlots and manure storage areas are defined by criteria set forth in 40 CFR 122.23 and are referred to by EPA as CAFOs. Minnesota has approximately 800 known feedlots that may be classified as CAFOs and, therefore, that are subject to EPA regulations. The MPCA administers EPA's animal feedlot program and issues National Pollutant Discharge Elimination System permits to CAFOs as part of the state animal feedlot regulatory program. The proposed rules establish permit type eligibility limitations and permit requirements based on the facility being classified as a CAFO or not (part 7020.0405). The agency has included the term "manure storage area" in the definition of CAFO to clarify that manure storage areas which store 1000 animal unit or more of manure are also CAFOs. This is supported by EPA in section 2.1 of their draft "Guidance Manual and Example Permit For CAFOs" document dated August 6, 1999. This document states that "EPA defines the animal feeding operation (AFO) to include the confinement area and the storage and handling areas necessary to support the operation (e.g., waste storage areas)." Therefore, the definition and meaning of CAFO in these rules is needed and reasonable to establish a distinction between CAFOs and non-CAFOs and to cite the EPA regulation that establishes the criteria for determining which facilities are CAFOs.

Subpart 6. Certificate of Compliance. The agency has added the term "manure storage area" to this definition. This was needed to clarify that manure storage areas located where no animal feedlot existed were issued certificates of compliance under the existing rules. This is a reasonable addition because, as discussed in other parts of this SONAR, the presence of and potential pollution from the manure is the most important factor considered by this program in the regulation of livestock operations.

Subpart 6a. Commencement of Construction. The agency proposes to include this definition in the revised rules because feedlot and manure storage area construction related to animal unit expansions and/or construction on a manure storage area cannot begin until a permit has been obtained and/or the applicable notification requirements have been met. This definition is needed to clearly identify for the owner, delegated counties and the agency precisely when construction begins and when construction beyond a point is prohibited without a permit or submittal of a notification. Providing a definition for commencement of construction clarifies and fulfills this need. This definition is based on part 7001.1020, subp. 8, item A, and has been modified to apply specifically to animal feedlots and manure storage areas. This definition does not in any way limit pre-construction investigation work needed to gather site-specific information for site planning and design. The proposed rules are intended to limit activities that the owner can do prior to permitting or construction activities. The activities are limited to those that after which the cost to stop construction is not so high that it is difficult or impossible to stop. For example, the proposed rule would not allow the installation of perimeter drain tile systems prior to permit issuance. The cost of these systems may be significant enough that stopping a project after this point would be a significant loss to the owner. One intent of the proposed rule is to limit the amount of money an owner would lose due to constructing a facility that cannot be issued a permit due to things such as facility design or location. Another intent of the proposed rule is minimize the number of contentious disagreements between the MPCA and facility owners as a result of the owner proceeding beyond the point at which the cost to make changes becomes significant. In cases where the owner has a significant investment in a site or facility, the incentive for the owner to continue the project is great. These contentious disagreements result in delays and increased costs for both the owner and the MPCA. It is reasonable to define as clearly as possible the point at which construction commences to avoid these unnecessary costs and delays.

Subpart 7. Change in Operation. The agency proposes to repeal this definition from the rules. This term is no longer used, therefore, it is reasonable to repeal this definition.

Subpart 7b. Composite liner. This definition sets forth the meaning for a manure storage area liner system that achieves theoretical seepage rate of 1/560 inch of depth per day or less. There are several typical liner systems which can currently be designed and installed to achieve the seepage rate standard. See Exhibit M-20. Typical liner materials used include at least a double liner consisting of a geomembrane (flexible membrane) liners such as polyvinyl chloride and high density polyethylene or geosynthetic liners which typically have bentonite-clay materials contained within a synthetic fabric, placed over two or more feet of cohesive soil. The lower seepage rate (compared to the seepage rate requirement of 1/56 inch of head per day or less for other areas) is required for manure storage areas in areas with geological conditions which are susceptible to soil collapse, sinkhole formation or other areas with a high potential for contaminating drinking water supplies. In the karst areas, the lower seepage rate is beneficial to reduce the risk of inducing soil collapse (due to movement of soil under the manure storage area due to seepage through the liner system).

The proposed rules also require two feet of compacted soil under the primary liner material, which provides a secondary barrier to the contents seeping into the ground. The phrase "other comparable liner materials" is needed because the changing nature and availability of these products requires that the rules be flexible enough to accommodate equivalent products that are yet-to-be developed. The proposed definition is reasonable because the seepage rate standard is achievable and is necessary in areas which are susceptible to soil collapse or sinkhole formation. See the Statement of Need and Reasonableness discussion for the proposed part 7020.2100, subp. 3, item B, subitem 3 for more discussion.

Subpart 7c. Compost. The agency proposes to include a definition for compost in the proposed rule because a part 7020.2150, which specifically addresses composting of manure, has also been proposed. Therefore, it is reasonable to include this definition to clarify for readers the agency intent on the type of activities to be managed as compost and not raw manure.

Subpart 8. Corrective or protective measure. The agency has added the term "manure storage area or pasture" to the definition of corrective or protective measure. This was needed to clarify requirements for manure storage areas and pastures, which create or maintain a pollution hazard can be required by the agency or county to install these measures. This is a reasonable addition because, as discussed in other parts of this SONAR, the presence of and potential pollution from the manure (whether at an animal feedlot, manure storage area, or pasture) is the most important factor considered by this program in the regulation of livestock operations.

Subpart 8a. Construction short-form permit. The term "construction short-form permit" is used in the proposed rules to identify a permit issued by the agency or county feedlot pollution control officer to owners of feedlots or manure storage areas with fewer than 1,000 animal units that are proposing to construct or expand. The construction short-form definition is reasonable to include in the rule because it allows the term to be used in the text without repeating the citation and provides a clear distinction from the interim permit. Providing this distinction between interim and construction short form permits is needed because under the existing rule, the agency and delegated counties issue interim (A) and interim (B) permits. The interim (A) permits are primarily for new and expanding construction activities and the interim (B) permits are for addressing pollution problems. The agency intends to clearly distinguish between the two permit types by name the construction permit appropriately and restoring the original intent of the interim permit to be issued for pollution problems.

Subpart 9. County feedlot pollution control officer. The agency proposes several modifications to the definition for county feedlot pollution control officer. First, to relate "county feedlot pollution control officer" to "delegated county" the phrase "a county employee or officer" is proposed to so that the definition reads "an employee or officer of a delegated county." Second, the phrase, "knowledgeable in agriculture" is deleted because the definition and applicable parts of this rule do not provide specific criteria for a qualified candidate. Therefore, "knowledgeable in agriculture" does not contribute to the meaning of the definition and it is reasonable to delete it. And last, the agency proposes to replace the phrase "receive and process animal feedlot permit applications" with "perform the duties under part 7020.1600." The phrase "receive and process animal feedlot permit applications" does not adequately express the range of duties of a county feedlot pollution control as proposed in part 7020.1600. The phrase "perform the duties under part 7020.1600" provides broader scope and resolves this problem and, therefore, it is a needed and reasonable change.

Subpart 9a. Delegated county. State statutes allow a county board to assume responsibility for processing animal feedlot permit applications. This responsibility is authorized by the agency and upon approval by the agency, a county becomes delegated, and subsequently designates a county feedlot pollution control officer. Upon delegation, most of the regulatory work is done at the local level and, in particular, by the designated county feedlot pollution control officer. Providing this definition in the revised rules is needed and reasonable because it clearly distinguishes between a delegated county and a county feedlot pollution control officer. It establishes the fact that delegation means authorization and that the feedlot regulatory work done by a delegated county parallels the feedlot permit processing conducted by the state.

Subpart 9b. Design engineer. The addition of this definition is needed and reasonable because it clarifies the individuals that may prepare designs and reports for manure storage areas as required under this chapter. The definition also eliminates the need to use the phrase "professional engineer, licensed in the state of Minnesota or qualified Natural Resources Conservation Service (NRCS) staff person working under NRCS approval authority" in each of the many uses of the term "design engineer" throughout the manure storage requirements parts of this rule. Engineers not licensed by the state of Minnesota are not considered "design engineers" under these parts unless they are a qualified NRCS staff person as described above. All design plans and specifications, construction reports and other submittals prepared by registered professional engineers and NRCS staff persons must comply with applicable statutes and rules. Designs by NRCS staff persons are also expected to comply with appropriate NRCS practice standards and procedures. For these reasons, it is reasonable to define the term "design engineer" and establish these minimum qualifications.

Subpart 9c. Discharge. Discharge includes animal manure or manure-contaminated runoff from an animal feedlot, manure storage area, land application site or manure transportation or processing equipment, that enters any water of the state in any quantity or concentration by any means. Discharge is a generic word that potentially has a wide array of meanings and without a definition, the meaning may be selectively interpreted or misinterpreted. The proposed definition is intended to be used broadly and to include any discharge of pollutants to waters of the state, intentional or unintentional. Many terms are commonly associated with the discharge of manure such as manure-contaminated runoff, dumping and seeping which are among those included in the definition. These terms are intended to convey the meaning that any release of pollutants to waters of the state from a feedlot, manure storage area or field is a discharge. The proposed definition also includes an exception for seepage within the parameters and under the conditions allowed in this chapter. Specifically, these parameters and conditions are:

- Seepage within the permeability requirements for manure storage areas (1/56, 1/560 of an inch of head per day or 1 x 10^{-7} cm/sec); and
- Seepage through structures for which the proposed rules contain a construction standard in lieu of a permeability specification that are constructed in compliance with the specifications proposed in these rules.

Subp. 11a. Expansion or expanded. The term, expansion or expanded, is defined for this chapter because they are used often throughout the rule and a clear and consistent meaning is essential. The terms mean any proposed increase in the capacity of an animal feedlot to hold animals over what is authorized or any increase in the storage capacity of a manure storage area. Inherent in this definition is that any new feedlot or manure storage area is, by definition, expanding. The definition is needed to distinguish between an increase in animal units at animal feedlots and manure storage areas (including an increase in manure storage volume at a manure storage area located where no animal feedlot exists) within the quantity authorized. For example, an owner that has a permit authorizing 500 animal units but has only 300 present, is not expanding for the purposes of this definition when increasing the number of animal units to 500. However, the same owner is expanding if there is an increase above 500 animal units, whether or not construction will be needed. In this situation, the owner may simply be extending the area available for livestock by installing more fencing or may be using an open lot, which was not used under the existing permit. Similarly, expanding the storage capacity of a manure storage area with or without an increase in animal numbers is an expansion under this definition. This definition establishes a trigger for permit or notification requirements for the owner when increasing the capacity of a site. Any animal feedlot or manure storage area that is expanding is required to obtain a permit, obtain a permit amendment or submit a notification. The proposed definition is reasonable since expansion of an animal feedlot or manure storage area can result in an increase in the potential for negative environmental impacts from the facility and a clear trigger for regulatory review is needed.

Subpart 12a. Flow distance. Flow distance is a new term that defines a distance measurement, which may be a measurement other than a simple straight-line distance. The definition is needed to establish a difference between a straight horizontal distance and the distance manure-contaminated runoff may travel following preferential flowpaths before reaching waters of the state. It is reasonable to define the term “flow distance” because the intent of the agency is to establish a setback, which relates to a level of runoff treatment or buffering effect. The term “flow distance” allows facilities to take into consideration the mitigating effects of runoff traveling a longer distance than the straight-line distance from the source to waters of the state. Increasing the flow distance decreases the potential for negative environmental impact on waters of the state. The proposed definition is reasonable since it encourages owners to increase the minimum distance that runoff must travel to waters of the state and allows them to do so in an area much smaller than would be necessary with a 300-foot setback requirement.

To protect waters of the state from manure-contaminated runoff, the proposed rule typically restricts manure-handling and application operations in areas adjacent to or near these waters. The established straight-line setback distance for stockpiling is 1,000 feet from lakes and 300 feet from most other surface waters. Under the flow distance concept stockpilers may place sites much closer than 300 feet to a surface water provided a barrier in the form of a berm or natural rise of lands is present to divert runoff such that it travels a minimum of 300 feet before it enters the surface water. This mechanism provides flexibility to stockpilers and to owners of fields containing stockpile sites. It allows stockpiles to be placed closer to access roads and it keeps the stockpiles closer to the perimeter so that field operations are not disrupted. At the same time, the flow distance requirements meets other feedlot setback requirements in the degree of protection provided. Therefore, this provision is both needed and reasonable.

Subpart 13. Interim Permit. This definition has been modified to refer to the more detailed description of the interim permit applicability to owners, issuance and requirements compared to the current definition which simply states that the permit expires within 10 months of issuance. This change is need and reasonable because the applicability and procedures for interim permits have been expanding in the proposed rule (for example, specifically the 10-month period has been changed to 24 months).

Subpart 13a. Intermittent Streams. The addition of intermittent streams to the definitions is needed because it is used in the definition of special protection areas and in the land application requirements. Intermittent streams are used to identify watercourses that, in seasonally wet conditions or during periods of heavy precipitation convey water to ditches, streams and other waters of the state. The agency has designated the United States Geological Survey (USGS) quadrangle maps as the reference for identification of intermittent streams. See Exhibit P-6. The USGS maps were chosen as the reference because these maps identify seasonally wet streams with sufficient detail to allow interested parties to identify them. United States Geological Survey Quadrangle maps are available at local Soil and Water Conservation Service offices, delegated county feedlot offices, and at the Minnesota Department of Natural Resources website (www.dnr.state.mn.us). The proposed definition is reasonable because it provides a readily available and consistent method for identifying these waters.

Subpart 13b. Manure-contaminated runoff. The agency proposes to add this definition to the proposed rule to described liquids that contain or have come in contact with manure that flow from an animal feedlot, a manure storage area or a land application site. The intention of the definition is to make it clear that any liquid that has been in contact with manure is manure-contaminated runoff. The definition will help to prevent misinterpretation, disputes or confusion related to compliance issues associated with runoff from areas containing manure. These matters can arise easily since manure-contaminated liquids can originate from, and may occur in so many forms at, a feedlot site.

Manure or liquid may be generated from the urine of animals, from precipitation which lands on the site, or from external water that enters a feedlot or manure storage area and picks up manure particles. Interested parties must be clear that the origin of the liquid that combines with manure to create manure-contaminated runoff is not relevant; the fact that the liquid has been in contact with manure is relevant. The definition of manure-contaminated runoff is also important in what it does not say. Unlike the term discharge, this definition does not specify or imply a discharge to waters of the state. While manure-contaminated runoff can result in pollution, pollution is not necessarily the outcome of all manure-contaminated runoff. For example, runoff control structures collect manure-contaminated runoff but neither the runoff nor the manure stored in basin is considered to be pollution. This neutral connotation of manure-contaminated runoff is important to distinguish situations where manure-contaminated runoff is present but a discharge to waters of the state has not occurred. This term is also important, for example, when the agency or delegated county identifies a potential problem at a facility where an actual discharge has not been observed, but the presence of manure-contaminated runoff very near waters of the state has been observed. This distinction allows the agency or delegated county to use the definition of pollution hazard under part 7020.0300, subp. 19a, item B, where the term “potential” is used. The agency or county could then issue an interim permit to initiate correction of the potential problems.

Subpart 14. Manure storage area. The term, manure storage area, is used throughout the rule as a term to identify those parts of livestock operations that are used to store animal manure either at, or separate from, an animal feedlot. Modification to this definition is needed to more clearly establish the applicability of these rules to manure storage areas and processing operations (e.g., manure compost sites) and to distinguish manure storage areas from manure accumulations or mounding. As part of this modification, the phrase “associated with an animal feedlot” has been deleted so that manure storage areas constructed independent of the location where the manure was produced are included in the meaning of the term “manure storage area”. The phrase “until it can be utilized as domestic fertilizer or removed to a permitted animal manure disposal site” has also been deleted because it does not provide any useful criteria for a manure storage area; there are other uses of animal manure. This deletion does not change the meaning. The term “processed” has been added to the definition to include storage at operations where manure may be treated by methods other than land application such as composting.

For clarity, the agency has added language to specifically identify manure stockpiling sites and manure composting sites as manure storage areas. The term “animal holding” area has been inserted to make it clear that manure pack and mounding applies only for manure packs or mounds that have been created within an animal holding area. The addition of the reference to part 7020.2000, subp. 3, has been added to clarify that while manure packs and mounding are not manure storage areas, they are regulated by the feedlot rules. These are needed and reasonable modifications to this definition because they clarify the agency’s intention to regulate manure storage areas, whether at an animal feedlot or at a separate facility.

Subpart 15. New animal feedlot. The term "new animal feedlot" refers to the construction, establishment or operation of an animal feedlot or manure storage area at a location where none existed in the past or to a reactivation of an animal feedlot, at the same location that it had been in operation in the past, which has not been used for at least three years. Under the current rule, an owner may leave the animal feedlot empty for up to five years without having to submit a permit application. The modification from five to three years in this definition is needed to better address the deterioration of animal holding and manure storage areas that occurs when these facilities are not used for extended periods. Some components of a facility deteriorate during periods of disuse, such as below-ground earthen and concrete manure storage structures, which are particularly susceptible to damage when they stand empty for long periods. Each freeze-thaw cycle subjects these structures to stresses which cause fissures, cracks and other structural damage to develop and each season subjects earthen liners to erosion from rainfall and runoff. Significant erosion and freeze-thaw desiccation of an earthen liner can occur in three years or less and is very likely to occur if not maintained for more than about three years. Under these circumstances, the only regulatory option to assure that reactivated facilities are safe to resume operation is to require more frequent review and inspection.

The proposed changes accomplish this goal by requiring the facility to meet new facility standards. The term "abandoned" has created confusion in the past due to the perception that an "abandoned" structure should not or could not be returned to service. The deletion of the expression "has been abandoned" is also reasonable because it eliminates this confusion, and the definition is complete without it. For these reasons, the proposed changes to this definition are reasonable.

Subpart 16. National Pollutant Discharge Elimination System (NPDES) permit. The term NPDES permit means a federal permit that is issued by the agency under authority granted by the United States Environmental Protection Agency. The phrase "point source including" has been deleted since a CAFO, according to Section 502 of the Clean Water Act, is a "point source" and the proposed rule does not address regulatory domains other than animal feedlots, manure storage areas and pastures. The term "concentrated animal feeding operations" has been replaced by its more commonly used acronym "CAFO." The changes to this definition are reasonable because they help clarify the applicability of NPDES permits within this rule.

Subpart 17. Owner. Addition of the phrase "manure storage area or pasture" to the definition of owner is needed to establish consistency in this rule with regards to ownership of animal feedlots, manure storage areas and pastures which are regulated under the rule. In the current rule, it is somewhat unclear if a manure storage area that is not located at an animal feedlot is subject to the permitting requirements of Minn. R. ch. 7020. The proposed rule requires manure storage areas to be treated equal to animal feedlots with respect to permit requirements. Owners of animal feedlots, manure storage areas or pastures are also required to register under the proposed rule and apply for an interim permit if determined to be a pollution hazard. Therefore, the addition of this phrase to the definition of owner is reasonable.

Subpart 18. Pastures. The term "pasture" is used to define a type of livestock operation where the animal's feeding needs are primarily met through grazing perennial grasses and forages. The existing and proposed rules do not consider a pasture to be an animal feedlot which is subject to permitting, provided that temporary supplemental feeding device is located outside of any special protection area and the pasture is not designated a pollution hazard by the commissioner or county feedlot pollution control officer. If the temporary supplemental feeding devices are located in a special protection area, the facility would be considered potential pollution hazard and could be required by the agency or delegated county to relocate the feeding devices and to eliminate any actual or potential pollution hazards created by the feeding devices placement.

The proposed amendments are intended to make the definition of "pastures" more closely match the image of a grass covered area in which animals graze. Experience with the current definition has demonstrated its weaknesses. Some feedlot owners have attempted to use the definition of "pastures" to argue that an animal feedlot in question is a pasture based on the fact that vegetation, no matter how little, grows in some part of the area. The proposed amendments clarify the requirement that a cover of perennial grasses or forages must be maintained. The intent of this again is to make the definition match the image of a grass covered area in which animals graze. Even with this amendment, someone will still try to argue that if a single blade of grass is growing in an area, the area is a pasture and therefore, a permit is not required. The intent is to require a vegetative cover throughout the pasture, such that soil erosion and runoff from the area is not a problem. In an attempt to establish clear guidelines for what constitutes a pasture, the proposed amendments also establish the requirement that supplemental feeding devices must be located outside of special protection areas. The proposed amendments still allow supplemental watering devices to be located within special protection areas. The supplemental feeding devices must be located outside of special protection areas to minimize the impact of the animals congregating around the feeding device. By requiring the feeding device to located outside special protection areas, the animals will spend the majority of the time away from waters of the state and the chance of manure contaminated runoff form entering the waters is significantly reduced. Watering devices are allowed in the area to minimize the cost of pumping the water from the water body to the watering device. These pumps are operated by cattle pushing the pump with their nose and therefore pumping the water uphill or long distances to the watering device could create unnecessary cost to these owners. Since the watering device will be closer to the feeding device, it is reasonable to assume that the animals will prefer to drink from the watering device as from the water body (for pastures for which the proposed rules allow the animals to have direct access to the water body).

Animals at those animal feedlots that meet the definition of CAFO are not allowed direct access to a water body under the proposed rules. For these reasons, it is reasonable to amend the definition of "pastures" to require the vegetative cover to be a perennial grass or forage and to require temporary feeding device to be located outside of special protection areas.

Subpart 18a. Permanent stockpiling site. This definition is needed because the proposed feedlot rules regulate manure stockpiling in two categories; permanent stockpiling sites and short-term stockpiling sites. Both types of stockpiling are manure storage methods that consist of placing relatively dry manure in piles on either natural relatively low permeability soils or on constructed pads having much lower permeability. The distinction between the two types of stockpiling are based on a range of criteria including how long the stockpile is maintained prior to land applying the manure and the volume of manure stored. The definition also states that a permanent stockpile site is a manure storage area. This definition establishes that any stockpile not operated to meet the short-term stockpile requirements is, by definition, a permanent site. This ensures that all stockpiles are regulated.

Subpart 19. Permit. The agency proposed several modifications to the definition of the term “permit”. The agency proposes to delete the phrase “at no charge to the applicant.” This rule language governs fees for state permits and the agency is proposing to change the permit fee rules to charge fees for SDS permits that regulate feedlots with 1,000 or more animal units. See need and reasonableness discussion under part 7002.0270, item F. The phrase “county feedlot pollution control officer” has been added because County feedlot pollution control officers (CFOs) are authorized to issue permits under this chapter. Adding CFOs to the definition is needed and reasonable revision because provides accuracy to the definition.

The agency has also modified the language to read “which may contain requirements, conditions, and/or schedules for achieving compliance with the discharge standards, management of animal manure, construction, and/or operation of animal holding areas and manure storage areas” to the existing definition is intended to clarify the wide range of compliance requirements place on owners in permits and that must be followed. The term, animal holding areas, is intended to be broad and include, for example, such areas as pastures, livestock sale barns, or transfer stations and fairgrounds. Feedlot permits not only regulate discharges of manure; they regulate operational methods and practices for management of feedlot pollutants. Adding this language completes the meaning of what a permit is. Therefore, this change is reasonable to make to the existing definition.

The proposed definition identifies the types of permits which may be issued by the agency and/or CFO to owners of animal feedlots, manure storage areas and pastures. By doing this the agency is able to use the generic term “permit” whenever permits or permitting related-matters are addressed in the rule. This is a reasonable approach since it allows use of the broad term instead of listing all permit types each time a general reference to any permit is used throughout the rule. In addition, listing the names of the permits issued under this amended rule helps distinguish these permits from the various permits (e.g., SW-A, 5-year and interim) and certificates of compliance that were issued under the current rule. The SW-A permit, the 5-year permit and the certificate of compliance will no longer be issued under the amended rule. However, even if an owner was issued one of these documents previously under the existing rule, there exists the requirement for the owner to apply for a permit under the amended rule pursuant to part 7020.0405, depending on the specific factors present at the facility.

Finally, while not specifically stated in this definition, all owners of CAFOs issued an NPDES permit will be issued a combined NPDES/state disposal system (SDS) permit. Because the federal regulations only address discharges of pollutants to surface waters, the combined NPDES/SDS permit is needed and reasonable to allow the agency to regulate the discharge of pollutants from CAFOs to all waters of the state including groundwaters, and to address air quality and other issues such as those addressed in the permit application section under part 7020.0505, subp. 4, item B. The agency also realizes efficiencies in processing applications and taking permit actions on CAFOs by issuance of a combined NPDES/SDS permit.

Subpart 19a. Pollution hazard. The agency proposes to add the definition of pollution hazard, in exchange for the potential pollution hazard definition deleted (see subpart 20 discussion in this SONAR). This definition is intended to more clearly identify what specific criteria must be met to be a pollution hazard by referring to the criteria incorporated into the proposed rule in parts 7020.2000 to 7020.2225.

Item A of this definition describes two criteria that must be met: (1) that an owner is not complying with the standards in parts 7020.2000 to 7020.2225 and (2) that the owner has not obtained a NPDES or SDS permit. This item is needed because it is integral to the permitting system in parts 7020.0405 to 7020.0535. The application of these permits to owners not meeting the standards is discussed in more detail in this SONAR for part 7020.0405. However, the key issue with respect to this definition is that an owner can clearly interpret what specific factors must be followed so that they are not defined as a pollution hazard. It is important to note here that an owner is not necessarily creating or maintaining an actual pollution hazard to waters if they are a “pollution hazard” under item A. Under this scenario, the owner has not demonstrated to the commissioner through the NPDES or SDS permitting process that their alternative approach (to those in parts 7020.2000 to 7020.2225) will not create or maintain a pollution hazard. This provision is reasonable because, when considered with the permitting structure presented in part 7020.0405, it allows an owner to propose alternative methods by stepping through a more involved permitting process. This is also reasonable for the concerned public and the agency because it allows the commissioner to more closely review design, construction or operation methods which do not fit the standard methods, resulting in greater assurance that facilities will not create or maintain actual pollution hazards.

Item B of this definition is needed to give the commissioner or county feedlot pollution control officer the ability to designate a facility a pollution hazard upon inspection. The main differences between this definition and the old “Potential pollution hazard” definition are that the proposed definition specifically requires an inspection; and the definition specifies factors that must be considered when determining the extend of pollution hazard present at a facility. These criteria are again needed and reasonable because they set boundaries on the discretion of the inspector.

The term “potential” has also been included in item B to allow the commissioner or county feedlot pollution control officer to designate a facility that has a high risk of pollution in the future. Two examples are provided to illustrate the meaning of potential.

> First, a liquid manure storage area under construction which appears to have significant construction defects which must be corrected prior to manure being added to the manure storage area. Under this example, the permitting authority could require the owner to obtain an interim permit to correct a problem, whether the owner was originally issued a construction short-form permit (300-1000 animal units) or no permit (fewer than 300 animal units). This is reasonable, because in reality the owner

would not have complied with building the manure storage area according to the original plans and specifications, which met the standards in part 7020.2100. Therefore, the facility could be considered a pollution hazard under item A, either way the owner is subject to an interim permit to correct the potential or likely problem.

Second, consider the example of an owner that proposes a facility of 299 animal units located just a few feet outside of the shoreland setbacks in part 7020.2005 and is located at the top of a steep ravine leading to the water body. The commissioner or county feedlot pollution control officer could require an interim permit, which could include many of the same conditions in a construction short-form permit to have better oversight of the new or expanding facility. This is reasonable because the proposed facility is just outside two of the permitting thresholds including the 300 animal unit threshold for a construction permit and the location restrictions. In several discussions with county feedlot officers during 1999, many expressed concern that the word “potential” should be removed from the definition. However, the agency proposes to include “potential” because several counties also expressed the desire to have permitting authority for facilities under 300 animal units which have potential pollution problems.

Subpart 19b. Process generated waste waters. The agency proposes to add this definition which is needed to provide consistency with federal regulations (as defined in 40 CFR 412.11 (d), Exhibit A-13). This definition is reasonable because it provides clarity to regulatory agencies and facility owners that more than manure is regulated under the federal feedlot regulations and this rule.

Subpart 19c. Process wastewaters. The agency proposes to add this definition to provide consistency with federal regulations (as defined in 40 CFR 412.11 (c)). This definition is reasonable because it provides clarity to regulatory agencies and facility owners that more than manure is regulated under the federal feedlot regulations and this rule. An example of the wastewater to be addressed under this definition is the runoff of liquid from a silage storage area. This wastewater does not contain manure, but still has pollutants such as high levels of biochemical oxygen demand, which can significantly impact waters of the state and therefore, should not be overlooked.

Subpart 20. Potential pollution hazard. The agency proposes to delete the definition of potential pollution hazard in exchange for the pollution hazard definition in subpart 19a. The definition contained a complex set of general criteria that reference sensitive locations, geological conditions, discharge standards, shoreland, sinkhole, well considerations and water quality standards. These criteria have been incorporated into the proposed rule in parts 7020.2000 to 7020.2225, and the agency found that this grouping of criteria under one concept did not fit well with redesigns made to the permitting system and establishment of the standards in parts 7020.2000 to 7020.2225. The deletion of the term is reasonable because of this redesign of the rule, which no longer uses these terms in the regulatory framework.

Subpart 20a. Separation distance to bedrock. The addition of this definition is needed to provide a clear and consistent meaning of "separation distance to bedrock" when used mainly in the liquid manure storage area, part 7020.2100. This definition is reasonable because it accomplishes this goal by providing a less cumbersome read of the rule parts where it is used. The definition identifies the separation distance as between any stored manure and bedrock, throughout all areas of the liner system.

This definition is also needed to eliminate the past confusion when design engineers or contractors viewed the separation distance requirements to mean either: the distance between the manure and bedrock (as in this definition); or the distance between the bottom of the liner and bedrock. The confusion has not been a critical problem when dealing with concrete liners, since the liner itself is only 4 to 5 inches thick. However, when considering a 4-foot thick earthen/cohesive-soil liner which requires a separation distance of 5 feet, the actual required distance between manure and bedrock could vary from 5 to 9 feet if a clear definition is not established. Under the proposed definition, the separation distance of 5 feet for this example with a liner thickness of 4 feet would result in one foot between the bottom of the liner and bedrock.

Subpart 21. Shoreland. "Shoreland" is a statutory definition cited in the existing rule. The agency proposes to modify the definition by adding a citation to Minn. Stat. § 103F.205, subd 4. The revision will allow the meaning of shoreland to remain consistent with any changes that are made to the statutory citation of shoreland. On the basis that this modification ensures regulatory consistency, this revision is needed and reasonable.

Subpart 21b. Short-term stockpiling site. This definition is needed because the proposed feedlot rules regulate manure stockpiling in two categories; permanent stockpiling sites and short-term stockpiling sites. Both types of stockpiling are manure storage methods that consist of placing relatively dry manure in piles on either natural relatively low permeability soils or on constructed pads having much lower permeability. The distinction between the two types of stockpiling are based on a range of criteria including how long the stockpile is maintained prior to land applying the manure and the volume of manure stored. This definition states that a short-term stockpile site is a manure storage area that complies with part 7020.2125, subp. 1 to 3. This definition is needed and reasonable because it establishes clear criteria by which a stockpile can be identified as either a short-term or permanent stockpile.

Subpart 22. Sinkhole. The sinkhole definition has been modified to align with definitions found in current literature as described in "Sinkholes and Sinkhole Probability" maps published by the Minnesota Geological Survey. See Exhibit M-21. The map describes a sinkhole as: "Sinkholes are closed depressions that form by the solution of underlying soluble bedrock and function as connections between surface and ground waters. Sinkholes are intermediate in size between larger karst features such as blind valleys and smaller karst features such as solution pits." It is needed and reasonable to revise the definition to reflect the most contemporary meaning and understanding of this term.

Subpart 23. Special protection area. The agency proposes to add the term “special protection area” to the definitions to identify land that borders selected waters of the state. The designated areas are lands within 300 feet of Department of Natural Resource protected waters and wetlands and some intermittent streams and identifiable ditches on United States Geological Survey quadrangle maps. The special protection area definition is used in the proposed rule for land application of manure, part 7020.2225. For example, manure applied within special protection areas must meet more rigorous requirements than manure applied outside of the special protection areas.

The primary reason for establishing the special protection area system is potential pollution risk associated with manure and its proximity to waters of the state. Unless protective measures are present, manure that is generated, stored, land applied, or otherwise handled near those waters creates a higher environmental risk than when these activities are conducted a greater distance from these waters. As stated in Basis and Justification for Minnesota Land Application of Manure Guidelines “(t)he 300-foot distance chosen as the special management zone for surface water protection is believed to represent a reasonable distance which provides a reasonable degree of environmental protection base on the literature, yet not be unreasonable to livestock producers.” See Exhibit L-2. For this reason, it is reasonable to base the definition of “special protection area” on a setback of 300 feet.

The intent of the defining “special protection areas” is to provide a framework for protecting the most valuable and important waters of the state (as opposed to all waters of the state, which is broader in scope). The proposed definition represents the agency’s effort to develop rules that will provide the greatest environmental benefit without resulting in unreasonable restrictions for those being regulated. The agency accomplishes this end by selecting waters that are of highest priority to the public, those identified by the DNR Public Waters classification system which was created by the DNR in accordance with Minn. Stat. § 103G.201 to identify waters bodies of greatest importance. These waters are also identified on DNR Protected Waters and Wetlands maps. See Exhibit P-8.The definition also includes land with 300 feet of intermittent streams and some identified ditches because these water bodies and watercourses ultimately flow to lakes and other public waters. It is, therefore, reasonable that land bordering these water bodies and watercourses are subject to a higher level of protection.

Special protection areas can be clearly and consistently identified on maps which are readily accessible. Protected waters and wetlands are identified on DNR protected waters maps. Intermittent streams and ditches are identified on United States Geological Survey (USGS) 7.5 minute and 15 minute Quadrangle Maps. These maps are available through the Minnesota Department of Natural Resources website (www.dnr.state.mn.us); Minnesota Department of Administration; Minnesota’s Bookstore, 117 University Avenue, St. Paul, Minnesota 55155; and Maps Distribution USGS Map Sales, Box 25286 Federal Center, Bldg. 810, Denver, Colorado 80225. These maps are also available at public libraries, local Soil and Waters Conservation District (SWCD) offices, MPCA offices and most delegated county offices. Therefore, the means of identification of special protection areas by owners of animal feedlots and manure storage areas for permit application requirements and manure land application purposes is reasonable.

Subpart 24. State disposal system permit or SDS permit. SDS permits are those permits that are issued under statutory authority in Minn. Stat. ch. 115. The agency also has the authority to issue permits through the federal permitting program known as NPDES permit program. Owners that meet the criteria of a CAFO, will be issued a combination permit that contains the requirements for both NPDES and SDS permits. The intent of the proposed definition is to clearly identify the authority under which state permits for animal feedlots and manure storage areas are issued. SDS permits are issued according to the agency's procedures required in part 7001. Interim permits and construction short form permits are exempt from certain procedural elements required under part 7001.

Subpart 25. Unpermitted/Non-certified Liquid Manure Storage Area. This definition is needed and reasonable to eliminate the need to use the two criteria throughout the applicable requirements in this rule. The two criterion, of which the owner need only meet one, for defining an unpermitted manure storage area include: not having an agency or delegated county permit or certificate of compliance for the manure storage area although the owner was required to apply for and obtain a permit or certificate of compliance prior to the construction and/or operation of the manure storage area; and not complied with the pre-operational requirements of part 7020.2100 and permit requirements. This definition is also reasonable because it provides the owner a clear listing of the criteria without having to refer directly to the section requiring corrective action on an unpermitted manure storage area.

Subpart 26. Waters of the State. The term "waters of the state" describes the bodies of water that are to be protected under the proposed rules. The term is very broad. Those areas designated as special protection areas are areas in which the risk of polluting waters of the state is high either due to the areas proximity to water and the risk of direct runoff to it is high or the presence of a conduit (i.e., ditch, pipe, or intermittent stream) to easily transporting pollutants to waters of the state. The definition included here is identical to the statutory definition established in Minn. Stat. § 115.01, subd. 22. One clarifying note is that the term "irrigation systems" which is included in the definition is not intended to prohibit land application of liquid manure in accordance with part 7020.2225, for example, from a center pivot irrigation system, or traveling gun.

Registration Program

<u>7020.0350 Registration Requirements for Animal Feedlots, Manure Storage Areas and Pastures</u>

The agency is proposing to incorporate a regulatory tool known as registration into the agency's feedlot program. Registration is an administrative approach to regulation that collects fundamental information from all parties subject to a set of regulations and puts it into an organized information and management system. The agency proposes to use registration in the feedlot for the following reasons:

- As a tool to locate livestock and manure storage facility owners and identify high priority environmental problems;

- As a method of conveying regulatory and education information to livestock and manure storage facility owners; and
- As a tool to collect data for the further development and implementation of the feedlot regulatory program.

Livestock and manure storage area facility owners must satisfy the registration requirement in one of three principal ways. First, they may submit a completed registration form to a delegated county feedlot officer or agency. Second, their operation may be identified on a level II inventory that has conducted by the county. Submittal of a completed permit application is a third alternative by which owners may meet registration requirements.

All feedlots must be registered in 2001. Registered owners must update their registration every four years. Registration consists of providing:

- Property identification information;
- Owner information;
- Basic facility operational information; and,
- Location information.

A main feature of the registration program is that the registration requirements have been designed to correspond to the basic facility data collected from level II feedlot inventories. Level II feedlot inventories are inventories that have been conducted by counties according to the Feedlot Inventory Guidebook. See Exhibit I-1. Many counties have completed level II inventories. See Exhibit C-5. Information from these inventories may be used to complete or partially complete the data requirements of the registration program, provided that the inventory data can be supplemented with the required additional information. As a result, in counties where level II inventories have been conducted, much of the work needed to accomplish registration has already be completed. For counties that do not maintain a current level II inventory, registration implementation will typically consist of four steps. Livestock and manure storage facility owners will be identified through the use of existing data such as tax records, existing topographic maps that show feedlot sites, and producer association records. Identified owners will be mailed forms. Completed and returned forms will be processed. Additional follow-up to owners not responding will be achieved by phone calls, drive by sighting, and working through township officials.

The impetus for developing a registration program emerged in April of 1999. The agency's original administrative approach to regulating feedlots was through a comprehensive permitting program. Under that system all feedlots were proposed to be permitted. However, when the plan for permitting everyone was matched with agency resources, it became apparent that staffing levels were not sufficient to conduct a comprehensive permitting program. See letter dated June 4, 1999, in Exhibit I-5. As an alternative the agency proposed a registration system in combination with a limited permitting program. The strategy was to shift the tools used for achieving regulatory compliance from permitting to inspections and from the agency to the county programs. The inspection program would be supported by a high quality database identifying the location of most feedlots in the state. The database would be maintained through the registration program. The registration component was refined in the course of several FMMAC meetings and was, ultimately, supported as a useful tool in regulating livestock and manure storage area facilities.

Subpart 1. Generally, subpart 1 establishes a registration data component to the feedlot program. Subpart 1 contains provisions that are key to shaping the registration program. The provisions contained in subpart 1:

- State that registration applies to not only animal feedlots, but also to pasture operations and manure storage facilities.
- Establish an October 1, 2001 deadline for meeting registration requirements.
- Define the information that is required to be gathered and maintained. The information required must meet the level II inventory information required in the Feedlot Inventory Guidebook and also include minimal supplemental information as described below.

The agency is proposing that the registration requirements apply to pastures. Pastures are livestock operations where the livestock are primarily grown and produced by grazing them on grasslands or other fields with growing plants. Beef-grazing and cow/calf operations are typical examples of pasture operations. In many of the northern counties of the state, this is the most common type of livestock agriculture.

One of the needs to require registration of pasture operations relates to the goal of regulation. The registration program is intended to keep the agency informed on the general status of livestock operations in the state. This includes information on such areas as animal numbers and density. For this information to be accurate it is necessary that the agency has data on pasture operations. It should be noted that information will only be required from pasture operations with 50 or more animal units unless the pasture is in shoreland. It should also be noted that grazing operations that do not meet the definition of pastures as described in 7020.0300, subpart 18, will be subject to registration under the classification of a feedlot. Finally, the registration requirement should not be interpreted to mean that the level of regulation will increase for this category of feedlots.

Another reason why the agency proposes to require pasture operations to be registered is that it’s not always easy to distinguish a pasture operation from other types of livestock operations. Some livestock operations are a combination of pasture and feedlot operations. For example, at some livestock operations livestock are pastured during the growing season and, then, confined to open lots and buildings during the winter months. Owners of these operations may be unclear as to whether or not they are required to register. For the above reasons including the need for accuracy of information, planning regulatory strategy, and avoiding creating a confusing regulatory picture for livestock owners, it is needed and reasonable that registration covers all significant livestock operation including pasture operations.

The agency is proposing that registration includes a deadline by which livestock and manure storage area facility owners must be registered. The reason is that, for the information to be useful, it must be current. This is true whether the information is being used to prioritize and direct inspections, to serve as a mailing database, or to use for analysis in doing program development. The deadlines established by the agency for registration are intended to keep the information current to within four years. The agency believes that this span of time strikes a balance between having a database that contains information reasonably representative of the livestock and manure storage area facilities in Minnesota and a regulatory requirement that is not overly burdensome to those who are subject to it.

The agency is establishing deadlines in two phases. There is the initial phase under which registration is required by October 1, 2001. There is the on-going phase, which is set up on a repeating basis of four-year cycles. The rationale for setting October 1, 2001, as the initial registration deadline is based on a sequence of events that begins with the adoption of the proposed rule. As of November 1999 the agency is estimating that adoption of the rule will occur sometime in August of 2000. At or about the time of adoption, the agency will initiate an outreach and information program to educate affected parties on the contents of the revised rule. This rather intense educational phase should last between six months and one year and be completed by the summer of 2001. The agency's strategy is that the registration deadline should occur near the end of the educational phase. The reason is that livestock and manure storage area facility owners should be at a peak in their understanding of the proposed rules and its obligations. At this time they will be most aware of their registration obligations and will be most likely to comply with them. It is reasonable for the agency to establish procedural requirements that are designed to accommodate practical considerations. The need and reasonableness for registration deadlines established after October 1, 2001 is addressed in this SONAR for subpart 4, item B.).

Subpart 1, items A to K is a list of information requirements that must be met in order for registration to be complete. The agency proposes to establish the information requirements in items A to K for the following reasons:

- The requirements provide owner and property identification needed for the purpose of inspections and to provide data for agency planning and analysis purposes.
- The requirements provide adequate information for the agency to reasonably assess the pollution-risk factor of a facility.
- The requirements allow information from level II or level III inventories to be used along with minimal supplemental information, to meet information requirements for registration.

This set of information requirements developed from discussions with FMMAC at meetings on June 14, 1999, and on August 11, 1999. At these meetings many viewpoints regarding the goals of registration and the information needed from owners to meet those goals were shared. Exhibit I-2. Emphasized and agreed upon in these discussions were the general guidelines that the registration form should:

- Yield information needed to identify feedlot location and prioritize problem feedlots;
- Provide assurances that registration would not result in punitive enforcement actions;
- Be reasonably short and easy to use; and

- Not be intrusive.

One aspect of the discussion on registration did not get fully resolved. This controversy centered on the amount of compliance information that an owner should be required to disclose on the registration form. For example, one of the proposed information requirements required owners to disclose whether or not their manure pit had ever overflowed. Some thought that it would be counterproductive to require feedlot owners to submit this information. They thought that owners would be reluctant to provide information that would indicate non-compliance and, therefore, make registering these owners more difficult. Others thought that putting compliance evaluations on the registration form simply fulfilled an agency regulatory philosophy of making owners more responsible for evaluating the compliance status of the operation and design of their facility.

The agency created two prototype registration forms to clarify issues related to the type of information needed to be obtained from registration. See Exhibit I-3. One form was designed after the level II inventory described in the Feedlot Inventory guidebook. The level II inventory requirements require livestock operation owners to disclose feedlot size, animal type, type of manure storage and distance to surface water. The other form was designed to provide a more comprehensive assessment of potential pollution problems. It required livestock and manure storage area facility owners to disclose the occurrences of non-compliance at the facility such as a manure storage basin overflow or the over application of manure to land. This was presented to FMMAC prior to the October 11, 1999 meeting but a decision on the matter of registration content was not finalized.

The agency is proposing to use the information requirements according to A to K because it satisfies two important considerations related to the registration program. One is that it provides adequate information for the agency to reasonably assess the pollution-risk factor of a facility and to generate a comprehensive database on livestock operation location. Second, the information requirements contained in A – K should be available from many of the level II inventories that have already been conducted by the counties. This linkage between the two systems (level II inventories and registration) allows existing information from level II inventories supplemented with readily available additional information to be used to meet registration requirements.

The Feedlot Inventory Guidebook is an inventory guide that was put together by several state agencies in 1991. See Feedlot Inventory Guidebook Exhibit I-1. It has become established as an authoritative and useful regulatory guide for conducting animal feedlot inventories in Minnesota. It is the reference guide used by counties to conduct feedlot inventories. Legislative appropriation funds for the feedlot grant program are based on level II and level III feedlot inventories as described in the Feedlot Inventory Guidebook. The agency is proposing that the Feedlot Inventory Guidebook and the corresponding level II inventory be made an integral part of the registration program. While the value of using information from Feedlot Inventory Guidebook inventories for registration has been discussed, it is important for clarity to discuss how the Feedlot Inventory Guidebook affects the terms and conditions of the registration program.

The registration information requirements contained in subpart 1 are defined by the Feedlot Inventory Guidebook and by items A to K. It may seem confusing that both of these methods are used to define and identify registration requirements. The reason for this is that while the agency wants to continue to use the Level II inventory of the Feedlot Inventory Guidebook as the definitive guide for establishing registration information requirements, the agency, also, wants to make sure that registration provides the four basic categories of feedlot information – owner, property, operations and pollution-risk.

Often, the information contained on a level II feedlot inventory conducted by a county will meet all information requirements listed in A to J of subpart 1. However, agency experience is that most counties use a code on their inventory spreadsheets for identifying facility owner name, address and location. This code may be in the form of a property identification number, a watershed designation, a fire number or a key to geo-locational computer software such as Arcview. As a result the submitted inventories do not directly identify the owner and property information as required by subpart 1, items B to D. The agency needs easily accessible owner, address and property information to achieve the goals of registration. Therefore, the agency proposes to itemize the information requirements A to J as a way to avoid receiving level II inventories that do not fully comply with registration requirements. Itemizing the information requirements also removes any ambiguity between the agency and the county as to what a level II inventory as described by the Feedlot Inventory Guidebook means.

Item A requires that a completed registration form be dated. The feedlot registration program has time-related parameters and, therefore, a provision is needed to establish the date when the registration information was completed.

Item B is information that is required to identify the names and addresses of the owners. This information is needed for the agency to provide information and to otherwise correspond with the owners of animal feedlots, manure storage areas, and pastures.

Item C is information that is required to identify the location of an animal feedlot, pasture or manure storage area. Location information must be provided in the standard format of county, township, section, and quarter section. Facility location is information needed to support the conducting of inspections and to aid in feedlot program planning and analysis.

Item D. According to item D, owners of animal feedlots, pasture or manure storage areas that have been permitted or received a certificate of compliance must record the permit/certificate of compliance on the registration form. The significance of a certificate or a permit number is that it indicates that a facility has been reviewed for compliance by either the agency or county staff. As a result, a permitted facility or a facility with a certificate is likely to have a lower potential to pollute than a facility that has not been permitted or does not have a certificate of compliance. This information is useful for regulatory strategies that rely on evaluating pollution-risk. Certificates and permit numbers are also useful for retrieving information on databases and for accessing records.

Item E requires that registration data be obtained on the method of livestock confinement used by owners of animal feedlots. The type of holding areas used to confine livestock correlates to the level of pollution risk at a facility. For example the opportunity for runoff is much greater from a livestock operation with open lots than one where animals are maintained under a roof at all times. This is useful information for the agency to have when prioritizing feedlots for such purposes as conducting inspections.

Item F requires that registration data be maintained on the number and type of livestock confined at livestock operations. The amount of waste generated at a livestock operation is in direct proportion to number of animals located at the site. Also, manure characteristics differ among animal types. Therefore, this is important information for the agency to have available to assess an operation's potential to pollute. This information is also fundamental for conducting feedlot program planning and analysis.

Item G contains registration requirements related to the distance of manure production/storage to surface waters. One of the prime indicators for evaluating the level of pollution risk at a site where manure is produced and/or stored is the distance from these sites to surface waters. The setback requirements from surface waters for siting new feedlots, manure stockpiling, and the land application of manure documents is evidence of this fact. This is essential information for the agency to have when prioritizing feedlots for such purposes as conducting inspections.

Item H addresses registration requirements related to manure storage areas. The type of manure storage used at a feedlot may affect its potential to pollute surface or ground water. For example, the agency is concerned about the pollution threat that exists at facilities with unlined earth basins. A database that contains records of facilities with a particular type of manure storage such as unlined basins will allow the agency to systematically address and implement solutions to resolve these problems.

Item I contain registration requirements for information on distances from the manure production/storage facility to wells. The potential for well contamination is related to the distance from the well to manure sources. While this circumstance is seldom observed to be a hazard at most animal feedlot, manure storage area and pasture operations, it is part of the level II inventory of the Feedlot Inventory Guidebook, and to maintain consistency between the level II inventory and registration, it is reasonable to include this item as an information requirement.

Item J requires that the name of the person completing the registration be identified. For the ability of the agency to check on the reliability of data it is needed and reasonable to have a provision that allows the agency to contact the person responsible for completing the requirements of registration.

Item K allows the agency to modify the registration form according to environmental priorities. This form will be modified when additional information is needed to assess and better understand environmental problems. The recent concern over regional buildup of air pollutants from concentrated areas of feedlots is an example of a possible shift in environmental priorities.

The modification allowed by this provision is limited to the extent that it allows the agency to add questions seeking additional relevant information to address future feedlot program needs.

To guide this process the agency will use environmental outcome methods in the program plan to identify environmental problems that warrant seeking additional information from livestock operation and manure storage areas. The agency will also collaborate with BWSR to revise the Feedlot Inventory Guidebook to ensure that questions on the registration form and the feedlot guidebook inventories are consistent. For the ongoing usefulness of the registration form, it is needed and reasonable that the agency have the flexibility to make changes that will collect information related to evaluating environmental problems.

Subpart 2 identifies the owners of animal feedlots, manure storage areas and pastures that are subject to registration requirements. They are categorized into two groups as described under items A and B.

Item A states that owners of animal feedlots, manure storage areas and pastures with 50 or more animal units are subject to registration requirements. From an administrative resource and pollution-impact standpoint, the agency does not view it as practical to maintain registration information on animal feedlots, manure storage areas and pastures outside of shoreland below 50 animal units. This threshold is also related to statutory provisions. Minn. Statute 116.07, subdivision 7(g), limits the permitting authority of the agency to feedlots with 50 or more animal units outside of shoreland and to feedlots with 10 or more animal units in shoreland. For consistency and uniformity, it is reasonable for the agency to establish this requirement.

Item B states that owners of animal feedlots, manure storage areas and pastures with 10 or more animal units and less than 50 that are within shoreland are subject to registration requirements. The need and reasonableness for establishing this provision is the same as item A.

Subpart 3 establishes procedures for registering for the registration period ending October 1, 2001. Livestock and manure storage area facility owners must register according to one of three methods as described in items A to C.

Item A sets forth a process for registering whereby a livestock and/or manure storage area owner completes a registration form supplied by the agency and submits it to the commissioner. It requires that the form be submitted by October 1, 2001. This method of registration is needed for owners who are not able to meet registration requirements through methods described under items B and C.

Two aspects related to the registration process must be considered in evaluating the reasonableness of this provision. For the provision to be reasonable there must be reasonable assurances that the agency and county registration program has a system and capacity to reliably provide registration forms to the owners. Also, for the provision to be reasonable, the form must be relatively simple and easy to complete.

As part of the rule revision the agency has prepared a feedlot program plan to implement the terms of the proposed rule. Under that plan the agency has allocated 2.5 full-time equivalent (FTE) to administer the registration program. See page 12 in Exhibit I-4. The plan accounts for all the various duties that must be conducted in order to adequately implement a registration program. In addition the MPCA as well as other agencies are planning information and outreach efforts to educate owners on the requirements of the new rules. These efforts should help familiarize the owners with registration forms and an understanding of how to fill them out. Finally, the proposed rules on delegation require that counties plan and implement a registration program. The combination of these measures by the agencies and the counties should provide reasonable assurance that livestock and manure storage facility owners receive adequate notification and materials to comply with the requirements. Therefore, owner registration by submittal of a form is a reasonable requirement.

The registration form and the completion of it are a factor in the reasonableness of requiring livestock and manure storage facility owners to comply with this provision. As was discussed under subpart 1 the registration form was designed to be simple and easy to use. The proposed registration form is two and one-half pages in length and contains approximately 30 blanks to fill in. See Exhibit I-3. Under most circumstances livestock and manure storage area facility owners will have all the information needed to complete the form at arms-length. The registration form should not take more than 15 minutes to complete. Based on this analysis of practical considerations this provision is a reasonable requirement.

Item B allows a permit application filed by a livestock and/or manure storage area facility owner between the adoption date of the proposed rule and the October 1, 2001 registration deadline to satisfy the registration requirements of this part. The information supplied by a permit applicant on a feedlot permit application form is comprehensive and includes all items of information required for registration under subpart 1. Therefore, the agency already has the necessary information and the owner should not need to be required to submit it again. It is reasonable for the agency to establish procedures that reduce the regulatory burden for parties subject to regulations.

Item C contains conditions under which a county level II or level III inventory satisfies the registration requirement for an owner subject to registration. To preserve the integrity of the registration program the agency requires that a level II or level III inventory meet a set of specific requirements. These requirements are set forth in subitems (1) to (4).

The agency registration program has been designed so that owners in counties with level II or level III inventories that meet the criteria of this part are considered to have met registration requirements. It exempts livestock and manure storage area facility owners in counties with eligible level II or level III feedlot from having to complete and submit a registration form. The agency is proposing this feature of registration as a way to reduce the regulatory burden for owners. It allows the owners to save the work and inconvenience of having to submit a registration form. The level II or level III inventory option may affect owners in as many as 21 counties since this is the number of counties that have done these inventories. Approximately, 40 counties will have completed level II or level III inventories by 2001. See Exhibit C-5.

Because of the work reduction for the agency as well as regulated parties this feature of the proposed registration requirement is reasonable.

Subitem (1) sets forth the first of four criteria that must be met in order for a level II or level III feedlot inventory to satisfy the registration requirement. It requires that in order for an inventory to be used to satisfy registration requirements it must meet at least the level II criteria of the Feedlot Inventory Guidebook.

The level II information items in the Feedlot Inventory Guidebook match the information requirements listed in item A and items E to J of subpart 1. See Exhibit I-1. This provision is needed is to provide specificity so that a clear link is established between each information item in the Feedlot Inventory Guidebook and each information item under subpart 1. As was discussed under section titled "The role of the Feedlot Inventory Guidebook and the roles of inventories" in subpart 1, information submitted on inventories to the agency by counties can vary. By clearly identifying the information items in subpart 1 that must be present in the level II inventory and including the required supplemental information, the counties are relieved of any uncertainty as to whether their inventory procedure and content is meeting registration requirements.

Subitem (2) requires that in order for a level II inventory to be used as the basis to satisfy registration requirements it must have been conducted subsequent to October 1, 1997. This requirement is needed to ensure that registration information obtained from inventories will be current to within four years. The SONAR under subpart 1 explains that in order for registration information to be useful to the feedlot program, it must be reasonably up-to-date.

Subitem (3) requires that in order for a level II inventory to be used to satisfy registration requirements it must contain information according to subpart 1, items B to item D. Subpart 1, items B to D are information requirements related to owner name, owner address, and feedlot location. While feedlot inventories may contain this information, a level II inventory, according to the Feedlot Inventory Guidebook, does not require this information to be listed. Therefore, this information criteria must be made a requirement in order for a level II or greater feedlot inventory to satisfy the requirements of registration.

Subitem (4) requires that in order for a level II or greater inventory to be used to satisfy registration requirements it must be submitted to the commissioner. This requirement is needed to provide documentation that registration requirements for owners identified on the inventory have been met through a level II inventory. Submittal to the agency of level II inventory information should not be a difficult or time-consuming task. Delegated counties are already accustomed to this practice in order to meet feedlot grant application requirements.

It should be noted that counties will need to submit level II inventories on an on-going basis in order for animal feedlot, manure storage area and pasture operation owners identified on the inventory to meet registration update requirements. This needs to be done because, under subpart 4, owners are required to update their registration on four-year intervals.

The consequence of counties failing to meet at least the level II requirements of this provision depends on whether or not a county is delegated. Delegated counties are required by the proposed rules on delegation to submit registration information to the agency on an annual basis. Therefore, they are responsible for ensuring that level II inventories are submitted to the agency in accordance with this provision. Failure by non-delegated counties to submit level II inventories according to the terms of this provision will result in the obligation of the owner to individually register.

Subpart 4 establishes a registration program for the time period after October 1, 2001. Item A provides registration terms and conditions for livestock and manure storage facility owners who were not registered prior to October 1, 2001. Depending on their status they are divided into one of two groups as identified in subpart 4, item A, subitems (1) and (2).

Subitem (1) states registration procedures that are required for owners that commence operations and that are not required to submit a permit application. Under the proposed permitting system livestock and manure storage facility most owners with less than 300 animal units will be able to commence operations without applying for a permit. It is necessary to have a procedure that describes the registration process that applies to these facilities. As explained in subpart 3, item A it is reasonable to require this group of livestock and manure storage facility owners to submit information to the agency on a form that is provided by the agency.

Subitem (2) states registration procedures required for livestock and manure storage facility owners that submit a permit application prior to commencing operations. Under the proposed permitting system livestock and manure storage facility owners with more than 300 or more animal must apply for a permit application. It is necessary to have a procedure that describes the registration process that applies to these facilities. As explained in subpart 3, item B, it is reasonable that submittal of permit application satisfies the registration requirement.

Subpart 4, item B addresses registration requirements for the period of time subsequent to October 1, 2001. Under this provision an on-going registration program consisting of four-year cycles is established. It means the registration program will complete a cycle every 4-years. For example, the registration period following October 1, 2001 will complete October 1, 2005 and the registration period subsequent to October 1, 2005 will complete October 1, 2009. All livestock and manure storage facilities must register within each 4-year period.

The agency's purpose for proposing on-going registration is that the registration data must be accurate and timely in order for it to be useful. The agency intends to use the information to prioritize high-risk feedlots, to support a communication and outreach plan, and to contribute to developing agency regulatory strategy. All of these uses depend on accurate and up-to-date data. Therefore, on-going registration is a necessary component of the registration program.

The 4-year time frame ensures that the data collected is kept reasonably current. It's important to note that registration may be accomplished at any time during a 4-year period. The intent of this design is so that the registration program can be conducted in a reasonable manner. It allows the county feedlot programs and the agency to spread out the workload required to implement the program. This enables the agency and the counties to maintain consistent staffing levels to support their operations. Therefore, this design feature of the registration program constitutes a reasonable approach for conducting feedlot regulatory activity.

Subitem (1) contains procedures for registering livestock and manure storage areas for the time period after October 1, 2001. It addresses livestock and manure storage area facility owners who must submit a registration form or who submit a permit application to the commissioner or delegated county. It states that owners subject to this provision must use the procedures as identified under subpart 4, item A, subitems (1) and (2). The SONAR for this part is the same as for subpart 3, items A and B.

Subitem (2) lists the criteria that a level II or level III inventory must meet in order for a livestock or manure storage area facility owner to use this option to satisfy registration requirements. As explained in this SONAR for subpart 1, the agency registration program has been designed so that owners in counties with level II or level III inventories that meet the criteria of this part are considered to have met registration requirements if the owner participates in the level II or level III inventory, and the supplemental information in subitem (2)(b) is included.

Subitem (2), units (a) to (d) contain the requirements necessary for a level II or level III inventory to satisfy registration requirements. They are identical to the provisions in subpart 3, item C, subitems (1) to (4) with two exceptions. One exception is that the provisions apply to the registration time period after October 1, 2001. The second exception is that subpart 1, item K has been added as an information requirement. Subpart 1, item K allows the agency to alter the information requirements when a shift in environmental priorities has been demonstrated. In order for a level II or level III feedlot inventory to satisfy the registration information requirements of subpart 1, after October 1, 2000, it must contain subpart 1, item K.

Subpart 5 sets forth the agency's enforcement terms for livestock and manure storage area facility owners that do not meet registration requirements. The provision identifies a penalty as an enforcement option that the agency may use for owners who are subject to registration but are not in compliance with registration requirements. Under the provision the penalty is applicable for each four-year period in which the owner has been subject to the registration requirement but has failed to register.. The agency's authority to conduct enforcement actions for violations of pollution rules and regulations is established in Minn. Statute 115.071.

The agency bases the need to explicitly state the enforcement authorities for this provision on practical considerations. Registration will be a high profile component of the feedlot program. It will apply to the vast majority of livestock and manure storage area facility owners in the state. As a result the number of violations will be large even if a small percentage don't comply with the registration requirement. Under these circumstances the agency must be ready to respond with clarity to non-compliance. This provision is an initial step to providing that clarity.

The alternative is for the agency to be silent about its authority to enforce the registration requirement. The ramifications of this approach may help explain the necessity of the proposed provision. To successfully implement the registration program the agency must rely on the motivation and willingness of the owners to comply. If registration compliance is not supported by enforcement and a small segment, let's say 20 percent, perceive that registration is not viewed as significant, it will put a tremendous burden on the agency to get that group to comply. It will diminish the motivation of those subject to the requirement and the agency will have to work harder to accomplish the goals of registration.

On the other hand, if the agency actively moves forward on enforcement without adequate advance notice, it will surprise those who fail to register. They will claim that they were unaware of enforcement consequences and the agency will be faced with a host of objections. Responding to these challenges will consume agency resources and divert it from more productive efforts.

Under either one of the above scenarios, failure to be clear regarding enforcement of registration will have detrimental consequences for the agency to be able to conduct its business. It is needed and reasonable for the agency to establish provisions that will protect the agency's ability to effectively conduct normal and routine operations.

Finally, while the proposed provision clearly sets forth an intention of the agency to consider enforcement for registration non-compliance, the provision does not make a penalty mandatory nor does it stipulate a penalty amount. The language is flexible and it allows those responsible for enforcement a choice in employing its authority. Thus, the flexibility provided in the terms of the provision constitutes a reasonable approach to addressing this aspect of the registration requirement.

Permit Program

As discussed in the Statement of Reasonableness as a Whole, there are many possible ways to regulate animal feedlots, manure storage areas and pastures. The agency has in the past chosen to regulate them primarily through issuing permits and certificates of compliance. Permits were required when construction was proposed at an animal feedlot or manure storage area. Along with the permit, the facility that applied for the permit might be inspected at some point before, during, or after the construction was completed. Inspections and outreach have not been a significant part of the strategy for regulating animal feedlots, manure storage areas and pastures. The proposed rules and draft feedlot program plan (Exhibit I-4) place much greater importance on outreach, education and inspections that in the past. This part discusses the reasonableness of each part of the proposed permit program.

<u>7020.0400 Permits and Certificates Issued Prior to the Effective Date of this Part</u>

This part establishes the status of permits and certificates of compliance issued prior to the effective date of this proposed rule. The proposed part defines and describes each of permit and certificate types previously issued to ease the potential confusion over the many types of documents that have been issued by the agency or delegated counties over the last twenty years.

Subpart 1. This proposed provision contains the requirements for owners holding SW-A permits to comply with parts 7020.0400 to 7020.0535 and obtain a new permit, if required under these parts. The permit application will then be reconsidered by the agency or delegated county pursuant to these parts and Minn. R. ch. 7001. This provision requires these owners to comply will all parts of this chapter upon it's effective date. This provision is needed because some SW-A permits did not include any expiration date and are therefore are still in effect. Since many of these permits probably don't accurately represent the facilities to which they were issued, it is reasonable to require owners to obtain a new permit, if required, and to register in accordance with part 7020.0350. The current rule states under part 7020.0600 that "(t)he conditions and provisions of all agency animal feedlot permits issued under Minnesota rules SW 51 to 61 before December 25, 1979, shall continue to be in effect. Upon application for a change in operation or change of ownership of an existing, permitted animal feedlot, the permit shall be reconsidered pursuant to these parts." This does not clarify the status of permits issued to owners that never apply for a permit modification. For this reason, it is reasonable to clearly state that owner holding these permits must comply with this part on the effective date of this part.

Subpart 2. This provision requires an owner having certificates of compliance to comply with the permitting requirements of these parts. This includes registering in accordance with part 7020.0350, applying for permits as applicable and conforming to the technical standards in parts 7020.200 to 7020.2225. This is reasonable because many owners may consider that they are in compliance by having been sent the certificate of compliance letter, when they most likely will be required to comply with additional requirements compared to what was required at the time the certificate of compliance was issued. One example is the requirement to develop a manure management plan according to part 7020.2225, subp. 4.

Subpart 3. Interim A (issued for construction activities under the current program) and Interim B (issued for correction of a pollution hazard under the current program) are issued with expiration dates no longer than 10 months from the date of issue. The proposed rules will allow interim permits that were issued prior to the effective date of the proposed rule to expire on the date stated in the permit. The issue to be addressed within the proposed rules is for interim permits that have been issued but the work authorized and/or required under those permits has not been completed by the expiration date of the permit.

The proposed rules treat construction short-form, SDS and NPDES permits like Interim A permits of the existing rule. Any of these permits can authorize construction and expansion at an animal feedlot or manure storage area. Therefore, it is reasonable to require the owner that was issued an Interim A permit for construction under the existing rules and that has not been completed by the expiration date of the permit to apply for a construction short-form, SDS or NPDES permit, which ever is applicable.

The proposed rule treats interim permits (as defined in proposed rule part 7020.0300, subp. 13) like the Interim B permits issued prior to the effective date of the proposed rule. Interim B permits are those that are issued to correct a "potential pollution hazard." Under the proposed rules, interim permits will be issued to "pollution hazards." The proposed rules also replace the term "potential pollution hazard" with "pollution hazard." The proposed rules will require owners that were issued an Interim B permit and have not completed the work authorized and required under the permit to follow the requirements under part 7020.0535, subp. 5. Part 7020.0535, subp. 5 establishes the requirements for owners issued an interim permit under the proposed rule that have not completed the work required under the interim permit. The reasonableness of part 7020.0535, subp. 5 is discussed in detail under that part of this Statement of Need an Reasonableness. Given the similarity between the proposed interim permits and Interim B permits issued prior to the effective date of the proposed rule, it is reasonable to requires owner that have not completed the requirements under and Interim B permit to follow the requirements of 7020.0535.

Subpart 4. This subpart states that status of any NPDES or SDS permit prior to the effective date of this part is unaffected. Those permits will expire in accordance with the terms and conditions of each individual permit. While the proposed rule clarifies who is required to apply for an NPDES or SDS permit, it does not change any conditions, requirements, or permitting processes for owners subject to specific permit requirements. It is reasonable to clearly state this in the proposed rules.

<u>7020.0405 Permit Requirements</u>

Subpart 1. This part of the proposed rule establishes the types of permits that will be issued by the agency; some of these permits will also be issued by delegated counties. This part also establishes which type of permit for which owners of animal feedlots or manure storage areas that are in certain categories must apply. This part also identifies the owners of certain animal feedlots, manure storage areas and pastures that are not required to apply for a permit and the processes to be followed when ownership of a permitted facility changes.

There are four type of permits that will be issued by delegated counties and/or the agency. These are: National Pollution Discharge Elimination System (NPDES) permits, State Disposal System (SDS) permits, construction short-form permits, and interim permits. As stated above, the proposed rules are intended to require permits for only those owners of animal feedlots or manure storage areas that:

- Are required to obtain a permit under federal requirements;
- Have 1000 animal units or more and are not required to obtain a permit under the federal requirements;
- Are designated a pollution hazard;
- Are proposing to construct or expand and are of sufficient size so as to have a significant potential to be objectionable to local residents; and/or
- Are proposing a construction or operating methods that are unique and need further evaluation from the agency.

Item A. This item states that an owner shall apply for a NPDES permit if the facility meets the criteria for a Concentrated Animal Feeding Operation (CAFO). The Minnesota statutory amendment states that animal feedlots with 1,000 animal units or more must apply for and obtain an NPDES permit. The requirement to obtain an NPDES permit for all animal feedlots with more than 1,000 animal units as written in the federal regulations is an issue undergoing further review by the EPA.. Some argue that the requirement to obtain a NPDES permit applies only to those with more than 1,000 animal units that also discharge or have discharged. The focus of EPA's further review is to clarify which facilities having 1000 animal units or more have the potential to discharge and are therefore required to obtain a NPDES permit. Minn. Stat. § 116.07, subd. 7c, clarifies what facilities must obtain an NPDES permit, at least for Minnesota. Any animal feedlot with 1,000 or more animal units is required to apply for and obtain a NPDES permit. Therefore, it is reasonable to propose that the owner of any animal feedlot that meets the definition of CAFO must apply for an NPDES permit.

The proposed rules also state that manure storage areas that meet the definition of CAFO must apply for a NPDES permit. The US EPA, Office of Waste Management stated in Guidance Manual and Example NPDES Permit for Concentrated Animal Feeding Operations, Review Draft, August 6, 1999. See Exhibit P-2. "The NPDES permit regulations [40 CFR 122.23(b)(1)] give the permitting authority (EPA or NPDES-authorized States) considerable discretion in applying the AFO definition. EPA defines the AFO to include the confinement area and the storage and handling areas necessary to support the operation (e.g., waste storage areas)." It is reasonable to include manure storage areas in the category required to apply for a NPDES permit since the pollution threat at a facility is associated with the manure produced or stored at a facility and not solely by the animals themselves.

Finally, it should be noted here that all NPDES permits issued by the agency for animal feedlots and manure storage areas will be a combination NPDES/SDS permit. This is consistent with the agency's current practice for feedlot NPDES permits and is needed and reasonable to allow the agency to address issue outside the regulatory framework of the federal regulations which address only surface water issues. Some of the specific issues that the agency has addressed under SDS and NPDES/SDS permits are described in more detail in this SONAR under subpart 1, item B, subitem 1. The agency is also currently working on a draft general NPDES/SDS permit that may apply to the majority of CAFOs in the state.

Subitem 1. This subitem states that an owner shall apply for a SDS permit if the facility has the capacity to hold 1,000 or more animal units or the manure produced by 1000 or more animal units and is not a CAFO. As stated in the statement of reasonableness for 7020.0405, subp. 1, the federal requirement under 40 CFR 122.23 for all animal feedlots with more than 1,000 animal units is under further review and discussion. It is anticipated that at some point in time, the federal requirement for all animal feedlots with more than 1,000 animal units will be legally challenged. If the legal challenge is successful and the federal requirement then becomes that only facilities that have had a discharge or are currently discharging are required to obtain an NPDES permit, the agency will have the SDS permit to issue to these facilities. This is consistent with Minn. Stat. § 116.07, subd. 7c, and the agency's policy that any animal feedlot or manure storage area with 1,000 or more animal units must apply for and obtain an operating permit. If the proposed rule did not include the requirement included in this subitem, these facilities would not be required to obtain any state or federal feedlot permit.

In addition, the agency intends to use the SDS permit as it has under the current program to address program issues which the federal regulations do not cover under an NPDES permit program. These include:

- Potential impacts to ground water from owners of animal feedlots and manure storage areas operations, manure storage areas and land application activities. The agency currently issues SDS permits for other large industrial and municipal waste facilities to protect ground water from waste storage and land application;
- Air quality issues such as odor and air emissions. The agency has included provisions for addressing air quality issues in SDS and interim permits under the current program. In addition, the proposed rule requires owners having 1000 animal units or more to develop and implement an air emissions plan (part 7020.0505, subp. 4, item B, subitem 1.
- Need to provide an opportunity for public notice and feedback on facilities having a comparable animal unit size and potential to impact neighbors. The opportunity for public input should not be limited to surface water issues like the federal NPDES permit program.
- Incorporation of site or facility-specific provisions into the permit to address mitigation measures in an environmental impact statement or to obtain a negative declaration in an environmental assessment worksheet (EAW). Following the Environmental Quality Board’s recent revisions to Minn. R. ch. 4410. More feedlot facilities will likely undergo environmental review in the future and therefore more facilities may need site specific conditions incorporated into their permit.

The agency may also realize some reduction in administrative burden if a large number of facilities having 1000 animal units or more attempt to demonstrate that they are not a CAFO and request that they do not need a NPDES permit. The SDS permit process (general or individual) may save significant staff review time on these requests and minimize contested case requests by having essentially the same requirements as the NPDES/SDS permit. Finally, since the pollution threat at a facility having 1000 animal units or more is primarily associated with the pollutants in the manure produced or stored at a facility, no measurable distinction between the potential for pollution from these facilities and CAFOs exist. For these reasons, it is reasonable to require any animal feedlot or manure storage area with 1,000 or more animal units that has been determine to not be a CAFO to apply for a SDS permit.

Subitem 2. This proposed subitem requires that any facility that has been determined to be a pollution hazard that can not be, or has not been, corrected under an interim permit to apply for a SDS permit. This is one possible course of action to be taken if an owner fails to fulfill all parts of an interim permit that has been issued to correct a pollution problem. A key difference in the interim permit and SDS permit for addressing pollution problems is that the SDS permit is placed on public notice and is subject to public comment. If the problem is such that it cannot be resolved in the 24-month period allowed under the proposed interim permit, it is significant enough that the interested parties should have the right to be informed of the action and given the opportunity to comment on the problem and proposed solution. Another course of action for the agency could be to proceed with an enforcement action. The course of action taken will depend upon several factors including the apparent level of effort that the owner made to comply with the permit conditions. For these reasons, the proposed requirements of this subitem are reasonable.

Subitem 3. This proposed subitem requires the owner that is proposing an alternative construction or operating method other than those established in the technical standards to apply for a SDS permit. This proposed subitem also requires the owner to hold a SDS permit for alternative operational methods as long as those operational methods are employed. As discussed in the Section IV(A), *Reasonableness as a Whole*, one reason for incorporating the technical standards into the proposed rules is to reduce or eliminate the need for issuing permits to some facilities. The technical standards are the minimum location, construction and operating requirements for animal feedlots, manure storage areas and pastures to minimize the environmental impact of these facilities. It is not the intent of the agency to limit the construction and operating methods that have been developed or may be developed in the future that achieve the same environmental goals. For this reason, it is reasonable to allow an owner to use those methods that the owner can demonstrate to the commissioner that the proposed method is at least as protective of the environment. Since the methods that will be proposed by the owner will be different from what the agency has thoroughly reviewed and are incorporated in this proposed rule, it is reasonable to require the owner to apply for a permit in which the proposed project undergoes a more thorough review by agency staff and is placed on public notice and subject to public comment. This process is different form the variance process provided under part 7020.0505, subp. 6, which presents and opportunity for owners to avoid hardship by proposing construction or operational methods that are less protective than the technical standards in this rule.

This subitem does not allow an owner to obtain a SDS permit as an alternative to the locational requirements in parts 7020.2000 to 7020.2225. These requirements, such as setback distances, locating in shoreland, a floodplain, proximity to sinkholes and separation distance to bedrock, etc., are not intended to be exempted or varied by the requirement for an SDS permit. Since there is nothing that can achieve an equivalent environmental result as not locating in an environmentally sensitive area or area in which a failure of a system (e.g., liquid manure storage area located over shallow bedrock) can quickly and significantly damage the state's water resources, it is reasonable to exclude the locational requirements from these provisions, and restrict application of this subitem only to construction and operating methods.

Subitem 4. This proposed subitem requires the owner that is proposing to construct or expand an animal feedlot or manure storage area for which conditions other than those established in the technical standards were assumed: such as a mitigation measure in an environmental impact statement or in obtaining a negative declaration in an environmental assessment worksheet must apply for a SDS permit unless required to apply for a NPDES permit. As discussed below in this SONAR for parts 7020.0505 and 7020.0535, the proposed construction short-form and interim permits are not subject to the public notice and comment require as are NPDES and SDS permits. Interim permits under the current rules are not subject to the public notice and comment requirements. The reason for excluding construction short-form permits from the public notice and comment requirements is primarily to streamline the permitting process. This is reasonable because essentially all conditions that will be placed into a construction short-form permit are included in the rule and will, therefore, be open to public comment during this rulemaking. Since a construction short-form or interim permit is issued in accordance with Minn. R. ch. 7001 and 7020, these permits are subject to the provisions under which an interested party can request a contested case hearing over the issuance of the permit; this protects an interested person's ability to participate in the permitting of that facility. However, construction short-form and interim permits are not required to be noticed as broadly as SDS and NPDES permit actions. For example, NPDES and SDS permits are noticed, while construction short-form and interim permits are not required to be noticed. If an environmental impact statement or an environmental assessment worksheet negative declaration requires measures that are something other than what is required under the proposed rules, all interested parties should have an opportunity to be notified of the measures and have the opportunity to provide comments. The NPDES and SDS permit processes provide these opportunities: construction short-form and interim permits do not. For this reason, the proposed subitem is reasonable.

Item C. This proposed item requires the owner of a animal feedlot, manure storage area or pasture that has been determined to be a pollution hazard to apply for an interim permit unless the owner is required to apply for a SDS or NPDES permit. This is the same function as the Interim B permits have under the current rule.

Item D. This proposed item requires the owner of a animal feedlot or manure storage area with 300 to 999 animal units that is proposing to construct or expand in accordance with the proposed technical standards to apply for a construction short form permit unless the owner is required to apply for a SDS or NPDES permit. This is the similar to the function the Interim A permits issued under the current rule. A primary difference between Interim A and construction short-form permits is that the owner issued a construction short-form permit is constrained to only those location, construction and operating methods established in the technical standards and no such constraints exist under the current Interim A permits. For purposes of public participation and informing interested parties, it is reasonable to clearly limit the application of the construction short form permit to activities specified in the technical standards. This proposed item also states that owners that have been determined to be a pollution hazard must apply for an interim permit even if the owner is planning an expansion. This is reasonable because a condition of interim permits is that no expansion can be stocked with animals prior to correction of the pollution hazard.

Subpart 2. This proposed subpart states that no owner that is required to apply for a permit under these proposed rules may expand prior to obtaining that permit. Expansion, as defined in 7020.0300, subp. 11a states that expansion "means construction or any activity that has resulted or may result in an increase in animal units at an animal feedlot or an increase in storage capacity of a manure storage area that is not located at an animal feedlot." This means increasing the capacity of the facility to hold animals or animal manure; not merely increasing the number of animals at the facility, which may fluctuate significantly over time. In addition to expansions, this provision includes construction of a new animal feedlot or new manure storage area where none previously existed. This subpart is intended to state as clearly as possible that if a permit is required, it must be obtained prior to beginning the construction associated with the expansion. It is reasonable to require the owner to obtain the permit prior to construction or expansion because the owner may be required to submit additional information for agency or delegated county review necessary to determine compliance with applicable rules. This is also reasonable because until the permit is issued, the public retains the opportunity to request, for example, a contested case. If this occurs, it is in all parties best interest that construction not commence until the contested issues are resolved.

This subpart also states that stocking an expansion at an animal feedlot, manure storage area or pasture that has been determined to be a pollution hazard is prohibited until the pollution hazard has been completely corrected. This is needed to ensure that the existing problems are resolved prior to creating the potential for additional manure-related pollution problems. If left unresolved prior to expansion, the expansion may or likely would exacerbate the problem. The agency is taking a preventative approach by ensuring proper operation prior to creating a greater potential for manure-related problems. This is an effective and reasonable means of ensuring that pollution hazards are corrected.

Subpart 3. This subpart identifies the owners that are not required to apply for a permit under these parts. Item A states that no permit is required for facilities meeting the requirements of part 7020.2003, subparts 4 to 6. More specifically this applies to feedlots if the facility:

- Has fewer than 300 animal units;
- Has runoff from at least one open lot and the facility is not a CAFO or maintain an imminent threat to humans or the environment;
- Is not a new animal feedlot;
- Owner has registered with the agency or delegated county; and
- Owner has agreed to the compliance schedule for achieving compliance with part 7050.0215 for all open lots at the facility.

This item is intended to clearly state that the estimated 8,000 to 12,000 animal feedlots in Minnesota that are under 300 animal units with open lot runoff are not required to apply for a permit provided they comply with part 7020.2003, subparts 4 to 6. As discussed in Section IV(A), Reasonableness as a Whole, the most efficient means to deal with a large number of regulated facilities such as this is through rules rather than issue individual permits to each of them. All eligible animal feedlots are, by definition, similar and therefore, it is reasonable to regulate them similarly and in fact as a unit. The proposed rules do this and as such permits for each of these facilities are unnecessary. Given the large number of small animal feedlots with open lot runoff, it is reasonable to regulate them in the most efficient means available and therefore to not require the owners of this large, but narrowly defined group, to apply for permits.

Items B and C. These proposed provisions state that no permit is required if: the facility in question is a pasture that that has not been identified as a pollution hazard; or the facility in question is only a short-term stockpile site that is not owned by an owner of an animal feedlot or manure storage area. Both pastures and short-term stock piling sites are subject to the technical standards. If the person responsible for the site complies with these requirements of the technical standards, the risk of ground or surface water contamination is small. If the technical standards are not complied with, the site can be determined to be a pollution hazard and a permit is then required. Enforcement action is also an option available to the agency or delegated county. Since these present a reduced threat to the environment, it is reasonable to not require the owner to apply for a permit.

Subpart 4. This proposed subpart establishes the procedures to be followed by owners when a feedlot or manure storage area is sold or otherwise goes through a change in ownership. Under item A, this subpart states that owners holding an NPDES or SDS permit must submit a complete application for permit modification. This is reasonable because it is required under the existing feedlot rules and is therefore consistent with current practice.

Under item B, the proposed rule requires the owner to submit the change in ownership information on a form provided by the commissioner. This is intended to provide a simplified process and to minimize administrative burden on owners of facilities and on the agency and delegated counties by reducing the processing of permit applications. This is reasonable because it is an area that has not resulted in significant environmental protection or improvement under the current program and will allow all parties to focus more on actual pollution prevention and reduction activities. .

7020.0505 Permit Application and Processing Procedures

This part of the proposed rule establishes the minimum requirements for all permit applications for animal feedlots, manure storage areas and pastures and identifies the processing requirements for those permit applications.

Subpart 1. In subpart 1, the agency proposes that only complete permit applications will be processed by the permitting authority (i.e., delegated counties or the agency). Subpart 4 of this part establishes the minimum content requirements of an application. Subpart 4 contains the permit application content requirements for documentation that the owner has notified local governing bodies (required for any construction under part 7020.2000, subp. 5) and local residents (required for the construction or expansion of any animal feedlot or manure storage area larger than 500 animal units under part 7020.2000, subp. 4). These two notification requirements are needed to ensure local awareness of projects that may affect them. Minn. Stat. § 116.07, subd. 7a, requires neighbor notification of proposed construction or expansion of facilities with 500 or more animal units. The proposed notification required under part 7020.2000, subp. 4 is intended to meet that statutory requirement. Further discussion of the details of these notifications is in the Statement of Reasonableness for part 7020.2000, subparts 4 and 5. Since many of the issues regarding the permitting of animal feedlots, manure storage areas and pastures are directly related to land use and the proximity of these facilities to local residents, it is reasonable to ensure that local residents and governing bodies are aware of a project.

Staff experience suggests that owners often fail to notify local residents and governing bodies of plans to construct or expand an animal feedlot or manure storage area. If the permit application process requires the owner to submit evidence of complying with the required notifications and the permitting authority does not act on incomplete permit applications, the owner has a greater incentive to comply with these requirements. For this reason, it is reasonable to not act on permits that are incomplete.

Item A. This item states that all SDS and NPDES permit application must be submitted to the commissioner with a copy going to the county feedlot pollution control officer. Since the agency is not allowed to further delegate the processing of NPDES permits to delegated counties and the administrative and logistical problems of delegating counties to issue SDS permits is too great at this time, these applications must be processed by the agency. The option to allow delegated counties the ability to issue SDS permits was considered and rejected due to the fact that the county processes for issuing these permits would have to be equivalent to the agency processes including all the public notice and hearing requirements. It was staff's opinion that very few counties have the resources and abilities to undertake this process for more than a small number of facilities. For these reasons, it is reasonable for the proposed rules to require all SDS and NPDES permit applications to be submitted to the commissioner for processing with copies going to counties so the county feedlot pollution control officer is aware of proposed activities. It is also reasonable to require owners to submit a copy of the permit application to the delegated county because the local feedlot officer can likely better assist the owner in completing the necessary application requirements and provision insight to local issues that may affect the proposed project. The agency foresees that owners could submit the application directly to the delegated county and the county feedlot officer would them forward the application to agency with comments and recommendations. This process is essential to the coordinated effort between the agency and delegated counties.

Item B. This item states that Interim and construction short-form permit applications may be submitted to the commissioner or county feedlot pollution control officer at the owners discretion. The current rule also allows owners to submit applications for interim permits to the commissioner or county feedlot pollution control officer, at his/her discretion. As stated in Section IV, Reasonableness as a Whole, a goal of the proposed rule is to streamline the permitting process and to shorten the time that is needed to issue a permit. The proposed construction short-form permit is intended to do this. One means of shortening the time to issue a permit is to allow counties to issue them. Counties have, in the past been able to issue interim permits much more quickly than the agency in most cases. For these reasons, it is reasonable for the proposed rule to allow construction short-form and interim permit applications to be sent to the commissioner or county feedlot pollution control officer at the owners discretion.

Subpart 2. This subpart establishes the schedules and timelines for submitting a permit application. Item A establishes the schedule by which the owners of CAFOs and animal feedlots or manure storage areas with 1,000 or more animal units must submit an application. Minn. Stat. § 116.07, subd. 7c(a)(3), provides "after January 1, 2001, all existing feedlots with 1,000 or more animal units must be issued an individual or general National Pollutant Discharge Elimination System permit." Considering the magnitude of the effort that will be required to accomplish processing permits for this group by January 1, 2001, the application deadline of June 1, 2000, is reasonable.

Item B. This item establishes the timeline by which the owners of animal feedlots, manure storage areas and pastures that have been determined by the commissioner to be a CAFO in accordance with EPA guidelines and agency policy, October 12, 1999, memorandum from G.

Pulford to G. Wegwart) must submit permit applications. The proposed rule requires the owner to submit the application within 30 days of a written order of the commissioner. See Exhibit P-3.

The agency anticipates that when an animal feedlot, manure storage area or pasture has been determined be a significant pollution source, it will attempt to seek the owner's cooperation to obtain a timely resolution and elimination of the pollution problem. This process may include issuance of an interim permit, which is the tool most frequently used by the agency if the matter can be resolved within a short time period. The process could also include the use of other tools such as notice of violation or, if necessary, escalating enforcement tools such as an administrative penalty order. In any case, a variety of tools are available and one such tool is the NPDES permit if the facility is designated a CAFO. If the designation process is used, the MPCA staff will contact the owner and conduct an on-site inspection. During the inspection, MPCA staff will be able to apprise the owner of the issues of concern. As early as that time, the owner can begin anticipating corrective actions and planning for them. At the end of the designation process, the MPCA will notify the owner of the decision and, from that point, the owner will have a minimum of 30 days to submit the appropriate application. With the advance contacts with the MPCA and the intervening time period between the inspection and the MPCA's decision, 30 days after the MPCA's notice should be sufficient time to collect the required information and prepare and submit the application. MPCA also needs to balance the fact that the facility is a significant pollution source and timely resolution is needed. For these reasons, it is reasonable to require the submittal within 30 days of the notice of the MPCA's CAFO determination.

Item C. This item establishes the timeline under which an application for a new animal feedlot or manure storage area that is required to apply for a SDS or NPDES permit must be submitted. This proposed item requires submittal 180 days prior to the planned date of commencement of construction. This timeline is intended to allow enough time for the agency and owner to address all issues so the permitting process does not result in a delay of the commencement of construction. It is reasonable to attempt to minimize any construction delays caused by the permitting process.

Item D. This item establishes the timeline under which an application for a new animal feedlot or manure storage area that is required to apply for a construction short-form permit must be submitted. This proposed item requires submittal 90 days prior to the planned date of commencement of construction. Since construction short-form permits will be able to be issued much quicker than SDS or NPDES permits, it is believed that 90 days will be sufficient time for processing. This timeline is intended to allow enough time for the agency and owner to address all issues so the permitting process does not result in a delay of the commencement of construction. It is reasonable to attempt to minimize any construction delays caused by the permitting process.

Item E. This item establishes the timeline under which an owner of an animal feedlot, manure storage area or pasture that has been determined to be a pollution hazard must submit an application. As discussed in the Statement of Reasonableness, the definition of "pollution hazard," covers numerous fact situations. These situations can range from a facility with a small and infrequent amount of runoff from an open lot that needs to be addressed but is not an immediate threat to an incorrectly installed liquid manure storage area that discharges large amounts continuously and therefore must be addressed immediately. The proposed rule requires the owner to submit an application for an interim permit as required by the commissioner or county feedlot pollution control officer but the owner has at least 15 days after receiving a written request to submit the permit application. Staff estimate that fifteen days is the minimum amount of time needed to produce a complete application. Since there is a wide a range of conditions that could be designated as a pollution hazard, and the need to submit an application should be adjusted to reflect the immediacy of the problem, it is reasonable to allow the commissioner or county feedlot pollution control officer flexibility to adjust that timeline to fit the specific facts of each situation.

Subpart 3. The agency proposes that applications must be submitted on a form provided by the commissioner. For reasons of consistency and ease of processing, it is reasonable to require applications to be submitted on a standard form.

Subpart 4. The agency, through subpart 4, establishes the minimum contents of a permit application. Item A establishes the minimum information that is required of all facilities applying for any permit. The information required is the minimum information upon which a reasonable, considered permitting decision can be based. The majority of the information contained under this item is required under the current rule under part 7020.0500, subp. 2. Subitems 1, 3, 4, 5, 7, 8, 9, and 12 are restatements and clarifications of the requirements of the current part 7020.0500, subp. 2.

Subitem 2 requires the applicant to state the legal name and address of the business if it is different than that of the information required in subitem 1. Since businesses can have complex ownership arrangements, the owner(s) are not always on-site resident owners and all owners are ultimately responsible for the facility’s compliance, it is reasonable to require this information in any permit application.

Subitem 6. Subitem 6 contains the agency's proposal for implementation of the other rule provisions. requires a list of all existing and proposed manure storage areas including all existing and proposed liquid manure storage areas and permanent stockpile sites and plans for proposed liquid manure storage areas. The current rule requires plans for liquid manure storage areas larger than 500,000 gallons. As discussed in the Statement of Need, the environmental impact of manure can be significant. Failure of a liquid manure storage area has the potential to make local waters unfit for consumption and/or unable to support fish. For this reason, it is reasonable to require the identification of all storage areas including all liquid manure storage area and permanent stockpile site plans with an application.

Subitem 10. Subitem 10 contains the agency's proposal that owners subject to the requirement to apply for a NPDES or SDS permit must include manure management plans with the application. The current rule requires all applications to include a manure management plan. Animal feedlots and manure storage areas that are required to apply for a NPDES or SDS permit are large facilities that generate a large quantity of manure. These are the facilities that could have the greatest difficulty finding enough acreage on which to apply the manure and the impact of misapplying a large quantity of manure can be significantly greater that the quantity of manure generated from a small facility. In an effort to streamline the permitting process and to require no more paper from applicants that what is needed and will be reviewed by the permitting authority, the proposed rules excluded construction short-form and interim permits from the requirement to submit the manure management plan with the application. The proposed rules still allow the permitting authority to require the owner to submit the manure management plan with the application under subitem 12. The proposed rules (part 7020.2225, subp. 4) also require all animal feedlots and manure storage areas with more than 100 animal units to prepare and maintain a manure management plan. For these reasons, it is reasonable to require only those owners that are required to apply for a NPDES or SDS permit to submit this plan with an application.

Subitem 13. The agency proposes in subitem 13 to require owners that are required to obtain a NPDES permit to submit the additional form by US EPA for NPDES permit applications, NPDES form 2B. See Exhibit P-7. In an effort to streamline the proposed rule and permitting structure, the agency anticipates having a single application form for NPDES, SDS, construction short-form, and interim permits and the federal form only applies to NPDES permit applications. This will allow owners to complete only one form for any permit except the combined NPDES/SDS permit. Staff believes that this will be less confusing for the owners. For these reasons, the proposed subitem is reasonable.

Item B. Item B, as proposed contains, additional permit application content requirements for animal feedlots or manure storage areas that are capable of holding 1,000 or more animal units. These facilities are very large facilities that are often the most controversial and present unique issues due to the size of the facility. Therefore, it is reasonable to establish additional application requirements for these facilities.

Subitem 1. Under subitem 1, the agency proposes that applications from facilities having 1000 or more animal units contain an air emissions plan for the control and abatement of air emissions. This plan must include a description of methods and practices that will minimize air emissions from the animal feedlot and a description of measure to mitigate air emissions if an exceedance of the State ambient air quality standard for hydrogen sulfide is measured. As discussed in the Statement of Need, gaseous emissions from manure can affect human health at high concentrations including: nausea, headaches, eye irritation, throat and respiratory irritation vomiting, shallow breathing, modified olfactory function, coughing, sleep disturbances and loss of appetite. Air emissions from animal feedlots and manure storage areas is a serious matter that the agency has been attempting to address in recent years and continues to address through research and air quality monitoring. Research has primarily focused on control of hydrogen sulfide. However, according to the agency's Feedlot Air Quality Summary: Data Collection, Enforcement, and Program Development (MPCA Air Quality Feedlot Work Group, March 1999) (Exhibit G-3), "Researchers have indicated that the chemistry of feedlot odor may contain 168 separate chemical substances." This report made the following recommendations:

- Further research is needed in the following areas:
  - to identify which factors may affect the animal unit/hydrogen sulfide ambient air concentration relationship.
  - to determine if a relationship between hydrogen sulfide/odor emissions and animal species exists.
  - to identify which animal housing and ventilation styles affect hydrogen sulfide and odor emissions.
  - to determine if atmospheric emissions of ammonia need to be regulated in Minnesota.
- MPCA field staff need a more effective method of screening for ammonia emissions in the field.
- The MPCA, Counties, and producers need further research into the effectiveness, management and cost of mitigation methods for hydrogen sulfide and odors.

The Minnesota Office of the Legislative Auditor Animal Feedlot Regulation report, January 28, 1999. See Exhibit G-1. The Legislative Auditor's Report made comments similar to the above-cited recommendations. Indicating that more research is needed in the area of effective control of air emissions from animal feedlots and manure storage areas. Given that the methods to control air emissions from these facilities is still being researched, it is reasonable to not establish specific control and abatement measures in the proposed rule. Since odors and air emissions from these facilities are significant issues, it is reasonable to require owners address these issues proactively in their permit application.

Subitem 2. The agency proposes that an additional plan for preventing pollution by eliminating or reducing toxic pollutants, hazardous substances and hazardous wastes at feedlots. Pollution prevention is the least costly and most environmentally advantageous method for dealing with pollution. A well-followed pollution prevention plan will save money, reduce liability and prevent contamination of our precious natural resources. An “audit” of what chemicals or wastes are presently purchased or on location at the feedlot is the first course of action. Next, the owner should legally dispose of all hazardous wastes and purchase less toxic alternatives in the future. The Department of Agriculture has a toll free number (1-800-657-3986) which farmers can call to find out where and how to dispose of pesticides. Call the toll free number to also receive brochures on pesticide disposal. Antifreeze and used oil, according to state law, can either be returned to dealers who sold antifreeze or oil or the dealer must inform the customer who to contact for disposal. Household hazardous wastes (oven cleaners, nail polish remover, etc.) can be disposed of at scheduled county household hazardous waste collections. For these reasons, this subitem is reasonable.

Subitem 3 requires that an emergency response plan that will list procedures to contain or manage any unauthorized discharge be submitted with the permit application. The plan must also state that the proper authorities will be notified and identify specific steps that will be taken to mitigate any adverse effect of an unauthorized discharge. Animal feedlots and manure storage facilities may contain many types of pollutants and chemicals that are susceptible to spills such as herbicides, fertilizers, oils, grease, silage juices, etc. An emergency response plan will assure the public and agency that if a discharge occurs, the owner will be prepared and equipped to reduce any damage to the environment. For this reason, this subitem is reasonable.

Item C requires the owner to submit evidence that the owner has complied with the local government notification requirements of part 7020.2000, subp. 5. This notification requirement is needed to ensure local awareness of projects that may be objectionable to local residents. Further discussion of the details of this notification requirement is in the Statement of Reasonableness for part 7020.2000, subp. 5. Since many of the issues regarding the permitting of animal feedlots, manure storage areas and pastures are directly related to land use and the proximity of these facilities to local residents, it is reasonable to ensure that local governing bodies are aware of a project.

Item D requires the owner to submit evidence that the owner has complied with the local resident notification of proposed construction or expansion of any animal feedlot or manure storage area larger than 500 animal units as requirements of part 7020.2000, subp. 4. These two notification requirements are needed to ensure local awareness of projects that may be objectionable to local residents. Minn. Stat. § 116.07, subd. 7a, requires neighbor notification of proposed construction or expansion of facilities with 500 or more animal units. The proposed notification required under part 7020.2000, subp. 4 is intended to fulfill that statutory requirement. Further discussion of the details of these notifications is in this SONAR for part 7020.2000, subp. 4. Since many of the issues regarding the permitting of animal feedlots, manure storage areas and pastures are directly related to land use and the proximity of these facilities to local residents, it is reasonable to ensure that local residents are aware of a project.

Item E is a restatement of the requirement under part 7020.0500, item D of the existing rule.

Subpart 5. Establishes the permit processing requirements that the permitting authority must follow. Items A and B state that NPDES and SDS permits must be issued, reissued, revoked, or modified in accordance with Minn. R. ch. 7001 and this part. Minn. R. ch. 7001 establishes the permitting requirements for all permits to be issued by the agency unless specifically stated in other rule parts (e.g., Minn. R. ch. 7007 establishes all permitting requirements for air emission permits). The current rule is silent on the fact that these NPDES and SDS permits are issued in accordance with Minn. R. ch. 7001. This has resulted in some confusion among owners regarding the permit processing requirements. This item is intended to clarify that confusion. It is reasonable to clarify the permitting process.

Item C states that construction short-form and interim permits must be processed in accordance with this rule and cites parts 7020.0505 to 7020.0535 and part 7020.1600, subp. 4. Parts 7020.0505 to 7020.0535 establish the requirements for issuing construction short-form and interim permits as applicable to the commissioner and county feedlot pollution control officer. Part 7020.1600, subp. 4 establishes the permit processing requirements specifically applicable to delegated county permit processing. Construction short and interim permits are intended to streamline the permitting process. One of the methods of streamlining the process and reducing the amount of time to issue any permit is to increase the number of government units that can issue the permit. That is one reason for proposing to allow delegated counties to issue construction short-form permits. This item states how those permits are to be processed. To make the process of issuing construction short-form and interim permits as transparent as possible, it is needed and reasonable to state in this item the process for processing these permits.

Subpart 6. This subpart is a restatement and revision of part 7020.0900 of the current rule. The revision incorporates all of the proposed technical standards, parts 7020.2000 to 7020.2225.

7020.0535 Construction Short-Form and Interim Permits

This part of the proposed rule establishes the minimum requirements for construction short-form and interim permit applications and identifies the processing requirements for those applications. Construction short-form and interim permits are not subject to the public notice and comment process to which NPDES and SDS permits are subject. As stated in the Reasonableness as a Whole, these permits are intended to streamline the permitting process and reduce the amount of time needed to process a permit application. Construction short-form permits are intended to be issued to animal feedlots and manure storage areas that are proposing to construct or expand in accordance with the technical standards of the proposed rule. These standards, parts 7020.2000 to 7020.2225, establish the locating construction and operating requirements for all animal feedlots, manure storage areas and pastures. If an owner is proposing to do something that is not included in the technical standards (e.g., constructing a permanent manure storage site out of recycled tires), the proposed rules prohibit the owner from applying for a construction short-form permit.

The intent of the proposed rules is not to limit innovation in the matters addressed by the proposed technical standards. The intent is to use the permitting authorities' resources as efficiently as possible. For these reasons, the proposed rules require facilities that that apply for a construction short-form permit to comply with the technical standards. This limits the types of construction and operating methods that any eligible facility can employ but the methods in the technical standards incorporate the most commonly used construction and operating methods. Also for these reasons, owners that propose to construct or operate an facility in a method other than those set forth in the technical standards can do so by applying for and obtaining an SDS permit issued by the agency. Seethe SONAR for part 7020.0405 for further discussion on this topic.

Subpart 1. This subpart proposes the applicability for owners of animal feedlots and manure storage areas. This part applies to the owners that are applying for a construction short-form or interim permit.

Subpart 2. Permit applications submitted prior to the effective date of this part. This subpart establishes the process for permit applications submitted prior to the effective date of this part. The proposed rules state that the application can, if the facility is eligible for a construction short-form permit, be accepted as a construction short-form application if the owner so requests. The construction short-form permit application date will be the date on which the original application was made. In order to minimize duplication of effort on the part of the owner, it is reasonable to accept these applications as construction short-form permit applications.

Subpart 3. Delegated county procedures for denial and revocation. Item A establishes the procedures for denial of a construction short-form or interim permit. The procedures (as set forth in part 7001) are the same as those under the current rule for the denial of an interim permit. Given the similarity between the proposed construction short-form and the interim A permits that are issued under the current rule, it is reasonable to follow these same procedures for construction short-form permits. This item also states that the owner has the same rights of fundamental fairness as afforded other permits issued by the agency. This statement is made for the purpose of clarity.

Item B establishes the procedures for revocation of a construction short-form or interim permit. The procedures are the same as those under the current rule for the revocation of an interim permit with the exception of extending the amount of time that the commissioner has to review the revocation and make a decision. The proposed rules allow 60 days for commissioner review; the current rule allows 15 days. Given the agency backlog on permitting and other actions, 15 days does not allow enough time for the commissioner to review and act on a revocation action by a delegated county. Sixty days will provide enough time. It is reasonable to allow the agency enough time to make an informed decision regarding the revocation of a permit issued by a delegated county. Given the similarity between the proposed construction short–form and the interim-A permits that are issued under the current rule, it is reasonable to follow these same procedures for construction short-form. This item also states that the owner has the same rights of fundamental fairness and appeal as afforded other permits issued by the agency. This statement is made for the purpose of clarity.

Subpart 4. This subpart states that an owner that is required to obtain a NPDES or SDS permit and obtains a construction short-form or interim permit instead shall be subject to enforcement action for construction and/or operation without a permit. Construction short-form and interim permits are not subject to the same public notice and comment requirements as are NPDES and SDS permits. The public participation aspects of these permits (NPDES and SDS) are fundamental to the rights of interested parties to be informed and to provide input on a proposed project. The public participation requirements for a NPDES permit are a requirement of the federal regulations. For these reasons, it is reasonable to place the owners of these facilities on notice that they are subject to enforcement action for constructing or operating without a proper permit.

Subpart 5. Duration of construction short form and interim permits. This subpart establishes the duration of construction short-form and interim permits. Both permit shall have a duration of 24 months. Staff experience suggests that 24 months is sufficient time to complete the vast majority of construction projects and corrective and protective measures that will be permitted under the proposed permits. The current rules set forth a duration of 10 months for interim permits. Staff experience suggests that this is not sufficient time to complete large projects. Frequently the owner issued an interim permit for 10 months requests an extension to the permit. The permitting authority then reissues the permit for another 10 months. Occasionally, the permit is reissued for a third 10-month period. It is reasonable to increase the duration for interim permits and establish the duration of construction short-form permits for a length, which will accommodate the vast majority of the projects that will be permitted under these permits.

The proposed rules also limit the amount of time, which the permitting authority can extend a construction short-form or interim permit. Construction short-form permits may be extended for one 24-month period; interim permits for 90 days. Construction short-form permits will be issued to owners that are proposing to construct or expand an animal feedlot or manure storage area with more than 299 and less than 1,000 animal units (after expansion) in accordance with the proposed technical standards. Facilities that construct or expand in compliance with the technical standards will be fairly well defined; the risk of environmental problems from these facilities is significantly reduced from those that do not comply with the technical standards. Staff experience suggests that the number facilities that will need an extension beyond the 24-month period will be very small. However the risk of environmental harm in extending the period to 48 months is believed to be insignificant. For these reasons, it is reasonable to allow construction short-form permits to be extended for one 24-month period.

Under the proposed rules, interim permits will be issued to only those facilities that have been determined to be a pollution hazard. The definition of pollution hazard includes: 1) a facility that does not comply with the technical standards (parts 7020.2000 to 7020.2225) and was not issued a SDS or NPDES permit establishing an alternative construction or operating method; or 2) a facility that presents a potential or immediate source of pollution to waters of the state. By definition, the problems identified that cause a facility to be defined as a pollution hazard must be corrected. Some must be corrected in a very short time frame (e.g., a failed liquid manure storage area that is discharging significant quantities of manure directly to a water body) and others can be corrected over a slightly longer time frame (e.g., a poorly designed or constructed clean water diversion system that allows clean water to wash over an open lot during heavy rainfall periods). The intent of the proposed use of the interim permit is to provide a cooperative method by which the commissioner of county feedlot pollution control officer can get a pollution problem addressed quickly. If the pollution hazard cannot be corrected in a 24-month period and 90 day extension, the correction of that problem should be addressed at a higher level; either through an enforcement action or a permitting process that includes more public participation such as a SDS permit. The agency has a great interest in ensuring that identified pollution problems are corrected in a timely manner. For these reasons, it is reasonable to allow only one 90 extension to the proposed interim permits.

The proposed rules require the owner to notify the commissioner or county feedlot pollution control officer at least 90 days prior to the expiration of the construction short-form or interim permit. This will allow the permitting authority time to review the need for an extension and to determine what course of action is appropriate. This is especially important for interim permits since these permits will only be issued to correct a pollution hazard. The notification requires the owner to include permit and facility identification information, the reason for not completing the work, and the estimated timeline for completion. This is the minimum amount of information needed to make an informed decision regarding the permit authority’s course of action. In addition to the information described, any feedlot that is subject to the neighbor notification required under part 7020.2000, subp. 4, those with 500 animal units after construction or expansion, must redo the required notification and provide evidence of having done so. The date that the original permit was issued and the proposed completion date must also be included in the notification. The proposed re-notification is intended to keep local residents informed. If, at the outset, the owner knows that the project will take longer than 24 months to complete, the owner should apply for a SDS permit for the proposed construction. Under the SDS permit, only one notice is required. It is reasonable to require projects that are known to take longer than 24 months to be permitted through the public notice and comment processes of the SDS permit. This additional notification should also provide incentive to the owners to complete the projects on time or to apply for an SDS permit which provides more opportunity for public participation. For these reasons, this proposed subpart is reasonable.

Subpart 6. This subpart sets forth the content requirements for construction short-form permits issued by the agency or delegated county. As stated in the Reasonableness as a Whole, one intent of the proposed technical requirements is to allow for more streamlined permitting for construction of animal feedlots and manure storage areas. This is accomplished through the inclusion into all permits the following statement: “The permittee shall comply with Minnesota Rules, parts 7020.2000 to 7020.2225 and all applicable requirements.” This statement would replace all of the technical requirements that would otherwise have to be stated individually in each permit. The ability to include all of these conditions in a single statement significantly reduces the amount of time needed to process any single permit. The agency anticipates that construction short-form permits could be as short as one or two pages containing the above statement and the information required in items A to H.

Items A to D include all the information needed to identify the owner(s) and the facility. This information is needed and reasonable to include in a construction short-form and interim permit.

Items E to G include the information that defines the essential limits of the facility, these being the number and types of animal feedlots, the maximum number of animal units allowed at the facility, and the number and types of manure storage areas. Plans and specifications will be incorporated by reference into each permit. These will be used to determine if the facility has been changed or expanded in compliance with the rules. Part 7020.0505, subp. 4, item A, subitem 6 require plans and specifications to be included in each permit application.

Item H requires the general permit conditions of part 7001.0150, excluding item P, to be incorporated by reference into each permit. These are general conditions included in each permit issued by the agency under Minn. R. ch. 7001.

Subpart 7. This subpart establishes the additional requirements for permit content for interim permits. Items A and B set forth the requirement that each interim permit contain a description of the corrective and protective measures needed to bring the animal feedlot, manure storage area or pasture into compliance with the technical requirements and a timeline implementing those measures. This statement of the corrective and protective measures is needed to enable an inspector to determine if the facility has complied with all needed measures to correct a pollution problem. For these reasons, it is reasonable to include this statement in each interim permit. Included in the technical requirements are the applicable discharge standards. Therefore, all facilities issued an interim permit will be required to come into compliance with the discharge standards with 24 months of the issuance date of the permit.

Item C is a restatement of the requirement in the current rule under part 7020.0500, subp. 4, item B, subitem 2.

Subpart 8. This proposed subpart establishes the requirement that no owner issued an interim permit that authorizes the expansion of an animal feedlot shall stock that expansion until the pollution problem that for which the interim permit was issued is corrected. The intent of this provision is to provide an incentive for owners to correct a pollution problem as soon as possible. Given the agency's great interest in correcting all pollution problems it is reasonable to require owners correct identified pollution hazards prior to stocking expansions. This issue is also discussed in this SONAR under part 7020.0405, subp. 2.

Delegated County Program

7020.1600 Authorities and Requirements for Delegated Counties

The agency proposes to change the existing title of 7020.1600 from "County Processing Procedure for Animal Feedlot Permit Applications" to "Authorities and Requirements for Delegated Counties." The purpose of the proposed change is to accurately reflect in the title the content of this part. The current title to part 7020.1600 implies that county programs are limited to processing permit applications. This does not accurately reflect the proposed content of this chapter. It is needed and reasonable to make changes that result in accurate and clear articulation of the rules.

This part provides the administrative procedures for the agency to delegate authority to counties for the purpose of implementing the feedlot permit application process. This arrangement with the counties is known as the "County Feedlot Program." The program has continued to expand since the 1978 rule allowing this state-local government arrangement was adopted. Today, 51 counties are delegated to administer the state feedlot program on behalf of the agency.

There are benefits resulting from administering programs at a local level. The feedlot owners may receive a more timely response on permit issuance, more accessibility and quicker answers to regulatory questions and a greater understanding by the regulator of the owner's concerns with local feedlot issues. A county program draws on natural strengths of local commitment by all constituents.

The agency supports the growth of the county role in feedlot regulation. The approach of having more permitting done at the local level has been successful. Several counties have permitted nearly all of their feedlots; other counties are doing more than 100 feedlot inspections annually. See Exhibit C-1.

The legislature has also supported the growth of the role of local governments in permitting feedlots. Beginning in 1995, the legislature appropriated funds to support the program. As of

1999, counties with delegated feedlot permitting programs may be eligible to receive up to $80 per feedlot annually for administering the program, an increase of $55 per feedlot since 1995.

To promote administration of the feedlot permit program at the local level, the agency needs to modify and expand the present rules governing the delegation of authority to administer the feedlot permit program. The needed changes include expanding the permitting authorities of the counties, increasing the emphasis on inspections, adding training requirements and increasing the level of accountability demonstrated by the county in implementing the feedlot permit program. The proposed rule changes can be broken down into the following set of responsibilities and authorities.

- Implement feedlot registration requirements;
- Process permit applications and issue construction short-form permits for new or expanding feedlots with 301 – 999 animal units;
- Process permit applications and issue interim permits for feedlots with 50 – 999 animal units that have been determined to be a potential pollution hazard;
- Develop and implement a comprehensive inspection program;
- Develop and implement a program for handling and tracking complaints; and
- Complete training requirements as required by the agency.

The following text discusses the principal reasons why the agency is justified in modifying the existing rules. This discussion identifies the main arguments why it is necessary and reasonable to expand county delegation authorities and, at the same time, include rules that increase the level of county accountability for satisfying the requirements of delegation.

By statute the agency is given the duty and responsibility to administer laws related to control of pollution and protection of the environment. The agency is also responsible for supervision of all programs relating to pollution and protection of the environment. Since the legislature has chosen to use the county as a means of administering feedlot regulatory responsibilities, the agency must have mechanisms in place to ensure that the counties are satisfactorily performing the necessary regulatory functions.

One of the agency strategies for the regulation of feedlots under the proposed rules is to emphasize more inspections and “field presence” than was the strategy 20 years ago. Because the agency relies on the county feedlot program to administer the feedlot rules, the agency is requiring the counties to have the same emphasis. Therefore, it is needed and reasonable that these requirements be explicitly identified in the rules.

Essentially, the revised rules do not impose new requirements upon the county. It clarifies inherent duties that are already there. Efforts to track and locate feedlots (i.e., registration), inspections, follow-up on complaints are duties and tasks that would occur in the normal course of administering an animal feedlot permit processing program. The agency recognizes that the existing language in statute and rules seems to limit the scope of duties for delegated county programs to permit processing-related duties. For example much of the language Minn. Stat. § 116.07, subp. 7, is framed in terms of “processing applications for permits.” The agency interpretation of this language is that, while it describes a particular model of the delegation program, it was not intended to limit the range of duties that could be designed into the program. Rather, the original delegation language took on this part because, when the delegation program was first initiated, it was for a feedlot regulatory program that relied most on permitting. The agency's view is that the dominating principle in establishing the delegated program is that counties be given a choice of whether or not they wanted to participate in administering feedlot regulations. Counties have the freedom to choose the program; it is not mandated. Within this context of choice, the terms and conditions of the agreement should be allowed to change provided they are in the best interest of establishing an effective program. As discussed in this SONAR under subpart 3 of this part, the revisions of the rules on delegation are being proposed because they are needed for an effective program.

The revisions provide more clarity and specificity to the rule. With increased clarity and specificity, counties will have more knowledge and a better understanding of their roles, therefore enhancing compliance with the rules.

The revisions take into account the changes and growth that has occurred to the county feedlot program since feedlot concerns became a major public issue in the early 1990s and since the onset of the feedlot grant program in 1995. Due to these two factors, the agency and the counties have worked together to increase the strength and capability of the county program. Counties have greatly expanded their regulatory efforts and the agency has taken steps to add more training, support and oversight to the county program. The growth and strengthening of the county feedlot program is evidenced by development of a guidance document on the role and responsibilities of a county feedlot officer in 1996. See Exhibit C-2. Then in 1998, a team of agency staff and county representatives met to develop an even more comprehensive document addressing all components of the delegation agreement between the county and the agency. See Exhibit C-3. This policy was a joint effort of the counties and the agency. By incorporating these and other policy developments into the revised rules, the agency is providing reliability and predictability for county feedlot programs to meet regulatory requirements.

The agency has designed the proposed changes to provide flexibility to the counties. Therefore, while the general level of obligations and requirements for the county is increasing, the proposed rules are devised to give the counties freedom to meet the requirements according to their individual circumstances. The flexibility begins from the start of a county's application for delegation. Counties, in a contract called a delegation agreement, create a program designed to fit the unique circumstances of their county. This agreement is then reviewed and negotiated with the agency on an annual basis. Through the partnership approach, flexibility is incorporated into the terms and conditions that make up the delegation agreement.

During rule-revision development, concerns were raised that these rule changes would result in increased costs for the delegated counties. The cost for a county to administer the county feedlot program has grown as the agency has continued to raise performance requirements for counties with delegated programs. However, financial support to the counties has also steadily increased. In 2000, most counties will receive more than twice the amount per feedlot as they did in 1995. See Exhibit C-4. Also, at least eight counties are presently meeting all core elements related to permit processing, including compliance follow-up and routine inspections. This is one indicator that the match between delegated county responsibilities and funding is adequate.

Subpart 1. The existing language of subpart 1 describes the steps that are required for a county to receive delegation. To improve the understanding of the rules on delegation, the agency proposes to rewrite the existing subpart so that it identifies all the major components of the delegation process. These parts are county board resolution, commissioner authorization, a signed delegation agreement, periodic delegation agreement review, and delegation withdrawal/revocation.

The resulting changes to the provisions of the existing subpart are discussed individually below. The title of subpart 1 has been changed from "duties of the county board" to "scope" to more accurately reflect the content of this subpart.

Item A of the existing rules requires that, as part of the delegation process, the county board must submit a resolution and, along with it, a statement describing the county's plan for processing permits. The agency proposes to move the part of the provision that requires submittal of a permit processing plan and to subpart 3, item B where all delegation application requirements are located. For order and clarity it is reasonable to group requirements of a common type together.

Item B. For clarity the agency has restated the existing language of this provision.

Item C. For order and clarity, the agency proposes a reordering of item C. The agency proposes to move the existing provisions of item C to subpart 2. The agency proposes to use item C to set forth the requirement that the delegation process must contain an agreement that is signed by the county board and the agency. The provision identifies this agreement as a "delegation agreement." The delegation agreement is a document that contains the county plans, procedures and goals for implementing the feedlot permit rule. Criteria for developing this document is provided in the proposed rule under subpart 3, item B.

This provision indicates one of the significant changes the agency is proposing to make to the county feedlot program. The proposed agency feedlot program that will be supported by this rule revision expands the administrative role of the county and, along with that, raises the counties' level of accountability. The delegation agreement requirement of this provision is one of the ways in which the agency proposes to incorporate greater accountability into the rules. As will be explained more fully in this SONAR for subpart 3, item B, the delegation agreement requirement means that, prior to receiving delegation, counties must present their plans, procedures and goals for accomplishing all the core duties related to administering the delegated permit program. This includes the county's plans for permitting and registration, inspections, education and assistance, and staff training.

Item D is a new provision proposed by the agency. It requires that the delegation agreement required in item C is reviewed periodically by the agency. Along with item C, this provision establishes the backbone of the agency's strategy to incorporate accountability into the delegated program. With the expanded role of the counties there must be an appropriate level of accountability. This provision requiring periodic review of the delegation agreement is a principal component to assist in achieving that goal. Therefore, for emphasis and clarity, it is appropriate that this provision be identified as one of the five main elements of the review process. The need and reasonableness regarding the periodic review requirement is provided in this SONAR to subpart 3.

Item E states that the rules on delegation contain a process by which the agency or a delegated county may terminate/withdraw from the delegation agreement. These provisions are cited in subpart 6 and subpart 7 in the existing rules and have been moved to subpart 5 and subpart 6 of the proposed rules. Because provisions for termination and withdrawal are an important consideration regarding the delegation process they have been identified in this subpart which acts as an overview of the rules on delegation.

Subpart 2. The agency proposes to reorder subpart 2 to add clarity to the general organization of the rules on delegation. The agency proposes to move the existing rule provisions on permit processing procedures from subparts 2 to 4. The agency proposes to use subpart 2 to state the requirements that must be fulfilled by a county feedlot officer of a delegated county.

Subpart 2 sets forth the specific duties and requirements that must be fulfilled by a county feedlot officer (CFO) of a delegated county. The existing rule establishes four specific duties of the CFO; the proposed rule identifies 11 specific duties. Some of the increase in this list is simply a matter of being more explicit about the duties listed in the existing rule. Other duties proposed as requirements for the CFO are totally new. These changes reflect the shift in strategy of the state feedlot program to place more responsibility and accountability at the county level. The recent Legislative Auditors Report criticized the agency for failing to conduct adequate oversight of the county feedlot programs. See Exhibit G-1. Under the proposed feedlot program counties will have more responsibilities and, therefore, accountability becomes even more important. It is reasonable for the agency to establish requirements under which the county's performance in administering the rules is at a level of effort that matches the state administration of the rules.

Item A requires the county feedlot officer to administer the feedlot program registration requirements as stated in part 7020.0350. Under part 7020.0350 all feedlots are required to register. The information obtained from registration is a fundamental need. It will be used to prioritize feedlots into basic categories of those most likely to be pollution problems. It will be used to create mailing lists needed for communication, education, technical assistance and outreach. It will be used to identify feedlot locations for inspection purposes. It will be used by policy makers to design on-going strategies. Therefore, the registration program is instrumental and needed to implement core feedlot regulatory tools.

The methods and practices used to conduct a registration program consist of tasks that are core to administering a feedlot program. This includes gathering information and conducting outreach as well as maintaining a database. These tasks are normal duties for a county feedlot officer (CFO) acting in an administrative capacity. Therefore, it is reasonable that the rule identify the duties for conducting feedlot program registration as part of the CFO's responsibilities.

Also, the registration program allows level II inventories to satisfy feedlot registration requirements. According to the records from the GEIS study, 44 counties are planning to have level II inventories completed by the year 2000. See Exhibit C-5. This fact indicates that county programs have already incorporated registration expectations as part of their program. Therefore, this provision is reasonable in that it is incorporating into the rule, regulatory policies that are already common practice.

Item B requires CFOs to conduct follow-up registration measures when feedlot owners have not registered within the required deadlines. The agency views this provision as a needed requirement to ensure effectiveness of the registration program. The value of registration is that it yields for regulators and policy makers a reliable and accurate of record of the number and location of feedlot operations in the state. Registration will not provide this product unless feedlots are registered.

The agency intends to use a variety of approaches to encourage feedlot owners to register. But, even with a well-implemented communications campaign, the agency recognizes that registration efforts will continue to be needed once the registration deadline has been past. In view of these circumstances it is needed and reasonable to incorporate into the rule a provision ensuring that CFOs will implement follow up registration measures once the registration deadline is passed.

Item C is a modification of subpart 1, item C(1), of the existing rule and it addresses CFO requirements for making permits applications available to feedlot owners. These modifications were made to make the provision consistent with the permitting requirements of the proposed rule. The essential meaning of the existing rule has not changed. The modification of this part includes a clarifying sentence that permit application forms used by the CFO must be in accordance with proposed chapter 7020 permit content rule requirements.

Item D is a modification of subpart 1, item C(3), of the existing rule and it addresses CFO requirements for reviewing and processing permit applications. These modifications were made to make the provision consistent with the permitting requirements of the proposed rule. For clarity, this part identifies interim and short-form construction permits as the permits that a CFO has the authority to issue.

The purpose of the provision is to provide instructions to the CFOs for issuing permits. Specific requirements apply to the issuance of interim and short-term permits. The CFOs must be aware of these requirements and comply with them in order that the permitting program is administered consistently and in accordance with agency design. The CFO is also expected to conduct permitting responsibilities according to the delegation agreement document that was prepared by the county and approved by the agency. It is reasonable for the agency to establish requirements that will result in satisfactory administration of agency rules.

Item E is a new provision proposed by the agency and it requires CFOs to conduct inspections as agreed upon by the county in the delegation agreement. The delegation agreement provision under subpart 3, item B, contains specific conditions that require the county to set goals and plans for various types of inspections. The CFO is required by this provision to use plans contained in the delegation agreement as a blueprint for conducting inspections. As a result, the inspection work done by a CFO should cover all categories and types of feedlots in a county. This includes large and small feedlots, feedlots that are new or expanding, and feedlots that have registered as well as those that have not.

The result of this provision is that it should work to resolve some of the perceived weakness in the existing program related to credibility. Comments from public comment letters as well as meeting during the rule revision process have criticized the program for issuing too much paper not verified by inspections, and for doing very little inspection work at feedlots that were unpermitted. This is evidence that a strong inspection component in the country program is needed.

Inspections are important to not only initiate corrective actions at facilities with pollution hazards. They are needed to support other regulatory tools used by the agency. For example, inspections are needed to verify that feedlot owners are complying with the permit requirements and registration requirements. Otherwise the importance of compliance by feedlot owners with these regulatory devices may diminish. Therefore, a strong inspection is necessary for all components of the feedlot program to operate effectively.

There are several reasons why it is reasonable for counties to administer the inspection part of the program. One of the primary reasons is that inspection work is logistically intensive. Driving to inspection sites can be time-consuming. It is not unusual for agency staff to drive one to two hours to reach a site. In most cases CFOs can reach these sites much more quickly. Therefore, from a time and resources standpoint, it makes sense for the counties to carry out the inspection duties. A second factor that bears on the reasonableness of this approach is that regulatory inspections, by nature, can generate uneasiness and fear by the regulated parties. If the counties do the inspections some of these factors that create anxiousness disappear. The county staffs have the built-in rapport of living in the community. Visits by them can help reduce, for the feedlot owner, the degree of unfamiliarity that may be present with agency staff visits.

The county feedlot grant program provides up to $80.00 per feedlot to counties to administer the feedlot program. At this level of support it is reasonable to require counties to perform inspections as part of their delegation responsibilities. Under the feedlot grant program, counties with significant livestock operations will receive more than $25,000. This should adequately fund, at least, a half-time county feedlot officer position. A half-time position should enable most counties to accomplish a reasonable inspection program.

Item F is a new provision proposed by the agency and it requires that CFOs review and process complaints. The need for this provision stems from the regulatory importance of complaints and from the agency strategy to greatly increase the role of counties in regulating feedlots.

Complaints are a key area of administering a feedlot permit program. The citizens of the state trust the agency to be able to intervene quickly when a feedlot problem develops. The ability of the agency to respond to complaints creates an important regulatory awareness for the feedlot owners as well as the general public. Also, the agency finds that feedlots with the most serious pollution problems are often identified as a result of complaints. These types of problems may not be identified as quickly through other regulatory avenues and therefore complaints provide the value of early identification and remediation. Therefore, the effective handling of complaints is important to the agency and, the agency must have a provision that makes clear the accountability for those performing complaint follow-up and processing. For this reason, this provision is a needed requirement in the rules on delegation.

Practical factors also bear on the value of requiring CFOs to review and process complaints. The CFO is typically located closer to the site of the complaint. They can respond to the complaint more quickly. Less regulatory resources are used. If several visits are required to resolve the complaint these logistical factors become even more significant.

Under the proposed feedlot program, CFO compliance duties such as complaint follow-up will increase from currently levels of responsibility. Expanding county permitting authorities for feedlots that need corrective action, requiring counties to have an inspection plan for all feedlots and requiring CFOs to conduct follow-up measures on all complaints have shifted CFOs duties to a role that clearly requires them to make compliance determinations. During rule development CFOs have expressed concern regarding the shift in their role from primarily assistance to one that combines assistance with compliance duties. The agency is working with the counties regarding these concerns. The main goal has been to distinguish between compliance and enforcement duties.

While the intention of the agency is to involve counties in the role of determining compliance and putting owners on schedules to correct pollution hazards, there is no intention by the agency to incorporate an enforcement component into the duties of the county programs. The agency's view is that, when CFOs encounter enforcement situations, they refer the matter to the state. Typically, this would include a situation where a CFO discovers a blatant violation (e.g., pumping, piping dumping manure to waters of the stare).

Enforcement is, also, a concern where there is a persistent failure by a feedlot owner to correct pollution hazards. This includes such situations as the persistent failure of a feedlot owner to install clean water diversions or buffer strips to prevent runoff from an open lot to nearby surface waters. Under these circumstances, the agency expects the CFO to document these deficiencies in an inspection report and to provide notification to the owner that the feedlot is in non-compliance and is subject to all agency rules and regulations including the authority to enforce compliance. In most cases, the CFOs compliance duties end at that point and, they should refer the matter to the agency or their county attorney for resolution.

The agency recently developed a policy document that clearly states that the agency continues to be ultimately responsible for enforcement. See Exhibit C-3. This is intended to be an assurance to CFOs that, when necessary, their delegation authority gives them the flexibility to refer feedlot compliance issues to the state for resolution.

Item G requires CFOs to provide assistance to owners of feedlots and manure storage areas in completing permit applications. This CFO requirement is contained in the existing rules under 7020.1600, subp. 1, item C.

Item H sets forth general recordkeeping requirements for CFOs. This provision is a modification of 7020.1600, subp. 1 (C) of the existing rules. The existing provision has been modified by adding the requirement that the records for complaints and inspections must be kept on forms provided by the commissioner. The agency proposes this change in order to improve the agency's feedlot database and consistency in the data collected and data storage. The agency is frequently asked by the public and interest groups seeking information on a certain issue for information about evidence related to a problem or the level of inspection activity that has been conducted. The Legislative Auditor report commented on the need for the feedlot program to track and maintain a record of complaints. See Exhibit G-1. The use of agency forms will help standardize the information and make it easier to log information into a database. Since this requirement will enhance the consistency of information as well as improve the efficiency of regulatory activity, it is a needed and reasonable revision to the existing rule.

Item I is a new CFO requirement proposed by the agency. It requires CFOs to submit an annual report to the agency. The content of the report is defined by criteria listed in the provision. These criteria require CFOs to submit data on permitting, inspection, complaint and education activities.

This requirement is needed by the agency to provide adequate oversight of the county feedlot program. To conduct a review the agency needs information on the performance of the county in administering the program. This provision ensures that the agency will receive the necessary information to do a satisfactory program evaluation. The Legislative Auditor has criticized the agency for inadequate oversight of the county feedlot programs. See Exhibit G-1. With the proposed expanded role of the counties in administering the feedlot program, the need for performance results related to county program increases.

For the agency to conduct a review it must have timely information on essential areas of the county program. The annual report provides this type of information. It shows performance results by the county in the fundamental components of the program. It provides these results annually.

Several factors bear on the reasonableness of this requirement. One factor is that delegated counties are familiar with an annual reporting requirement. Delegated counties have been required to submit annual report since the establishment of the feedlot grant program in 1995. See Exhibit C-6. For consistency and reliability, it is reasonable to codify existing practices into the rules.

A second factor demonstrating the reasonableness of this provision is that the criteria proposed for the annual report is consistent with the requirements of the delegation agreement as described under subpart 3, item B. These common criteria include permitting, inspections, complaints, education and training. Linking the terms of the delegation agreement and the annual report together should provide clarity and simplicity regarding an understanding of the feedlot program requirements for the CFO.

The CFOs must submit the annual report by April 1 of the year following the calendar-reporting year. This is a needed requirement in order for the agency to complete its oversight responsibilities in a timely manner. The deadline of April 1 is reasonable because it allows the CFO 3 months of time following the end of the reporting year to submit the report.

Item I, subitems 1 to 6. Item I, subitems 1 to 6 lists county feedlot program information that the CFO must submit to the agency on an annual basis. The data required pertains to county program registration, permitting, inspection, and education efforts. With the exception item I, subitems 1 and 6, this data is currently required in the existing CFO report. See Exhibit C-1. Item I, subitems 1 to 5 indicate county performance in the core components of the feedlot program and, therefore, is needed by the agency to conduct an adequate review. These requirements will not be a difficult task for counties to do as they will be compiling this information as normal part of their program operations. Therefore, these provisions are reasonable requirements.

Subitem 6. This subitem contains the agency's proposed requirement that the annual report to contain an analysis of performance results for the year along with recommendations for the subsequent year. This requirement is consistent with the purpose of the delegation agreement as well as the process proposed by the agency for negotiating changes to the agreement. It is needed and reasonable for the agency to set forth requirements needed to support successful implementation of the delegation agreement and to ensure adequate information is submitted to support MPCA’s oversight role

Item J requires county feedlot officers to participate in training necessary to perform CFO duties. This provision is needed to ensure that County Feedlot Officers (CFOs) will have the skills and knowledge to match the increased duties and responsibilities they will receive under the proposed revisions to this chapter. It is reasonable to establish training requirements to ensure that the county program is effective.

The agency presently has an active training program for CFOs. Training sessions are provided for CFOs in a number of venues throughout the year. This includes a 3-day annual training event as well as other special training events devoted to single topics such as concrete construction and nutrient management. Training is also a part of CFO quarterly regional meetings. The agency tracks training participation on annual reports and emphasizes training as a priority in policy documents to CFOs. CFOs have generally supported the need for on-going training and development to effectively do their work. Therefore, on the evidence of the value and support of existing training practices for CFOs, it is reasonable to make CFO training a requirement of the rules on delegation.

Subpart 3. For order and clarity the agency proposes to reorder the contents of subpart 3. The agency proposes to move the existing provision regarding permit issuance procedures to part 7020.0535, subp. 3; the agency then proposes to use subpart 3 to set forth the county's application requirements for delegation.

The proposed requirements for counties to become delegated are similar to the requirements of the existing rule. The main difference is that the agency is proposing a new part under item B that requires counties applying for delegation to submit a document that the agency has termed a "delegation agreement." In this document the county must describe the goals and measures they will use to implement the core components of the feedlot permit processing program. This provision requires them to discuss permitting, inspections, registration, complaint and response, education and outreach and staffing levels. The agency must approve the agreement. The need and reasonableness of this requirement is discussed under item B.

The lead paragraph of subpart 3 contains two significant provisions related to the delegation application process. One of the provisions requires that counties, delegated prior to adoption of the rule, prepare a delegation agreement document according to the criteria of this subpart and submit it to the agency by June 1, 2001. The second provision requires that delegation agreement documents be reviewed annually by the county and the agency. The SONAR for these provisions follows.

The first of these provisions serves the fundamental purpose of upgrading the delegation conditions of counties delegated prior to the rule adoption and to bring about needed improvements in feedlot programs in existing delegated counties. Although many existing counties have strong feedlot programs, some of them do not adequately administer the feedlot program. The 1999 Legislative Auditors report supports this assessment. See Exhibit G-1.

This provision requiring counties with existing delegation agreements to prepare a delegation agreement document is reasonable in that this requirement is consistent with the requirements for new counties who request delegation. This provision is also reasonable in that it provides the counties a reasonable time frame of one-year following rule adoption to prepare and submit a delegation agreement document to the agency.

The second provision in the lead paragraph of subpart 3 requires annual review of the delegation agreement document by the agency and the delegated county. This requirement is needed to ensure that the delegation agreement document is reviewed on a regular basis. The review satisfies an obligation of the agency to oversee the county program and maintain accountability. More importantly the review ensures that the delegation agreement document is assessed and evaluated for change. This creates an opportunity for the feedlot program to be as effective as possible. Factors such as past performance results of the county, changing feedlot demographics, changes in technology and changes in the strategy for administering feedlot regulations can be addressed during the periodic review and annual revisions.

An important part of the concept of the periodic review is the partnership nature of the review. Both parties of the delegation agreement will be working together to update and make appropriate changes to the agreement. It should be pointed out that, in instances where an amicable review of the agreement is not obtainable, subpart 5 and subpart 6 of this part allow either the agency or the county to terminate the delegation.

Item A requires a county to submit a resolution as part of their application for delegation. This is a requirement of the existing rule and is located in subpart 1, item A.

Item B states that counties applying for delegation authority must submit an agreement to the agency explaining their plans and goals for administering the feedlot program. The provision contains a list of specific criteria that the county must address in the agreement. The provision includes the condition that the commissioner must approve the agreement.

The backbone of the agency's strategy to conduct oversight of the county program is through use of the delegation agreement set forth in the requirements of this provision. With the expanded regulatory role proposed for the counties, the agency needs more accountability mechanisms than are provided in the existing rule to ensure that components of the program are administered effectively. The delegation agreement document satisfies a major part of this need.

The delegation agreement provision is a reasonable approach for the agency to use to address the matter of accountability. The agency recognizes that in order for county delegation to be an attractive program to counties it must be responsive to the needs and preferences of the individual counties. This approach does that by giving the counties the flexibility to design the program that they see as most appropriate for their county. At the same time, it gives the agency assurance that the county will follow through with core aspects of the feedlot permit application process.

The agency views the nature of the work needed to complete the delegation agreement document as negotiation. Counties may put forth a plan for implementing the rules and the agency has an opportunity to respond with any concerns it might have. Differences and concerns can be resolved through discussions and meeting and the delegation agreement can be subsequently signed by the agency and county. Because the delegation agreement fits this approach of giving counties flexibility and commitment, it is reasonable for the agency to use it as an approach to maintain and facilitate a working agreement between the county and the agency.

Subitem 1 contains the agency's proposed requirement that counties to submit in their delegation agreement document an inspection plan that addresses three categories of feedlots. Under these categories counties must have a general inspection plan that subjects all feedlots with less than 1,000 animal units to an inspection. Counties also must have specific plans for inspecting construction projects at new and expanding facilities and for inspecting feedlots that are operating under the interim corrective measure conditions as defined in part 7020.2003, subp. 5. The need for the agency to require counties to use inspections as part of a program to regulate feedlots is discussed in subpart 2, item E.

Unit (a). The agency proposes that counties have an inspection strategy that will result in the identification of feedlots with pollution hazards. Correction of pollution problems at existing feedlots is a primary goal of the agency feedlot program. The intent of this provision is that counties will develop an inspection plan that will result in inspections being conducted at feedlots most likely to contain pollution hazards. Under this category the agency will expect to see counties develop a method for prioritizing feedlots according to their potential to be a pollution hazards. Some of the most likely criteria would be feedlots in shoreland, feedlots under 300 animal units and feedlots that have never applied for a permit application. Preparation of a plan to address these feedlots should support the implementation of these inspections. It should also ensure that these inspections are carried out systematically. A systematic approach is important in that it creates a regulatory atmosphere whereby feedlots in high-risk categories will recognize that they are subject to inspections. It is reasonable for the agency to establish requirements that will enhance the uniform and consistent implementation of the rules.

Unit (b). In this subitem, the agency proposes that counties submit in the delegation agreement document a plan for inspecting feedlot construction projects. This requirement is consistent with a principal agency strategy to protect the environment by insuring that new construction is built according to feedlot construction technical standards. Historically, this is the most common type of inspection that delegated counties have performed. While the agency will not require every construction site to be viewed, the intent of this requirement is that inspections should be done at a frequency to demonstrate that agency design standards are being followed and that proper construction practices are being observed.

Unit (c). The agency proposes that counties set goals for inspecting feedlots that are operating under the interim corrective measures option as described in part 7020.2003, subp. 3 to 6. Under this option feedlot owners are given until 2009 to fully comply with state water quality standards provided they agree to implement a set of low-cost corrective measures before October 1, 2003. This agreement will be executed by a signature of the feedlot owner on an agreement form provided by the agency. Because of the minimal documentation required, an inspection is the only way for the agency to guarantee the integrity and credibility of the agreement. The on-site inspection will indicate whether the feedlot owner has installed corrective measures according to part 7020.2003, subp. 5. It is needed and reasonable for the agency to establish procedures to verify that regulated parties are in compliance with their regulatory agreement.

Subitem 2. Under subitem 2, the agency addresses feedlot requirements at feedlots with more than 300 animal units. Inspection categories are the same as they are for feedlots with less than 300 animal units under item B, subitem 1, except that unit c does not apply to feedlots with more than 300 animal units. The need and reasonable rationale for this provision are the same as item B, subitem 1, units a and b.

Subitem 3. Subitem 3 contains the requirements for the counties to state goals that they plan to use for implementing the permitting system. Under the proposed rules counties will be responsible for most permitting duties under 1,000 animal units. This is an important responsibility as it is the chief regulatory tool that will be used to regulate construction at new and expanding feedlots and to correct pollution problems at existing feedlots. To accomplish its oversight duties, it is needed and reasonable for the agency to require counties to develop and submit plans for an area that is a core component of the feedlot program.

Subitem 4. The agency proposes that counties have plans and goals for administering the proposed registration requirements. The agency is relying on feedlot registration as a primary tool to track and maintain regulatory oversight of feedlots with less than 300 animal units. It ranks with inspection and permit processing as the main parts of the feedlot program. It is reasonable for the agency to require counties to develop and submit plans for an area that is a core component of the feedlot program.

Subitem 5. In subitem 5, the agency proposes that counties state the procedures and goals they intend to use for addressing the complaint component of feedlot regulation. Complaints are a fundamental area that must be handled effectively for the successful implementation of feedlot regulations. The counties are in an ideal position to respond quickly to complaints as well as to understand the circumstances that will be required for resolution. Additional SONAR discussion and justification for this provision is provided under subpart 2, item F.

Subitem 6. Subitem 6 contains the proposed requirements that counties provide in their delegation agreement document a strategy for providing assistance to feedlot owners. It is a modification of subpart 1, item C, unit (4) of the existing rules. The proposed provision requires that CFOs provide compliance assistance. Compliance assistance means that CFOs will be a resource for owners to solve their feedlot problems. This assistance will be chiefly in the form of assisting owners to locate resources and to develop a corrective action plan. CFOs may provide information regarding low-cost measures such as the use of clean water diversions, buffer strips and regular lot scraping. This assistance role is especially important for those feedlot owners under 300 animal units who choose and are eligible for the interim corrective measures plan. Compliance assistance does not mean that CFOs provide actual design and review services for construction that is governed by the technical standards. It should be noted that CFOs have expressed concern that assistance, especially compliance assistance, might mean that they have to do enforcement as part of the program. As explained under subpart 2, item F, this is not a correct interpretation of this requirement.

Subitem 7. The agency proposes that counties must indicate in their delegation agreement document the number of staff they intend to use to administer the feedlot program. This is a new requirement and the agency is proposing it as a way to evaluate whether or not the county has adequate staffing to execute the plans.

The agency is proposing this requirement as a result of past experience with the county programs. Records from annual reports since 1995 indicate that the level of staffing from county to county varies significantly. See Exhibit C-7. The reports show that several counties have more than 1 FTE conducting feedlot duties while others as invested as little as one-tenth of an FTE. While feedlot program accomplishments are not always directly related to staffing levels, extremely low level of staffing would raise reasonable concerns regarding the ability of a county to adequately administer the program.

This requirement does not mean the counties must meet a standard or quota. The agreement is intended to give counties the ability to design a program according to their needs and the concept of the delegation agreement document is that is negotiable. Therefore, the staffing level requirement is reasonable because it allows both parties to make adjustments for achieving the intended goal.

Item C requires agency authorization before the county delegation becomes effective. This is a requirement of the existing rule and is located in 7020.1600, subp. 1, item B.

Item D requires the county to designate a county feedlot officer as part of the requirement for obtaining delegation. This is a requirement of the existing rule and is located in subpart 1, item C. The specific duties of the CFO are contained in subpart 2.

Subpart 4. Subpart 4 contains the procedure requirements that must be observed by delegated counties when processing feedlot permit applications. Permit procedure requirements are located under 7020.1600, subp. 2, of the existing rules. The agency proposes to modify the existing procedural requirements to be consistent with the proposed changes in the permitting system and to incorporate changes resulting from the broadening of permit issuance authorities for delegated counties.

The SONAR discussion for the proposed changes to the permitting system is provided under part 7020.0405. The SONAR discussion for expanding the permit issuance authority of the counties is provided under item A.

Item A establishes the county's authority to issue construction short-form and interim permits. The rules governing construction and short-form permits are set forth in 7020.0535. As a result of this provision counties are allowed to process and issue permits for most feedlots under 1,000 animal units.

The need for the agency to shift more permitting responsibility to the counties can be explained in terms of the benefits associated with having regulators located close to the sites they are regulating. These benefits include a greater capacity to respond, a greater understanding of local issues and greater local commitment to regulations than is provided by direct administration from the agency. Other factors demonstrating need and reasonableness for expanding county permitting authority are listed below:

- Existing strong county programs demonstrate that local regulation is an effective approach.
- Counties are eligible to receive significant financial support to administer the program.
- On-going training provides county feedlot officers with the necessary technical and administrative skills.
- Counties have generally welcomed the opportunity to do more permitting.

- Counties are given the option to forward difficult and complex permit applications to the agency.

Item B is a restatement of subpart 2, item C of the existing rule. It contains a set of criteria under which counties must forward permit application to the agency for processing. The agency proposes to amend the criteria. The SONAR for these changes is discussed in item B, subitems 1 to 6.

Subitem 1. Subitem 1 is a modification of a permit processing procedure under part 7020.1600, subp. 2, item C of the existing rules. The agency proposes under this subitem that feedlot applications from facilities that are subject to permitting requirements under part 7020.0405 must be forwarded to the agency for application. The feedlots subject to these permitting requirements are feedlots that require NPDES or SDS permits.

The need and reasonableness associated with the NPDES permit application requirement is that delegated counties do not have authority to issue NPDES permits. Regarding the SDS permit application requirement, the agency view is that counties, generally, do not have the technical capacity needed for an adequate review. SDS permits are used for facilities where permit application reviews are complex. This includes feedlots with more than 1,000 animal units that may be subject to a SDS permit. It includes feedlots with less than 1,000 animal units that, for technical or administrative reasons do not meet interim and short-term construction permit requirements. It is needed and reasonable for the agency to establish procedures that promote a competent and credible permit program.

Subitem 2. This subitem restates the requirements subpart 2, item C, subitem 4 of the existing rule. It requires counties to forward applications to the agency for feedlot or manure storage areas in those cases where manure is not used as a domestic fertilizer.

Subitem 3. The agency proposes that counties forward to the agency permit applications for owners of feedlots with 500 or more animal units that are proposing to construct liquid-manure storage near specific topographical features characteristic of limestone geology. These features, including sinkholes, caves and disappearing streams, may contain direct conduits to ground water and are a serious pollution threat. In order to ensure that proposed construction near these features is safe and reliable, a high level of technical expertise to review the project is needed. Most counties do not have these resources available; the agency is staffed with professional engineers than can provide the necessary expertise. Therefore, it is reasonable to establish a provision that requires counties to forward these applications to the agency for review.

The provision is, also, reasonable because considers the level of the potential pollution threat created by feedlot size and the distance of a facility to a geographically sensitive feature. If either the facility size increases or the proximity of a structure to one of the sensitive geologic features decreases, the magnitude of the pollution threat will increase. The size threshold of 500 animals units and the distance threshold of 1,000 feet are parameters used to establish rule provisions for similar applications in feedlot-related rules and regulations. It is reasonable for the agency to establish provisions that promote uniformity.

Subitem 4. Subitem 4 contains the agency's proposed requirements that counties to forward permit application to the agency from owners proposing to construct new feedlots or modify existing feedlots in a vulnerable drinking water supply management area. The need and reasonableness for proposing this version is similar to subitem 3. Drinking water supply management areas inherently pose a higher pollution risk and proposed feedlot construction in them warrants more scrutiny than feedlots operating in more typical settings. Agency staff has the expertise available to evaluate additional geographical factors and structural designs connected with these projects. Therefore, it is reasonable that the counties forward applications to the agency for review. The provision contains a condition that limits the application of the provision to feedlots with 500 or more animal units. The reasonableness of this condition is explained in paragraph two of subitem 3.

Subitem 5. This subitem contains the agency's requirements that counties forward permit applications to the agency from owners of feedlots in sensitive geographical areas that have less than 300 animal units and who are proposing to construct liquid manure storage to correct a pollution hazard. In order to ensure that proposed construction in sensitive areas is safe and reliable, a high level of technical expertise to review the project is generally needed. Most counties do not have these resources available. On the other hand, the agency is staffed with professional engineers than can provide the necessary expertise. Therefore, it is reasonable that the counties forward applications to the agency for review.

Subitem 6. The agency has proposed in this subitem that the counties to forward those applications where the feedlot owner is applying for a variance to accomplished proposed changes. Counties do not have the authority to grant variances of MPCA rules under the delegation. Therefore, it is needed and reasonable that the counties forward these applications to the agency for review.

Item C is a restatement of the existing rule. It provides counties the option to forward any permit application to the agency for either technical assistance or permit issuance. For clarity and completeness the agency has amplified the existing language. Under the revised provision, the county must submit a request along with the application stating the desired action sought by the county. The agency in return agrees to complete permit issuance as requested and to keep the county informed during the processing of the application. The result of adding these conditions is that it improves communication between the county and the agency. It is reasonable for the agency to incorporate processes that clarify and improve the effectiveness in administering of rules.

Subpart 5. The agency proposes to delete subpart 5 of the existing rule. The SONAR for this is discussed below. The agency proposes to use subpart 5 to establish the provision stating the procedure for counties who wish to discontinue their delegation agreement. For clarity and completeness the agency has added language to explicitly state that a request for withdrawal must be sent to the commissioner. Subpart 5 of the existing rule establishes a time frame of 15 days in which the commissioner is allowed to review permit applications forwarded by the county. Agency experience in processing permit applications indicates that 15 days is not a realistic amount of time for staff to conduct an adequate review. The inflow of applications to the agency varies significantly according to the time of the year. During some periods of the year, such as early spring, the volume of permit applications makes it impossible to meet a 15-day schedule. Application complexity is also a factor that slows down the permit review process. Most of the permit applications received by the agency from the county are for the most problematic feedlots. These are feedlots where the significance of the pollution hazards, the history of noncompliance, or technical difficulties are such that careful review is warranted. The agency considered increasing the duration time limit from 15 days to 60 days, but concluded that the complex and unpredictable nature of these permit applications is such that no time limit can reasonably be established. Therefore, the agency proposes deletion of this provision. It is a needed and reasonable to delete a provision when it is shown to be inconsistent with facts upon which it was established.

Subpart 6 is that same as part 7020.1600, subp. 7, of the existing rule. For clarity and completeness the agency proposes to add language that explicitly identifies Minn. R. ch. 7020 as the basis for which to establish revocation of county authority. Similarly, the agency proposes to replace “application review” with “delegation” to make it explicit that revocation applies to all terms and conditions of the delegation agreement.

Standards for Discharge, Design, Construction, Operation and Closure

The proposed rule consists of four main subject areas: registration, permitting, county feedlot programs and standards for discharge, design, construction, operation and closure (technical standards). Among the many possible ways to regulate animal feedlots and manure storage areas, the agency has in the past chosen to regulate them through issuing site specific permits and certificates of compliance as discussed in this SONAR under parts 7020.0400 and 7020.0405. The permitting requirements of the proposed rules are a relatively small, but very significant, part of the shift in the strategy for regulating animal feedlots, manure storage areas and pastures. In addition to the proposed rules revisions, the agency has undertaken the task of redesigning the feedlot program at the agency in an attempt to optimize (from an environmental outcome standpoint) the use of staff resources. The general direction of the redesign has been to emphasize work to be done “in the field” and to de-emphasize paper reviews to determine if an environmental goal will be achieved. As discussed in this SONAR under parts 7020.0400 and 7020.0405, the impetus for the redesign of the program was to make the best use of the agency and delegated county staff to achieve the best possible environmental outcome. The proposed rules, as a whole, are intended to allow the agency and delegated counties to shift staff resources from primarily doing paper reviews to doing a significantly increased number of inspections, education and outreach activities. The proposed rule is intended to allow and encourage the agency and delegated counties to focus efforts and resources for regulating facilities from reviewing paper work to greater field presence and one-on-one contact with facility owners.

The four main portions of the proposed rule, registration, permitting, county feedlot programs and technical standards are all designed and intended to work together to achieve the best possible environmental outcome while considering the resources available to the agency and delegated counties. The proposed technical standards in parts 7020.2000 to 7020.2225 establish the minimum location, construction, and operational requirements needed to minimize the environmental impact of these operations. One of the reasons for including the technical standards in the proposed rule is to reduce the need to use permitting as the regulatory tool for a large number of animal feedlots, manure storage areas and pastures. The proposed rules include clearly stated technical standards that are broadly applicable. By including clear technical standards and making them broadly applicable, the need for issuing individual site-specific permits that impose location, construction and operating conditions on any facility, is greatly reduced. These technical standards also reduce the amount of time needed to draft and issue permits for facilities required to obtain a permit. This time savings is realized through establishing the general requirements applicable to all facilities, compared to the current feedlot regulatory program which does not address general requirements other than the discharge standards.

The proposed permitting system is also intended to take advantage of the technical standards by reducing the number of permits the agency or county must issue. The proposed rules generally allow owners with fewer than 300 animal units to construct and operate within the constraints of the technical standards without applying for or obtaining a permit. Owners with more than 300 animal units that propose to locate, construct and operate in accordance with the proposed technical standards will be able to do so under a streamlined permitting system called "construction short-form" permits. Owners with fewer than 1,000 animal units will not be required to apply for an operating permit, provided the facility is constructed and operated in accordance with the technical standards and the facility is not a CAFO that is required to obtain a NPDES permit.

Finally, the proposed regulatory system is a somewhat new approach to regulating these facilities. In many ways, the proposed system is about owners accepting responsibility for the environmental performance of their facility and the agency accepting that these owners will do what is needed, and what is required in the technical standards, if they know up front and understand what is needed and why it is needed.

7020.2000 Overview

The Overview section is a general adaptation and reconfiguration of 7020.0400, General Requirements, of the existing rule. It is comprised of six subparts. Subpart 1 contains some of the most core requirements for which all facility owners and persons involved in handling manure must comply. The remaining subparts are provisions that address subjects that do not fit into the major technical sections comprising the proposed rules.

Subpart 1. In General. Subpart 1 contains the fundamental provision making up the feedlot rule with respect to the technical standards in parts 7020.2000 to 7020.2225. The statement that all owners of animal feedlots, manure storage areas and pastures, and any person handling manure are subject to the applicable requirements. For clarity, this statement is needed to inform all persons that, if their operation produces, stores, disposes, transports or utilizes animal manure or process waste waters, they are subject to these rules in general and more specifically to one or more of the technical standards sections. This provision is reasonable because it demonstrates an important distinction regarding regulation of manure-related operations by making it very clear that all persons, whether or not they are required to apply for a permit, are subject to all technical requirements of these rules.

Subpart 2. Animal manure and wastewaters not used as domestic fertilizer. This provision informs owners who use and/or dispose of manure by means other than application to land, that they must do so in a manner that does not result in pollution. The reference to applicable rules is needed and is intentionally broad because there will continue to be new methods of processing and handling manure that are not addressed in these technical standards. This is reasonable because the agency fully intends, upon inquiry from an owner, to assist the owner in determining what applicable rules apply to their proposed alternative methods. This subpart also requires owners not using manure as domestic fertilizer to apply for an NPDES or SDS permit. This is reasonable because it allows the agency to review the proposed operational methods prior to implementation by the owner and allows for public noticing and comment of new or unique operational methods that may affect them. The agency may also assist the owner, if necessary, in determining if any additional regulations govern the proposed operation.

Subpart 3. Manure packs and mounding. This is a new provision proposed for the feedlot rule. It requires feedlot owners and operators, who use “manure packs” or “mounding” as a component of their manure handling system, to remove the manure from the feedlot on an annual basis. Mounding is a practice where manure to pushed together to create a raised area in open yards that cattle can stand on to keep dry during times of the year when the feedlot is wet and soft. “Manure pack” refers to a form of manure handling where the manure is allowed to accumulate in the area the animals are confined and where the hoof traffic of the animals presses the manure into a dense mat. These practices are typically used at feedlots with less than 1,000 animal units. One might expect that these forms of manure handling would be classified as stockpiles and, therefore, be subject to the proposed stockpiling rules. There are, at least, two reasons for not doing this. One, is that mounding is addressed by the rule requirements that control runoff from open lots. It does not make sense to establish standards for both open lot runoff and manure pack/mounding runoff when the open lot runoff is already addressed by the rule.

A second reason for treating manure packs/mounding different than stockpiles is that cattle traffic within confinement areas is constantly packing and compressing loose material, including manure, into a packed-layer. This layer acts to create a seal between the manure liquids and a high water table or seasonally saturated soils that may be located below the surface of the lot. This reduces the risk of ground water contamination that can occur from leaching. The agency has limited the time that these manure accumulations can be maintained at one site to one year before they must be removed. This is required as a precaution to prevent damage if use of the confinement area is interrupted and manure seal deteriorates. An example of this situation occurring is where cattle are confined to a yard in the winter but are pastured during the growing season. Also, while the sealing phenomena created by hoof traffic is recognized, there is evidence indicating that some leaching of manure materials in to the soils under feedlots continues to persist. A study has shown that an increase in nutrient buildup occurs in the soils at operations that use these practices. With limited research available and with the dependence by some feedlots owners on these practices, the agency believes the one-year removal requirement is an acceptable compromise.

Subpart 4. Newspaper notification of proposed construction or expansion. This provision is needed to allow adequate notification of local neighbors of proposed constructing or expanding animal feedlots or manure storage areas and to eliminate common misinterpretation of statutory requirements under Minnesota statute section 116.07, subdivision 7a. Incorporating this into the proposed rule is reasonable because it will help provide consistency in how these notifications are completed and the owner clearly knows what specific information to publish. This provision identifies the specific information needed in the notification, which if completed, will meet the requirements of the statute.

Under the current statutory notification requirements, the owner of a facility having 500 animal unit or more, must only include the livestock type and proposed capacity, and the notice can be completed in person, first class mail or by publication in local a newspaper, not more than 10 business days after submitting a permit application. The agency has had several instances where persons interested in a project have challenged the legal accuracy of a notice. For example, one notice stated that the owner was building a swine operation with more than 500 animal units, when the owner was proposing a swine operation that consisted of over 800 animal units. A second example is where on several occasions, a letter was sent to the owners neighbors, but the neighbors maintained that they had not received the notification until the project was already approved by the permitting authority. This provision is also reasonable because it will prevent these types of misunderstandings, and will require that the notice has been completed prior to obtaining a SDS or NPDES permit from the agency or a construction short form or interim permit from the agency or delegated county. For more discussion on the need and reasonableness of these notifications, see parts 7020.0505, subpart 4, "contents of permit applications" and 7020.0535, subpart 2, discussion of when a permit application is "complete" and can be processed by the agency or delegated county.

Subpart 5. Government notifications of proposed construction or expansion. Item A of this subpart is needed to fill the gap of a permit application not being required for facilities constructing or expanding to a capacity fewer than 300 animal units. The provision requires notification to the delegated county, or the agency in non-delegated counties, of a proposed project at least 30 days prior to commencing construction. The notification must be on a form provided by the commissioner and contain the information listed in subpart 4 items A to F and the anticipated date of starting construction. This is reasonable because owners with fewer than 300 animal units who are constructing or expanding do not need to apply for or obtain a permit prior to commencing construction, and there would be no mechanism in place to allow the agency or delegated county the ability to plan for inspections or conduct a summary review of the location or manure storage plans. The second part of this provision states that the owner who has submitted liquid manure storage area plans to the agency or delegated county, has met this requirement. This is reasonable because it eliminates duplication of notifications by the owner.

The discussion of the permitting sections of this SONAR (parts 7020.0405 to 7020.0535), discuss in detail the permitting structure proposed in this rule. Several county feedlot officers and members of FMMAC have proposed an alternative approach to include the requirement that all facilities constructing or expanding between 50 and 300 animal units be required to apply for a construction short form permit. This provision should be deleted if the permit system changes to require the construction short form permits for owners having 50 to 300 animal units.

Item B of this subpart is needed to inform local governmental units, especially in non-delegated counties, of proposed projects and for facility owners to become aware of any other requirements or restrictions outside of the state and federal regulations. This is reasonable because it provides a mechanism for communication between the owner of a proposed facility and all levels of government that potentially have requirement is addition to state and federal regulations.

Subpart 6. Record of livestock owners and manure sources. This provision requires owners of animal feedlot and manure storage areas to maintain records of the names of persons who own livestock which are raised at the feedlot or whose facility produced the manure which is stored in a manure storage area (if not produced at the feedlot). This issued was discussed briefly at the October 11, 1999, FMMAC committee meeting. The primary commenter suggested that MPCA require the names of all livestock owners to be identified in a permit application and/or registration form. The FMMAC group as a whole thought that having this information up front was not possible for many facilities because of the nature of the operations. For example, a cattle feeder may have several cattle from many different owners being feed at their facility and the names and numbers often change from year to year. Therefore, it would be unreasonable to require the owner to reapply for a permit or reregister based on just a change in ownership of a portion of the livestock raised at the facility. As an alternative, the group discussed that it was reasonable to require the owner to record this information, maintain it on file for at least three years and make it available upon request by the commissioner or county feedlot officer.

This information is needed by the commissioner or county feedlot officer if and when a pollution problem arises that requires consideration of formal enforcement actions. This provision is further reasonable because it allows the agency the needed information to seek penalties and corrective actions from all potentially responsible parties and also provides an incentive to owners of livestock to be involved in and assist the facility where their livestock are raised in maintaining compliance with the rules.

7020.2002 Hydrogen Sulfide Ambient Air Quality Standard Applicability

This provision is intended to address the Governor Ventura's direction that the agency address the purpose of the vetoed Chapter 204, House File 1235, a bill relating to the regulatory requirements for feedlots. The Governor addressed this issue in a letter to speaker of the house, The Honorable Steven Sviggum, dated May 25, 1999 (Exhibit G-4). This provision compromises at the midpoint of the recommended 14-21 day period that farmers should be allowed, as described in the Governor's veto letter. This issue was also one of the nine priority issue discussed during the six FMMAC meetings held from May-October 1999 (Exhibit O-4). During the October 11, 1999, meeting FMMAC also discussed the reasonableness of including a five-year sunset date for the provision.

The exemption from the hydrogen sulfide standard only applies during agitation and pump-out of a liquid manure storage area and if the owner complies with the requirements in items A to C. Exempting only liquid storage areas is reasonable because the agency's experience has been that they are by far the most likely to have emissions that could exceed the standard. In addition, providing an exemption only during pump-out and agitation is reasonable because this is the most likely time of operation that an exceedance would occur. The exemption, in general, is reasonable because it allows owners of liquid storage areas to operate in compliance with the law, while implementing best management practices to minimize emissions. At this date, the base of knowledge on how to control hydrogen sulfide emissions from liquid manure systems (during agitation and pump-out) suggests that costly remedial measures or equipment are often needed. It is reasonable to allow the livestock industry some time to address hydrogen sulfide emissions in a cost effective manner. For this reason, the agency proposes that this provision expire on July 1, 2005. The five year sunset date was originally proposed in legislation for an air quality easement that an owner could obtain from their neighbors, however, the agency believes that the five year period is needed and reasonable here because it will allow the agency, Minnesota Department of Agriculture, University of Minnesota Extension Service, FMMAC, and producer groups to better address air emissions of hydrogen sulfide resulting from the agitation/pump-out event.

This provision also states that the agency retains it's emergency powers authority under Minnesota Statutes, section 116.11. This is needed so that owners who obtain exemption under this part realize that they may be required to address hydrogen sulfide emissions from their facility, if human health is threatened by their operation. It is reasonable to restate the agency's authority here because owners may view this as an exemption from being required to implement additional remedial measures or equipment. However, this is not the case. Owners eligible under this part are exempt only from the hydrogen sulfide ambient air quality standard itself.

As mentioned above, the allotment of 17 days annually was selected as an approximate midpoint between the two bills that attempted to address the issue in statute, one selecting 14 days and the other 21 days. The agency proposes 17 days annually because it allows owners of most facilities throughout the state adequate time to complete pump-out and agitation of the storage areas. Some of the moderate to larger sized facilities will conduct agitation and pump-out for more than 17 days annually, however, they may not need an exemption on each of these additional days. The agency believes it is reasonable for the owner to select the days which are most likely to create a potential exceedance of the standard. In this way, owners will better understand the factors involved (e.g., wind direction and speed, temperature, distance to property line) and are better able to minimize potential emissions from the sources at their facility.

Item A requires the owner to notify the commissioner or county feedlot officer of the anticipated number of days and the start date of agitation and pump-out. This is reasonable to allow the agency or county to schedule an inspection and air sampling monitoring to better assess the potential for emissions at the facility. It is also reasonable because the agency can then respond to any complaints directed at the facility and inform the complainant the best management practices (BMPs) the owner of the facility is following in item C.

Item B requires the owner to inject or incorporate the manure into the soil within 24 hours of land application. This is reasonable because it is a BMP for minimizing hydrogen sulfide and other air emissions during land application of manure and implementation of this BMP will likely help offset some of the emissions created by the agitation and pump-out event.

Item C requires the owner to implement BMPs for the control of odor during agitation and pump-out activities. BMPs are needed and reasonable to further minimize the potential and actual air emissions from liquid storage facilities. At this time, the agency does not have a published list of acceptable BMPs for incorporation into this rule. However, the agency is working with the University of Minnesota Extension Service to develop BMPs that are effective for various types of facilities and management practices. The agency expects thes BMPS to be published in the next two years and, in the interim will provide guidance to owners on a range of BMPs to minimize air emissions.

7020.2003 Water Quality Discharge Standards

Subpart 1. Animal feedlots, manure storage areas and pastures. This provision identifies a specific set of geological conditions and manmade structures or sites that an owner of a feedlot must prevent runoff from entering. This provision is needed because the discharge standards described in the following parts refer to discharges to waters. The prohibited sites which include sinkholes, fractured bedrock, wells, surface tile intakes, mines and quarries, may not be viewed as waters of the state even though they often provide a direct conduit to waters of the state. Because these systems can act to directly transfer pollutants and manure to surface waters, and many persons would not readily recognize the potential impact of these discharges, it is reasonable to prohibit these discharges to sensitive areas and direct conduits to waters of the state.

The provision identifies animal manure, process generated waste water and process wastewaters. This broad approach is needed, for example, to address concerns with milkhouse waste discharges for which without treatment or containment often flow directly to tile intakes, or to slopes and ravines that drain to surface waters. To clarify and ensure that farmers comply with this requirement. Milkhouse waste is wastewater from the dairy milking center. It includes wastes from the milking parlor (manure, feed solids, hoof dirt) and the milkhouse (bulk tank rinse water and detergent used in cleaning). The North Central Regional Extension publication titled, "Pollution Control Guide for Milking Center Wastewater Management" (Exhibit M-33) describes the constituents of milkhouse waste to include cleaning chemicals, organic materials, bacteria, viruses and parasites. The contaminants with the greatest potential to impact water quality are waste milk, cleaning chemicals and manure. These contaminants can affect water quality through the addition of solids, phosphorous, ammonia-nitrogen and chlorides. In addition, the biochemical oxygen demand of milkhouse waste can be as high as 1500 milligrams per liter as compared to 250 milligrams per liter for untreated municipal sewage. Chronic releases of untreated milking center wastewater have been identified as one cause of declining groundwater contamination and could adversely affect drinking water quality and create health hazards. The above mentioned North Central Regional Extension publication highlights the results of Canadian research on milking center wastes. In particular, one study (Miller et al. 1987, paper referenced in Exhibit M-33) estimates that milk room wastes accounted for nearly 12 percent of annual phosphorus discharges from agricultural activities within the Lake Erie Basin. Although circumstances may differ in Minnesota from those in Canada, it can be gleaned from this study that milk house waste has the potential to have a significant impact on Minnesota's water resources.

Subpart 2. CAFOs and facilities with 1000 animal units or more. This provision requires CAFO facilities and other non-CAFO facilities having 1000 or more animal units to meet the federal effluent limitation standards in Title 40 Code of Federal Regulations, part 412 (Exhibit A-13) which for feedlot facilities is no discharge. However, the federal regulations provide the owner of a NPDES permitted facility, after application of best available technology economically achievable, a discharge under the following conditions: "process waste pollutants in the overflow may be discharged to navigable waters whenever rainfall events, either chronic or catastrophic, cause an overflow of process waste water from a facility designed, constructed and operated to contain all process generated waste waters plus the runoff from a 25-year, 24-hour rainfall event for the location of the point source." This provision is needed to clearly state that the no discharge standard is required for all CAFOs. That no discharge standard for all CAFOs is already in MPCA's water quality rules, part 7050.0212, subpart 1. The proposed rule language also specifies that facilities of 1000 animal units or more must comply with the federal discharge standards. As discussed in this SONAR for the definition of CAFO under part 7020.0300, subpart 5a, facilities with 1,000 or more animal units are CAFOs. However, if a facility in this category is determined through a future process to demonstrate that it does not meet the definition of CAFO, the facility would be issued an SDS operating permit. If these owners are determined to be non-CAFOs, they will be issued an SDS permit and required to meet the same discharge standard. This provision is reasonable because it is consistent with federal regulations. For facilities which demonstrate they are not CAFOs and that have 1000 animal units or more, it is reasonable to hold them to the same standard, because the potential for pollution still exists with the volume of manure present and/or handled at the facility. Further discussion of the need and reasonableness of the SDS permit applicability to non-CAFOs with 1000 animal units or more is discussed in this SONAR under part 7020.0405, subpart 1, item B.

Subpart 3. Other facilities. This subpart set forth the discharge limitations for all non-CAFOs (facilities with 0 to 999 animal units), except for those under 300 animal units and eligible for the long-term schedule of compliance under subparts 4 to 6. The referenced standard under part 7050.0215 essentially requires owners not subject to federal regulations to meet a 5-day biochemical oxygen demand (BOD_5) limit of 25 milligrams per liter (based on the arithmetic mean of all samples taken with a calendar month) and if discharging to or affecting a lake or reservoir also meet the nutrient control requirements in part 7050.0211, subp.1. For facilities under 300 animal units some discharge is allowed, provided it meets the effluent limits described above for BOD_5, and nutrient requirements, if applicable. The application of this standard is described below in several examples.

The agency realizes that some of the owners under this category currently maintain a pollution hazard and, therefore, intends that these owners be required to obtain the applicable Interim, SDS or NPDES permit to correct the problems at their facility. An example of an owner that would likely be out of compliance with this provision would be a feedlot housing 400 animal units and having manure-contaminated runoff. Manure originating from the feedlot flows across a barren field and discharges manure solids and untreated manure-contaminated runoff into a stream. A second example of an owner that would be in compliance with this subpart, would be one housing 400 animal units that has manure-contaminated runoff from an open lot, but the manure-contaminated runoff is routed through designed filter strip without having manure solids or manure-contaminated leaving the end of the filter strip. The first example maintains a pollution hazard while the second example complies with this provision by having no discharge.

A critical component in the effectiveness of the filter strip systems is the ongoing operation and maintenance of the systems. The issue of filter strip operation and maintenance, as well as planning considerations and specific design criteria for filter strips, are discussed in the Minnesota Natural Resources Conservation Service draft Filter Strip practice standard, Code 393B (Exhibit T-6). Whether or not a filter strip system is designed according to the NRCS draft standard, the design must provide adequate storage capacity so that use of the filter area is limited to times when the vegetation is actively growing and able to provide treatment of the nutrients in the manure and must also have underlying soils that are dry enough to handle the hydraulic loading or volume of liquid released on the filter. The agency's intent with filter strip systems is that they are designed and operated like a land application site where the nutrient rates and hydraulic loading rates are appropriate for the vegetation and soil conditions present.

A third and more difficult example is where the feedlot is much like the first example above, except that instead of the manure-contaminated runoff entering a stream, the manure-contaminated runoff is routed through a cropped field and dead ends in the field prior to reaching surface waters. Provided that the manure-contaminated runoff does not pond in the field, create an area of stressed vegetation or enter groundwater through shallow bedrock, the manure-contaminated runoff is not likely to create a pollution hazard to surface or ground water and therefore would be in compliance with this provision assuming the agronomic rate requirement is adhered to, and the flow complies with all other applicable rules. The significance of the phrase "corrective or protective measure" in subitem 2 is found in the existing definition, under 7020.0300, subpart 8. The definition states "...a practice or condition...which prevents or reduces the discharge of pollutants from an animal feedlot to a level in conformity with agency rules." The specific agency rule discussed here is the surface water discharge standard located in chapter 7050, which establishes a 25 mg/L BOD_5 limit. Again, the chapter 7050 standard requires that no manure or manure-contaminated runoff from these animal feedlots and manure storage areas may enter surface waters exceeding the effluent limit of 25 mg/L BOD_5.

Finally, the feedlot described in the third example would meet the requirements of this provision, because the manure and runoff from the feedlot would not enter surface waters and would be adequately treated in the cropped field. A subtle, but important, example of the treatment potential and function of a cropped field relates to the direction of tillage patterns relative to the runoff. Consider that a tillage pattern running parallel to the runoff would tend to act as a channel while a pattern that is perpendicular to the flow would tend to distribute the runoff much better. As with the filter systems, operation and management of other treatment systems is important for their success. Grassed waterways, road ditches and channelized flow paths are not considered treatment systems under this subitem because they are included in the definition of waters of the state.

Subpart 4. Eligible open lot feedlots with fewer than 300 animal units. This provision identifies the eligibility criteria for facilities not subject to subparts 2 and 3. It is needed to set the animal unit capacity, operational criteria and registration requirements the feedlot owner must meet to be eligible for the long-term schedule of compliance in subparts 5 and 6. The requirement of 300 animal units or less is reasonable because this number provides consistency with the EPA's 300 animal unit boundary for animal feeding operations and with other sections of chapter 7020 which provide animal unit thresholds that distinguish specific requirements for the different sized feedlots. The provision requires any facility expanding to 300 animal units or more to meet the requirements of subpart 2 or 3, as applicable. As discussed in more detail below, the long-term (2003/2009) schedule of compliance is reasonable for facilities with fewer than 300 animal units because many, if not most, of these facilities have avoided the immediate complete fix requirement of the existing rules because the costs are often too great to bear when considering the short (2 years or less) schedule allowed under the existing frame work of the interim A and B permits issued by the agency and delegated counties. These owners may have also avoided the current program because of the unknowns of what will I have to do and by when. By providing a reasonable and achievable schedule and requirements, the owners will know up front what specifically is required and by when. The provisions under subparts 4 to 6 are reasonable because they provide a realistic and achievable schedule for owners to comply with and allow the agency a much better chance of meeting the desired environmental improvements at these facilities when compared to the current program. This provision further requires the eligible owner to comply with subparts 5 and 6 which identify the interim and final corrective and protective measures necessary to comply with the schedule of compliance. This is needed and reasonable because it directs the owner to the specific requirement that will apply upon meeting and accepting the eligibility requirements.

This provision also requires that portions of a facility that do not meet the eligibility requirements are not eligible for the long-term compliance schedule. This provision is needed and reasonable because the intent is to address open lot runoff problems which cannot be corrected on a short term schedule, and not to allow discharges for example, from a manure storage area or feed storage area to be eligible for the 2003/2009 schedule. This is reasonable because discharges from a feed storage area or manure storage area are typically much easier to address by covering the area open to precipitation or moving the storage area to a new location. Open animal lots are much more problematic to address, because of many factors such as, livestock access to buildings, permanent feed bunks or concrete slabs in the open lot areas and fencing are much more difficult to simply move or cover.

Item A requires that the feedlot be an existing facility. This is a needed and reasonable requirement because the intent is to allow a more cost effective means to install corrective measures and a new facility should not be approved or constructed with pollution problems.

Item B requires that the facility have manure-contaminated runoff from at least one open lot, but that manure-contaminated runoff from the facility cannot create or maintain an immediate threat to human health or the environment under subitem (1) and the facility cannot be a CAFO under subitem (2). The first part that requires manure-contaminated runoff from an open lot relates to the discussion above that areas that are not open lots are not eligible for this compliance schedule. Again, this is reasonable because the intent is to address manure-contaminated runoff problems from open lots. Subitem (1) is needed and reasonable to allow the agency to require corrective actions at an accelerated schedule if actual or imminent threat to waters or human health are observed during an inspection of the facility. Examples of what the agency would consider imminent threats include: a fish kill in a lake or stream resulting from the feedlot runoff; manure-contaminated runoff to a water body where humans swim or are likely to have direct contact; or a manure discharge into one of the areas identified in subpart 1. Subitem (2), which excludes CAFOs from eligibility for the 2003/2009 compliance schedule under this part is needed and reasonable because the case-by-case designation of a feedlot under 300 animal units as a CAFO would likely be undertaken only where a significant pollution hazards exists. Further discussion of the case-by-case CAFO designation process is provided in Exhibit P-3.

Item C requires that the owner be registered according to part 7020.0350. This is needed and reasonable because the agency and delegated counties need the registration information to accomplish the inspection prioritization planning and to have a mechanism for contacting the owners of these feedlots. In practice registration of the facility will most likely be completed at the same time the owner completes the requirements of Item D.

Item D requires the owner to submit a certification form to the commissioner or county feedlot officer that they agree to the conditions of subparts 5 and 6 of this part. This is needed to provide a formal agreement between the owner and the agency or county that the owner accepts the long-term 2003/2009 schedule. This is reasonable because it acts much like an application for a permit, where an owner acknowledges and agrees to the requirements of this chapter when proposing to operate a livestock facility. This is also reasonable because it provides the owner the opportunity to better understand the obligations being placed on him/her as an alternative to the immediately applicable requirements of subpart 3. The certification form will have a provision that provides a conditional waiver of civil penalties for past violations of part 7050.0215 caused solely by passive manure-contaminated runoff from open lots only and for failure to apply for a permit provided the owner maintains compliance with subparts 5 and 6. The term passive is intended to clarify that the civil penalty waiver applies to runoff events for which the owner has not acted to increase or promote manure-contaminated runoff from the lot. For example, a runoff event during a precipitation event without further human involvement would be a passive event. Examples of runoff events that would not be passive events include: if the owner adds to the volume of runoff or concentrations of pollutants in the runoff by stacking manure along the furthest down gradient area in the lot; or has directed water flow to manure covered areas to help flush the lot. This provision is needed and reasonable because it significantly increases the likelihood that a higher percentage of owners in this group will accept this schedule, even though they have not applied for a permit to correct their problems under the current program. If they are otherwise still subject to civil penalties for past violations, they will be much less likely to come forward to the agency or delegated county.

Subpart 5. Interim corrective measures for eligible open lots. This subpart requires feedlot owners that are eligible under subpart 4 to complete one of two relatively low-cost, interim improvement options at the feedlot by October 1, 2003. For the majority of these feedlots, the low-cost improvements identified in this subpart are in the range from $1,500 to $10,000, while a very small portion of these feedlots may have interim improvements that cost up to $20,000. Low-interest loans and government cost share dollars that pay up to 50 percent of these costs are available to many of these feedlot owners. Specific interim options include subitem (1) installation of clean water diversions and roof gutters for areas contributing to runoff from the feedlot and establishing buffer or filter areas having 100 feet or more of non-channelized flow through grasses, or (2) demonstrate that the treatment system achieves at least 50 percent removal of pollutants discharged from the feedlot. Under subitem (1) unit (b), the goal is that the buffer or filter not have channelized flow, visible evidence of manure solids, or areas of dead vegetation during the growing season within 50 feet of the end of the buffer or filter.

In general, the interim improvements are a reasonable approach to this category of feedlots for several reasons. First, unlike the federal regulation of zero-discharge for feedlots having 300 animal units or more and meeting one of two discharge methods, feedlots with fewer than 300 animal units are not held to this same federal standard unless they are designated a CAFO. This allows the commissioner to consider an interim solution for this category of feedlots. Second, a good portion of these feedlots discharge manure to surface waters because they do not have adequate runoff controls in place. Therefore, it is reasonable that 50 percent reduction in manure-contaminated runoff at the estimated 8,000 to 12,000 feedlots in this category, will result in significant environmental improvements on a statewide basis. This is further realized when comparing the current permitting approach that requires a feedlot to make complete improvements that can be significantly more expensive and under the current rules only a small number of these feedlots have an economic situation that allows 100% improvements in any year. These complete fixes are typically designed as collection and storage basins that range in costs from about $40,000 to $90,000 at the majority of feedlots (see Exhibit E-1). In some cases the high-end costs can reach $120,000 or more, especially when a composite liner system is needed because adequate soils are not readily available at or near the site or that minimal separation distance to bedrock is available at the site. This approach has proven to provide incentives for owners to avoid the permitting process altogether, resulting in improvements at only a very small percentage of these feedlots, and a corresponding small effect on overall environmental improvements. Third, by setting the date of October 1, 2003 for completing the interim measures, the provision is reasonable because it allows the feedlot owner adequate time and flexibility to consider multiple options and develop a long-term plan for the feedlot. Finally, this provision is reasonable because this group of feedlots, due to their smaller size, generally do not have the financial resources that the larger feedlots have that are needed to install more costly improvements for a complete fix on a short compliance schedule.

Item A requires owners meeting the eligibility requirements of subpart 4 to operate and manage the facility to minimize discharges of manure and manure-contaminated runoff from open lots at all times. This is reasonable, for example, because it requires owners to scrape manure off open lots on a regular frequency to minimize manure-contaminated runoff from the lot.

The interim improvement requirements under Item B, subitem (1)(a) and (b) which require roof gutters, diversions and vegetated buffer areas or filter strips to be installed and operational by October 1, 2003, are reasonable because these measures minimize the volume of rain and snowmelt water that would otherwise pass through the feedlot or manure storage area and mix with the manure. This clean water diversion in turn results in a significant reduction in the volume of manure-contaminated runoff that must be handled and, because the manure will have a higher solids content, the manure will not be able to flow as easily as it would with a higher water content. Under the second part of this subitem, the treatment distance of 100 feet or more is reasonable because it establishes a clear requirement for owners to achieve. This provision provides an incentive to minimize open manure storage or open lot surface area. Staff believe that 100 feet of treatment distance will be more than needed in some cases and less than needed in others. However, staff's experience indicates that a distance of about 100 feet of non-channelized flow will provide needed interim environmental controls at the vast majority of sites.

The interim improvement requirements established in Item B, subitem (2), which require that the owner demonstrate that the treatment system achieves at least a 50 percent reduction in phosphorus and BOD_5, is reasonable because it again establishes a clearly defined requirement for the owner to achieve. It is also reasonable because, similar to the discussion above, significant environmental improvements will be gained statewide through the approach of 50 percent or better reduction in pollutant loadings at most of the feedlots compared to getting complete fixes at a small percentage of these feedlots.

The most readily available tool for demonstrating 50 percent reduction is the model "An Evaluation System To Rate Feedlot Pollution Potential" (Exhibit M-34) or more commonly known as the Feedlot Model. Using the Feedlot Model for a comparative analysis such as this is a reasonable approach for demonstrating the 50 percent pollutant reduction because it is widely available to private and NRCS design engineers, other technical assistance personnel such as Soil and Water Conservation District (SWCD) staff, county feedlot officers (CFOs) and MPCA staff. In addition, evaluating various corrective and protective measures and rating pollution potential at animal feedlots are the type of application that the Feedlot Model was developed for. Contrary to current understanding by some users of the Feedlot Model, the model was not intended to, and the agency does not acknowledge use of the modeling results to determine compliance with the effluent limits in part 7050.0215. Again, the agency believes this is the best tool available to demonstrate compliance with the 50 percent reduction criterion for interim measures under this part. This provision requires that the modeling be completed by a person who has completed training in use of the model. The model is relatively simple to run including any of the computer program versions or manually. The requirement to have a Feedlot Model-trained person demonstrate the 50 percent pollutant reduction is reasonable because, while relatively simple, the model requires an understanding of the significance of the input values and how to apply each to specific feedlot sites to obtain a meaningful evaluation. Currently, training is available to most NRCS, SWCD and agency staff through the Board of Soil and Water Resources. The agency also intends to provide training in use of the model to the county feedlot pollution control officers.

Staff considered concerns from rule commenters that this option, subitem (2), would be less protective of the environment than the subitem (1) option and should only be allowed if subitem (1) cannot be accomplished at the feedlot. There is a possibility that less than adequate improvements will result at some at feedlots that demonstrate a 50 percent pollutant reduction. The agency intends to consider these facilities on a case-by-case basis through the commissioner's authority to designate a feedlot as a pollution hazard and require corrective or protective measures in an interim permit or by the case-by-case designation as a CAFO process provided in Exhibit P-3. The primary criteria to be used when determining the extent of the problem are, again, if there is an immediate threat to human health or the environment (e.g., a fish kill or discharge to a conduit to drinking waters). The MPCA's intent with this approach is to identify these significant hazards based on a systematic inspection program conducted by MPCA staff and CFOs.

Finally, subpart 5, item B(2) requires the owner to maintain records of the Feedlot Model modeling results until the owner has completed the requirements of subpart 6. The owner is also required to make these results available to the agency or county feedlot officer upon request. This is reasonable because it allows the owner to demonstrate compliance with this provision and provides the agency or county an opportunity to review the modeling records to evaluate how the input values and modeling results compare to actual facility operation.

Subpart 6. Final corrective measures for eligible open lots. The requirements of subpart 6 are identical to the requirements of subpart 3 except that these requirements are triggered in item A upon the October 1, 2009, date; or in item B when the owner chooses to make a change at the feedlot which increases the number of animal units housed at the feedlot. This requirement is reasonable for feedlots expanding in animal number because they likely have the financial resources to install corrective or protective measures to eliminate discharges if they have the resources to expand their facility in animal numbers. It is also reasonable, because it is consistent with the MPCA's current policy on requiring feedlots to eliminate violating discharges prior to completing a planned expansion in animal numbers. The requirement to comply with subpart 2 or 3 upon an expansion in animal numbers applies to owners at any time after the owner has completed the certification form under subpart 4 and agreed to the terms and conditions of this part.

The October 1, 2009, date for completing final corrective measures was selected to provide owners with sufficient time to defer costs of installing final corrective measures over an extended time period. The 2009 date was selected for two primary reasons. First, the agency has viewed the overall feedlot program plan for feedlots, manure storage areas and pastures as an approximate ten-year plan. See Draft Feedlot Program Plan, Exhibit I-4. This plan includes the agency's goal of inspecting all facilities within the state within the ten year period. Second, the year 2009 is the date by which USDA/EPA desire that all animal feeding operations (AFOs) have and are implementing a comprehensive nutrient management plan (Exhibit G-2). Therefore the

2009 date is reasonable because it is consistent with the agency's Draft Feedlot Program Plan and USDA/EPA's AFO Strategy.

7020.2005 Location Restrictions and Expansion Limitations

Subpart 1 contains the agency's proposed restrictions for locating new animal feedlots and manure storage areas near environmentally-sensitive areas or that could become direct conduits to surface waters or ground water. Current feedlot rules do not contain location or setback requirements, yet preventing manure and runoff from manure from entering surface and ground water is essential and a major goal of the feedlot regulations. Location restrictions in the proposed rule will reduce the potential of animal manure runoff that if allowed to enter surface or ground water, can cause serious water pollution. Manure and runoff from feedlots can promote algae and weed growth in lakes and rivers, can deplete oxygen, can be toxic to aquatic life and can pollute both surface and ground water by introduction of large concentrations of nitrates and pathogens.

Subpart 1 prohibits a feedlot owner from locating new feedlots within a shoreland; floodplain; within 300 feet of a sinkhole; 100 feet of a private well; or 1,000 feet of a community water supply well or other wells serving a school or child care center in certain geologic conditions. The specifics regarding the sensitivity of these locations to impacts from manure or manure-contaminated runoff are discussed in detail in the following paragraphs. The proposed rules contain only the restriction needed at a statewide level. These facilities are also subject to any established location standards in local government zoning ordinances. The agency believes that it is reasonable to establish location restrictions in rule to provide a minimum level of protection for all of Minnesota and to provide the feedlot owner information on the agency's expectations. The specific restrictions are reasonable for the reasons provided in the discussion for that standard.

The location restrictions are needed to protect human health and the environment. The agency's basic statutory authorities outlined in Minn. Stat. ch. 116 charge to protect human health and the environment regardless of the program being implemented. Subpart 1 and the other provisions under part 7020.2005 do not establish facility locations based on aesthetic and nuisance conditions, such as proximity to residential development or highways. Aesthetic and nuisance restrictions are under the jurisdiction of local governmental zoning ordinances. The location restrictions in this subpart address impacts of facilities in the areas particularly sensitive to discharges of manure or manure-contaminated runoff.

Geologically sensitive areas are normally considered to be areas where bedrock is susceptible to dissolution and ultimately forming cracks, fissures and large holes visible at the soil surface. This type of bedrock is normally referred to as karst geology and has very little protection from soil covering. Sinkholes, holes in the bedrock, provide a pathway for rapid transmission of surface runoff into ground water, circumventing any treatment or filtering capacity of the natural soil that overlays the bedrock. The 300-foot setback was chosen to increase the amount of pathogen die off and ammonia volatilization before surface runoff can enter the sinkhole. Essentially, as the runoff would move toward the sinkhole, the runoff would seep into the upper layers of soil and be taken up by vegetation, absorbed to the soil particles, or be altered by soil bacteria. The outcome of the natural treatment system is reduced risk to human health and the environment. A setback distance of 300 feet provides an area of natural protection from contaminated runoff that might occur if there is failure of a manure storage system or manure handling equipment. This 300-foot setback does not preclude the project proposer from meeting any of the manure storage requirements of part 7020.2100 pertaining to construction of manure storage areas in karst areas. The 300-foot setback is reasonable because sinkholes are large openings usually at a low spot in the landscape and accept drainage from a broad range. By keeping the facilities farther from the sinkhole, the likelihood that other surface water flow will carry the manure-contaminated runoff to the sinkhole is lessened.

Subpart 1 also establishes a restriction on the proximity of animal feedlots or manure storage areas to private wells. Private wells are owned and used by a single property owner for livestock or human consumption. The definition for private wells is found in the Minnesota Department of Health rules, Minn. R. ch. 4720. Private wells are susceptible to surface runoff of manure, particularly older wells that may not have been constructed under current standards requiring casing and grout. Contaminated runoff that seeps into the ground in the vicinity of private wells can cause acute contamination of the water source. In addition, contaminated runoff may travel into the ground water along the interface of the well casing and the surrounding soil resulting in no treatment of the runoff before it reaches the ground water supply. Therefore, it is important that animal feedlots and manure storage areas not be constructed near wells. The 100-foot setback provides an area of natural protection to allow for pathogen die-off, ammonia volatilization, and seepage into the soil prior to reaching the well.

Restrictions from municipal or community wells are also contained in subpart 1. Municipal wells and community wells are defined in Minn. R. ch. 4720, and usually serve persons or activities outside of the well owner. The number of individuals who could be negatively impacted by a contaminated well is significantly higher with these well types than with a private well. Municipal wells are susceptible to surface runoff for the same reasons as private wells. However, a larger setback of 1,000 feet is required to protect a larger wellhead area. Municipal wells, in particular, pump at higher rate than private wells and thus, any contamination entering the ground water could be drawn to these wells from a larger area as they drawdown the ground water level. This requirement does not preclude tighter requirements that have been developed by municipalities in their wellhead protection area plans as required by the Minnesota Department of Health. The setback is reasonable due to the larger pumping capacity, the greater number of people potentially impacted, and that the distance provides a buffer zone should the municipality need to expand its well field.

Shoreland areas are susceptible to impacts from a number of activities because of the proximity to surface water. The shoreland typically has the potential to be a direct conduit to the surface water for erosion, contaminants, or other types of impacts. Subpart 1 provides a setback restriction to prevent impacts from manure or manure-contaminated runoff. Per the proposed subpart, new animal feedlots or manure storage areas shall not be constructed within shoreland. The restriction is consistent with the Minnesota Department of Natural Resources' Statewide Standards For Management of Shoreland Areas, part 6120.0300, subp. 7, item C, unit 1.

Construction within shoreland areas poses a significant risk to the adjacent waterway if failure or mishandling of the manure management systems were to occur. It is reasonable that the agency's rules are consistent with those rules developed by the Minnesota Department of Natural Resources, which is the agency responsible for managing activities within shoreland areas. Additionally, local zoning authorities also use this restriction as a protection measure and the proposed rule would be consistent with those efforts. It would be unreasonable for the agency to establish a provision that would put feedlot owners in violation of other rules.

Similarly, the agency proposes that a restriction for new feedlots or manure storage areas be established regarding floodplains. Floodplains are areas prone to rapid water movement during flood events. The greater the likelihood for flooding, once in ten years, defines an area as a floodplain. Feedlots need to be located outside of floodplain areas to ensure floodwaters do not impact the feedlot, manure storage structures, or cause manure-contaminated runoff during flood events. Once again, the Minnesota Department of Natural Resources manages activities within floodplains. It is reasonable to alert feedlot owners that the activities associated with feedlots and manure management are not consistent with the state's rules regarding floodplains.

The proposed location requirements were selected in the event that a facility fails to adequately contain the manure it generates, a site's natural conditions can help to protect ground water and surface water, and control migration of the manure if a failure were to occur. For instance, if a manure spill were to occur it would have greater travel distance to permit seepage into before reaching a surface waterbody or other environmentally sensitive receptor.

Historically, feedlots were sited on near surface waterbodies to permit the animals access to water. Additionally, this land was not highly productive cropland when regularly lost to floods or erosion patterns along a streambank. Unfortunately, the same natural conditions that make these sites desirable for siting feedlots also raise the level of environmental risk. Thus, it is necessary for animal feedlot operations to locate where the natural condition will minimize the impact of any manure releases.

Although the facility design and operation provisions require containment and land application of all manure generated on site, these precautions do not guarantee total containment. Releases can occur due to human error in facility operations or a failure in the structural or mechanical components. Corrective actions to contain and recover pollutants are not assured of complete success either. In summary, it would be unwise to rely solely on engineered solutions for protection; but rather, the natural setting must provide a second line of protection.

Item A. Under subpart 1, two special conditions are addressed relative to the restriction standards. Item A establishes an exemption to these location requirements as they pertain to construction in the Red River of the North floodplain. The Red River of the North floodplain is a unique floodplain. This floodplain was created as a lakebed, not a river valley, according to geologists. The floodplain lies in the dried lakebed of glacial Lake Agassiz, and therefore, has very subtle slopes and generally very little change in topography. This flatness tends to exacerbate flooding since there is only a very shallow gradient to promote runoff of snowmelt and precipitation, slowing drainage. There is no topography to constrain flooding, which results in water spreading out over a very wide area. This results in a gradual flooding of large tracts of land. Because such a large area is affected when flooding occurs in this area the Red River is closely monitored and warnings about flooding are giving well in advance of the actual flooding event. This allows residents within the floodplain to take precautions before the flooding event occurs. In addition to the different nature of the flooding in the Red River floodplain, this floodplain encompasses a large area of land of which about 75 percent is in agricultural use. The flooding potential of the Red River of the North is closely monitored and precautions are often instituted before a flooding event occurs. Other floodplain areas in the state are located in river valleys that were carved areas of more topographic change and result in a more rapid flooding that can be devastating to farm structures. Because of the large amount of area encompassed by the flooding, and the difference in the nature of the flooding events in this area it is reasonable to exempt the Red River of the North from this locational requirement. The selection of 1000 feet is consistent with the typical floodplain zone or shoreland setbacks for lakes. While 1000 feet is greater than the shoreland or flood zones associated with rivers and streams, the agency believes it is reasonable to provide a greater zone of protection due to the topography of this watershed. It would be unreasonable to establish the entire floodplain as a restrictive zone, as animal production would be restricted in a large portion of Minnesota's northwestern corner. However, the setback restriction is a figure consistently used in managing activities in this area pertaining to lakes and other surface waterbodies and does not require a change in scope for most activities.

Item B. Item B addresses the re-establishment of feedlots in shoreland areas. One operating practice that owners have employed over the years has been to enter and leave markets for livestock as the prices rise and fall. Under this practice, an owner may raise one type of animal for several years when the market is favorable and raise another when that market is favorable after leaving the facilities for the first animal unused for some time in the process. The proposed rules are intended to allow this practice and still limit owners from reusing facilities that are located in shoreland areas where an animal feedlot or manure storage area should not be located due to environmental concerns.

The proposed definition of "new animal feedlot" means an animal feedlot or manure storage area that existed previously and has been unused for a period of three years or more. With the proposed prohibition of establishing a new animal feedlot or manure storage area in shoreland, the proposed rules would have prohibited owners from using existing facilities that could be slightly older than three years. This could result in a situation where an owner has invested a significant amount of money in the facility and has not been able to recover the cost of the facility.

The proposed rules are intended to allow the owners that have left a market for some time due to unfavorable prices to continue to use the facility and operate in a method that allows the owner to enter and leave markets based on the profitability of the market. The proposed rules are also intended to prohibit an owner from abandoning a facility that is in a bad location and then reopen it many years later. As stated in the Statement of Need, the impact of run off from an animal feedlot or manure storage area in shoreland can have a devastating impact on the water quality. For this reason, it is reasonable to limit the amount of time that an animal feedlot or manure storage area can be abandoned and then reopened. The proposed rules state that if the facility has been unused for ten or more years, that it cannot be reopened. Ten years is a reasonable amount of time to allow owners of these facilities to close and for market reasons. It is reasonable to believe that if an owner is not using a facility for more than 10 years that the cost of that facility has been recovered or written off and new activity at the location should be considered to be a new animal feedlot.

Subitem 1 permits the re-establishment of feedlots in shoreland areas provided the facility has not have been out of operation for more than 10 years and an interim permit is obtained under part 7020.0405. This is needed to reasonably address existing facilities that had substantial capitol investments made in feedlot building and manure storage areas and have only been out of operation for a short time. The requirement to obtain and interim permit ensures that the facility is brought into compliance with the current standards and if the standards are not attainable the reopening of the facility would be prevented permanently. The primary intent of this subitem is to allow the permitting authority to inspect the facility prior to restocking and requiring the owner to take whatever measures are necessary to comply with the technical standards including the discharge standards. For these reasons, the proposed requirement for these owners to apply for and obtain an Interim permit is reasonable. The agency believes this provision to be reasonable as the facilities will meet the proposed technical and operational standards while making use of existing investments.

Subitem 2 expressly resuming operations of facilities located in shoreland areas and out of operation for ten years or more. These facilities would typically require more investment than warranted for the safe operation in a shoreland area. It is also believed that facilities not operating in these areas for more than ten years have in the past experienced difficulty in operating in an environmentally-safe manner and should not be permitted to start up again. The agency believes that a facility not operating for more than ten years is essentially a new facility and therefore, it is reasonable that they be required to meet the locational restrictions placed on new facilities.

Subpart 2 limits an existing feedlot with fewer than 1,000 animal units located in a shoreland area to expand up to 1000 animal units. As discussed in the Statement of Need, the consequences of large amounts of manure can be significant, resulting in fishkills if the discharge is very large over a relatively short period of time or resulting in a waterbody that cannot support fish if the discharge is chronic. The intent of this requirement is to limit the amount of manure that will be present in these areas. For these reasons, it is reasonable to prevent the expansion of feedlots or to require protective measures of facilities that pose water quality hazards.

Feedlot owners will be able to determine the elevation of the ordinary high water mark by obtaining a Protected Water Inventory Map from the local SWCD, Watershed District, County Auditors office, local DNR office, County Zoning office, or County Engineer’s office. If the ordinary high water mark is unavailable from this map, the local Minnesota Department of Natural Resources staff will establish the mark or it can be determined using the following US Army Corp. of Engineers definition. The definition reads: “The "ordinary high water mark" on non-tidal rivers is the line on the shore established by the fluctuations of water and indicated by physical characteristics such as a clear, natural line impressed on the bank; shelving; changes in the character of soil; destruction of terrestrial vegetation; the presence of litter and debris; or other appropriate means that consider the characteristics of the surrounding areas.

Subpart 3 reads as a prohibition for the expansion of animal feedlots and manure storage areas in floodplains except in the Red River of the North floodplain. Animal feedlots and manure storage areas in the Red River of the North floodplain may expand only if the facility is at least 1,000 feet from the ordinary high watermark. The floodplain is estimated to extend nearly 100 miles from the ordinary high watermark. Given the size of the Red River floodplain, it would be reasonable to prohibit expansion within this area.

7020.2010 Transportation of Manure

This provision requires that manure haulers use practices that will prevent the deposition of manure on roadways during transport to land application sites. The existing rule controls pollution from manure hauling equipment by requiring them to be leakproof. While leakproof containers reduce the likelihood of manure spillage on roadways, it does not address other ways in which manure may be deposited on roadways. It does not, for example, address situations where manure, loaded above the level of the containment device, lands on the roadway from wind or cornering or other forces. This type of spillage is as common as problems associated from leakage. The proposed language address all situations by the establishment of a performance standard and not by defining the type of equipment to be used. The proposed language is because the performance measurement allows operators to decide how to meet the standard based on conditions unique to their manure management system. Additionally, the provision is consistent with other agency rules governing the transport of waste materials and the Department of Transportation’s rules for transporting waste or raw materials. The negative impacts associated with manure spillage to surface waters indicates the need that this sector be treated like other sectors posing risk to the environment.

Under existing language, roadways that are used for hauling manure from the feedlot to adjacent fields are exempted. This provision has been difficult to interpret. Also, the increase in increase in population of non-farm residences is increasing the traffic on all roads. For these reasons, the agency proposes to delete current roadways exemptions so that the rule applies to all roads.

7020.2015 Livestock Access to Waters Restriction

The agency intends with this proposed part to minimize or eliminate the water quality impact of locating livestock in close proximity to a waterbody so that the livestock do not have body contact with these waters. The primary concerns are manure directly from the livestock either from direct deposition or the animal bathing and thus, removing caked mud/manure from its body. A secondary impact would be manure-contaminated runoff from feeding areas directly along the lakeshore. Since pastures by nature have the potential to produce significantly less runoff, the proposed language focus on the direct access to lakes for animals fed in or housed in pastures. The agency believes provision provides a performance measurement that is flexible enough for the livestock owner to develop a management approach capable of meeting the standard. This part requires that livestock owners prevent or control livestock from entering any lake, which has been classified by the DNR as a natural environment lake, general development lake or general recreational lake. The DNR defines these lakes in Minn. R. pt. 6120.3000. These lakes are most likely used by humans and thus, the deposition of manure directly in the lake will put human health at risk.

When animals enter these lakes, they deposit fecal material directly into these waters creating both a pollution and health hazard. The average dairy cow produces approximately 115 pounds per day of manure, which, if allowed to enter the lake, would contribute 0.57 pounds of Nitrogen and 0.24 pounds of Phosphorus daily to the water. These amounts can have significant impact. It has been estimated that every one pound of phosphorus added to the surface water will generate 500 pounds of algae growth. In addition to the direct deposit of manure from the animal, the shoreland where the cattle congregate and/or enter the lake also becomes eroded and manure packed. This results in sediment and additional manure entering the lake during periods of precipitation.

The state of Minnesota has established a number of rules to protect its lakes from environmental degradation. Since 1974, the state of Minnesota has required proper individual sewage treatment within shoreland areas. This was done in recognition of the significant impact that human sewage could have on the lakes water quality. Animal manure also has a very significant potential for impacting surface water and, therefore, the state of Minnesota clearly needs to address this problem.

Subpart 1. This proposed subpart reads that the owner of any animal feedlot that meets the criteria for CAFO or has a feedlot supporting more than 1000 animal units the livestock must be prohibited entering the identified lakes. Since the federal discharge standard for CAFOs is zero discharge, it is reasonable to propose this prohibition.

Subpart 2. This proposed subpart states that any non-CAFO animal feedlot is required to fence identified lakes by October 1, 2001, to prohibit entry to identified lakes. As stated earlier in this SONAR, manure and manure-contaminated runoff can lead to significant water quality and health problems. For this reason, it is reasonable to prohibit livestock at all animal feedlots from entering the identified lakes. Since these facilities will not have been subject to this requirement prior to the effective date of this proposed rule, it is reasonable to allow the owners sufficient time to comply with this requirement. For this reason, it is reasonable to delay the compliance date. The compliance date of October 1, 2001, was selected because it did not require immediate compliance and yet, eliminated the undesirable practice quickly. Since the solution is likely the installation of a fence, the agency believes that the time frame is reasonable. No agency or delegate county review is required and thus, no administrative oversight should slow the process to control access to the lake.

Subpart 3. This proposed subpart states that any facility that meets the definition of pasture (part 7020.0300, subp. 18) is required to prohibit (item A) or control the access of livestock to identified lakes by October 1, 2001 (item B). The proposed rules require that if the owner chooses to control, rather than prohibit, access to the identified lakes, the control measures must conform to the measures established in Minnesota Natural Resources Conservation Service, Field Office Technical Guide practice codes (Exhibits T-1 and T-2) and the United States Department of Agriculture, Natural Resources Conservation Service, National Range and Pasture Handbook (Exhibit T-3). These methods are intended to minimize the water quality impact of livestock entering and leaving waterbodies by minimizing erosion of the shore and reducing the desirability to the livestock of standing in the water. The agency believes that these methods have been sufficiently reviewed by livestock managers at a national level to ensure they are sufficiently protective. Additionally, the agency believes it is reasonable to incorporate existing practices utilized in other programs that meet the agency's goals to protect human health and the environment.

Proposed part 7020.0300, subp. 18, defines pastures as areas where grass or other growing plants are used for grazing and where the concentration of animals is such that a vegetation cover of perennial grasses or forages is maintained during the growing season and temporary supplemental feeding devices are located outside special protection areas. This proposed definition restricts the use of the term pasture to grass-covered areas, which produce little or no runoff during the growing season. This definition also requires that supplemental feeding device be located at least 300 feet from the waterbody. The proposed setback keeps the livestock from congregating at the shoreline and increasing the erosion and runoff from the area. The proposed rules allow watering within 300 feet of the shore to reduce the cost to pump water to stock tanks. As stated above, the proposed rules are intended to be less stringent for operations that meet the proposed definition of "pasture" to provide an incentive to owners to operate in this manner. Well-managed pastures have significantly less environmental impact than open lots and for this reason, it is reasonable to propose this incentive.

<u>7020.2025 Animal Feedlot or Manure Storage Area Closure</u>

This part sets out the minimum requirements for closure of a facility by the owners once the facility has ceased to operate.

Item A. Item A requires that within one year of ceasing operation, a feedlot owner must remove and land apply manure and manure-contaminated soils in accordance with the proposed land application provisions (part 7020.2225) of this chapter. This subpart sets out the procedures necessary to close an animal feedlot operation in a manner that protects human health and the environment. This time frame should not be a burden to owners or operators since manure is typically removed annually at most feedlot operations. Also, it is advantageous to the owner to land apply manure before it declines in nutrient value. It is reasonable that the agency establish expectations for the proper closure of these facilities. The time frame of one year was selected to ensure that the facility was properly closed to reduce risks, but allowed the feedlot owner the opportunity to properly land apply the material when it would be most valuable in terms of nutrients and availability to crops.

Item B. In item B, the agency requires the owner to establish vegetative cover to facilitate more nutrient uptake and prevent erosion and runoff. Item B also requires the owner to maintain this vegetative cover for at least five years. While it's not possible to say that five years will remove all of the excess nutrients or that five years is longer than is necessary, this time will remove a significant amount of the nutrients and is not excessively long because the crop taken from this land will have value.

Items A and B are both reasonable because if left untreated concentrations of manure and nutrient overloaded soil could pose potential ground-water problems through leaching and surface-water problems through run off.

Item C. Under item C, the agency requires the facility owner or operator to notify the commissioner or CFO at least 60 days after closure of the facility. The notification is needed to allow the agency or delegated county to verify that the facility has been closed according to the requirements in items A and B. The agency needs verification because it is responsible to ensure closure activities are completed in a manner that protects human health and the environment. It is reasonable that the agency and CFO understand that a facility is no longer in operation and has been closed properly.

7020.2100 Liquid Manure Storage Areas

The existing feedlot rules require plans to submitted with a permit application for proposed manure storage structures (existing part 7020.0500, subp. 2, item C). The existing rule requires that only plans for structures of 500,000 gallons capacity or greater be prepared or approved by a professional engineer or Natural Resources Conservation Service (NRCS) employee. The proposed rule, part 7020.2100, will primarily codify current program practices and policy and formalize many of the specific provisions currently used by the agency and delegated counties during the review of permit applications and processing of interim, SDS and NPDES permits issued for proposed liquid manure storage areas. This part is needed to provide predictability and reliability to the regulated parties and is reasonable because it makes these requirements readily available for owners and the general public. This section is essential for the program as a whole when considering the proposed modifications to the permitting program, under which not all owners are required to apply for and obtain a permit prior to constructing. This part will also assist the agency and some delegated counties in improving permit application review and issuance times and focusing resources on facilities that pose the greatest environmental risk and greater field presence. These issues were both identified in the Program Evaluation Report by the Legislative Auditor as areas needing improvement in the current program. See Exhibit G-1. The agency has also drafted feedlot program goals to address the issues of field presence and permit review and issuance time. See Exhibit I-4.

In general the need and reasonableness of the provisions in part 7020.2100 relate to the hazards to groundwater posed by storing liquid manure which were also discussed in this SONAR, but are discussed briefly here to highlight the specific issues related to storing liquid manure. Manure contains a number of materials which have the potential to pollute ground water including compounds which may be converted to nitrate, as well as microorganisms that may cause disease in humans that consume ground water as a drinking water supply. The following are primary drinking water standards for compounds or microorganisms that may be associated with manure. See Exhibit M-22.

Nitrate	10 mg/1
Total coliform organisms	1 most probable number per 100 milliliters

While typically manure contains very low concentrations of nitrate, it does contain very high concentrations of nitrogenous compounds such as ammonia, urea, uric acid, and other organic forms of nitrogen, which may be converted to nitrate by microorganisms in the soil. Nitrate is readily used by plants or some soil microbes. However, ground water can leach nitrate out of the plant rooting zone in the upper layers of the soil, and eventually move to an aquifer. Nitrate generated from materials leached from the manure storage system and carried by ground water flow to a drinking water source may create potential human or livestock health effects. In particular, babies consuming drinking water that exceeds 10 mg/1 nitrate may develop methemoglobinemia, or “blue-baby syndrome,” which can be fatal.

There are a number of other parameters monitored in ground water to detect manure-related pollution, including chloride and sulfate, for which there are secondary drinking water standards. Pollutants such as phosphorus can be transmitted in soluble form through ground water and may in some circumstances return to surface waters. See Exhibit M-23. There may also be pathogens (disease-causing microorganisms) in the manure such as Escheri coli, Salmonella, and Cryptosporidium. See Exhibit M-24. While soils can act as a “filter” to trap bacteria and protozoans to prevent movement to ground water, microorganisms may still travel through macropores in the soil such as fractures, earthworm burrows, or decayed root channels to shallow aquifers that may be in contact with drinking water supply wells. This can result in these microorganisms being transported through the drinking water system, particularly if contaminated ground water enters defects in well casings. See Exhibit M-25. Analysis for fecal coliform bacteria serves as an indicator that fecal material is present in the water source, and that pathogens could be present in the water sampled. Discharges to surface waters from spills also are a concern.

Phosphorus in various forms is also present in manure. Aquatic plant growth in most surface waters is limited by phosphorus concentration, and additional inputs from manure in runoff or from a discharge from manure-storage systems will result in increased aquatic plant production. This can increase the rate of eutrophication of lakes and wetlands, and decrease water clarity. Manure can also increase the level of total suspended solids and turbidity in the surface water.

In addition, livestock production-related materials such as antiseptics, antibiotics, footwash materials, etc., may be put into the system along with the manure. These can be a direct hazard to water, if leached from the storage system or discharged into surface waters. In order to limit and minimize the potential for pollution of ground water from the nitrate, phosphorus, bacteria and other hazardous compounds, it is needed and reasonable to require that liquid manure storage areas be designed, constructed and operated according to the standards required in this part. The need and reasonableness of each subpart is described in more detail below.

Finally, MPCA staff, with assistance from consulting engineers, government agency staff, producers and manure management consultants, have discussed policy issues related to earthen manure storage basins and other liquid storage structures which are summarized in the following documents:

- Animal Manure Storage Pond Groundwater Quality Evaluation (Exhibit M-4);
- Manure Storage Criteria and Policy Development in Minnesota (Exhibit M-5);
- Effects of Clay-lined Manure Storage Systems on Groundwater Quality in Minnesota: A Summary (Exhibit M-1);
- Seepage From Earthen Manure Storage Systems (Exhibit M-3);
- Clay-lined Earthen Manure Basins (Exhibit M-2); and
- MPCA Soils Investigations for Feedlots and Manure Storage Facilities (Exhibit M-26).

The agency has also developed guidelines to assist designers and regulatory staff in the development and review of plans and specifications. These guidelines incorporate recent research and are derived, in part, from the Natural Resource Conservation Services (NRCS) Standards 425 (Exhibit M-15) and 313 (Exhibit M-9), and from meetings and work products of the Feedlot and Manure Management Advisory Committee's. Many of the provisions in the guidelines and of this rule part are based on recommendations of the FMMAC concrete and earthen basin task forces. FMMAC's Concrete Manure Storage Task Force and Earthen Basin Task Force assisted in the development of the following:

- MPCA Guidelines for Concrete Manure Storage Structures (Exhibit M-11);
- MPCA Contractor's Inspection Record of Manure Pit Construction (Exhibit M-16);
- MPCA Photographic Inspection of Concrete Manure Storage Pits (Exhibit M-17);
- MPCA Guidelines for Design of Cohesive Soil Liners for Manure Storage Structures (Exhibit M-18); and
- MPCA Guidelines for Alternative Liners for Earthen Storage Structures (Exhibit M-14).

Subpart 1. Subpart 1 sets out the content of this rule part which is the permitting, design, construction and operation of liquid manure storage areas. Subpart includes three requirements: (1) that, except those meeting the site restrictions of subpart 2, all liquid manure storage areas must be designed constructed, maintained and operated according to subparts 3 to 7; (2) that owners must submit a permit application as applicable in part 7020.0405; and (3) that owners not required to apply for a permit must complete the notification requirements of subpart 5. These provisions are needed to inform the owner that this part applies broadly to design, construction, maintenance and operation of liquid manure storage areas, and not just to owners that are required to obtain a permit. These provisions are reasonable because they direct the owner to the applicable section which may apply to their liquid manure storage area.

An important requirement of this provision is that owners must submit their plans and specifications to the commissioner or delegated county feedlot pollution control officer. For this example, the inclusion of the reference to subparts 3 to 7 is reasonable as it directs the owner to subpart 4 where the requirement to submit plans and specifications is expressly stated. This is appropriate as the agency or delegated county has authority to review proposals for construction of manure storage areas, which is needed to ensure that these storage areas are designed, located and will be constructed in a manner consistent with the applicable technologies in order to prevent pollution of ground and surface waters.

The requirement in this part to submit plans to the agency or delegated county are also in the facility owner's best interests. The owner is prohibited from beginning construction until the permit application has been reviewed and approved in the form of a permit or the owner has not been asked to modify the proposed design if no permit application is required. In this way, potential sources of negative impacts on water quality will be better identified and controlled or minimized. In addition, the MPCA has the opportunity to assess the likelihood of any potential future damage to the structure. The opportunity for agency review may provide additional protection to the owner from potential financial loss that might result if construction were to begin and the structure was later determined to be in non-compliance as a result of site or structural deficiencies. Ultimately, the responsibility of proper design and construction lies with the operator/owner along with any liability for environmental damage resulting from these structures. The agency intends to conduct a summary review on the majority of these plans and specifications, while focusing staff resources and review efforts on the proposals, which present the greatest risk to the environment. It would seem, therefore, reasonable and desirable to have the agency or delegated county advise and assist the owner and design engineer during design process instead of waiting until the formal review process following submittal of the plans.

Subpart 2. Subpart 2 lists four main geographical situations where construction or expansion of liquid manure storage areas is prohibited. An exception is made when construction or modification is required to resolve existing pollution hazards at a feedlot having fewer than 300 animal units. The need and reasonableness of this exception is described in this SONAR under item C. The location and expansion restrictions under part 7020.2005 are referenced in this provision to clarify that those restrictions apply to this part. The need and reasonableness of these restrictions is described in this SONAR under part 7020.2005. In summary, referencing part 7020.2005 here prohibits liquid manure storage areas within a 100-year flood plain as structures located within the floodplain may be damaged or inundated from floodwater and within shoreland as provided in part 7020.2005, subparts 1 and 2. The floodplain provision will eliminate one of the highest-risk pollution threats created as a result of manure storage location. A 100-year floodplain area has a one in 100 chance of flooding in any given year. Thus, it is inappropriate to build a storage structure in such an area where it can potentially be damaged by flood water, and potentially result in large quantities of manure to be carried away by flood water. The shoreland provision minimizes the potential for surface water pollution from manure and process wastewater discharges.

Item A. In item A, the agency proposes to prohibit construction of liquid manure storage systems with a capacity of more than 250,000 gallons where geologic conditions are suitable for sinkhole development and where four or more sinkholes exist within 1000 feet of the proposed site. In order to trigger the criteria in this provision, the facility has to have four or more sinkholes within 100 feet and be in a geologic setting suitable for sinkhole development. This is reasonable because a facility within 1000 feet of four sinkholes and located where the first bedrock encountered is the Jordan Sandstone or a stratigraphically lower unit. It would be unreasonable to limit construction at that facility because the underlying bedrock unit results in little to no potential for karst sinkhole development. The 250,000-gallon limit in this provision is reasonable to minimize the probability of negative impacts resulting from sinkhole formation under a liquid manure storage area causing a failure of the system and to minimize the degree of negative impact resulting from failure of a liquid storage area liner. The larger the liquid storage structure, the greater the probability that a failure will occur. See Exhibit M-27. If failure occurs, the 250,000-gallon limit also limits volume of manure reaching waters of the state. The agency has also developed draft guidance to further address the issue of reducing the environmental risks associated with constructing liquid manure storage areas in the karst region. See Exhibit M-13.

In item B, the agency proposes to set minimum separation distances to bedrock in the karst region for construction of liquid manure storage systems. These proposed restrictions are needed to reduce potential water quality risks associated with constructing liquid manure storage systems in those areas, which are the highest risk for failure. The current rules do not directly address sinkhole risks and separation distances to bedrock in the karst region.

Three potential water quality risks associated with liquid manure storage systems in the karst region include: 1) seepage of contaminants through the liner and underlying soil to fractured bedrock and subsequently to ground water; 2) soil subsidence below the structure which breaches the integrity of the concrete, geosynthetic or soil liner, causing a slow and perhaps undetectable leaking of manure from the storage system to ground water; and 3) a large sinkhole forming below a manure storage system leading to a rapid flow of manure into ground water or causing a collapse in a basin sidewall and a pouring out of manure onto the ground surface. Item A addresses the risks associated with the second and third risk noted above. Item B affects the risks associated with all of the above stated risks of constructing liquid manure storage systems in the karst region.

Manure entering ground water will discharge into streams within a period of time ranging from hours to decades depending on the site-specific hydrogeology. The karst region of Minnesota maintains a large number of high quality trout streams. A rapid discharge of a large quantity of manure into a stream will destroy the aquatic life for a stretch of the stream and also result in increased nutrient loading into the receiving waters of the Mississippi River system. Manure which flows in the ground water for a longer period before discharging into streams will be more diluted and may not destroy aquatic life, but will threaten drinking water supplies as it travels toward the stream, and contribute to stream pollution upon discharge.

Between 1974 and 1992, sinkholes opened below three of the twenty-two municipal wastewater treatment ponds in Minnesota's karst region. Sinkholes developed in Altura's ponds in 1974 during construction and in 1976 when it first filled to capacity. A sinkhole developed in a Lewiston pond in 1991 after eighteen years of use. Several sinkholes developed in a Bellchester pond in 1992 after twenty-two years of use. The amounts of partially treated wastewater draining into sinkholes at the three respective sites was 3.7, 2.3, and 7.7 million gallons. The ponds were constructed of earthen materials with a designed theoretical seepage rate not to exceed 3500 gallons per acre per day, and they were constructed in areas with less than 20 feet to bedrock.

These failures clearly demonstrate the potential for sinkholes to develop in southeastern Minnesota when large quantities of liquids are stored in sinkhole prone areas with minimal barriers between the liquid and underlying materials. Similar problems could develop when storing liquid manure on top of permeable liner materials. There are some notable differences between these failed municipal wastewater treatment systems and manure storage systems currently being constructed. The maximum allowable design seepage rate proposed for earthen manure storage systems is 1/56 of an inch per day, seven times less than the old municipal wastewater ponds. It is also important to note that the contaminant concentrations in manure are often over 100 times greater than municipal wastewater pond liquids, and thus the environmental consequences of a catastrophic manure release could be much worse than municipal pond failures.

Sinkhole mapping and research completed during the past two decades has made it easier to determine the relative soil subsidence risks when siting new liquid manure storage systems in Southeastern Minnesota. Sinkhole probability maps have been completed for three counties and additional hydrogeologic investigation has been conducted in the other karst areas. The probability of sinkhole formation has been found to vary tremendously across the region. Some areas have in excess of 50 sinkholes per square mile and other areas have no sinkholes. Often high density clusters of sinkholes are adjacent to areas with scattered individual sinkholes. Bedrock composition, topographic position in the landscape and thickness of glacial materials over bedrock have all been found to affect the likelihood of sinkhole formation.

Most sinkholes in southeastern Minnesota appear where there is less than 40 to 50 feet of surficial cover over carbonate and sandstone bedrock. The proximity of nearby sinkholes are the single best predictor of new sinkhole development. On a scale of several kilometers, new sinkholes in Winona County have tended to develop in the areas of existing sinkholes, especially near newly developed sinkholes.

Item A. In item A, the agency prohibits construction of liquid manure storage systems (over 250,000 gallons) in areas, which clearly show historical evidence of soil collapse and formation of sinkholes. Item A is needed to prevent construction of large liquid manure storage systems which can pose a great risk to water quality when located in areas where soil collapse is likely. Item A is reasonable because 1) areas of such high sinkhole densities are limited in the karst region; 2) storage systems can still be approved above 250,000 gallons in such areas to resolve existing non-compliance issues at feedlots in accordance with Item C, and 3) manure storage systems holding less than 250,000 gallons could still be constructed. Where four or more sinkholes are found within 1000 feet of a proposed liquid manure storage system, but the geologic conditions change between the sinkholes and proposed site so that conditions are not suitable for sinkholes at the proposed site, then construction of liquid storage exceeding 250,000 gallons may be allowed.

Item B. Proposed restrictions in Item B will limit construction in many other vulnerable sites in the karst region. The minimum depth to bedrock required in Item B depends on the size of the manure storage system as determined by the volume of manure and process wastewater contributing to the storage system, and the type of liner to be used. Greater separation distances to bedrock are required for larger facilities, because the risk of a sinkhole forming, soil subsidence or ground water contamination is greater for a larger facility than a smaller one, assuming all other things are equal. Use of a concrete or composite liner will reduce seepage rates and can be expected to result in a reduced risk of inducing soil collapse compared to a cohesive soil liner. In addition, a concrete or composite liner will be expected to seep less and therefore not need as much underlying soil for removal and treatment of contaminants.

Item B is reasonable because it still allows for construction of liquid manure storage systems in many areas of southeastern Minnesota. The concrete and composite liners are currently in common use in this part of the state, and the separation distances will reduce the risk of soil collapse below a manure storage system and will allow for treatment of contaminants which seep through any liner materials. In addition, in accordance with Item C, exceptions can be made to resolve existing non-compliance issues. Subitems 1, 2 and 3 describe proposed separation distances for three different size categories of feedlots, 1) less than 300 animal units, 2) 300 to 999 animal units and 3) 1000 or more animal units. Thresholds in Item B based on animal units thresholds were chosen to conform with other parts of the rules which are based on these same animal unit thresholds.

Where soil and geologic conditions are not suitable for sinkhole formation, then the proposed requirements in item B would not apply. These proposed requirements are for construction of new liquid manure storage systems, and do not pertain to existing manure storage structures.

While liquid manure storage systems can increase risks for ground water, these systems are overall a favorable option for water quality since they prevent runoff of manure to surface waters and increase the probability that the manure can be applied to cropland in a safe manner. The proposed separation distances were chosen to significantly reduce the risks to ground water associated with constructing liquid manure storage systems in the karst region, yet make it feasible for most farms to construct manure storage systems. There will, however, be many areas where the separation distance will not be attainable for below ground systems adjacent to existing farms. In these locations, the producer may pipe manure over to a location where adequate separation distances are found, or manage manure as solids, or construct an above ground manure storage system such as a steel slurry store which is lined with a material to prevent corrosion.

Subitem 1. For feedlots with less than 300 animal units, the agency proposes to require a minimum of five feet of separation distance from liquid manure to bedrock and to require in areas with less than 20 feet of separation to require a concrete-lined, above ground or composite lined system be used.

Subitem 2. In subitem 2, the agency proposes to require separation distances from manure to bedrock at all feedlots with 300 to 999 animal units to be 30 feet or more when using cohesive soil liners, 10 feet of more when using a composite or concrete liner, and 5 feet or more when using either an above ground manure storage area, concrete underlain by a secondary liner, or composite liner with three feet of compacted cohesive soil below the synthetic liner.

Subitem 3. In subitem 3, the agency proposes to require separation distances from manure to bedrock for new storage systems at all feedlots with 1000 or more animal units to be 40 feet or more when using cohesive soil liners, 15 feet of more when using a composite or concrete liner, and ten feet or more when using either an above ground manure storage area, concrete underlain by a secondary liner, or composite liner with three feet of compacted cohesive soil below the synthetic liner.

The proposed requirements in item B, subitems 1 to 3 are needed to provide increased levels of ground water protection as natural soil protection diminishes, and to provide increased protection for liquid manure storage at larger feedlots. These proposals are reasonable for the reasons previously stated.

Item C. Under item C, the agency proposes to allow an exemption to the site restrictions in part 7020.2005 and items A and B if the system is being constructed as a pollutant abatement system to address a pollution hazard at an existing facility having fewer than 300 animal units. This is reasonable because the relative risk of ground water pollution from a new or modified manure storage basin in these restricted areas is much smaller than the risk to surface water quality from ongoing manure-contaminated runoff from open lots, for example. Furthermore, a storage basin may be the best or only feasible option for addressing the runoff problems at the facility when the alternative is closure or abandonment or the facility. This provision does not allow facilities with 300 animal units or more an exemption to the site restrictions in part 7020.2005 and items A and B. However, these owners may apply for an NPDES or SDS permit under part 7020.0405, subp. 1, to modify a liquid manure storage area if the existing liquid manure storage area is determined to be a pollution hazard.

Subpart 3. This subpart contains the basic requirements for liquid manure storage area liners including minimum storage capacity, liner requirements and prohibited liner penetrations.

Item A. Item A requires that new or modified liquid manure storage areas at facilities with 1,000 animal units or more be designed to provide for a minimum of nine months of storage capacity. Due to factors such as weather, soil conditions, crops and the owner's schedule, a small window of opportunity may exist to land apply the manure. This provision is needed to provide owners with a relatively large volume of manure the flexibility to deal with the range of outside factors and enhances the opportunity for the manure to be spread at agronomic rates and in an environmentally sound manner. This provision also lowers the risk of basin overflow. This provision is not intended to require all new liquid storage areas to have nine months storage capacity, provided the storage capacity at the facility as a whole is at least nine months. For example, a dairy facility of 1200 animal units could build a one-month storage pit from which the manure could be transferred to the main storage area which has (or would have) at least 9 months storage capacity. This provision is reasonable because it provides an adequate storage volume to minimize the land application of manure and waster waters during the winter months when runoff problems are most likely due to frozen or snow covered soils. The agency's recommendations are for owners to design liquid manure storage areas for a storage term of seven to 12 months. See Exhibit M-18. The vast majority of new liquid storage areas proposed since about 1993 include provisions for 12 months of storage capacity. Designing for 12 months capacity has been the trend in recent years primarily to give the owners greater flexibility in managing and land applying their manure. This issue is also addressed and recommended by the American Society of Agricultural Engineers (ASAE) in ASAE Engineering Practice EP393, "Solid and Liquid Manure Storages," section 2.2.1.1. See Exhibit M-6. While the ASAE standard recommends only 180 days, the agency's experience has been that it is often difficult for owners to get into the fields to land apply the manure in spring or fall due to wet soils conditions. Therefore it is reasonable to extend the ASAE recommendation into the rule to 9 months to provided added assurance that owners of facilities over 1000 animal units have adequate flexibility to properly manage liquid manure.

Item B. This provision identifies the requirements for various liquid manure storage area liner systems. In some settings, unless a liner is installed to limit seepage, leakage from below-ground manure storage systems may pollute ground water as discussed above. Numerous studies, cited in a literature review by Parker, et al., have indicated elevated manure-related pollutant concentrations down-gradient from unlined manure storage systems, particularly in soils which have a rapid rate of permeability, or where fractured bedrock is present. See Exhibit M-28. A substantial number of projects in Minnesota where the basin is greater than about one-half acre in surface area have encountered permeable, water-bearing soils during construction.

Studies have indicated that biological and physical seals can develop to retard the movement of pollutants out of unlined storage systems. Physical seals are those formed by solids in the stored waste plugging the soil pores and restricting flow. Biological seals are a layer of microorganisms that form near the stored waste and may use nutrients seeping out of the storage system. Both will restrict seepage out of the storage system or, alternatively, will change pollutants leaching from the system into compounds that are not of a concern from a ground water perspective. Studies of physical and biological seals have reported that these seals take from 6 weeks to 6 months to form. See Exhibit M-29. However, these seals are not uniform; they may not restrict flow as much as properly installed liners; and can be damaged by various physical and chemical forces that may increase leakage. See Exhibit M-25.

It has been observed that a liner is necessary for manure storage systems to protect ground water in areas where there are soils of rapid permeability, particularly where there is a potential for water-bearing sand or gravel layers. In summary, the primary reasons for the liner are:

- Manure contains pollutants which can degrade ground water quality;
- Impacts on ground water from manure storage systems have primarily been observed in soils of rapid permeability where no liner was installed to retard seepage;
- Seepage from the system will preferentially flow through more permeable soils;
- Soils of rapid permeability (e.g., layers of poorly-graded sands and gravels) are present at shallow depth in much of Minnesota, in both small and large deposits;
- Sand and gravel layers or "lenses" can readily transmit ground water, and can serve either as aquifers or reservoirs to recharge ground water; and
- Sand and gravel layers or "lenses" may also transmit ground water back to surface water at ground/surface water interfaces such as ditches, streams, lakes, etc.

Based on these factors, it is reasonable to conclude that installation of a liner to restrict seepage from manure storage systems is required in order to protect ground water where water-bearing soil layers exist. Because installation of a liner will eliminate or limit seepage of pollutants through soil macropores that can serve as conduits for ground water flow, while native soils generally will not, it is reasonable to require a liner to be installed in liquid manure storage areas.

Subitem 1. Under subitem 1, the seepage standard of 1/56 of an inch per day (or 500 gallons per acre per day) throughout the design life of the structure is specified. Five hundred gallons per acre per day, or 1/56 inch per day, is the maximum seepage limit set for municipal stabilization ponds and industrial wastewater ponds in Minnesota, by the MPCA's Recommended Design Criteria for Stabilization Ponds, March 1993 (Exhibit M-8) and is also the required standard in the Great Lakes-Upper Mississippi River Board of State and Provincial Public Health and Environmental Managers, Recommended Standards for Wastewater Facilities, 1997 Edition, Chapter 90, Section 93.422, Exhibit M-30). The agency has also required this seepage standard to be met under the existing program and has issued permits for these types of structures and incorporated requirements for meeting this standard in these permits. See Exhibit M-18. An example of one such permit is provided in Exhibit M-19. This limit is based on potential impacts of stored wastes on ground water considering dilution and practical considerations of material available for construction of liners. Therefore, it is suggested that this be adopted as design seepage limit standard for manure storage systems. Five hundred gallons per acre per day is approximately the same as 1/56 inch per day. The amount of seepage that will occur from a liquid storage system depends on the depth of the liquid in the structure, the thickness and type of liner material used, liner damage that has occurred, and type of underlying soil. Sidewalls are the areas most prone to damage. Liner materials that are capable of restricting seepage to 1/56 of an inch per day or less, if installed and maintained properly, include:

- Recompacted (remolded) cohesive clay-type soils, typically with a Plasticity Index of between 10 and 30 percent and hydraulic conductivity of 10^{-7} cm/sec or less;
- Flexible membrane liners (plastic or rubber);
- Geosynthetic clay liners;
- Concrete (designed and constructed as in subitem (2)); and
- Corrosion-resistant steel manure tanks (e.g., glass lined).

As described, earlier in this section of this SONAR, the agency has provided further guidance on siting, design and construction of these liner systems. See Exhibits M-14, M-17, M-18, M-31 and M-32.

Subitem 2. The agency specifies the concrete liner requirements as needing water stops or joint sealant materials in all construction joints, and sealing of all cracks which may extend through the concrete liner. Requiring sealed joints and cracks is needed and reasonable because staff have observed several cases for which structures built without these standard materials and methods for liquid storage result in excessive seepage which has been observed at the interface of the concrete floor and vertical wall. The agency has also experienced several projects where the structure failed a water balance test prior to sealing the joints and cracks. The water balance test basically defines a failure as the pit could not be statistically demonstrated to meet the 500 gallons per acre per day standard. On one occasion, the contractor had to seal the joints and cracks several times to achieve a passing water balance test. This example is not the norm; however, it does demonstrate that even under high quality concrete work and sealant efforts a significant potential for excessive seepage from the structures exists. This provision is also reasonable because it provides consistency with the USDA, NRCS Conservation Practice Standard, Waste Storage Facility Code No. 313, which requires concrete liners to have non-metallic water stops in all construction joints. See Exhibit M-9.

NRCS Code 313 also requires that the floor thickness be a minimum of 5 inches and have reinforcing steel based on American Concrete Institute (ACI) 360, "Design of Slabs on Grade." The proposed rule provision, which mirrors this requirement, is needed and reasonable because it provides consistency for all concrete structures built in Minnesota and provides the necessary structural elements to achieve a liquid-tight structure. The NRCS Code 313 further specifies the steel requirements as:

> "The minimum reinforcing steel area shall be 0.15 percent of the cross-sectional area of concrete. Maximum reinforcing spacing shall be 24 inches. Reinforcing steel shall be supported in its intended location by appropriate chairs or concrete blocks. Reinforcing steel shall be deformed reinforcing bars. Welded wire reinforcement shall not be used."

The agency intends that the above requirements of NRCS Code 313 be followed when designing and constructing concrete manure storage tanks. Again, this is reasonable to provided consistency for concrete pits constructed in the state. This allows a contractor to use the same construction methods and practices from site to site, which under the current program is not taking place. Several engineers design pits with reinforcing steel, while others do not. Several counties already require a five-inch thick steel reinforced floor while the state program has only a policy of 4 inches. This consistent approach will ultimately provide higher quality structures and better assurance (because of the liquid-tightness standard) that the structures are not impacting ground water. The agency believes that these requirements will result in construction of concrete manure storage areas which achieve or exceed the seepage limiting requirements of the Non-concrete liners discussed in subitem 1. The use of a method specification for this subitem is needed and reasonable because there are no reliable theoretical methods to estimate the seepage from concrete structures where cracks and joints dominate the seepage characteristics.

Subitem 3. The agency proposes in subitem 3 that all composite-lined or above-ground manure storage areas be designed and constructed to achieve a theoretical seepage rate of not more than 1/560 inch per day, which equates to about 50 gallons per acre per day throughout the design life of the structure. Much like the need and reasonableness of the 1/56 inch standard in subitem 1, this standard is needed and reasonable to further limit the seepage from liquid storage facilities in areas that are highly sensitive to ground water contamination including the karst situations identified in subpart 2, item D. This seepage rate standard for composite liners has been demonstrated to be achievable under liner installations defined as good to great (course notes from David Daniel, Clay Liners and Geosynthetic Clay Liners for Manure Storage, February 1997. See Exhibit M-20. As discussed in this SONAR under subpart 2 items C and D, requiring a lower permeability liner in the areas susceptible to sinkhole formation is reasonable to minimize the likelihood of sinkhole formation and, therefore, a catastrophic failure

Item C contains specifications for the liner design that are needed to protect the integrity of the liner. Specifically, no water supply systems, fuel lines, electrical conduit or other equipment, apart from the manure handling or transfer system, may be designed or constructed to penetrate the liner of a manure storage structure. This is a reasonable request as the producer has a considerable investment in the liner, which will be compromised if equipment penetrates it. Manure would then have a conduit from the containment structure and ground water or surface waters could be threatened. If piping or equipment functioning as part of the manure handling or transfer system penetrates the liner, then it must be identified in the design plans and specifications. The design plans must include details on the location and purpose of the penetrations, including their dimensions and the methods and materials used to provide a seal between each penetration and the liner. With properly identified and sealed penetrations, the investment by the producer and the environment will benefit. This item is reasonable since it allows for penetrations necessary for a properly functioning system as long as provisions are made for sealing spaces between the object penetrating the liner and the liner materials.

Subpart 4. Subpart 4 lists the manure storage structure plans and specifications that are required for the construction or modification of a liquid manure storage area. The provision requires that these plans be submitted with a complete permit application or at least 90 days prior to commencement of construction if no permit is required (i.e., for a facility under 300 animal units). This provision is needed to allow the agency or delegated county the opportunity to review the proposed project and to have the plan available when conducting an on-site inspection during construction. Submittal of these plans is reasonable because it requires that the owner have the critical planning and design elements of a proposed project completed well before commencing construction. Submittal also allows the agency or county adequate time to review and allows the owner adequate time to address any design concerns or non-compliance with these standards prior to commencement of construction.

This provision also requires plans and specification for liquid manure storage structures having a capacity of more than 20,000 gallons to be prepared and signed by a registered professional engineer or NRCS staff person having approval authority for the project. This provision is needed to address the requirements of Minn. Stat. § 116.07, subd. 7j, and it states:

> “Until new rules are adopted that provide for plans for manure storage structures, any plans for a liquid manure storage structure must be prepared or approved by a registered professional engineer or a United States Department of Agriculture, Natural Resources Conservation Service employee."

This provision is reasonable because it continues the requirement for a registered engineer of NRCS staff person to prepare and sign the plans, but also allows smaller pits of 20,000 gallons or less to be installed without this signature requirement, provided the other requirements of part 7020.2100 are complied with. This is further reasonable because it saves the owners building small pits from paying typical engineering costs for preparation and signature of plans from $1,500 to $5,000, depending on the size of the structure. An estimated cost of installing a 20,000 gallon pit ranges from $5,000 to $15,000, which would result in a conservative estimate of 10 percent of the overall costs going to the engineer's signature for the plans. Finally, this requirement is reasonable because it encompasses many of the smaller, often pre-constructed pits such as septic tank pits, which may be used at facilities for very short-term storage. It would be unreasonable to require these pits to have an engineer's signature, when typically they have already passed engineering design standards and testing at the plant where they were manufactured.

Item A. Item A contains the content list for the required preliminary site investigation. The results and interpretation of the site and soils investigation need to be submitted with the permit application. A site investigation is needed because it is one of the most critical parts of the project. The investigation evaluates the physical characteristics and, therefore, the adequacy and vulnerability of the soil in a proposed area. This is the only means by which soil substructure can be checked for such problem conditions as the presence of a sand lenses or shallow bedrock. A site evaluation is necessary at proposed manure storage system sites in order to identify site characteristics that may pose a challenge to construction, operation and maintenance of the system, in order to protect ground water. Some designers have proposed that no liner be installed if no soils of rapid permeability are encountered during the preliminary site investigations. However, soil investigations throughout Minnesota have indicated that preliminary soil investigations at a site may not detect all types of soil deposits, when the borings or test holes miss them. This presents a design and cost/benefit challenge to a designer and project proposer. That is, if a designer were to propose that no liner be installed based on preliminary investigations at the site, then the project proposer runs the risk that unexpected site limitations (i.e., the unexpected presence of water-bearing soils in the project area) will be present. This will result in either the determination that now a different liner must be installed or a change in the location of the basin is needed. With this unplanned change comes a corresponding unexpected increase in cost and time for the project, or that no provisions are made to cut off more permeable soils from seepage, thus resulting in potential pollution of ground water.

The required investigation includes, as stated in item A, subitem 1, an analysis of the foundation soils for stability to ensure they are of sufficient strength so that failure of a berm or wall is minimized. Having soils of sufficient strength will minimize the risk of costly engineering modifications or problems during and after construction. A thorough and accurate soils investigation saves money by minimizing soil stability problems and can thereby prevent construction delays. Proper design, materials, construction and maintenance of liquid storage systems are required to prevent failures that may result in flow to surface waters, or seepage to ground water. Improperly constructed and maintained structures have failed, in some cases resulting in catastrophic damage to surface waters, or pollution of ground water. Typical causes of failures of above-ground manure storage structures include inadequate wall or dike strength, damage to dike walls from various causes (see also SONAR under subpart 7, Operation and Maintenance Plan) and use of permeable materials that won't restrict leakage. Below-ground structures have typically caused ground water pollution when manure has seeped out through soil layers of moderate to rapid permeability, either because no liner was installed, the liner was not installed properly to restrict seepage, or damage to the linear occurred.

In Item A, subitems 2 to 6, the agency proposes requirements for soils investigations at the site of a proposed liquid manure storage area.

Subitem 2. In this subitem, the agency specifies the minimum number of soil borings or soil profile records that must be obtained from within the boundaries of the proposed storage area, requiring at least two records for the first half-acre of surface area and at least one additional record for each acre or portion thereof. The provision also requires soil profile records to be obtained in sufficient numbers to represent the range of soil conditions throughout the proposed site. For example a one-acre basin would require that a minimum of three soil profile records be obtained. However, if in this same one-acre basin example, the basin is proposed in an area of shallow soils over bedrock and the depth to bedrock varies considerably in the first three borings or records, the site investigator is required to obtain additional borings until the range of bedrock depth has been delineated. The minimum number of borings is needed so that design engineers obtain sufficient site information not limited to soil type, texture, depth to saturated soils, and depth to bedrock. The number of boring or records is reasonable because the design engineer needs this information to properly design the basin and evaluate the site conditions for conformance to this part. In addition, significant construction delays are often avoided by a proper site and soils investigation. Agency staff has observed several sites where sand lenses and/or a seasonally high water table was present, and that was not identified in a pre-design site investigation. These projects saw significant delays and increased construction costs to address the problems on-site. Additional soils borings would likely have identified the potential for these problems and resulted in the designer being able to prepare for the site conditions and avoid delays. Under the current permitting program, the agency requires this information for all proposed liquid manure storage areas. See Exhibits M-11, M-18 and M-26.

Subitem 3. The agency proposes to require the soil records to be obtained to a depth of at least five feet below the bottom of the proposed liquid manure storage area, except when required deeper in subitem 4. The depth of five feet is needed to evaluate the foundation soils as required in subitem 1 and, for example, to further evaluate the soil conditions for the presence of the water table or saturated soils and to properly design a perimeter drainage tile system as required in subitem 9. This provision is reasonable because, like subitem 2, it minimizes the likelihood of construction or operation related problems if sufficient site information is not obtained. Under the current program and as stated in the agency's guidelines for cohesive soil and concrete-lined manure storage areas, the agency has required design engineers to obtain soils information to this depth and the NRCS required designs to meet this requirement. See Exhibits M-11, M-15 and M-18.

Subitem. 4. The agency proposes in subitem 4 that in areas susceptible to soil collapse or sinkhole formation, soil records be obtained to a depth of at least 10 feet below the bottom of the proposed liquid manure storage area or until bedrock is encountered. The need and reasonableness of this provision are similar to subitem 3, however, this information is also needed to evaluate conformance to subpart 2, item B. Under the current program, the agency has required design engineers to obtain soils information to a depth of at least 10 feet below the bottom of the proposed system and the NRCS required designs in these areas to obtain soils information to a depth of at least ten feet below the bottom of the proposed system. See Exhibits M-11, M-15 and M-18.

Subitem 5. The agency proposes that soil records to identify the soil texture, depth to the regional water table and depth to the seasonally high water table. As mentioned above this information is needed and reasonable to properly design the manure storage area including the perimeter drain tile system, to minimize the likelihood of construction related delays and defects and for conformance to the requirements of this part. Under the current program, the agency has required design engineers to obtain this information and the NRCS required designs to obtain this information. See Exhibits M-11, M-15 and M-18. The agency also provides guidance on recommended soil testing practices and methods prior to construction (Exhibit M-10).

Subitem 6. The proposed language contains the requirement for soil profile information to be obtained by a method that can identify abrupt changes in soil texture and sand lenses of one-half inch or greater. This provision is needed for reasons similar to those stated in this SONAR under subitem 5. Under the current program, the agency has required design engineers to obtain this information. See Exhibits M-11 and M-18. These agency guidance documents further describe several acceptable methods for obtaining this information. They include: rotary augers (continuous sampling is not acceptable); hollow stem augers or Shelby tubes; and backhoes.

Subitem 7. The agency requires, in areas having susceptibility to soil collapse or sinkhole formation, the owner to include a map of the proposed area showing the location of all open and filled sinkholes, depression areas, know caves, resurgent springs, disappearing streams, karst windows and blind valleys within one-half mile of the proposed site. Research has shown that the potential for sinkholes and thus the potential for failure of the structure is more likely to occur in areas with less than approximately 50 feet of soils above the bedrock. This provision allows the agency to obtain the information necessary to make a credible assessment for the concerns outlined in subpart 2, item B. The agency has developed draft guidance to assist in collecting the information under this provision and to further address the issue of reducing the environmental risks associated with constructing liquid manure storage areas in the karst region. See Exhibit M-13. For more discussion on the need and reasonable of this provision, see the discussion under subpart 2, item B.

Subitem 8. In subitem 8, the agency requires an evaluation on whether ground water intrusion will cause construction problems, delays, and damage to the liner or flow into the basin. This provision is needed and reasonable because if ground water flows into the structure it may: expose liner construction problems and significant delays; damage the liner as water seeps into the storage system at levels above the level of manure in the structure during operation; and/or fill the storage system much faster than anticipated due to water intrusion resulting in greater potential for overflow from the storage structure.

Subitem 9. The agency proposes in subitem 9 an evaluation of the need for a drain tile system, where required to control the elevation of the water table in accordance with item J. This requires the plans to included provisions to: (a) lower the elevation of the water table or saturated soils to below the bottom of the liner; (b) locate the tile a horizontal distance of at least two feed outside the footing of a concrete lined structure; (c) install an independent drain tile system for each manure storage structure; and (d) install a tile riser, manhole or other access which allows collection of the water samples for each independent drain tile system. Under (a) the seasonal high water table must be lowered to at least two feet below the bottom of a cohesive soil liner or other non-concrete liner. See Exhibits M-11 and M-18. These provisions are needed and reasonable because groundwater and saturated soils are the most common problem related to construction and proper operation of below ground manure storage structures. Without consideration of the factors and adequate plans to control the potential problems, the risk of structural failure or ongoing excessive seepage to groundwater is significantly increased. Installation of a functional perimeter tile system and monitoring access also allows the agency, delegated county and/or owner to demonstrate whether or not the facility is negatively impacting groundwater. Another factor for owners and designers to consider related to subitems 8 and 9 is the potential for future monitoring or the perimeter tile water. The agency discusses this issue in more detail in a document on Ground Water Monitoring at New Feedlots and Manure Storage Areas in Minnesota. See Exhibit M-12.

Subitem 10. Subitem 10 allows the agency to require additional information on site-specific unique characteristics. This flexibility is needed as new research, laws and practices are developed. The agency can request additional information without having to incur the expense and time of rewriting the rules and requesting the information in specific rule language. This is reasonable because it is in the existing rule and is needed to give the agency flexibility to request additional information as technology changes or as new and/or unique site circumstances arise.

Item B. In item B, the agency requires additional information if the site is located in a drinking water supply management area approved by the Minnesota Department of Health. It is reasonable to require further assessments of the above areas to ensure protection of community public water supplies. This information will allow the agency to make a credible assessment to protect drinking water source protection areas from the threat of storage-related pollution impacts. It also will result in the owner making plans with the knowledge of whether there are possible additional considerations and protection measures needed due to the proposed site location’s proximity to a public water supply system. The requested information includes: (1) the location of the animal feedlot and land application sites on a map of the drinking water supply management area; (2) a copy of the vulnerability assessment completed by the water supplier; (3) a description of the vulnerability of the specific manure storage and land application sites as described in the above assessment; and (4) a copy of all parts of the wellhead protection plan or source water protection plan which pertain to animal feedlots and manure management.

Item C. Under item C, the agency proposes to request that the design plans include the estimated storage term based on the volume of manure produced. It further directs that new or modified manure storage structures at feedlots with more than 1,000 animal units be designed to provide for a minimum of 9 months of storage. Due to factors such as weather, soil conditions, crops and the operators’ workload, a small window of opportunity exists to spread the manure.

This provision adds needed flexibility to deal with these factors and enhances the opportunity for the manure to be spread at agronomic rates and in an environmentally sound manner. This provision also lowers the risk of basin overflow. Thus, adequate storage capacity must be designed and used.

Item D. The agency proposes in item D that manure storage structures open to precipitation or runoff meet one additional storage volume requirement. This is a needed provision in that it prevents the possibility of accidental manure overflow caused from a precipitation, snowmelt or other runoff event. This provision is reasonable because it provides an adequate storage volume to minimize the land application of manure and waster waters during the winter months and is standard practice as described in NRCS Code 313 Waste Storage Facility (Exhibit M-9) and ASAE Engineering Practice EP393 (Exhibit M-6).

Item E. The agency propose to require that design specifications be brought and discussed at a pre-construction conference. Attendees at the conference must include the design engineer, liner contractors, feedlot owner and the inspector of the facility. During this conference, the construction design and specifications should be discussed, as well as the quality assurance/quality control (QA/QC) plan for the project and each party's responsibilities. The conference will encourage and facilitate communication among all parties. Everyone involved will have clear expectations of what is required of them. These measures needed and reasonable because they promote quality control and contribute to the production of safe and reliable manure storage structures. Several county feedlot officers require this conference under their program and based on their experience is an essential step to producing a quality structure.

Item F. This item contains proposed specifications to restrict seepage from liquid manure storage structures according to the site restrictions and liner specifications in subparts 2 and 3. This requirement is needed and reasonable in the plans and specifications so that the agency and county have these readily available for initial review to evaluate compliance with this part and for construction inspection purposes.

Item G. The agency proposes to require the location of the borrow site, the soil type and texture (as determined from the soil investigation), volume of liner soil available to ensure that enough volume exists and the testing protocol for soil plasticity index, sieve analysis and optimal moisture for compaction. An MPCA guidance document providing construction specifications, recommended ASTM testing methods and other liner design information is available from the MPCA. See Exhibit M-10. This provision is reasonable because it requires that the designer identify adequate soils for construction of the intended liner. This also minimizes the chances of construction changes on-site, which often result in increased costs for the owner.

Item H. Item H contains the site plan to be included which identifies the location of soil borings relative the location of the proposed manure storage area. This is needed and reasonable because the boring must be taken from the site of storage area to accurately assess the adequacy of the site. Also, the elevations of the boring relative to the planned depth of the structure are critical and needed to maintain the required separation distances to bedrock and seasonally saturated soils.

Item I. Item I contains the requirements for plan details for all liner penetrations according to subpart 3, item C. This is needed and reasonable because the areas where piping or other material pass through the liner are the most likely areas where seepage will occur.

Item J. In item J, the agency proposes that manure storage design plans contain measures for control of the water table or saturated soils at sites where these conditions create ground water forces that may interfere with and damage the liner if they are not controlled. County soil surveys and soil borings are sources of information for identifying the potential of a shallow regional water table. This provision is reasonable because many areas in Minnesota have soils that are seasonally saturated. This shallow, temporary saturation can cause impacts such as liner damage, water intrusion and problems during construction and operation. Therefore, it is reasonable to require that measures/additional design systems be taken in an area of saturated soils. This information is needed to ensure that the perimeter tile will lower the water table or saturated soils, will not serve as a conduit for manure flow, and can be used as a ground water monitoring system in the future if there is reason to suspect seepage problems. These requirements are reasonable because they may save the feedlot owners future expenses, which could result from high water table or the need to install ground water monitoring devices. Additional guidance on controlling the water table or seasonally saturated soils is provided in the agency's guidance documents for concrete and cohesive-soil lined manure storage areas. See Exhibits M-11 and M-18.

Item K. The preparation of, and conformance to, a construction quality assurance/quality control (QA/QC) plan are two of the most important factors in building a high-quality liner system. Construction QA/QC includes holding pre-construction conferences, materials sampling and testing and conducting inspections throughout the construction process. It is important that a knowledgeable design engineer or other qualified consultant prepare the QA/QC plan. Implementation of the QA/QC plan during the construction process will require a qualified soils analyst with experience in cohesive soil liner construction to be on-site during placement of the liner material. Sampling and testing for all manure storage structure projects must be conducted by a qualified technician as well. MPCA guidance documents listed at the beginning of this SONAR section are available from the MPCA for recommendations on ASTM sampling and testing methods for liquid manure storage areas. Item K also requires that the QA/QC plan, including inspection and testing methods and frequencies, be included in the design plans. This requirement has been in practice for almost a decade and is reasonable as review of the plan by MPCA will provide a record on file with MPCA documenting the quality of construction. This is protection for the owner as once again, the owner of the facility is responsible for any environmental effects caused by the structure. Additional guidance on QA/QC plan development is provided in the agency's guidance documents for concrete and cohesive-soil lined manure storage areas. See Exhibits M-11, M-16, M-17 and M-18.

Item L requires that the specifications for liner material protection be submitted to the MPCA. Manure storage liners can be damaged in a number of ways. Damage may occur during the construction phase or during the operational phase. Protection from damage needs to be addressed for liners comprised of earthen, geotextile, reinforced concrete or other combinations.

Damage protection must specifically be planned for the following events: a) drying and cracking during and after liner construction; b) manure agitation and pumping; c) freezing and thawing; d) erosion; and e) other physical damage. The MPCA guidance document recommends for example, that there must be concrete ten feet in any direction from the location where agitation and pumping equipment will be operated (e.g., 20 foot x 20 foot pad on bottom and sidewall) plus protection from equipment traffic if equipment travels down the liner sidewall. See Exhibit M-18.

Item M requires the plans to include discussion and provisions for special site considerations such as building a storage pit under an existing barn, relining an existing unpermitted structure or installing a liner in an existing basin that has severe seepage problems. This is a reasonable provision because each of these example has significant engineering challenges present which may impact the quality of the proposed structure. For example, a pit under an existing barn poses potential problems with excavation of the earth fill, backfilling of vertical concrete walls and access of equipment.

Item N requires that a plan for operation, periodic inspection and maintenance of the storage area be developed and submitted (see also SONAR in subpart 7). All manure storage structures require correct operation along with periodic inspections and maintenance to continue to provide safe and reliable service. Seepage rates will increase if the liner becomes damaged. Damage to the manure storage basin sidewall is particularly a concern with clay liners. Clay liner damage can also occur from careless agitation and pumping of the manure or erosion of sidewalls from wave action and/or precipitation runoff. A list of additional operating and maintenance concerns are identified below. Guidance on reducing risks from damage to Geomembrane and Geosynthetic Clay Liners is available in the guidance documents referenced at the beginning of this section. In general the owner should provide a plan which requires: (a) maintaining a good vegetative cover on the berms and outside slopes of basins; (b) keeping the vegetation mowed to prevent the growth of trees or brush; (c) performing an annual visual inspection of the outside slopes and berm of the basin for signs of erosion, seepage from the structure, or rodent burrows. Burrowing animals should be removed and burrows required with bentonite or compacted soils; (d) maintaining a fence around the perimeter of the structure to prevent children and animals from accidentally falling into the basin; (e) controlling the wastewater level to maintain the minimum design freeboard; and (f) for lagoon systems, a wastewater monitoring protocol should be included for periodic analysis of wastewater for compliance with design loading rates. In addition, the plan should include recommendations for best management practices to prevent lagoon upsets that may result in odor or air emission problems and decreases in lagoon treatment rates.

Subpart 4. Construction and notification requirements. The ultimate quality of the manure storage structure depends greatly on the site-specific conditions and the handling of construction materials whether they be concrete, soils or other materials during construction. Requirements similar to the following have been in place under the current program and have been incorporated into permits issued for construction actives for several years. See Exhibit M-19. Proper placing, consolidating, finishing and curing are essential to produce a manure storage structure, which meets the approved plans and specifications. The potential for ground water degradation from poorly-lined earthen manure storage systems has been demonstrated from monitoring throughout North America. Both the proper design and proper construction are critical to achieve a manure storage structure, which protects water quality.

Item A requires owners to construct manure storage areas (permitted by either the agency or delegated county feedlot officer) in accordance with the design plans and specifications prepared by the design engineer and submitted to the agency or delegated county. This requirement has been in place under the current program and has been incorporated into permits issued for construction actives for several years. See Exhibit M-19. This provision also requires that proposed engineering changes or modifications to the plans and specifications related to the liner specifications, location, depth or separation distance to bedrock must be submitted to the agency or county feedlot officer prior to construction. These provisions are needed and reasonable to maintain the integrity of and relationship between the design and construction processes. It is also reasonable to only require the critical types of design changes to be submitted to the agency. The changes requiring submittals are reasonable because they all relate to the ability of the liner system to be constructed properly and maintain the required seepage rate.

Item B. The agency proposes that the owner must notify the agency or county feedlot officer and the design engineer of intent to construct at least 3 days prior to commencing construction and also specifies the specific information needed in the notification. This requirement has been in place under the current program and has been incorporated into permits issued for construction actives for several years. See Exhibit M-19. The opportunity to inspect or otherwise verify proper procedures and methods is necessary for the agency and counties to achieve regulatory oversight of the liquid manure storage construction. This notification mechanism creates an effective oversight mechanism without providing hardship to the regulated party. It helps support the agency's role as a source of environmental-related information and it provides the agency an avenue to communicate any final concerns it may have. It is reasonable because the owner has the required information readily available and has several options available on the method of notification including letter, phone and facsimile. In addition, the owner typically must inform the design engineer prior to construction or of the date when the pre-construction conference will be held and one call completing each of these tasks is not unreasonable.

Item C. Item C contains the proposed requirements that the owner also needs to notify the agency or delegated county feedlot officer within 3 days following completion of manure storage construction. The provision is needed in order for the agency to fulfill its compliance monitoring duties. This requirement has been in place under the current program and has been incorporated into permits issued for construction actives for several years. See Exhibit M-19. The provision is reasonable in that it is designed to accommodate both the owner and the agency or delegated county. The provision allows the agency the opportunity to inspect the structure, if it determines it is appropriate to do so, prior to the basin becoming filled with the manure. On the other hand, the provision allows the owner to begin use of the basin as soon as technical specifications allow. As with notification of commencement of construction above, the notification information must include the permit number, site owner's name, site location, and the design engineer and contractor working on the project. Acceptable means of notification includes letter, telephone, facsimile or electronic mail.

Item D. In item D, the agency proposes that a final construction report must be sent by the owner or the design engineer to the agency within 60 days of the completion of a new or modified manure storage structure. This requirement has been in place under the current program and has been incorporated into permits issued for construction actives for several years. See Exhibit M-19. The final construction report is a technical document that subjects a construction project to systematic review by an industry professional design engineer. This systematic review is needed and reasonable to verify that the project was built according to specifications and to disclose any deficiencies or problems that may be present. This report helps provide the agency, county, owner and general public with greater assurance that construction of the storage area was completed according to the plans and specifications and with the standards required in this proposed rule.

The terms of the provision were designed to allow use of the basin prior to submittal of a final construction report. This was to done to allow the manure storage facility to be put into use prior to submittal of the final report. This is reasonable as it is often difficult for an engineering firm to development and prepare a report in less than 60 days during the construction season and a delay in use of 60 days may cause hardship to the livestock owner/operator. The ultimate protection of the environment is ensured by making it clear that an unsatisfactory construction report may require the facility owner to remove the manure from the basin and perform necessary corrective action.

Subpart 5. Inspections of liquid manure storage areas. Installation of liners to restrict seepage from liquid storage systems requires considerable expertise, to achieve a seepage rate less than 1/56 inch per day (or 1/560 inch per day as required in subpart 3, item B, subitem 3). Some construction contractors are familiar with materials, technologies, and methods required to achieve this seepage limit, but others are not. Therefore, adequate project oversight by qualified persons is required to ensure proper construction, both to protect ground water (from poor construction) and to ensure that the project owner receives the product designed and bid on. Testing and inspection of materials and professional review of construction documents promote quality construction. Typically, an independent third party such as the designer of structure provides both an opportunity for guidance to contractors unfamiliar with proper construction methods, and protection to the owner, who generally is unfamiliar with the subtleties of construction of these types of structure. This also provides a greater assurance to the public that these structures are being constructed so as to prevent pollution of ground and surface water. Currently there are not enough qualified agency or delegated county inspectors to provide inspections for all the projects proposed.

The owner or operator of an animal feedlot where a concrete manure storage structure will be constructed or installed (and with a capacity of 20,000 gallons or greater) must have inspections completed during the construction process. These inspections are critical to ensure that the structure is being built according to plans, to protect the producers' investment. The inspector must have one or more of the following qualifications:

- Minnesota-registered professional engineer;

- Qualified NRCS staff person; or
- American Concrete Institute (ACI) or Minnesota Department of Transportation (MnDOT), Concrete Field Testing Technician Grade/Level 1 and Concrete Field Inspector Level II certified.

It is reasonable to require a qualified individual to inspect and certify that the critical stages of construction in this item are completed properly because a quality construction process requires knowledge of the potential consequences of construction changes and variances from the approved design. A qualified person is therefore needed, because the inspector must observe and record findings related to conformance to the design plans and specifications and construction standards at the critical stages of construction specified in subitems 1 to 5. These are reasonable requirements for all liquid manure storage project and have been recommended by the agency for several years. See Exhibits M-11 and M-18.

Item C. The agency will under this item require certification by the contractor installing the liner that the manure storage structure was constructed in conformance with the design plans and specifications and construction standards for all stages of construction listed above. This is reasonable because it requires the contractor to be knowledgeable in liquid storage construction, which can differ significantly from earthwork on road projects or concrete work in parking lots, as examples. It also provides the owner with some assurance that the contractor used proper materials and methods and that the owner has received what was bid on and paid for.

Item D. Item D contains the agency's proposal that requires the owner to submit the following information to the design engineer for incorporation into the construction report required in subpart 5, item D:

- Name and qualifications of the inspector;
- Inspector’s findings, in accordance with item B; and
- Liner contractor’s certification required in item C.

As discussed above, these inspections and certifications which are incorporated into the design report help assure that ground waters are protected by installation of a liner system that meets or exceeds standards. If and when a liquid storage area is suspected of being a contributor to ground water pollution, the construction report can also help identify potential areas of concern or demonstrate that the basin or pit is a very unlikely source of the pollution hazard.

Subpart 6. Operation and Maintenance. It has been observed that physical and biological seals, and even constructed liners may be damaged by any combination of the following factors: freeze/thaw cycles; animal burrows (earthworm, insects, rodents, etc.); drying and cracking of clay liner materials (desiccation); effects of manure agitation and pumping equipment; soil erosion (on sidewalls); roots of vegetation; wave action and hydrostatic pressure from ground water. Damage to either constructed liners or physical or biological seals will typically result in increased seepage, and greater potential from ground water pollution. Therefore, an operation and maintenance plan is warranted to detect and repair any damaged areas of the liner. Designs and specifications should include provisions for liner protection during and after construction, and during routine operations. To help operators do an adequate job in operating and maintaining the structure, an operation and maintenance plan needs to be written, submitted to the agency and complied with. The lack of inspection and and/or structural failure. Earthen basins are vulnerable to erosion, to deep-rooted plant growth and to burrowing animals. Anyone of these conditions may contribute to eventual dike failure. Concrete structures are typically part of total confinement operations and are constructed under the animal livestock holding areas. Lack of inspection may result in overflow. Other problems include the formations of cracks and risk of seepage in the concrete as well as the corrosion and weakening of the steel superstructure used to create a floor above the pits. These problems can be avoided if the feedlot owner conducts regular inspections and provides routine maintenance. Therefore, this provision is reasonable because it provides a pollution prevention benefit and, at the same time, it is not expensive for the producer to implement.

<u>7020.2110 Unpermitted or Non-Certified Liquid Manure Storage Areas</u>

Subpart 1. Schedule for facilities with 1000 animal units or more or that constructed after June 3, 1991. Under subpart 1, owners of unpermitted basins built after June 3, 1991; or owners that have 1000 animal units or more, are required to select one of three options to resolve the potential negative environmental impacts created or maintained by the basin. Item A eliminates potential noncompliance by reconstruction of the unpermitted manure storage area according to part 7020.2100, and item B eliminates the problem by completing closure of the storage area according to part 7020.2025. Item C specifies the third option which requires that the owner locate and submit original design plans for the manure storage area and a construction report stating that the storage area was constructed according to rule and regulations and standard engineering principals and practices, This subpart also requires that the owner complete one of the three options by October 1, 2001.

Items A and B, which require construction of a liner or closure of the manure storage area, are needed and reasonable options to protect the environment from potentially significant damage from an excessively seeping manure storage areas. The reasons are identical to those described in this SONAR under part 7020.2100, which describes the specific water quality and human health hazards related to excessive seepage from liquid manure storage areas.

Item C will likely apply to only a very small number of feedlots, however, it is needed and reasonable because in dealing with unpermitted basins in the past, some feedlots have this information and simply failed to go through the permitting process or complete the process once started. This will apply mainly to feedlots that obtained assistance from the Soil Conservation Service/Natural Resources Conservation Service (NRCS) in design and construction inspection. The requirement that a construction report, or red-lined set of design plans from NRCS, is needed because this is the piece that demonstrates with some confidence that the basin was installed properly. It is reasonable to require that this potential pollution hazard be addressed and eliminated because of the high potential for significant environmental impacts that an excessively seeping basin can create.

The proposed rule allows these owners until October 1, 2001, to complete the liner or close the manure storage area. Given the costs of properly installing a liner, or constructing a completely new system (averaging from about $40,000 to $80,000, with a typical upper limit of about $120,000 for most earthen or synthetic liners), it is reasonable to allow the owner some time to complete the project. The schedule for this group allows over a year from the expected effective date of the rule for the owner to complete one of the three options. This is reasonable time considering that the owner is over 1000 animal units and likely has the resources available to correct the problem or that the problem is significant enough due to the volume of manure that it must be corrected quickly.

The June 3, 1991, criterion is needed because on this date the agency issued a press release (Exhibit M-7) which was widely distributed throughout the state and which identified the requirement for applying for a permit when proposing an earthen manure storage basin and that the plans required a registered engineer's or NRCS staff persons signature. It is therefore justified that the agency consider basins built after this date at any sized facility without proper permitting and design, to address their unpermitted basin on a relatively fast schedule. These owners had a reasonable opportunity to obtain information on the required procedures and therefore should not be given as flexible a schedule as the owners meeting the requirements of subpart 2 or 3.

Subpart 2. Schedule for eligible facilities with fewer than 1000 animal units. This provision requires unpermitted basin owners with fewer than 1000 animal units and that commenced construction of the unpermitted structure before June 3, 1991, to complete one of four options to address the unpermitted structure by October 1, 2003. This provision does not apply to owners meeting the requirements of subpart 3. Similar to the discussion in this SONAR under subpart 1, the October 1, 2003, date for addressing the potential problems is reasonable because it allows adequate time for the owner to plan for and complete any required work and also allows approximately four years to cover the costs associated with correcting any problems with the basin. The four options listed as alternative requirements have been in place under the current program (see guidelines Exhibit T-5) and has been incorporated into permits issued for unpermitted basins for several years (see permit example, Exhibit T-4).

Item A of this subpart provides the same options as items A to C in subpart 1 for the owner to complete. The need and reasonableness of the options is discussed under subpart 1.

Item B of this subpart describes the fourth option to address the unpermitted structure under which the owner must have a design engineer conduct a soils investigation at the site of the structure meeting the requirements of subitems (1) to (6). The soils investigation report by the design engineer must demonstrate compliance with applicable NRCS design and construction standards and that the in-place soils are limiting seepage to the groundwater in accordance with these standards. See Exhibits M-9 and M-15. This option allows the commissioner or county feedlot officer to approve the structure for continued use with little to no remedial work on the storage structure. The key point here is that the soils report must demonstrate that seepage is adequately limited by meeting three key sections of the NRCS Code No. 425 or No. 313 including: (a) sealing/lining waste storage ponds; (b) vertical separation to groundwater; and (c) vertical separation to bedrock. This is reasonable because if it cannot be demonstrated that the basin liner is providing adequate protection against negative environmental impacts, then the structure should not be allowed to maintain potential negative impacts to the environment. It is also reasonable to allow these structures to continue being used if it can be demonstrated that they are not negatively impacting the environment.

The quality and content of soils reports that are submitted under the current unpermitted basin program is that many simply describe the soil profile, with no assessment of the adequacy of the soils to limit seepage. These types of reports place a high degree of administrative burden on regulatory staff who must then attempt to evaluate the site based solely on soil records and incomplete information. Similar to the discussion of other parts of this rule, the MPCA's intent here is to place this responsibility with the owner (to hire a design engineer to complete the report) and allow regulatory staff to focus on more inspections and on reviewing only soils reports from higher risk locations. The process of the owner being responsible for demonstrating that the soils information meets the NRCS standard will reduce the number of reports that regulatory staff must review, because design engineers will not "certify adequacy" at many of the same types of sites that the agency is currently getting soils records for unpermitted basins. Many of these soils reports currently include minimal soils information and little to no assessment of the integrity of the basin and are simply submitted with the thought of "let's see if MPCA thinks this is adequate," without giving any further assessment of the basin. Staff expect that unpermitted basins located in areas of coarse soils, sand lenses and high water tables will not be demonstrated to meet the required standards in most cases. For these reasons the soil investigation requirements of subitems 2 to 6 are needed to allow demonstration of the adequacy of the structure to a high level of confidence. Without this detailed soils information, demonstration of the potential for negative impacts from the structure would be very difficult.

Subpart 3. This subpart only applies to feedlots with fewer than 300 animal units that are under the long-term discharge compliance schedule under part 7020.2003, by being registered and accepting of the conditions under that part. This provision also applies only when reconstruction or closure of the liquid storage area is required. Closure or reconstruction would primarily be required based on the inability of a design engineer to demonstrate compliance with NRCS Practice Codes through a soils investigation. Under item A of this subpart, by October 1, 2003, the owner is required to notify the commissioner or agency of the option, which they intend to follow and complete. This is reasonable because the owner will have roughly three years from the effective date of this rule to determine which of the two options is best suited to their feedlot (reconstruction or closure). This provision does not require the owner to complete actual site work upon the October 1, 2003, deadline. That site work must be completed by October 1, 2009. For example, the owner could fully intend and notify the commissioner that an earthen basin will be closed by October 1, 2009. The owner could then modify this decision, and notify the commissioner, allowing for sufficient time before actual completing the reconstruction prior the October 1, 2009, deadline. This provision does not intend that the owner have the option to conduct a second soils investigation to demonstrate that the basin meets the NRCS standards. This provision is also reasonable because it is consistent with the goals and intent of the discharge standards in part 7020.2003 for these owners which also allows an additional six years or until October 1, 2009, under item B, to complete remedial work. The proposed rule deals with this issue resulting in improving environmental performance and maximizing the decision making flexibility for the owner and giving the owner sufficient time to plan and implement and finance the necessary improvements.

7020.2120 Poultry Barn Floors

The agency has determined that a poultry barn floor liner is needed in a variety of situations in Minnesota due to the potential for groundwater contamination. The potential for groundwater contamination has been evidenced by the following research: North Dakota Department of Health study, "Nitrogen Concentrations Under Turkey Barn Floors" (Exhibit S-2), the University of Delaware studies by Kenneth Lomax, "Nitrogen Barriers for Broiler House Floors" (Exhibit S-3) and "Soil Nitrogen Concentrations Under Broiler Houses" (Exhibit S-1), Investigation report prepared by Tiry Engineering (Exhibit B-3) and by the University of Minnesota report, "A Preliminary Study on Seepage from Deep Bedded and Poultry Litter Systems"(Exhibit B-2). In addition, the agency has recommendations for proper siting, design and construction of poultry barn floors in the guidance document "Technical Guidelines for Poultry Barn Floors." See Exhibit B-1.

A clay liner is expected to be the primary option chosen as a poultry barn floor liner or barrier. The requirements for soil-lined floors are similar to those the agency has required for soil-lined poultry barn floors and include specific soils to be used and specific construction methods to be followed. An example of these types of construction requirements is provided in an interim permit issued for construction of a poultry barn floor. See Exhibit B-4. In spite of the research cited above, several issues are often raised when a soil or clay liner is required in "clay-rich" areas of the state:

Issue 1: Clay in some areas of Minnesota is as much as several hundred feet thick. Isn't it possible to investigate a facility with existing clay and demonstrate that a clay liner is not needed to protect ground water?

Response: Dr. Daniel's work demonstrates that this is not practicable. In his book titled, " Geotechnical Practice for Waste Disposal", he notes, "It is extremely difficult and expensive to prove that a naturally occurring stratum of soil and or rock uniformly possesses low hydraulic conductivity. For this reason, use of a natural soil liner as the sole means for protecting ground water from contamination is not normally recommended." In addition, sand lenses have been discovered during MPCA inspections in many areas where clay was supposedly very deep and homogeneous. The variability of Minnesota's soils and geology is very great.

Issue 2: Where suitable soils exist at the excavation site, the same soils that were over excavated may be replaced as the liner material. Is this reworking of the soils necessary?

Response: Undisturbed glacial till typically has large numbers of macropores such as fractures, earthworm casts, decayed root channel, etc., that water flows through. Research indicates that macropore flow, not flow through soil clods, is the predominant mechanism of ground water flow in glacial tills, and for movement from the surface to aquifers. If this weren't true, field tile lines wouldn't function effectively in many soils. A constructed clay soil liner should be a uniform liner of clay without fractures. In order to achieve this uniform liner, the clay is placed in thin (six inch or less) layers at proper clay and moisture content, then compacted until clods are joined together in a layer without cracks through it. These layers or lifts are than laid on top of each other, and joined together through compaction using equipment like a sheepsfoot roller, with teeth long enough to penetrate the lift (to join the top layer to the one below it) and also provided kneading action to join soil clods together. When completed, there should not be channels for water to flow through the liner. The purpose of this construction process is to create a uniform seal where no cracks exist

Issue 3: Natural bulk densities produced from compaction by glaciers are greater than can be achieved using compaction equipment.

Response: Density is not directly related to permeability, but rather is a measurement of weight per unit volume. Proctor density is a measurement of soil pore space and the compaction effort applied to soil. It can be a reflection of permeability, but it is not a direct measurement. Soils can meet construction specifications for proctor density and still be relatively permeable. The fractures in glacial till that have developed over time due to freeze/thaw cycles, shrinking and swelling of the clay, penetration of plant roots, etc., have resulted in the formation of channels that water can flow through. These soils are very dens, and it is true that the densities of these soils may be greater than can b achieved during a clay liner construction. However, the cracks tat are present do no all close completely when the soils become saturated. The purpose of the liner construction is to remove the cracks and disrupt the areas where water can flow easily, even if the soil ends up slightly less dense. Properly constructed clay liners will have a much lower permeability than natural clay soils even if they are not as dense as the soil was before e construction

When assessing the proposed options for construction of poultry barn floors, it is necessary to keep in mind the difference between storing dry manure and liquid manure. Dry manure lacks a hydraulic head which "pushes" the contaminates toward groundwater. Instead, in dry litter systems, the concern is over the soil porosity drawing out the liquid from the litter into the underlying soil layers. This contamination eventually reaches the groundwater. This difference allows us to require a wider variety of options for creating a sufficient liner without compromising environmental protection. The need for greater options than those provided in the agency's guidance was discussed in detail during the FMMAC meetings held from May 1999 to October 1999. See Exhibits B-1 and Exhibit O-4. The specific options resulting, in part from those FMMAC meetings, include:

Subpart. 2. Concrete or asphalt will provide a barrier that will prevent ground water contamination. Cracking in the clay and asphalt will need to be managed. Using concrete or asphalt will result in a durable satisfactory liner. This type of liner option will most likely be used be livestock owners or operators who want a durable floor and who are in area that is lacking in clay suitable to build a clay liner. The required minimum thickness of 3.5 inches is reasonable because forms used for most of these buildings consists of common two-by-fours, which have actual dimensions of 1.5 inches by 3.5 inches.

Subpart. 3. The requirements for constructing a clay lined floor are needed to ensure and adequate liner is being installed that will protect ground water. The 12” clay floor option prevents ground water contamination through a combination of impermeable soils and a porosity differential between the clay and the uncompacted natural soil underneath. The 8” option relies less on the thickness of the impermeable layer and more on the porosity differential between the 8 inches of clay and the required sand or geotextile underlayment. This increase porosity differential further prevents migration of contamination into underlying layers. Either option is sufficient to prevent ground water contamination. With both options it is critical to achieve a sufficient hydraulic conductivity in the clay. This is why the standard proctor specification must be met. In both options it is critical to repair the clay that is damaged that is why the repair requirements have been included. Finally, as shown in the example permit for a soil-lined poultry barn floor. See Exhibit B-4. The agency has required a 12-inch floor under the current program for several years. For these reasons, the provisions for soil-lined floor options are needed and reasonable.

Subpart 4. Construction requirements for polyvinyl chloride (PVC) lined floors. A polyvinyl chloride liner is allowed. Again, this option may be used in areas where clay is not present in sufficient quantities at or near the building site. This option simplifies construction compared to a soil-lined floor and the performance of PVC as a liner is well-proven though its common use in landfill systems throughout the country. A protective layer is needed on top of the PVC liner to protect the liner from damage during cleaning of the barns. This option is reasonable because it provides an protective and cost effective alternative to the concrete or asphalt lined floors where adequate soils are not present.

Subpart. 5. This provision is needed to document the quality of the construction process. This is reasonable because it allows the agency to substantiate that quality construction has been undertaken and for the owner to demonstrate that the facility was built in accordance with these rules.

Subpart 6. This provision contains the agency's proposed requirements that the owner to notify the agency or county feedlot officer of intent to construct at least three days prior to commencing construction and within three days following the completion of construction. This subpart also specifies the specific information needed in the notification. The opportunity to inspect or otherwise verify proper procedures and methods is necessary for the agency and counties to achieve regulatory oversight of the construction. This notification mechanism creates an effective oversight mechanism without providing hardship to the regulated party. It helps support the agency’s role as a source of environmental-related information and it provides the agency an avenue to communicate any final concerns it may have. It is reasonable because the owner has the required information readily available and has several options available on the method of notification including letter, phone and facsimile.

<u>7020.2125 Manure Stockpiling Sites</u>

Subpart 1. Through inspections and enforcement actions, the agency has documented the environmental damage that can result from poorly operated, maintained, and or located stockpiles. Photographs taken of stockpile sites document the runoff and resultant crop kill and gullies that form. See Exhibit S-7. Ponding of leachate occurs around many sites, creating a condition for increased risk of ground water contamination. Photographs in Exhibit S-7, also show evidence of killed vegetation that was killed due to runoff contamination from a stockpile. Other photographs show evidence of manure piled next to drainage ditches, at the outlet of the tile line and of manure runoff entering the tile intake. Letters from county feedlot pollution control officers indicate that they observe runoff in road ditches as well. See Exhibits S-4 and S-5.

Preliminary data indicates that ground water quality beneath open feedlots and manure storage pits is impacted. Additional research suggests that poultry manure has the potential to cause ground water pollution through infiltration into the subsurface soils and runoff contaminated with fecal coliform. Researchers concluded that rainfall on well-structured soil will cause the preferential movement of fecal coliform, and could contribute to fecal coliform concentrations in shallow ground water that exceeds standards for domestic discharges, 200 fecal coliform MPN per 100 milliliter of sample. See Exhibit S-8.

In addition, several studies have demonstrated that manure on bare ground for a long period of time can result in a significant environmental issue. The studies were conducted on soils under poultry barns to measure the nitrogen impact from manure on the soil. Soil nitrogen concentrations under a soil floor increased significantly in the top 30 centimeters of soil during a one-year period. See Exhibit S-3.

Although the agency finds sufficient data to support the need to establish minimum standards for stockpiling manure, it does not believe all stockpiling activities warrant the same standard. The proposed rule has requirements for two types of manure stockpiling – short-term and permanent. Subpart 1 contains the restrictions and requirements for permitting, location, design, construction, operation and maintenance of short-term and permanent stockpiling sites. The intent of this proposed part is to prevent ground and surface water contamination from stockpiles of manure.

The location standards are the same as for other animal feedlot facilities and are found in part 7020.2005. Similarly, the need and reasonableness are found in the discussion for part 7020.2005, which addresses the separation distances for any manure holding facility or operations with the potential to generate manure-contaminated runoff. Location restrictions specific to manure stockpiles are presented and discussed in subpart 2, item C.

Item A. In Item A, the agency proposes the requirement that the location and construction of stockpiles be such that prevent manure-contaminated runoff from the site does not discharge to waters of the state. This item is intended to clarify the agency position that manure or manure-contaminated runoff should not impact surface water.

This requirement is needed due to the enormous oxygen depleting properties of manure, which in the case of hog or cattle manure are 200 times stronger than untreated municipal sewage. See Exhibit S-9. For example, a manure stockpile from a feedlot of 300 animal units has a pollution risk equivalent to that of a municipal plant serving 60,000 people.

Given the significant environmental impact from manure contaminating ground and surface water as discussed in the statement of need in general and above, it is reasonable to regulate the practice of stockpiling manure. Additionally, part 7020.2003 proposes a water quality discharge standard consistent with the federal regulations, 40 CFR 412, and existing Minnesota rules, 7050.0215. The provisions of the water quality standard are discussed in that section of this SONAR relating specifically to part 7020.2003. It is reasonable to provide operators of manure stockpiles a mechanism to avoid the need for a federal or state permit if management design, location and management options will provide the necessary protection for waterbodies.

Thus, the most cost-effective manner to meet the provisions of part 7020.2003 and maintain stockpiles appropriate for a specific animal feedlot operation is to prevent any discharge from the stockpile. The impact of manure-contaminated runoff has been discussed thoroughly in this SONAR. While treatment options for runoff exist, the agency believes that it is more reasonable to clearly define for the feedlot owner that no discharge should occur than to have the feedlot owner run models or continually prove that a small discharge from a current feedlot stockpile will have no impact. Many small operations and the poultry sector utilize scraping techniques and may be exempt from the permit requirements of the federal and state rules. It is, therefore, reasonable that their standards put them outside the need for permitting by allowing a discharge that would require treatment before reaching water bodies.

Item B. Item B requires manure be stockpiled at a three to one horizontal to vertical ratio or have, at a minimum, a 15 percent solids content. Stockpiling manure on bare ground outside of the confines of an earthen or concrete storage structure has many environmental risks, including rapid infiltration to ground water and runoff to surface waters. The impacts of contaminants from manure and manure-contaminated runoff have been thoroughly discussed in the need and reasonableness as a whole earlier in this document. Thus, it is important that stockpiling of manure be accomplished in a manner that does not create or add to the risk of managing manure. Stockpiling of manure is allowed only for solid manure, or manure with no free liquids that could create management problems on the stockpile pad and infiltrate or runoff the pad. Additionally, since the manure on a stockpile will require at least two moves; placement for storage and retrieval land applying the manure, it is must be in a condition to permit easy movement. Land application would occur as soon as the weather and cropping patterns allow. The stockpiling ration and percent solid requirements are intended to ensure that only solid manure is stored in stockpiles and management options are not hampered.

All materials have an angle of repose, the slope held by a material before it will naturally slough off due to gravity forces overpowering the other forces hold the material in place and that they will hold the pile shape. For instance, the ability to pile sand to a certain height on a particular footprint is less than the ability to place a finer soil regime. This angle will vary to some degree based on the soil moisture but typically a general angle of slope exists for most material types. In establishing limits capable of protecting the environment for stockpiling manure, the agency needed to consider such factors as the typical equipment available to most feedlot owners, the amount of manure to be stockpiled, the condition of the stockpiled manure, and the cost of meeting the standard. Consider if the agency limited the slope to a six to one horizontal to vertical ratio as compared to the proposed standard. The six to one pile would be flatter and thus, require a larger pad to hold the same volume of manure than the steeper three to one ration. The additional problems caused by the flat stockpile would include more surface area in contact with precipitation and thus, potentially more difficulty in managing the manure since it will be wetter, less runoff down the outside slope; and the distance a feedlot owner would be placing material after the first levels of manure are in place. On the other hand, if the agency picked a steeper slope, the feedlot owner would need a smaller pad to store the same volume of manure, but the manure may not remain at a stable slope as precipitation starts to be absorbed and increase the moisture content. Thus, the three to one ration provided a reasonable compromise in minimizing construction costs for stockpile pads but did not present operational issues with the height or instability of the pile.

The angle of repose for a particular material is based on a number of factors, one of which is the moisture content. For manure to be stockpiled, the agency selected 15 percent moisture as a minimum standard. The percent moisture was selected because it ensured that the feedlot owner could easily manage the material for placement and retrieval prior to land application; because combined with the slope ratio a protective standard for the stockpile integrity will be achieved; and feedlot owners can easily adapt existing efforts to meet the standards or can appropriately plan for the manure management system in a new facility. A higher moisture content would create management difficulties in moving the manure and in stabilizing the stockpile. The agency believes that the percent moisture and the slope are reasonable standards because they allow the feedlot owner to maximize the use of existing systems while minimizing costs associated with stockpile pads.

Item C. Item C prohibits the use of rock quarries, gravel or sand pits and any mining excavation sites for storage of manure. Soils in these areas have intentionally been removed. In many situations, very little distance between the base of the excavation and the ground water table may exist. Thus, manure placed in an excavated pit would have a greater potential to pollute ground water. These areas would have no soil to allow the natural attenuation or reduction of pollutants to occur before manure contaminants would enter ground water. In other situations, the quarry may no longer be used because ground water was hit and there is no separation from ground water. In a third scenario, mining has stopped because soils with low permeability are at the surface and precipitation and run-on are forming ponding water. In the last two scenarios, a feedlot owner using these areas would be in direct violation of Minn. R. ch. 7020. Based on the environmental risk of using mined areas for manure stockpiling, the agency believes it is reasonable to prohibit the storage of manure in these areas. Additionally, these areas are often not conducive to moving the manure back out for land application.

For this reason, stockpiles are prohibited from being placed on fractured bedrock as well. The probability of nitrates, phosphorus and other nutrients entering ground water is greater in the excavated areas. Since stockpiles in these areas have a higher risk of contaminating ground water, thus, it is reasonable to prohibit stockpiles in these areas.

Item D. In item D, the agency proposes to limit the size of short-term stockpiles. The limit is highly linked to the agronomic needs of the crop on the tract of land not to exceed 320 acres. The volume of manure permitted on a short-term stockpile is based on the agronomic needs of the crop raised on the specific track of land on which the manure will be applied. In the item, the agency further proposes that the agronomic needs of the crop comply with the application rates in the land application section of the proposed part 7020.2225.

The agency has observed stockpiles up to one-quarter mile long. Such stockpiles without proper controls present a risk to ground water through infiltration and surface water from contaminated runoff. Earlier proposals suggested that due to the need prevent nuisance conditions and runoff from large quantities of stockpiled manure, the stockpile size would not exceed 10,000 square feet. A recent visit by agency staff to a farm with a turkey manure stockpile illustrates that this square footage limitation was impractical. The amount of manure would have required multiple stockpiles on the land parcel if the stockpile were limited to 10,000 square feet. Manure is stockpiled on land to be used for its fertilizer value and large quantities could be stockpiled in order to apply the manure at agronomic rates. For an average tract of land of 320 acres (one-half section), the stockpile would need to be formed at a height of 15 to 20 feet if the base or footprint was limited to 100 feet by 100 feet. Only feedlot owners that owned payloaders or who rented a payloader could achieve that height. The cost of renting a payloader could exceed $300 per day. Feedlot owners without access to this equipment would need to form several shorter stockpiles, which would create management difficulties and potentially create more runoff. For these reasons, the agency elected not to establish a square foot limit.

Since the purpose of stockpiling manure was for use as a nutrient source for croplands, the agency elected to pursue a requirement based on the amount of manure to properly land apply the manure on a tract of land. The volume of manure permitted for short-term stockpiles was discussed and consensus reached at the FMMAC meetings in 1999. The agency believes the final standard is reasonable because it allows the feedlot owner stockpile manure near the sites it will be land applied but does not increase the environmental risk.

Subpart 2. Subpart 2 contains the additional requirements proposed by the agency for short-term stockpiling. The requirements for this subpart require compliance by October 1, 2001, (approximately one year after the effective date of this part) allowing feedlot owners time to plan for any operational changes that the proposed rule would require. The agency believes a specific date is required to place feedlot owners on notice that the standards will be effective and the agency will have specific expectations when agency staff or CFOs conduct an inspection. The agency further believes that the proposed date is reasonable in that it allows the feedlot owner to consider possible stockpile locations during the winter season as other plans for cropping specifics are prepared. No capital outlay will be required and thus, establishing a longer time frame for compliance is unnecessary.

Item A. The agency proposes, in item A, that the manure in the short-term stockpile be removed from the stockpile site within 180 calendar days from the initial use of the stockpile and land applied in accordance with the proposed feedlot land application requirements, part 7020.2225. Item A does provide for the feedlot owner to extend this time frame provided the conditions of subitems 1 and 2 are met. Subitem 1 provides for a maximum time frame of one year from the date when the stockpile was initially established for the feedlot owner to land apply the stockpiled manure. In subitem 2, the agency proposes that the feedlot owner submit an extension notice to the commissioner or the delegated county. The notification form will be provided by the commissioner and on it must be a description the soil or weather conditions that prevented the removal or land application of the manure and the location of each short-term stockpile that will remain after the 180 days.

Early in the development of the proposed rules, the agency proposed three categories of stockpiling: short-term, less than 60 days; long-term, 12 months or less; and permanent stockpiling, longer than 12 months. Although poultry and turkey producers liked the earlier draft, especially the ability to store manure on stockpile sites up to a year with few restrictions, agency staff, county feedlot officers and environmentalists had concerns had concerns. Particularly, the categories of short-term and long-term stockpiling seemed arbitrary and would be difficult to verify. For example, a manure stockpile, under the proposal, would change from a short-term to a long-term stockpile after the passage from 60 to 61 days. Monitoring for compliance is difficult if not impossible for short or long term piles through a visual inspection of a large manure stockpile. Although subpart 3 of this part requires that records be kept of when the stockpiles were established, an inspector driving by, or neighbor, would not have this information and only with a complete audit of land application dates, estimated manure generation, etc. could verification be complete. The agency and delegated counties needed a method to visually determine the difference in stockpiles. Also, some producers argued that permits for each stockpile would be administratively burdensome for agency, delegated counties and producers without any more assurance on the length of time manure had been stockpiled. The agency agreed and sought solutions that would not require permits for stockpiles only. However, the agency believed it important to develop a system that was not administratively burdensome, was easy to field verify and limited the time a stockpile can remain on bare soil to protect the environment.

At least three studies have been conducted that demonstrate that manure placed directly on bare ground for a long period of time can result in a significant environmental issue. The studies were conducted on soils under poultry barns to measure the nitrogen impact from manure on the soil. Since the manure in the poultry barn is not exposed to precipitation (and would not have the higher water content resulting in greater leaching of nitrogen into the soil), it is reasonable to believe that an open stockpile would have a greater impact on the soil under the stockpile than was measured under the barns in the studies. See Exhibits S-1, S-2 and S-3.

An existing poultry barn with a new (barrier) floor installed was compared to a new poultry barn with no floor over a period of approximately one year. The study concluded that "Soil nitrogen concentrations beneath the barrier floor of a new house did not increase while the concentrations under a typical soil floor increased significantly in the top 30 centimeters of soil beneath the litter during the project period". See Exhibit S-3. Therefore, the agency believes that the duration that manure can be placed on bare ground should be limited.

In addition to short and long-term stockpiles being difficult to monitor for compliance, poultry and turkey producers and other producers would not have really benefited from a 60-day stockpile category as they argued that two "windows of opportunity" to land apply the manure exist. The two opportunities were each five to six months apart, April through May and mid-October through mid-November. See Exhibit S-6. Thus, their schedule, as described, did not lend itself to the previous short-term limit but does fit in with the current six-month short-term limit. The agency believes that the 180-day time frame for a short-term stockpile is reasonable because allows sufficient time for the accumulation of manure over the winter months, a time land application is discouraged, and over the cropping season when again access to land application sites would be limited.

Complaints of large manure stockpiles being observed in the same place year after year over sandy soils and runoff from stockpiles into tile intakes and abandoned wells have been received by the agency. The following pollutants may be contained in manure and associated bedding materials and could be transported by runoff water and process wastewater from confined animal facilities:

- Oxygen-demanding substances;
- Nitrogen, phosphorus, and many other major and minor nutrients or other deleterious materials;
- Organic solids;
- Salts;
- Bacteria, viruses, and other micro-organisms; and
- Sediments.

Fish kills may result from runoff, wastewater, or manure entering surface waters, due to ammonia or dissolved oxygen depletion. The decomposition of organic materials can deplete dissolved oxygen supplies in water, resulting in anoxic or anaerobic conditions. Methane, amines, and sulfide are produced in anaerobic waters, causing the water to acquire an unpleasant odor, taste, and appearance. Such waters can be unsuitable for drinking, fishing, and other recreational uses.

The high nutrient and salt content of manure and runoff from manure-covered areas, contamination of ground water can be a problem if storage structures are not built to minimize seepage. Animal diseases can be transmitted to humans through contact with animal feces. Runoff from fields receiving manure will contain extremely high numbers of bacteria if the manure has not been incorporated or the bacteria have not been subject to stress. A more detailed discussion on the impacts of pollutants found in manure and manure-contaminated runoff is found under the Section III, Need for the Rules, of this SONAR.

According to the U.S. Department of Agriculture and EPA, "Dry manure, such as that produced in certain poultry and beef operations, should be stored in production buildings or storage facilities or otherwise stored in such a way so as to prevent polluted runoff." They go on to state that "Poultry operations that remove waste from pens and stack it in areas exposed to rainfall or adjacent to a water course may be considered to have established a crude liquid manure system." See Exhibit G-2.

Based on the above evidence that the duration manure of piled on bare ground should be limited and potential problems with timing land application, it is reasonable to limit the duration of a short-term stockpile site to 180 days and to allow an extension only if weather conditions prevent timely application.

Subitem 1. Subitem 1 contains the agency's proposed limitation on the maximum time a manure stockpile may exist under the category of short-term. The proposed subitem indicates that land application of the manure must occur within one year after the stockpile was initially established. A maximum time frame is needed to ensure that extensions are not regularly granted through the notification process of subitem 2 with no land application ultimately occurring. The agency routinely receives complaints that a stockpile has existed in a particular location for more than one year with no ability to substantiate the time frame. A maximum time frame of one year is reasonable because the short-term stockpile is usually sited near the field where land application will occur and thus, given the windows of opportunity, an equivalent of six months of the year would be available for land application and the weather and soil conditions should be acceptable at some period during that time.

Subitem 2. In subitem 2, the agency proposes that the feedlot owner provide the notice to extend beyond the time frame associated with short-term stockpiling before the 180-day time frame expires on a form provided by the agency. The commissioner or the CFO would need to be notified. Notification is required because these facilities will typically change locations regularly and without some minimal tracking system, the agency or delegated county would be unable to respond to complaints without extensive field verification and thus, be unable to deal with more appropriate issues. The provision is reasonable as minimal effort is required of the feedlot owner and no extra or special approvals must be obtained. The notification can be avoided with careful planning and management.

Units a and b. Subitem 2 also contains the agency's proposed conditions under which the storage duration of a short-term stockpile may occur without further design and construction restrictions being applied by the agency or delegated county. Unit a indicates that the feedlot owner must indicate the weather and soils conditions that prevented land application within the 180-day time frame. Unit b contains the requirement that the feedlot owner provide the location of the stockpile. The provisions in units a and b are needed to allow the agency or delegated county to track those stockpiles that have extended beyond the 180-day time frame through no fault of the feedlot owner. This information allows the agency or delegated county to verify the location and respond to complaints timely. The information requested on the notification is minimal in nature and is known by the feedlot owner. It is reasonable to track extended short-term stockpiles to ensure that they do not become permanent stockpiles without the protection methods incorporated into those standards.

Subpart 2, item B. The agency proposes in item B that a vegetative cover be established on the site after the manure is removed and remain for at least one full growing season before the site can be reused as a short-term stockpile site. An exception is proposed for sites located within the confines of a feedlot containing less than 100 animal units of hooved animals. Feedlot owners with cows confined to lots do not need to re-establish vegetation after the manure is removed because the soil under the feedlot becomes compacted by the animals' hooves, forming a seal against infiltration. See Exhibits S-12 and S-13. To meet the requirement for vegetative cover, the feedlot would need to remain vacant during the calendar year preceding or following the calendar year in which the site is used. It is unreasonable to require a feedlot owner not to utilize the open lot for two out every three years. The feedlot owner would incur unnecessary costs in designing and maintaining sufficient areas to confine the animals under such a scenario.

The selection of 100 animal units was made based on the agency's knowledge on size of existing feedlots and planned feedlots for hooved animals. The feedlot being used to confine a herd equivalent of 100 animal units is typically only a few acres. The amount of area subject to erosion and sediment runoff would be limited by site controls or location of the site. The capitol outlay needed to control surface water movement through the small feedlot is minimal and can be accomplished with inexpensive diversion berms. However, once the feedlot is large enough to confine a herd equivalent to more than 100 animal units the amount of non-vegetated ground expands considerable and the potential for erosion and sediment runoff grows. The feedlot owner is now managing an area that will require surface water controls that may need to divert water from a mini-watershed. The agency believes that management of the larger confined feedlots puts the environment at unnecessary risk to runoff and a better management system is available to the feedlot owner. The agency believes the use of 100 animal units is reasonable as it accounts for most existing small operations and still allows controls to be reasonably developed for the site without significant cost to the feedlot owner.

The purpose of establishing vegetation on soil is to remove buildup of nutrients (i.e., nitrates and phosphorus) that have occurred. High nutrient buildup of soils is common where land areas have been used as feedlot sites or manure stockpile sites. Nutrient buildup in the soil is generally a precondition for the potential pollution of ground water. Therefore, it is reasonable to require that owners re-vegetate land following its use as a stockpile site. The site cannot be used for a year to allow for one full growing season and the resultant uptake of nutrients by the vegetation.

Item C. Item C, as proposed, contains the minimum setbacks specifically to short-term stockpiles of manure. Because these stockpiles will be utilized on the fields that will ultimately received the manure, it is important that the stockpile be established in low risk areas for ground water and surface water impacts. The agency believes it is reasonable to provide a set of performance standards for locating the stockpiles as they will not receive an individual site review through a permitting process, which would evaluate the location for potential risks. By codifying the agency's expectations relative to locating stockpiles, feedlot owners have the knowledge to establish manure stockpiles without creating unnecessary environmental risks. The agency believes it is reasonable to provide the feedlot owner the location requirements considered acceptable in a likely portion of the proposed rules so that the feedlot owners may plan accordingly and not be required to move a stockpile prematurely because it is located in an area deemed unacceptable based on environmental risk. Additionally, it is reasonable to let other interested parties know the agency's expectations so that they can respond to risks they feel are relative to the location standards. Since short-term stockpiles are not required to be permitted the rule process is the only opportunity for public input into these standards.

Subitem 1. In subitem 1, the agency proposes to establish a setback of 300 feet of flow distance and at least 50 feet horizontal distance, to waters of the state, sinkholes, rock outcropping, open tile intakes, and any uncultivated wetlands that are not seeded to annual farm crops or crop rotations involving pasture grasses or legumes. Two-thirds of Minnesotans drink the ground water. For purposes of protecting public health it is critical that runoff from manure, which is high in nitrates, be prevented from discharging to ground water. Protection of this important resource is essential. Subitem 1 establishes the setback distances needed to encourage manure-contaminated runoff to infiltrate into subsurface soils before reaching the geologic formation, landscape conditions, and manmade structures that would act as direct conduits to ground water.

The setback distances were developed based on the typical topsoil for Minnesota and the infiltration rate of water. It is expected that the setbacks provide sufficient assurance that infiltration will occur and direct discharges to the above natural and manmade conveyances to ground water will be avoided. The proposed setbacks are reasonable because they protect the ground water resources of Minnesota and yet allow the producer the flexibility to place the short-term stockpile anywhere on a field where these setbacks are achieved. The provisions are less intrusive to the producer than a technical standard with pre-established setbacks from roadways, driveways, ditches, etc. that would eliminated much of the field and thus, potentially result in management difficulties for the producer in placing the stockpile as near the land application site as possible.

Subitem 2. The agency proposes to establish in subitem 2 a setback of 300-feet flow distance to any road ditch that flows to the features identified in subitem 1 or 50 feet of any road ditch where subitem 1 does not apply. Road ditches typically outlet at some point to a surface waterbody. It is important that manure-contaminated runoff or manure not enter these drainage devices. Again, the setbacks were establish to encourage infiltration into the subsurface soils prior to reaching the ditch but are not so intrusive that the only location available to site a stockpile is in the center of a field. It is important to retain flexibility for the producer in locating the stockpile while ensuring sufficient protection of surface waterbodies from manure-contaminated runoff. The agency believes that it has found a reasonable balance between the flexibility and protective standard remembering that no regulatory review will occur at these sites prior to their establishment.

Subitem 3. Under subitem 3, the agency proposes to establish a setback distance for short-term stockpiles from drinking water wells. The setback is proposed to address private water supply wells and not community wells. Subitem 3 defines the restriction to be 100 feet from any private water supply or abandoned well and 200 feet from any private well with less than 50 feet of watertight casing and that is not cased through a confining layer at least 10 feet thick.

Community wells are not addressed in this subitem because an overall location restriction exists in part 7020.2005 and it is unlikely that the field designated for land application of manure from a short-term stockpile would be near the confines of a community well system. The producer will not be traveling significant distances to develop the stockpile due to the operational difficulties it presents in moving the manure.

Pathogens, such as Cryptosporidium, have been linked to impairments in drinking water supplies and threats to human health. Nitrogen, in the form of nitrate, can contaminate drinking water supplies drawn from ground water, and can be deadly to infants. For health reasons, the nitrate standard in drinking water is 10 milligrams per liter. See Minn. R. pt. 4717.7100 to pt. 4717.8100. Thus, it is necessary to require that stockpiles be located away from wells that have not been constructed in such a manner as to prevent the direct migration of runoff into the ground water.

The setback distances and well construction criteria are based on the minimum standards required to protect the ground water from receiving direct manure-contaminated runoff. Wells, not constructed in the manner described in subitem 3, are most vulnerable to direct runoff and are typically associated with older farmsteads. It is important that these vulnerable wells not risk and ultimately those using the well for drinking water at risk from manure-contaminated runoff. The setbacks encourage infiltration prior to reaching the well and yet are not so exclusive that the producer could not locate a short-term stockpile near the farmstead to permit the management of manure and an efficient manner. Other provisions in the proposed rules do not require that the short-term stockpile to be located at the field designated for land application. It would be unreasonable to establish setbacks that would prohibit the scrape and stack operations associated with small operations. The agency believes that it has proposed a standard that reasonably balances the need for protecting ground water and allowing the feedlot owner flexibility in managing the feedlot.

Subitem 4. In subitem 4, the agency proposes to establish a setback of 100 feet from field drain tile that are three feet or less from the soil surface. Because many short-term stockpiles will be established near the field that will receive the manure, it is important to consider all conditions that could serve as direct conduits to surface water or ground water. One such hazard encounter in many fields is drain tile used to control soil moisture for cropping purposes. When the tile inlet is at ground surface or near the surface, manure-contaminated runoff would be drawn directly into the tile. At this point, the tile would become a conduit of manure-contaminated runoff to the surface waterbody. This places the surface water at risk for contamination. Thus, a setback of some distance is needed.

The setback is intended to allow sufficient time for runoff to infiltrate into the subsurface soil before reaching the tile inlet. The agency proposes that 100 feet is an appropriate setback. Since the feedlot owner will be managing the manure stockpile to minimize runoff, the purpose of the setback is to gain some time for natural protection systems to occur before the tile inlet is reached. The 100-foot setback allows for the minimal runoff that may occur from a short-term stockpile to infiltrate into the subsurface soils. A setback greater than 100 feet removes an unacceptable amount of cropland from usage. Likely this land would be grassed and thus, have little market value as an income source. A setback less than 100 feet would provide insufficient time for the runoff to infiltrate and be treated through the soils natural processes. The proposed setback would not be imposed on drain tile inlets deeper than three feet because studies have shown that most bacteria and nitrates are reduced in risk within three feet of the sources. This treatment standard is consistent with the agency's approach to managing individual sewage treatment systems, Minn. R. ch. 7080. The feedlot owner has reasonable alternatives to the setback distance in that the tile inlet only need be covered with more soil. The additional soil can be shaped and sloped to direct runoff away from the inlet. The agency believes that the proposed setback is a reasonable standard that provides protection to water resources while not removing land from production.

Item D. In item D, the agency proposes that the feedlot owner maintain a two-foot separation distance between the base of the stockpile and the seasonal high water table or saturated soils. Information on saturated soils can be determined using the USDA/NRCS Soil Manual or a site-specific soils investigation. See Exhibit S-18. The agency believes it is necessary to maintain a minimum separation between the base of the stockpile and the ground water. As previously discussed the potential for contaminant to reach surface water or ground water places these water resources at risk. Additionally, it was explained that short-term stockpiles are not reviewed prior to establishment and locational standards are important to protect environmentally-sensitive or at risk resources. Near surface ground water is a condition that will place the drinking water or nearby surface waterbody at risk for contamination. It is important to minimize this risk.

Under the proposal, stockpiles are allowed to sit on bare soil or minimally-vegetated soil that will be exposed to precipitation for up to six months. A stockpile of manure will release liquids particularly after a precipitation event. The agency believes that a two-foot separation distance to the seasonal high water table or saturated soils when considered with the other setbacks already discussed ample protection to the ground water will be provided. The seasonal high water table does not mean that ground water exists to that level throughout the year. Likely, the seasonal high water table is associated with the spring snow melt and spring rains, or other conditions where precipitation occurs over an extended period of time. For these reasons, the agency does not feel that the entire minimum protection distance be required as was in subitem 3. The agency believes that it is reasonable to ensure that some protection exists by way of the two-foot separation but that it is unreasonable to require a short-term stockpile to meet the three-foot minimum discussed in subitem 3, when the high water mark is also temporary.

Item E. The agency proposes in item E to prohibit the establishment of short-term stockpiles under specific site conditions. The agency finds that particular site conditions do exist that provide no natural protection against contaminants associated with manure. Therefore, it is important that these locations not be considered as potential stockpile sites. It is necessary to define these conditions in rule to provide the standard by which a stockpile will be judged. Establishment of the prohibited locations in rule alerts the feedlot owner on conditions that would place nearby water resources at risk, particularly when no special design or construction requirements are placed on short-term stockpiles. Subitems 1 to 3 contain the proposed prohibitions.

Subitem 1. The agency proposes to prohibit the establishment of a manure short-term stockpile on land with slopes greater than six percent. Steeper slopes in many parts of the state are associated with coarser soil particles and could result in rapid infiltration. Secondly, slopes greater than six percent encourage the flow direction across the site soils down the hill not into the site soils. Again, this infiltration in coarse soils places ground water resources at risk for contamination and the runoff jeopardizes nearby surface waters. The agency believes the slope is reasonable because it is a well-used standard for controlling of runoff including Minn. R. ch. 7041, sewage sludge land application. The six percent slope allows for land application of manure without requiring the need for immediate incorporation as the risk for runoff is controlled prior to the natural breakdown of the manure occurring. It is reasonable to establish for manure a prohibition consistent with other agency programs governing land application of materials.

Subitem 2. In subitem 2, the agency proposes to prohibit the establishment of short-term stockpiles on land with slopes between two and six percent, except where clean water diversions and erosion control structures are installed. As discussed in subitem 1, it is necessary to restrict the degree of slope (increased slope equals increased runoff due to gravity) where stockpiles may be established. Additionally, the agency must considered surface water run-on to the stockpile increasing the likelihood of manure-contaminated runoff. The agency does find it reasonable to allow the establishment of stockpiles where the producer has already taken precautions to control surface water flow and erosion. Clean water diversions and erosion control structures are not only intended to keep soils on the land but keep soil and runoff from reaching surface water. Thus, protection systems exist and should be accounted for in the siting process.

Subitem 3. The agency finds it particularly necessary to control risks to ground water through rapid infiltration of manure-contaminated liquids through coarse soils on the site. Subitem 3 contains the agency's proposal to prohibit short-term stockpiles on sites where the soil texture is coarser than a sandy-loam to a depth of five feet. These coarse soils not only allow liquids to be quickly move through them but have the least attenuative properties regarding contaminant protection. These liquids would be a small amount of free moisture in the manure, precipitation that falls on the manure and runs off and the precipitation that soaks into the manure stockpile and is then released if the saturation point is reached. Soil type, again can be identified using the information available in the USDA/NRCS Soil Manual or a site specific soils investigation. It is reasonable to prohibit the location of stockpiles in locations with coarse soils because if a field were found to have this material throughout a number of sensitive conditions may exist relative to the proximity to ground water. Typically fields would not have coarse soil conditions across the entire site. Rather, it is reasonable to expect that on some portion of the site will be found acceptable. The agency expects this provision to impact only specialized incidents where a field may sit on a potential gravel resources or an old river bed.

Subpart 3. Subpart 3 contains recordkeeping requirements for feedlot owners utilizing short-term stockpiles. The records must be kept by the feedlot owner producing the manure for three years for all short-term stockpiles. The proposed requirements do not require that these records be submitted to the agency or delegated county. The records are only submitted should the agency or delegated county request. Records are needed and serve a variety of purposes outside the agency's or delegated county's responsibilities. Most importantly the information retained by the feedlot owner is useful in maintaining a proper nutrient balance on cropland, understanding how the manure is utilized, and finally building confidence with neighbors that the manure is being managed responsibly.

For example, the size of a stockpile is limited to the agronomic needs of a crop on a tract of land not to exceed 320 acres. If a neighbor or inspector questioned the stockpile's size, the animal feedlot owner would have the documentation to justify the amount of material stored and how it was used in the past. The inspector will be able in reviewing the data correlate application rates and if, an adjustment is needed to the stockpile. A second example of when records might be requested relates to compliance determinations with regard to location of the stockpile to sensitive and prohibited areas outlined in subpart 2. It is reasonable that minimal records that provide valuable information to the producer be kept for planning and response needs. Again, given that the records are needed to determine compliance and the proposed requirements are one of the least intrusive options for demonstrating compliance, it is reasonable to require these records. A minimum of three years is the amount of time agency rules in other programs require for keeping records available and was selected for consistency.

Items A through E contain the specific requirements that the owner must track for the purposes of this subpart. It is necessary to provide the minimum information the agency expects on a report. Since the report will be used to help verify operations at the site, it is important that the owner understand what is needed. The proposed reporting requirements are:

- Location of the stockpile;
- Date on which each stockpile was established;
- Volume of manure stockpiled;
- Nutrient analysis of the manure; and
- Date(s) the stockpiled manure was land applied.

As discussed above, none of the above provisions require the owner to conduct extensive testing; to hire an outside consultant for completion; or to seek out information not available through normal operations under a manure management plan needed for part 7020.2225, land application. The information will exist and will not add additional costs to the owner. Based on the discussion above concerning the value and limited cost of tracking items A to E, it is reasonable to establish in rule the information an inspector would expect to find.

Subpart 4. Subpart 4 lists the additional requirements the agency is proposing for permanent stockpile sites. Permanent stockpile sites are different from short-term sites in that manure will be on the same site for longer than 180 days. Therefore, a facility that stockpiles manure exposes the manure to increased snowmelt and rainfall, logically generating more runoff the longer it is stockpiled. Additionally, because the stockpile is a long-term commitment for manure management, the risk for contaminants seeping into subsurface soils will increase as essentially manure will be on the stockpile pad at all times. For these reasons, it is necessary that the stockpile pad be constructed with a liner and runoff containment system. Owners have until October 1, 2001, to comply with the permanent stockpile requirements in items A to D. In addition, the owner must install a liquid manure storage area to collect and contain manure-contaminated runoff, if necessary to comply with the discharge standard of part 7020.2003.

Item A. In this item, the agency proposes that permit applications be submitted as required under part 7020.0405, subp. 1. Since the establishment of a permanent stockpile requires the construction of a lined pad and runoff control system, it is necessary to look at a more detailed review occur prior to construction. Part 7020.0405 contains permit requirements based on the number of animal units producing manure for the stockpile and other risks associated with the type of facility under consideration. It is reasonable to consider additional review and inspection for permanent stockpiles because the long-term stockpiling of manure increases the risk that the contaminants contained in manure could infiltrate to ground water or runoff to surface water and present the environmental and human health impacts discussed in the need portion of this SONAR.

Item B, subitem 1. The agency proposes in this subitem the requirements for the liner at the stockpile site. Subitem 1 establishes that the liner must be at least two-feet thick and constructed of soils with a hydraulic conductivity of 1×10^{-7} centimeters per second or less after construction. It is necessary that the requirement for the design and construction of the required liner be provided in rule. This proposed standard is an existing regulatory standard for solid waste storage, solid or food waste compost sites, domestic sewage and industrial waste facilities, and is proposed for the minimum standard to be used in constructing liquid manure storage areas, part 7020.2100. Permanent stockpiles are defined as a permanent form of manure storage. Thus, they are comparable to below-ground earthen or concrete manure storage structures. It is reasonable to require a pad or liner be designed and constructed to prevent the infiltration of contaminated liquids into ground water. The basis for the hydraulic conductivity is detailed in the reasonableness for part 7020.2100. It is reasonable that since the liquid manure storage areas and permanent stockpiles are managing the same material the minimum standards be equivalent.

Subitem 2. In this subitem, the agency proposes that the stockpile pad may be constructed of materials other than soil if the material will have a hydraulic conductivity less than 1×10^{-7} centimeters per second. It is necessary to allow for the use of materials other than soil provided the performance standard is met. If soils with a low hydraulic conductivity are not available near the intended location of the stockpile pad costs to construct the pad can escalate rapidly. Once the transport of soil exceeds much more than 15 miles the cost to transport and place will nearly double or triple. Since the cost of material is the largest expense in designing and constructing a stockpile pad, it is reasonable that the agency provide for the use of alternatives meeting the performance standard and thus, allow the feedlot owner the flexibility to make a business decision on the type of material to use. Additionally, the feedlot owner may prefer to use a different material because of operational ease. For instance, concrete is often easier to maintain and work on than a soil liner. The initial cost of construction for concrete could easily be offset by the operational savings on maintaining the soil liner after the placement and removal of manure several times. The agency is concerned with environmental protection and not the business decision relative to the type of material used.

Item C. Item C contains the agency proposed requirements relative to protecting the stockpile from surface water run-on. The requirements state that the site must be constructed using a diversion structure, elevated platform construction, or other devices to prevent surface waters from entering and passing through the stockpile site (run-on). Furthermore, where up gradient slopes exceed two percent, clean water diversions of sufficient height to prevent run-on must surround at least three sides of the permanent stockpile site. These requirements are needed and reasonable to prevent storm water and snowmelt from infiltrating manure stockpiles and carrying away the leachate off the pad into surrounding soils and eventually ground water. Diversion must be of sufficient height to prevent outside water from passing over the diversion structures during snowmelt or rainfall events (less than the 25-year, 24-hour storm event). These provisions are consistent with the protection standards used in locating a facility and it is reasonable that if contaminated runoff must be prevented from moving to surface water the management of runoff generation also occur. Thus, it is reasonable to utilize proper construction techniques to keep surface water away from the stockpile.

Item D. Item D requires that a permanent stockpile be operated and maintained to protect the integrity and structural reliability of the structure. The pad will be subject to routine scraping and wear and tear from heavy equipment. Properly constructed basins and liners do little good if damaged. Additionally, the construction of the stockpile pad is not small and this investment to protect the environment must be part of the normal animal feedlot operations. Therefore, it is reasonable to require that the integrity of the system be maintained. While the agency proposes a protection standard, it does not establish an inspection schedule, testing requirements or similar means to determining the liner integrity, but rather allows the feedlot owner to make such decisions through the material used to construct the liner or as needed, repair to the soil liner through re-construction methods including compacting and resurfacing.

Item E. Item E contains the standard for the owner to notify the commissioner or CFO of intent to construct at least three days before beginning construction. After completion of construction, the owner must also notify the commissioner or county feedlot officer of its completion.

Subitems 1 to 4. The agency proposes that notification be completed by letter, telephone or facsimile. Subitems 1 to 4 establish the information to be provided in the notice. This information must include the permit number, if applicable; the name of facility, if different than the owner; the site location and name of the contractor responsible for installing the liner. This information is needed and reasonable to allow the opportunity for inspection during construction by the agency or CFO. The information is available to the feedlot owner at no additional effort or costs. Sharing the information with the agency or CFO ensures that the feedlot owner is constructing the stockpile in compliance with the rules and within the time frame outlined in the rules or individual permit for the facility. It is reasonable that the regulatory authorities understand the construction activities taking place within their area and have the opportunity to do a construction compliance evaluation prior to the feedlot owner expending money for a system due to failure because of poor quality materials or poor construction.

Item F. Item F contains the agency proposal that permanent stockpiles comply with subpart 2, item D. This provision establishes special separation distances between the base of the stockpile and the seasonal high water tables. Just as explained in subpart 2, item D, the need to protect ground water from infiltrating liquids contaminated with manure is important to the use of the ground water for human consumption. It is reasonable that all stockpiles have similar locational standards as minimum goals for protection ground water.

7020.2150 Manure Compost Sites

Minnesota leads the nation in having the largest number of municipal solid waste compost facilities (six with several others being considered). Minnesota was one of the first states in 1990 to ban yard waste from being landfilled or incinerated and last year composted over 850,000 cubic yards of yard waste in over 150 yard waste facilities. Compost rules, as part of the solid waste rules (7035.2836) were revised in 1993 in order to adopt the U.S. Environmental Protection Agency biosolids metal standards (40 CFR 503) and to expedite marketing of the compost.

Despite the interest and success in composting residential waste streams, composting agricultural wastes including manure has been almost nonexistent. Only two manure compost permits have been issued in Minnesota, although there are 40,000 feedlots in the state. Ironically, agriculture is well-suited to composting: the amount and biodegradability of manure, coupled with the availability of land and the benefits of adding compost to the soil make animal feedlots ideal places to compost.

Benefits of adding compost to soil include improved manure handling, enhanced soil tilth and fertility, and reduced environmental risk. The composting process produces heat, which drives off moisture and destroys pathogens and weed seeds. With good management, it produces a minimum of odors. Farmers in eighteenth and nineteenth-century America practiced composting. Mechanization, chemical fertilizers and pesticides changed farming in the 20th century. Compost was perceived to be unnecessary and as a result, composting largely disappeared from farms. Compost is gaining in popularity on farms on the East Coast of the United States and, in California especially, among organic farmers. Composting can replace chemical fertilizers while protecting the environment as it converts the nitrogen contained in manure into a more stable organic form, which is less susceptible to leaching. Compost has also been found to reduce soil-borne plant diseases without use of chemical controls. The disease-suppressing qualities of compost are widely recognized. See Exhibit S-10.

The agency has received telephone calls from farmers who want to compost manure but are reluctant to do so because they believe a permit is required under all circumstances. This belief comes from the overall permitting requirements for small feedlot operations. In an effort to clarify when permits would be required under the revised rule and permitting system, a new section is proposed by the agency on manure composting. Basically, the short-term stockpile requirements must be met if composting on a section of land for less than six months, and the permanent stockpile requirements must be followed when composting on the same section of land for longer than six months. Therefore, a permit and requirements for a liner and runoff pond will not be required if the land under the composting material is re-vegetated every six months. An SDS permit is required if the site has manure composting on it from 1,000 animal units or more. In the event that the site meets the criteria for a CAFO, then an NPDES permit will be required.

Less leachate is produced from composting material than from simply placing manure in a pile. Little, if any, air passes through a pile of manure. Under these circumstances, the anaerobic microorganisms dominate the degradation that inevitably takes place. All of the undesirable effects associated with anaerobic degradation occur: low temperatures, slow decomposition and the release of hydrogen sulfide, and other malodorous compounds. Water in the pile is not vaporized by high temperatures and the pile remains wet and anaerobic. This combination produces leachate, which contains a liquid with partially degraded organic compounds.

A study of compost utilization as a soil amendment for crops was conducted by the University of Minnesota under the direction of the Minnesota Office of Environmental Assistance. This study includes data on the relative leaching characteristics of compost. The study concluded that contaminants are less likely to leach from composted manure than raw manure. See Exhibit S-14.

Subpart 1. In subpart 1, the agency proposes requirements for owners who compost manure. The provisions establish that the stockpile requirements are the minimum standards for compost site locations, design and construction. Additionally, subpart 1 states that compost made from manure and solid waste must comply with the solid waste compost rule part 7035.2836, subparts 4 to 7 (the solid waste compost rules), and that owners composting dead animals comply with the Board of Animal Health rule part 1719.4000.

This is needed to direct composters to the appropriate regulations, dependent on their respective feedstocks. It is reasonable to have farmers follow the solid waste compost rules if they are composting solid wastes with their manure. It is appropriate that the more protective standard apply when combining feedstocks to produce a compost product.

While the agency is not responsible for the management of dead animals, it is reasonable that feedlot owners, who have more direct relationship with the agency relative to managing their facility, be directed to the proper Board of Animal Health rules, the agency with jurisdiction over the proper management of dead animals. The agency believes that providing the information is a service to animal feedlot owners and assists in ensuring that all aspects of the feedlot operation are maintained to protect human health and the environment.

Subpart 2. Subpart 2 lists the operational requirements for composting manure. Item A directs the owner to the stockpile portion of Minn. R. ch. 7020, which is part 7020.2125. The animal feedlot owner must establish the compost site in the same manner as one would locate, design and operate a stockpile. The requirements of part 7020.2125 are discussed in this SONAR for that section and immediately precedes this discussion. Thus, if a person is composting manure for 180 days, the site would need to be re-vegetated for one growing season prior to reuse. The re-vegetation allows the plants to utilize any nutrients in the soil from the composting material. If inclement weather prevented the timely removal of the compost, a feedlot owner could write the agency or county feedlot pollution control officer and request an extension for up to one year. The next batch of composting material would have located away from the previous site in order to allow for vegetation to grow at the previous location. If a person decided not to move the location of the composting material every six months, a liner and diversion structures would need to be constructed to place the manure on.

Just as the stockpiling of manure has risks associated with it, so does the development of a compost site. It is important that the risks be minimized. Since composting is simply a more active management program than stockpiling manure in that turning and working with the pile are standard, it is reasonable that similar operational and locational standards be used to minimize risks.

Item B. In item B, the agency proposes that a compost site even operating as a short-term stockpile, less than six months at any one location, be required to meet the diversion standards applicable to permanent stockpiles. This provision is necessary because successful composting requires that temperature, moisture and air be maintained at proper levels. By establishing a diversion system around the compost site, the animal feedlot owner will be able to control the amount of surface water run-on and may then estimate moisture content by matching existing moisture with final product and account for precipitation in the operations. Until the composting process has proceeded to final compost, the manure on a compost pile has similar risks associated with it as raw manure stockpiled. Thus, it is reasonable that, for the protection of human health and the environment, similar standards apply.

Item C requires that one of three systems be used for composting and ultimately for regulating pathogens in the compost. A major advantage of composting manure is the pathogen kill that occurs from the intense heat and resultant elevated temperature during aerobic composting. Composting manure offers protection against E. coli, a bacterium associated with waste from the intestinal tract and in manure. E. coli has been found in wells not adequately protected. In addition to proper locating and operating of manure management systems, another protection measure is to compost in a manner that kills the bacteria. There are not waiting periods when applying raw manure to food chain crops or crops grown for human consumption although there are restrictions for spreading biosolids, which is generated from treatment of human wastewaters and has similar bacteria as manure. Subitems 1 to 3 establish the type of composting operations the agency believes are sufficient to kill E. coli and other pathogens.

A USDA-researched method referred to as a process to further reduce pathogens (PFRP) describes the procedure to kill pathogens. The use of PFRP for regulating pathogens in biosolids was adapted by EPA in the final 40 CFR 503 rule which was published in the Federal Register on February 19, 1993. This operational standard was based on extensive experimental data and years of experience and, in the judgment of EPA, is protective of public health and the environment. See Exhibit S-15.

The choice of composting method for most farms is usually windrows or aerated piles, as these methods are much less costly than an in-vessel composting method. Windrows can be turned with a bobcat, front-end loader or bucket loader on a tractor, equipment that typically exists on a farm. It may be possible for a farmer to avoid the expense of special windrow turners by adapting farm equipment (augers, conveyors, harvesting machines, etc.) to mix and move the composting material. For a full discussion of these composting methods, chapter 4 in the On-Farm Composting Handbook should be reviewed. See Exhibit S-10.

Subitems 1 to 3. The three options for meeting PFRP are a windrow method, static aerated pile method or enclosed vessel method. These methods are identical to those required of solid waste or food waste composting under Minn. R. pt. 7035.2836. The system used is at the discretion of the animal feedlot owner but must have the ability to reach an operating temperature of 55 degrees Celsius (131° Fahrenheit) for a specified period of time. The temperature standard ensures not only that pathogens are killed, but that proper aerobic conditions are occurring in the pile and with those, the proper operation of the composting process. These options are discussed in detail in the SONAR for Minn. R. pt. 7035.2836, dated February 23, 1988.

Subpart 3. Subpart 3 lists the recordkeeping and reporting requirements the agency believes are necessary for animal feedlot owners required to apply for and obtain a permit. A permit is required according to criteria under part 7020.0405, subp. 1, item A or B. A permit is required for operations composting 1,000 animal units or more of manure at any given time.

Item A. Owners of permitted operations must, according to item A, analyze and maintain records for pH, moisture content, particle size, NPK and soluble salt content of the final compost product. This information should be provided to compost users to help assure successful compost use and satisfaction with the results from using the compost. The parameters are also important for managing potential phytotoxicity and proper land applications. For these reasons, the solid waste compost rules require the pH, moisture content, particle size, NPK ratio and soluble salt content to be analyzed for a solid waste compost as well (Minn. R. pt. 7035.2836, subp. 5, item J, subitem 4, units a to e). The importance of these parameters is further discussed in the SONAR for part 7035.2836, dated February 23, 1988.

Carl Rosen, Ph.D., a soil scientist in the Department of Soil, Water and Climate at the University of Minnesota, lists these parameters and others as those to measure in a compost in his paper, "Horticultural Use of Compost: Key Factors to Measure." See Exhibit S-11. According to Dr. Rosen, "the primary goal of composting is to end up with a less odorous, and more stable organic matter source that can be beneficially used. General uses of composts for these purposes have been as a soil conditioner, mulch, sphagnum peat substitute in potting mix and a slow release source of nutrients. Understanding what compost properties to measure and how to interpret the measurements is essential to ensure success in growing plants with compost amendments… Of these key properties, high pH, excessive salts and lack of nitrogen are most likely to cause problems for plant growth. Measuring all the key properties prior to planting will help to improve the chances of success when using compost for production of horticultural plants." See Exhibit S-11.

It is reasonable to require testing for and maintenance of records for these different parameters as it will be of benefit to the composter and end user to determine how and where the compost can be utilized. If the compost is used inappropriately (for example, an alkaline compost on a pH-sensitive crop that is acid loving) and is phytotoxic to the crop, records will be of benefit to determine what went wrong and how to correct the problem.

Customers may request information on these qualities and it will benefit the composter to have this information available. It also demonstrates to the county, neighbors and agency that a quality product is being produced.

Item B. The agency in item B requires that if an owner has an NPDES or SDS permit, the required annual report must include the quantities and sources of manure and bulking agents delivered to the facility; the temperature and retention time; and the information recorded under Item A in the annual report. It is reasonable to require that composters supply this information if they met the criteria and are issued an NPDES or SDS permit as those permits require disclosure of the amount and source of manure. Understanding how manure is being managed, either through composting or direct land application, will assist the agency, delegated county and producers in looking for problem areas and opportunities to improve the management system.

The amount of bulking agents (i.e., straw, sunflower hulls, corn stalks, and other carbonaceous material) is needed along with the amount of the manure composted to calculate if aerobic conditions are most likely being met. The manure in most cases will need an equivalent amount of bulking material to allow for passive aeration of the pile. Documenting the time and temperature of the PFRP process is important and highly desirable from the farmers' point of view to demonstrate that pathogens have indeed been killed. The temperature and retention time could be made available to customers as well, which should be an advantageous selling point. It is reasonable for the farmer to include this information in any required report as it demonstrates that proper composting operations have occurred and the data is required to be taken by the farmer in any event. Finally, it is also reasonable to require that the farmer include the records for pH, moisture content, particle size, NPK and soluble salt as these parameters have already been required to be tested for in each final batch of compost. It is needed by the MPCA to determine that a quality product has been made and should be of interest to customers as well.

7020.2225 Land Application of Manure

Applying manure to the land has many benefits to soil physical and chemical properties. Manure adds nutrients to soils that are essential for plant growth. Manure can increase soil organic matter in soils with very low organic matter and can improve soil structure and tilth. Research has shown that manure application can also slow the rate of soil erosion. However, research and monitoring has also shown that land application of manure can also result in pollution of Minnesota's surface and ground water. See Exhibit A-1.

Excess nitrogen applied to the soil will result in elevated nitrate transport to aquifers or tile drainage waters. Runoff from a field that has had manure applied can cause acute problems such as fish kills or chronic problems due to excess nutrient and bacteria transport to lakes and streams. This pollution can result even when manure is applied at acceptable rates, especially when manure is applied to the ground surface near waters.

The existing rules do not establish standards that adequately protect waters from the impacts associated with manure application activities. Therefore, the agency proposes to replace the existing general statements in the rules with a more specific set of standards. The land application standards being proposed have gone through an extensive development process that involved the parties directly impacted by this rule. A summary of this process follows, beginning with some historical background information about manure application regulations and guidelines in Minnesota.

The land application requirements, under the existing rules part 7020.0400, subp. 3, state that animal manure shall "be applied at rates not exceeding local agricultural crop nutrient requirements except where allowed by permit." The rules also require, under part 7020.0500, subp. 2, item C, that all feedlot permit applications include a manure management plan that describes "manure handling and application techniques, and acreage available for manure application." No other specific requirements are provided in the current agency feedlot rules regarding land application of manure.

In 1981, the agency developed voluntary guidelines for manure application to provide more specific recommendations. A draft revision of the guidelines was developed in 1992. While the guidelines were intended to foster voluntary adoption measures to protect water quality, it was recognized that certain language from past guidelines had been incorporated into some local feedlot ordinances and provisions in some permits.

A Feedlot Advisory Group (FLAG) was established by the agency in 1989 and representation included producer and farm groups, environmental organizations, and state, federal and local agencies. The purpose of FLAG was to provide increased discussion and coordination regarding concerns surrounding animal production and water pollution and the agency's efforts in this area. A Land Application of Manure Task Force was established by FLAG to review existing guidelines and make recommendations for revising the agency's manure application guidelines. The task force was also asked to provide comments and direction regarding feedlot rule revisions pertaining to manure application. The Feedlot and Manure Management Advisory Committee (FMMAC), which replaced FLAG, directed the task force to continue working on the guidelines and rules.

Following eight task force meetings over a two-year period, a report on manure application guidelines was submitted to FMMAC in August 1995. The Manure Application Guideline Report was unanimously approved by FMMAC in November 1995. See Exhibit L-1. The resulting guidelines were supported by a document entitled "Basis and Justification for the Minnesota Land Application of Manure Guidelines" dated July 1995. See Exhibits A-1 and L-2.

With a technical foundation established through the guidelines development process, the Land Application of Manure Task Force began in September 1995, discussing possible rule language related to manure application. At a minimum, the task force was to provide recommendations for greater definition of the existing Minn. R. ch. 7020 "crop nutrient needs" language and the manure management plan language. The Task Force was also to consider other options and rules for ground water and surface water quality protection.

The Land Application of Manure Task Force members working on rule development were primarily the same members who participated in the task force which developed the manure application guidelines. Task force members, representing varying backgrounds, representations and viewpoints, worked together to develop rule recommendations which were reasonable, environmentally protective, understandable and, to the degree possible, enforceable. The various viewpoints were not equally represented on the task force, and therefore the goal of the task force was not to seek majority opinion. Rather, the intent was to create a forum where varying viewpoints and experiences could be voiced, discussed and considered by the agency when drafting the recommended rule revision and report to FMMAC.

Most task force members desired a set of rules which were fair, meaningful, justifiable, and flexible. Some task force members also desired rules that were fairly comprehensive from an environmental protection standpoint. These aims tended to move the feedlot rules away from simplicity. Realizing that overly complex rules would be difficult to communicate to people and would be less likely to be followed, the goal was to develop rules that met a reasonable balance of simplicity and specificity.

The task force recommendations for rule language were developed during five meetings between September 1995 and June 1997. After much discussion and several revisions, the task force was able to reach general agreement on much of the proposed rule language. There were, however, a few issues for which agreement was not completely reached by all members. The principle issue of disagreement related to requirements for spreading around the numerous open tile inlets, which are used in the state for water drainage purposes.

A July 1, 1997, report to FMMAC described the Land Application of Manure Task Force recommendations concerning rule revisions. See Exhibit L-3. The FMMAC members suggested a few minor changes to the task force recommendations. The proposed rule language is based primarily on recommendations made by the Land Application of Manure Task Force, but also reflects comments made by FMMAC members, and comments made during and following several public meetings as draft rules were presented at numerous seminars around the state. The current proposed rules in part 7020.2225 regarding land application of manure were approved by FMMAC during the October 11, 1999, meeting.

Subpart 1. In General.

Item A. Under item A, the agency proposes to outline in general terms when manure application practices are not acceptable, and what is expected of cropland managers who receive manure from other feedlots. It is reasonable to provide this information in rule to avoid miscommunication and allow feedlot owners to plan for the necessary tasks involved in land application. Additionally, codifying the guidelines provides for consistent implementation and eliminates the need for most facility owners to receive individual permits to address land application requirements.

Item A, subitem 1. Subitem 1 addresses placing manure directly into waters of the state. The direct application of manure into waters and conduits to waters is easily avoidable with little to no cost to producers, and can lead to acute or chronic water quality problems.

The agency is proposing to allow manure application onto seasonally saturated soils which are seeded to annual farm crops or crop rotations involving pasture grasses or legumes. Allowing land application of manure in these areas is reasonable because they do not serve as aquatic habitats that can be negatively affected by manure application. Additionally, these areas do not meet the definition in the state water quality standards for wetlands (Minn. R. pt. 7050.0130, item F) because they do not support a prevalence of hydrophytic vegetation. Rather, they are cropped land which will need additional nutrients, either commercial fertilizer or manure, for optimal growth.

Item A, subitem 2. Subitem 2 is needed to address manure entering waters of the state indirectly as rainfall or snowmelt waters carry manure off the field in runoff waters. The state water quality standards prohibit sewage, industrial waste, or other wastes from being discharged from either a point or a nonpoint source into the waters of the state in such quantities or in such manner to cause pollution, Minn. R. pt. 7050.0210, subp. 13. See Exhibit L-4. The agency proposes to prohibit pollution resulting from runoff water containing manure from entering waters of the state. This prohibition is reasonable because it is consistent with the pollution prohibition standard under Minn. R. ch. 7050. Including this language in the rules clarifies that land application practitioners have the responsibility for ensuring that manure is not washed off the field by runoff from precipitation and snowmelt such that it causes water pollution.

The agency proposes to prohibit pollution of waters of the state resulting from rainfall and snowmelt transporting manure from the land application sites. Some minor amount of manure often will be transported from land application sites to surface or ground waters during many snowmelt and normal storm events, even when all MPCA and University recommendations are being followed. For this reason, it was considered unrealistic to include rule language prohibiting all manure from entering waters of the state during subsequent runoff events. The agency proposes that Minn. R. ch. 7020 include language stating that manure can not enter waters of the state at such quantities as to cause pollution.

Item B. Manure application into road ditches is prohibited under Item B. Since a majority of road ditches are waterways that convey water to lakes and streams, the prohibition is needed to prevent water pollution when manure is applied to these areas. Even though not all road ditches lead to waters of the state, prohibiting use of all road ditches for the application of manure is reasonable because establishing and maintaining a process for approving ditch use would not be administratively feasible, and few farmers have a need or desire to apply manure into road ditches. In addition, ground water from disposal practices on ditch sides may cause runoff to the lowest part of the ditch. In those areas, applied manure can pool after precipitation events and then exceed the nitrogen uptake of the vegetation in the lower ditch areas. This could give rise to violations of Minn. R. pt. 7060.0600, subp. 1 or 2.

Some road ditches are not waterways and manure could be applied into such ditches without adverse effects on surface water quality. However, careful inspections of road ditches are needed to determine which ones lead to waters and which do not. Producers will apply manure into road ditches for several reasons, including nutrient additions to increase hay crop yields in road ditches; preventing soil compaction since equipment for application can be driven on the roads while spreading into road ditches; and during certain times of the year (e.g., later winter and early spring) manure storage systems begin to fill and it is very difficult to get equipment into the farm fields for manure application. In McLeod County, a local ordinance prohibited spreading in road ditches without authorization from the county. Requests for approval to apply in road ditches were only received for a couple miles of road ditches.

Due to concern from producers for restricting application in all road ditches, the Task Force recommendations to FMMAC included the following proposed rule language: "Manure application into road ditches is prohibited, unless the road ditch is not a drainage course, waterway or water course that leads to a water of the state and written authorization is obtained from the agency or delegated county authority." The agency in reviewing this language believed that a process for road ditch inspections and written authorization would not be practical because:

- Added demand it would pose on limited staff resources to conduct ditch inspections;
- Need for short turnaround times for approval decisions;
- Experience that most road ditches will lead to waters of the state; and
- Ground water quality can be threatened in road ditches that do not lead to waters of the state.

For these reasons, the agency staff recommended that the rules do not allow exceptions for road ditch application.

Item C. Item C is needed to clarify that all feedlots and all manure application must meet the requirements of part 7020.2225, except for when the rules explicitly exempt feedlots below certain animal unit thresholds. It is reasonable to match the requirements to the risk, as has been done throughout the proposed rule.

Item D. Under Item D, the agency proposes to identify the requirements of people who receive manure from other feedlots. This item is needed to clarify that those who do not own feedlots must meet certain requirements when they receive manure from livestock or poultry operations for use as a domestic fertilizer. The proposed requirements are reasonable since the environmental protection requirements applicable to manure application on land owned or leased by the feedlot operator would be generally consistent with requirements of manure, which is sold or given away to land not leased or owned by the feedlot operation. The 100 animal unit threshold is consistent with the 100 animal threshold for when a manure management plan must be developed in subpart 4, item A.

Item D, subitem 1. Subitem 1 clarifies that all feedlot owners have responsibility to ensure that the manure generated from their facility is handled in ways that do not cause pollution. Specifically, Subitem 1 requires the landowner receiving manure for land application to comply with the manure management plan of the original feedlot generating the manure. When manure is sold or given away, the feedlot owner can specify certain environmental protection practices that must be followed as part of the agreement to receive the manure. Subpart 4, item E identifies the minimum items of a manure management plan that are required when ownership of manure is to be transferred. Subitem 1 is needed to clarify for the receiver of the manure that they have a duty to comply with the manure management plan developed by the owner of the feedlot where the manure was generated. The agency considered establishing a program that required tracking and signatures at each step in the manure transfer process. However, the agency believes that a program similar to the cradle to grave approach for other waste types was not warranted with regard to manure management. Subitem 1 is reasonable because it clarifies that the feedlot owner is responsible for ensuring that manure generated at a feedlot will be handled in a manner consistent with state and local laws and environmental protection policies, without significant administrative oversight. The person receiving the manure maintains the right to reject the manure if they do not wish to comply with the manure management plan.

Item D, subitem 2. Subitem 2 requires when the owner of land where manure will be applied either follow the manure management plan developed by the feedlot owner offering the manure for use or develop a management plan for land application specific to the land where the manure will be applied. When ownership of manure is transferred, the ability of the feedlot owner to develop specific and comprehensive manure management plan is lost or limited. Much of the information in a manure management plan is largely dependent on the crops to be grown, cropping history, and site-specific soil conditions. This information is known by the cropland manager where the manure is to be applied, and is not known by the feedlot owner or operator who transfers ownership of manure. Subitem 2 is needed so that a complete manure management plan is available from the combined manure management plan information from the feedlot owner and the person owning or managing the cropland where the manure is to be applied. The manure management plan is a critical factor in protecting human health and the environment from impacts associated with the improper management of manure. Subitem 2 is reasonable since it makes the manure management-planning requirements similar for transferred and non-transferred manure. The planning information to be supplied by the receiver of the manure can be developed any time prior to application of the manure.

Subpart 2. Manure nutrient testing requirements. The agency proposes that manure from all manure storage systems and stockpiling sites generated from feedlots with more than 100 animal units to be tested for nutrient content before it is land applied. The testing requirement is needed because all manure does not contain the same nutrient characteristics. The concentration of key nutrient components (nitrogen and phosphorus) must be identified to avoid manure application rates that create conditions for a potential water pollution problem. Manure nutrient testing results show extreme variability in manure nutrient content among feedlots. Manure applications rates determined only using published average manure nutrient content values often results in excess nutrient additions or result in insufficient crop nutrients being applied if the actual nutrient content in a specific manure is less than book values. If applied in excess, the remaining nutrients are then available for moving into surface water or ground water supplies. Manure nutrient testing gives producers greater confidence in using the manure to supply crop nutrient requirements.

Testing is not proposed for stored manure generated from feedlots with less than 100 animal units. The amount of manure from these facilities is such that it has been well tested and using the average manure nutrient concentrations obtained from publications is recommended. The cost and labor involved in manure nutrient testing can be high in proportion to the potential water quality damage that may result from as light over-application of such limited quantities of manure. Some task force members stated that it is not reasonable to expect the small feedlot operators to test all stockpiles of manure. Many farmers have numerous small stockpiles that each have different nutrient contents. The nutrient content, even within the same stockpile, usually varies. The environmental protection afforded by manure testing compared with using book values for these small stockpile sites would not be very great in relation to the uncertainties and cost associated with manure testing. Since most semi-solid and liquid manure storage systems in Minnesota hold manure from more than 100 animal units, most of the liquid and semi-solid manure in the state will need to be tested in accordance with the proposed rule.

Even with manure testing, there is still some uncertainty regarding manure nutrient content. Reasons for the uncertainty include the large variability within and among manure storage sites; the variability in nutrient content with different seasons and climate; the laboratory analyses that are usually not completed until after the manure has already been applied; and the errors in laboratory analysis. One recent study showed that 17 sub-samples of solid beef manure are needed to obtain an analysis that is within 10 percent of the true nitrogen content. See Exhibit L-13.

The Land Application of Manure Task Force originally suggested that manure nutrient testing be conducted at all manure storage sites generated from 50 animal units, rather than the 100 animal units currently being proposed. The primary reason for the 50 animal unit threshold was to remain consistent with other MPCA permitting thresholds at 50 animal units. Comments from FMMAC members and others in the regulated community recommended using a higher threshold, such as 300 animal units, due to the uncertainties noted above and the labor and costs associated with obtaining a more accurate test result. A 100-animal unit threshold is reasonable since it would require sampling of most liquid manure storage systems in the state and all of the larger stockpiles of manure, but would not require the rigorous sampling to obtain an accurate nutrient analysis on each small solid manure stockpile site.

Item A. During the first few years of manure testing, there is a need to test at a greater frequency and in more locations to determine the range and variability in nutrient content from the animals at a specific feedlot. After obtaining results from three consecutive years, the feedlot owner will have the information needed to determine the appropriate ongoing testing procedures and testing frequency. This item is needed to establish the average manure nutrient content for the individual farm and the variability from year to year. Three years is a reasonable amount of time since it balances the need for accuracy, likely to be somewhere in the 5 to seven year range, and the need to be comfortable that the results are relatively accurate. A one or two year cycle will not account for weather changes or perhaps some feed alterations being completed. The third year helps shift the balance in one direction or another. It must also be clarified that the feedlot owner may sample annually, if they believe it important.

Item B. Item B requires that the manure needs to be re-tested when any change occurs in the feedlot operation or climate that would be expected to cause a change in manure nutrient content. The task force recommended that the rules should not force feedlot owners into using the test results as the absolute and only number when establishing land application options. Task force members stated that there needs to be some flexibility to allow the feedlot owner adjustments to the nutrient value considered in the development of land application options. Also, the task force recommended that feedlot owners be given some flexibility regarding the needed frequency of ongoing sampling. The needed frequency will be different for different operations. The proposed rules were written with the intent of allowing this flexibility. It is particularly important to test the manure following any change that would be expected to affect nutrient content. It is reasonable to establish in rule the minimum times considered appropriate to retest manure generated at a particular feedlot because results in testing manure when it is most beneficial for the feedlot owner and the environment. Once again, the rule does not prohibit more frequent testing by the feedlot owner but balances the need for information to land apply manure in an environmentally-sound manner and the cost of testing.

Item C. The task force recommended that there be some sort of a minimum frequency stated in the rules to make the rules more enforceable and so that producers do not forever rely on the initial three-year testing period required in item A. Therefore, the agency proposes that testing must be conducted at least once every four years as a check on the original testing completed. Item C is needed to ensure that the manure nutrient content does not radically change in an unexpected manner and so that the producer maintains confidence in the fertilizer value of the manure.

The cost to analyze manure for nitrogen, phosphorus and potassium averages roughly $25 per sample. If a producer has three manure storage systems, the costs during the first few years for nutrient analysis will be approximately $200 to $500. Minimum costs every four years would be approximately $75 to $120. Feedlot owners or the recipient of the manure for land application may achieve commercial fertilizer reductions or improved crop yield due to the manure testing, possibly off-setting the cost of manure testing and resulting in a net financial gain for some producers. It is reasonable to expect the feedlot owner to understand the nutrient content of the manure produced and incorporate this information into the management plan for the manure. Additionally, since many forces may create the need to change feedstocks, breeds, etc., it is reasonable that a regular accounting of the manure nutrient value be made.

Item D. A manure nutrient analysis is useful to the producer only if the methods used to analyze the manure are reliable. Item D is needed to ensure that manure is not over-applied or under-applied due to inaccurate testing methods. The Minnesota Department of Agriculture certifies laboratories for manure nutrient testing. At the time of this writing, the Minnesota Department of Agriculture has certified 24 laboratories in Minnesota. It is roughly estimated that 20,000 feedlots will need manure testing under this subpart. Several task force members stated that the agency needs to allow field-testing methods that are proven to be accurate for manure analysis, rather than only allow laboratory analyses. Thus, the proposed rules contain a commissioner-approved on-farm testing option for manure. On-farm testing is advantageous since the results are available immediately and usually cheaper than tests completed by a laboratory. These methods can be proven by comparing on-site testing results with the results of a certified laboratory. This approach is reasonable as it guarantees the feedlot owner and agency's confidence in the resulting numbers and allows for controlled innovation for reducing cost and time in testing manure.

Item E. Nutrient concentrations within any given solid manure stockpile or liquid manure storage system is variable. For example, if a sample of manure was taken from the top of a stockpile or the top of a liquid manure pond, that sample would not be representative of the nutrient content of the entire stockpile or liquid system. A misrepresentative sample can lead to over-application or under-application of nutrients. Procedures have been established and published by the University of Minnesota Extension Service for taking a representative manure sample from solid or liquid storage areas. See Exhibit L-6. Item E is needed to prevent procedures that would lead to excessive nutrient application and subsequent loss of nutrients to ground water or surface water. Item E is reasonable since it is in the best interest of the producer to obtain the most accurate and representative manure sample possible to ensure economically and environmentally sound nutrient management practices.

Subpart 3. Nutrient Application Rate Standards. The agency proposes to establish a standard for the amount of nitrogen that can be land applied. The agency also proposes to establish a standard for the amount of phosphorus that can be applied in special protection areas in accordance with subpart 6, item B.

Item A. The agency proposes to limit manure application to a rate that does not exceed expected crop nitrogen needs for non-legume crops and expected nitrogen removal for legumes. The standard of nitrogen application is needed to ensure that the capacity of a land application site to utilize the manure is not being exceeded and thus, allow excess nitrogen to move into ground water or surface water via tile lines. It is reasonable to use the expected crop utilization of nitrogen because the rate is based on the site-specific crop nutrient needs and expected nitrogen available to the crop at that site. Averaged or published data cannot account for the specific conditions under which land is being managed and thus, may result in over or under application rates needed to ensure that a successful crop results.

In order to understand the need and reasonableness of nutrient rate standards in Item A, it is important to understand how nitrogen is taken up by plants and moves in the soil. A discussion on plant uptake of nitrogen follows.

The total nitrogen in manure is not available for crop uptake. Much of the nitrogen is bound in organic forms, although varying amounts of plant available ammonium nitrogen are also present. The organic nitrogen will gradually change into inorganic forms of nitrogen (ammonium and nitrate) and is now available to plants. This process involves the conversion of organic nitrogen into ammonium followed by a conversion of ammonium into nitrate. Factors affecting these transformations include soil microbial populations, temperature, moisture, rate of application, method of application, soil characteristics and type of manure. Estimates based on agricultural research can be made of the percent of organic nitrogen that is converted to ammonium. The ability to estimate plant available nitrogen from manure has improved with additional research and may be further refined from the results of future research.

Legume crops, such as alfalfa and soybeans, are able to produce their own plant available nitrogen from atmospheric nitrogen, and therefore do not need additional nitrogen. However, when soil nitrogen is available to legumes, they will use that available soil nitrogen rather than using atmospheric nitrogen. This allows legumes to receive considerable quantities of manure without leaving much excess nitrogen in the soil.

Nitrogen movement in soil is related to the form of nitrogen existing in the soil. Organic nitrogen, which is immobile in the soil, is converted to ammonium when the soil temperature is above about 50°F. Ammonium nitrogen can be held by the soil as a result of the soil chemistry, moving very little until the soil is over-saturated with ammonium. Ammonium, under the presence of oxygen, will convert to nitrate, which moves freely in the soil along with soil water. For example, a heavy rainfall could potentially move much of the nitrate nitrogen from soil to ground water. The excess plant available nitrogen in the soil following crop nitrogen uptake can partially move through the soil towards ground water in the form of nitrate.

Existing rules prevent manure application in excess of crop nutrient needs, but they do not specify which crop nutrient should be considered. Applying manure based on crop nitrogen needs will be different from application rates based on phosphorus, potassium, zinc or other micronutrient needs. Application rates based on nitrogen will usually allow for greater manure application rates than rates based on other nutrients. Excess soil nitrogen can cause water quality problems in most areas of Minnesota; whereas, the environmental effects of excess phosphorus are not as universally problematic.

Item A, subitem 1. Crop nitrogen needs and removal rates and nitrogen availability from manure and legumes have been determined from University research and are important to consider in preventing excessive nitrogen application rates. The agency proposes that the crop nitrogen needs, removal rates, and the expected amount of plant-available nitrogen from manure be based on the most recent University of Minnesota recommendations. See Exhibit L-7. To establish a state-wide standard for nitrogen application based on crop utilization, the agency references in the proposed rules field-tested methods for estimating the crop nitrogen needs and removal as affected by crop yield goals, previous crop, and soil organic matter levels; and for estimating the fraction of manure nitrogen that becomes available for plant use during the first and second years after application. The agency proposes not to publish a specific rate table in the rules due to the widespread availability of University of Minnesota recommendations at county extension offices. If specific rate tables were proposed, the agency would need to consider rules revisions when new research results are found and recommendations are refined. Establishing these tables outside of the proposed rules is reasonable because the table rate values are not developed by the agency, but are based on the research done by the University of Minnesota and produced in cooperation with other agencies. Thus, the recommendations are made to match the plant needs and the ability to meet these needs by a neutral party to the regulatory process not the agency or delegated county. Additionally, the University of Minnesota’s research will ensure that science would be used in making these recommendations.

Item A, subitem 2. Estimates of plant available nitrogen from manure are also available from University research. See Exhibit L-7. However, site-specific soil, crop rotation, and climate conditions can result in University estimates that over-predict or under-predict the amount of nitrogen available from manure. In addition, manure nutrient test results for solid manure are often off by 10 to 20 percent. For these reasons, the task force strongly recommended that the producer not be necessarily locked into one number for nitrogen as that expected to be available from a particular manure source, and consequently, recommended the allowable 20 percent deviation.

It is not intended that standard practice be to apply manure at rates 20 percent greater than University of Minnesota recommendations, since the University has already developed the recommendations to provide sufficient nutrients to crops under most situations. Subitem 2 is needed, however, to allow some degree of flexibility to account for the thousands of soils and the climatic variability found in Minnesota. It is reasonable to allow this deviation to prevent manure users in suffering crop yield losses as a result of following the proposed rules meant to protect human health and the environment. Additionally, subpart 5 requires that records be maintained by the user of the manure. These records will provide information on the actual amount of manure applied and why deviations may have occurred. The importance of these records is explained later in this SONAR under subpart 5, Recordkeeping.

The agency realizes that some extreme situations and site conditions exist where deviations greater than 20 percent are necessary to meet crop nutrient needs, and has made an allowance to exceed the 20 percent deviation when nutrient deficiencies are found. For the reasons stated above, this is a reasonable approach to establishing nutrient levels for manure and ultimately the application rates. Since under the permitting approach defined in the proposed rules, do not require the manure management plan to be submitted by every feedlot owner, it is reasonable to establish when specific criteria may be altered by the feedlot owner without first obtaining the agency’s approval. This method of managing manure places the responsibility on the person most knowledgeable about the conditions under which manure is being applied to cropland.

Item A, subitem 3. There are many possible sources of soil nitrogen, in addition to manure. Often the manure alone does not cause excess nitrogen to remain in the soil, but it is the combination of nitrogen from manure, commercial fertilizers, soil organic matter, and plowdown of the previous crop that results in soil nitrogen levels much greater than crop nitrogen needs or uptake. The agency proposes under subitem 3 to clarify that the application rate for a site is limited by the combination of all nitrogen sources.

The Minnesota Department of Agriculture has interviewed livestock producers in different regions of the state. See Exhibit L-14. The findings from these interviews show that excessive nitrogen rates are not typically due to over-application of manure or over-application of commercial fertilizer alone. The most common reason for over-application of nitrogen is the combination of manure and commercial fertilizer, and altering the application rates to adequately account for nitrogen leftover in the soil from growing legumes during the previous year.

Thus, the agency believes it is reasonable to establish the components that are necessary to develop a balanced nutrient management system not just a manure application plan. Additionally, by understanding all factors contributing to the nitrogen levels on a particular soil will all the producer to save money by reducing or eliminating the most costly component.

Item B. The agency proposes that manure applied to land in special protection areas must comply with the phosphorus rate requirement described under subpart 6, item B, if a permanent vegetated buffer is not planted between the water or channel and the field receiving manure. The phosphorus requirement was placed under subpart 6 instead of this item so that all land application requirements for special protection areas are consolidated in one area in the rules. The consolidation is intended to make it easier for persons using the rules.

The Land Application of Manure Task Force agreed on the need to limit phosphorus build-up in soils along surface waters and channels to surface waters. Both the task force and FMMAC also had considerable discussion of phosphorus application rate standards on land away from these special protection areas. These discussions are summarized in the following section.

If manure could be economically distributed across the state, the state would need much less commercial phosphorus fertilizer to meet crop phosphorus needs. Most current manure application practices are focused on applying manure based on the crop's nitrogen needs. This practice often results in two to four times more phosphorus being applied than the crop will remove, and, for some solid manures, up to 15 times more phosphorus is applied than is removed by the crop. In general, soil phosphorus levels increase when manure is continually applied at nitrogen-based rates.

Even without any manure or fertilizer additions, it is estimated that more than one-half of Minnesota’s soils already have enough phosphorus to meet the crop's phosphorus needs. As soil phosphorus levels increase from added manure or fertilizer, there is a corresponding increase in runoff phosphorus concentrations. Phosphorus added to surface water will lead to additional weed and algae growth, which can subsequently result in lower aquatic oxygen levels. Thus, it is reasonable to manage manure application on those areas most sensitive to runoff from fields receiving too much phosphorus.

Phosphorus is most likely to move into waters from the land adjacent to surface waters and channels leading to surface water. See Exhibit L-9. There are more uncertainties about the effects of over-application of phosphorus further up in the watershed away from waters and channels. Many watersheds have considerable amounts of phosphorus that do not have much runoff, or are located in areas where there is little risk of runoff to surface waters or channels leading to surface waters, particularly, when the manure is injected.

The primary reasons for not placing strict phosphorus control restrictions on the land more than 300 feet from surface waters include the uncertainties about how phosphorus travels throughout a watershed; how far phosphorus moves across the landscape; and what are acceptable phosphorus levels in soils throughout the watershed to protect water quality. Additionally, there are many concerns about the economic and social ramifications related to phosphorus restrictions on land outside of the surface water corridor areas. Finally, phosphorus transport and effects on receiving waters varies from area to area across the state and stringent phosphorus control measures may be better addressed through watershed planning efforts, local restrictions, and permit conditions.

Some of the socio-economic concerns about phosphorus based manure application restrictions include:

- Producers have set up their farms and farmland over the years with the assumption that manure could be applied at nitrogen based rates. Many farms do not have enough land to apply manure at phosphorus based rates.
- Manure hauling costs increase significantly when the manure has to be applied on fields further away from the barns. Phosphorus based rates would require additional land and thus additional hauling costs (and associated environmental costs with increased transportation distances).
- Many soils have high native phosphorus levels. Regulations requiring manure application to be based strictly on crop phosphorus needs would prohibit manure application, thereby causing hardship for numerous producers.

The task force considered requiring phosphorus rate limitations outside of the 300-foot special protection areas near surface waters and channels. Some task force members expressed environmental concerns about extremely high soil phosphorus build-up on all soils, including those located more than 300 feet from surface waters or channels. While the areas of greatest concern are those soils near surface waters or runoff channels, runoff waters and eroded soil sediment can move hundreds of yards before entering waters and channels with definable banks. In addition, phosphorus has been shown to move down towards ground water in some soils that have extremely high phosphorus levels. See Exhibit L-19. Once phosphorus reaches ground water, it can be transported to surface waters.

Depending on the assumptions of nitrogen volatilization losses, manure nutrient content, and crop nitrogen needs, it is possible for producers to meet the proposed rule requirements for manure application based on nitrogen, while at the same time greatly overloading soil phosphorus. For example, if it is assumed that alfalfa can use 300 pounds of nitrogen, the manure contains 10 and 9 pounds per ton of N and P_2O_5, respectively; and nitrogen losses will be 50 percent, the rate of manure application to supply 300 pounds of plant available nitrogen would be 60 tons per acre. This would contribute 540 pounds of P_2O_5 per acre, which is nearly 500 pounds more than the crop needs. If this rate of application occurs year after year, soil phosphorus levels could build to extremely high levels. Extreme phosphorus over-application could also occur on corn-ground or other crops, if producers apply the manure strictly based on crop nitrogen uptake.

Several suggestions were made about how to deal with phosphorus outside of the 300 foot special protection areas, including:

- Upper limits on soil phosphorus test levels;

- Upper limits on manure application to legumes;
- Upper limits on annual manure phosphorus rates;
- Upper limits on long term phosphorus rates;
- Upper limits on short- or long-term phosphorus rates only when surface applying phosphorus;
- Restrict manure application to every other year or every third year when phosphorus exceeds a certain level; and
- Use education rather than rules to address phosphorus outside of the 300 foot special protection area zones.

While there is a potential threat of phosphorus transport to surface waters from outside of the 300-foot special protection zones, the literature indicates that the most critical areas for phosphorus control are those areas in close proximity to waters or channels leading to waters. See Exhibit L-9. The degree of phosphorus impacts also depends on the nature of the watershed soils, topography, land management practices, receiving waters, and other variables. See Exhibits L-5, L-10, L-11, and L-17.

Given the uncertainties and variability regarding water quality effects associated with soil phosphorus build-up; the socio-economic issues previously discussed; and other technical considerations, initial recommendations were that the rule revision for land outside the special protection areas consider annual phosphorus limitations only for surface application. With surface application, the manure is in a position to be more easily transported during subsequent snowmelt and precipitation events. When manure is placed below the ground surface, the manure, pathogen, ammonia and phosphorus transport risks are significantly reduced. See Exhibit L-2, pages 20 and 21.

In response to concerns about extremely high rates of surface application, the task force suggested the following language to prevent extreme over-application of phosphorus on land outside of special protection areas: "When surface applying manure without incorporating within 48 hours, the manure application rate must be limited so that the estimated plant available phosphorus provided by manure does not exceed five times the expected crop phosphorus uptake for any one year period, unless otherwise authorized by the Commissioner."

Several concerns were raised about this language including that the language:

- Increased the complexity of the land application rules and the disadvantages of this added complexity may outweigh the environmental protection which would result;
- Could have sent the wrong message out to producers that it is okay, or recommended, to apply manure at rates up to five times crop phosphorus removal;
- Did not account for site-specific conditions such as very low phosphorus soils or flat soils a great distance from waters and channels;
- Did not address phosphorus related issues associated with injected or incorporated manure; and
- Did not address that the rate of phosphorus application is only one factor affecting pollution from phosphorus, and the other factors are more influential.

Due to these concerns, which were expressed by the agency staff, FMMAC appointed a working group to review the phosphorus issue and develop, if necessary, revised recommendations to bring back to a subsequent FMMAC meeting. The working group included the agency staff, four researchers from the University of Minnesota and five FMMAC representatives. The work group decided to recommend that there not be a specific rate restriction for phosphorus outside of special protection areas. While the rate of application is the most important factor affecting transport of nitrogen to waters, the transport of phosphorus to waters is less affected by rate and more affected by soil type and soil phosphorus levels and the combination of the erosion control practices used; the proximity to waters; the land slopes; the method of application, and several other factors. The working group decided to recommend that soil phosphorus testing be required as part of the manure management plan and that this testing serve to trigger various actions as proposed in subpart 4, item B and subpart 4, item D, subitem 12. These recommendations were approved by FMMAC at the subsequent meeting and are further discussed in the corresponding parts of this SONAR.

Subpart 4. Manure Management Plan Requirements. The current rules require that a manure management plan be submitted with a feedlot permit application. The proposed rules add specific requirements on the information to be included in the manure management plan, and require these same plans to be updated and maintained at all feedlot facilities with more than 100 animal units. The additional requirements provide the information needed to ensure that manure is applied in a manner and rate that does not exceed crop nutrient requirements and subsequently present hazards to water quality.

A comprehensive manure management plan describes how manure generated at a given livestock facility is expected to be utilized to protect the environment while maintaining or improving soil and plant resources. The final manure management plan describes intended manure application locations, amounts, timing, methods and the information needed to determine environmentally, agronomically and economically acceptable application practices. A complete manure management plan accounts for crop rotations and nutrient crediting from previous years' crops and nutrient additions. An annual plan allows for the feedlot owner to adjust for changes in the amount of manure production, manure nutrient test results, crop rotations, soil nutrient test results, and other practices, which affect the available nutrient amounts or crop nutrient needs on fields receiving manure.

Given the complexities associated with manure management, it is extremely difficult to apply manure in an environmentally and agronomically-sound manner without some forethought, calculations and planning prior to applying the manure. A manure management plan is a fundamental tool used by producers to provide assurance that manure is applied at proper rates, times and locations. Combined with accurate records, the manure management plan also provides additional assurance that a particular facility is impacting the environment.

Step-by-step guidelines are available to assist a producer in developing their own manure management plan without the need for hired or government assistance. See Exhibit L-15. However, existing technical assistance experts in Minnesota Extension Service, Soil and Water

Conservation Districts, Natural Resources Conservation Service, and private crop consultants can also provide assistance to producers to develop a manure management plan.

Item A. Item A indicates who must complete a manure management plan and when the plan must done. The agency proposes to require a manure management plan to be prepared upon application for an NPDES, SDS or Construction Short-form permit. Additionally, subitems 2 and 3 require the development of manure management plans by feedlot owners for with more than 100 animal units, which are not required to apply for a permit. Manure management plans are currently required to be submitted as part of the application for a feedlot permit under part 7020.0500, subp. 2, item C. The existing rules have required a manure management plan to be submitted only when applying for a feedlot permit.

In addition to preparing a manure management plan for submittal with a permit application, the agency proposes that a current manure management plan is kept by owners of animal feedlots with 100 animal units or more. Item A requires feedlot owners with 100 animal units or more have a manure management plan, even if they do not have a permit. Requiring unpermitted feedlots to have a manure management plan is reasonable because it provides the information needed to ensure practices are used that abate water pollution and meet the requirements in subpart 1. It is just as important for those not applying for a feedlot permit to maintain an updated manure management plan as it is for those applying for a feedlot permit.

The Land Application of Manure Task Force recommended manure management plans to be prepared for anyone over 50 animal units rather than 100 animal units. This threshold was set to be consistent with the existing 50 animal unit threshold for permitting. Some task force members raised concerns about the reasonableness of requiring feedlot operators with 50 to 100 animal units to complete a manure management plan. This size of operation will not typically hire a consultant to complete a plan due to the expenditures.

The threshold of 100 animal units is reasonable since it requires manure management plans linked to most, over 75 percent, of the manure applied in the state. Also, the development of a manure management plan can be more realistically accomplished than if the threshold were 50 animal units. There are numerous feedlots between 50 and 100 animal units, yet they represent a relatively small fraction of manure generated in the state. The limited technical assistance for developing manure management plans will be more readily available with the threshold set at 100 animal units.

In the past, the manure management plans were not comprehensive, but showed that the producer had enough acreage available to potentially apply their manure at nitrogen based agronomic rates. The plans developed under the proposed rules will be more comprehensive when meeting the requirements under item D. A more comprehensive manure management plan is needed to consider all sources of nitrogen for purposes of maximizing crop productions, saving money, and ultimately protect human health and the environment. If the document meets the proposed standards under this part and the recordkeeping requirements of subpart 5, the feedlot owner will be able to answer compliance questions and adjust to crop needs in an effective manner. A comprehensive manure management plan is reasonable because it addresses human health and environmental concerns while providing the producer valuable information on achieving maximized cost production at least costs. Also, while the proposed rules define what should be in the manure management plan, they do not limit the information nor detail how the plan should be written. This allows the producers to develop a manure management plan most useful to their operations and not to the agency's review staff.

The agency proposes to phase-in the requirement for having an updated manure management plan. There will be some cost to producers who seek outside help from consultants in order to complete the manure management plan. In some cases, it is expected that this cost will be offset by fertilizer savings realized from improved nutrient management practices. Technical assistance for writing the plans would not be sufficient to help complete the plans in a year or two. The phased-in approach allows producers with 100 to 300 animal units up to the year 2005 to meet the requirements. This approach should allow those with expertise in writing plans to assist more producers who need the help. The agency expects that feedlot owners would proceed immediately in developing a comprehensive manure management plan, but at a minimum, would require that a plan be developed whenever a permit is modified for existing facilities, or a the time of permit application for new facilities. At the outside, the agency would expect that the manure management plan for existing facilities be developed or updated when registration comes due the second time for a particular facility (2005).

Item A, subitem 1. Subitem 1 provides for a manure management plan to be completed when application is made for an NPDES or SDS permit. Subitem 1 is needed so that the largest feedlots and those representing pollution hazards must develop plans within the shortest time period, and so that manure management plans are developed prior to construction activities. It is reasonable to require manure management plans from these feedlot owners because feedlot owners with large numbers of animals have the potential to pose grater environmental risks due the amount of manure to be land applied and improper planning; and, because construction activities often result in a need to adjust manure management practices.

Item A, subitem 2. Subitem 2 provides for the preparation of a manure management plan by a feedlot owner when feedlots with 300 or more animal units even when not applying for a permit. The proposed rule establishes the date of October 1, 2002 as the time considered reasonable for feedlot owners with facilities having 300 or more and less than 1000 animal units to complete their plans. The proposed rules allow the development of the plan to coincide with anticipated technical resource availability.

Item A, subitem 3. Subitem 3 provides for feedlot owners having fewer than 300 animal units to complete their manure management plan by October 1, 2005. subitem 3 is reasonable since it allows small to moderate-sized feedlots up to five years to complete the plan after the rules go into effect. More time is needed for completion of these plans since they represent a large fraction of the total number of feedlots in the state and the technical assistance for completion of the plans is limited. While many of these feedlot operators have completed a manure management plan in the past, most of the plans have become outdated or they were not specific enough to be very useful.

Subitem (4) is needed to establish a deadline for when manure management plans must be completed for facility expansions and new facilities which exceed the 100 and 300 animal unit thresholds after the deadline dates established under subitems (2) and (3). This increase in animal units can be achieved by either constructing or just adding animals to an existing site. This subitem is not intended to extend the deadlines established under subitems (2) and (3). This subitem applies to new sites with 100 or more or which expand to 100 or more animal units after the year 2005. This also applies to sites which expand to 300 or more animal units between the year 2002 and 2005 and are not required to have a permit. Where one of these situations apply, the owners will have the one year period to complete the plan. The MPCA proposes to require manure management plans to be completed within one year of exceeding the applicable animal unit threshold. Many facilities will be required under subitem (1) to have the plan prepared by the date that the permit application is submitted to the MPCA or delegated county. This subpart addresses those facilities that would have an animal unit capacity less than 300 animal units after the construction is completed. These construction projects are not required to be regulated by a permit if the construction is completed in accordance with the applicable standards under parts 7020.2000 to 7020.2225. The proposed language provides these facilities one year from the time that animals are placed on the site to complete the plan. This time frame is reasonable because it provides enough time to complete the plan or seek the technical assistance sometimes needed for development of a manure management plan. Often addition of animals are in response to market conditions and allowing a one year period to address these additions is reasonable.

Item B. The agency proposes to require that the manure management plan be at the animal feedlot facility and be available to agency or delegated county. With the estimated required number of manure management plans in Minnesota approaching 20,000, it is unreasonable to expect the agency and delegated counties to review and file each manure management plan each year. However, the plan would be reviewed if for any reason an inspection of the facility was conducted or there were reasons to doubt that proper manure application practices were occurring, or there are high-risk situations for phosphorus transport.

Item B, subitem 1. Subitem 1 is needed to clarify that the only types of permit application requiring an attached manure management plan is an application for an NPDES or SDS permit. A manure management plan is required to be completed for a construction short form, item A, subitem 1; however, in accordance with this subitem, the manure management plan does not have to be submitted to the agency or delegated county for approval. Subitem 1 is reasonable since the agency has limited time to review plans, the provision provides a clear statement of expectations on who needs to submit plans, and the management plan is principally for the benefit of the feedlot owner. The agency or delegated county may request plans from anyone in accordance with item B, subitem 4, if it believes it necessary.

Item B, subitem 2. Under subitem 2, the agency proposes the submittal of a manure management plan to the agency or delegated county when manure intended for application on soils with very high phosphorus levels (75 parts per million [ppm] Bray P1 or 60 parts per million Olsen) in special protection areas and within 300 feet of open tile intakes. These lands are in close proximity to surface waters where phosphorus could be readily transported to lakes and streams. Subitem 2 is needed to ensure that review of management practices occurs when risk to the environment is real due to the proximity of waters and having such elevated phosphorus levels or steep slopes that phosphorus will move with any runoff component. Subitem 2 is reasonable because most soils in Minnesota have less than 75 ppm Bray P1 or less than 60 ppm Olsen test phosphorus, and since manure application on these areas is not expressly prohibited. If the agency or delegated county reviews the site conditions and manure test results and finds that the intended manure application practices will not harm water quality, manure application would be allowed.

Soil phosphorus testing is required in item D, subitem 11. The 75/60 ppm thresholds were selected to be at a level where an increased risk of phosphorus desorbing from soil particles and being washed off the land surface from rain or snowmelt exists. This process is also largely dependent on soil type. The need and reasonableness of this subitem is also referenced in this SONAR for subpart 3.

Item B, subitem 3. The agency proposes a higher soil phosphorus threshold (150 ppm Bray P1 or 120 ppm Olsen) for requiring submittal of a manure management plan when applying manure outside of special protection areas. Subitem 3 is needed to assure that phosphorus will not be transported vertically into ground water or laterally in surface runoff to nearby lakes and streams. With repeated manure applications of high phosphorus manures at nitrogen based rates, soil phosphorus levels can build to levels that can cause pollution problems. Subitem 3 establishes a trigger level, whereby the risk of continued application of manure can be further evaluated. It is reasonable to establish a trigger level since most soils currently have soil phosphorus levels well below these trigger values and exceeding these limits does not necessarily preclude continued manure application. The reviewing authority can consider the sensitivity of the receiving waters to phosphorus, soil type, soil slope and other factors before deciding whether continued manure on such fields cause pollution of waters of the state. The need for plan re-submittal would be determined by the reviewing authority.

Item B, subitem 4. Subitem 4 clarifies that a manure management plan can be requested by the agency or delegated county at any time. Such a standard is reasonable because it maintains the ability of these regulatory bodies to obtain information in evaluating compliance yet allows the feedlot owners to retain control of the plan and does not assume that manure mis-management occurs regularly. Other options or time frames for review would unnecessarily add administrative burdens to the feedlot owner and the regulatory authority.

Item C. The agency proposes that the animal feedlot owner to review and update the manure management plan each year. This requirement clarifies the importance of the manure management plan and the criteria keeping a maintained plan. Making the animal feedlot owner responsible for the review and revision of the plan is consistent with part 7020.2000, subp. 2, that defines the feedlot owner as responsible for ensuring proper land application of manure. The plan review by the feedlot owner without formal regulatory review and approval is reasonable because the process will ensure manure management plans represent current management practices and documents that the owner is complying with the required standards. A manure management plan will be of very little use unless it is reviewed each year and adjusted for changes in manure production, nutrient test results, crop rotations and other farming and manure management practices. However, it would be unreasonable to expect any regulatory authority to review all plans annually and respond in a timely fashion to the feedlot owner to permit implementation.

Item D. The agency proposes to establish a list of information that must be included in the manure management plan. The list in item D ensures that all feedlot owners are aware of the information needed in a manure management plan. The provisions of item D are reasonable because the same information needed by a feedlot owner to make good decisions regarding manure management and ensure that other provisions of Minn. R. ch. 7020 are met. By requiring these items to be included in the plan, the plan can be used as a worksheet for ensuring other provisions of Minn. R. ch. 7020 are fulfilled. The requirements for a manure management plan are not overly prescriptive to all changes and improvements related to manure management planning as new systems are developed. The items were selected to represent elements agreed upon by the task force or FMMAC as being essential for making agronomically- and environmentally-sound manure application rate, timing, and placement decisions.

Item D, subitem 1. The agency proposes to require that the manure management plan include a description of the manure storage/handling system. This requirement provides information on the manure storage or handling system prior to land application, expected quantities of manure, and expected nutrient losses during storage. It is reasonable that the provisions of subitem 1 be included because it provides information needed to complete the other parts of the manure management plan without asking the feedlot owner to spend money since these are known informational items.

The agency requires the manure management plan to state the expected amount of annual manure that will need to be land applied. This information is needed to accurately develop the land application plan. This requirement is currently stated in general terms under part 7020.0500, subp. 2, item A, which requires the permit application to identify the maximum number of animals of each type which can be confined to the animal feedlot. The permit application and manure management plan are submitted to the agency together under the existing rules. For new manure management plans, the amount of annual manure can be calculated from the number of animal units reported on the permit application by using estimates of manure production per animal as reported by the Midwest Plan Service and University of Minnesota. For existing operations, the manure volume can be determined by examination of manure pumping and hauling records from previous years. This provision is not new but rather a codification of current practices.

The agency also proposes under subitem 1 to require identification of the expected annual amount of manure nutrients that will need to be land applied. This information is also needed to accurately develop the land application plan and use the available nutrients most efficiently. Again, subitem 1 is reasonable because it only asks the feedlot owner to document the information needed to safely implement a land application program and obtain the maximum benefit of available nutrients. The amount of nutrients is calculated by multiplying manure volume by the nutrient test results in subpart 2 or by published average manure nutrient concentrations.

Item D, subitem 2. The agency proposes to require that the methods and equipment used to land apply manure described in the manure management plan. The type of application equipment and methods used directly affect the amount of nutrients that will be available for plants. This information is important to the feedlot owner and regulatory authority in wisely utilizing the manure generated at any one feedlot. The information required in subitem 2 is reasonable because it is available information to the feedlot owner, requires only a minimal level of effort to consider impacts on nutrient availability, retains the feedlot owners flexibility in determining how manure will be land applied, and is contained and recommended by existing publications from the Minnesota Extension Service. See Exhibit L-8.

The agency also proposes to require manure application equipment calibration procedures in the manure management plan. Calibration is needed for many spreaders to understand the rate at which the equipment disperses the manure. Without this information, it is easy to over-apply or under-apply the manure compared to the intended rate. Requiring calibration procedures in the plan is reasonable because calibration can be accomplished with little to no money and without consuming much time. Additionally, the value of the entire manure management plan is greatly reduce if there is poor information about the rate at which the equipment applies the manure.

Item D, subitem 3. The agency proposes that the plan include maps on field locations and acreage available for applying manure or aerial photographs of these locations. The information in subitem 3 is needed to document where the manure will be deposited. This requirement is reasonable because it is information that is readily known to the person land applying the manure, must be considered in developing application rates, allows proper planning by watershed groups, and establishes clear expectations of the agency for manure management and recordkeeping. The current rules require that the manure management plan to include the acreage available for manure application, part 7020.0500, subp. 2, item C.

Item D, subitem 4. Subitem 4 requires that a description of manure nutrient test methods be included in the manure management plan. This is reasonable because these methods must meet the criteria under subpart 2, and this documentation will provide an opportunity for evaluation. The agency also proposes to have the testing frequency stated in the report. This is reasonable because the testing is required to be conducted at a minimum frequency proposed under subpart 2, items A and C, but the testing frequency may exceed the minimum requirements. The expected nutrient content of the manure to be applied is also proposed to be required in the plan. This information is needed as a basis for determining proper rates of application. It is reasonable to include this information since it can be obtained through the proposed testing requirement in subpart 2, or, for new operations, can be obtained in Minnesota Extension Service publications. See Exhibit L-8.

Item D, subitem 5. Under subitem 5, the agency proposes that the manure management plan include manure application rates and assumptions used to determine the rates. The application rates provide evidence as to how the feedlot owner developed the final decision for land applying manure once all the information about site, crop and manure conditions have been evaluated. The manure management plan forms the basis for the requirements under subparts 1 and 3 to be met. Subitem 5 requires that the crop nitrogen and phosphorus needs determined under subpart 3, items A and B be included. These needs are matched with available sources of nitrogen and phosphorus. Assumptions used to determine rates of application may also include crop yield goals, soil organic matter levels, and nitrogen from previous year's legumes. Again, subitem 5 is only documenting the process used to make a decision and not requiring new information.

Item D, subitem 6. The agency proposes to require the feedlot owner to plan the total manure nitrogen and phosphorus rates to be applied on each field and for each crop in the rotation. The information proposed in subitem 6 is needed so that the producer and agency know the amount of nutrients applied and at what application rate as determined under subitem 5. This is reasonable since this information can be readily calculated and is essential for applying the manure at rates meeting the nitrogen and phosphorus rate standards in subparts 3 and 6. It is also important for the producers to know this information so that commercial fertilizer is not applied excessively in addition to the manure nutrients.

Item D, subitem 7. In subitem 7, the agency proposes that the manure management plan identify what fraction of the nutrients are expected to become available to crops during the first two years of application. The availability of nutrients to crops is needed to permit the feedlot owner to determine the maximum manure application rate for compliance with standards set in subparts 3 and 6 for both growing seasons following application. This is reasonable since the information can be readily obtained from Minnesota Extension Service publications. See Exhibit L-8.

Item D, subitem 8. Subitem 8 contains the requirement that the feedlot owner include in the manure management plan the months when the manure is expected to be land applied. Consideration of the time for land application ensures that the feedlot owner utilize manure application practices consistent with winter application setbacks in subpart 6, item A, and other planning considerations proposed in subpart 4, item D, subitems 10 and 14. The provisions of subitem 8 are reasonable since producers generally do know and need to know when they will be applying manure. To meet the requirements of subitem 8, the feedlot owner need no extra assistance or expend costs, yet has the information readily available to support decisions made regarding manure application rates.

Item D, subitem 9. Subpart 1, item A, subitem 2, prohibits the land application of manure polluting of waters of the state. The agency proposes the manure management plan to describe the protective measures intended to minimize the risk of off-field manure transport when land applying manure in areas that may create a pollution problem. Such areas include floodplains, soil within 300 feet of public waters, intermittent streams, uncultivated wetlands, surface tile intakes, sinkholes without constructed diversions, drainage ditches, and soils with less than three feet above limestone bedrock. The proposed requirement is reasonable because it only serves document decisions made to comply with the requirement under subpart 1. The feedlot owner is not required to develop new information.

Minimum requirements are proposed in subparts 6, 7 and 8 for protection of lakes, streams, public waters, wetlands, intermittent streams, un-bermed drainage ditches, open tile intakes, and sinkholes. However, these minimum requirements may not provide enough protection to meet the proposed requirements in subpart 1, item A, subitem 2. Specific minimum requirements are not established elsewhere in the proposed rule for manure application in floodplains, around wetlands that are not classified as public waters wetlands, and areas with shallow soil above fractured limestone bedrock. Subitem 9 is needed to ensure that adequate measures are considered to protect water quality in these potentially vulnerable settings. Subitem 9 is reasonable because it allows feedlot owners the flexibility to choose management options that are most conducive to the farm operation and the environmental sensitivity of the area.

The agency proposes to expand what the term, protective measures, means when developing the manure management plan. This additional clarification is reasonable because it does not limit the options for trying to prevent manure runoff from contaminating waters, but does provide some management components that could be evaluated for addressing such problems.

Item D, subitem 10. Under subitem 10, the agency proposes that information regarding the application of manure onto frozen or snow-covered soil to be included in the manure management plan. These manure application conditions present unique hazards to Minnesota and this requirement is needed to ensure that these hazards are evaluated and managed appropriately. The following information provides the background regarding proposed rule considerations concerning winter application of manure.

The August 1995 MPCA report entitled "Basis and Justification for Manure Application Guidelines," pages 29 to 32, describe the increased risk of water quality impacts with winter application. See Exhibit L-2, pages 29 to 32. Existing research shows some increased potential for phosphorus, bacteria and oxygen demanding substances to be transported on frozen soils compared to non-frozen soils. However, the increased risk from solid manure applied to frozen soil was not found to be very great due to the mulching effect of the solids and bedding in the manure, and no research was identified describing the effects of liquid manure application during winter conditions. Phosphorus runoff from winter application was only slightly higher in the solid manure application plot compared to control plots with no manure. In general, the research comparing contaminant transport from manure applied at different times of the year is limited.

Pathogen survival is typically greatest during the wintertime. Since manure cannot be incorporated into frozen soils, pathogens are left at the surface where they are more likely to be transported to waters in snowmelt runoff. Water quality risks associated with winter application of manure were believed to be great enough to prohibit winter application in special protection areas (subpart 6, item A). See Exhibit L-2, pages 29 to 32 and Exhibit A-1.

Task force opinions and recommendations were more varied regarding winter application restrictions to sloping land outside of the 300 foot special protection area zones and land within 300 feet of open tile intakes (see discussion under subpart 6).

Reports comparing runoff of winter manure application from varying slopes were not found in the literature search. Water and sediment runoff potential is greater for steeper-sloped land with other factors being equal. If manure runs off from steeply sloping land, then there is a greater risk of contaminant transport to surface water, even if the surface water is more than 300 feet from the application site. There is also a risk that pooled areas of manure at the toe of the slope following snowmelt runoff would increase risks of ground water contamination. For these reasons, the following rule language was initially proposed: "Manure must not be applied onto frozen or snow-covered land with slopes greater than six percent, except for solid manure applied during periods with no snowmelt onto land with NRCS or MPCA approved conservation practices."

Several concerns were identified with the above proposed rule language.

- Some argued that solid manure does not contain that much more solids than liquid manure, and therefore there should not be different requirements for solid and liquid manure. Very little research has been conducted on liquid manure runoff applied to frozen soils.
- The MPCA, NRCS, and others identified problems in determining what was an approved conservation plan and the administrative difficulties associated with approving the conservation plans.
- Many farms in southeastern Minnesota and parts of central Minnesota reportedly do not have enough land with slopes less than six percent so that they can avoid winter application to such slopes. Information from the NRCS database (NRI) on soil slopes showed that throughout the entire state, about 93 percent of cropland acres have soils with slopes less than six percent. However, the land around Becker, Hubbard, Beltrami, Itasca, Clearwater and Mahnomen counties had 13 percent of its cropland with slopes exceeding six percent. The region composed mostly of Houston, Fillmore, Winona, Olmsted, Wabasha and Goodhue counties had 34 percent of cropland with slopes exceeding six percent.
- If there is an early freeze-up, farmers who normally plan to fall-apply would not be able to apply manure onto their land with slopes exceeding six percent. Early freeze-ups are unpredictable and common. Minnesota has a shorter growing season than most states and there is limited time in the fall to apply manure between the time of crop removal and soil freezing.
- Winter application to a slopes less than six percent can also create problems for water quality under certain conditions. The rules should not imply that all winter application to slopes less than six percent is environmentally acceptable.

It was suggested that for farming situations where winter slope restrictions for liquid and semisolid manure could not be reasonably met, the producer could obtain authorization from the agency, provided that this practice is conducted on land where there is minimal chance of runoff to surface waters or sinkholes. This recommendation was unacceptable to the agency because it is not administratively feasible.

In response to the above noted concerns, the proposed rule language was modified to require a description of protective measures to be included in the manure management plan for winter application. This final approach of requiring specific information in the manure management plan related to winter application is reasonable because it creates a heightened awareness of water quality concerns associated with winter application on sloping land, but yet allows the feedlot owner flexibility regarding how to minimize potential risks to water quality. The agency proposes to require basic information regarding the fields that will have the winter and slope conditions described in the subitem to be in the manure management plan. It is reasonable to clearly identify areas of special concern in the proposed rules so that expectations are known by all feedlot owners. The agency proposes to require the methods that will be used to minimize the risk of manure contaminated runoff to be described in the plan. See the discussion under item D, subitem 9.

Item D, subitem 11. In subitem 11, the agency proposes to require that soil phosphorus tests be conducted as part of the manure management planning process. Depending on the soil pH, the tests are to be a Bray P1 or Olsen test. These test methods are the two commonly-accepted tests for soil phosphorus in Minnesota. This information is useful to identify the land that needs additional manure applications to supply crop phosphorus needs or should be used carefully as an application site depending on the application rate. The soil phosphorus testing is needed to comply with subpart 4, item B, subitems 2 and 3; subpart 4, item D, subitem 12, and subpart 6, item B, subitem 2. The need for the proposed soil phosphorus testing is further described in this SONAR for subpart 3. Subitem 11 is reasonable since it provides information useful for soil nutrient management and to check compliance with other parts of the rules. Additionally, the costs of sampling need only be incurred once every four years. The soil phosphorus testing will create further awareness among feedlot owners regarding the fields will benefit most from manure applications and those most at risk from over application based on nitrogen application rates.

Item D, subitem 12. Under subitem 12, the agency proposes that the manure management plan include a description of how phosphorus from manure will be managed to minimize phosphorus transport to surface waters and prevent the soil phosphorus building to the levels stated in subpart 4, item A, subitems 2 and 3. This information is needed to address the concerns described earlier in this SONAR under subpart 3 concerning phosphorus rate restrictions outside of special protection areas and to prevent pollution of surface waters as a result of manure application. This requirement is reasonable since it allows the feedlot owner flexibility to implement phosphorus application provisions based on site-specific soils, residue management, slopes, proximity to waters, manure nutrients, crop rotations and hydrologic conditions.

The soil phosphorus levels triggering this additional level of planning are listed in subpart 4, item B, subitems 2 and 3. Research on phosphorus transport from agricultural lands is progressing at a rapid rate. Therefore, the proposed rules in subitem 12 allow the flexibility to adjust the soil phosphorus thresholds, which trigger additional planning to ensure that manure application does not cause pollution of waters of the state. It is reasonable to adjust the threshold numbers since these thresholds are only used to trigger increased planning levels; the changes must be published in the state register; and the rules will allow conformance with scientific knowledge over time.

Item D, subitem 13. Subitem 13 contains the requirement to establish nitrate soil testing in the manure management plan where such testing is recommended by the University of Minnesota Extension Service and other technical assistance experts. Nitrate testing in the soil is needed to meet the requirements under subpart 1 and subpart 3. Soil nitrate testing indicate any necessary adjustments needed in the manure application rates to minimize excess nitrate movement to ground water. This requirement is reasonable since it only requires testing when the residual soil nitrate may be high due to past land use practices, fertilizer application rates, types of manure land applied and related information. Most feedlot owners would not be required to meet this standard.

The University of Minnesota has conducted research to show situations when the soil nitrate test is environmentally beneficial for making adjustments to nitrogen application rates. This testing is not universally recommended. The situations where the soil nitrate test is recommended and the procedures for taking these samples are described in Minnesota Extension Service publications. See Exhibit L-12. These recommended procedures will be refined as new research becomes available.

Item D, subitem 14. The agency proposes in subitem 14 to require in a manure management plan the type of cover crop to be used when manure is applied in June, July, or August on fields that have been harvested and will not have active growing crops for the remainder of the growing season. Manure nitrogen that is applied to fields during summer months can be lost to ground water before a crop can remove this soil nitrogen. Therefore, establishment of a cover crop is needed so that the crop can use the manure nitrogen before it will be lost in the subsurface waters. With manure applications during the fall months, there is a reduced fraction of nitrogen that will be transported to ground water. It is reasonable to require this provision be met to ensure the establishment of a cover crop is not prohibitively costly and can have additional benefits, including reduced soil erosion.

Item E. When the manure ownership is transferred for the purposes of land application to fields not owned or leased by the feedlot owner, the agency proposes that the feedlot owner include in a manure management plan only those requirements in item D, subitems 1, 2, 4, 8, 9, 12, 13 and 14. These types of planning provisions can be made independent of knowledge of the specific fields where the manure is to be applied. The subitems of the manure management plan exempted for the producer in item E are those items that require specific knowledge of the fields intended for use in the land application program. These exempted items are required to be completed by the receiver of the transferred manure in accordance with subpart 1, item D. Please also see SONAR associated with subpart 1, item D.

Item E is needed so that the feedlot owner understands how much manure and nutrients will be hauled so proper arrangements can be made to have the manure land applied. This requirement is reasonable because the feedlot owner whose facility is producing the manure to be transferred to others will often not have knowledge regarding how the purchased manure will be used on land application sites and the crop-specific information needed for a comprehensive manure management plan.

A common practice, particularly for the poultry industry, is for feedlots to transfer ownership of their manure to either commercial manure applicators or producers who will then apply the manure onto land that is not owned by the feedlot owner. Such facilities that produce the manure will have estimates of the manure volume to be generated and the nutrient content of manure. However, they will not know the soil and crop characteristics for the land that the manure gets applied. For this reason they will be unable to develop a comprehensive manure management plan meeting all requirements in item D. While the producers of manure to be transferred do not retain all control of manure after transfer, the producer may make conditions of transfer contingent on the manure receiver following certain measures to protect surface waters from manure runoff or high phosphorus runoff resulting from manure application.

Manure application benefits soil in many ways. Manure adds macro- and micro-nutrients needed for plant growth, increases soil organic matter in low organic matter soils, and increases the soil's ability to hold water and resist compaction and crusting in many soils. Manure is most likely to be applied at proper rates and used for its soil enhancing properties when it can be viewed as a desirable and valuable resource rather than a waste. As additional restrictions are placed on application of manure, it is possible that the perceived value of this resource diminishes. If regulations are too tight, then non-livestock farmers will have less desire for manure and it then may be more likely to be over-applied on the land owned by the producers. It is for these reasons that the Land Application of Manure Task Force recommended to keep the rules from being overly burdensome for receivers of transferred manure.

Subpart 5. In subpart 5, the agency proposes that records of manure application practices be maintained. Items A and B relate to recordkeeping requirements for those who manage the cropland where manure is applied. However the requirements in items A and B only apply when the manure being applied originates from a feedlot with more than 100 animal units. Item C describes the proposed recordkeeping requirements for feedlot owners who do not apply manure onto land they manage. Item D includes recordkeeping requirements for commercial manure applicators spreading manure onto land not owned or leased by the feedlot owner.

Item A. The agency proposes to require that the manager of the cropland where manure is applied keep records of the land application information. Records of manure application practices are needed for three primary reasons. First, records enable owners to accurately account for nutrient additions to their fields so that excess fertilizer or additional manure is not added to fields that have already received manure. Second, records enable feedlot owners to better plan for manure application during future years. Third, records enable a feedlot owner to verify that they are complying with the requirements under Minn. R. ch. 7020 and enable MPCA or delegated county to check compliance with rules governing manure application.

The amount of time it takes to keep the records depends on the size of the farm and complexities of crop rotation and manure management. More time will be required for larger farms with multiple fields of varying crop types. Records are only required to be kept for people receiving manure from 100 animal units so as to be generally consistent with the animal unit threshold for requiring a manure management plan. The 100 animal unit threshold for record keeping is intended to include manure that is either owned by the feedlot facility, has transferred ownership of manure, or a combination of the two. Feedlots with less than 100 animal units increasingly represent a relatively small fraction of manure generated in the state, estimated by the agency to be less than 25 percent.

Item A, subitems 1 and 2. These subitems define the length of period feedlot owners are required to keep records. Subitem 1 proposes to require records to be kept for six years for fields within 300 feet of public waters, intermittent streams, and drainage ditches. Six years is needed near surface waters to enable the feedlot owner to ensure that phosphorus rates over a six-year period are not exceeding crop phosphorus removal as required in subpart 6, item B, subitem 2. Subitem 2 proposes that records be kept for three years for fields other than as being in special protection areas. Three years of records are needed in other areas to keep track of nutrient carry-over from the previous two-years of manure application and legume plowdown. Additionally, three years is consistent with recordkeeping provisions found in other agency rules. The subitems also require that should enforcement action be initiated all records must be maintained during the duration of the enforcement proceedings.

Item B. This item outlines the information the agency proposes for the maintaining of the land application records. The proposed requirements are reasonable because the type of information required for records is only that information necessary to enable the feedlot owner to track nutrient rates and compliance with the requirements in part 7020.2225. Many of the requirements for recordkeeping are similar to or identical to manure management plan requirements in subpart 5, item E. The records identify actual manure management activities. The manure management plan differs in that it only identifies specific plans for the manure prior to application. The manure management plan and records can be different since unforeseen circumstances will often prevent manure application practices. The agency intends that enforcement be completed on failure to protect the environment and thus, it is reasonable that information be maintained to allow such a determination.

Recordkeeping requirements in other parts of Minn. R. ch. 7020 that relate to the requirements of part 7020.2225, subp. 5, item B, are listed in Table 6.

Table 6. Recordkeeping Requirements for Manure Application and Manure Management Plans.

Record content requirements under part 7020.2225, subp. 5, item B	**Related part 7020.2225 requirement and compliance concerns**
Subitem 1: Field locations and cropland acreage where manure is applied.	Subpart 4, item D, subitem 3 and subparts 6, 7, and 8: Field locations and acreage available for applying manure.
Subitem 2: Volume or tonnage of manure applied on each field.	Subpart 2 and subp. 4, item D, subitem 6: Total manure nitrogen and phosphorus rates to be applied on each field and for each crop in rotation.

Record content requirements under part 7020.2225, subp. 5, item B	Related part 7020.2225 requirement and compliance concerns
Subitem 3: Manure test nitrogen and phosphorus content, as required by subpart 2.	Subpart 2: Manure nutrient testing requirements and subpart 3 – nutrient application rate standards.
Subitem 4: Dates of application.	Subpart 4, item D, subitem 8: Expected months of application, and subparts 6 and 7.
Subitem 5: Dates of manure incorporation when incorporating within 10 days.	Subpart 3, item A; subpart 6, item B: Also needed to estimate the fraction of total nitrogen which will become available to the crop.
Subitem 6: Expected plant-available amounts of nitrogen and phosphorus released from manure and commercial fertilizers on each field where manure is applied.	Subpart 3 and subpart 7.
Subitem 7: A description of deviations from the manure management plan including documentation of the justification for any remedial nitrogen applications which exceed the nitrogen rate standard in subpart 3.	This is needed to make it clear that deviations from the manure management plan are allowed and to aid in compliance checks when deviations occur.
Subitem 8: Soil nutrient test results.	Subpart 4, item D, subitems 11 and 13, and subpart 6, item B.

Together, the manure management plan and the land application records provide a complete picture of application practices. As changes in weather and farm prices change, the actual manure application practices may change from what was intended and stated in the manure management plan. The closer to the time of application that the manure management plan is written or updated, the greater chance that the manure management plan and the records coincide. A feedlot owner is allowed to deviate from the manure management plan provided the deviations do not result in a violation of this part or permit conditions and these changes are recorded as required under subitem 7.

Due to the numerous items proposed to be required in the manure management plan and the detailed records which will need to be kept, the Minnesota Extension Service, in cooperation with the MPCA and other agencies, has obtained a federal grant to provide training to feedlot owners and those assisting feedlot owners. See Exhibit L-16. The training will describe how to develop a manure management plan and how to keep records in accordance with the proposed rules.

Item C. This item outlines the recordkeeping responsibilities for the feedlot owner when manure is spread on sites <u>not</u> owned or leased by the feedlot owner. Records are needed when livestock producers sell or give away their manure to others so that the agency and delegated counties can track compliance with part 7020.2225. These requirements are reasonable since the information in the records is either easily known by the facility producing the manure, or will be supplied by the receiver of the manure.

Item C, subitem 1. In subitem 1, the agency proposes that the feedlot owner record the volumes or weight of manure delivered; the nutrient content of the manure delivered; the name and address of the receiver of the manure; the location where the manure was applied; and the rate of application. This information is needed for understanding the fate of the generated manure, and so that the livestock or poultry feedlot owner generating the manure can track application practices and make any necessary adjustments concerning where or to whom the manure goes. Subitem 1 is reasonable since the volume or tonnage of manure, nutrient content, and receiver of the manure is easily known by the producer. The location and rate of application will be mailed to the livestock producer by commercial applicators per subitem 2 or can be otherwise tracked by the feedlot facility.

There are, however, situations such that the location where the manure is applied and the rate of application can not be tracked. This can occur when manure stockpiles or liquid manure is mixed or composted together with manure from other sources. This information must be maintained for three years. The length of record retention is reasonable because it generally is consistent with the retention schedule proposed under Item A, subitem 2 and other agency rules.

Item C, subitem 2. Commercial applicators often take manure from the livestock facility and apply it onto cropland for a fee. This practice is particularly common with poultry manure. Commercial applicator records are necessary to track compliance from the livestock facility to the receiving field. Subitem 2 reflects the need to understand how manure is being managed by commercial applicators. If the manure is purchased by a commercial applicator, the livestock facility will typically only keep records of the commercial applicator name and not the cropland to which the manure is applied. Even more important it the lack of knowledge a feedlot owner may have on the final application site.

The agency proposes to require commercial applicators to keep records in accordance with subitem 1, and to submit a copy of the records within 60 days to the owner of the animal feedlot, which produced the manure. The information is needed to track compliance with part 7020.2225 when ownership of manure is transferred. It is reasonable because the commercial applicator will easily know the information if they are keeping detailed records of stockpiling practices, and since the records can be mailed to the feedlot facility at minimal cost.

Subpart 6. The agency proposes to establish requirements for manure application requirements for land within special protection areas.

Item A. The agency proposes that manure being spread onto frozen or snow-covered ground not be applied any closer than 300 feet from surface waters and channels to surface waters, also defined as special protection areas. A winter setback from surface waters is needed to prevent excessive amounts of nutrients, pathogens and oxygen demanding substances to move in snowmelt to surface waters. The need was further discussed in association with subpart 4, item D, subitem 10. This requirement is reasonable since feedlot owners without adequate manure storage capacity to make it through the winter will have two options: avoid applying manure in the winter to entire fields which are adjacent to surface waters; and, avoid applying manure in the 300-foot setback zone from surface waters during winter months and fertilize this area with manure or commercial fertilizer during the fall or spring months. These options were deemed reasonable by the land application of manure task force because winter application to land more than 300 feet from surface waters is still permitted; and there will usually be time to apply manure to the 300-foot corridor areas before or after soil freezing and snow cover.

Reasons for choosing the distance of 300 feet are described in "Basis and Justification for the Minnesota Land Application of Manure Guidelines" dated July 1995. See Exhibit L-2, pages 28 and 29.

Item B. The agency proposes to require pollution prevention measures when applying manure during non-winter months to land within 300 feet of surface waters and channels leading to surface waters. It is proposed that two different options be given to feedlot owners. The options allow the feedlot owner to maintain a permanent vegetative buffer along the water or waterway; or to place the manure below the soil surface; apply at a rate and frequency that prevents soil phosphorus from accumulating over time; and maintain a 25-foot setback. The need for non-winter manure application restrictions on land within 300 feet from surface waters and channels, is described in "Basis and Justification for the Minnesota Land Application of Manure Guidelines" dated July 1995. See Exhibit L-2, pages 28 and 29.

The primary environmental concerns with near surface water application relate to storm events and runoff following surface application of manure, and soil phosphorus build-up caused by repeated application of manure at rates based solely on crop nitrogen needs/removal. Storm events can carry phosphorus, ammonia, pathogens and biological oxygen demand to nearby receiving waters. The amount of phosphorus in the surface layer of soil correlates with the concentration of dissolved phosphorus in runoff. Phosphorus will also move to waters while being bound to soil particles as these particles are eroded. Phosphorus enriched sediment is most likely to be transported to waters when located in close proximity to waters and channels to waters.

There is more than one way to minimize environmental risk when applying manure to land near surface waters. One way is to treat the runoff waters with vegetation before the water discharges into a lake, stream, or channel to a lake or stream. Another way is to prevent contaminant transport by placing the manure below the soil surface prior to any rainfall. Preventing soil phosphorus accumulation will further reduce the environmental risks associated with phosphorus transport. The proposed rules are reasonable since they allow greater flexibility for feedlot owner and an adequate degree of environmental protection.

Item B, subitem 1. Vegetated buffers have been shown in numerous studies to be effective treatment options in reducing runoff contaminants such as nutrients, BOD and bacteria. See Exhibit L-2, pages 21 and 22. The primary mechanisms for contaminant removal include a reduction in runoff volume by increased infiltration; a decrease in runoff velocity resulting in sedimentation of contaminants that are adsorbed to particulate matter; and an increased adsorption of pollutants by soil particles under the influence of a lower ionic concentration regime than found on the manure application site. A vegetated buffer will not remove all contaminants and the degree of contaminant removal depends on such variables as the soil type, slope, manure type, and buffer width. A buffer width of 50 to 100 feet will provide significant treatment of contaminants and does not take large areas of land out of agricultural production.

In all cases, the proposed rules provide farmers with a choice of avoiding the other manure application restrictions (subitem 2) if they maintain the 50 to 100 foot wide strip of permanent vegetation along the water or channel. In some areas, well-established buffers already exist. Where buffers do not already exist, producers would have the option of taking some land out of production. A 100-foot wide vegetative buffer amounts to less than two and one-half acres of a 40-acre field if one side of the field abuts the water. If the stream splits the 40-acre field then nearly five acres would be affected with a 100 foot wide strip. If this is not feasible, then the agency proposes that feedlot owner would have the choice of meeting the requirements under subitem 2.

The required buffer width is greater (100 feet) for lakes and streams compared to other waters and channels protected within Special Protection Areas. The additional 50-foot safety measure was added to lakes and perennial streams to provide greater assurance that the waters which are more sensitive to phosphorus and other contaminant additions receive greater protection. Also, the Land Application of Manure Task Force considered 100 feet of buffer along the numerous wetlands and intermittent streams to be unreasonable, since it would require taking too much land out of production.

Item B, subitem 2. Feedlot owners, who choose not to maintain a 50- to 100-foot wide vegetated buffer along waters and waterways, yet would like to apply manure onto fields adjacent to these waters and waterways would still be able to apply the manure as long as they limit rates over a six-year period to equal phosphorus removal (when soil phosphorus concentrations exceed 21 ppm Bray P1); the manure is placed below the soil surface; and manure is applied no closer than 25 feet from the water or channel in the special protection areas.

Item B, subitem 2, unit a. A 25-foot setback, unit a, from lakes, streams and other waters associated with special protection areas is needed to ensure that manure does not enter the water or waterway during the process of applying the manure, or via shallow ground water which is commonly found in this zone so close to surface waters. The 25-foot setback was considered reasonable by the task force and the agency because the amount of land that would be taken out of production would be very small; or if the feedlot owner keeps the land in crop production, the feedlot owner could make one pass with commercial fertilizer along these waterways in order to provide the needed nutrients.

Item B, subitem 2, units b and c. Immediate incorporation and a phosphorus based rate or frequency of application greatly reduces the risk of manure transport to surface waters and minimizes the risks associated with soil phosphorus in runoff from the application site. These options were generally deemed reasonable by the Land Application of Manure Task Force since they are not excessively costly for the feedlot owner; they greatly reduce the environmental concerns associated with manure application near waters; and they are not overly complex.

The primary additional farmer costs associated with this option is the supplemental commercial nitrogen fertilizer usually needed to be applied during some years within the 300-foot special protection zone. Another possible cost would be to obtain equipment needed to inject or incorporate the manure. The primary environmental concern expressed by the Land Application of Manure Task Force under the option in subitem 2 is that manure can still be applied to soils having a pre-existing elevated soil phosphorus levels.

Many soils have naturally high soil phosphorus. Under the proposed rules, farmers with high phosphorus soils would need to either apply manure to the zones along the 300-foot strip of land during fewer years and would need to add supplemental commercial nitrogen fertilizers during some years, or maintain the permanent vegetated buffer. Additions of phosphorus at a phosphorus-based rate will not increase the environmental risk. But for soils already having high phosphorus soils, these soils would continue to be fertilized.

Research shows that both erosion rates and soil P levels are important variables affecting risk to water quality degradation, and both variables are considered in the voluntary MPCA manure application guidelines for land within 300 feet of surface waters. See Exhibits L-1 and L-17. However, erosion is not factored into the required setback rule restrictions. A goal of the task force was to develop rules that were not overly complex in anticipation that they would likely be more understood and followed. Adding soil erosion rates as another variable into the rules would significantly increase the complexity of the rules. Erosion rate estimates are calculated from numerous soil and crop residue factors. Feedlot owners often do not know the erosion rate estimates for their fields, and many producers only know whether or not they have more or less than five tons of soil erosion per acre per year. The added environmental protection by factoring erosion rates to the rules was generally not believed to outweigh the disadvantages of added rule complexity.

However, if manure is to be applied to soils with soil phosphorus levels exceeding 75 ppm (Bray P1) or 60 ppm (Olsen) in the special protection areas, then the manure management plan would need to be reviewed by the agency or delegated county, in accordance with subpart 4, Item B. During review of the manure management plan, the agency or delegated county can review soil slope, erosion rates, and other factors affecting phosphorus transport.

Another concern expressed by some task force members was that the requirements under Item B do not pertain to most wetlands less than 10 acres. Wetlands are protected in several ways throughout the proposed rules, as listed below:

- Application of manure is prohibited to enter any uncultivated wetland during the process of applying the manure, as already described in rule subpart 1, item A;
- Manure management plans must describe protective measures to minimize the risk of off-field manure transport when applying manure within 300 feet of all uncultivated wetlands in subpart 4, Item D, subitem 9;
- There is a 300 foot winter application setback from all public waters wetlands, including all type 3, 4 and 5 wetlands greater than 10 acres (in subpart 5, item A). If winter application within 300 feet of other wetlands is to occur, the manure management plan

must indicate the soil and water conservation measures, timing of application, application locations and other manure management practices that will minimize the risk of off-field manure transport in subpart 4, item D, subitem 10; and
- In addition, application of manure during non-winter conditions within 300 feet of public waters wetlands is subject to the restrictions listed in this subpart.

All uncultivated wetlands are provided with some degree of protection throughout these rules. Public water wetlands are protected from filling and drainage through other laws. The proposed rules are reasonable since they will not add to management difficulties for feedlot owners with these smaller wetlands management challenges that could contribute to further wetland loss.

Item C. The agency under item C proposes to prohibit liquid manure from being dispensed from spray irrigation equipment outside of special protection areas. This proposed rule is needed since application of manure through irrigation systems increases risk of contaminant transport in wind drift. The 300-foot setback is proposed to reduce the risk of phosphorus and pathogen transport to the water body via the air or from surface runoff. The proposed rule is reasonable since irrigation equipment is rarely used in Minnesota for manure application and thus, the proposed restriction will not affect many producers. Also, in most areas there is adequate land away from the 300-foot setback zones to allow for spray irrigation activities. The spray distance of 50 feet is put into the proposed rules to clarify that spraying the manure onto the soil from behind a truck or tractor is still allowed.

Subpart 7. The proposed rules require manure to be injected or immediately incorporated within 300 feet of open tile intakes so that it is no longer readily available for transport to surface waters. The 300-foot distance was selected to coincide with the 300-foot distance used to define special protection areas. Rules protecting manure from runoff into open tile inlets is needed since open tile inlets are direct conduits of field runoff waters to drainage ditches or streams. Open tile intakes are also typically located on land that has low permeability and fewer soil conservation practices. Manure application concerns near open tile intakes are heightened during winter months and other situations when manure can not be injected or immediately incorporated, therefore leaving the manure more vulnerable for surface runoff into these conduits to surface waters.

The Land Application of Manure Task Force had a difficult time determining a reasonable approach to minimize manure runoff into these drains. The proposal to require immediate incorporation or injection within 300 feet of open tile inlets met much resistance with the Land Application of Manure Task Force. The following concerns were raised:

- Equipment does not allow injection or immediate incorporation during frozen soil conditions. A 300-foot winter setback would leave about seven acres around each surface tile inlet with no manure/nutrients. Many fields have several surface tile inlets. The farmer would either need to go back on all of these seven-acre plots and apply commercial fertilizer; apply manure during non-winter months; or not apply nutrients to these areas. Either a decrease in crop yield would occur, or farmers must invest additional time and expense to go back onto the fields and fertilize these areas during non-winter months.

- On tile drained lands, spring application is not feasible due to wet soils and compaction problems. In the summer and early fall the crop is in the ground. This leaves only mid to late fall and winter for spreading. With an early freeze, a winter application restriction around tile intakes would leave only a very narrow window of time for application in these fields. Many farms have most of their fields with intakes, and setback rules would require a patchwork of spreading around the intakes in the earliest part of the fall.
- Manure application is not the only problem with open tile intakes. Commercial fertilizers, sediment, and pesticides are also transported into open tile intakes. Alternative drainage methods need to be investigated. Manure runoff may contribute to the problem, but the real problem is the technology devised to drain the fields. Ongoing and proposed research may lead to alternative technologies.
- The question was raised about whether a strict setback of 25 to 50 feet could be an alternative to the 300-foot immediate incorporation zone. It was agreed by most task force members that small setbacks do not provide a lot more protection than no setback because the water often becomes ponded in the area around the open tile intake.

As a compromise to the conflict between need and reasonableness, the task force and FMMAC suggested the immediate incorporation restriction be phased in over time so that by a certain date manure must be immediately incorporated or injected if applied within 300 feet of an open tile intake. Until that time, open tile intakes would not be ignored since the manure management plans must include a description of how manure transport to open tile intakes will be minimized. In addition, the rules leave open the possibility for other options. There is ongoing research evaluating the effects and alternatives of open tile intakes. If other best management practices are developed to minimize pollutant transport from manure application around open tile intakes, and the MPCA approves these techniques, then producers may instead adopt these approved alternatives.

Item A. The agency proposes to require all liquid manure applied within 300 feet of open tile intakes to be injected or incorporated within 24 hours of application, and that this requirement will not be phased in but will become effective from the date these rules become effective. This is needed to prevent liquid manure from flowing into open tile intakes during application or in rain events following application. This is reasonable since liquid manure is usually injected or immediately incorporated throughout the state.

Item B. The agency proposes to allow for approximately four years after the effective date of the rules (October 1, 2004) before non-liquid types of manure would be required to be immediately incorporated within 300 feet of open tile intakes. This is needed to prevent bacteria, phosphorus, and other contaminants from entering surface waters via tile intakes. It is reasonable to allow this grace period for solid manure since it can be more challenging to manage manure for immediate incorporation of solid manure compared to liquid manure, and since solid manure presents a slightly reduced risk of contaminant transport into tile intakes.

Subpart 8. This subpart contains the agency's proposed language with regard to application near sinkholes, mines, quarries and wells.

Item A. A 50-foot setback is proposed between manure application sites and active or inactive water supply wells, sinkholes, mines and quarries. This is needed to reduce the chance of pathogen migration to well water and other ground water. The proposed setback is reasonable since a 50-foot setback is the distance Minnesota Department of Health requires between wells and many common potential contaminants, including animal holding areas (Minn. R. ch. 4725).

A member of the task force suggested that the manure application setback distance be increased for public water supply wells. This issue was discussed with staff from the wellhead protection program at the Minnesota Department of Health. The increased setback for public water supply wells was not added into the proposed rule because each city will be developing wellhead protection plans to protect their wellhead area, and the needed setback distance will vary greatly among wells. In many situations, a 50-foot setback would be more than enough to protect a public water supply well, and in other situations several hundred feet may be needed. Each city will work to protect their own well based on the individual characteristics of the well construction, soils, geology, and land uses.

Item B. A 50-foot setback distance was not considered adequate to protect manure runoff from sinkholes when manure is surface applied (without immediate incorporation) onto land which slopes into the sinkhole since sinkholes are often in low lying areas where surface runoff concentrates. The proposed distance for which manure needs to be incorporated up slope of a sinkhole was increased to 300 feet, which coincides with the 300-foot distance associated with manure application near surface waters proposed under subpart 6, item B, subitem 2, unit b.

V. CONSIDERATION OF ECONOMIC FACTORS

Minnesota’s farm economy was in a state of transition in 1999 when these rules were being drafted. The Minnesota legislature and the Governor’s office were very sensitive towards the needs of the farm community during this period of transition. The Minnesota Pollution Control Agency strove to incorporate the most economically sensitive approach to protect Minnesota’s, air, and water from the pollution caused by livestock production. The rule has also undergone intense review by the Feedlot Manure Management Advisory Committee (FMMAC), a team of agribusiness people, University experts, environmentalists, and local government officials, to arrive at the best possible approach for regulating Minnesota’s livestock industry.

A. Classes of Persons Affected by the Proposed Rule

Minnesota Statutes Section 14.131, Minnesota Statute section 115.43, subdivision 1, and Minnesota statute 116.07 subdivision 6 require the MPCA to address the economic impacts of the proposed rules. One of these requirements is to estimate the probable costs of complying with the proposed rule. These costs are summarized in this section. In addition, section 14.131 requires a description of the classes of persons who probably will be affected by the proposed rule, including classes that will bear the costs of the proposed rule and classes that will benefit from the proposed rule.

In general, the classes of persons that will most likely be affected by the proposed rules include owners and operators of animal feedlots and manure storage areas; persons involved in the storage, transportation, disposal and utilization of manure, which includes commercial manure applicators; those interested in management of domesticated animals or related facilities; delegated counties, counties interested in applying for delegation to implement a feedlot program; and those interested in Minnesota's water resources.

The MPCA broke these general groups into four categories of classes for the economic impact analysis purposes. The four categories discussed in more detail below include:

- Owners and operators of animal feedlots, manure storage areas and pastures;
- Delegated counties;
- Persons concerned about environmental quality; and
- State government.

Owners and Operators of Livestock Facilities

This group is evaluated by animal type sector (dairy, beef, swine, and poultry) and animal unit capacity category (10 or 50 to less than 300 animal units, 300 to less than 1,000 animal units and 1,000 and more animal units) as appropriate to the rule parts being discussed in the overall economic impact analysis. In general, this class will be affected by the proposed rules. This class will experience a slight increase in costs under the rules as proposed compared to the requirements under the existing program. The major areas of impact include that costs associated with: the air emissions plans required for all facilities greater than 1,000 animal units (part 7020.0505, subpart 4, item B (1)), the restriction to keep livestock on pastures out of lakes (part 7020.2015, subpart 3), the restrictions associated with design standards which do not allow piping to penetrate manure storage area liners (part 7020.2100, subpart 3, item C), the requirement to have construction inspections for liquid manure storage areas (part 7020.2100, subpart 6), and the requirement to hire a design engineer to evaluate the soils investigation and prepare a report (part 7020.2110, subpart 2, item B). All facilities owners in this class will not be impacted by these costs. The proposed rules do offer cost benefits for some facility owners and operators in the form of a streamlined permitting process for the majority permits, and a stepped approach to solving open lot runoff problems at facilities with less than 300 animal units.

Delegated Counties

More than 50 counties have accepted delegation to process permits under Chapter 7020. In general, there will be no additional cost over existing requirements. The proposed rule is designed to be flexible to meet the needs; resources; and the varying demands associated with the varied number of feedlots, manure storage areas and pastures that are unique to each county. Some counties will elect to increase staff and establish aggressive goals that will require additional resources. However, this is not a requirement of the proposed rules. The MPCA is proposing to include a new program component - registration, increase inspections, require the preparation of an annual report, and increase the scope of potential permittees from facilities with less than 300 animal units to facilities with less than 1,000 animal units that are not required to have an NPDES or SDS permit. The work associated with these responsibilities will be offset by the reduction in work that will result from eliminating the requirement to issue certificates of compliance and removing the requirement to have a permit to construct, expand or modify an animal feedlot or manure storage area that will result in less than 300 animal units when the construction is done in accordance with the proposed technical standards.

Persons Concerned About Environmental Quality

This class includes people that live near livestock facilities, citizens concerned about environmental impacts associated with livestock agriculture and citizens concerned with water and air quality in Minnesota. Persons in this class will not experience a direct cost impact because they are not conducting activities that are regulated by Chapter 7020. However, this class will realize a cost benefit over time in the form of a cleaner environment, as existing pollution issues, such as runoff from small open lots, are resolved.

State Government

The proposed rules will not impact state government agencies other than the Minnesota Pollution Control Agency (MPCA), which is the only state agency that regulates animal feedlots, manure storage areas, and pastures for pollution issues. The MPCA currently has a regulatory program for this purpose. The MPCA is proposing to add the registration to this existing program. Registration will require administrative work that is currently not being performed by the MPCA. The MPCA is also re-designing the existing regulatory program. See the Program Plan (Exhibit I-4) for a discussion of this re-design effort. The MPCA is not requesting additional resources because the work required to complete registration will be offset by the reduction in work realized from streamlining the permitting process and reducing the time required to issue permits; eliminating the certificate of compliance, which typically doubled staff work load in conjunction with permitting; and removing the requirement to have a permit to construct, expand or modify an animal feedlot or manure storage area that will result in less than 300 animal units when the construction is done in accordance with the proposed technical standards.

Table 7. Discussion of Cost Differences Between Current Requirements and Proposed Requirements

Rule Part	Heading/Title	Cost Differences Between Proposed and Existing Requirements
7001.0020, Item F.	Agency Permit Procedures, Scope	<u>State government impacts</u> This rule part only refers to administrative procedures that will be performed by MPCA staff and delegated counties. No additional costs are expected from changes

Rule Part	Heading/Title	Cost Differences Between Proposed and Existing Requirements
		to these procedures because procedures for interim permits and NPDES, and SDS permits remain the same. Proposed amendments relate to a new permit tool, construction short-form permit, which will have the same procedural costs as the interim permits. <u>Delegated Counties</u> Introduction of construction short form permit will result in little or no additional procedural costs because the process established under this part is the same as the process for the existing interim permits currently being issued by the delegated counties.
7002 7002.0210 to 7002.0280	Permit Fees Permit Fee Structure for NPDES, SDS, Construction Short Form and Interim Permits	<u>State Government</u> The MPCA will realize no additional fee revenue from the proposed amendments. The MPCA has included in its fee allocation, the expected fee revenue from issuing an NPDES permit to all facilities with 1000 or more animal units. Therefore, fees proposed to be collected for the SDS permit will replace the fees that would have been collected as NPDES permit fees. <u>Livestock Owners and Operators</u> The proposed changes do not change the fee amounts that are already established under Chapter 7002. The MPCA is currently charging fees for NPDES permits that regulate animal feedlots, manure storage areas or pastures. SDS permit fees are the same as NPDES permit fees and will only be issued to facilities that would normally receive an NPDES permit, therefore no additional costs will be incurred. The MPCA is proposing no fees for Interim Permits, Construction Short-form permits, and SDS permits issued to facilities with less than 1000 animal units.
7020 7020.0200 7020.0205 7020.0250 7020.0300	General Scope Incorporation By Reference Submittals And Records Definitions	These parts are for clarification purposes and the actual requirements would result in incurred costs are discussed in other parts of the rules.
7020.0350	Registration	<u>State Government</u>

Rule Part	Heading/Title	Cost Differences Between Proposed and Existing Requirements
	Requirements For Animal Feedlots, Manure Storage Areas and Pastures	The registration program will be a new responsibility for the MPCA. However, The MPCA is not requesting additional resources to administer this program. Instead the agency is redesigning its permitting procedures to free up existing resources to administer this program. See Exhibit I-4. The information received through the registration process will allow the MPCA to more effectively determine pollution concerns and then use its resources more effectively by targeting its efforts. Livestock Owners and Operators The cost is negligible; the only cost associated with this requirement is the cost to complete the form, which only requires information that should be readily available to the owners/operators. This should require only a minimal amount of time. Many operators will meet this requirement without spending any additional time because the will have met the requirement as the result of a level 2 or 3 county inventory or a permit application submitted after the effective date of these proposed rules. Delegated Counties Impacts for the registration program are included in the discussion under part 7020.1600. Persons Concerned with Environmental Quality Because of this program, the MPCA will be receiving more information about the potential pollution sources. This information will allow the MPCA to more effectively make decisions that will result in environmental gains for the state.
7020.0400	Permit Program	This part is for clarification purposes only.
7020.0405	Permit Requirements	State Government The proposed rules will result in a streamlined permit delivery system for the agency. The combination of the short-form permit, interim permit, and technical standards that are proposed in this rule will result in less administrative time for completing a permit. Livestock Owner and Operators

Rule Part	Heading/Title	Cost Differences Between Proposed and Existing Requirements
		Proposed rules will regulate the same animal unit category range (50 animal units and 10 animal units in shoreland) as in the current rules. The MPCA's proposal to use technical standards established in the rules to develop interim and construction short form permits will result in a streamlined permitting process. This streamlined process is expected to benefit the facility owners in a positive way by minimizing construction cost overruns that result from permit backlogs and issuance delays. The proposed rules do not require owners with less than 300 animal units to acquire a permit for the construction of a new facility or the expansion of an existing facility if construction is in accordance with the technical standards established in the proposed rules. This will save these owners the time and expense of completing a permit application, working with the MPCA or a delegated county to acquire a permit, and retrofitting construction plans to meet the permit process requirements. <u>Delegated Counties</u> See discussion under part 7020.1600.
7020.0505	Permit Applications	<u>State Government</u> The proposed rules will require no additional administrative costs to process a permit application because the items proposed to be required on the permit application are essentially the same items currently required under part 7020.0500. <u>Livestock Owner and Operators</u> The existing requirements and the proposed requirements are the same 7020.0505 subpart 4 item B requires the preparation of an air emission plan, pollution prevention plan, and an emergency response plan. This rule part results in additional costs for livestock owners and operators. These costs have been estimated and included in the additional costs part of the Implan modeling section of the economic impact analysis proposed as a permit application requirement for facilities with 1,000 or more

Rule Part	Heading/Title	Cost Differences Between Proposed and Existing Requirements
		animal units. Facilities under 1,000 animal units may be requested to submit the air emission plan if the MPCA determines the facility poses a high priority environmental issue. Submitting the plan, when required, with the permit application is a new requirement. Air emission plans are currently required when the site specific evaluation conducted as part of the permit development process or an environmental assessment determines there is a need for this plan. An engineer or other professional with expertise in this area is not required to complete these plans. Direct costs will be incurred if a facility owner elects this service. Indirect costs will be incurred by owners that prepare their own plans. The MPCA will be providing guidance on how to prepare an effective plan to help owners prepare their own plans and minimize the time required to prepare the plans. The MPCA estimates that 6 to 15 hours are required to prepare this plan. Subpart 4, item D, requires certification of notification. This notification is required by statute and affected owners are currently meeting this notification. Therefore there is no additional cost. <u>Delegated Counties</u> Existing interim permit applications require the same information for most applications. Therefore, there will be no additional costs for the delegated counties associated with processing the proposed applications.
7020.0535	Construction Short-Form and Interim Permits	<u>State Government</u> Establishing the permit requirements in the rules helps the MPCA establish a streamlined permit process. Staff time is not spent re-designing the permits each time that one needs to be issued and minimal negotiation is required to develop the permit. This approach reduces staff resources needed to issue interim and construction short form permits. <u>Livestock Owner and Operators</u> The conditions and requirements proposed to be required under the construction short form permits and the interim permits are essentially the same requirements that are

Rule Part	Heading/Title	Cost Differences Between Proposed and Existing Requirements
		currently required under interim A and B permits. The technical standards under parts 7020.2000 to 7020.2225 that are being proposed to be permit requirements have been established and utilized as regulatory policy and currently are being incorporated into interim A and B permits. Therefore, the requirements under the proposed construction short form permits and the interim permits will impose no additional costs to facility owners compared to current permit requirements. Establishing the permit requirements in the rules rather than as individual permits streamlines the permitting process, which is expected to benefit the facility owners in a positive way by minimizing construction cost overruns that result from permit backlogs and issuance delays. Delegated Counties Delegated counties will realize the same benefits as state government.

Rule Part	Heading/Title	Cost Differences Between Proposed and Existing Requirements
7020.1600	Authorities and Requirements for Delegated Counties	State Government The MPCA is proposing a new component to the county delegation – the delegation agreement. This new tool will require an MPCA staff person to annual review the delegation agreements and work with each county to update the agreements when necessary. This work will require little time because it will be combined with the existing work being done for the county block grants. Delegated Counties The MPCA is proposing to include the administration of registration, increased inspections, the preparation of an annual report, increasing the scope of potential permits from facilities with less than 300 animal units to facilities with less than 1000 animal units that are not required to have an NPDES or SDS permit. The work associated with these responsibilities will be offset by the reduction in work that will result from eliminating the requirement to issue certificates of compliance and removing the requirement to have permit to construct, expand or modify an animal feedlot or manure storage area, that will result in less than 300 animal units when the construction is done in accordance with the proposed technical standards. We don't expect counties to hire new staff or to incur new expenses for additional equipment needed to run the program, however the changes in the specific activities that are done by CFO's for example, time spent under the current program processing permit application and issuing permits would be shifted to implementing the registration program and greater field presence. This shift is realized in part through the construction short form permit process. The construction short from permit and technical standards work together to reduce the amount of time draft and issue permits. Staff will also have additional time that is currently being spent to issue permits to owners with than less than 300 animal units constructing a new facility or expanding and existing facility. In addition, the delegation agreement proposed in the rule amendments provides the flexibility to design the

Rule Part	Heading/Title	Cost Differences Between Proposed and Existing Requirements
		program to meet a county's individual resources, goals and needs. This will not necessarily require an increase in staff. A county may choose to increase their staff size.
7020.2000 to 7020.2225	Standards for Discharge, Design, Construction, Operation and Closure	Livestock Owners and Operators Expected to result in cost savings to producers due to reduced delays in commencing construction for new facilities and expansions of facilities that are under 300 animal units in capacity. Under 300 animal unit facilities account for an estimated 80% of the facilities that exist in Minnesota. Historically, the agency has accumulated a backlog of permit applications resulting in unanticipated delays for producers. Unanticipated delays often result in unanticipated costs for producers such as increased costs of construction. An example of this would be if as a result of a permit delay, construction was delayed until winter resulting in more costly construction. In addition delays result in lost production time resulting in lost revenues for producers. The registration program should result in significantly reduced delays resulting in significant cost savings to the industry. There is no data available on exactly how much delays are costing the industry therefore there is no dollar value assigned to these costs savings.
7020.2000	Overview	This section contains requirements for manure not used as domestic fertilizer, manure packs and mounding and notifications to the local public and agency or delegated county. These requirements exist under the current feedlot program, therefore, there are no additional costs anticipated by this part.
7020.2002	Hydrogen Sulfide Ambient Air Quality Standard Applicability	Livestock Owners and Operators This exemption is anticipated to effect a very small number of facilities. Cost savings may be realized at facilities that struggle to lower their emissions during agitation and pumpout. There is no data from which to make a calculation on the amount of cost savings that could result from this rule part. It is expected that the amount of cost savings will be insignificant to the livestock sectors as a whole. Persons concerned with environmental quality

Rule Part	Heading/Title	Cost Differences Between Proposed and Existing Requirements
		This provision may result in costs (e.g., air conditioning systems, clothes dryers instead of hanging on clothes-lines, etc.) for neighbors of facilities for which BMPs are not working adequately to limit emissions.
7020.2003	Water Quality Discharge Standards	<u>Livestock Owners and Operators</u> This rule part is expected to result in cost savings to livestock facilities that have runoff from open lots and are under 300 animal units. Example: John Doe has a 200 head dairy operation with outside open lots that currently have a runoff problem. John Doe hasn't expanded or built any new operations for a number of years and therefore has not had his facility reviewed by MPCA to see if it is in compliance with 7020 feedlot rules and 7050.0215 discharge standards. If John Doe decided to get a MPCA permit or was discovered by MPCA staff under the current program, he would receive an interim B permit. This permit would require him to develop a plan to fix his existing problem within 10 months. After plans were submitted he would be issued an interim A permit which would give him another 10 months to install the corrective system. This would give him a grand total of 20 months to install corrective measures. If the proposed rules were adopted, John Doe would have more time to correct his system. He would have until October 1, 2003 to install inexpensive corrective measures to reduce runoff by approximately 50%, and he would have another 6 years to install final corrective measures to reduce pollution completely. Therefore the new rules would result in a costs savings for John Doe because he has a much longer time in which to come into compliance.
7020.2005	Location Restrictions and Expansion Limitations	<u>Livestock Owners and Operators</u> Current MPCA requirements do not allow construction or expansion of facilities that would impact water quality. Location or expansion of facilities in the areas restricted by the proposed language would result in impact to water quality and therefore would not be allowed under the current program. Most of the farms located within shoreland were built prior to 1974 when the shoreland ordinance went into effect. The shoreland ordinance was

Rule Part	Heading/Title	Cost Differences Between Proposed and Existing Requirements
		established to restrict construction in these environmentally sensitive areas. As a result most counties in the state have prohibited construction within these shoreland areas The rule language won't prohibit them from continuing to use these barns if they are not causing an environmental impact. It will just impact future expansion opportunities within the setback areas. Persons Concerned about Environmental Quality This proposed rule part will result in increased protection of water quality, benefiting persons concerned about environmental quality.
7020.2010	Transportation of Manure	Livestock Owners and Operators No new additional costs. This rule part is not requiring anything different than would be required under the current Minnesota Department of Transportation Rules or the Current MPCA requirements. See SONAR for this rule part for more explanation.
7020.2015	Livestock Access to Waters Restriction	Livestock Owners and Operators Subpart 1 and Subpart 2 are no different than current requirements. Pasture facilities covered by subpart 3 are not directly addressed by the existing requirements. This rule part results in additional costs for livestock owners and operators. These costs have been estimated and included in the additional costs part of the Implan modeling section of the economic impact analysis. Persons Concerned about Environmental Quality This proposed rule part will result in increased protection of water quality, benefiting persons concerned about environmental quality.
7020.2025	Animal Feedlot or Manure Storage Area Closure	Livestock Owners and Operators No new additional Costs. This rule part is not imposing any additional costs beyond those that are imposed under current requirements. The requirements of this proposed rule part are identical to current MPCA requirements.
7020.2100	Liquid Manure Storage Areas	Livestock Owners and Operators

Rule Part	Heading/Title	Cost Differences Between Proposed and Existing Requirements
		The existing requirements and the proposed rule are identical in all aspects except; 7020.2100 subp 3 item C which doesn't allow any piping to penetrate the liners, 7020.2100 subp 4 item A which requires installation of drain tile at all systems, and 7020.2100 subp 6 which requires inspection of construction of liquid manure storage areas. This rule parts result in additional costs for livestock owners and operators. These costs have been estimated and included in the additional costs part of the Implan modeling section of the economic impact analysis. Persons Concerned about Environmental Quality This proposed rule part will result in increased protection of water quality, benefiting persons concerned about environmental quality.
7020.2110	Non-Certified or Unpermitted Liquid Manure Storage Areas	Livestock Owners and Operators The existing requirements and the proposed rules are identical in all aspects except subpart 2, item b that requires the owner to have a design engineer conduct a soils investigation and submit a soils investigation report. This results in additional costs for livestock owners and operators. These costs have been estimated and included in the additional costs part of the Implan modeling section of the economic impact analysis. Persons Concerned about Environmental Quality This proposed rule part will result in increased protection of water quality, benefiting persons concerned about environmental quality.
7020.2120	Poultry Barn Floors	Livestock Owners and Operators Current requirements for poultry barn floors to be constructed to standards equivalent to the standards proposed in the new rule language. Therefore there will be no additional costs associated with the proposed rule language. The proposed rule language provides a larger number of options than what was been allowed under current requirements.
7020.2125	Manure Stockpiling	Livestock Owners and Operators A lot of the operations as they are operating now will fit

Rule Part	Heading/Title	Cost Differences Between Proposed and Existing Requirements
	Sites	under the proposed permit stockpiling requirements. The permit-stockpiling requirement may require them to construct a cement pad or establish a system that results in cost savings. However, from discussions at FMMAC meetings and owners and operators the agency has concluded that most owners in this situation will change their stockpile practices to be in compliance with the short-term stockpile requirements. Therefore owners avoid the potential cost increases associated with the proposed permanent stockpiling requirements, short-term stockpiling or other measures that may result in cost impacts. Therefore any costs associated with this rule part are insignificant due to the proposed requirements. The requirements do not require the installation of any type of barrier but rather place requirements on the management of stockpiling sites. <u>Persons Concerned about Environmental Quality</u> This proposed rule part will result in increased protection of water quality, benefiting persons concerned about environmental quality.
7020.2150	Manure Compost Sites	<u>Livestock Owners and Operators</u> Currently manure composting is regulated by 7035.2836. This proposed language does not impose any additional costs. More discussion can be found in this SONAR for this rule part. <u>Persons Concerned about Environmental Quality</u> This proposed rule part will result in increased protection of water quality, benefiting persons concerned about environmental quality.
7020.2225	Land Application of Manure	<u>Livestock Owners and Operators</u> The current rule requires a manure management plan to be included as part of the application process. The proposed rule requires a manure management plan and adds a requirement for manure testing and soil testing. This additional testing does have a cost associated with it, however, as discussed in this SONAR for this rule part the costs may be off set by the costs savings associated with more accurate commercial fertilizer applications as a result of the knowledge acquired by the testing. A

Rule Part	Heading/Title	Cost Differences Between Proposed and Existing Requirements
		commonly used manure management planning tool is the computer program entitled Manure Application Planner. This program will show the commercial fertilizer cost savings associated with accurately accounting for the nutrient content of your manure and the nutrient needs of your cropland. An example of the information this program provides has been included (Exhibit E-6). Other papers discussing the value of manure have been included (Exhibits E-7 to E-10). The MPCA feels that the costs associated with manure management planning under the proposed rules are offset by the costs realized by more accurate commercial fertilizer use. Therefore, the various agriculture sectors should not incur any additional costs and may in fact realize costs savings. <u>Persons Concerned about Environmental Quality</u> This proposed rule part will result in increased protection of water quality, benefiting persons concerned about environmental quality

B. Modeling of Economic Impact

Economic impact analyses were used to estimate the effects of proposed rules for feedlot operators. Production cost increases in Minnesota's agricultural production sectors are assumed to be the primary economic effects of proposed rule changes. Analysis indicates that total annual production cost increases could begin in 2000 at $4.2 million per year, and last until 2002. After that, annual cost increases are expected to drop to $1.2 million.

Some other findings include:

- The proposed rules will not likely have a significant effect on Minnesota's general economy;
- There may be slight declines (in the 0.1 per cent to 0.2 per cent range) in output and employment in the agricultural sectors that are directly affected by the proposed rules;
- In economic sectors that are not directly affected by the proposed rules it is likely that there will be no noticeable impact; and
- Directly affected sectors: dairy, cattle, hog and poultry production; will likely incur nearly all of the economic burden imposed by the proposed rules.

Economic impact analysis estimated the effects of proposed regulations that will apply to feedlot operators. Environmental regulations' direct economic effects generally take the form of increasing production costs. Conventional regulations require manufacturers to install and operate pollution control equipment. Fees impose direct costs on waste dischargers. Trading systems generally operate from a regulatory basis that imposes costs, which are redistributed as trading partners exchange pollution allowances. And administrative costs accompany nearly all environmental policy changes.

Cost changes are generally the first effects considered in an economic impact analysis of environmental regulations. Costs are the most obvious economic effects, especially to the communities and firms that confront new regulations. However, market activity spreads direct cost impacts beyond the point of initial contact. (Recent analyses indicate that dynamic responses to market change tend to dampen direct impacts.) When firms that produce goods or provide services incur new costs, they must find financial means to cover the new costs. Five options are generally available:

- Increase selling prices;
- Cut expenses in some other area of business activity;
- Accept reduced profits;
- Make productivity-enhancing changes that will lower production costs; or
- A combination of the first four options.

All of the financial options imply further impacts on customers, competitors, suppliers, employees or investors. Moreover, policy changes that influence government spending and taxes affect taxpayers and those who benefit from government programs.

Cost increases are not the only economic effects of environmental policy changes. Often, costs imposed on one firm mean increased sales for other firms. In the case of a regulation that requires installation of pollution control equipment, manufacturers, designers, installers, monitoring and analytical firms may all sell goods or services to regulated firms. A thorough environmental economic impact analysis takes into account all economic effects (direct and indirect, costs and increased sales) and combines them in an evaluation of the net effects expected from a change in environmental policy. However, in order to make a conservative estimate, this analysis excludes offsets due to increased sales in some sectors. The next section has a brief description of the model used to simulate environmental policy changes.

Simulation of Economic Impacts

Simulation of the economic effects related to proposed rule changes is a three-step process. First, an economic model calculates a "baseline" that describes current economic conditions. Next, variables within the model are changed to simulate the effects of the proposed rules and the model's estimates are recalculated under the changed conditions. This step yields a "simulation forecast." Finally, differences between the baseline and the simulation forecast estimate the economic impacts of the simulated changes. The graph illustrated in Exhibit E-5 shows a picture of how the analysis is made.

The graph shows differences between the simulation forecast and the baseline. The differences estimate the impact of the proposed change on employment. When the simulated effect is above the baseline value, higher employment is expected. Lower employment is expected when the simulation drops below the baseline. Comparing simulation and baseline values yields an estimate of *net* impacts.

Estimates of economic impact first cover direct effects on specific economic sectors, such as agricultural production sectors. Impact estimates broaden out to include indirect effects (caused by changes in producers' supply and demand) and induced effects (caused by changes in consumer demand) on all of the state's economic sectors.

The IMPLAN Model

This model simulates economic impacts by solving a set of equations that describe the interrelated activities of the state's economy. National data compiled by federal agencies comprise IMPLAN's statistical foundation. Input/output (I/O) tables, developed by the U.S. Commerce Department's Bureau of Economic Analysis, provide a foundation structure for the model's description of Minnesota's economy. The I/O tables describe how economic sectors relate to each other.

An economy, like a natural system, consists of identifiable groups that interact in complex and dynamic ways. Business firms, nonprofit organizations and governments produce goods and services (supply) to meet the consumption needs (demand) of people and their organizations. A firm's output can satisfy either final demand (e.g., groceries) or intermediate demand (e.g., paper stock), in which case the product is used to make new goods or provide new services.

Each economic sector in the I/O tables relates to every other sector in a way that is based on the resources (in the form of goods or services) it demands from other sectors. Likewise, each sector supplies some part of its final output to other sectors and/or to final demand. The strength of these relationships varies, depending on the specific conditions of each sector. Consider an example:

Rows in the I/O table show the units of output from one sector that provide intermediate inputs (e.g., raw materials used to manufacture goods) for itself and other sectors along with output of finished goods and services. The service sector in this table provides 10 units to agriculture, 70 units to manufacturing, 55 units to itself and 105 units to final demand. This adds up to 240 units, which is called gross output. Columns show each sector's demand for goods and services, and the "value added" produced in each sector. The service sector buys 20 units of agricultural output, 90 units of manufacturing output and 55 units of its own output. Value added is the measure of the value that economic activity within a sector has added to the inputs it buys. Notice that the value added is equal to gross output less the sum of the inputs demanded by the sector. In the example, value added for the service sector is 240 - (20+90+55) = 75.

Table 8. Hypothetical Economic Input-Output Table.

	Agriculture	Manufacturing	Services	Final Demand	Gross Output
Agriculture	60	60	20	60	200
Manufacturing	40	25	90	80	235
Services	10	70	55	105	240
Value Added	90	80	5	245	
Gross Output	200	235	240		

The example is kept simple for instructive purposes. IMPLAN's basic I/O tables have over 500 economic sectors. The value of the I/O tables for this analysis is that any change made in one sector has effects in all other sectors. This feature means that the IMPLAN model provides a comprehensive way to take indirect effects into account. The model also takes into account the relative strengths of intersectoral impacts, which depend on the extent to which some sectors rely on other sectors for productive inputs or economic demand. Thus, changes induced in one specific sector will have only slight effects on another sector that either demands little of the changed sector's output or supplies few of the changed sector's inputs. Conversely, a heavily dependent sector will be strongly affected by induced changes. A Social Accounting Matrix extends IMPLAN's I/O foundation to include the "institutions" (such as households and government) that demand final goods and services from producing firms.

Relationships in the IMPLAN model are linear. That is, changes cause impacts that are proportionate to the relative size of the change. For example, if a ten per cent change in output for one sector causes a two per cent change in overall output, then decreasing the original change to five per cent will decrease the overall impact to one per cent. The linearity assumption is made for simplicity. Economic impacts in the real world do not occur as simple linear extensions of past trends. Many factors (e.g., price changes, labor mobility, interest rates, consumers' choice, producers' choices, taxes, etc.) come into play when economic decision makers adapt to change. Capacity limits require available models to accept trade-offs. If a model is to include detailed and adaptable independent variables, its scope is usually rather broad. That is, a model with detailed economic arguments usually covers only a relatively few economic sectors. On the other hand, if a model covers a more specific range of economic sectors and regions, it usually is not as detailed in its economic arguments. Models that cover all bases are large and too expensive. In the interest of economy, time and adequate coverage of agricultural production sectors, the MPCA used the IMPLAN model for simulation analysis.

Results from the IMPLAN model are defined in terms of a set of standard economic variables. Usually, readers are interested in evaluations that cover employment and output. Other measures of economic impact are also available (e.g., value added), and will be provided only if they are called for later on.

Before looking at the results, a warning about models seems useful. Models are analogous to maps. Like maps, they have many possible purposes and uses and no one map or model is right for the entire range of uses. It is inappropriate to think of models or maps as anything but crude (but in many cases absolutely essential) abstract representations of complex territory, whose usefulness can best be judged by their ability to help solve the navigational problems faced. Models are essential for policy evaluation, but are often also misused since there is '... the tendency to use such models as a means of legitimizing rather than informing policy decisions. By cloaking a policy decision in the ostensibly neutral aura of scientific forecasting, policy-makers can deflect attention from the normative nature of that decision ...'[1]

Impacts Estimated by the Model

Current Conditions

Current IMPLAN estimates derive from 1996 statistics (the latest data available in IMPLAN) compiled by federal agencies such as the Commerce Department and the Bureau of Labor Statistics. Our analysis focuses on three features of the state's economy:

- The economic variables that usually interest everyone, economic output and employment;
- Estimated impacts on the overall state economy; and
- Estimated impacts in the agricultural production sectors that will be affected directly by the proposed rules.

Estimates of economic output and employment for the entire state and in the affected sectors are presented in Table 9.

Other economic variables and regions can be analyzed, if it turns out that reviewers want to know more about the proposed rules' economic impacts with respect to other economic variables or in regions smaller than the entire state.

[1] Costanza, Robert, "Ecological Economics: Reintegrating the Study of Humans and Nature," Ecological Applications, 6(4), 1996, pp. 978 – 990. Also cited within this paragraph are: a) Levins, R., 1966, "The Strategy of Model Building in Population Biology," American Scientist, 54:421-431, b) Robinson, J.B. 1991, "Modeling the Interactions between Human and Natural Systems," International Social Science Journal, 130:629-647, and c) Robinson, J.B. 1992, "Of Maps and Territories: the Use and Abuse of Socio-economic Modeling in Support of Decision-making," Technological Forecasting and Social Change, 42:147-164.

Table 9: Baseline Economic and Employment Values for 1996.

Summary Statistics	State Total	Dairy	Hogs	Poultry	Cattle
Economic Output (Millions of Dollars)	$263,003	$1,378	$1,171	$782	$503
Employment (Number of Jobs)	3,066,081	6,403	13,797	2,660	2,178

Estimated Costs

The Implan model has been run using the cost estimates for the proposed requirements that are expected to result in a cost increase for the Livestock Owners and Operators. As noted in the discussion of the cost differences between the existing requirements and proposed requirements, the MPCA anticipates cost savings associated with certain rule parts. Values for these cost savings have not been quantified and were excluded from the model. By excluding the cost savings, the model would be showing a conservative estimate for the amount of impact on each of the livestock sectors. The MPCA anticipates that the impact to each of the major livestock sectors would be less if cost savings were included in the modeling.

Table 10. Estimated Costs of Proposed Rule Parts on Major Livestock Sectors.

Proposed Rule Part	Estimated Costs for Dairy Sector (Dollars)	Estimated Costs for Beef Sector (Dollars)	Estimated Costs for Swine Sector (Dollars)	Estimated Costs for Poultry Sector (Dollars)
7020.0505, subp. 4, item B, in year 2000	150,000	350,000	920,000	80,000
7020.0505, subp. 4, item B in year 2001	150,000	350,000	920,000	80,000
7020.0505, subp. 4, item B in year 2002	150,000	350,000	920,000	80,000
7020.0505, subp. 4, item B in year 2003 and beyond	30,000	70,000	180,000	20,000
7070.2015, Subp. 3 in year 2000	630,000	370,000	40,000	------
7070.2015, Subp. 3 in year 2001	630,000	370,000	40,000	------

Proposed Rule Part	Estimated Costs for Dairy Sector (Dollars)	Estimated Costs for Beef Sector (Dollars)	Estimated Costs for Swine Sector (Dollars)	Estimated Costs for Poultry Sector (Dollars)
7070.2015, Subp. 3 in year 2002	630,000	370,000	40,000	------
7020.2100, Subp. 3 in year 2000 and beyond	50,000	10,000	90,000	------
7020.2100, Subp. 4 in year 2000 and beyond	10,000	--------	30,000	------
7020.2100, Subp. 6 in year 2000 and beyond	250,000	50,000	450,000	------
7020.2110, Subp. 2, item B in year 2000	700000	20000	10000	------
7020.2110, Subp. 2, item B in year 2001	700,000	20,000	10000	------
7020.2110, Subp. 2, item B in year 2002	700,000	20,000	10,000	------

Explanation of Cost Estimates

Minn. R. pt. 7020.0505, subp. 4, item B, requires an air Emissions plan, pollution prevention plan and emergency response plan to be included with the permit application for facilities greater than 1000 animal units. The MPCA is assuming it will take three years to get the existing 800 facilities over 1000 animal units issued with NPDES permits. Therefore the costs associated with preparing plans for these 800 facilities will be spread over the year 2000, 2001, and 2003. In addition, MPCA expects to issue about 200 or less new or revised permits for facilities greater than 1000 animal units annually. This costs has been added to the cost of getting the existing 800 facilities into compliance in the years 2000,2001,2002. An estimate of $1,500 dollars was used for the preparation of these plans. The annual cost of this rule part for the years 2003 and beyond is shown in the table and has been used in the IMPLAN model. The estimate of 200 facilities was projected by looking at the number of permits issued in recent years for facilities greater than 1000 animal units (Exhibit E-4). The dollar amounts for these additional costs were broken down by sector as shown in Table 10. Table 10 does not address costs for non-major animal type sectors (e.g., horses, sheep and non-traditional animal types) for which the agency assumes that there will be little or no cost.

Minn. R. pt. 7020.2015 Livestock Access to Lakes Restriction Subp. 3, Pastures. This part requires livestock operators to fence livestock out of lakes or to restrict access. The costs for fencing are dependent on the type of fencing and are expected to range from approximately $.50-$1.50 (Exhibit E-12). The costs for controlling access will be widely variable depending on which option is chosen. The options range from the low cost option of preparing a prescribed grazing plan to the expensive option of controlling access with a concrete ramp and fencing. The range is estimated to be from 50 to 5000 dollars or more depending on site conditions. The agency is using the midpoint of this range as an average cost for each of the sectors. The number of facilities impacted by this requirement is unknown. However, the MPCA database (Exhibit E-11) indicated that there are approximately 2010 facilities within 100 meters of a lake under 300 animal units in the MPCA's database. MPCA's database is estimated to contain about 40% of all facilities. Facilities under 300 animal units are expected to constitute nearly all of the facilities that are within 1000 meters of a lake. Therefore the MPCA roughly estimates that there are approximately 5000 facilities in total are located within 1000 meters of a lake. The MPCA does not know how many of these have pastures that are adjacent to lakes. To ensure that we do not neglect any additional costs associated with this rule Subpart, the MPCA is estimating that approximately 25% of these facilities will have pastures that are adjacent to lakes. This will give what the agency feels is a conservative estimate of the number of facilities that will be impacted by this rule part. The costs for getting the existing facilities into compliance has been spread out over the years 200o,2001, and 2002. The dollar amounts for these additional costs were broken down by sector as shown in Table 10.

Minn. R. pt. 7020.2100 liquid manure storage areas, subpart 3, design standards. This part results in an additional cost to avoid running lines through concrete pits and manure basins. MPCA estimates this will cost an average of $500.00 per facility to keep all pipelines outside of the storage structures. Using data for recent years (Exhibit E-4) and choosing a number higher than expected, the MPCA estimates that there will be approximately 300 or less for manure storage structures built annually. The dollar amounts for this additional cost were broken down by sector as shown in Table 10.

Minn. R. pt. 7020.2100 Liquid Manure Storage Areas subpart 4, Design Plans and Specifications. This subpart will require a drain tile to be installed at all facilities. Currently, permits issued by feedlot operators require drain tile to be installed under almost all conditions. Therefore this is expected to impact only 20 projects per year at 2000 dollars per project. The dollar amounts for this additional cost are broken down by sector and shown in Table 10.

Minn. R. pt. 7020.2100 Liquid Manure Storage Areas, Subpart 6 Inspection. The additional costs associated with requiring an inspection are estimated at $2500 per facility. This is expected to impact 300 or fewer facilities per year. The dollar amounts for this additional cost were broken down by sector as shown in Table 10.

Minn. R. pt. 7020.2110 Unpermitted or Non-Certified Liquid Manure Storage Areas, Subpart 2 item B requires a design engineer certified soils investigation. The hiring of the design engineer is an additional cost over what is currently required. This cost is estimated to be approximately $1000 per facility. There are an estimated 6000-8000 facilities with unpermitted basins. The MPCA is estimating that approximately 3000 of these facilities will elect the option of hiring a design engineer to certify soils investigations indicating whether or not their basin is adequate. This rule part has a deadline of October 1, 2003. Therefore these costs have been spread out over the years 2000,2001,2003. The costs were broken down by sector as shown in Table 10.

The annual cost estimates from 2000 to 2002 add up to a little over $4 million. Estimated costs decline after 2002 and are expected to total slightly more than $1 million until all affected facilities are upgraded to meet the proposed rule requirements. These estimated annual costs are summarized in Table 11.

Table 11. Summary of Estimated Annual Costs.

Economic Sector	Annual Costs 2000 to 2002	Annual Costs 2003 and Beyond
Dairy	$1,790,000	$340,000
Beef	$800,000	$130,000
Swine	$1,540,000	$750,000
Poultry	$80,000	$20,000
Total	$4,210,000	$1,240,000

Simulation Assumptions, Conservative Bias

Recall the discussion in the Introduction section about the financial options business firms' have when they confront the need to comply with costly regulations. Five options were mentioned:

- Increase selling prices;
- Cut expenses in some other area of business activity;
- Accept reduced profits;
- Make productivity-enhancing changes that will lower production costs; or
- Combination of the first four options.

Individual farm operators cannot influence prices, but they can manage price risk by using futures markets to guarantee a favorable price. We expect that farm operators will comply with the proposed rules by choosing the mix of financial options that best suit their financial conditions. However, available information does not support even qualified guesses about the specific choices that farm operators will make. So the simulation of economic impacts assumes that all farm operators will choose the second option – cutting other expenses in order to pay for compliance. The affect of this assumption on the IMPLAN baseline is to reduce directly the economic output of the agricultural sectors that will be affected directly by the proposed rules. Simulating the rules' impacts in this way has two advantages:

- It is simple, perhaps even simplistic. It can be easily described and easily introduced into the IMPLAN model.
- It is conservative. If there is a chance that the proposed rules may have a significant economic impact, we want to be sure that chance is recognized in the simulation analysis. Assumptions should not hide possible economic impacts. Using conservative assumptions about the proposed rules' financial effects helps to highlight potential negative impacts.

Simulation Results

When economic output in the affected sectors is reduced by the estimated annual costs of the proposed rules, small reductions in total output and employment result. Model simulations were made for two periods. Requirements that apply from 2000 to 2002 are expected to impose higher costs than the requirements that will take effect after 2002. Simulated impacts are greater during the 2000 – 2002 period because assumed cost increases are significantly greater.

Direct effects are the cost increases (simulated as output reductions) that occur when feedlot operators comply with the proposed rules. Indirect effects occur when changes in one economic sector cause changes in the sectors that either sell inputs to or buy products from the affected firms. For example, a reduction in output from feedlots will likely cause a reduction in feed grain purchases. Induced effects occur when changes in household income change final demand patterns. If farm proprietors make less profit, farm households will cut back on their purchases of goods and services.

Although the simulated reductions (during the 2000 to 2002 time period) in directly affected sectors appear small, they may not be considered insignificant. There is no standard that tells us when an economic impact should be considered significant. Consider, for discussion, a rule of thumb that relates to news coverage of economic issues. News media tend to pay attention to economic changes when they reach or exceed one tenth of a percentage point. Changes in employment, gross domestic product, prices and trade balances that exceed 0.1 per cent tend to get noticed. Smaller changes are not reported as often by news media. Changes of one per cent or greater are nearly always reported and can cause significant concern if they move in the wrong direction. So, the rule of thumb has two parts: 1) changes greater than 0.1 per cent should be noticed and discussed and 2) changes greater than one per cent should be considered significant.

Simulation results show that the proposed rules are unlikely to have a noticeable effect on the overall state economy. However, the results do show that there may be noticeable short-term impacts in the dairy, hog and cattle production sectors. These noticeable impacts do not exceed 0.2 per cent for any of the affected sectors. Estimated impacts in the affected sectors drop below 0.1 per cent after 2002. Simulation results show no significant, or even noticeable, impacts in other economic sectors.

Bear in mind the conservative assumptions built into the simulation estimates. Affected farm operators are assumed to use only one financial strategy in complying with the proposed rules. No offsets are built into the simulation to take into account increased farm purchases of equipment or services. So the scenario described in the simulation results should be considered as an unlikely, perhaps a "worst case," possibility. When the time comes for farm operators to comply with the proposed rules, they will likely use every opportunity to reduce the costs of compliance. In a very real and practical sense, the financial impact of the proposed rules depends significantly on farm operators and the decisions they make about the timing and efficiency of new expenditures. They will probably make use of all their financial options. Farm operators also will probably schedule facility modifications so that costs are incurred when economic conditions are more favorable than they are now.

Table 12. Simulated Economic and Employment Impacts, Years 2000 to 2002.

	State Total	Dairy	Hogs	Poultry	Cattle
Decreased Economic Output (Thousands of Dollars)					
Direct Effects	$4,210	$1,790	$1,540	$80	$800
Indirect Effects	$2,446	$11	$398	$2	$120
Induced Effects	$1,333	$3	$3	$5	$3
Total Effects	$7,989	$1,804	$1,941	$88	$924
Percent of Total Output	0.00%	0.13%	0.17%	0.01%	0.18%
Decreased Employment (Percent) [1]					
Direct Effects	28.0	8.0	17.0	0.0	3.0
Indirect Effects	23.0	0.0	4.0	0.0	1.0
Induced Effects	18.0	0.0	0.0	0.0	0.0
Total Effects	69.0	8.0	21.0	0.0	4.0
Percent of Total Employment	0.00%	0.12%	0.15%	0.00%	0.18%

[1]Percentages are based on totals in Table 9.

Market Conditions

Recall the short discussion about mathematical models that ended the Introduction in Section A. Models should be used when they are needed, but their results usually should not be taken as final answers to detailed questions. The IMPLAN simulation results are needed to provide a general context for evaluation of the economic impacts that may result when a few sectors incur regulatory compliance costs. However, the model cannot give us a completely accurate picture of likely future economic impacts because the model relies on limited data. IMPLAN's estimates are based on 1996 data. None of the economic changes that have occurred since 1996 are taken into account in IMPLAN.

Table 13. Simulated Economic and Employment Impacts, Years 2003 and Beyond.

	State Total	Dairy	Hogs	Poultry	Cattle
Decreased Economic Output (Thousands of Dollars)					
Direct Effects	$1,240	$340	$750	$20	$130
Indirect Effects	$804	$4	$194	$0	$19
Induced Effects	$368	$1	$1	$1	$1
Total Effects	$2,412	$345	$945	$21	$150
Percent of Total Output	0.00%	0.03%	0.08%	0.00%	0.03%
Decreased Employment (Percent) [1]					
Direct Effects	10.0	2.0	8.0	0.0	1.0
Indirect Effects	8.0	0.0	2.0	0.0	0.0
Induced Effects	5.0	0.0	0.0	0.0	0.0
Total Effects	23.0	2.0	10.0	0.0	1.0
Percent of Total Employment	0.00%	0.03%	0.07%	0.00%	0.05%

[1]Percentages are based on totals in Table 9.

Agriculture is undergoing structural changes, both in Minnesota and throughout the United States. "Structural change" means that the numbers, sizes and types of firms in an economic sector are changing more rapidly than is usual. It is important to remember that nearly all economic systems are dynamic. Business firm numbers and sizes change constantly. Some firms grow, even during recessions, and some firms decline, even during economic expansions. The feature to note about current conditions in the agricultural economy is that the pace of structural change has increased in recent years.

Changes in our regional and national farm economies now have the attention of hundreds of researchers, business firms and government agencies. This short review of agricultural market conditions covers material compiled by:

- A literature review prepared for the Environmental Quality Board's generic environmental impact statement (GEIS) on animal agriculture;
- A January 1999 program evaluation report on the MPCA's feedlot programs – the report was prepared by the Office of the Legislative Auditor;
- The US Department of Agriculture's Economic Research Service;
- The Minnesota State Colleges and Universities' Farm Business Management program and its regional farm business management associations;
- Reports from the University of Minnesota's Applied Economics department; and
- Reports from the Kansas City Federal Reserve Bank's Center for the Study of Rural America.

Readers, who want to study agricultural market conditions in more detail may find these sources useful, particularly the literature reviews for the GEIS.

Popular media report that up to eight per cent of Minnesota farms may go out of business within the next year (St. Paul Pioneer Press, October 24, 1999). Researchers, policy makers and business representatives suggest a variety of factors as the reasons for change in agricultural sectors:

- Low prices for agricultural commodities;
- Technological change;
- Foreign competition;
- Low foreign demand for American agricultural commodities;
- Federal and state agricultural policy;
- Federal trade policy;
- Monopolistic practices; and
- Vertical integration (manufacturers' control of input suppliers or output buyers) of food processing firms.

There is considerable dispute about which factors have the greatest impact. Debaters sometimes disagree on whether influences are positive or negative (e.g., the effects of technological change). Some researchers have taken a closer look at economic effects caused by factors comparable to the subject of specific concern in this SONAR: environmental regulations. The Environmental Quality Board's GEIS literature review cites studies that have tested to find out how agricultural production markets respond to environmental regulations.

One set of studies, cited in the GEIS literature review, compared growth in hog inventories in thirteen states from 1988 to 1995.[2] Differences in states' environmental regulations were among the independent factors included in the tests. Findings were mixed – some regulatory factors or indexes were related to growth, but other regulatory factors were not related to growth.

Another study cited in the GEIS literature review (p. D/E-58) compiled hog industry statistics from a number of sources and commented on noticeable relationships.[3] The study concluded that environmental regulations influence facility location decisions. No empirical tests were included in this study.

An empirical study of dairy farm budgets, cited in the GEIS literature review, found that the size of a dairy operation affected a firm's ability to comply with federal environmental regulations:

Moderate size dairies were found to be affected more adversely by being required to meet the specified Region VI EPA regulations than large size dairies. Dairies that were already in financial trouble could be put out of business by requirements to conform with the Region VI EPA standards. Many of these dairies, however, could go out of business regardless of the EPA requirements, albeit at a later date.

Large scale dairies that were not already in financial trouble appear to be able to amortize the extra capital investment costs associated with meeting the Region VI EPA requirements. This suggests that moderate size dairies faced with needing to make investments to meet the EPA standards may choose to expand the scope of their operations, if financially able. While such expansion would require an even larger investment, it also would hold the potential for making the dairy more efficient and competitive.

The GEIS literature review concluded:

> We could find few published empirical analyses of the cost of livestock operations' compliance with environmental regulations. One reason for the dearth of work on this area may be that the regulations are evolving so rapidly and vary so much across localities and farm types. It is difficult to arrive at a small number of representative farm situations

[2] Mo, Y, Abdalla CW, 1988. "Analysis of Swine Industry Expansion in the US: The Effect of Environmental Regulation," Staff Paper 316. Department of Agricultural Economics and Rural Sociology, Pennsylvania State University.
and
Mo, Y, Abdalla CW, 1988. "Analysis Finds Swine Expansion Driven Most by Economic Factors," Feedstuffs: 20
both studies cited in the Environmental Quality Board's GEIS literature review, p. DE-57.
[3] Drabenstott, M, 1998. "This Little Piggy Went to Market: Will the New Pork Industry Call the Heartland Home?" Economic Review of the Federal Reserve Bank of Kansas City. cited in the Environmental Quality Board's GEIS literature review, p. DE-57.

> that can be analyzed to provide results that are able to generalize the range of farm situations that are out there, and that will stay relevant into the future. (p. D/E-59).

Findings reported in the Environmental Quality Board's GEIS literature review tend to agree with the results of the IMPLAN model simulation. Environmental regulations may, under some conditions, have a significant impact on livestock operations. But empirical studies do not provide strong support for estimates of the extent of any economic impacts. Factors besides environmental regulations are proving to be more influential in determining the scope and pace of economic change in the agricultural sectors of the economy.

Conclusion of Modeling and Literature Analysis of Economic Impacts

Implementing the proposed feedlot rules will probably not have a significant impact on Minnesota's general economy. This conclusion is supported by simulation analysis that is based on a regional economic model and by a review of expert opinion in the GEIS literature review.

Other conclusions are less definite. Findings based on the simulation model show that economic impacts could be significant in some agricultural sectors, if farm operators cannot or do not take advantage of cost-minimizing financial options. Simulation analysis also indicates that some agricultural sectors will likely incur noticeable economic impacts (i.e., a change in output or employment greater than 0.1 per cent), but the specific extent of these impacts is indeterminate because they depend on the timing and direction of market developments. That is, farm operators are expected to wait for favorable economic conditions before they take steps to comply with the proposed rules. Farmers' financing choices are unpredictable now, but they will have a significant effect on the costs incurred and the economic impacts that result.

A survey of expert opinion, compiled in the GEIS literature review, indicates that structural changes are underway which will likely cause continued decrease in the number of livestock farms. General market forces are the strongest current influences on the structure of agricultural sectors. Empirical evidence is mixed with respect to the effects of environmental regulations on agricultural market structure.

The proposed rules will impose costs on some farm operators and the burden may prove too large for some operators to bear. However, the likeliest scenario will show slight declines in output and employment in directly affected sectors, without significant losses in agricultural or other sectors. This conclusion is based on: a) interpretation of a simulation introduced into an economic model and b) a review of relevant parts of the GEIS literature review.

C. Comparison of Costs: Current Versus Proposed Requirements

A scenario illustrating the costs of the current requirements as compared to the cost of the proposed requirements has been included below. Additional scenarios are included as an Exhibit (E-2). The scenarios are based on situations similar to what MPCA staff have experienced when conducting field inspections, but are fictional. When calculating costs for activities that require facility owner labor, the hourly rate of $8 is used. MPCA staff understand that hourly rates realized by individual facility owners vary greatly. However, a value was needed to represent costs incurred when the rules require facility owners to complete an activity. The $8 hourly rate was determined by using the net farm income of $15,754 from 1998 as reported in the 1999 Minnesota Agricultural Statistics, page 15 (Exhibit E-3). The net income was used instead of the gross farm income because farm owners pay many farm expenses, such as labor, from the gross receipts and therefore the gross income would be inflated compared to the actually hourly rate realized by the facility includes both crop and livestock facilities. This also influences the annual net income value. However, most livestock facilities also have crop production.

Scenario 1: John Deere currently owns a 125 head dairy facility (175 animal units) that is located outside of any restricted areas according to rule part 7020.2005, as proposed. John's facility has an open lot with a runoff problem and an earthen basin. John owns 500 acres of cropland on which he land applies manure produced from the dairy facility. John has never received a permit or certificate of compliance for his operation from the MPCA or delegated county.

Table 14: Economic Impact Scenario Number 1: 125 Head (175 Animal Unit) Dairy Facility.

Issue	**Runoff Problem to Surface Water**	**Unpermitted Earthen Basin**
Current Rule Parts	Potential pollution hazard, part 7020.0300, subp. 20.	Unpermitted manure storage basin and reconstruction required. Rule violation; part 7020.0400, subp. 1, prohibits construction of manure storage area without a permit or certificate of compliance.
Proposed Rule Parts	Pollution hazard, part 7020.0300, subp. 19a, extension for compliance with water quality standards, part 7020.2003, subp. 4.	Part 7020.2110, subp. 3.
Current Require-ments	Apply for an interim permit. Permit will require submittal of plans for corrective measures, once plans are submitted then an Interim A permit is issued. Permit requires installation of corrective measures within 10 months.	Potential pollution hazard because will allow seepage into groundwater. Interim permit and fix within 10 month required.

Issue	Runoff Problem to Surface Water	Unpermitted Earthen Basin
Costs for Current Require-ments	6 hours @ $8 = $48 + *$5 for county copies + $3,000 installation of corrective measures = $3,053 2 hours to complete permit application form. Soil conditions (review soil survey manual) Hydrogeologic conditions (only required for earthen basin installation) Map or aerial photos (*copy from County office) 2 hours to prepare manure management plan (assistance available from MN Extension Service or possibly county office) 2 hours to prepare plans for roof gutters and diversions as corrective measures. $3,000 to installation of roof gutters (130 feet gutters @ $20 per foot = $2,400) and diversions (300 feet @ $2 per foot = $600) for corrective measures.	No additional costs to acquire interim permit because unpermitted basin would be included in interim permit for runoff problems. $38,000 Replace existing manure storage area (cost for Soil lined storage pond 176 animal units constructed in 1995 from page 2 of Exhibit E-1.)
Proposed Require-ments	Apply for an interim permit. Submit plans for corrective measures. Permit requires installation of corrective measures within 24 months. Submit a certification accepting the 2003/2009 deadlines for correcting his open lot runoff problem and complies with these deadlines Follows technical standards such as developing manure management plan and retain it on site. Perform manure and soil testing in accordance with manure management requirements	Comply with the unpermitted basin requirements by 2003

Issue	Runoff Problem to Surface Water	Unpermitted Earthen Basin
Costs for Proposed Require-ments	2.5 hours @ $8 + $3,000 installation of corrective measures = $3,037 0.5 hour to complete facility registration form and certification form. 2 hours to prepare plans for roof gutters and diversions as corrective measures. $3,000 to installation of roof gutters and diversions.	$38,000 Replace existing manure storage area (Cost for Soil lined storage pond 176 animal units constructed in 1995 from page 2 of Exhibit E-1.) $1,000 cost for soil investigation conducted by design engineer
Estimated Cost Difference from Current Rules and Proposed Rules	Slight cost savings in owner time because a permit application is not required. In addition, the owner has nearly 3 years to plan the most beneficial financing for the $3,000 corrective measure cost. The current rule requires measures for planning corrective measures to begin immediately. Part 7020.2003, subp. 4, as proposed, requires the corrective measure to be made by October 1, 2003. Costs for preparing manure management plan are delayed until October 1, 2005.	$1000 cost increase due to proposed rules requiring a soil investigation conducted by a design engineer

D. Estimated Cost to Correct Pollution Problems at all Existing Facilities not yet in Compliance

As discussed in the Statement of Need, many existing animal feedlots in Minnesota are not yet in compliance with the water pollution effluent limits for animal feedlots set forth in Part 7050.0215. These limitations are based on the Minn. stat. sec. 115.01, subd. 13, pollution of waters, and Minn. stat. sec. 116.06, subd. 14, land pollution. The proposed rules do not change these standards or the applicability of these standards. The proposed rules delay for some facilities the date on which compliance with these standards must be demonstrated. For these reasons, the proposed rules either reduce or have no impact on the cost of complying with the effluent limitations currently in Minnesota Rules. For reasons of completeness and transparency, this portion of this Statement of Need and Reasonableness will discuss the estimated cost to bring all animal feedlots into compliance with the effluent limitations in Minnesota Rules.

Based on staff experience and the fact that until recently the vast majority of livestock facilities had fewer than 300 animal units, the agency believes that the majority of the facilities that remain out-of-compliance with the effluent limitations have fewer than 300 animal units. Staff experience indicates that as many as 20 to 40 percent of the facilities (8,000 to 12,000) with fewer than 300 animal units could have open lots and runoff from these lots in excess of the effluent limitations in part 7050.0215. The estimated cost to bring all animal feedlots in Minnesota into compliance with the effluent limitations is therefore based on the assumption that the vast majority of this cost is the cost to bring those facilities with fewer than 300 animal units with open lot runoff into compliance.

It is very difficult to estimate the economic cost to bring all of the livestock facilities that are currently not in compliance with the effluent limitations into compliance. The data available from which to estimate projected costs is limited. These estimates were derived using the best available data and supplementing professional judgments wherever data is lacking. All values were derived using estimates that were based on what MPCA staff believe are "worst case" scenarios.

To estimate the costs that are likely to be incurred by Minnesota livestock owners or operators to come into compliance with the effluent limitations, the analysis was conducted by dividing the industry into sectors. A summary of these estimated cost is provided in Table 15.

Cattle and Calve Facilities

The 1997 census of Agriculture (Exhibit E-3) estimates that Minnesota has approximately 30,913 farms in Minnesota that have cattle and calves as a component of their operations. The census states that there are approximately 15,745 beef cow operations and 9,603 milking cow operations. Therefore, of the 30,913 farms with cattle and calves, there are an estimated 5,565 facilities where we are unable to determine if they are included in the dairy sector or beef sector. Assuming that the 5,565 are of the same distribution as the 25,348 that are accounted for, 3,457 are beef cow operations and 2,108 are milking cow operations. Therefore, there are an estimated 19,202 beef and 11,711 milking cow operations in Minnesota.

Dairy Sector

The MPCA database indicates that approximately 96% (11,243) of dairy facilities in Minnesota have fewer than 300 animal units. Assuming that 20 to 40 percent of these facilities are not yet in compliance with the effluent limitations, 2,249 to 4,497 dairy facilities have runoff problems that will require capital expenditures to correct existing problems.

A summary of the past 5 years of Natural Resource Conservation service projects at dairy facilities gives and estimated average cost per dairy farm needing fixing at $36,000 (Exhibit E-1). Assuming that this is the cost bring each of the facilities into compliance with the effluent limitations as required by both current and proposed rules, the estimated cost to bring the dairy sector into compliance with the effluent limitations is $81 to $161.9 million.

Beef Sector

The 1997 census of agriculture estimates that there are approximately 19,202 beef cattle operations in the state of Minnesota. Of these 19,202 sites, MPCA data estimates that 90% (17,282) of these have fewer than 300 animal units. Assuming that 20 to 40 percent of these facilities are not yet in compliance with the effluent limitations, 3,457 to 6,913 beef facilities have runoff problems that will require capital expenditures to correct existing problems.

A summary of the past 5 years of Natural Resource Conservation service projects at dairy facilities gives and estimated average cost per beef farm needing fixing at $19,000 (Exhibit E-1). Assuming that this is the cost bring each of the facilities into compliance with the effluent limitations as required by both current and proposed rules, the estimated cost to bring the beef sector into compliance with the effluent limitations is $65.7 to $131.3 million.

Swine Sector

The 1997 Census of agriculture estimates that Minnesota has 7,512 hog and pig farms. Review of the MPCA database indicates that approximately 12% of hog facilities have open lots without runoff controls. Assuming that 12 percent of these facilities are not yet in compliance with the effluent limitations, 901 swine facilities have runoff problems that will require capital expenditures to correct existing problems.

A summary of the past 5 years of Natural Resource Conservation service projects at swine facilities gives and estimated average cost per swine facility at $43,000 (Exhibit E-1). Assuming that this is the cost bring each of an estimated 901 facilities into compliance with the effluent limitations as required by both current and proposed rules, the estimated cost to bring the swine sector into compliance with the effluent limitations is $38.8 million.

Table 15. Summary of Cost Estimates for Correcting Problems at all Existing Facilities not yet in Compliance.

Economic Sector	Number of Existing Facilities[1]	Number of Existing Facilities Potentially Impacted	Total Estimated Cost of Compliance (Millions of Dollars)
Diary	11,711	2,250 to 4,500	81 to 162
Beef	19,202	3,450 to 6,900	66 to 131
Swine	7,512	900	39
Poultry	3,189	Insignificant	Insignificant
Total	41,614	6,600 to 12,300	186 to 332

[1]According to the 1997 Censuses of Agriculture

Poultry Sector

Most modern poultry facilities are total confinement and therefore are not likely to have runoff problems that will require capital expenditures to correct existing problems. Therefore we are assuming there will be little or no cost for this sector for runoff from existing facilities.

Other Sectors

The agency estimates that the number of facilities in other sectors (e.g., horses, sheep and non-traditional animal types) needing corrective measures is insignificant relative to the numbers of facilities in the major livestock sectors. Therefore, the agency has not estimated the costs to correct problems at these existing facilities.

Summary of Cost to Comply with Current Effluent Limitations

The proposed rules do not increase the cost of complying with the effluent limitation. The effective implementation of the program plan with an increase in field presence will result in more facilities incurring cost to come into compliance with the current effluent limits. As stated in the Reasonableness as a Whole section of this document, a major goal of the proposed rules is to minimize the impact of these expenditures by allowing owners of the largest group of noncompliant facilities (fewer than 300 animal units with runoff from an open lot) to come into compliance over the next nine years.

The proposed rules require all animal feedlots and manure storage areas to be included in a county's Level 2 inventory that has been submitted to the agency or register with the agency. The information gathered by the agency will allow the agency to determine a better estimate of the total cost of complying with the effluent limitation.

VI. ADDITIONAL NOTICE

The formal rule revision process began in early 1995. The first notice of solicitation for public comment was published in June of 1995. Three subsequent notices of solicitation were published; the final one in August of 1998. Beginning in December of 1995, MPCA rule revision staff began meeting regularly with the chief advisory committees as well as other major interest groups. Of the groups, Feedlot and Manure Management Advisory Committee (FMMAC), has been the main advisory group. Drafts of revised rules have been presented for discussion in, at least, eight FMMAC meetings in the past three years. Delegated counties' feedlots officers (CFOs) an advisory group that also met frequently. Regional meeting of the CFOs are convened quarterly and rule revision drafts were generally an agenda item at these meetings.

Subcommittees were formed to draft concepts and language for particular areas of the feedlot rules. Subcommittees consisted of a balance of producer, regulatory and environmental interests. Subcommittees that were set up included land application, stockpiling and manure storage committees. In addition, MPCA staff either presented or disseminated draft rule information at major governmental and trade association meetings around the state, including the Association of Minnesota Counties, Association of Minnesota Townships, and the County Attorney Association. Finally, staff met upon request. Among these groups were the Pork Producers Association, the Association of Turkey Growers, the Minnesota Center for Environmental Advocacy, the Dairymen Association, Clean Water Action, and Minnesota Cattlemen

Association. The agency published a rule update four times during the rule-revision period, which was mailed to over 4,500 individuals on an interested party mailing list.

In addition to the efforts made above, the agency has completed addition efforts to involve groups and individuals into the process. These efforts are summarized below.

A. Request for Comments

Four "Request for Comments" periods were conducted during the feedlot rule revision effort. Three of these formal comment periods were conducted in 1995 and one was done in 1998. The agency received approximately 200 comments during the four formal comment periods. Many additional comments on the rules were received by the agency outside of the official comment periods. Agency staff has reviewed these comments and they are maintained on file;

B. Public Informational Meetings

The agency accomplished rule-revision communication, education and outreach by making presentations to a wide-range of interest groups. These meetings began in 1995 and have continued through the rule revision process. See Exhibit O-1. The agency both sponsored meetings and responded to requests for presentations. These meetings were held with livestock producers, producer associations, environmental organizations, county feedlot officers, professional associations, industry consultants, state and federal agencies, and local, state and federal regulators. On many occasions staff met, when requested, with key representatives of potentially affected interests. The agency continues its public information efforts relative to these rules. In November 1999, the agency held eight meetings around the state on the most up-to-date rule draft. The meetings were well attended by all interested parties listed above. The meeting started with a short summary of the rules with one-on-one sessions between staff and interested individuals. See Exhibit O-1.

C. Rule Revision Updates

Staff created a mailing list by selecting organizations determined to have the greatest stake in the rule revision process. Chief constituencies included legislative officials, county regulators, producer groups and environmental organizations. See Exhibit O-2. Additional parties were added to the mailing lists as a result of submitting comments or by request. Four rule updates were prepared and sent to interested parties during the rule revision process. See Exhibit O-3. The updates discussed concepts important to the rule revision, as well as specific rule proposals. The updates were sent to all parties identified on the mailing lists.

D. Feedlot and Manure Management Advisory Committee (FMMAC)

The state feedlot advisory committee known as FMMAC and established by statute was very involved in the rule amendment process. There were particularly involved from May to October 1999 in working towards the final proposed rule. See Exhibit O-4. This included a land application taskforce, a manure storage construction taskforce, a stockpiling taskforce, and a county delegation taskforce.

VII. IMPACT ON FARMING OPERATIONS

Minn. Stat. § 14.111 (1995) requires an agency to provide a copy of the proposed rule changes to the commissioner of agriculture no later than 30 days prior to publication of the proposed rule in the State Register. A copy of the proposed rule was sent to Commissioner Hugoson on November 19, 1999, with a cover letter explaining this rulemaking in light of agricultural operations. See Exhibit G-5. In addition, the agency sent a copy of the proposed rule to Carol Milligan, Department of Agriculture contact for other state agency rule review, on November 19, 1999, to allow her the opportunity to review the documents and make a determination of the rule's impact on farming operations.

In drafting this rule, MPCA worked closely with the Department of Agriculture management and staff. Department of Agriculture has staff on FMMAC and they attended all FMMAC meetings over the past four years that were held on the proposed rule. In addition, Department of Agriculture staff met frequently with the MPCA rule team and management on various rule topics and issues over the past four years, and the suggestions they provided helped shape the final proposed rule.

Overall, the proposed rule will have a significant impact on the livestock and poultry industry in Minnesota. Minnesota is among the top five states in turkey, hog and milk production and the livestock industry totals over $4 billion in cash receipts. The MPCA is the principal agency responsible for regulating the feedlots that contain the turkeys, hogs and livestock in Minnesota, and at last estimate, there were 45,000 farms with feedlots. Thus, the proposed feedlot rules, with their main purpose being to protect Minnesota citizens and Minnesota's lakes, streams, wetlands and/or drinking water sources from the pollution caused by animal manure, will have extensive and wide-ranging agricultural impacts.

VIII. COMMISSIONER OF FINANCE REVIEW OF CHARGES

As required by Minn. Stat. § 16A.1285, the Commissioner of Finance has reviewed the charges proposed in this rule. The Commissioner of Finance's comments and recommendations are attached. See Exhibit F-4.

The agency is proposing under Minn. R. pt. 7002.0270, item F, to clarify that annual fees will only be charged for NPDES permits and SDS permits that regulate animal feedlots and manure storage areas with 1,000 or more animal unit capacity. The proposed rule changes will not establish a new fee rate or increase existing fee rates and will not have a revenue impact. The agency requested the Commissioner of Finance to review the proposed rules in accordance with Minn. stat. § 16A.1285. See Exhibit F-4 for the Commissioner of Finance's response.

Fee rule changes are being proposed as part of the agency's effort to re-design the regulatory program for animal feedlots, manure storage areas and pastures.

The agency is proposing to add item F under Minn. R. pt. 7002.0270 to clarify permit fees as they correspond to the proposed re-structured permit requirements. The agency is proposing no fee changes for National Pollutant Discharge Elimination System (NPDES) and Interim permits. The re-design of the permit system will establish a new permit tool, the Construction Short-form permit and the agency is proposing no fees for this permit. Lastly, the agency proposes to clarify how the fees already established under Minn. R. pt. 7002.0310 for State Disposal System (SDS) permits will be applied under the proposed permit system.

The agency proposes to require some facility owners to have SDS permits. The SDS permit is an agency permit tool established under Minn. R. ch. 7001. However, this permit is not currently required under Minn. R. ch. 7020 and has been rarely used to regulate feedlot and manure storage facilities. Now that the SDS permit will be part of the permit requirements under Minn. R. ch. 7020, the agency believes it to be reasonable to clarify how the existing fees for these permits will be charged for SDS permits that regulate animal feedlots, manure storage areas and pastures. The fees are currently charged for SDS permits that regulate other water quality issues.

The agency is proposing that fees be charged for permits that regulate facilities with 1,000 or more animal units because they will be regulated under an operating permit. An operating permit is required for the life of the facility compared to permits issued for a short term that address construction projects or site specific problems. The agency anticipates that most, if not all, of these facilities will be required to have an NPDES permit and therefore, be required to pay fees as required under the current program. However, if a facility with 1,000 or more animal units is determined not to meet the federal requirement to have an NPDES permit, the agency proposes to require an SDS operating permit and charge the same fee that is currently being charged for the NPDES permit. The agency anticipates that it will be the rare exception to issue a facility in the 1,000 or more animal unit category an SDS permit instead of an NPDES permit. However, the fee for the SDS permit is needed to treat the facilities within this animal unit category the same and to prevent creating an administrative problem for the program. The agency believes it is reasonable to require similar fees because the review and administrative efforts are equivalent between an NPDES permit and an SDS permit.

NPDES permits issued to regulate animal feedlots and manure storage areas are currently charged the application and annual fees under Minn. R. pt. 7002.0310, subp. 2, item B, under the category "Other Non-municipal (any flow)" ($85 application fee and $1,230 annual fee) and subp. 3, under the category "general" ($85 application fee and $260 annual fee). Subpart 2, "Nonmajor NPDES and state disposal permit fees," is used to calculate fees for these permits because the regulated facilities do not meet the definition of "major NPDES facility" under Minn. R. pt. 7002.0220, subp. 4. Item B, "Nonmunicipal permits" is used to calculate these fees because the regulated facilities do not meet the definition of "municipality," which is addressed under item A. The "Other Non-municipal " category is used because the regulated facilities do not discharge sewage, which is the only other fee type in this permit fee category. Subpart 2 establishes fees for permits tailored to address an individual facility and subpart 3 establishes fees for general permits, which are designed to meet the regulatory needs of a group of facilities with similar environmental concerns.

As established in the part heading, "Nonmajor NPDES and state disposal permit fees," Minn. R. pt. 7002.0310, subp. 2, establishes fees for SDS permits. Therefore, the agency proposes to charge the fees under subpart 2, item B, and subpart 3 to the SDS operating permits for facilities with 1,000 or more animal units as it currently does for the NPDES permits in this animal unit category. Since applying existing fees in a new way may be considered a "new fee," the agency proposes to require to begin charging fees for the 1,000 or more animal unit SDS permits after July 2, 2001 to comply with 1999 Minnesota Session Laws chapter 231, sec. 2, subd. 2, and plans to follow the Legislative approval process required for rules developed by the agency under Minn. Stat. § 14.18, subd. 2, to comply with the approval requirement under 1999 Minnesota Session Laws chapter 250, article I, sec. 49.

The agency is proposing to require SDS permits for some facilities with less than 1,000 or more animal units. Most of these facilities will be issued an SDS permit for construction or the correction of a pollution hazard and not be issued an operating permit. Since SDS permits for facilities with less than 1,000 animal units are more similar in scope and duration to the Interim and Construction Short-form permits, the agency is proposing not to charge fees for these permits. Again, it is reasonable that the fee reflect the level of administrative effort expended to issue the permit.

There are approximately 40,000 animal feedlots, manure storage areas, and pastures in Minnesota. This number is an estimate because Minnesota does not currently have a comprehensive inventory of these facilities. The agency anticipates that less then two percent of this total will be assessed state permit fees under the draft rule amendments. However, most, if not all, of these fees would already be required under the existing feedlot regulatory program. For the purpose of discussing fees, the agency estimates that animal feedlot, manure storage area and pasture facilities are distributed as presented in Table 16.

Table 16. Estimated Number of Existing Facilities Subject to Permit Fees.

Category of facility in animal units	**Estimated number of facilities in category**	[1]**Estimated number required to have an NPDES permit under the current program**	[1]**Additional number required to pay fees under the proposed rules**
0 to 299	32,000	0	0
300 to 999	7,200	40	0
1,000 or more	800	800	0 now [2]

[1] The number of estimated permits represented in columns 3 and 4 are anticipated to be processed and issued over a six year period.
[2] EPA determination finds no NPDES permit required then number added to this column, but subtracted from 3rd column.

IX. NOTIFICATION TO THE COMMISSIONER OF TRANSPORTATION

Minn. Stat. § 174.05 requires the MPCA to notify the Commissioner of Transportation of rulemakings that concern transportation related issues. The Commissioner of Finance's has been notified of these proposed rules by the agency. See Exhibit F-4.

X. LIST OF WITNESSES AND EXHIBITS

A. Witnesses

In support of the need for and reasonableness of the proposed rules, the MPCA anticipates having the witnesses listed below testify at the rulemaking hearings. Along with the names of the individuals who are available to testify are the principal topics on which they would testify.

Ronald Leaf, P.E.: The proposed amendments in general, history of the feedlot program, the permitting program and various technical standards.

David Wall: Land application of manure and karst-related technical standards.

Christopher Lucke, P.E.: Various technical standards and consideration of economic factors.

Robert McCarron: Consideration of economic factors.

Don Hauge: History of this rulemaking effort, the registration program and the delegated county programs.

Mike Mondloch: The proposed amendments in general, the permitting program.

Deborah Olson: Permit fees and rulemaking processes.

Myrna Halbach, P.E.: Feedlot Program Plan, the agency's efforts in the delegated county program and composting technical standard.

Gary Pulford: Feedlot program coordination with other state agencies and the process and outcomes of agency's work with the Feedlot and Manure Management Advisory Committee.

Roberta Wirth: Composting and manure stockpiling technical standards.

B. Exhibits

In support of the need for and reasonableness of the proposed rules, the MPCA anticipates that it will place the following Exhibits into the hearing record:

KEY:

A = Need as a Whole
B = Poultry Barn Floors
C = County Program
E = Economics
F = Permit Fees
G = General Information
I = Registration Program
L = Land Application
M = Liquid Manure Storage
O = Outreach
P = Permit Program
S = Stockpiling
T = Technical Standards (misc.)

Exhibit Number	Title
A-1	Generic Environmental Impact Statement on Animal Agriculture: A Summary of the Literature Related to the Effects of Animal Agriculture on Water Resources (G). Mulla, David J. et. al. Prepared for the Environmental Quality Board, September 1999.
A-2	Nitrate in Ground Water - Existing Conditions and Trends, excerpt from Nitrogen In Minnesota Ground Water, pages B-1 to B-70. Prepared by the Legislative Water Commission, December 1991.
A-3	Phosphorus Export Coefficients: and the Reckhow-Simpson Spreadsheet: Use and Application in Routine Assessments of Minnesota Lakes, A Working Paper, Steven Heiskary and Bruce Wilson, Minnesota Pollution Control Agency, November 1994.
A-4	Lake Shaokatan Restoration Project: Final Report, prepared by David J. Schuler, Environmental Engineer for the Yellow Medicine River Watershed District. Received by MPCA on August 20, 1996.
A-5	Surface Water Nitrogen, excerpt from Nitrogen In Minnesota Ground Water, pages E-1 to E-10. Prepared by the Legislative Water Commission, December 1991.
A-6	Potential Health and Environmental Effects of Nitrogen Contaminated Ground Water, excerpt from Nitrogen In Minnesota Ground Water, pages A-6 to A-15. Prepared by the Legislative Water Commission, December 1991.
A-7	Gulf of Mexico Hypoxia Assessment Plan, prepared by Committee on Environment and Natural Resources Hypoxia Work Group, March 1998.
A-8	Cropland: Contributions to Ground Water Nitrogen and Best Management Practices to Reduce Nitrogen Contamination, Chapter G from Nitrogen In Minnesota Ground Water, pages G-1 to G-63. Prepared by the Legislative Water Commission, December 1991.
A-9	Nitrate Concentrations Leaching Below Row-Crops In Minnesota - A Review, prepared by Dave Wall, Minnesota Pollution Control Agency, May 7, 1996, draft.
A-10	Report On Noncommercial Manure Applicator Training and Certification to the 1999 Minnesota Legislature, prepared by the Minnesota Department of Agriculture, Agronomy and Plant Protection Division, January 1999.

Exhibit Number	Title
A-11	Seepage From Earthen Manure Storage Systems, Minnesota Pollution Control Agency fact sheet, July 1997.
A-12	Generic Environmental Impact Statement on Animal Agriculture: A Summary of the Literature Related to Air Quality and Odor (H). Jacobson, Larry D. et. al. Prepared for the Environmental Quality Board, September 1999.
A-13	Code of Federal Regulations, Title 40, Part 412.
A-14	Code of Federal Regulations, Title 40, Section 122.23.
A-15	EPA, FRL-5817-3, Region 10, Notice of Final General Permit for Concentrated Animal Feeding Operations, Comment #1.
A-16	Minnesota Agricultural Statistics, State Rankings: Minnesota's Rank Among States, Michael Hunt, George Howse, Minnesota Agricultural Statistics Service, 1998.
A-17	Minnesota's Nonpoint Source Management Program, Assessment Chapter, Minnesota Pollution Control Agency, 1994.
A-18	Generic Environmental Impact Statement on Animal Agriculture. Prepared for the Environmental Quality Board, September 1999.
B-1	Technical Guidelines for Poultry Barn Floors, Minnesota Pollution Control Agency fact sheet, March 5, 1998.
B-2	A Preliminary Study on Seepage From Deep Bedded and Poultry Liter Systems, J. Zhu, R. V. Morey, D. R. Schmidt and G. Randall, University of Minnesota, August 1999.
B-3	Investigation report: Adequacy of clay as a floor system for poultry barns, Tiry Engineering, M. J. Tiry, P.E., November 23, 1994.
B-4	Example of MPCA interim permit for turkey barn floor construction, MPCA-I 2179(A)R, April 17, 1998.
C-1	MPCA Annual County Feedlot Officer Report examples.
C-2	MPCA Delegated County Feedlot Officers, Minnesota Pollution Control Agency Fact Sheet, November 1997.
C-3	Feedlot Program Activities Involving Interaction Between MPCA and Counties. Minnesota Pollution Control Agency, Draft Fact Sheet, October 22, 1999.
C-4	1995 and 1999 legislative appropriation language for county feedlot grant program. Laws of Minnesota, Chapter 632, Section 3(a), and Laws of Minnesota, Chapter 231, Section 2, Subdivision 2.
C-5	Environmental Quality Board, Generic Environmental Impact Statement on Animal Agriculture: Status of County Conducted Feedlot Inventories in Minnesota, October 4, 1999.

Exhibit Number	Title
C-6	Cass County Environmental Services 1995, 1996 and 1997 MPCA Feedlot Grant Annual Report Examples.
C-7	Minnesota Center for Environmental Advocacy compilation of responses to county feedlot officer survey.
E-1	Minnesota Natural Resources Conservation Service project summary for 1994 to 1997. Expert opinion on runoff control system costs: E-mail from Mr. Mark Gernes, Winona County, Minnesota to Mr. Don Hauge, Minnesota Pollution Control Agency, October 1, 1999, 1:15 PM; Letter from Mr. Robert Romocki Natural Resources Conservation Service to Mr. Ron Leaf, Minnesota Pollution Control Agency, March 24, 1999; Fax from University of Minnesota Extension Service, Wabasha County to Mr. Ron Leaf, Minnesota Pollution Control Agency, March 25, 1999, 1:33 PM.
E-2	Additional Example Economic Impact Scenarios.
E-3	1997 Census of Agriculture – State Data, Table 1, United States Department of Agriculture, National Agricultural Statistics Service, 1997.
E-4	AGWASTE database data on permitted facilities. Minnesota Pollution Control Agency. Is there a date for this data? Under what rule or authority do we collect this data? Not used.
E-5	Graph of Baseline Versus Simulation Forecast.
E-6	Manure Management Plan for Dick Bergland, producer, Manure Application Planner, Version 2.0, April 1995.
E-7	The Advantage of Manure, Stanley Burman, Agren, Inc. Paper presented at the manure management conference, hosted by the West North Central Region of the Soil and Water Conservation Society on February 10 – 12, 1998, Ames, Iowa. Paper published in Extended Abstracts of Papers and Posters Presented, Manure Management , In Harmony with the Environment and Society.
E-8	Case Study: Economic Impact of Restricting Phosphorus Fertilization on a Minnesota Dairy, J. G. Schimmel, R. A. Levins, Z. Vincze, University of Minnesota Extension Service, and Minnesota Pollution Control Agency. Paper presented at the manure management conference, hosted by the West North Central Region of the Soil and Water Conservation Society on February 10 – 12, 1998, Ames, Iowa. Paper published in Extended Abstracts of Papers and Posters Presented, Manure Management , In Harmony with the Environment and Society.

Exhibit Number	Title
E-9	Economies of Scales in Swine Manure Utilization; Raymond E. Massey, John A. Lory, John Hoehne, Charles Fulhage, University of Missouri; Paper presented at the manure management conference, hosted by the West North Central Region of the Soil and Water Conservation Society on February 10 – 12, 1998, Ames, Iowa. Paper published in Extended Abstracts of Papers and Posters Presented, Manure Management , In Harmony with the Environment and Society.
E-10	Manure Spreading Costs, Peter Wright, Cornell Cooperative Extension; Paper presented at the manure management conference, hosted by the West North Central Region of the Soil and Water Conservation Society on February 10 – 12, 1998, Ames, Iowa. Paper published in Extended Abstracts of Papers and Posters Presented, Manure Management , In Harmony with the Environment and Society.
E-11	Bartz, Carrie, Email from Carrie Bartz, Minnesota Pollution Control Agency to Paul Trapp Minnesota Pollution Control Agency regarding the estimate number of animal feedlots within 1,000 meters of a lake.
E-12	Swanson, Scott L., Email from Kim Brynildson, Minnesota Pollution Control Agency to Randy Ellingboe, Minnesota Pollution Control Agency regarding Mr. Swanson's (U. S. Department of Agriculture) estimated cost of fencing.
F-1	Manure Production Table form Midwest Planning Service, MWPS-18 manual.
F-2	FY99 Legislative Budget Initiative -- Animal Feedlot Fees.
F-3	Four laws are important to the proposed fee discussion: 1) Minnesota Statutes section 116.07, subdivision 4d. 2) 1999 Minnesota Session Laws chapter 231, section 2, subdivision 2. 3) 1999 Minnesota Session Laws chapter 250, Article I, section 49. Minnesota Statutes section 14.18, subdivision 2. Minnesota Statutes section 16A.1285
F-4	Department of Finance Comments and Recommendations.
G-1	Animal Feedlot Regulation: A Program Evaluation Report, prepared by the Office of the Legislative Auditor, January 1999.
G-2	United States Department of Agriculture, United States Environmental Protection Agency, Unified National Strategy for Animal Feeding Operations, March 9, 1999; and January 14, 1999, response letter from Gene Hugoson, Commissioner of Minnesota Department of Agriculture, Lisa Thorvig, Acting Commissioner of Minnesota Pollution Control Agency, and Ron Harnack, Executive Director of Minnesota Board of Water and Soil Resources. March 9, 1999.
G-3	Feedlot Air Quality Summary: Data Collection, Enforcement and Program Development, produced by Minnesota Pollution Control Agency, March 1999.

Exhibit Number	Title
G-4	Letter from Governor Jesse Ventura to Speaker Sviggum regarding legislation veto, May 25, 1999.
G-5	Letter from MPCA Commissioner Karen A. Studders to MDA Commissioner Eugene Hugoson Regarding Notification of Draft Feedlot Rules That Potentially Affect Farming Operations, November 17, 1999.
I-1	Feedlot Inventory Guidebook, prepared by the Minnesota Board of Water and Soil Resources. June 1991.
I-2	June 14 and August 16 Feedlot and Manure Management Advisory Committee, MPCA staff meeting minutes.
I-3	DRAFT Registration form examples: Level II inventory model and self-evaluation model, Minnesota Pollution Control Agency.
I-4	DRAFT Animal Feedlot Program Plan, Minnesota Pollution Control Agency, August 25, 1999.
I-5	Letters for FMMAC meeting dates April 5, 1999; May 6, 1999; May 26, 1999; June 10, 1999; June 14, 1999; and August 16, 1999.
L-1	Guidelines: Land Application of Manure for Water Quality Protection, Minnesota Pollution Control Agency, June 1996.
L-2	Basis and Justification for Minnesota Land Application of Manure Guidelines, written by Minnesota Pollution Control Agency staff Dave Wall and Gregory Johnson in association with the FMMAC Minnesota Land Application of Manure Task Force, June 1996.
L-3	Land Application of Manure Task Force: Report to the Feedlot and Manure Management Advisory Committee Regarding Proposed MPCA Rule Revision Recommendations for Manure Application, Draft July 1, 1997.
L-4	Minnesota Rules part 7050.0210, General Standards for Dischargers to Waters of the State.
L-5	Agricultural Phosphorus and Eutrophication: A Symposium Overview, Daniel, T.C., Sharpley, A. N., and Lemunyon, J. L., Journal of Environmental Quality, 27:251-257, 1998.
L-6	Livestock Manure Sampling and Testing, Wagar, Tim; Schmitt, Mike; Clanton, Chuck; and Bergsrud, Fred. University of Minnesota Extension Service, FO-6423-B, 1994.
L-7	Fertilizer Recommendations for Agronomic Crops in Minnesota. Rehm, George; Schmitt, Michael; and Munter, Robert. University of Minnesota Extension Service, Bu-6240-E, 1995.

Exhibit Number	Title
L-8	Manure Management in Minnesota. Schmitt, Michael A. University of Minnesota Extension Service,FO-3553-C, 1999.
L-9	Hydrologic Controls of Phosphorus loss from Upland Agricultural Watersheds. Gburek, William J. and Sharpley, Andrew N.; Journal of Environmental Quality, 27:267-277, 1998.
L-10	Agronomic and Environmental Management of Phosphorus. Rehm, George; Lamb, John; Schmitt, Michael; Randall, Gyles; and Busman, Lowell. University of Minnesota Extension Service, FO-6797-B, 1997.
L-11	The Nature of Phosphorus in Soils. Busman, Lowell; Lamb, John; Randall, Gyles, Rehm, George; and Schmitt, Michael. University of Minnesota Extension Service, FO-6795-B, 1977.
L-12	Using the Soil Nitrate Test in Minnesota. Rehm, George; Schmitt, Michael; and Eliason, Roger. University of Minnesota Extension Service,FO-7310-B, 1999.
L-13	Variability of Manure Nutrient Content and Impact on Manure Sampling Protocol. Conference Proceedings from Animal Production Systems and the Environment. Iverson, Kirk V.; Davis, Jessica G.; and Vigil, Merle F.. Colorado State University and USDA-ARS Great Plains Research Station. 1998.
L-14	Minnesota Department of Agriculture. Nutrient Management Assessment Program,
L-15	Developing a Manure Management Plan. Busch, Dennis; Busman, Lowell; and Nesse, Phil. University of Minnesota Extension Service, BU-6957-D, 1997.
L-16	319 Grant Proposal, April 1999. Education to Improve Feedlot, Manure and Nutrient Management.
L-17	Phosphorus Transport to and Availability in Surface Waters. Randall, Gyles; Mulla, Dave; Rehm, George; Busman, Lowell, Lamb, John; and Schmitt, Michael. University of Minnesota Extension Service, FO-6796-B, 1997.
L-18	Phosphorus Loss in Agricultural Drainage: Historical Perspective and Current Research. Sims, J. T., Simard, R. R. and Joern, B. C., Journal of Environmental Quality, 1998.
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XI. CONCLUSION

Based on the foregoing, the proposed rules are both needed and reasonable.

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Gordon E. Wegwart, P.E.
Assistant Commissioner
Commissioner's Office

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Cancer Epidemiology

Colorectal cancer risk and nitrate exposure through drinking water and diet

Nadia Espejo-Herrera[1,2,3], Esther Gràcia-Lavedan[1,2,3], Elena Boldo[3,4,5], Nuria Aragonés[3,4,5], Beatriz Pérez-Gómez[3,4,5], Marina Pollán[3,4,5], Antonio J. Molina[6], Tania Fernández[6], Vicente Martín[3,6], Carlo La Vecchia[7], Cristina Bosetti[8], Alessandra Tavani[8], Jerry Polesel[9], Diego Serraino[9], Inés Gómez Acebo[3,10], Jone M. Altzibar[3,11,12], Eva Ardanaz[3,13], Rosana Burgui[3,13], Federica Pisa[14], Guillermo Fernández-Tardón[3,15], Adonina Tardón[3,15], Rosana Peiró[3,16], Carmen Navarro[3,17,18], Gemma Castaño-Vinyals[1,2,3,19], Victor Moreno[3,20,21], Elena Righi[22], Gabriella Aggazzotti[22], Xavier Basagaña[1,2,3,19], Mark Nieuwenhuijsen[1,2,3,19], Manolis Kogevinas[1,2,3,19] and Cristina M. Villanueva[1,2,3,19]

[1] ISGlobal, Centre for Research in Environmental Epidemiology (CREAL), Barcelona, Spain
[2] Departament de Ciències Experimentals i de la Salut, Universitat Pompeu Fabra, Barcelona, Spain
[3] CIBER Epidemiología y Salud Pública (CIBERESP), Madrid, Spain
[4] Cancer and Environmental Epidemiology Unit, National Centre for Epidemiology, Carlos III Institute of Health, Madrid, Spain
[5] Cancer Epidemiology Research Group, Oncology and Hematology Area, IIS Puerta De Hierro, Madrid, Spain
[6] Research Group on Gene-Environment Interactions and Health, , University of León, León, Spain
[7] Department of Clinical Sciences and Community Health, Università degli Studi di Milano, Milan, Italy
[8] Department of Epidemiology, IRCCS - Istituto di Ricerche Farmacologiche Mario Negri, Milan, Italy
[9] Unit of Epidemiology and Biostatistics, IRCCS, CRO Aviano National Cancer Institute, Aviano, Italy
[10] University of Cantabria, IDIVAL, Santander, Spain
[11] Public Health Division of Gipuzkoa, San Sebastián, Spain
[12] Biodonostia Research Institute, San Sebastián, Spain
[13] Navarra Public Health Institute, Pamplona, Spain
[14] SOC Igiene ed Epidemiologia Clinica, Azienda Ospedaliera Universitaria, Udine, Italy
[15] Oncology Institute IUOPA, Universidad de Oviedo, Asturias, Spain
[16] Centre for Research in Public Health, Valencia, Spain
[17] Department of Epidemiology IMIB-Arrixaca, Murcia Regional Health Council, Murcia, Spain
[18] Department of Health and Social Sciences, University of Murcia, Murcia, Spain
[19] IMIM (Hospital del Mar Medical Research Institute), Barcelona, Spain
[20] Catalan Institute of Oncology, Bellvitge Biomedical Research Institute (IDIBELL), Barcelona, Spain
[21] University of Barcelona, Barcelona, Spain
[22] University of Modena and Reggio Emilia, Modena, Italy

Ingested nitrate leads to the endogenous synthesis of N-nitroso compounds (NOCs), animal carcinogens with limited human evidence. We aimed to evaluate the risk of colorectal cancer (CRC) associated with nitrate exposure in drinking water and diet. A case-control study in Spain and Italy during 2008-2013 was conducted. Hospital-based incident cases and population-based (Spain) or hospital-based (Italy) controls were interviewed on residential history, water consumption since age 18, and dietary information. Long-term waterborne ingested nitrate was derived from routine monitoring records, linked to subjects' residential histories and water consumption habits. Dietary nitrate intake was estimated from food frequency questionnaires and published food composition databases. Odd ratios (OR) were calculated using mixed models with area as random effect, adjusted for CRC risk factors and other covariables. Generalized additive models (GAMs) were used to analyze exposure-response relationships. Interaction with endogenous nitrosation factors and other covariables was also evaluated. In total

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Correspondence to: Cristina M. Villanueva; ISGlobal, Centre for Research in Environmental Epidemiology (CREAL), Doctor Aiguader, 88 08003 Barcelona, Spain, Tel: +34932147344; Fax: +34932147302; E-mail: cvillanueva@creal.cat

1,869 cases and 3,530 controls were analyzed. Average waterborne ingested nitrate ranged from 3.4 to 19.7 mg/day, among areas. OR (95% CIs) of CRC was 1.49 (1.24, 1.78) for >10 versus ≤5 mg/day, overall. Associations were larger among men versus women, and among subjects with high red meat intake. GAMs showed increasing exposure-response relationship among men. Animal-derived dietary nitrate was associated with rectal, but not with colon cancer risk. In conclusion, a positive association between CRC risk and waterborne ingested nitrate is suggested, mainly among subgroups with other risk factors. Heterogeneous effects of nitrate from different sources (water, animal and vegetables) warrant further research.

What's new?
Nitrate ingested in food and water can react with amines and amides in the gastrointestinal tract, leading to the formation of N-nitroso compounds (NOCs), which are carcinogenic in animals. In humans, nitrate and several NOCs are probable carcinogens. The aim of the present investigation, a case–control study in Europe, was to examine links between nitrate intake and colorectal cancer (CRC). The findings indicate that CRC risk is increased for waterborne nitrate intake at levels below current international guidelines, particularly in subgroups with other risk factors. Nitrate intake from animal sources was further associated with increased rectal cancer risk.

Introduction

Nitrate is a widespread contaminant in drinking water due to the overuse of fertilizers in agriculture[1] and urban sewage.[2] Expensive and infrequently used methods such as reverse osmosis are necessary to effectively remove nitrate from drinking water.[3] In addition, nitrate is a main dietary component of vegetables, and an approved food additive for preserved meat, together with nitrite.[4]

Nitrate ingestion through diet and drinking water are the main routes of human exposure. Ingested nitrate is reduced to nitrite, which subsequently reacts with amines and amides to produce N-nitroso compounds (NOCs) in the gastrointestinal system. The intake of vitamins C and E may inhibit endogenous nitrosation, whereas meat intake and chronic gastrointestinal acidic or inflammatory conditions, may increase it.[5] Additionally, exogenous NOCs are ingested through processed meat, canned or cured food, alcohol and tobacco smoking.[6] NOCs are carcinogenic in several animal species,[7] but human evidence is limited, therefore nitrate is classified as probable human carcinogen (group 2A) under conditions resulting in endogenous nitrosation.[8]

Colorectal cancer (CRC) is one of the most frequent cancers worldwide, representing 10% of the global cancer incidence. More than 1 million new cases and 694,000 deaths are registered annually in both sexes.[9] The high intake of energy, red or processed meat[10] and alcohol, as well as physical inactivity and obesity, are established risk factors.[11] Increased CRC risk has been suggested with dietary nitrite[12] or dietary NOCs.[13,14] Recently, a prospective study found an increased risk among subjects with high dietary nitrate and low vitamin C intake.[15] However, few studies have evaluated the risk of CRC associated with nitrate in drinking water. Existing evidence provided by case–control or cohort studies is inconsistent,[5,16] particularly for levels below the current regulatory limit (50 mg/L of nitrate as NO_3^- in the European Union, or 10 mg/L as NO_3-N in the United States),[17] which is a common scenario in high-income countries.

We evaluated the association between CRC risk and the exposure to nitrate through drinking water and diet, taking into account endogenous nitrosation factors and other covariates.

Methods

Study design and population

We pooled data from two case-control studies conducted in Spain (the Spanish Multi-case Control study on Cancer, MCC-Spain)[18] and Italy (part of the European Union Project on Health Impacts of long-term exposure to Disinfection by-products in Drinking Water, HI-WATE),[19] between 2008 and 2013. Study areas comprised eleven provinces (nine from Spain, two from Italy) (see Table 1). CRC cases were identified as soon as possible after the diagnosis through active searches including periodical visits to the hospital departments (*i.e*., oncology, gastroenterology, general surgery, radiotherapy and pathology). Participant hospitals (17 in Spain, 10 in Italy) were the reference centers for oncologic diseases in each study area. Only CRC cases diagnosed within the recruitment period, with histological confirmation (ICD-10 codes: C18, C19, C20, D01.0, D01.2), without previous cancer history, aged 20-85 years, living in the hospitals' catchment areas, and being able to answer an epidemiological questionnaire, were enrolled. Controls were hospital-based (Italy) or population-based (Spain), and were frequency matched to cases by sex, age and residence area. Hospital-based controls were randomly selected among patients admitted to the same hospitals as cases for acute, non-chronic diseases, unrelated to alcohol, tobacco, dietary habits or to known CRC risk factors (52.2% had acute surgical conditions, 9.0% non-traumatic orthopedic disorders, 6.0% trauma and 32.8% other illnesses). Population-based controls were randomly selected

Cancer Epidemiology

Table 1. Characteristics of the study population included in the analyses of waterborne ingested nitrate: 1,869 cases of colorectal cancer (1,285 colon and 557 rectum)[1] and 3,530 controls

	Cancer cases				
	Colon *n* (%)	Rectum *n* (%)	Colorectal *n* (%)	Controls *n* (%)	*p* values[2]
Study area					
Spain					
Asturias	38 (3.0)	21 (3.8)	59 (3.2)	202 (5.7)	
Barcelona	430 (33.4)	189 (33.9)	629 (33.6)	910 (25.8)	
Cantabria	79 (6.2)	40 (7.2)	119 (6.4)	279 (7.9)	
Gipuzkoa	83 (6.5)	24 (4.3)	107 (5.7)	333 (9.4)	
León	162 (12.6)	77 (13.8)	243 (13.0)	352 (10.0)	
Madrid	143 (11.1)	62 (11.1)	206 (11.0)	658 (18.6)	
Murcia	13 (1.0)	12 (2.2)	25 (1.3)	39 (1.1)	
Navarra	72 (5.6)	24 (4.3)	98 (5.2)	230 (6.5)	
Valencia	52 (4.0)	24 (4.3)	76 (4.1)	131 (3.7)	
Italy					
Milan	118 (9.2)	56 (10.0)	184 (9.8)	270 (7.6)	
Pordenone/Udine	95 (7.4)	28 (5.0)	123 (6.6)	126 (3.6)	<0.001
Sex					
Men	784 (61.0)	382 (68.6)	1,184 (63.4)	1,840 (52.1)	
Female	501 (39.0)	175 (31.4)	685 (36.6)	1,690 (47.9)	<0.001
Age (quartiles)					
≤57 years	226 (17.6)	109 (19.6)	341 (18.2)	947 (26.8)	
58-65 years	294 (22.9)	151 (27.1)	449 (24.0)	870 (24.6)	
66-72 years	335 (26.1)	110 (19.8)	455 (24.3)	833 (23.6)	
>72 years	430 (33.5)	187 (33.6)	624 (33.4)	880 (24.9)	<0.001
Education					
<Primary school	334 (26.0)	147 (26.4)	484 (25.9)	585 (16.6)	
Primary school	478 (37.2)	222 (39.9)	707 (37.8)	1,176 (33.3)	
Secondary school	345 (26.8)	147 (26.4)	505 (27.0)	1,101 (31.2)	
University	128 (10.0)	41 (7.4)	173 (9.3)	668 (18.9)	<0.001
Physical activity (METs hour/week)[3]					
<8 (<8.5)	862 (67.1)	376 (67.5)	1,252 (67.0)	2,266 (64.2)	
8–16 (8.5–34.4)	178 (13.8)	80 (14.4)	266 (14.2)	550 (15.6)	
>16 (>34.4)	245 (19.1)	101 (18.1)	351 (18.8)	714 (20.2)	0.121
Smoking[4]					
Never	549 (43.2)	202 (36.3)	761 (41.0)	1,535 (43.6)	
Ever	723 (56.8)	354 (63.7)	1,093 (59.0)	1,986 (56.4)	0.073
Non-steroidal anti-inflammatory drugs use[4]					
Never	848 (68.4)	371 (68.2)	1,241 (68.6)	2,134 (62.6)	
Ever	391 (31.6)	173 (31.8)	569 (31.4)	1,274 (37.4)	<0.001
Oral contraceptives use[4,5]					
Never	355 (71.1)	124 (72.5)	486 (71.6)	940 (55.9)	
Ever	144 (28.9)	47 (27.5)	193 (28.4)	742 (44.1)	<0.001
Colorectal cancer in first degree relative[4]					
No	1,005 (83.8)	450 (85.6)	1,479 (84.5)	3,065 (91.5)	
Yes	194 (16.2)	76 (14.4)	271 (15.5)	285 (8.5)	<0.001

Table 1. Characteristics of the study population included in the analyses of waterborne ingested nitrate: 1,869 cases of colorectal cancer (1,285 colon and 557 rectum) and 3,530 controls (Continued)

	Cancer cases				
	Colon *n* (%)	Rectum *n* (%)	Colorectal *n* (%)	Controls *n* (%)	*p* values[2]
Body mass index (Kg/m²)[4]					
≤18.5–24.9	407 (31.7)	194 (34.8)	610 (32.7)	1,338 (37.9)	
25–29.9	585 (45.6)	243 (43.6)	840 (45.0)	1,482 (42.0)	
≥30	292 (22.7)	120 (21.5)	418 (22.4)	707 (20.1)	0.001
Energy intake (kcal/day)[4]					
<1,626	366 (31.7)	132 (26.0)	508 (30.2)	1,058 (33.4)	
>1,626–2,071	341 (29.6)	167 (32.9)	513 (30.4)	1,058 (33.3)	
>2,071	446 (38.7)	208 (41.0)	664 (39.4)	1,057 (33.3)	<0.001
Fiber intake (g/day)[4]					
<17	439 (38.1)	195 (38.5)	646 (38.3)	1,058 (33.4)	
17–23.5	373 (32.4)	156 (30.8)	537 (31.9)	1,058 (33.3)	
>23.5	341 (29.6)	156 (30.8)	502 (29.8)	1,057 (33.3)	0.002
Alcohol intake (g/day)[4]					
≤8	512 (44.4)	217 (42.8)	740 (43.9)	1,615 (50.9)	
>8	641 (55.6)	290 (57.2)	945 (56.1)	1,558 (49.1)	<0.001
Vitamin C (mg/day)[4]					
<117	415 (36.0)	208 (41.0)	634 (37.6)	1,058 (33.4)	
117–186	405 (35.1)	168 (33.1)	583 (34.6)	1,058 (33.3)	
>186	333 (28.9)	131 (25.8)	468 (27.8)	1,057 (33.3)	<0.001
Vitamin E (mg/day)[4]					
<8.5	420 (36.4)	177 (34.9)	603 (35.8)	1,058 (33.4)	
8.5–12.0	382 (33.1)	168 (33.1)	562 (33.4)	1,058 (33.3)	
>12.0	351 (30.4)	162 (32.0)	520 (30.9)	1,057 (33.3)	0.138
Red meat (g/day)[4]					
<20	321 (27.8)	117 (23.1)	444 (26.4)	1,058 (33.4)	
20–40	362 (31.4)	167 (32.9)	537 (31.9)	1,058 (33.3)	
>40	470 (40.8)	223 (44.0)	704 (41.8)	1,057 (33.3)	<0.001
Processed meat (g/day)[4]					
<17	355 (30.8)	132 (26.0)	498 (29.6)	1,058 (33.4)	
17–34	369 (32.0)	148 (29.2)	520 (30.9)	1,058 (33.3)	
>34	429 (37.2)	227 (44.8)	667 (39.6)	1,057 (33.3)	<0.001
Water intake (L/day)					
<0.9	389 (30.3)	185 (33.2)	584 (31.2)	1,181 (33.5)	
≥0.9–1.4	410 (31.9)	167 (30.0)	584 (31.2)	1,209 (34.2)	
>1.4	486 (37.8)	205 (36.8)	701 (37.5)	1,140 (32.3)	0.001

[1]Numbers of colon and rectum cases do not add 1,869 since 27 cases were undefined.
[2]*p values for Chi2 test* comparing controls versus CRC cases, calculated ignoring missing values in covariables.
[3]METs: Metabolic equivalents of task. Categories for physical activity were specific for each country. Cut offs for Italy are between parenthesis.
[4]Numbers do not add total cases and controls because of missing observations.
[5]Descriptive for women.

from administrative records of primary health care centers located within the hospitals' catchment areas in Spain, where universal health coverage is available. Potential participants were contacted telephonically on behalf of their family physician. For each control needed, five potential participants of similar age, and same sex and hospital catchment area were selected. If contact with the first person of the list was not achieved (after at least five attempts at different times of the day), or if he/she refused to participate, the following person of the list was approached.[20] The study protocol was approved by the ethics committees of the participating institutions, and all participants signed an informed consent before recruitment.

Individual information and response rates

Study subjects were interviewed face-to-face by trained study personnel. Interviews were conducted in the hospitals (cases and hospital-based controls) and in primary health care facilities or nearby research centers (population-based controls). Questionnaires used are available online (http://mccspain.org). Data collected included sociodemographic characteristics; residential history from age 18 years to recruitment; water type consumed in each residence (municipal/bottled/well/other); amount of daily water intake (including water per-se, coffee, tea and other water-based beverages); smoking habits; history of gastric ulcer, diabetes, inflammatory bowel disease or Crohn's disease, use of non steroidal anti-inflammatory drugs (NSAIDs); oral contraceptive (OC) use, and hormonal replacement therapy (HRT); leisure physical activity since age 16 (Spain) or 15 years (Italy); family history of CRC, and information on the quality of the interview. Long-term exposure levels to trihalomethanes (THMs) in drinking water were available for the study population. Dietary information, corresponding to 2 years before recruitment, was collected using validated food frequency questionnaires (FFQs).[21,22] The FFQs included 140 (Spain) or 78 (Italy) food-items, and were administered during the interview in Italy (as part of the main questionnaire) or self-administered in Spain. Average response rates among cases were 58% in Spain (ranging from 33% to 80% among areas) and 95% in Italy, and among controls were 52% Spain (ranging from 30% to 68% among areas) and 95% in Italy. Average response rate for the FFQ in Spain was 88%. In total, 2,371 cases (1,905 Spain, 466 Italy) and 4,159 controls (3,590 Spain, 569 Italy) were interviewed.

Nitrate levels in municipal drinking water

We collected data for the municipalities covering 80% of total person-years in each area. We sent a standardized questionnaire to local authorities and water companies to ascertain current and historical nitrate measurements at the distribution system, and water source characteristics (surface/groundwater proportion). Monitoring levels for 2004–2010 were provided in Spain by the SINAC (*Sistema de Información Nacional de Aguas de Consumo*), and by the Regional Environmental Health Agency (Milan) and the Local Health Authority (Pordenone/Udine) in Italy. Measurements below the quantification limits (QL) (5% of measurements) were imputed half the QL value. If the QL value was missing, the measurement was imputed half of the most frequent QL reported (1.0 mg/L). More details on environmental data available are presented in Supporting Information (Table 1).

Nitrate levels in non-municipal drinking water

Data from the most consumed bottled water brands were available from previous reports in Spain[23] and Italy.[24] Nitrate levels in wells and springs outside the municipal water distribution system were measured in September 2013 in the area of León (Spain), where non-municipal well water consumption was the highest among the study areas (28% of controls in the longest residence). A total of 28 water samples were collected in 21 municipalities. The proportion of well water consumption in other areas ranged from 0.3% to 24% in the longest residence (33 years long, on average). These were considered as missing values given the lack of well water data in those areas.

Estimation of long-term nitrate levels in drinking water

We explored heterogeneity of nitrate levels within each municipality, by comparing the levels available for different sampling points, to identify water zones, defined as geographical areas supplied from a homogeneous water source and with similar nitrate levels. Most of the municipalities comprised only one water zone, and some of the municipalities (*e.g.*, Barcelona and Milan) had water zones already defined with different water sources. Long-term nitrate levels were estimated for 349 water zones, in total (Supporting Information Table 1). We calculated annual average by water zone using available measurements. For years without measurements, we back extrapolated the average of total measurements in the water zone back to 1940, as long as water source remained constant. Nitrate levels in ground water sources are usually higher than in surface sources.[25] Therefore, we used ground water percentage as a weight to calculate nitrate estimates when water source changed, assuming that levels increased proportionally to the percentage of ground water supplied. This assumption was evaluated for each water zone, and was applied uniformly in all municipalities where data was not sufficient to conduct this evaluation. In municipalities without nitrate measurements (covering 0.5% of the total person-years), we assigned the levels of neighboring municipalities supplied with similar surface/ground water proportion ±10%. We defined a reliability score for each annual nitrate estimate, ranging from 0 (lowest reliability) to 2 (highest), that penalized estimates that were imputed, calculated based on few number of measurements, and more distant in time to an actual measurement. We used this score for sensitivity analyses.

Estimation of waterborne nitrate exposure

We linked nitrate levels with residential histories by year and municipality (or water zone) covering an exposure period from age 18 to 2 years before the interview ("adult life"), among cases and controls. Since more nitrate measurements were available in recent decades, our "main exposure period" covered from 30 to 2 years before the interview. We also evaluated an exposure period from age 18 to 30 years ("early adult life"). We calculated average residential levels (mg/L as NO_3^-) and average waterborne ingested nitrate (mg/day) for each exposure period.

We calculated waterborne ingested nitrate according to amount and type of water consumed. We assigned residential levels when subjects reported tap water consumption. Published levels in bottled water brands were averaged using the sales frequency of each brand as a weight and were assigned when bottled water consumption was reported (6.1 mg/L in Spain and 3.8 mg/L in Italy). Levels from well water samples in León (range 0.5–93 mg/L) were assigned to well water consumers in this area, according to the postal code of wells' location. The annually assigned levels were averaged and multiplied by the daily water intake (mean $\pm$ SD = 1.4 ± 0.8 L/day in cases and 1.3 ± 0.9 L/day in controls). Water intakes above the 99th percentile (4 L/day), considered non plausible, were treated as missing values in the analyses.

To address the potential misclassification of the water type consumed (municipal/bottled) in recent residences, we calculated an alternative variable of waterborne ingested nitrate. We assumed that subjects reporting bottled water consumption and living during at least 10 years in the current (or previous) residence, consumed municipal water before the year 2000 and bottled water thereafter. This was assumed based on results from a subgroup with information on water type changes within residences ($n = 174$), showing that among 86% of subjects reporting bottled water consumption in the current residence, actually switched from municipal to bottled water after the year 2000. Similar calculations were done for Italy, using the cutoff at 1980 according to Italian data.

Estimation of dietary nutrients and nitrate

Data collected through FFQs were used to estimate the average daily intake of food groups and nutrients (vitamins C, E, and energy). Nutrients' contents were calculated using published food composition databases.[26,27] Dietary nitrate intake (mg/day) was estimated based on average intake of food items (g/day) and published nitrate content (mg/100 g) in food items including vegetables,[4] animal products and others.[28,29] Nitrate contents (mg/100 g) were calculated for 21 vegetables (including tubers), 13 fruits, 17 foods from animal sources (including red, white, processed meat and dairy products), 3 frequently consumed foodstuff (bread, rice and pasta) and 1 alcoholic beverage (beer). For these calculations "red meat" included: beef, lamb and pork meat. "Processed meat" included: bacon, hot dogs, smoked ham, Spanish cured ham and other cured sausages.

Statistical analyses

Subjects with nitrate exposure covering less than 70% of the last 30 years before the interview, and with unsatisfactory quality interview ($n = 24$) were excluded, leading to 1,869 cases and 3,530 controls analyzed. Nitrate exposure variables were categorized attempting to have subjects from different areas in all categories and high numbers in the reference. Odds ratios (OR) and 95% confidence intervals (CI) of CRC were calculated using mixed models with "area" as random effect. Basic models were adjusted for sex, age, study area and education. Potential confounders were explored overall and separately for men and women, including: smoking (never/ever), physical activity (measured in METs Metabolic equivalents of task/hour/week), body mass index (BMI), history of CRC in first degree relatives, NSAIDs use, OC use and HRT (in women), intake of energy, fiber, alcohol and endogenous nitrosation modulators (intake of vitamin C, vitamin E, red meat, processed meat and gastric ulcer history). Only variables that changed the risk estimates $\geq$10% were retained in the adjusted models.[11] In alternative analyses, models were adjusted for THM levels (residential and waterborne ingested) in the main exposure period. Missing values in categorical covariables were coded as another category. We evaluated the exposure-response relationship between waterborne nitrate exposure and CRC risk using generalized additive models (GAMs).

We stratified analyses of waterborne ingested nitrate by sex, cancer site, endogenous nitrosation modulators and other potential effect modifiers. Strata of quantitative variables ($\leq$ or $>$ median) were defined according to the distribution in controls. We compared the models with and without the interaction term using the likelihood ratio test, and p values less than 0.10 were considered indicative of multiplicative interaction. Stratified analyses by endogenous nitrosation factors were also conducted for men and women separately. We conducted several sensitivity analyses including the use of alternative variables of waterborne ingested nitrate in different exposure windows, and excluding exposure estimates (residential levels) with low reliability score (score value <0.50 $N = 1{,}077$). STATA version 12.0 (Stata Corp, College Station, TX) was used for all statistical analyses.

Results

Characteristics of the population analyzed are shown in Table 1. Family history of CRC, high BMI, high intake of energy, alcohol, red meat and processed meat were more frequent among cases (Chi^2 p values <0.05). The amount of water intake was also higher among cases (t test p values <0.05). Compared with the excluded, the subjects analyzed showed a higher proportion of controls, were younger, with lower physical activity, more frequent use of NSAIDs, and had lower ($\leq$5 mg/L) or higher ($\geq$10 mg/L) residential nitrate levels (Supporting Information Table 2).

On average (mean $\pm$ SD), this population had 3.3 ± 1.6 residences in adult life, and the time living in the most recent residence was 29.3 ± 14.9 years. The number of years (mean $\pm$ SD) with nitrate measurements available ranged from 4.0 ± 1.7 to 13.4 ± 1.5, among study areas. Nitrate measurements were available for 19% of the main exposure

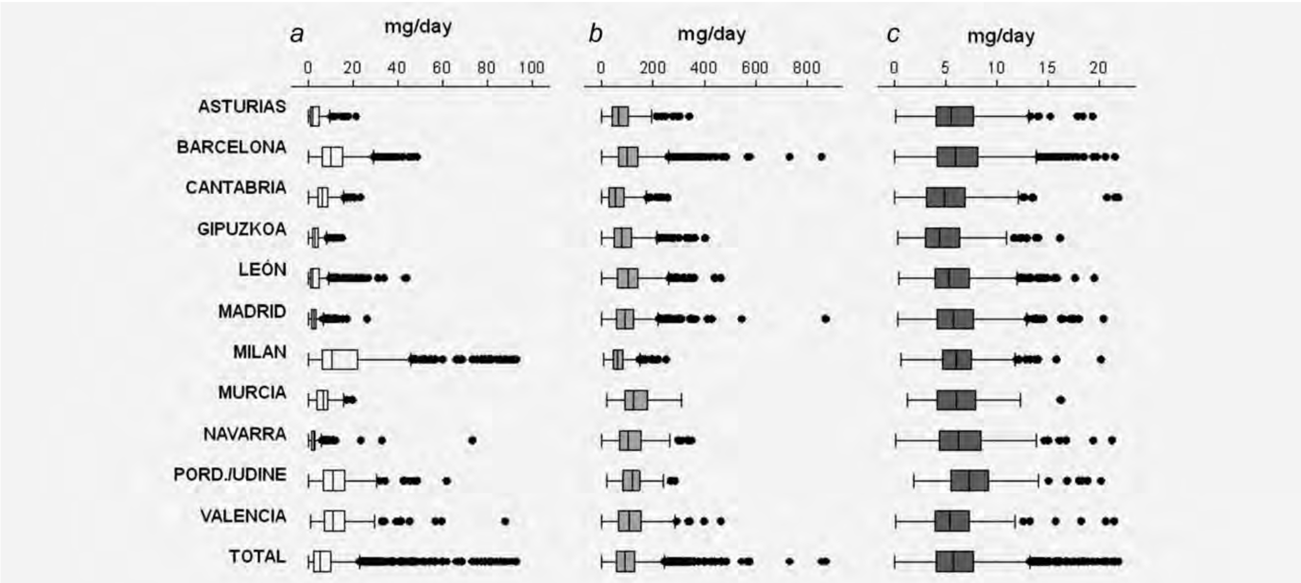

Figure 1. Average nitrate exposure levels among study areas. (*A*) Waterborne intake in the main exposure period (excluding intakes >105.8 mg/day, $n = 5$). (*B*) Dietary intake from vegetable sources (excluding intakes >1,000 mg/day, $n = 2$). (*C*) Dietary intake from animal sources (excluding intakes >22 mg/day, $n = 16$).

period (from 30 to 2 years before the interview), on average. Municipal water consumption was longer than bottled or well water consumption (19.2 ± 12.6 *vs.* 10.5 ± 16.5, and 0.8 ± 4.2 years, respectively), with differences among regions (Supporting Information Table 1).

Figure 1 shows average nitrate exposure levels through drinking water and diet during the main exposure period (from 30 to 2 years before the interview). Waterborne ingestion (mean ± SD) ranged from 3.4 ± 3.3 to 19.7 ± 22.6 mg/day, and residential levels ranged from 1.6 ± 0.9 to 30.0 ± 4.4 mg/L, among areas. The levels were similar in other exposure periods (results not shown). A high correlation was found between waterborne nitrate ingestion during the main exposure period and alternative exposure periods (*Spearman* correlation coefficients $r = 0.98$ with levels in adult life, and 0.91 with levels in early adult life). Dietary nitrate intake (mean ± SD) was 118 ± 72 mg/day (102 ± 70.5 mg/day from vegetables and 6.2 ± 3.3 mg/day from animal sources).

Table 2 shows the risk of CRC associated with waterborne ingested nitrate, overall and stratified by sex, for colon and rectum cancers sites. Adjusted ORs (95%CIs) of CRC for >10 versus ≤5 mg/day were 1.49 (1.24–1.78) overall, 1.50 (1.21–1.87) among men and 1.41 (1.04–1.91) among women. Interaction by sex was statistically significant for colorectal and colon, but not for rectal cancer. Results differed moderately by cancer site. The analyses of the alternative exposure periods led similar results, as well as the sensitivity analyses excluding subjects with low reliable score, or the subjects with less reliable interviews. Stratified analyses by time living in the current residence (≤15 years, >15–30 years and >30 years) also led similar results (not shown in tables). The ORs decreased slightly with additional adjustment for chloroform levels, while slightly increased after adjustment for brominated THMs (see Supporting Information Table 3).

Average residential nitrate levels were also associated with increased CRC (see Supporting Information Table 4), although the ORs were higher than those observed with waterborne ingested nitrate. These variables were moderately correlated, overall (*Spearman* correlation coefficient $r = 0.66$), but with wide differences among areas (*e.g.*, −0.04 in Madrid to 0.39 in León). In sensitivity analyses, areas with more than 10% of cases (Barcelona, León and Madrid) and Italian areas were alternatively excluded from the models. The ORs (95%CI) for the highest exposure category (>10 *vs.* <5 mg/L) decreased mostly after excluding Barcelona and Italian areas, but remained statistically significant. The ORs were higher among men versus women (interaction p values <0.001), and slightly higher for colon versus rectum tumors.

Figure 2 shows the GAMs for waterborne ingested nitrate. A small increase in CRC risk was found at ingested levels between 10 and 30 mg/day, among men and overall. At higher levels, the exposure-response curve was flat, with wide CIs. Area-specific GAMs showed heterogeneous exposure-response curves between areas (Supporting Information Fig. 1).

Table 3 shows stratified analyses by dietary endogenous nitrosation factors and fiber intake, overall and by cancer site. High ORs (95%CI) were found in the groups with highest waterborne ingested nitrate and highest red meat intake, particularly among men: 1.71 (1.30, 2.26) (see results by sex in Supporting Information Table 5). Results for processed meat were similar to results for red meat, overall (not shown in tables). Inverse ORs (95%CI) of CRC were found among the groups with low ingested nitrate and high vitamin E

Table 2. Colorectal cancer risk associated with waterborne nitrate ingestion during the main exposure period in all population ($n = 5,399$) and stratified by cancer site and sex

Mean nitrate ingestion	≤5 mg/day			>5–10 mg/day			>10 mg/day		
	Cases	Contr.	OR[1] (95%CI)	Cases	Contr.	OR[1] (95%CI)	Cases	Contr.	OR[1] (95%CI)
Cancer site Colorectal[2]									
All	778	1,899	1.00 (ref.)	447	803	1.17 (0.98, 1.38)	644	828	1.49 (1.24, 1.78)
Men	498	918	1.00 (ref.)	289	454	1.16 (0.94, 1.44)	397	468	1.50 (1.21, 1.87)
Women	280	981	1.00 (ref.)	158	349	1.20 (0.90, 1.58)	247	360	1.41 (1.04, 1.91)
Colon[2]									
All	527	1,899	1.00 (ref.)	324	803	1.28 (1.06, 1.55)	434	828	1.52 (1.24, 1.86)
Men	322	918	1.00 (ref.)	202	454	1.26 (0.99, 1.61)	260	468	1.51 (1.17, 1.94)
Women	205	981	1.00 (ref.)	122	349	1.33 (0.97, 1.80)	174	360	1.46 (1.04, 2.05)
Rectum[2]									
All	244	1,899	1.00 (ref.)	110	803	0.93 (0.70, 1.23)	203	828	1.62 (1.23, 2.14)
Men	169	918	1.00 (ref.)	80	454	0.94 (0.68, 1.28)	133	468	1.55 (1.16, 2.08)
Women	75	981	1.00 (ref.)	30	349	0.87 (0.52, 1.45)	70	360	1.49 (0.89, 2.48)

[1]Odds ratios (OR) and 95% confidence intervals (CI). Results of mixed models with "area" as random effect, adjusted for: sex, age, education, body mass index, physical activity, non-steroidal anti-inflammatories use, family history of colorectal cancer and intake of energy. Analyses for women were also adjusted for oral contraceptives use.
[2]Interaction *p values* by sex = *0.01* for colorectal, *0.05* for colon and *0.15* for rectal cancer.

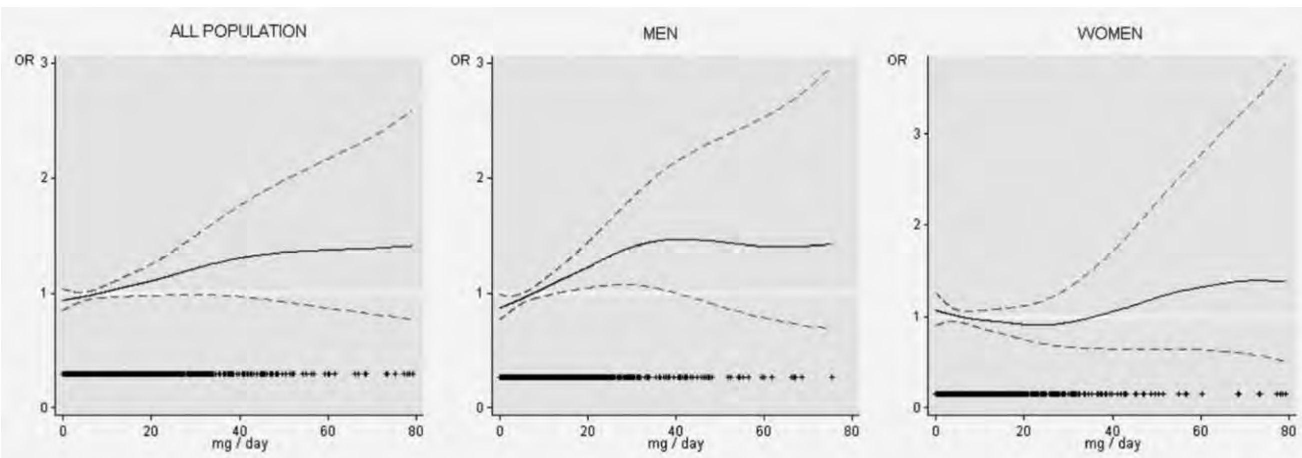

Figure 2. Exposure-response relationship between average waterborne ingested nitrate (mg/day) during the main exposure period and colorectal cancer risk. Generalized additive models (GAMs) adjusted for study area, sex, age, education, physical activity, body mass index, use of non-steroidal anti-inflammatory drugs, family history of colorectal cancer and energy intake. Subjects with ingestion levels >80 mg/day ($n = 21$) were excluded from these analyses.

(0.73, 0.59–0.89), and high fiber intake (0.65, 0.53–0.80). Results by cancer site showed similar results for colon cancer, but inverse ORs with vitamin C and fiber were found for rectum cancer. Stratified results did not differ by diabetes diagnosis, or smoking (not shown).

Table 4 shows the risk of CRC (overall and by cancer site) associated with dietary ingested nitrate. An association (OR, 95%CI) with nitrate intake from animal sources was found for rectal cancer (1.55, 1.17–2.05) while no association was observed for colon cancer (1.06, 0.87–1.30). Ingestion from total diet or vegetables led to null or inverse associations with CIs around the null value for both cancer sites. Waterborne and dietary ingested nitrate were poorly correlated (*Spearman* correlation coefficient for nitrate from total diet: 0.07, vegetables: 0.06 and animal sources: 0.07). The adjustment of waterborne ingested nitrate analyses' for dietary nitrate intake (through different sources) did not change the main results (results not shown).

Discussion

Results of this large case–control study suggest a positive association between CRC risk and long-term exposure to nitrate in drinking water, at levels below 50 mg/L of NO_3^-, particularly in subgroups of the population, such as men and

Table 3. Colorectal cancer risk associated with waterborne ingested nitrate levels in the main exposure period. Joint effect with endogenous nitrosation factors and other dietary covariables in all population and by cancer site

Covariable	Nitrate intake	Colorectal cancer ($n = 4,858$[1])		Colon cancer ($n = 4,326$[1])		Rectal cancer ($n = 3,680$[1])		
Intake	mg/day	Cases	OR[2] (95%CI)	Cases	OR[2] (95%CI)	Cases	OR[2] (95%CI)	Controls
Red meat								
≤29 g/day	≤4.4	296	1.00 (ref.)	209	1.00 (ref.)	85	1.00 (ref.)	842
	>4.4	380	1.09 (0.88–1.35)	265	1.12 (0.88, 1.44)	107	1.08 (0.76, 1.55)	744
>29 g/day	≤4.4	349	1.24 (1.02–1.51)	221	1.17 (0.93, 1.47)	124	1.49 (1.09, 2.02)	742
	>4.4	660	1.56 (1.26–1.94)	458	1.66 (1.30, 2.12)	191	1.57 (1.11, 2.21)	845
Interaction p values			0.27		0.12		0.90	
Vitamin C								
≤137 mg/day	≤4.4	343	1.00 (ref.)	218	1.00 (ref.)	121	1.00 (ref.)	766
	>4.4	589	1.20 (0.98–1.47)	409	1.36 (1.08, 1.71)	168	0.99 (0.73, 1.36)	820
>137 mg/day	≤4.4	302	0.83 (0.68–1.01)	212	0.92 (0.73, 1.15)	88	0.67 (0.49, 0.91)	818
	>4.4	451	0.95 (0.77–1.18)	314	1.09 (0.86, 1.38)	130	0.77 (0.56, 1.07)	769
Interaction p values			0.73		0.35		0.45	
Vitamin E								
≤10 mg/day	≤4.4	355	1.00 (ref.)	238	1.00 (ref.)	112	1.00 (ref.)	806
	>4.4	531	1.15 (0.94, 1.42)	373	1.26 (1.00, 1.59)	149	1.03 (0.75, 1.43)	780
>10 mg/day	≤4.4	290	0.73 (0.59, 0.89)	192	0.73 (0.57, 0.93)	97	0.75 (0.54, 1.04)	778
	>4.4	509	0.87 (0.70, 1.09)	350	0.94 (0.73, 1.21)	149	0.81 (0.57, 1.15)	809
Interaction p values			0.74		0.89		0.85	
Fiber								
≤20 g/day	≤4.4	344	1.00 (ref.)	224	1.00 (ref.)	115	1.00 (ref.)	741
	>4.4	595	1.13 (0.92–1.38)	422	1.28 (1.01, 1.61)	159	0.90 (0.66, 1.24)	845
>20 g/day	≤4.4	301	0.65 (0.53–0.80)	206	0.71 (0.56, 0.89)	94	0.55 (0.40, 0.76)	843
	>4.4	445	0.84 (0.68–1.04)	301	0.92 (0.73, 1.18)	139	0.72 (0.52, 1.00)	744
Interaction p values			0.32		0.88		0.07	

[1]Numbers do not add 5,399 due to missing values in dietary variables and cancer site.
[2]Odds ratios (OR) and 95% confidence intervals (CI). Results of mixed models with "area" as random effect adjusted for: sex, age, education, physical activity, non-steroidal anti-inflammatory drugs use, family history of colorectal cancer and energy intake.

Table 4. Dietary ingested nitrate and colorectal cancer risk stratified by cancer site among population with available dietary information ($n = 4{,}858$)

Ingested nitrate from:	Median intake (mg/day)	Colorectal cancer		Colon cancer		Rectal cancer		Controls
		Cases[1]	OR[2] (95% CI)	Cases	OR[2] (95% CI)	Cases	OR[2] (95% CI)	
Animal sources								
<4.5 mg/day	3.1	473	1.00 (ref.)	352	1.00 (ref.)	112	1.00 (ref.)	1,058
4.5–6.8 mg/day	5.6	578	1.15 (0.98, 1.35)	378	1.03 (0.86, 1.24)	191	1.59 (1.22, 2.06)	1,058
>6.8 mg/day	9.4	634	1.16 (0.98, 1.38)	423	1.06 (0.87, 1.30)	204	1.55 (1.17, 2.05)	1,057
Continuous			1.03 (1.01, 1.05)		1.02 (1.00, 1.04)		1.04 (1.01, 1.07)	
Vegetable sources[3]								
<68 mg/day	42	597	1.00 (ref.)	392	1.00 (ref.)	194	1.00 (ref.)	1,058
68–118 mg/day	92	575	0.99 (0.85, 1.16)	397	1.04 (0.87, 1.24)	169	0.91 (0.71, 1.16)	1,058
>118 mg/day	179	513	0.83 (0.70, 0.99)	364	0.89 (0.73, 1.08)	144	0.75 (0.57, 0.99)	1,057
Continuous			1.00 (0.99, 1.00)		1.00 (0.99, 1.00)		1.00 (0.99, 1.00)	
Total diet[3]								
<83 mg/day	59	594	1.00 (ref.)	388	1.00 (ref.)	195	1.00 (ref.)	1,058
83–133 mg/day	108	564	0.97 (0.83, 1.14)	394	1.04 (0.87, 1.24)	161	0.85 (0.66, 1.08)	1,058
>133 mg/day	176	527	0.84 (0.70, 1.00)	371	0.90 (0.74, 1.10)	151	0.76 (0.58, 1.00)	1,057
Continuous			1.00 (0.99, 1.00)		1.00 (0.99, 1.00)		1.00 (0.99, 1.00)	

[1]This column does not add to total number of cancer cases since 46 were undefined site.
[2]Odds ratios (OR) and 95% confidence intervals (CI). Results of mixed models with "area" as random effect adjusted for sex, age, education, physical activity, non-steroidal anti-inflammatory drugs use, family history of colorectal cancer, body mass index and intake energy.
[3]Results are also adjusted for fiber intake.

subjects with high red meat intake. The associations slightly differed for colon and rectal cancer. A positive association was found between rectal cancer risk and nitrate intake from animal sources, but an inverse association is suggested with intake from vegetables.

This is one of the few studies evaluating CRC risk and nitrate exposure through drinking water. Our results are comparable to previous case–control studies from the United States, although those studies evaluated residential, but not ingested nitrate, at higher levels than those observed in our study. A 2.9-fold increased risk of proximal colon cancer for NO_3-N residential levels $\geq$10 mg/L (44 mg/L of NO_3^-) versus <0.5 mg/L has been reported.[30] Increased risk of colon cancer was found among subjects with residential NO_3-N levels >5 mg/L for >10 years and low vitamin C intake or high meat intake.[16] Other available studies had ecologic design or ignored endogenous nitrosation factors and individual water consumption data,[31,32] thus are not totally comparable to our study.

Dietary ingested nitrate levels in this study were similar to those observed in other western countries.[33] Our results are consistent with a cohort study[15] that found higher colon cancer risk with ingested nitrate from animal sources. Results from other studies on CRC and dietary nitrate, nitrite or NOCs are heterogeneous,[5,6,13,14] and most of them did not evaluate ingestion from different dietary sources. In contrast to results for animal-derived nitrate, inverse associations were found for high nitrate intake from vegetables. These results may not be confounded by the protective effect of fiber, since the analyses were adjusted for this variable. The presence of endogenous nitrosation inhibitors in vegetables and hypothesized beneficial effects of nitrate from vegetables[34] may partly explain these findings.

Our results suggest an interaction between waterborne nitrate exposure and sex for CRC and colon cancer, but not for rectal cancer. The associations were higher among men, similarly to other exposures such as dietary factors.[35] This may partly be attributed to the protective effect of estrogens and other hormonal factors.[36] We found higher associations in groups with high red meat intake. These results were consistent with previous studies that evaluated other cancer types associated with nitrate or nitrite exposure.[33,37] Although the interaction with red meat was not statistically significant, is plausible, because red meat contains amines, amides, and heme iron which may increase endogenous formation of NOCs.[38] Information on heme iron intake was not available in this study, but should be accounted to evaluate the interaction with red meat in future analysis.[39] In contrast, inverse associations were found in groups of high vitamin E or fiber intake. Vitamins E and C inhibit endogenous nitrosation, and a protective effect is biologically plausible. The combined intake of vitamins C and E showed similar effects to those shown for each vitamin. The protective effect of fiber was also expected, based on previous evidence on fiber intake and CRC risk.[40] Apart from endogenous nitrosation, changes in gastrointestinal microbiota,[41] and genetic variants of CYP2E1 (involved in NOCs' bio-activation),[14] may also play a role in carcinogenesis of ingested nitrate and should be explored in future analyses.

Confounding by other water contaminants such as THMs[42] was a concern. In this study, estimates of THMs intake were available, and were evaluated as potential confounders. Associations decreased slightly after adjusting for chloroform, and increased slightly after adjusting for brominated THMs or total THMs, but the differences were not statistically significant. The potential interaction of these frequent water contaminants requires further evaluation, since contradictory effects are suggested for chlorinated versus brominated THMs. Other water contaminants showed levels around or below the QL in our study areas,[23] and are not likely to be relevant confounders in the context of this study.

Although different response rates between study areas and relatively low rates among controls may be a limitation, nonparticipation is unlikely related to nitrate exposure. Potential exposure measurement error is a limitation, since nitrate measurements in drinking water were only available in recent years. Missing historical levels were estimated based on recent measurements and were assumed to remain stable over time, depending on groundwater percentages. This assumption may introduce measurement error, particularly for long-term periods (*e.g.*, adult life). Nitrate levels may differ widely between groundwater sources according to the depth of wells, and may change in time according to factors other than water source (*e.g.*, agricultural practices). Such information was not collected, since the questionnaire was not originally designed to estimate historical nitrate levels, and was not available in official reports. However, we analyzed the municipalities with longest nitrate records: Llíria (Valencia) and Donostia (Gipuzkoa), and no significant changes were found in nitrate levels over 17 years. The levels estimated for a 30-year period would be sufficient to evaluate the association with CRC risk, among this population. Additionally, we applied several strategies to address the potential exposure measurement error: we analyzed only the population with exposure information available for $\geq$70% of the main exposure period (30 to 2 years before the interview). We performed sensitivity analyses excluding less reliable exposure estimates, obtaining similar results to those shown in Table 2. We analyzed three different exposure periods, but results for adult life and early adult life are limited because are based on estimates with low reliability. In addition, nitrate estimates from different exposure periods were highly correlated. Studies in other settings, with larger availability of historical environmental data, are needed to increase the current evidence on waterborne nitrate exposure and CRC risk.

Since dietary information was collected with a FFQ, recall bias may not be totally ruled out in the analyses for dietary nitrate. The results for dietary nitrate intake may not be extrapolated for long-term periods, since dietary information corresponded to the last 2 years previous to recruitment. Estimates of dietary nitrate are prone to measurement error since we used the same nitrate contents in food products, regardless of potential country-specific levels. However, the database used is valid for all European countries, and includes specific Spanish and Italian measurements.[4] Data on relevant vegetable sources of nitrate was not completely available, and data on storage and processing (*i.e.*, washing, peeling and cooking) was not collected, which also may introduce error in calculations of nitrate intake from vegetables. Finally, dietary nitrite intake was not available, but this would not be a major limitation since the main exposure route expected is through endogenous nitrate reduction.[8]

The wide differences on nitrate levels between study areas, and the low variability within areas hampered the statistical analyses. We applied different approaches for all-area combined analyses, including unconditional logistic regression, GAMs, and meta-smoothing analyses[43] (previously used in multicentric studies on air pollution). Mixed models, with area as random effect were finally applied given the heterogeneity of results between study areas. This heterogeneity is a limitation, and is probably related to other environmental or individual factors that were not evaluated in this study. The results of mixed models differed slightly from results of the GAMs, particularly among women. Results among women may be less robust due to the smaller sample size, compared with men. Results of meta-smoothing analyses are not shown, because were equivalent to results of the GAMs.

A main strength of this study was the availability of detailed individual information, allowing the assessment of several potential confounders and effect modifiers, including other frequent water contaminants (THMs) and endogenous nitrosation factors. In addition, the FFQ information enabled us to assess nitrate exposure through different dietary sources. Nitrate measurements in non municipal water (wells) were measured and included in the exposure assessment for the area with the highest consumption of this water type (León). Finally, the main results were robust, as were replicated using different approaches for statistical analysis.

Conclusions

Overall, effects of nitrate exposure differed by exposure source (water, vegetables and animal dietary sources). A positive association is suggested between CRC risk and long-term exposure to nitrate in drinking water at levels below the European regulatory limit, particularly among subjects with other risk factors. Dietary nitrate from animal sources increased rectal cancer risk, but high intake from vegetables seems to decrease it. Further research is required to confirm these findings.

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Nitrate in drinking water and colorectal cancer risk: A nationwide population-based cohort study

Jörg Schullehner [1,2,3,4], Birgitte Hansen[2], Malene Thygesen[3,4], Carsten B. Pedersen[3,4] and Torben Sigsgaard[1]

[1] Department of Public Health, Aarhus University, Aarhus, Denmark
[2] Department of Groundwater and Quaternary Geology Mapping, Geological Survey of Denmark and Greenland, Aarhus, Denmark
[3] National Centre for Register-Based Research, Department of Economics and Business Economics, School of Business and Social Sciences, Aarhus University, Aarhus, Denmark
[4] Centre for Integrated Register-based Research, CIRRAU, Aarhus University, Aarhus, Denmark

Nitrate in drinking water may increase risk of colorectal cancer due to endogenous transformation into carcinogenic *N*-nitroso compounds. Epidemiological studies are few and often challenged by their limited ability of estimating long-term exposure on a detailed individual level. We exploited population-based health register data, linked in time and space with longitudinal drinking water quality data, on an individual level to study the association between long-term drinking water nitrate exposure and colorectal cancer (CRC) risk. Individual nitrate exposure was calculated for 2.7 million adults based on drinking water quality analyses at public waterworks and private wells between 1978 and 2011. For the main analyses, 1.7 million individuals with highest exposure assessment quality were included. Follow-up started at age 35. We identified 5,944 incident CRC cases during 23 million person-years at risk. We used Cox proportional hazards models to estimate hazard ratios (HRs) of nitrate exposure on the risk of CRC, colon and rectal cancer. Persons exposed to the highest level of drinking water nitrate had an HR of 1.16 (95% CI: 1.08–1.25) for CRC compared with persons exposed to the lowest level. We found statistically significant increased risks at drinking water levels above 3.87 mg/L, well below the current drinking water standard of 50 mg/L. Our results add to the existing evidence suggesting increased CRC risk at drinking water nitrate concentrations below the current drinking water standard. A discussion on the adequacy of the drinking water standard in regards to chronic effects is warranted.

Nitrate is leached to the aquatic environment, originating mainly from human activities, especially the use of fertilizers in intensive agriculture, and is a frequent drinking water pollutant.[1–3] Denmark is among the countries with the most intensive agriculture with two-thirds of its area under cultivation, resulting in pronounced nitrate pollution of groundwater.[4] The Danish drinking water structure is decentralized and based exclusively on groundwater.[5] The drinking water standard of 50 mg/L as nitrate ion was established to protect infants from the acute condition methemoglobinemia.[1] This standard is almost equivalent to the United States Environmental Protection Agency's maximum contaminant level of 10 mg/L as nitrogen.

However, physiological pathways of possible chronic effects have been suggested, due to endogenous transformation of nitrate into genotoxic *N*-nitroso compounds.[6] Most *N*-nitroso compounds are animal carcinogens,[7] and nitrate has been classified as probably carcinogenic to humans under conditions that favor endogenous nitrosation.[8] Colorectal cancer (CRC) is the third most frequent cancer worldwide,[9] with an age-standardized incidence rate of 43.6 (males) and 33.8 (females) per 100,000 persons per year in Denmark.[10]

Previous epidemiological studies on the association between nitrate in drinking water and CRC are few and yielded inconsistent results.[6] An ecologic study in Slovakia found a positive association between nitrate levels in drinking water and cancers in all digestive organs and CRC in particular.[11] A case–control study in Iowa showed an increased colon cancer risk at elevated nitrate levels in drinking water among susceptible subgroups with elevated endogenous nitrosation, that is, low vitamin C and high red meat intake.[12] A prospective cohort study of women carried out in the same area with a similar exposure assessment found no significant association between colon cancer and the quartile exposed to

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Correspondence to: Jörg Schullehner, Geological Survey of Denmark and Greenland, C.F. Møllers Allé 8, Building 1110, 8000 Aarhus C, Denmark, Tel.: +45-9133-3653, E-mail: jsc@geus.dk

What's new?
Nitrate is considered a probable carcinogen in humans owing to its potential for endogenous transformation into genotoxic *N*-nitroso compounds. Cancer risk related to nitrate pollution in drinking water, as a consequence of intensive agriculture using fertilizers, is of particular concern. Here, analyses of water quality data and health registry data with a high spatiotemporal resolution for 2.7 million people in Denmark reveal an increased risk of colorectal cancer (CRC) in association with nitrate exposure. CRC risk was elevated at nitrate concentrations below the current drinking water standard.

the highest concentrations, while the second and third quartiles showed increased risks, and an inverse association was observed for rectal cancer.[13] A case–control study of women in Wisconsin found no overall association with colon or rectal cancer, but an increased risk of proximal colon cancer at nitrate levels around the drinking water standard.[14] A recent case–control study from Spain and Italy showed the higher the intake of nitrate from drinking water, the higher the risk of colon and rectal cancer, also at levels well below the drinking water standard.[15]

A common limitation of previous studies is the limited ability to access historical nitrate exposure for study subjects. To identify potentially small chronic effects, long-term follow-up of a large population is necessary. Large studies with well-characterized long-term exposures and inclusion of private well users were called for[6] assessing populations with large exposure contrast, even if concentrations are below the drinking water standard.[16]

We addressed these limitations by using the rich population-based Danish registers including longitudinal health and residential information,[17] linked in time and space with the likewise longitudinal information on drinking water quality with high spatial and temporal resolution, covering the entire country from 1978 onward.[5,18] The link of these unique nationwide and longitudinal data sources enabled us to study the association between nitrate in drinking water and CRC on an individual level.

Methods

We followed all Danish residents for development of CRC considering nitrate in drinking water as the exposure of interest. Details are described in the following sections.

Study design and population

The unique personal identification number, which is assigned to all Danish residents, was used as key identifier to accurately link data from several registers. Prospectively collected and continuously updated information on date of birth, sex, residential history and vital status were retrieved from the Danish Civil Registration System.[17] The study period was January 1, 1978 to December 31, 2011, as residential history was geocoded for this period. We defined the cohort as all residents of Denmark, alive on their 35th birthday. We followed each individual from their 35th birthday until the onset of colon or rectal cancer, the end of study (31 December 2011), death, emigration or disappearance. Diagnoses of colon cancer (ICD-10 codes C18 and C19), rectal cancer (C20) and all other cancers were retrieved from the Danish Cancer Registry, which has a high validity and degree of completeness.[19]

Exposure assessment

The approach of assigning each household to its annual nitrate concentration is described in detail elsewhere.[18] In brief, we assigned annual average drinking water nitrate concentrations, registered at waterworks level, to the 2,852 public water supply areas and the 2,382,445 publicly supplied households within these. Privately supplied households (81,663) were identified and assigned nitrate concentrations of their private well. In total, 208,706 drinking water samples with precise sampling date and location were used in this study. We interpolated concentrations for years without available nitrate measurements at household level. An exposure assessment quality level based on the number of years to the closest nitrate sample was calculated for each household and year (for detailed explanation of the levels, see results from sensitivity analyses in Table 2).

We calculated each individual's average nitrate exposure between their 20th and 35th birthday by linking their residential history from 1978 onward in time and space to the longitudinal drinking water nitrate concentration data at the Danish households. To be able to calculate an individual's exposure, their exposure window had to overlap with the study period, that is, their 35th birthday had to be after the beginning of study (January 1, 1978) and before the end of study (December 31, 2011). For the main analyses, we included only individuals with a high exposure assessment quality, having lived at least 75% of the time at households with an associated nitrate sample taken within 1 year.

Covariates

Covariates were selected *a priori*. Socioeconomic status was based on the *highest attained education* of each individual from the educational registers and included in four categories: (*i*) primary school only, (*ii*) shorter education (high school and short vocational training), (*iii*) medium long education (vocational training and bachelors) and (*iv*) long education (academics).[20] We included information on any *previous cancer*

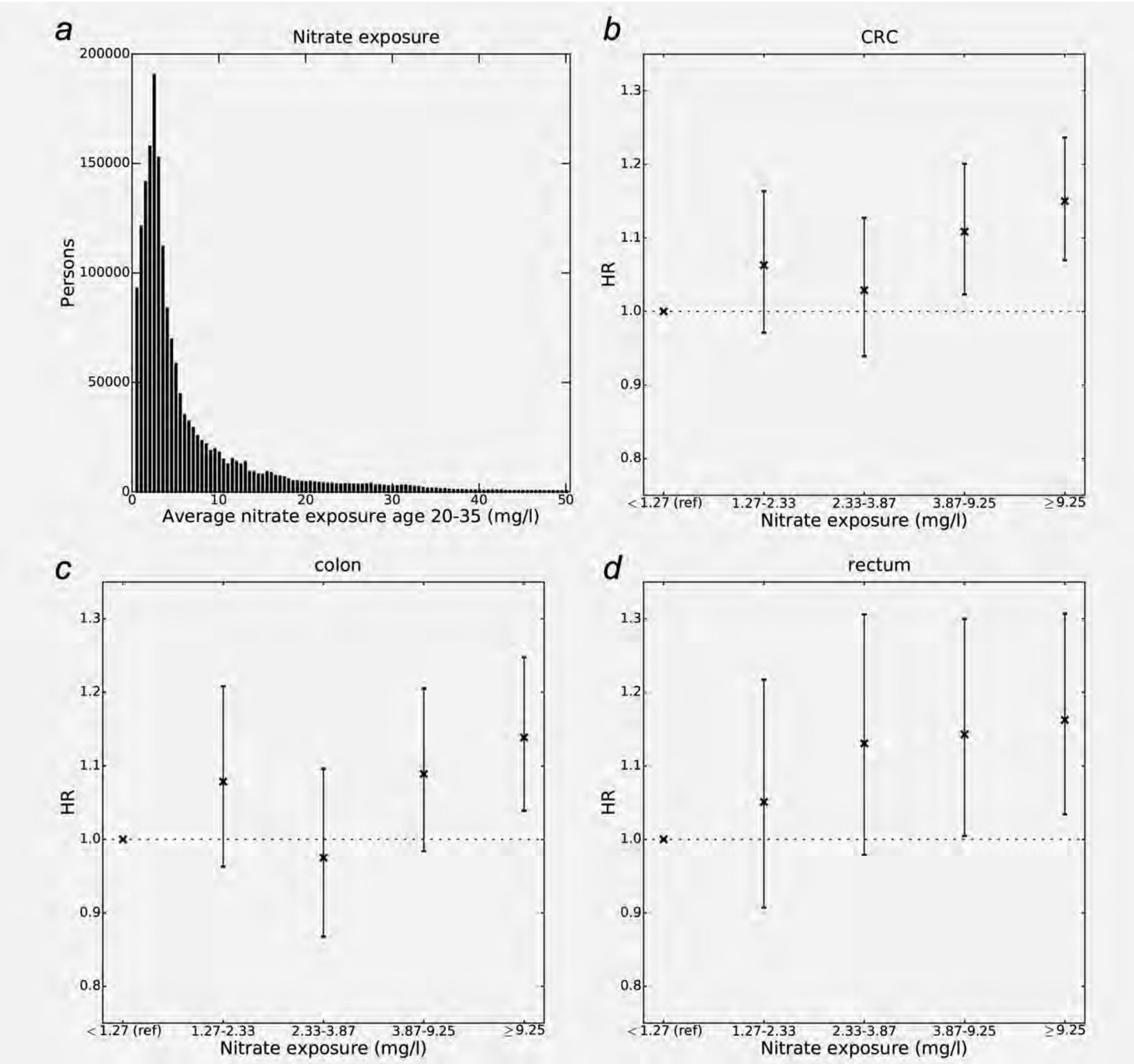

Figure 1. (*a*) Average drinking water nitrate exposure between age 20 and 35 of the study population (subjects exposed to > 50 mg/l [0.58%] not shown here). Hazard ratios (HR) and 95% CIs of nitrate exposure quintiles for (*b*) colorectal, (*c*) colon and (*d*) rectal cancer. Base adjustment.

diagnosis other than the outcome of interest, and *year of birth* in two-year bands to address birth cohort effects.

Statistical analyses

We assessed the association between drinking water nitrate and colon and rectal cancer as separate outcomes, and the combined outcome CRC. We used Cox proportional hazards models to estimate hazard ratios (HRs) using age as the underlying time scale while stratifying the baseline by sex. We included nitrate exposure as quintiles according to the distribution of nitrate exposure in the total population. The base adjustment controlled for age, sex, year of birth and previous cancer diagnosis. Additionally, we adjusted for highest attained education (2nd adjustment). We calculated a summary trend estimate, measuring the effect on a person exposed to the highest decile of nitrate concentrations in drinking water ($\geq$16.75 mg/L) compared with a person exposed to the lowest decile of nitrate concentrations in drinking water ($<$0.69 mg/L), utilizing data from the in-between deciles (nominal scoring of deciles). Results are reported with 95% confidence intervals (CIs). We checked the validity of the proportional hazards assumption by assessing the null hypothesis of a zero slope of the Schoenfeld residuals on time. Analyses were done in STATA 13.1.

Table 1. Adjusted hazard ratios (95% CIs) associated with high levels of nitrate exposure compared with low levels (trend estimate). Incident cases and study population size (*N*)

Cancer site	*N*[1]	Cases[1]	Base adjustment[2]	Second adjustment[3]
Colorectal	1,742,093	5,944	1.16 (1.08–1.25)	1.14 (1.06–1.23)
Colon	1,742,156	3,700	1.15 (1.05–1.26)	1.14 (1.04–1.26)
Rectum	1,742,255	2,308	1.17 (1.04–1.32)	1.13 (1.00–1.27)

[1]Incident cases for colon and rectal cancer are not mutually exclusive.
[2]Age, sex, year of birth and previous cancer diagnosis.
[3]Base and highest attained education.

Sensitivity analyses

Using the trend estimate, we assessed the robustness of our results considering potential bias due to private well users and quality, length and period of each individual's exposure assessment. We excluded persons with a previous cancer diagnosis other than the outcome of interest and residents of the Capital Region.

Ethical considerations

In keeping with Danish legislation, the Danish Data Protection Agency, the Danish Health Data Authority and Statistics Denmark approved this study.

Results

Of the 2,833,825 Danish residents whose exposure window concurred with the study period, 1,742,321 (61%) met the high exposure assessment quality criterion and were included in the main analyses. Persons who had a diagnosis before initiation of follow-up were excluded (CRC: 228; colon: 165; rectum: 66). The distribution of the average nitrate exposure between age 20 and 35 for this study population is shown in Figure 1a. During the 23 million person-years of follow-up, 5,944 persons were diagnosed with CRC, 3,700 with colon cancer and 2,308 with rectal cancer (Table 1 and Supporting Information, Table 1).

Figure 1 shows the HRs of the nitrate concentration exposure quintiles for (b) CRC, (c) colon and (d) rectal cancer. For both CRC and rectal cancer alone, the two highest exposure quintiles (>3.87 mg/L) showed statistically significant increased HRs. For colon cancer alone, only the highest exposure quintile (≥9.25 mg/L) was associated with a statistically significant increased HR. In the following, we focus on the trend estimate.

Individuals exposed to the highest level of drinking water nitrate (≥16.75 mg/L) had an increased risk of CRC [HR: 1.16 (95% CI: 1.08–1.25)] compared with individuals exposed to the lowest exposure level (<0.69 mg/L; see Table 1, base adjustment). Additional adjustment for education had only limited influence. Similar results were obtained when considering colon and rectal cancer as separate outcomes. Effect modification by sex was not observed (CRC: $p = 0.49$; colon: $p = 0.44$; rectum: $p = 0.99$; second adjustment). Stepwise reincluding individuals with a lower exposure assessment quality increased the study population to ultimately 2,692,508 individuals, followed for ~44 million person-years (Table 2). As exposure assessment quality decreased, the observed effect sizes decreased as well.

Additional sensitivity analyses yielded robust results (Table 3). The proportional hazards assumption was not violated in any of the presented models. A previous cancer diagnosis other than the outcome of interest was associated with increased HRs for all outcomes, and a protective effect of increasing levels of education was observed (results not shown).

Discussion

This is the first nationwide population-based study using a historical longitudinal assessment of long-term drinking water nitrate exposure to assess the associated risk of CRC. Our results showed the higher the level of nitrate in drinking water, the higher the risk of CRC. Considering colon and rectal cancer as separate outcomes, we found similar results. Results for CRC combined and rectal cancer alone showed statistically significant increased HRs in the two highest quintiles of exposure (>3.87 mg/L). For colon cancer, this was only seen in the highest quintile (≥9.25 mg/L), still at concentrations substantially below the current drinking water standard of 50 mg/L. This suggests a need of lowering the drinking water standard to adequately protect the public against chronic adverse health effects of nitrate in drinking water.

From Figure 1, a dose–response relationship is suggested, which is supported by the results for the trend estimate of 1.14 (95% CI: 1.06–1.23) for CRC, 1.14 (1.04–1.26) for colon cancer alone and 1.13 (1.00–1.27) for rectal cancer alone in the full adjustment. Hazard ratios were similar in all adjustments, indicating little influence of the included covariates and sensitivity analyses showed stable and robust results. Interestingly, the higher the exposure assessment quality, the higher effect sizes were observed (Table 2). Lower exposure assessment quality levels were due to interpolation of nitrate concentrations for years with no sample taken at the respective waterworks. Consequently, effect sizes were expected to attenuate with increasing levels of misclassification.[21]

Our results showed a statistically significant positive association between nitrate in drinking water and CRC at levels well below the current drinking water standard, which is in agreement with the findings of a recent case–control study.[15] Espejo-Herrera *et al*. found an increased risk for colon cancer from 5 mg/d waterborne nitrate intake (corresponding to drinking water concentrations of ~4.3 mg/L), and for CRC and rectal cancer from ~8.6 mg/L. Espejo-Herrera *et al*. had individual-level data on endogenous nitrosation factors, diet, lifestyle and water consumption, allowing controlling for established CRC risk factors and additional covariates. They observed higher effect sizes in groups with high red meat intake, in agreement with a previous study.[12]

Table 2. Stepwise reinclusion of individuals with at least 75% of their exposure window at given, or higher, exposure assessment quality level. Trend estimate: hazard ratios (95% CIs), study population size (*N*) and number of cases for colon and rectal cancer. Second adjustment (age, sex, year of birth, previous cancer diagnosis and highest attained education)

Exposure assessment quality	Explanation	*N*[1]	Colon	Rectum
High (main analyses)	At least one nitrate sample taken within 1 year at waterworks supplying the residence[2]	1,742,156	1.14 (1.04–1.26)	1.13 (1.00–1.27)
		Cases	3,700	2,308
Medium high	At least one nitrate sample taken within 5 years at waterworks supplying the residence[2]	2,139,124	1.11 (1.03–1.19)	1.10 (1.01–1.21)
		Cases	6,025	3,764
Medium	At least one nitrate sample taken within 10 years at waterworks supplying the residence[2]	2,299,309	1.08 (1.01–1.16)	1.10 (1.01–1.19)
		Cases	6,966	4,384
Medium low	At least one nitrate sample taken outside time window of 10 years at waterworks supplying the residence[2]	2,615,138	1.09 (1.02–1.16)	1.08 (0.99–1.16)
		Cases	8,652	5,495
Low	No nitrate sample taken at waterworks supplying the residence[2]	2,692,508	1.09 (1.03–1.15)	1.07 (0.99–1.15)
		Cases	8,844	5,618

[1]Study population *N* for colon cancer analyses.
[2]Residence: longitudinal data refers to exposure assessment quality of each individual's residence at any point in time during the exposure window.

Table 3. Sensitivity analyses: hazard ratios (95% CIs) of trend estimate and study size *N*. Full adjustment: age, sex, year of birth, previous cancer diagnosis and education

Scenario	*N*[1]	Colon	Rectum
Main analysis (Table 1)	1,742,156	1.14 (1.04–1.26)	1.13 (1.00–1.27)
Excluding private well users	1,684,944	1.14 (1.04–1.25)	1.13 (1.00–1.27)
At least 5 years of exposure data	1,562,072	1.15 (1.01–1.31)	1.07 (0.90–1.26)
At least 10 years of exposure data	1,351,232	1.18 (0.98–1.41)	1.06 (0.84–1.33)
Only individuals with colon/rectum cancer as first cancer diagnosis	1,681,694	1.13 (1.02–1.25)	1.11 (0.98–1.26)
New exposure window: age 30–40	1,798,350	1.13 (1.05–1.21)	1.07 (0.98–1.18)
Excluding capital region	1,195,094	1.18 (1.06–1.31)	1.09 (0.95–1.25)

[1]Study population *N* for colon cancer analyses.

While we could not include individual-level data on diet and lifestyle, the strength of our study lies in its large population size and the comprehensive long-term exposure assessment. By including the entire population (up to 2.7 million persons followed for up to 34 years), we avoided selection bias. Register data used in this study are deemed to be of very high validity and completeness.[17,19] All administrative, health and drinking water quality data were prospectively collected, thereby eliminating bias due to differential recall and loss to follow-up.

In contrast to previous studies, our exposure assessment was based on exhaustive longitudinal drinking water quality data, registered in one nationwide database. We did not need to model historical nitrate concentrations at the waterworks, but could rely on the actual measurements of nitrate concentrations in drinking water samples taken and analyzed by certified laboratories.[22] We used the physical drinking water supply areas to assign nitrate concentrations to each household and knew the precise residential history of all study participants. Here, our exposure assessment is superior to earlier studies that needed to model historical exposure both spatially and temporally, or estimated exposure by nitrate concentrations at a given location at a single point in time.

Estimating waterborne nitrate intake from residential tap water is reasonable in the Danish context; the annual bottled water consumption is the lowest in Europe with 26 L per person.[23] Furthermore, it has been shown that nitrate levels do not change within a given distribution system and that seasonal variations in drinking water nitrate levels at public supplies are negligible in Denmark.[24] Groundwater abstracted for drinking water production has a typical age (time since recharge) of 10–60 years.[24] We do not have adequate data to assess seasonal variability in private wells. However, seasonal variability in shallow wells has been observed in other locations.[25] Private wells are often shallower than public supply wells; therefore, we cannot exclude seasonal variability in private wells. Since Danish waterworks abstain from using chemical disinfection, confounding by disinfection by-products was not a concern in this study.[26] Water samples used in this study were taken after all treatment steps at the waterworks. The use of in-home water treatment installations to reduce nitrate concentrations is uncommon in Denmark and authorities have been restrictive in giving permission to use such installations at private wells.[27]

The possibility of including information on private wells is another strength of our work. It was earlier shown that the drinking water sampling frequency for private wells is much lower compared to public supplies.[5,18] Therefore, residing a long time at a privately supplied household decreased an individual's exposure assessment quality level. The stepwise inclusion of lower exposure assessment quality levels into the model was therefore crucial to include those who lived many years with private well supply. Even though we could only retrieve nitrate concentrations of approximately half of the 55,752 private wells that we identified,[18] we knew the location of the remaining wells and could therefore exclude their users in our sensitivity analyses.

Given our study design, we were limited to include only covariates available in nationwide registers. We could for example not control for individual-level information on lifestyle and diet. A study on the dietary intake of nitrate in the Danish population estimated an average nitrate intake of 61 mg/d for adults.[28] Therefore, at elevated levels as seen in parts of the Danish population (Figure 1a), drinking water will be a major source of nitrate exposure. As diet (e.g., red meat), alcohol intake, smoking and lifestyle factors such as physical inactivity are established CRC risk factors that we could not include in our analyses, the possibility of confounding our results needs to be considered. To address this issue, we adjusted our analyses for highest attained education, an especially appropriate proxy for lifestyle, smoking and diet in the Danish population.[29] Furthermore, studies suggest that dietary nitrate intake is not associated with CRC, or even has a protective effect, because of antioxidants and nitrosation inhibitors in nitrate-containing foods.[6] Nevertheless, any observational study of human health, including the present, cannot exclude the possibility of residual confounding by unobserved factors.

Another limitation is the omission of drinking water nitrite levels in our models. Nitrite is an intermediate in the endogenous transformation of nitrate into genotoxic *N*-nitroso compounds. Nitrite occurs in groundwater in the anoxic nitrate reducing zone but can also be formed at the waterworks due to oxidation of ammonium. Drinking water samples are historically not measured for nitrite to the same extent as nitrate. The restrictive drinking water standard of 0.01 mg/L nitrite is complied with at the large waterworks[30]; however, little is known for smaller waterworks and private wells. An earlier study showed that even though nitrite is taken up through drinking water and food, up to 77% of the total exposure to nitrite is due to the reduction of nitrate *in vivo*.[31] Furthermore, nitrate in drinking water could also be a proxy for additional agricultural pollutants, such as pesticides, which we did not consider here.

We used the average nitrate concentration an individual was exposed to between their 20th and 35th birthdays as the exposure estimate. We assumed that this exposure period was representative of the relevant relationship between exposure and outcome. As geocoded residences were available from 1978 onward, our main analyses included the early cases of CRC only, with an age at diagnosis below 69, before incidence rates peak. Shifting the exposure window to age 30–40, we could include more cases (until age 74), however, at the expense of moving the exposure closer to the time of disease onset. We observed a high agreement between the estimated nitrate exposures in the two competing exposure models. Changing the exposure window to age 30–40 did not substantially change the associated HRs.

In conclusion, our study adds to the growing body of evidence that suggests an increased risk of CRC at nitrate levels in drinking water below the current drinking water standard. Several studies carried out in different locations with different designs and each of their strengths and limitations imply this association. While our study contributed with a large study population, the resulting statistical power, and a detailed exposure assessment, other studies' strengths lay in the inclusion of a number of additional covariates. Considering all evidence, not only in the light of the precautionary principle, a discussion about a reduction of the drinking water standard is warranted.

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Review

Drinking Water Nitrate and Human Health: An Updated Review

Mary H. Ward [1,*], Rena R. Jones [1], Jean D. Brender [2], Theo M. de Kok [3], Peter J. Weyer [4], Bernard T. Nolan [5], Cristina M. Villanueva [6,7,8,9] and Simone G. van Breda [3]

1. Occupational and Environmental Epidemiology Branch, Division of Cancer Epidemiology and Genetics, National Cancer Institute, 9609 Medical Center Dr. Room 6E138, Rockville, MD 20850, USA; rena.jones@nih.gov
2. Department of Epidemiology and Biostatistics, Texas A&M University, School of Public Health, College Station, TX 77843, USA; jdbrender@sph.tamhsc.edu
3. Department of Toxicogenomics, GROW-school for Oncology and Developmental Biology, Maastricht University Medical Center, P.O Box 616, 6200 MD Maastricht, The Netherlands; t.dekok@maastrichtuniversity.nl (T.M.d.K.); s.vanbreda@maastrichtuniversity.nl (S.G.v.B.)
4. The Center for Health Effects of Environmental Contamination, The University of Iowa, 455 Van Allen Hall, Iowa City, IA 52242, USA; peter-weyer@uiowa.edu
5. U.S. Geological Survey, Water Mission Area, National Water Quality Program, 12201 Sunrise Valley Drive, Reston, VA 20192, USA; btnolan@usgs.gov
6. ISGlobal, 08003 Barcelona, Spain; cvillanueva@isiglobal.org
7. IMIM (Hospital del Mar Medical Research Institute), 08003 Barcelona, Spain
8. Department of Experimental and Health Sciences, Universitat Pompeu Fabra (UPF), 08003 Barcelona, Spain
9. CIBER Epidemiología y Salud Pública (CIBERESP), 28029 Madrid, Spain

* Correspondence: wardm@mail.nih.gov

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Abstract: Nitrate levels in our water resources have increased in many areas of the world largely due to applications of inorganic fertilizer and animal manure in agricultural areas. The regulatory limit for nitrate in public drinking water supplies was set to protect against infant methemoglobinemia, but other health effects were not considered. Risk of specific cancers and birth defects may be increased when nitrate is ingested under conditions that increase formation of *N*-nitroso compounds. We previously reviewed epidemiologic studies before 2005 of nitrate intake from drinking water and cancer, adverse reproductive outcomes and other health effects. Since that review, more than 30 epidemiologic studies have evaluated drinking water nitrate and these outcomes. The most common endpoints studied were colorectal cancer, bladder, and breast cancer (three studies each), and thyroid disease (four studies). Considering all studies, the strongest evidence for a relationship between drinking water nitrate ingestion and adverse health outcomes (besides methemoglobinemia) is for colorectal cancer, thyroid disease, and neural tube defects. Many studies observed increased risk with ingestion of water nitrate levels that were below regulatory limits. Future studies of these and other health outcomes should include improved exposure assessment and accurate characterization of individual factors that affect endogenous nitrosation.

Keywords: drinking water; nitrate; cancer; adverse reproductive outcomes; methemoglobinemia; thyroid disease; endogenous nitrosation; *N*-nitroso compounds

1. Introduction

Since the mid-1920s, humans have doubled the natural rate at which nitrogen is deposited onto land through the production and application of nitrogen fertilizers (inorganic and manure), the combustion of fossil fuels, and replacement of natural vegetation with nitrogen-fixing crops such as soybeans [1,2]. The major anthropogenic source of nitrogen in the environment is nitrogen fertilizer, the application of which increased exponentially after the development of the Haber–Bosch process in the 1920s. Most synthetic fertilizer applications to agricultural land occurred after 1980 [3]. Since approximately half of all applied nitrogen drains from agricultural fields to contaminate surface and groundwater, nitrate concentrations in our water resources have also increased [1].

The maximum contaminant level (MCL) for nitrate in public drinking water supplies in the United States (U.S.) is 10 mg/L as nitrate-nitrogen (NO_3-N). This concentration is approximately equivalent to the World Health Organization (WHO) guideline of 50 mg/L as NO_3 or 11.3 mg/L NO_3-N (multiply NO_3 mg/L by 0.2258). The MCL was set to protect against infant methemoglobinemia; however other health effects including cancer and adverse reproductive outcomes were not considered [4]. Through endogenous nitrosation, nitrate is a precursor in the formation of *N*-nitroso compounds (NOC); most NOC are carcinogens and teratogens. Thus, exposure to NOC formed after ingestion of nitrate from drinking water and dietary sources may result in cancer, birth defects, or other adverse health effects. Nitrate is found in many foods, with the highest levels occurring in some green leafy and root vegetables [5,6]. Average daily intakes from food are in the range of 30–130 mg/day as NO_3 (7–29 mg/day NO_3-N) [5]. Because NOC formation is inhibited by ascorbic acid, polyphenols, and other compounds present at high levels in most vegetables, dietary nitrate intake may not result in substantial endogenous NOC formation [5,7].

Studies of health effects related to nitrate exposure from drinking water were previously reviewed through early 2004 [8]. Further, an International Agency for Research on Cancer (IARC) Working Group reviewed human, animal, and mechanistic studies of cancer through mid-2006 and concluded that ingested nitrate and nitrite, under conditions that result in endogenous nitrosation, are probably carcinogenic [5]. Here, our objective is to provide updated information on human exposure and to review mechanistic and health effects studies since 2004. We summarize how the additional studies contribute to the overall evidence for health effects and we discuss what future research may be most informative.

2. Drinking Water Nitrate Exposures in the United States and Europe

Approximately 45 million people in the U.S. (about 14% of the population) had self-supplied water at their residence in 2010 [9]. Almost all (98%) were private wells, which are not regulated by the U.S. Environmental Protection Agency (EPA). The rest of the population was served by public water supplies, which use groundwater, surface water, or both. The U.S. Geological Survey's National Water Quality Assessment (USGS-NAWQA) Project [10] sampled principal groundwater aquifers used as U.S. public and private drinking water supplies in 1988–2015. Nitrate levels in groundwater under agricultural land were about three times the national background level of 1 mg/L NO_3-N (Figure 1) [11]. The mixed land use category mostly had nitrate concentrations below background levels reflecting levels in deeper private and public water supply wells. Based on the NAWQA study, it was estimated that 2% of public-supply wells and 6% of private wells exceeded the MCL; whereas, in agricultural areas, 21% of private wells exceeded the MCL [10]. The USGS-NAWQA study also revealed significant decadal-scale changes in groundwater nitrate concentrations among wells sampled first in 1988–2000 and again in 2001–2010 for agricultural, urban, and mixed land uses [12]. More sampling networks had increases in median nitrate concentration than had decreases.

A study of U.S. public water supplies (PWS) using data from EPA's Safe Drinking Water Information System estimated that the percentage of PWS violating the MCL increased from 0.28 to 0.42% during 1994–2009; most increases were for small to medium PWS (<10,000 population served) using groundwater [13]. As a result of increasing nitrate levels, some PWS have incurred expensive upgrades to their treatment systems to comply with the regulatory level [14–16].

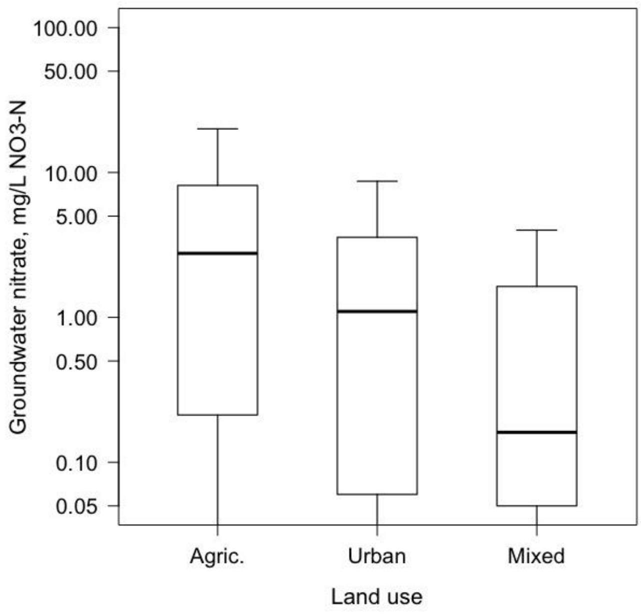

Figure 1. Boxplots of nitrate concentrations in shallow groundwater beneath agricultural and urban land uses, and at depths of private and public drinking water supplies beneath mixed land use. The number of sampled wells were 1573 (agricultural land), 1054 (urban), and 3417 (mixed). The agricultural and urban wells were sampled to assess land use effects, whereas the mixed category wells were sampled at depths of private and public supplies. Median depths of wells in the agricultural, urban, and mixed categories were 34, 32, and 200 feet, respectively. The height of the upper bar is 1.5 times the length of the box, and the lower bound was truncated at the nitrate detection limit of 0.05 mg/L NO_3-N.

In Europe, the Nitrates Directive was set in 1991 [17,18] to reduce or prevent nitrate pollution from agriculture. Areas most affected by nitrate pollution are designated as 'nitrate vulnerable zones' and are subject to mandatory Codes of Good Agricultural Practice [18]. The results of compliance with this directive have been reflected in the time trends of nitrate in some countries. For example, nitrate levels in groundwater in Denmark increased in 1950–1980 and decreased since the 1990s [19]. Average nitrate levels in groundwater in most other European countries have been stable at around 17.5 mg/L NO_3 (4 mg/L NO_3-N) across Europe over a 20-year period (1992–2012), with some differences between countries both in trends and concentrations. Average concentrations are lowest in Finland (around 1 mg/L NO_3 in 1992–2012) and highest in Malta (58.1 mg/L in 2000–2012) [20]. Average annual nitrate concentrations at river monitoring stations in Europe showed a steady decline from 2.7 NO_3-N in 1992 to 2.1 mg/L in 2012 [20], with the lowest average levels in Norway (0.2 mg/L NO_3-N in 2012) and highest in Greece (6.6 mg/L NO_3-N in 2012).

Levels in finished public drinking water have been published only for a few European countries. Trends of nitrate in drinking water supplies from 1976 to 2012 in Denmark showed a decline in public supplies but not in private wells [21]. In Spain, median concentrations were 3.5 mg/L NO_3 (range: 0.4−66.8) in 108 municipalities in 2012 [22], and 4.2 mg/L (range: <1−29) in 11 provinces in 2010 [23]. Levels in other countries included a median of 0.18 mg/L (range: <0.02−7.9) in Iceland in 2001−2012 [24], a mean of 16.1 mg/L (range: 0.05−296 mg/L) in Sicily, Italy in 2004−2005 [25] and a range from undetected to 63.3 mg/L in Deux-Sèvres, France in in 2005−2009 [26].

Nitrate levels in bottled water have been measured in a few areas of the EU and the U.S. and have been found to be below the MCL. In Sicily, the mean level was 15.2 mg/L NO_3(range: 1.2−31.8 mg/L) in 16 brands [25] and in Spain, the median level was 5.2 mg/L NO_3 (range: <1.0−29.0 mg/L) in 9 brands [23]. In the U.S., a survey of bottle water sold in 42 Iowa and 32 Texas communities found varying but generally low nitrate levels. Nitrate concentrations ranged from below the limit of detection (0.1 mg/L NO_3-N) to 4.9 mg/L NO_3-N for U.S. domestic spring water purchased in Texas.

There are few published studies of nitrate concentrations in drinking water outside the U.S. and Europe. Nitrate concentrations in groundwater were reported for Morocco, Niger, Nigeria, Senegal, India-Pakistan, Japan, Lebanon, Philippines and Turkey with maximum levels in Senegal (median 42.9 mg/L NO_3-N) [5]. In India, nitrate in drinking water supplies is particularly high in rural areas, where average levels have been reported to be 45.7 mg/L NO_3 [27,28] and 66.6 mg/L NO_3 [28]; maximum levels in drinking water exceeded 100 mg/L NO_3 in several regions [27,29]. Extremely high levels of nitrate have been reported in The Gaza Strip, where nitrate reached concentrations of 500 mg/L NO_3 in some areas, and more than 50% of public-supply wells had nitrate concentrations above 45 mg/L NO_3 [30].

3. Exposure Assessment in Epidemiologic Studies

With the implementation of the Safe Drinking Water Act in 1974, more than 40 years of monitoring data for public water supplies in the U.S. provide a framework of measurements to support exposure assessments. Historical data for Europe are more limited, but a quadrennial nitrate reporting requirement was implemented as part of the EU Nitrates Directive [17,18]. In the U.S., the frequency of sampling for nitrate in community water systems is stipulated by their sources (ground versus surface waters) and whether concentrations are below the MCL, and historically, by the size of the population served and vulnerability to nitrate contamination. Therefore, the exposure assessment for study participants who report using a public drinking water source may be based on a variable number of measurements, raising concerns about exposure misclassification. In a study of bladder cancer risk in Iowa, associations were stronger in sensitivity analyses based on more comprehensive measurement data [31]. Other studies have restricted analyses to subgroups with more complete or recent measurements [32–35], with implications for study power and possible selection biases. Sampling frequency also limits the extent to which temporal variation in exposure can be represented within a study population, such as the monthly or trimester-based estimates of exposure most relevant for etiologic investigations of adverse reproductive outcomes. In Denmark, limited seasonal variation in nitrate monitoring data suggested these data would sufficiently capture temporal variation for long-term exposure estimates [36]. Studies have often combined regulatory measurements with questionnaire and ancillary data to better characterize individual variation in nitrate exposure, such as to capture changes in water supply characteristics over time or a participant's duration at a drinking water source [31,33,37,38]. Most case-control studies of drinking water nitrate and cancer obtained lifetime residence and drinking water source histories, whereas cohort studies typically have collected only the current water source. Many studies lacked information about study participants' water consumption, which may be an important determinant of exposure to drinking water contaminants [39].

Due to sparse measurement data, exposures for individuals served by private wells are more difficult to estimate than exposures for those on public water supplies. However, advances in geographic-based modeling efforts that incorporate available measurements, nitrogen inputs, aquifer characteristics, and other data hold promise for this purpose. These models include predictor variables describing land use, nitrogen inputs (fertilizer applications, animal feeding operations), soils, geology, climate, management practices, and other factors at the scale of interest. Nolan and Hitt [40] and Messier et al. [41] used nonlinear regression models with terms representing nitrogen inputs at the land surface, transport in soils and groundwater, and nitrate removal by processes such as denitrification, to predict groundwater nitrate concentration at the national scale and for North Carolina, respectively. Predictor variables in the models included N fertilizer and manure, agricultural or forested land use, soils, and, in Nolan and Hitt [40], water-use practices and major geology. Nolan and Hitt [40] reported a training R^2 values of 0.77 for a model of groundwater used mainly for private supplies and Messier, Kane, Bolich and Serre [41] reported a cross-validation testing R^2 value of 0.33 for a point-level private well model. These and earlier regression approaches for groundwater nitrate [42–46] relied on predictor variables describing surficial soils and activities at the land surface, because conditions at depth in the aquifer typically are unknown. Redox conditions in the aquifer and the time since water entered the subsurface (i.e., groundwater age) are two of the most important factors affecting groundwater nitrate, but redox constituents typically are not analyzed, and age is difficult to measure. Even if a well has sufficient data to estimate these conditions, the data must be available for all wells in order to predict water quality in unsampled areas. In most of the above studies, well depth was used as a proxy for age and redox and set to average private or public-supply well depth for prediction.

Recent advances in groundwater nitrate exposure modeling have involved machine-learning methods such as random forest (RF) and boosted regression trees (BRT), along with improved characterization of aquifer conditions at the depth of the well screen (the perforated portion of the well where groundwater intake occurs). Tree-based models do not require data transformation, can fit nonlinear relations, and automatically incorporate interactions among predictors [47]. Wheeler et al. [48] used RF to estimate private well nitrate levels in Iowa. In addition to land use and soil variables, predictor variables included aquifer characteristics at the depth of the well screen, such as total thickness of fine-grained glacial deposits above the well screen, average and minimum thicknesses of glacial deposits near sampled wells, and horizontal and vertical hydraulic conductivities near the wells. Well depth, landscape features, nitrogen sources, and aquifer characteristics ranked highly in the final model, which explained 77% and 38% of the variation in training and hold-out nitrate data, respectively.

Ransom et al. [49] used BRT to predict nitrate concentration at the depths of private and public-supply wells for the Central Valley, California. The model used as input estimates of groundwater age at the depth of the well screen (from MODFLOW/MODPATH models) and depth-related reducing conditions in the groundwater. These estimates were generated by separate models and were available throughout the aquifer. Other MODFLOW-based predictor variables comprised depth to groundwater, and vertical water fluxes and the percent coarse material in the uppermost part of the aquifer where groundwater flow was simulated by MODFLOW. Redox variables were top-ranked in the final BRT model, which also included land use-based N leaching flux, precipitation, soil characteristics, and the MODFLOW-based variables described above. The final model retained 25 of an initial 145 predictor variables considered, had training and hold-out R^2 values of 0.83 and 0.44 respectively, and was used to produce a 3D visualization of nitrate in the aquifer. These studies show that modeling advances and improved characterization of aquifer conditions at depth are increasing our ability to predict nitrate exposure from drinking water supplied by private wells.

4. Nitrate Intake and Endogenous Formation of *N*-Nitroso Compounds

Drinking water nitrate is readily absorbed in the upper gastrointestinal tract and distributed in the human body. When it reaches the salivary glands, it is actively transported from blood into saliva and levels may be up to 20 times higher than in the plasma [50–53]. In the oral cavity 6–7% of the total nitrate can be reduced to nitrite, predominantly by nitrate-reducing bacteria [52,54,55]. The secreted nitrate as well as the nitrite generated in the oral cavity re-enter the gastrointestinal tract when swallowed.

Under acidic conditions in the stomach, nitrite can be protonated to nitrous acid (HNO_2), and subsequently yield dinitrogen trioxide (N_2O_3), nitric oxide (NO), and nitrogen dioxide (NO_2). Since the discovery of endogenous NO formation, it has become clear that NO is involved in a wide range of NO-mediated physiological effects. These comprise the regulation of blood pressure and blood flow by mediating vasodilation [56–58], the maintenance of blood vessel tonus [59], the inhibition of platelet adhesion and aggregation [60,61], modulation of mitochondrial function [62] and several other processes [63–66].

On the other hand, various nitrate and nitrite derived metabolites such as nitrous acid (HNO_2) are powerful nitrosating agents and known to drive the formation of NOC, which are suggested to be the causal agents in many of the nitrate-associated adverse health outcomes. NOC comprise *N*-nitrosamines and *N*-nitrosamides, and may be formed when nitrosating agents encounter *N*-nitrosatable amino acids, which are also from dietary origin. The nitrosation process depends on the reaction mechanisms involved, on the concentration of the compounds involved, the pH of the reaction environment, and further modifying factors, including the presence of catalysts or inhibitors of *N*-nitrosation [66–69].

Endogenous nitrosation can also be inhibited, for instance by dietary compounds like vitamin C, which has the capacity to reduce HNO_2 to NO; and alpha-tocopherol or polyphenols, which can reduce nitrite to NO [54,70–72]. Inhibitory effects on nitrosation have also been described for dietary flavonoids such as quercetin, ferulic and caffeic acid, betel nut extracts, garlic, coffee, and green tea polyphenols [73,74]. Earlier studies showed that the intake of 250 mg or 1 g ascorbic acid per day substantially inhibited *N*-nitrosodimethylamine (NDMA) excretion in 25 women consuming a fish meal rich in amines (nitrosatable precursors) for seven days, in combination with drinking water containing nitrate at the acceptable daily intake (ADI) [75]. In addition, strawberries, garlic juice, and kale juice were shown to inhibit NDMA excretion in humans [76]. The effect of these fruits and vegetables is unlikely to be due solely to ascorbic acid. Using the *N*-nitrosoproline (NPRO) test, Helser et al. [77] found that ascorbic acid only inhibited nitrosamine formation by 24% compared with 41–63% following ingestion of juices (100 mL) made of green pepper, pineapple, strawberry or carrot containing an equal total amount of ascorbic acid.

The protective potential of such dietary inhibitors depends not only on the reaction rates of *N*-nitrosatable precursors and nitrosation inhibitors, but also on their biokinetics, since an effective inhibitor needs to follow gastrointestinal circulation kinetics similar to nitrate [78]. It has been argued that consumption of some vegetables with high nitrate content, can at least partially inhibit the formation of NOC [79–81]. This might apply for green leafy vegetables such as spinach and rocket salad, celery or kale [77] as well as other vegetables rich in both nitrate and natural nitrosation inhibitors. Preliminary data show that daily consumption of one bottle of beetroot juice containing 400 mg nitrate (the minimal amount advised for athletes to increase their sports performances) for one day and seven days by 29 young individuals results in an increased urinary excretion of apparent total nitroso compounds (ATNC), an effect that can only be partially inhibited by vitamin C supplements (1 g per day) [82].

Also, the amount of nitrosatable precursors is a key factor in the formation of NOC. Dietary intakes of red and processed meat are of particular importance [83–87] as increased consumption of red meat (600 vs. 60 g/day), but not white meat, was found to cause a three-fold increase in fecal NOC levels [85]. It was demonstrated that heme iron stimulated endogenous nitrosation [84], thereby providing a possible explanation for the differences in colon cancer risk between red and white meat consumption [88]. The link between meat consumption and colon cancer risk is even stronger for nitrite-preserved processed meat than for fresh meat leading an IARC review to conclude that processed meat is carcinogenic to humans [89].

In a human feeding study [90], the replacement of nitrite in processed meat products by natural antioxidants and the impact of drinking water nitrate ingestion is being evaluated in relation to fecal excretion of NOC, accounting for intakes of meat and dietary vitamin C. A pilot study demonstrated that fecal excretion of ATNC increased after participants switched from ingesting drinking water with low nitrate levels to drinking water with nitrate levels at the acceptable daily intake level of 3.7 mg/kg. The 20 volunteers were assigned to a group consuming either 3.75 g/kg body weight (maximum 300 g per day) red processed meat or fresh (unprocessed) white meat. Comparison of the two dietary groups showed that the most pronounced effect of drinking water nitrate was observed in the red processed meat group. No inhibitory effect of vitamin C intake on ATNC levels in feces was found (unpublished results).

5. Methemoglobinemia

The physiologic processes that can lead to methemoglobinemia in infants under six months of age have been described in detail previously [8,91]. Ingested nitrate is reduced to nitrite by bacteria in the mouth and in the infant stomach, which is less acidic than adults. Nitrite binds to hemoglobin to form methemoglobin, which interferes with the oxygen carrying capacity of the blood. Methemoglobinemia is a life-threatening condition that occurs when methemoglobin levels exceed about 10% [8,91]. Risk factors for infant methemoglobinemia include formula made with water containing high nitrate levels, foods and medications that have high nitrate levels [91,92], and enteric infections [93]. Methemoglobinemia related to high nitrate levels in drinking water used to make infant formula was first reported in 1945 [94]. The U.S. EPA limit of 10 mg/L NO_3-N was set as about one-half the level at which there were no observed cases [95]. The most recent U.S. cases related to nitrate in drinking water were reported by Knobeloch and colleagues in the late 1990s in Wisconsin [96] and were not described in our prior review. Nitrate concentrations in the private wells were about two-times the MCL and bacterial contamination was not a factor. They also summarize another U.S. case in 1999 related to nitrate contamination of a private well and six infant deaths attributed to methemoglobinemia in the U.S. between 1979–1999 only one of which was reported in the literature [96,97]. High incidence of infant methemoglobinemia in eastern Europe has also been described previously [98,99]. A 2002 WHO report on water and health [100] noted that there were 41 cases in Hungary annually, 2913 cases in Romania from 1985–1996 and 46 cases in Albania in 1996.

Results of several epidemiologic studies conducted before 2005 that examined the relationship between nitrate in drinking water and levels of methemoglobin or methemoglobinemia in infants have been described previously [8]. Briefly, nitrate levels >10 mg/L NO_3-N were usually associated with increased methemoglobin levels but clinical methemoglobinemia was not always present. Since our last review, a cross-sectional study conducted in Gaza found elevated methemoglobin levels in infants on supplemental feeding with formula made from well water in an area with the highest mean nitrate concentration of 195 mg/L NO_3 (range: 18–440) compared to an area with lower nitrate concentration (mean: 119 mg/L NO_3; range 18–244) [101]. A cross-sectional study in Morocco found a 22% increased risk of methemoglobinemia in infants in an area with drinking water nitrate >50 mg/L (>11 as NO_3-N) compared to infants in an area with nitrate levels <50 mg/L nitrate [102]. A retrospective cohort study in Iowa of persons (aged 1–60 years) consuming private well water with nitrate levels <10 mg/L NO_3-N found a positive relationship between methemoglobin levels in the blood and the amount of nitrate ingestion [103]. Among pregnant women in rural Minnesota with drinking water supplies that were mostly $\leq$3 mg/L NO_3-N, there was no relationship between water nitrate intake and women's methemoglobin levels around 36 weeks' gestation [104].

6. Adverse Pregnancy Outcomes

Maternal drinking water nitrate intake during pregnancy has been investigated as a risk factor for a range of pregnancy outcomes, including spontaneous abortion, fetal deaths, prematurity, intrauterine growth retardation, low birth weight, congenital malformations, and neonatal deaths. The relation between drinking water nitrate and congenital malformations in offspring has been the most extensively studied, most likely because of the availability of birth defect surveillance systems around the world.

Our earlier review focused on studies of drinking water nitrate and adverse pregnancy outcomes published before 2005 [8]. In that review, we cited several studies on the relation between maternal exposure to drinking water nitrate and spontaneous abortion including a cluster investigation that suggested a positive association [105] and a case-control study that found no association [106]. These studies were published over 20 years ago. In the present review, we were unable to identify any recently published studies on this outcome. In Table 1, we describe the findings of studies published since 2004 on the relation between drinking water nitrate and prematurity, low birthweight, and congenital malformations. We report results for nitrate in the units (mg/L NO_3 or NO_3-N) that were reported in the publications. In a historic cohort study conducted in the Deux-Sèvres district (France), Migeot et al. [26] linked maternal addresses from birth records to community water system measurements of nitrate, atrazine, and other pesticides. Exposure to the second tertile of nitrate (14–27 mg/L NO_3) without detectable atrazine metabolites was associated with small-for-gestational age births (Odds Ratio (OR) 1.74, 95% CI 1.1, 2.8), but without a monotonic increase in risk with exposures. There was no association with nitrate among those with atrazine detected in their drinking water supplies. Within the same cohort, Albouy-Llaty and colleagues did not observe any association between higher water nitrate concentrations (with or without the presence of atrazine) and preterm birth [107].

Stayner and colleagues also investigated the relation between atrazine and nitrate in drinking water and rates of low birth weight and preterm birth in 46 counties in four Midwestern U.S. states that were required by EPA to measure nitrate and atrazine monthly due to prior atrazine MCL violations [108]. The investigators developed county-level population-weighted metrics of average monthly nitrate concentrations in public drinking water supplies. When analyses were restricted to counties with less than 20% private well usage (to reduce misclassification due to unknown nitrate levels), average nitrate concentrations during the pregnancy were associated with increased rates of very low birth weight (<1.5 kg Rate Ratio $(RR)_{per\ 1\ ppm}$ = 1.17, 95% CI 1.08, 1.25) and very preterm births (<32 weeks $RR_{per\ 1\ ppm}$ = 1.08, 95% CI 1.02, 1.15) but not with low birth weight or preterm birth overall.

In record-based prevalence study in Perth Australia, Joyce et al. mapped births to their water distribution zone and noted positive associations between increasing tertiles of nitrate levels and prevalence of term premature rupture of membranes (PROM) adjusted for smoking and socioeconomic status [109]. Nitrate concentrations were low; the upper tertile cut point was 0.350 mg/L and the maximum concentration was 1.80 mg/L NO_3-N. Preterm PROM was not associated with nitrate concentrations.

Among studies of drinking water nitrate and congenital malformations, few before 2005 included birth defects other than central nervous system defects [8]. More recently, Mattix et al. [110] noted higher rates of abdominal wall defects (AWD) in Indiana compared to U.S. rates for specific years during the period 1990–2002. They observed a positive correlation between monthly AWD rates and monthly atrazine concentrations in surface waters but no correlation with nitrate levels. Water quality data were obtained from the USGS-NAWQA project that monitors agricultural chemicals in streams and shallow groundwater that are mostly not used as drinking water sources. A case-control study of gastroschisis (one of the two major types of AWD), in Washington State [111] also used USGS-NAWQA measurements of nitrate and pesticides in surface water and determined the distance between maternal residences (zip code centroids) and the closest monitoring site with concentrations above the MCL for nitrate, nitrite, and atrazine. Gastrochisis was not associated with maternal proximity to surface water above the MCL for nitrate (>10 mg/L NO_3-N) or nitrite (>1 mg/L NO_2-N) but there was a positive relationship with proximity to sites with atrazine concentrations above the MCL. In a USA-wide study, Winchester et al. [112] linked the USGS-NAWQA monthly surface water nitrate and pesticide concentrations computed for the month of the last menstrual period with monthly rates of 22 types of birth defects in 1996–2002. Rates of birth defects among women who were estimated to have conceived during April through July were higher than rates among women conceiving in other months. In multivariable models that included nitrate, atrazine, and other pesticides, atrazine (but not nitrate or other pesticides) was associated with several types of anomalies. Nitrate was associated with birth defects in the category of "other congenital anomalies" (OR 1.18, 95% CI 1.14, 1.21); the authors did not specify what defects were included in this category. None of these three studies included local or regional data to support the assumption that surface water nitrate and pesticide concentrations correlated with drinking water exposures to these contaminants.

Using a more refined exposure assessment than the aforementioned studies, Holtby et al. [113] conducted a case-control study of congenital anomalies in an agricultural county in Nova Scotia, Canada. They linked maternal addresses at delivery to municipal water supply median nitrate concentrations and used kriging of monthly measurements from a network of 140 private wells to estimate drinking water nitrate concentrations in private wells. They observed no associations between drinking water nitrate and all birth defects combined for conceptions during 1987–1997. However, the prevalence of all birth defects occurring during 1998–2006 was associated with drinking water nitrate concentrations of 1–5.56 mg/L NO_3-N (OR 2.44, 95% CI 1.05, 5.66) and ≥5.56 mg/L (OR 2.25, 95% CI 0.92, 5.52).

None of the studies of congenital anomalies accounted for maternal consumption of bottled water or the quantity of water consumed during the first trimester, the most critical period of organ/structural morphogenesis. Attempting to overcome some of these limitations, Brender, Weyer, and colleagues [38,114] conducted a population-based, case-control study in the states of Iowa and Texas where they: (1) linked maternal addresses during the first trimester to public water utilities and respective nitrate measurements; (2) estimated nitrate intake from bottled water based on a survey of products consumed and measurement of nitrate in the major products; (3) predicted drinking water nitrate from private wells through modeling (Texas only); and (4) estimated daily nitrate ingestion from women's drinking water sources and daily consumption of water. The study populations were participants of the U.S. National Birth Defects Prevention Study [115]. Compared to the lowest tertile of nitrate ingestion from drinking water (<0.91 mg/day NO_3), mothers of babies with spina bifida were twice as likely (95% CI 1.3, 3.2) to ingest ≥5 mg/day NO_3 from drinking water than control mothers. Mothers of babies with limb deficiencies, cleft palate, and cleft lip were, respectively, 1.8 (95% CI 1.1, 3.1), 1.9 (95% CI 1.2, 3.1), and 1.8 (95% CI 1.1, 3.1) times more likely to ingest ≥5.4 mg/day of water NO_3 than controls. Women were also classified by their nitrosatable drug exposure during the first trimester [116] and by their daily nitrate and nitrite intake based on a food frequency questionnaire [117]. Higher ingestion of drinking water nitrate did not strengthen associations between maternal nitrosatable drug exposure and birth defects in offspring [38]. However, a pattern was observed of stronger associations between nitrosatable drug exposure and selected birth defects for women in the upper two tertiles of total nitrite ingestion that included contributions from drinking water nitrate and dietary intakes of nitrate and nitrite compared to women in the lowest tertile. Higher intake of food nitrate/nitrite was found to also modify the associations of nitrosatable drug exposure and birth defects in this study [118,119] as well as in an earlier study of neural tube defects conducted in south Texas [120]. Multiplicative interactions were observed between higher food nitrate/nitrite and nitrosatable drug exposures for conotruncal heart, limb deficiency, and oral cleft defects [118].

In summary, five out of six studies, conducted since the 1980s of drinking water nitrate and central nervous system defects, found positive associations between higher drinking water nitrate exposure during pregnancy and neural tube defects or central nervous system defects combined [38,120–123]. The sixth study, which did not find a relationship, did not include measures of association, but compared average drinking water nitrate concentrations between mothers with and without neural tube defect-affected births, which were comparable [124].

Table 1. Studies of drinking water nitrate [a] and adverse pregnancy outcomes published January 2005–March 2018.

First Author, Year, Country	Study Design Regional Description	Years of Outcome Ascertainment	Exposure Description	Pregnancy Outcome	Summary of Findings
Albouy-Llaty, 2016 France [107]	Historic cohort study Deux-Sèvres	2005–2010	Measurements of atrazine metabolites and NO_3 in community water systems (263 municipalities) were linked to birth addresses	Preterm birth	No association for >26.99 mg/L vs. <14.13 mg/L NO_3 in community water systems with or without atrazine detections, adjusted for neighborhood deprivation
Brender, 2013 Weyer, 2014 USA [38]	Population-based case-control study Iowa and Texas	1997–2005	Maternal addresses during the first trimester linked to public water utility nitrate measurements; nitrate intake from bottled water estimated with survey and laboratory testing; nitrate from private wells predicted through modeling; nitrate ingestion (NO_3) estimated from reported water consumption	Congenital heart defects Limb deficiencies Neural tube defects Oral cleft defects	≥5 vs. <0.91 mg/day NO_3 from drinking water spina bifida OR = 2.0 (95% CI: 1.3, 3.2) ≥5.42 vs. <1.0 mg/day NO_3 from water: limb deficiencies OR = 1.8 (CI: 1.1, 3.1); cleft palate OR = 1.9 (CI: 1.2, 3.1) cleft lip OR = 1.8 (CI: 1.1, 3.1)
Holtby, 2014 Canada [113]	Population-based case-control study Kings County, Nova Scotia	1988–2006	Maternal addresses at delivery linked to municipal water supply median nitrate (NO_3-N) concentrations; nitrate in rural private wells estimated from historic sampling and kriging	Congenital malformations combined into one group	Conceptions in 1987–1997: no association with nitrate concentrations Conceptions in 1998–2006: 1–5.56 mg/L NO_3-N (vs. <1 mg/L) OR = 2.44 (CI: 1.05, 5.66); ≥5.56 mg/L OR = 2.25 (CI: 0.92, 5.52)
Joyce, 2008 Australia [109]	Record-based prevalence study Perth	2002–2004	Linked birth residences to 24 water distribution zones; computed average NO_3-N mg/L from historical measurements; independent sampling conducted for 6 zones as part of exposure validation; also evaluated trihalomethanes (THM)	Premature rupture of membranes at term (PROM) (37 weeks' gestation or later)	ORs for tertiles (vs. <0.125 mg/L NO_3-N): 0.125–0.350 mg/L OR = 1.23 (CI: 1.03, 1.52); >0.350 mg/L OR = 1.47 (CI: 1.20, 1.79) No association with THM levels
Mattix, 2007 USA [110]	Ecologic study Indiana	1990–2002	Monthly abdominal wall defect rates linked to monthly surface water nitrate and atrazine concentrations (USGS-NAWQA monitoring data [b])	Abdominal wall birth defects	No correlation observed between nitrate levels in surface water and monthly abdominal wall defects Positive correlation with atrazine levels

Table 1. *Cont.*

First Author, Year, Country	Study Design Regional Description	Years of Outcome Ascertainment	Exposure Description	Pregnancy Outcome	Summary of Findings
Migeot, 2013 France [26]	Historic cohort study Deux-Sèvres	2005–2009	Measurements of atrazine metabolites and NO_3 in community water systems (263 municipalities) were linked to birth addresses	Small-for-gestational age (SGA) births	ORs for tertiles (vs. <14.13 mg/L NO_3) in community water systems with no atrazine detections: 14–27 mg/L OR = 1.74 (CI: 1.10, 2.75); >27 mg/L OR = OR 1.51 (CI: 0.96, 2.4); no association with nitrate when atrazine was detected
Stayner, 2017 USA [108]	Ecologic study 46 counties in Indiana, Iowa, Missouri, and Ohio	2004–2008	Counties had one or more water utility in EPA's atrazine monitoring program; excluded counties with >20% of population on private wells and >300,000 population. Computed county-specific monthly weighted averages of NO_3-N in finished drinking water; exposure metric was average 9 months prior to birth	Preterm birth Low birth weight	Average nitrate not associated with low birth weight and preterm birth Very low birth weight: RR for 1 ppm increase in NO_3-N = 1.17 (CI: 1.08, 1.25); Very preterm birth RR for 1 ppm increase = 1.08 (CI: 1.02, 1.15)
Waller, 2010 USA [111]	Population-based case-control study Washington State	1987–2006	Calculated distance between maternal residence and closest stream monitoring site with concentrations >MCL for NO_3-N, NO_2-N, or atrazine in surface water (USGS-NAWQA data [b])	Gastroschisis	Gastroschisis was not associated with maternal residential proximity to surface water with elevated nitrate (>10 mg/L) or nitrite (>1 mg/L)
Winchester, 2009 USA [112]	Ecologic study USA-wide	1996–2002	Rates of combined and specific birth defects (computed by month of last menstrual period) linked to monthly surface water nitrate concentrations (USGS-NAWQA data [b]); also evaluated atrazine and other pesticides (combined)	Birth defects categorized into 22 groups	Birth defect category "other congenital anomalies": OR for continuous log nitrate = 1.15 (CI: 1.12, 1.18); adjusted for atrazine and other pesticides: OR = 1.18, CI: 1.14, 1.21); No association with other birth defects

Abbreviations: CI, 95% CI confidence interval; OR, odds ratio; RR, rate ratio; USGS-NAWQA, U. S. Geological Survey National Water Quality Assessment; [a] nitrate units are specified as reported in publications. NO_3 can be converted to NO_3-N by multiplying by 0.2258; [b] USGS-NAWQA data for 186 streams in 51 hydrological study areas; streams were not drinking water sources.

7. Cancer

Most early epidemiologic studies of cancer were ecologic studies of stomach cancer mortality that used exposure estimates concurrent with the time of death. Results were mixed, with some studies showing positive associations, many showing no association, and a few showing inverse associations. The results of ecologic studies through 1995 were reviewed by Cantor [125]. Our previous review included ecologic studies of the brain, esophagus, stomach, kidney, ovary, and non-Hodgkin lymphoma (NHL) published between 1999 and 2003 that were largely null [8]. We did not include ecologic studies or mortality case-control studies in this review due to the limitations of these study designs, especially their inability to assess individual-level exposure and dietary factors that influence the endogenous formation of NOC.

Since our review of drinking water nitrate and health in 2005 [8], eight case-control studies and eight analyses in three cohorts have evaluated historical nitrate levels in PWS in relation to several cancers. Nitrate levels were largely below 10 mg/L NO_3-N. Most of these studies evaluated potential confounders and factors affecting nitrosation. Table 2 shows the study designs and results of studies published from 2005 through 2018, including findings from periodic follow-ups of a cohort study of postmenopausal women in Iowa (USA) [31,37,126–129]. In the first analysis of drinking water nitrate in the Iowa cohort with follow-up through 1998, Weyer and colleagues [130] reported that ovarian and bladder cancers were positively associated with the long-term average PWS nitrate levels prior to enrollment (highest quartile average 1955–1988: >2.46 mg/L NO_3-N). They observed inverse associations for uterine and rectal cancer, but no associations with cancers of the breast, colon, rectum, pancreas, kidney, lung, melanoma, non-Hodgkin lymphoma (NHL), or leukemia. Analyses of PWS nitrate concentrations and cancers of the thyroid, breast, ovary, bladder, and kidney were published after additional follow-up of the cohort. The exposure assessment was improved by: (a) the computation of average nitrate levels and years of exposure at or above 5 mg/L NO_3-N, based on time in residence (vs. one long-term PWS average nitrate estimate used by Weyer and colleagues); and (b) by estimation of total trihalomethanes (TTHM) and dietary nitrite intake.

Thyroid cancer was evaluated for the first time after follow-up of the cohort through 2004. A total of 40 cases were identified [37]. Among women with >10 years on PWS with levels exceeding 5 mg/L NO_3-N for five years or more, thyroid cancer risk was 2.6 times higher than that of women whose supplies never exceeded 5 mg/L. With follow-up through 2010, the risk of ovarian cancer remained increased among women in the highest quartile of average nitrate in PWS [129]. Ovarian cancer risk among private well users was also elevated compared to the lowest PWS nitrate quartile. Associations were stronger when vitamin C intake was below median levels with a significant interaction for users of private wells. Overall, breast cancer risk was not associated with water nitrate levels with follow-up through 2008 [128]. Among women with folate intake $\geq$ 400 µg/day, risk was increased for those in the highest average nitrate quintile (Hazard Ratio (HR) = 1.40; 95% CI: = 1.05–1.87) and among private well users (HR = 1.38; 95% CI: = 1.05–1.82), compared to those with the lowest average nitrate quintile. There was no association with nitrate exposure among women with lower folate intake. With follow-up through 2010, there were 130 bladder cancer cases among women who had used PWS >10 years. Risk remained elevated among women with the highest average nitrate levels and was 1.6 times higher among women whose drinking water concentration exceeded 5 mg/L NO_3-N for at least four years [31]. Risk estimates were not changed by adjustment for TTHM, which are suspected bladder cancer risk factors. Smoking, but not vitamin C intake, modified the association with nitrate in water; increased risk was apparent only in current smokers (p-interaction <0.03). With follow-up through 2010, there were 125 kidney cancer cases among women using PWS; risk was increased among those in the 95th percentile of average nitrate (>5.0 mg/L NO_3-N) compared with the lowest quartile (HR = 2.2, 95% CI: 1.2–4.2) [127]. There was no positive trend with the average nitrate level and no increased risk for women using private wells, compared to those with low average nitrate in their public supply. An investigation of pancreatic cancer in the same population (follow-up through 2011) found no association with average water nitrate levels in public supplies and no association among women on private wells [126].

In contrast to the positive findings for bladder cancer among the cohort of Iowa women, a cohort study of men and women aged 55–69 in the Netherlands with lower nitrate levels in PWS found no association between water nitrate ingestion (median in top quintile = 2.4 mg/day NO_3-N) and bladder cancer risk [131]. Dietary intake of vitamins C and E and history of cigarette smoking did not modify the association. A hospital-based case-control study of bladder cancer in multiple areas of Spain [33] assessed lifetime water sources and usual intake of tap water. Nitrate levels in PWS were low, with almost all average levels below 2 mg/L NO_3-N. Risk of bladder cancer was not associated with the nitrate level in drinking water or with estimated nitrate ingestion from drinking water, and there was no evidence of interaction with factors affecting endogenous nitrosation.

Several case-control studies conducted in the Midwestern U.S. obtained lifetime histories of drinking water sources and estimated exposure for PWS users. In contrast to findings of an increased risk of NHL associated with nitrate levels in Nebraska PWS in an earlier study [132], there was no association with similar concentrations in public water sources in a case-control study of NHL in Iowa [35]. A study of renal cell carcinoma in Iowa [34] found no association with the level of nitrate in PWS, including the number of years that levels exceeded 5 or 10 mg/L NO_3-N. However, higher nitrate levels in PWS increased risk among subgroups who reported above the median intake of red meat intake or below the median intake of vitamin C (p-interaction <0.05). A small case-control study of adenocarcinoma of the stomach and esophagus among men and women in Nebraska [133] estimated nitrate levels among long-term users of PWS and found no association between average nitrate levels and risk.

A case-control study of colorectal cancer among rural women in Wisconsin estimated nitrate levels in private wells using spatial interpolation of nitrate concentrations from a 1994 water quality survey and found increased risk of proximal colon cancer among women estimated to have nitrate levels >10 mg/L NO_3-N compared to levels < 0.5 mg/L. Risk of distal colon cancer and rectal cancer were not associated with nitrate levels [134]. Water nitrate ingestion from public supplies, bottled water, and private wells and springs over the adult lifetime was estimated in analyses that pooled case-control studies of colorectal cancer in Spain and Italy [135]. Risk of colorectal cancer was increased among those with >2.3 mg/day NO_3-N (vs. <1.1 mg/day). There were no interactions with red meat, vitamins C and E, and fiber except for a borderline interaction (p-interaction = 0.07) for rectum cancer with fiber intake. A small hospital-based case-control study in Indonesia found that drinking water nitrate levels above the WHO standard (>11.3 mg/L as NO_3-N) was associated with colorectal cancer [136]. A national registry-based cohort study in Denmark [32] evaluated average nitrate concentrations in PWS and private wells in relation to colorectal cancer incidence among those whose 35th birthday occurred during 1978–2011. The average nitrate level was computed over residential water supplies from age 20 to 35. Increased risks for colon and rectum cancer were observed in association with average nitrate levels ≥9.25 mg/L NO_3 (≥2.1 as NO_3-N) and ≥3.87 mg/L NO_3 (>0.87 as NO_3-N), respectively, with a significant positive trend. Because the study did not interview individuals, it could not evaluate individual-level risk factors that might influence endogenous nitrosation.

A case-control study of breast cancer in Cape Cod, Massachusetts (US) [137] estimated nitrate concentrations in PWS over approximately 20 years as an historical proxy for wastewater contamination and potential exposure to endocrine disruption compounds. Average exposures >1.2 mg/L NO_3-N (vs. <0.3 mg/L) were not associated with risk. A hospital-based case-control study in Spain found no association between water nitrate ingestion and pre- and post-menopausal breast cancers [138].

Table 2. Case-control and cohort studies of drinking water nitrate and cancer (January 2004–March 2018) by cancer site.

First Author (Year) Country	Study Design, Years Regional Description	Exposure Description	Cancer Sites Included	Summary of Drinking-Water Findings [a,b]	Evaluation of Effect Modification [c]
Zeegers, 2006 Netherlands [131]	Cohort Incidence, 1986–1995 204 municipal registries across the Netherlands	1986 nitrate level in 364 pumping stations, exposure data available for 871 cases, 4359 members of the subcohort	Bladder	Highest vs. lowest quintile intake from water (≥1.7 mg/day NO_3-N [median 2.4 mg/day] vs. <0.20) RR = 1.11 (CI: 0.87–1.41; *p*-trend = 0.14)	No interaction with vitamin C, E, smoking
Espejo-Herrera, 2015 Spain [33]	Hospital-based multi-center case-control Incidence, 1998–2001 Asturias, Alicante, Barcelona, Vallès-Bages, Tenerife provinces	Nitrate levels in PWS (1979–2010) and bottled water (measurements of brands with highest consumption based on a Spanish survey); analyses limited to those with ≥70% of residential history with nitrate estimate (531 cases, 556 controls)	Bladder	Highest vs. lowest quartile average level (age 18-interview) (≥2.26 vs. 1.13 mg/L NO_3-N) OR = 1.04 (CI: 0.60–1.81) Years >2.15 mg/L NO_3-N (75th percentile) (>20 vs. 0 years) OR = 1.41 (CI: 0.89–2.24)	No interaction with vitamin C, E, red meat, processed meat, average THM level
Jones, 2016 USA [31]	Population-based cohort of postmenopausal women ages 55–69 Incidence, 1986–2010 Iowa	Nitrate levels in PWS (1955–1988) and private well use among women >10 years at enrollment residence with nitrate and trihalomethane estimates (20,945 women; 170 bladder cases); no measurements for private wells Adjusted for total trihalomethanes (TTHM)	Bladder	Highest vs. lowest quartile PWS average (≥2.98 vs. <0.47 mg/L NO_3-N) HR = 1.47 (CI: 0.91–2.38; *p*-trend = 0.11) Years >5 mg/L (≥4 years vs. 0) HR = 1.61 (CI: 1.05–2.47; *p*-trend = 0.03) Private well users (vs. <0.47 mg/L NO_3-N on PWS) HR = 1.53 (CI: 0.93–2.54)	Interaction with smoking (*p*-interaction = 0.03); HR = 3.67 (CI: 1.43–9.38) among current smokers/≥2.98 mg/L vs. non-smokers/<0.47 mg/L NO_3-N); No interaction with vitamin C, TTHM levels
Mueller, 2004 USA, Canada, France, Italy, Spain [139]	Pooled case-control studies Incidence among children <15 years (USA <20 years) 7 regions of 5 countries	Water source during pregnancy and first year of child's life (836 cases, 1485 controls); nitrate test strip measurements of nitrate and nitrite for pregnancy home (except Italy) (283 cases, 537 controls; excluding bottled water users: 207 cases, 400 controls)	Brain, childhood	Private well use versus PWS associated with increased risk in 2 regions and decreased risk in one; No association with nitrate levels in water supplies Astrocytomas (excludes bottled water users): ≥1.5 vs. <0.3 mg/L NO_2-N OR = 5.7 (CI: 1.2–27.2)	Not described
Brody, 2006 USA [137]	Case-control Incidence, 1988–1995 Cape Cod, Massachusetts	Nitrate levels in public water supplies (PWS) since 1972 was used as an indicator of wastewater contamination and potential mammary carcinogens and endocrine disrupting compounds; excluded women on private wells	Breast	Average ≥1.2 mg/L NO_3-N vs. <0.3 OR = 1.8, (CI: 0.6–5.0); summed annual NO_3-N ≥ 10 vs. 1–< 10 mg/L OR = 0.9, CI: 0.6–1.5); number of years >1 mg/L NO_3-N ≥8 vs. 0 years OR = 0.9 (CI: 0.5–1.5)	Not described

Table 2. *Cont.*

First Author (Year) Country	Study Design, Years Regional Description	Exposure Description	Cancer Sites Included	Summary of Drinking-Water Findings [a,b]	Evaluation of Effect Modification [c]
Inoue-Choi, 2012 USA [128]	Population-based cohort of postmenopausal women ages 55–69 Incidence, 1986–2008 Iowa	Nitrate levels in PWS (1955–1988) and private well use among women >10 years at enrollment residence (20,147 women; 1751 breast cases); no measurements for private wells	Breast	Highest vs. lowest quintile PWS average (≥3.8 vs. ≤0.32 mg/L NO_3-N) HR = 1.14 (CI: 0.95–1.36; *p*-trend = 0.11); Private well (vs. ≤ 0.32 mg/L NO_3-N) HR = 1.14 (CI: 0.97–1.34); Private well (vs. ≤0.32 mg/L NO_3-N on PWS) HR = 1.38 (CI: 1.05–1.82); No association among those with low folate <400 µg/day	Interaction with folate for PWS (*p*-interaction = 0.06). Folate ≥400 µg/d: (≥3.8 vs. ≤0.32 mg/L NO_3-N) HR = 1.40 (CI: 1.05–1.87; *p*-trend = 0.04)
Espejo-Herrera, 2016 Spain [138]	Hospital-based multi-center case-control Incidence, 2008–2013 Spain (8 provinces)	Nitrate levels in PWS (2004–2010), bottled water measurements and private wells and springs (2013 measurements in 21 municipalities in León, Spain, the area with highest non-PWS use) Analyses include women with ≥70% of period from age 18 to 2 years before interview (1245 cases, 1520 controls)	Breast	Water nitrate intake based on average nitrate levels (age 18 to 2 years prior to interview) and water intake (L/day). Post-menopausal women: >2.0 vs. 0.5 mg/day NO_3-N OR = 1.32 (0.93–1.86); Premenopausal women: >1.4 vs. 0.4 mg/day NO_3-N OR = 1.14 (0.67–1.94)	No interaction with red meat, processed meat, vitamin C, E, smoking for pre- and post-menopausal women
McElroy, 2008 USA [134]	Population-based case-control, women Incidence, 1990–1992 and 1999–2001 Wisconsin	Limited to women in rural areas with no public water system (475 cases, 1447 controls); nitrate levels at residence (presumed to be private wells) estimated by kriging using data from a 1994 representative sample of 289 private wells	Colorectal	All colon cancers: Private wells ≥10.0 mg/L NO_3-N vs. <0.5 OR = 1.52 (CI: 0.95–2.44); Proximal colon cancer: OR = 2.91 (CI: 1.52–5.56)	Not described
Espejo-Herrera, 2016 Spain, Italy [135]	Multi-center case-control study Incidence, 2008–2013 Spain (9 provinces) and population-based controls; Italy (two provinces) and hospital-based controls	Nitrate levels in PWS (2004–2010) for 349 water supply zones, bottled water (measured brands with highest consumption), and private wells and springs (measurements in 2013 in 21 municipalities in León, Spain, the area with highest non-PWS use) Analyses include those with nitrate estimates for ≥70% of period 30 years before interview (1869 cases, 3530 controls)	Colorectal	Water nitrate intake based on average nitrate levels (estimated 30 to 2 years prior to interview) and water intake (L/day) Highest vs. lowest exposure quintiles (≥2.3 vs. <1.1 mg /day NO_3-N) OR = 1.49 (CI:1.24–1.78); Colon OR = 1.52 (CI: 1.24–1.86), Rectum OR = 1.62 (CI: 1.23–2.14)	Interaction with fiber for rectum (*p*-interaction = 0.07); >20 g/day fiber + >1.0 mg/L NO_3-N vs. <20 g/day + ≤1.0 mg/L HR = 0.72 (CI: 0.52–1.00). No interaction with red meat, vitamin C, E

Table 2. *Cont.*

First Author (Year) Country	Study Design, Years Regional Description	Exposure Description	Cancer Sites Included	Summary of Drinking-Water Findings [a,b]	Evaluation of Effect Modification [c]
Fathmawati, 2017 Indonesia [136]	Hospital-based case-control Incidence, 2014–2016 Indonesia (3 provinces)	Nitrate levels in well water collected during the raining season (Feb-March 2016) and classified based on >11.3 or ≤11.3 mg/L as NO_3-N and duration of exposure >10 and ≤10 years Analyses included participants who reported drinking well water (75 cases, 75 controls)	Colorectal	Water nitrate > WHO standard vs. below (> 11.3 vs. ≤11.3 mg/L NO_3-N) OR = 2.82 (CI: 1.08–7.40); > 10 years: 4.31 (CI: 11.32–14.10); ≤10 years: 1.41 (CI: 0.14–13.68)	Not described
Schullehner, 2018 Denmark [32]	Population-based record-linkage cohort of men and women ages 35 and older, 1978–2011 Denmark	Nitrate levels in PWS and private wells among 1,742,321 who met exposure assessment criteria (5944 colorectal cancer cases, including 3700 with colon and 2308 with rectal cancer)	Colorectal	Annual average nitrate exposure between ages 20–35 among those who lived ≥75% of study period at homes with a water sample within 1 year (61% of Danish population). Highest vs. lowest exposure quintile (≥2.1 vs. 0.16 mg/L NO_3-N); Colorectal: HR = 1.16 (CI: 1.08–1.25); colon: 1.15 (CI: 1.05–1.26); rectum: 1.17 (CI: 1.04–1.32)	No information on dietary intakes or smoking
Ward, 2007 USA [34]	Population-based case control Incidence, 1986–1989 Iowa	Nitrate levels in PWS among those with nitrate estimates for ≥70% of person-years ≥1960 (201 cases, 1244 controls)	Kidney (renal cell carcinomas)	Highest vs. lowest quartile PWS average (≥2.8 mg/L NO_3-N vs. <0.62) OR = 0.89 (CI 0.57–1.39); Years >5mg/L NO_3-N 11+ vs. 0 OR = 1.03 (CI: 0.66–1.60)	Interaction with red meat intake (p-interaction = 0.01); OR = 1.91 (CI 1.04–3.51) among 11+ years >5 mg/L NO_3-N and red meat ≥1.2 servings/day. Interaction with vitamin C showed similar pattern (p-interaction = 0.13)
Jones, 2017 USA [127]	Population-based cohort of postmenopausal women ages 55–69 Incidence, 1986–2010 Iowa	Nitrate levels in PWS (1955–1988) and private well use among women >10 years at enrollment residence. PWS measurements for nitrate and TTHM; no measurements for private wells (20,945 women; 163 kidney cases)	Kidney	Nitrate and TTHM metrics computed for duration at water source (11+ years) 95th percentile vs. lowest quartile PWS average (≥5.00 vs. <0.47 mg/L NO_3-N) HR = 2.23 (CI: 1.19–4.17; p-trend = 0.35) Years >5 mg/L (≥4 years vs. 0) HR = 1.54 (CI: 0.97–2.44; p-trend = 0.09) Private well users (vs. <0.47 mg/L NO_3-N in PWS) HR = 0.96 (CI: 0.59–1.58)	No interaction with smoking, vitamin C
Ward, 2006 USA [35]	Population-based case-control Incidence, 1998–2000 Iowa	Nitrate levels in PWS among those with nitrate estimates for ≥70% of person-years ≥1960 (181 case, 142 controls); nitrate measurements for private well users at time of interviews (1998–2000; 54 cases, 44 controls)	Non-Hodgkin lymphoma	Private wells: >5.0 mg/L NO_3-N vs. ND OR = 0.8 (CI 0.2–2.5) PWS average: ≥2.9 mg/L NO_3-N vs. <0.63 OR = 1.2 (CI 0.6–2.2) Years ≥5mg/L NO3-N: 10+ vs. 0 OR = 1.4 (CI: 0.7–2.9)	No interaction with vitamin C, smoking

Table 2. *Cont.*

First Author (Year) Country	Study Design, Years Regional Description	Exposure Description	Cancer Sites Included	Summary of Drinking-Water Findings [a,b]	Evaluation of Effect Modification [c]
Inoue-Choi, 2015 USA [129]	Population-based cohort of postmenopausal women ages 55–69 Incidence, 1986–2010 Iowa	Nitrate levels in PWS (1955–1988) and private well use among women >10 years at enrollment residence; PWS measurements for nitrate and TTHM; no measurements for private wells (17,216 women; 190 ovarian cases)	Ovary	Nitrate and TTHM metrics computed for reported duration at water source (11+ years) Highest vs. lowest quartile PWS average (≥2.98 mg/L vs. <0.47 mg/L NO_3-N) HR = 2.03 (CI = 1.22–3.38; *p*-trend = 0.003) Years >5 mg/L (≥4 years vs. 0) HR = 1.52 (CI: 1.00–2.31; *p*-trend = 0.05) Private well users (vs. <0.47 mg/L NO_3-N in PWS) HR = 1.53 (CI: 0.93–2.54)	No interaction with vitamin C, red meat intake, smoking for PWS nitrate Interaction with private well use and vitamin C intake (*p*-interaction = 0.01)
Quist, 2018 USA [126]	Population-based cohort of postmenopausal women ages 55–69 Incidence, 1986–2011 Iowa	Nitrate levels in PWS (1955–1988) and private well use among women >10 years at enrollment residence; nitrate and TTHM estimates for PWS (20,945 women; 189 pancreas cases); no measurements for private wells Adjusted for TTHM (1955–1988), measured levels in 1980s, prior year levels estimated by expert)	Pancreas	Nitrate and TTHM metrics computed for reported duration at water source (11+ years) 95th percentile vs. lowest quartile PWS average (≥5.69 vs. <0.47 mg/L NO_3-N) HR = 1.16 (CI: 0.51–2.64; *p*-trend = 0.97) Years >5 mg/L (≥4 years vs. 0) HR = 0.90 (CI: 0.55–1.48; *p*-trend = 0.62) Private well users (vs. <0.47 mg/L NO_3-N) HR = 0.92 (CI: 0.55–1.52)	No interaction with smoking, vitamin C
Ward, 2008 USA [133]	Population-based case control Incidence, 1988–1993 Nebraska	Controls from prior study of lymphohematopoetic cases and controls interviewed in 1992–1994; Proxy interviews for 80%, 76%, 61% of stomach, esophagus, controls, respectively. Nitrate levels (1965–1985) in PWS for ≥70% of person-years (79 distal stomach, 84, esophagus, 321 controls); Private well users sampling at interview (15 stomach, 22 esophagus, 44 controls)	Stomach and esophagus (adenocarcinomas)	Highest vs. lowest quartile PWS average (>4.32 vs. <2.45 mg/L NO_3-N): stomach OR = 1.2 (CI 0.5–2.7); esophagus OR = 1.3 (CI: 0.6–3.1); Years >10 mg/L NO_3-N (9+ vs. 0): stomach OR = 1.1 (CI: 0.5–2.3); esophagus OR = 1.2 (CI: 0.6–2.7) Private well users (>4.5 mg/L NO_3-N vs. <0.5) stomach OR = 5.1 (CI: 0.5–52; 4 cases, 13 controls); esophagus OR = 0.5 (CI: 0.1–2.9; 8 cases; 13 controls)	No interaction with vitamin C, processed meat, or red meat for either cancer
Ward, 2010 USA [37]	Population-based cohort of postmenopausal women ages 55–69 Incidence, 1986–2004 Iowa	Nitrate levels in PWS (1955–1988) and private well use among women >10 years at enrollment residence (21,977 women; 40 thyroid cases); no measurements for private wells	Thyroid	Highest vs. lowest quartile PWS average (>2.46 vs. <0.36 mg/L NO_3-N) HR = 2.18 (CI: 0.83–5.76; *p*-trend = 0.02) Years >5 mg/L (≥5 years vs. 0) HR = 2.59 (CI: 1.09–6.19; *p*-trend = 0.04); Private well (vs. <0.36 mg/L NO_3-N on PWS) HR = 1.13 (CI: 0.83–3.66) Dietary nitrate intake quartiles positively associated with risk (*p*-trend = 0.05)	No interaction with smoking, vitamin C, body mass index, education, residence location (farm/rural vs. urban)

ND = not detected; PWS = public water supplies; [a] nitrate or nitrite levels presented in the publications as mg/L of the ion were converted to mg/L as NO_3-N or NO_2-N; [b] Odds ratios (OR) for case-control studies, incidence rate ratios (RR) and hazard ratios (HR) for cohort studies, and 95% confidence intervals (CI); [c] Factors evaluated are noted. Interaction refers to reported $p \leq 0.10$ from test of heterogeneity.

Animal studies demonstrate that in utero exposure to nitrosamides can cause brain tumors in the exposed offspring. Water nitrate and nitrite intake during pregnancy was estimated in a multi-center case-control study of childhood brain tumors in five countries based on the maternal residential water source [139]. Results for the California and Washington State sites were reported in our previous review [8,140]. Nitrate/nitrite levels in water supplies were measured using a nitrate test strip method in four countries including these U.S. sites; most of these measurements occurred many years after the pregnancy. Measured nitrate concentrations were not associated with risk of childhood brain tumors. However, higher nitrite levels (>1.5 mg/L NO_2-N) in the drinking water were associated with increased risk of astrocytomas.

8. Thyroid Disease

Animal studies demonstrate that ingestion of nitrate at high doses can competitively inhibit iodine uptake and induce hypertrophy of the thyroid gland [141]. An early study of women in the Netherlands consuming water with nitrate levels at or above the MCL, found increased prevalence of thyroid hypertrophy [142]. Since the last review, five studies have evaluated nitrate ingestion from drinking water (the Iowa cohort study also assessed diet) and prevalence of thyroid disease. A study of school-age children in Slovakia found increased prevalence of subclinical hypothyroidism among children in an area with high nitrate levels (51–274 mg/L NO_3) in water supplies compared with children ingesting water with nitrate $\leq$50 mg/L (11 mg/L NO_3-N). In Bulgarian villages with high nitrate levels (75 mg/L NO_3) and low nitrate levels (8 mg/L), clinical examinations of the thyroids of pregnant women and school children revealed an approximately four- and three-fold increased prevalence of goiter, respectively, in the high nitrate village [143,144]. The iodine status of the populations in both studies was adequate. Self-reported hypothyroidism and hyperthyroidism among a cohort of post-menopausal women in Iowa was not associated with average nitrate concentrations in PWS [37]. However, dietary nitrate, the predominant source of intake, was associated with increased prevalence of hypothyroidism but not hyperthyroidism. Modeled estimates of nitrate concentrations in private wells among a cohort of Old Order Amish in Pennsylvania (USA) were associated with increased prevalence of subclinical hypothyroidism as determined by thyroid stimulating hormone measurements, among women but not men [145].

9. Other Health Effects

Associations between nitrate in drinking water and other non-cancer health effects, including type 1 childhood diabetes (T1D), blood pressure, and acute respiratory tract infections in children were previously reviewed [8]. Since 2004, a small number of studies have contributed additional mixed evidence for these associations. Animal studies indicate that NOC may play a role in the pathology of T1D through damage to pancreatic beta cells [146]. A registry-based study in Finland [147] found a positive trend in T1D incidence with levels of nitrate in drinking water. In contrast, an ecological analysis in Italy showed an inverse correlation with water nitrate levels and T1D rates [148]. A small T1D case-control study in Canada with 57 cases showed no association between T1D and estimated intake of nitrate from drinking water (highest quartile >2.7 mg/day NO_3-N) [149]. Concentrations of nitrate in drinking water (median ~2.1 mg/L NO_3-N) were not associated with progression to T1D in a German nested case-control study of islet autoantibody-positive children, who may be at increased risk of the disease [150].

In a prospective, population-based cohort study in Wisconsin (USA), increased incidence of early and late age-related macular degeneration was positively associated with higher nitrate levels ($\geq$5 mg/L vs. <5 mg/L NO_3-N) in rural private drinking water supplies [151]. The authors suggested several possible mechanisms, including methemoglobin-induced lipid peroxidation in the retina.

Potential benefits of nitrate ingestion include lowering of blood pressure due to production of nitric oxide in the acidic stomach and subsequent vasodilation, antithrombotic, and immunoregulatory effects [152]. Experimental studies in animals and controlled feeding studies in humans have demonstrated mixed evidence of these effects and on other cardiovascular endpoints such as vascular hypertrophy, heart failure, and myocardial infarction (e.g., [152–154]). Ingested nitrite from diet has also been associated with increased blood flow in certain parts of the brain [155]. Epidemiologic studies of these effects are limited to estimation of dietary exposures or biomarkers that integrate exposures from nitrate from diet and drinking water. Recent findings in the Framingham Offspring Study suggested that plasma nitrate was associated with increased overall risk of death that attenuated when adjusted for glomerular function (HR: 1.16, 95% CI: 1.0–1.35) but no association was observed for incident cardiovascular disease [156]. No epidemiologic studies have specifically evaluated nitrate ingested from drinking water in relation to these outcomes. Another potential beneficial effect of nitrate is protection against bacterial infections via its reduction to nitrite by enteric bacteria. In an experimental inflammatory bowel disease mouse model, nitrite in drinking water was associated with both preventive and therapeutic effects [157]. However, there is limited epidemiologic evidence for a reduced risk of gastrointestinal disease in populations with high drinking water nitrate intake. One small, cross-sectional study in Iran found no association between nitrate levels in public water supplies with mean levels of ~5.6 mg/L NO_3-N and gastrointestinal disease [158].

10. Discussion

Since our last review of studies through 2004 [8], more than 30 epidemiologic studies have evaluated drinking water nitrate and risk of cancer, adverse reproductive outcomes, or thyroid disease. However, the number of studies of any one outcome was not large and there are still too few studies to allow firm conclusions about risk. The most common endpoints studied were colorectal cancer, bladder, and breast cancer (three studies each) and thyroid disease (four studies). Considering all studies to date, the strongest evidence for a relationship between drinking water nitrate ingestion and adverse health outcomes (besides methemoglobinemia) is for colorectal cancer, thyroid disease, and neural tube defects. Four of the five published studies of colorectal cancer found evidence of an increased risk of colorectal cancer or colon cancer associated with water nitrate levels that were mostly below the respective regulatory limits [32,134,135,159]. In one of the four positive studies [159], increased risk was only observed in subgroups likely to have increased nitrosation. Four of the five studies of thyroid disease found evidence for an increased prevalence of subclinical hypothyroidism with higher ingestion of drinking water nitrate among children, pregnant women, or women only [37,144,145,160]. Positive associations with drinking water nitrate were observed at nitrate concentrations close to or above the MCL. The fifth study, a cohort of post-menopausal women in Iowa, had lower drinking water nitrate exposure but observed a positive association with dietary nitrate [37]. To date, five of six studies of neural tube defects showed increased risk with exposure to drinking water nitrate below the MCL. Thus, the evidence continues to accumulate that higher nitrate intake during the pregnancy is a risk factor for this group of birth defects.

All but one of the 17 cancer studies conducted since 2004 were in the U.S. or Europe, the majority of which were investigations of nitrate in regulated public drinking water. Thyroid cancer was studied for the first time [37] with a positive finding that should be evaluated in future studies. Bladder cancer, a site for which other drinking water contaminants (arsenic, disinfection by-products [DBPs]) are established or suspected risk factors, was not associated with drinking water nitrate in three of the four studies. Most of the cancer studies since 2004 evaluated effect modification by factors known to influence endogenous nitrosation, although few observed evidence for these effects. Several studies of adverse reproductive outcomes since 2004 have indicated a positive association between maternal prenatal exposure to nitrate concentrations below the MCL and low birth weight and small for gestational age births. However, most studies did not account for co-exposure to other water contaminants, nor did they adjust for potential risk factors. The relation between drinking water nitrate and spontaneous abortion continues to be understudied. Few cases of methemoglobinemia, the health concern that lead to the regulation of nitrate in public water supplies, have been reported in the U.S. since the 1990s. However, as described by Knobeloch et al. [96], cases may be underreported and only a small proportion of cases are thoroughly investigated and described in the literature. Based on published reports, [100] areas of the world of particular concern include several eastern European countries, Gaza, and Morocco, where high nitrate concentrations in water supplies have been linked to high levels of methemoglobin in children. Therefore, continued surveillance and education of physicians and parents will be important. Biological plausibility exists for relationships between nitrate ingestion from drinking water and a few other health outcomes including diabetes and beneficial effects on the cardiovascular system, but there have been only a limited number of epidemiologic studies.

Assessment of drinking water nitrate exposures in future studies should be improved by obtaining drinking water sources at home and at work, estimating the amount of water consumed from each source, and collecting information on water filtration systems that may impact exposure. These efforts are important for reducing misclassification of exposure. Since our last review, an additional decade of PWS monitoring data are available in the U.S. and European countries, which has allowed assessment of exposure over a substantial proportion of participants' lifetimes in recent studies. Future studies should estimate exposure to multiple water contaminants as has been done in recent cancer studies [31,33,127,129]. For instance, nitrate and atrazine frequently occur together in drinking water in agricultural areas [161] and animal studies have found this mixture to be teratogenic [162]. Regulatory monitoring data for pesticides in PWS has been available for over 20 years in the U.S.; therefore, it is now feasible to evaluate co-exposure to these contaminants. Additionally, water supplies in agricultural areas that rely on alluvial aquifers or surface water often have elevated levels of both DBPs and nitrate. Under this exposure scenario, there is the possibility of formation of the nitrogenated DBPs including the carcinogenic NDMA, especially if chloramination treatment is used for disinfection [163,164]. Studies of health effects in countries outside the U.S. and Europe are also needed.

A comprehensive assessment of nitrate and nitrite from drinking water and dietary sources as well as estimation of intakes of antioxidants and other inhibitors of endogenous nitrosation including dietary polyphenols and flavonoids is needed in future studies. Heme iron from red meat, which increases fecal NOC in human feeding studies, should also be assessed as a potential effect modifier of risk from nitrate ingestion. More research is needed on the potential interaction of nitrate ingestion and nitrosatable drugs (those with secondary and tertiary amines or amides). Evidence from several studies of birth defects [38,118–120] implicates nitrosatable drug intake during pregnancy as a risk factor for specific congenital anomalies especially in combination with nitrate. Drugs with nitrosatable groups include many over-the-counter and prescription drugs. Future studies with electronic medical records and record-linkage studies in countries like Denmark with national pharmacy data may provide opportunities for evaluation of these exposures.

Populations with the highest exposure to nitrate from their drinking water are those living in agricultural regions, especially those drinking water from shallow wells near nitrogen sources (e.g., crop fields, animal feeding operations). Estimating exposure for private well users is important because it allows assessment of risk over a greater range of nitrate exposures compared to studies focusing solely on populations using PWS. Future health studies should focus on these populations, many of which may have been exposed to elevated nitrate in drinking water from early childhood into adulthood. A major challenge in conducting studies in these regions is the high prevalence of private well use with limited nitrate measurement data for exposure assessment. Recent efforts to model nitrate concentrations in private wells have shown that it is feasible to develop predictive models where sufficient measurement data are available [41,48,49]. However, predictive models from one area are not likely to be directly translatable to other geographic regions with different aquifers, soils, and nitrogen inputs.

Controlled human feeding studies have demonstrated that endogenous nitrosation occurs after ingestion of drinking water with nitrate concentrations above the MCL of 10 mg/L NO_3-N (~44 mg/L as NO_3). However, the extent of NOC formation after ingestion of drinking water with nitrate concentrations below the MCL has not been well characterized. Increased risks of specific cancers and central nervous system birth defects in study populations consuming nitrate below the MCL is indirect evidence that nitrate ingestion at these levels may be a risk factor under some conditions. However, confounding by other exposures or risk factors can be difficult to rule out in many studies. Controlled human studies to evaluate endogenous nitrosation at levels below the MCL are needed to understand interindividual variability and factors that affect endogenous nitrosation at drinking water nitrate levels below the MCL.

A key step in the endogenous formation of NOC is the reduction of nitrate, which has been transported from the bloodstream into the saliva, to nitrite by the nitrate-reducing bacteria that are located primarily in the crypts on the back of the tongue [165–167]. Tools for measuring bacterial DNA and characterizing the oral microbiome are now available and are currently being incorporated into epidemiologic studies [168,169]. Buccal cell samples that have been collected in epidemiologic studies can be used to characterize the oral microbiome and to determine the relative abundance of the nitrate-reducing bacteria. Studies are needed to characterize the stability of the nitrate-reducing capacity of the oral microbiome over time and to determine factors that may modify this capacity such as diet, oral hygiene, and periodontal disease. Interindividual variability in the oral nitrate-reducing bacteria may play an important role in modifying endogenous NOC formation. The quantification of an individual's nitrate-reducing bacteria in future epidemiologic studies is likely to improve our ability to classify participants by their intrinsic capacity for endogenous nitrosation.

In addition to characterizing the oral microbiome, future epidemiologic studies should incorporate biomarkers of NOC (e.g., urinary or fecal NOC), markers of genetic damage, and determine genetic variability in NOC metabolism. As many NOC require α-hydroxylation by CYP2E1 for bioactivation and for formation of DNA adducts, it is important to investigate the influence of polymorphisms in the gene encoding for this enzyme. Studies are also needed among populations with medical conditions that increase nitrosation such as patients with inflammatory bowel disease and periodontal disease [8]. Because NOC exposures induce characteristic gene expression profiles [170,171], further studies linking drinking water intake to NOC excretion and gene expression responses are relevant to our understanding of health risks associated with drinking water nitrate. The field of 'Exposome-research' [172,173] generates large numbers of genomics profiles in human population studies for which dietary exposures and biobank materials are also available. These studies provide opportunities to measure urinary levels of nitrate and NOC that could be associated with molecular markers of exposure and disease risk.

Nitrate concentrations in global water supplies are likely to increase in the future due to population growth, increases in nitrogen fertilizer use, and increasing intensity and concentration of animal agriculture. Even with increased inputs, mitigation of nitrate concentrations in water resources is possible through local, national, and global efforts. Examples of the latter are the International Nitrogen Initiative [174] and the EU Nitrates Directive [17,18], which aim to quantify human effects on the nitrogen cycle and to validate and promote methods for sustainable nitrogen management. Evidence for the effectiveness of these efforts, which include the identification of vulnerable areas, establishment of codes of good agricultural practices, and national monitoring and reporting are indicated by decreasing trends in groundwater nitrate concentrations in some European countries after the implementation of the EU Nitrates Directive [19]. However, the effect of this initiative was variable across the EU. In the U.S., nitrogen applications to crop fields are not regulated and efforts to reduce nitrogen runoff are voluntary. Although strategies such as appropriate timing of fertilizer applications, diversified crop rotations, planting of cover crops, and reduced tillage can be effective [175], concentrations in U.S. ground and surface water have continued to increase in most areas [10]. Climate change is expected to affect nitrogen in aquatic ecosystems and groundwater through alterations of the hydrological cycle [176]. Climatic factors that affect nitrate in groundwater include the amount, intensity, and timing of precipitation. Increasing rainfall intensity, especially in the winter and spring, can lead to increases in nitrogen runoff from agricultural fields and leaching to groundwater.

11. Conclusions

In summary, most adverse health effects related to drinking water nitrate are likely due to a combination of high nitrate ingestion and factors that increase endogenous nitrosation. Some of the recent studies of cancer and some birth defects have been able to identify subgroups of the population likely to have greater potential for endogenous nitrosation. However, direct methods of assessing these individuals are needed. New methods for quantifying the nitrate-reducing bacteria in the oral microbiome and characterizing genetic variation in NOC metabolism hold promise for identifying high risk groups in epidemiologic studies.

To date, the number of well-designed studies of individual health outcomes is still too few to draw firm conclusions about risk from drinking water nitrate ingestion. Additional studies that incorporate improved exposure assessment for populations on PWS, measured or predicted exposure for private well users, quantification of nitrate-reducing bacteria, and estimates of dietary and other factors affecting nitrosation are needed. Studies of colorectal cancer, thyroid disease, and central nervous system birth defects, which show the most consistent associations with water nitrate ingestion, will be particularly useful for clarifying these risks. Future studies of other health effects with more limited evidence of increased risk are also needed including cancers of the thyroid, ovary, and kidney, and the adverse reproductive outcomes of spontaneous abortion, preterm birth, and small for gestational age births.

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Nitrate and nitrite ingestion and risk of ovarian cancer among postmenopausal women in Iowa

Maki Inoue-Choi[1,2], Rena R. Jones[1], Kristin E. Anderson[3,4], Kenneth P. Cantor[1], James R. Cerhan[5], Stuart Krasner[6], Kim Robien[7], Peter J. Weyer[8] and Mary H. Ward[1]

[1] Occupational and Environmental Epidemiology Branch, Division of Cancer Epidemiology and Genetics, National Cancer Institute, National Institutes of Health, Bethesda, MD
[2] National Institute on Minority Health and Health Disparities, National Institutes of Health, Bethesda, MD
[3] Division of Epidemiology & Community Health, School of Public Health, University of Minnesota, Minneapolis, MN
[4] Masonic Cancer Center, University of Minnesota, Minneapolis, MN
[5] Division of Epidemiology, Mayo Clinic, Rochester, MN
[6] Metropolitan Water District of Southern California, Los Angeles, CA
[7] Department of Exercise and Nutrition Sciences, Milken Institute School of Public Health, George Washington University, Washington, DC
[8] Center for Health Effects of Environmental Contamination, University of Iowa, Iowa City, IA

Nitrate and nitrite are precursors in the endogenous formation of *N*-nitroso compounds (NOC), potential human carcinogens. We evaluated the association of nitrate and nitrite ingestion with postmenopausal ovarian cancer risk in the Iowa Women's Health Study. Among 28,555 postmenopausal women, we identified 315 incident epithelial ovarian cancers from 1986 to 2010. Dietary nitrate and nitrite intakes were assessed at baseline using food frequency questionnaire data. Drinking water source at home was obtained in a 1989 follow-up survey. Nitrate-nitrogen (NO_3-N) and total trihalomethane (TTHM) levels for Iowa public water utilities were linked to residences and average levels were computed based on each woman's duration at the residence. We computed multivariable-adjusted hazard ratios (HR) and 95% confidence intervals (CI) using Cox proportional hazards regression. We tested interactions of nitrate with TTHMs and dietary factors known to influence NOC formation. Ovarian cancer risk was 2.03 times higher (CI = 1.22–3.38, $p_{trend} = 0.003$) in the highest quartile ($\geq$2.98 mg/L) compared with the lowest quartile ($\leq$0.47 mg/L; reference) of NO_3-N in public water, regardless of TTHM levels. Risk among private well users was also elevated (HR = 1.53, CI = 0.93–2.54) compared with the same reference group. Associations were stronger when vitamin C intake was <median ($p_{interaction} = 0.01$ and 0.33 for private well and public supplies, respectively). Dietary nitrate was inversely associated with ovarian cancer risk ($p_{trend} = 0.02$); whereas, dietary nitrite from processed meats was positively associated with the risk ($p_{trend} = 0.04$). Our findings indicate that high nitrate levels in public drinking water and private well use may increase ovarian cancer risk among postmenopausal women.

Ovarian cancer has the highest mortality rate among all cancers of the female reproductive system.[1] Given its poor prognosis, identifying risk factors is critical to decrease mortality from ovarian cancer. However, the etiology of this malignancy is poorly understood. A large variation in ovarian cancer incidence among countries[2] and the increased risk of ovarian cancer among immigrants to the United States from other countries with low ovarian cancer incidence such as Japan[3,4] suggest a role of environmental factors, including diet. However, few modifiable risk factors have been identified to date.

Nitrate is a common contaminant of drinking water. Nitrogen from nitrogen fertilizer applications and animal and

Epidemiology

Key words: nitrate, nitrite, ovarian cancer, diet, drinking water, disinfection byproducts

Abbreviations: BMI: body mass index; CI: confidence interval; CSFII: Continuing Survey of Food Intake by Individuals; DBP: disinfection byproduct; FFQ: food frequency questionnaire; HAA: haloacetic acid; HR: hazard ratio; IWHS: Iowa Women's Health Study; MCL: maximum contaminant level; NOC: *N*-nitroso compounds; RDI: recommended daily intake; TTHM: total trihalomethane.

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Correspondence to: Maki Inoue-Choi, PhD, MS, 9609 Medical Center Dr., Bethesda, MD, 20892, Tel.: 240-276-6329, Fax: 240-276-7835, E-mail: maki.inoue-choi@nih.gov

What's new?
While environmental factors such as diet are thought to have a role in ovarian cancer, few such factors have been identified. In the present study, the ingestion of nitrate and nitrite was investigated for possible involvement in ovarian cancer. Among postmenopausal women, risk of ovarian cancer was found to be positively associated with elevated nitrate levels in public drinking water supplies and with nitrite intake from processed meats. Elevated nitrate levels in private well water was linked to increased ovarian cancer risk among women with reduced vitamin C intake.

human waste can contaminate surface and groundwater drinking water sources. The maximum contaminant level (MCL) for public water supplies in the United States is 10 mg/L nitrate-nitrogen (NO_3-N) and is based on preventing methemoglobinemia or blue-baby syndrome in infants.[5] However, the long-term effects of chronic intake of moderately high levels (*i.e.*, $\geq$5 mg/L) of nitrate from drinking water on cancer risk are still not clear.[6,7] Nitrate is also a natural component of plants and is found at high levels in certain vegetables.[7] Nitrate and nitrite salts are also added as preservatives to processed meats such as bacons and hot dogs to prevent bacterial growth and to add color and flavor.[7]

About 5% of ingested nitrate is endogenously reduced to nitrite by bacteria in the oral cavity.[7] Under the acidic conditions in the stomach, nitrite is converted to nitrous acid, which can then be converted to nitrosating agents. Once formed, nitrosating agents can react with amines and amides to form nitrosamines and nitrosamides (collectively called *N*-nitroso compounds [NOCs]). Most NOCs are potent animal carcinogens[8] and ingested nitrate and nitrite are considered probable human carcinogens (2A) under conditions that result in endogenous nitrosation.[7] Nitrosamides directly alkylate DNA and may induce tumors in many organs, whereas nitrosamines must be activated by specific cytochrome P450 enzymes to be carcinogenic.[7] The organ specificity of tumor induction may therefore stem from tissue-specific cytochrome P450 enzymes, which vary in level across organs and species. Cytochrome P450 enzymes have been found in ovarian epithelial tissue of animals.[9,10] Certain nutrients are known to influence endogenous NOC formation in the stomach. Antioxidants, especially vitamin C, reduce the endogenous NOC formation in humans.[7] In contrast, heme iron, which is found mostly in red meats, has been shown to enhance total NOC formation.[11] However, epidemiologic evidence of such interactions on cancer risk is still evolving.

The Iowa Women's Health Study (IWHS) is a large ongoing prospective cohort study started in 1986. In prior analyses, we observed an increased risk of ovarian cancer among women who reported drinking public water with elevated nitrate levels; however, the association was not statistically significant based on a relatively small number of cases ($n = 82$).[12] With an additional 12 years of follow-up, we evaluated whether nitrate and nitrite intake from diet and drinking water (public supplies and private wells) were associated with ovarian cancer risk. We further evaluated whether the association between nitrate and nitrite intake and ovarian cancer risk was modified by dietary factors that may inhibit (vitamin C and E) or enhance (red meats) endogenous NOC formation and by levels of disinfection byproducts (DBPs) in drinking water.

Materials and Methods

The Iowa Women's Health Study (IWHS)

The study design of the IWHS has been described in detail.[13] In brief, a self-administered questionnaire was mailed to 99,826 women, aged 55–69 years, randomly selected from the Iowa State's driver's license list in 1986. Of these women, 41,836 (42%) completed the baseline questionnaire assessing a study participant's demographics, anthropometry, lifestyle, familial history of cancer, medical and reproductive histories, and dietary intake. Respondents and non-respondents were comparable in terms of baseline characteristics.[14] Five follow-up questionnaires (1987, 1989, 1992, 1998 and 2004) have been administered *via* mail. The IWHS was approved by the Institutional Review Boards of the University of Minnesota and the University of Iowa. Return of the completed questionnaire was considered as a subject's consent to study participation.

Dietary intake assessment

Dietary intake at baseline was assessed using the Harvard food frequency questionnaire (FFQ). Study participants were asked their usual intake frequency of 126 food items and the use of dietary supplements over the previous 12 months. The FFQ has been shown to have good validity and reproducibility for major macro- and micronutrients in the IWHS.[15] Nutrient intakes were computed by multiplying the frequency of consumption of each food by the nutrient content. Total intakes of vitamin C and E were calculated by combining intake from foods and dietary supplements.

The nitrate and nitrite contents of foods were determined from a literature review focusing on published reports for U.S. or Canadian populations as previously described.[16,17] We computed means of nitrate and nitrite values for foods weighted by the number of samples and accounting for preparation (raw, cooked and canned) when possible. Nitrate and nitrite contents of FFQ line items were computed by weighting the food-specific values by sex-specific intake amounts from the 1994–1996 Continuing Survey of Food Intake by Individuals (CSFII).[18] For each study participant, we computed nitrate and nitrite intake overall and from plant and animal sources separately, including from processed meats only.

Water nitrate and DBP estimation

Information on drinking water was collected in a follow-up questionnaire mailed in 1989. Participants were asked the main source of drinking water at their current residence (municipal water system, rural water system, bottled water, private well water, other) and how long they had been drinking water from the indicated water source (<1, 1–5, 6–10, 11–20, >20 years). Of the 36,127 women completing the questionnaire (89% response rate), 27,409 (78%) reported public (municipal or rural) water and 6,634 (19%) reported private well water. Of the 27,409 women reporting public water, 22,375 (82%) reported using their water source for ≥11 years and 19,282 (70%) used it for >20 years. Of the 6,634 private well water drinkers, 5,862 (88%) used their water source for ≥11 years and 4,953 (75%) used it for >20 years. Information on tap water consumption at home and work was not collected.

We estimated nitrate and DBP levels in drinking water supplies using an historical municipal water supply monitoring database for Iowa. The database included NO_3-N measurements from finished water samples (1955–1988). NO_3-N levels in water samples were analyzed at the University of Iowa Hygienic Laboratory using standard methods.[19,20] Total trihalomethanes (TTHMs) and the sum of five haloacetic acids (HAA5) are the regulated DBPs.[21] TTHMs are the sum of four trihalomethanes (chloroform, bromoform, bromodichloromethane and dibromochloromethane). HAA5 is the sum of monochloro-, dichloro-, trichloro-, monobromo- and dibromoacetic acids.

A detailed description of the exposure assessment of DBPs in drinking water, developed in the context of another study, may be found elsewhere.[22] Routine monitoring of TTHMs started in the mid-1980s, and HAA5 in the mid-1990s. Annual average estimates for each DBP before these time periods were based on expert assessments, which considered measured TTHMs and HAA5 concentrations available in databases and historical information on water source, disinfection (pre-, intermediate and/or post-treatment; use of chlorine and/or chloramines) and other water treatment practices (*e.g.*, filtration, coagulation, sedimentation, softening), as well as selected water quality parameters.[22,23] Of the 356 Iowa public water utilities that served ≥ 1,000 persons at the time of estimation, we selected 34 that represented six categories of source water (surface water, shallow groundwater with high levels of brominated THMs, shallow groundwater with low levels of brominated THMs, nonalluvial groundwater with high levels of brominated THMs, nonalluvial groundwater with low levels of brominated THMs, and mixed surface/groundwater systems). We estimated DBP levels for these 34 utilities, considering measured data, changes in source water and/or treatment/disinfection practices over time, and water quality data. Whenever a utility significantly changed its historical treatment/disinfection process or source water, new DBP estimates were made. These annual estimates of 34 representative utilities were assigned to other utilities that used the same water source and similar water treatment and disinfection scheme.

Our study participants included in the water contaminant analyses lived in a total of 473 cities. We estimated the median duration of reported drinking water source categories (1–5, 6–10, 11–20, >20 years) as 4, 8, 16 and 40 years, respectively, based on complete water source history data from female controls of comparable ages in population-based case–control studies conducted during the same time period in Iowa.[24] For each median duration, we computed the means for NO_3-N and DBPs and the number of years in the time period for which the annual estimates exceeded half the MCL (5 mg/L and 40 μg/L for NO_3-N and TTHMs, respectively). In the previous analysis,[12] average NO_3-N levels (1955–1988) were assigned to each participant regardless of duration at their water source. In this study, we assigned average NO_3-N levels depending on their residential cities as well as the duration of using the reported water source. The NO_3-N estimates for each woman in the current study were highly correlated with our previous estimates (Spearman correlation coefficient, $r = 0.94$).

Statistical analysis

We excluded women who met the following criteria at baseline (numbers of subjects are not exclusive): (1) previous cancer diagnosis ($n = 3,830$); (2) premenopausal at baseline ($n = 569$); (3) history of bilateral oophorectomy ($n = 8,064$); and (4) an incomplete FFQ (left ≥ 30 items blank) or implausible energy intake (<600 or >5,000 kcal/day) ($n = 3,102$). In addition, we excluded ovarian cancers other than common epithelial cancers, including cancers of germ cell, sex-cord-stromal and others ($n = 27$), resulting in 28,555 women in the analysis for dietary nitrate and nitrite. We further limited drinking water analyses to women who provided drinking water information and reported using their water source for ≥11 years. In addition, we excluded women who lived in cities with public water systems that derived <75% from the same water source. The latter exclusion should increase the validity of the exposure measurement, as contaminant levels can vary between surface and groundwater sources as well as by depth of groundwater sources.[12] As a result, 17,216 women (13,051 drinking public water and 4,164 drinking private well water) remained in the drinking water analyses.

Incident common epithelial ovarian cancers (1986–2010) were identified *via* the annual linkage with the State Health Registry of Iowa's cancer registry, which is part of the Surveillance, Epidemiology and End Results program of the National Cancer Institute. Diagnosis date, type, stage and morphology of each incident cancer were obtained. Vital status (the date and cause of death) is annually identified through the linkage with the State Health Registry of Iowa, supplemented with the National Death Index. Person-years were computed from the date of return of the baseline questionnaire to the date of first ovarian cancer diagnosis, bilateral oophorectomy (self-reported), emigration from Iowa (<0.5% annually), death or December 31, 2010, whichever came first.

Pair-wise correlations among NO_3-N and eight DBPs were evaluated using Spearman correlation coefficients (r). The eight DBPs were highly correlated ($r = 0.67$–0.98; Supporting Information Table S1) and we used TTHMs, the sum of the most prevalent DBP class measured, as a surrogate for total halogenated DBPs. Categorical variables were generated for water NO_3-N and TTHM levels (quartiles) and dietary nitrate and nitrite intake (quintiles). Because the range of nitrite intake from processed meats was narrow, we created a 4-level categorical variable (0, >0–0.09, 0.1–0.19, ≥0.2 mg/d) based on its distribution. We compared selected baseline characteristics by NO_3-N levels in public water and private well water use. Hazard ratios (HR) and 95% confidence intervals (CI) were computed using Cox proportional hazards regression as the measure of association with the lowest level as a reference group. We selected *a priori* several baseline characteristics that are risk or protective factors for ovarian cancer as covariates in the multivariable-adjusted model. These covariates included age (continuous), body mass index (BMI, continuous), familial history of ovarian cancer, number of live births (nulliparous, 1–2, 3–4, ≥5), age at menarche (≤ or >12), age at menopause (<45, 45–49, 50–54, ≥55), age at first live birth (<20, 20–24, 25–29, ≥30), oral contraceptive use (never, ever), estrogen use (never, ever) and history of unilateral oophorectomy. In the drinking water analyses, we mutually adjusted for NO_3-N and TTHMs levels (continuous) to evaluate the independent effect of each contaminant. Dietary nitrate and nitrite analyses were additionally adjusted for total energy intake and dietary factors (continuous) that were associated with ovarian cancer risk and were moderately correlated with dietary nitrate or nitrite intake in our study population (cruciferous vegetables, $r = 0.53$ and red meat, $r = 0.48$). Logarithmically transformed values were used for NO_3-N and TTHM levels and dietary factors as covariates, as their distributions were markedly skewed. We tested trends for associations across exposure levels using the median in each category as continuous variables. Because NO_3-N measurements in private well water were not available, ovarian cancer risk among private well water drinkers was compared with the risk among women in the lowest quartile of nitrate in public water. We tested interactions between water NO_3-N and TTHM levels as well as between nitrate (from drinking water or diet) and total vitamin C, E and red meat intake by stratified analyses (≤ or > median) and by including interaction terms (*i.e.*, cross products of dichotomous variables for vitamin C, E and red meats and median in nitrate or nitrite quartile or quintile as continuous variables) in regression models. We performed sensitivity analyses limited to women who reported using the same water source for >20 years. Statistical significance for all analyses was defined as $p < 0.05$.

Results

Mean age of study participants at baseline was 61.6 years (standard deviation, SD = 4.2 years). During the follow-up, 315 incident common epithelial ovarian cancers were identified. Of these, 190 ovarian cancers were included in water nitrate analysis (145 using public water supplies and 45 using private wells). Mean (SD) age at diagnosis was 73.2 (7.7) years. Higher risk for ovarian cancer was observed among women with a familial history of ovarian cancer, no history of unilateral oophorectomy, who were nulliparous and had fewer live births. Oral contraceptive use and ages at menarche and menopause were not associated with ovarian cancer risk; nor were demographic and lifestyle factors such as farm residence, age, BMI, cigarette smoking, physical activity, or alcohol intake. Median NO_3-N and TTHM levels for women drinking from public water supplies were 1.08 mg/L (range: 0.01–25.34 mg/L) and 4.59 μg/L (range: 0–200.88 μg/L), respectively. NO_3-N levels were not correlated with TTHMs or other DBP estimates ($r = -0.03$-0.29) (Supporting Information Table S1). A history of unilateral oophorectomy was slightly more prevalent among women with elevated NO_3-N levels in public water (Table 1). Other factors and dietary intake were not different across NO_3-N levels in public water. More than 90% of women who reported drinking private well water lived on a farm (72%) or in non-farm rural areas (19%) while about 95% of public water drinkers lived in towns. Compared with public water drinkers, more women on private well water had lower education levels, never smoked, had no history of unilateral oophorectomy and never used estrogens or oral contraceptives. Intakes of total calories and red meats (energy-adjusted) were higher among private well water drinkers than public water drinkers. In contrast, total vitamin C intake and energy-adjusted intakes of dietary nitrate and fruits and vegetables were slightly lower among private well users than public water drinkers.

Women who consumed water containing elevated NO_3-N levels were at higher risk for ovarian cancer ($HR_{Q4\ vs.Q1} = 2.14$, CI = 1.30–3.54, $p_{trend} = 0.002$; Table 2). This association did not change substantially by adjusting for TTHM levels. Longer duration of exposure to NO_3-N at levels exceeding half the MCL (5 mg/L) was associated with higher risk for ovarian cancer ($p_{trend} = 0.02$). Women who had ingested water with NO_3-N exceeding 5 mg/L for ≥4 years were at 1.6 times higher risk for ovarian cancer compared with women with no exposure to NO_3-N exceeding 5 mg/L (CI = 1.06–2.41). In contrast, neither average TTHM levels in public water nor years of exposure to TTHM levels exceeding half the MCL (40 μg/L) were associated with ovarian cancer risk. When stratified by low or high TTHM levels (≤ or >median, 4.60 μg/L), there was no evidence of interaction of NO_3-N with TTHMs (data not shown). None of the individual DBPs was associated with ovarian cancer risk (Supporting Information Table S2). Although not statistically significant, ovarian cancer risk was higher among private well users compared with those with the lowest NO_3-N levels in public water (HR = 1.53, CI = 0.93–2.54). Similar

Epidemiology

Table 1. Demographic, lifestyle, reproductive and dietary factors among 17,216 women and by mean nitrate levels in public water and private well water use

		Mean nitrate (mg/L nitrate–nitrogen) levels in public water				
	All	0.01–0.472	0.473–1.08	1.09–2.97	2.98–25.34	Private well water
N	17,216	3,263	3,269	3,504	3,015	4,165
Age, years (mean ± SD)	61.6 ± 4.2	61.8 ± 4.2	61.7 ± 4.2	61.7 ± 4.2	61.7 ± 4.2	61.2 ± 4.1
BMI, kg/m^2 (mean ± SD)	26.9 ± 5.0	26.8 ± 5.0	26.7 ± 4.9	26.6 ± 5.0	26.8 ± 5.0	27.4 ± 5.1
Education, ≥ high school (%)	83.8	83.7	84.3	83.5	86.1	81.8
Residence location (%)						
Farm	19.6	3.3	3.3	2.1	2.5	71.9
Rural area (not farm)	6.2	1.7	2.3	1.4	3.0	19.1
Town	74.2	95.0	94.4	96.5	94.5	9.0
Smoking, ever (%)	34.3	37.2	38.9	40.3	37.2	21.3
Physical activity, low (%)	47.3	46.6	47.0	47.8	47.1	47.8
Unilateral oophorectomy (%)	9.8	11.3	10.2	9.8	9.7	8.7
Estrogen use, ever (%)	31.8	33.3	32.4	33.6	33.3	27.6
Oral contraceptive use (%)	19.8	20.7	21.0	19.5	19.0	19.1
Age at menarche ≥ 13 years (%)	57.4	58.4	57.4	56.7	56.6	58.0
Age at menopause ≥ 50 years (%)	53.8	51.9	53.2	52.5	53.0	57.3
Number of live births (mean ± SD)	3.1 ± 1.9	3.1 ± 2.0	3.0 ± 1.9	2.9 ± 1.8	2.9 ± 1.8	3.5 ± 2.0
Age at first live births, years (mean ± SD)	21.0 ± 7.7	20.7 ± 8.0	20.8 ± 7.8	20.7 ± 8.1	21.0 ± 7.8	21.5 ± 6.8
Total calorie intake, kcal (median)	1,731	1,699	1,693	1,702	1,694	1,839
Total vitamin C intake, mg/d (median)	188	189	189	188	192	186
Total vitamin E intake, mg/d (median)	9.5	9.5	9.5	9.5	9.5	9.5
Energy-adjusted intake[1] (median)						
Nitrate, mg/d	60.8	61.0	61.1	61.7	61.5	59.2
Fruits and vegetables, servings/wk	23.6	23.5	23.9	23.9	23.8	23.0
Red meat, servings/wk	3.0	2.9	1.9	2.9	2.8	3.5
Processed meat, servings/wk	0.7	0.7	0.7	0.7	0.7	0.7

[1]Intake adjusted for 1,000 kcal/d of total energy intake.

elevated risks were observed among private well drinkers who lived on a farm (HR = 1.49, CI = 0.87–2.55) or in rural areas or towns (HR = 1.64, 95% CI = 0.83–3.24). These associations remained unchanged after adjusting for dietary nitrate and nitrite intake. When limiting analyses to women who reported using the same water source for >20 years, all observed associations became slightly stronger.

The association between higher nitrate levels in public water and ovarian cancer was stronger among women with low vitamin C intake (≤ median, 190 mg/d, $p_{\text{trend}} = 0.005$) compared with those with high intake (> median, $p_{\text{trend}} = 0.12$); however, the interaction was not statistically significant ($p_{\text{interaction}} = 0.33$, Table 3). The elevated risk among private well water drinkers was observed only among women with low vitamin C intake (HR = 3.30, CI = 1.44–7.56, $p_{\text{interaction}} = 0.01$). We also attempted to use different cutpoints for total vitamin C intake including the recommended daily intake (RDI) for non-smoking adult women (=70 mg/d) and the first quartile of total vitamin C intake in our study population (=125 mg/d). Similar stronger positive associations between water nitrate and ovarian cancer risk were observed among women with lower vitamin C intake (data not shown); however, CIs in the low vitamin C intake group were wide due to small numbers of ovarian cancer cases. A stronger association between NO_3-N levels in public water or private well use and ovarian cancer risk was observed among women with high *vs.* low red meat intake although the interaction was not statistically significant.

Mean (SD) dietary nitrate and nitrite intakes were 123.3 mg/d (83.4 mg/d) and 1.2 mg/d (0.5 mg/d), respectively. Total dietary nitrate intake and nitrate intake from plants (*e.g.*, high nitrate vegetables such as lettuce, celery, beets, spinach and broccoli) were highly correlated ($r = 0.99$). On average, about 38% of dietary nitrite intake came from

Table 2. Exposures to nitrate–nitrogen (NO_3–N) and total trihalomethanes (TTHMs) in public water and ovarian cancer risk

				HR (95% CI)		
	Median	*N*	Cases	Age-adjusted	Model 1[1]	Model 2[2]
NO_3-N (mg/L)						
0.01–0.472	0.31	3,263	23	1.0	1.0	1.0
0.473–1.08	0.75	3,269	32	1.41 (0.82–2.41)	1.36 (0.80–2.34)	1.27 (0.73–2.21)
1.09–2.97	1.68	3,504	41	1.66 (1.00–2.76)	1.55 (0.92–2.59)	1.45 (0.85–2.44)
2.98–25.34	3.81	3,015	49	2.34 (1.42–3.84)	2.14 (1.30–3.54)	2.03 (1.22–3.38)
p_{trend}				0.0005	0.002	0.003
Private well water	–	4,165	45	1.50 (0.91-–2.49)	1.53 (0.93–2.54)	–
Years of NO_3-N >5 mg/L[3]						
0	0	9,206	91	1.0	1.0	1.0
1–3	1	1,871	22	1.20 (0.75–1.91)	1.05 (0.64–1.72)	1.08 (0.65–1.77)
≥ 4[4]	8	1,974	32	1.66 (1.11–2.49)	1.60 (1.06–2.41)	1.52 (1.00–2.31)
p_{trend}				0.01	0.02	0.05
TTHMs (μg/L)						
0–0.89	0.47	3,112	27	1.0	1.0	1.0
0.90–4.59	1.95	3,612	33	1.07 (0.64–1.78)	1.10 (0.65–1.86)	1.08 (0.64–1.82)
4.77–14.31	10.67	3,524	55	1.82 (1.15–2.89)	1.86 (1.146– 3.00)	1.64 (1.00–2.70)
14.50–200.88	76.32	2,803	30	1.27 (0.76–2.14)	1.31 (0.77–2.24)	1.24 (0.73–2.13)
p_{trend}				0.78	0.74	0.80
Years of TTHMs >40 μg/L[3]						
0	0	9,838	110	1.0	1.0	1.0
$>$ 0–35	3	1,442	17	1.05 (0.63–1.76)	1.00 (0.59–1.70)	0.99 (0.59–1.68)
≥ 36[4]	40	1,771	18	0.93 (0.56–1.53)	0.90 (0.54–1.50)	0.91 (0.55–1.52)
p_{trend}				0.84	0.69	0.72

[1]Adjusted for age, BMI, family history of ovarian cancer, number of live births (0, 1–2, 3–4, ≥ 5), age at menarche ($\leq$ or >12), age at menopause (<45, 45–49, 50–54, ≥ 55), age at first live birth (<20, 20–24, 25–29, ≥ 30), oral contraceptive use (never, ever), estrogen use (never, ever) and history of unilateral oophorectomy.
[2]Additionally mutually adjusted for logarithmically transformed values of NO_3–N or TTHMs levels in public water.
[3]Half the maximum contaminant level (MCL) determined by the U.S. Environmental Protection Agency.
[4]The median years of exposures to a half of MCL among women who exposed during the reported duration of exposure.

animal sources and 15% came from processed meats. Higher dietary nitrate intake was observed among IWHS participants reporting higher age, BMI, education level, alcohol intake, physical activity level and estrogen use.[25] Women reporting higher dietary nitrate intake also reported higher intake of total calories, cruciferous vegetables, red meats and vitamins C and E. Higher dietary nitrate intake was associated with lower ovarian cancer risk ($HR_{Q5\ vs.Q1} = 0.61$, CI = 0.40–0.95; $p_{trend} = 0.02$, Table 4). Dietary nitrite intake was not associated with ovarian cancer risk. Similarly, neither dietary nitrite intake from plant nor animal sources was associated with ovarian cancer risk. However, higher nitrite intake from processed meats was marginally associated with higher ovarian cancer risk after adjusting for confounders ($p_{trend} = 0.04$). On a continuous scale, the risk was 12% (CI = 4–20%) higher with each 0.1 mg increment in nitrite intake from processed meats. These associations did not change by additional adjustment for total vitamin C and E intakes. There was no interaction between dietary nitrate or nitrite intake and total vitamin C, E or red meat intakes.

Discussion

We found higher risk for epithelial ovarian cancer among women drinking water from public supplies with higher nitrate levels, regardless of TTHM levels. Ovarian cancer risk also appeared higher among women drinking private well water compared with the lowest NO-N_3 quartile in public water supplies, and we observed a statistically significant interaction with vitamin C intake. Higher dietary nitrate intake was associated with lower risk for ovarian cancer, whereas higher nitrite intake from processed meats was associated with higher risk.

Epidemiologic studies of dietary nitrate intake have predominantly evaluated stomach cancer and many studies reported null associations or inverse trends.[7,26] One explanation for these findings is the potential interaction between

Epidemiology

Table 3. Ovarian cancer risk in relation to nitrate–nitrogen (NO_3-N) levels in drinking water stratified by high or low total vitamin C and red meat intakes

	Vitamin C ≤190 mg/d				Vitamin C >190 mg/d				
	N	Cases	HR (95% CI)[1]	p_{trend}	*N*	Cases	HR (95% CI)[1]	p_{trend}	$p_{interaction}$
NO_3-N (mg/L)									
0.01–0.472	1,625	7	1.0	0.005	1,638	16	1.0	0.12	0.33
0.473–1.08	1,629	14	1.85 (0.74–4.65)		1,640	18	1.16 (0.59–2.29)		
1.09–2.97	1,762	26	3.17 (1.37–7.32)		1,742	15	0.83 (0.40–1.70)		
2.98–25.34	1,467	24	3.39 (1.45–7.95)		1,548	25	1.60 (0.85–3.02)		
Private well water[2]	2,125	29	3.30 (1.44–7.56)	–	2,040	16	0.77 (0.38–1.54)	–	0.01
	Red meats ≤5 servings/wk				Red meats >5 servings/wk				
	N	Cases	HR (95% CI)[1]	p_{trend}	*N*	Cases	HR (95% CI)[1]	p_{trend}	$p_{interaction}$
NO_3-N (mg/L)									
0.01–0.472	1,812	13	1.0	0.18	1,451	10	1.0	0.002	0.14
0.473–1.08	1,853	21	1.61 (0.81–3.22)		1,416	11	1.04 (0.43–2.50)		
1.09–2.97	2,032	26	1.69 (0.86–3.30)		1,472	15	1.36 (0.60–3.06)		
2.98–25.34	1,788	25	1.82 (0.93–3.57)		1,227	24	2.59 (1.23–5.48)		
Private well water[2]	1,629	15	1.34 (0.64–2.82)	–	2,536	30	1.68 (0.82–3.44)	–	0.63

[1]Adjusted for age, BMI, family history of ovarian cancer, number of live births (0, 1–2, 3–4, ≥5), age at menarche (≤ or >12), age at menopause (< 45, 45–49, 50–54, ≥55), age at first live birth (< 20, 20–24, 25–29, ≥30), oral contraceptive use (never, ever), estrogen use (never, ever) and a history of unilateral oophorectomy.
[2]HR and 95% CI were computed with the lowest quartile of nitrate among public water drinkers as a reference group.

nitrate and antioxidants, which are abundant in major dietary sources of nitrate such as green leafy and root vegetables.[27,28] Antioxidants, such as vitamins C and E, inhibit NOC formation by reducing nitrite to nitric oxides, and thus decreasing the level of NOCs and NOC-induced DNA adducts.[29,30] Therefore, a potentially carcinogenic effect of dietary nitrate intake may be reduced or eliminated by the protective effects of high antioxidant intake from fruits and vegetables. Indeed, dietary nitrate intake was highly correlated with total vegetable intake ($r = 0.84$), and moderately correlated with antioxidant intakes ($r = 0.36$–0.46) in our study.

Carcinogenic effects of NOCs in the ovary have been shown in animal studies.[9,10] However, to date, NOCs and their precursors nitrate and nitrite have been evaluated in relation to ovarian cancer risk in only a few epidemiologic studies. Ovarian cancer risk was evaluated in relation to dietary nitrate intake in two prospective cohort studies and these studies found no associations.[12,31] Dietary nitrite intake and ovarian cancer was assessed in only one prior cohort study.[31] In that study, total nitrite intake and nitrite intake from plant sources were not associated with epithelial ovarian cancer risk, but higher nitrite intake from animal sources was associated with higher risk ($HR_{Q5\ vs.\ Q1} = 1.34$, CI = 1.05–1.69, $p_{trend} = 0.02$). Processed meats contain added nitrate and nitrite as well as high amounts of amines and amides, precursors of NOCs. Ingestion of nitrate in combination with nitrosatable precursors has been shown to increase the formation of NOCs.[32] Furthermore, red and processed meats contain heme iron, a component of myoglobin, which promotes the formation of NOCs.[11] Therefore, nitrate and nitrite added to processed meats may result in exogenous and endogenous NOC formation. Three large prospective cohort studies have found statistically non-significant trends towards positive associations between processed meat intake and ovarian cancer.[33–35] Meta-analysis of four prospective cohort studies found a borderline positive exposure response between processed meat intake and ovarian cancer risk (HR = 1.05, CI = 0.98–1.14 for an intake increment of 100 g per week).[36]

Unlike dietary nitrate, nitrate from drinking water is not accompanied by micronutrients that could inhibit endogenous nitrosation. Therefore, nitrate from drinking water could result in more endogenously formed NOCs than nitrate from foods. Previous epidemiologic studies, including our study,[12] have shown associations between nitrate levels in public water and the risk of cancer, including bladder,[12] stomach and colorectal cancers.[6,7] However, ovarian cancer has been assessed in relation to nitrate in public water only in our previous analysis in the IWHS, as one of multiple cancer outcomes.[12] In our previous analysis including 82 incident ovarian cancers, we observed a positive association between higher nitrate levels in public water supplies and the risk of ovarian cancer ($HR_{Q4\ vs.\ Q1} = 1.86$, CI = 0.82–4.26); however, this association did not reach statistical significance level. In the current study, we found a statistically significant more than two-fold risk for ovarian cancer among women in the highest (median = 3.81 mg/L) compared in the lowest (median = 0.31 mg/L) NO_3-N quartiles in public water supplies.

Epidemiology

Table 4. Dietary nitrate and nitrite intake and ovarian cancer risk among 28,555 women

				HR (95% CI)	
	Median	*N*	Cases	Model 1[1]	Model 2[2]
Nitrate (mg/d)					
Total intake					
Q1: 3.87–65.43	49.5	5,711	59	1.0	1.0
Q2: 65.44–92.04	78.9	5,711	73	1.18 (0.83–1.68)	1.05 (0.73–1.50)
Q3: 92.05–121.96	106.2	5,711	54	0.86 (0.58–1.26)	0.72 (0.48–1.06)
Q4: 121.97–165.48	140.2	5,711	74	1.21 (0.84–1.74)	0.96 (0.66–1.41)
Q5: 165.54–2,083.52	209.2	5,711	55	0.85 (0.56–1.27)	0.61 (0.40–0.95)
p_{trend}				0.37	0.02
Per 10 mg/d	–	–	–	0.99 (0.98–1.01)	0.98 (0.96–1.00)
Nitrite (mg/d)					
Total intake					
Q1: 0.11–0.80	0.7	5,709	62	1.0	1.0
Q2: 0.81–1.02	0.9	5,716	52	0.84 (0.56–1.26)	0.80 (0.53–1.21)
Q3: 1.021–1.23	1.1	5,716	65	1.12 (0.73–1.72)	1.04 (0.68–1.59)
Q4: 1.239–1.53	1.4	5,703	70	1.26 (0.79–2.02)	1.14 (0.71–1.82)
Q5: 1.537–7.13	1.8	5,711	66	1.20 (0.68–2.12)	1.03 (0.58–1.84)
p_{trend}				0.24	0.50
Per 0.1 mg/d	–	–	–	1.00 (0.97–1.04)	0.99 (0.95–1.03)
Animal sources					
Q1: 0–0.26	0.2	5,638	63	1.0	1.0
Q2: 0.26–0.36	0.3	5,689	44	0.68 (0.45–1.02)	0.72 (0.48–1.08)
Q3: 0.36–0.47	0.4	5,597	83	1.29 (0.89–1.88)	1.39 (0.96–2.02)
Q4: 0.47–0.61	0.5	5,668	59	0.89 (0.59–1.37)	0.98 (0.64–1.50)
Q5: 0.61–3.47	0.7	5,648	66	1.04 (0.64–1.67)	1.18 (0.72–1.91)
p_{trend}				0.45	0.25
Per 0.1 mg/d	–	–	–	1.04 (0.98–1.11)	1.06 (1.00–1.13)
Processed meats					
0	0	4,872	54	1.0	1.0
$>$ 0–0.09	0.04	19,770	212	0.94 (0.69–1.28)	1.01 (0.74–1.38)
0.1 – 0.19	0.13	2,537	32	1.15 (0.73–1.82)	1.27 (0.80–2.01)
$\geq$ 0.2	0.26	1,135	17	1.46 (0.82–2.58)	1.65 (0.93–2.94)
p_{trend}				0.10	0.04
Per 0.1 mg/d	–	–	–	1.10 (1.03–1.19)	1.12 (1.04–1.20)
Plant sources					
Q1: 0.04–0.47	0.4	5,701	64	1.0	1.0
Q2: 0.47–0.61	0.5	5,717	62	0.88 (0.61–1.28)	0.82 (0.56–1.19)
Q3: 0.61–0.76	0.7	5,712	57	0.87 (0.59–1.28)	0.77 (0.52–1.14)
Q4: 0.76–0.98	0.9	5,721	67	1.01 (0.67–1.51)	0.86 (0.57–1.29)
Q5: 0.98–6.39	1.2	5,704	65	0.96 (0.60–1.52)	0.77 (0.48–1.24)
p_{trend}				0.79	0.54
Per 0.1 mg/d	–	–	–	0.99 (0.95–1.03)	0.97 (0.92–1.01)

[1]Adjusted for age, BMI, family history of ovarian cancer, number of live births (0, 1–2, 3–4, $\geq$5), age at menarche ($\leq$ or $>$12), age at menopause ($<$ 45, 45–49, 50–54, $\geq$55), age at first live birth ($<$ 20, 20–24, 25–29, $\geq$30), oral contraceptive use (never, ever), estrogen use (never, ever), history of unilateral oophorectomy and total energy intake (logarithmically transformed).
[2]Additionally adjusted for logarithmically transformed values of cruciferous vegetable and red meat intake.

For the first time, we found evidence suggesting a higher risk for ovarian cancer among women who were private well water drinkers. In Iowa, agricultural application of nitrogen is the major source of environmental nitrate contamination. Nitrate levels can be high in private wells in agricultural areas because of their location close to crop fields treated with nitrogen fertilizer and livestock manure, and because private wells are not regulated and may not be routinely monitored. In the United States, the average NO_3-N levels in streams and groundwater in agricultural areas are over 3 mg/L whereas average levels in urban areas and areas with mixed land use are about 1.5 mg/L and 1 mg/L, respectively.[6] About 22% of private wells in agricultural areas in the United States exceed the nitrate MCL (10 mg/L NO_3-N).[6] A survey of rural private wells in Iowa in 1988–1989 found that 18% of wells exceeded the MCL for nitrate. In addition, 37% of these rural private wells had levels greater than 3 mg/L, typically considered indicative of anthropogenic pollution.[37] We observed similarly elevated risk of ovarian cancers among private well users in farm and non-farm areas. Most of Iowa land is used for agriculture with row crops and grasslands covering 90% and urban areas accounting for only 1% of the state surface area.[38] Therefore, private wells located in non-farm rural areas or towns are likely to be in close proximity to farms and thus impacted by the agricultural use of nitrogen fertilizers. Nitrate levels in private well water are determined by many factors including geological characteristics and agricultural practices.[37] Well depth is the best predictor of well-water nitrate contamination with higher nitrate levels found in shallower wells. NO_3-N levels in 35% of private wells less than 15 m deep exceeded the MCL (about 28% of private wells in Iowa are less than 15 m deep).[37,39] Unfortunately, information on well depth was not collected in our study.

It should be noted that elevated nitrate levels may be an indicator of contamination with other chemicals or bacteria.[40] In agricultural areas, wells with elevated nitrate levels may also have elevated levels of herbicides, some of which are suspected carcinogens. For example, atrazine, a triazine herbicide, is one the most frequently detected pesticides in Iowa groundwater, and occupational exposure is a hypothesized risk factor for ovarian cancer.[41,42] Exposures to pesticides *via* drinking water are likely to be substantially lower than occupational exposures but few studies have been conducted. Atrazine and its metabolites have been detected in Iowa public water supplies, although levels are usually below the MCL and detections are not as frequent as for nitrate.[43] The 1988–1989 state-wide survey revealed that pesticides were present in about 5% of private wells in Iowa.[37] DBPs in drinking water have been associated with higher risk for bladder cancer and possibly other sites.[44] We evaluated, for the first time, DBPs in drinking water in relation to ovarian cancer and found only non-significant, uneven elevations of risk for the DBP metrics in our analysis. Evaluation in other populations would be valuable.

Ovarian cancer is a relatively rare cancer, but a large sample size as well as a long follow-up period enabled us to study 190 cases in relation to water contaminants. Emigration from Iowa rarely occurred in our cohort (<0.5% annually), enabling a nearly complete follow-up of the cohort and likely detection of most incident ovarian cancers. The attainment of water nitrate and DBP data through a linkage with a historical public water monitoring database is another strength of our study. In addition, reported duration of water source use enabled us to estimate the length of exposure to water contaminants, which is a key factor in exposure assessment. The majority of our cohort participants lived in the same address for more than 10 years at the post-enrollment drinking water data collection, which enabled us to estimate long-term exposures to nitrate and DBPs in drinking water. Our study has limitations as well. Dietary intake was assessed at cohort baseline and may have changed during the long follow-up period. However, dietary intakes assessed at cohort baseline and at the 2004 follow-up survey were reasonably correlated (*e.g.*, $r = 0.44$ for total calorie, 0.39–0.42 for macronutrients, 0.36 for total vegetables and 0.24 for processed meat products) and earlier exposures are likely to be the most relevant for cancer risk. Potential misclassification of dietary intake assessed using a FFQ is also probable. Furthermore, dietary intake assessment by a FFQ cannot capture important information related to the nitrate content and NOC formation such as food storage and cooking methods. Because information on study participants' daily water consumption was not available, patterns in individuals' water consumption such as the amount and timing as well as water consumption outside of their home (*e.g.*, work) was not taken into account in our exposure assessment. In addition, we did not have information on other factors that may influence nitrate metabolism to include in our analyses. For example, factors that affect the number of nitrate-reducing bacteria in saliva, such as mouthwash use and oral hygiene, may alter the rate of nitrate–nitrite conversion by saliva.[7] Similarly, proton-pump inhibitor use increases the pH in the stomach and may increase NOC formation.[45] Finally, study included only postmenopausal white women; therefore, interpretation of our results is limited to this population, and future studies should evaluate these exposures among all women including premenopausal women and other ethnic groups with ovarian cancer.

In conclusion, this study indicates that nitrate from public drinking water may be associated with higher risk of ovarian cancer among postmenopausal women. Our results suggest that postmenopausal women who drink private well water may be at higher risk for ovarian cancer, especially with low vitamin C intake. Our findings also support the hypothesis that dietary nitrite intake from processed meats increases ovarian cancer risk. Additional confirmatory studies with a larger number of ovarian cancer cases are warranted and could result in a novel target for ovarian cancer risk reduction.

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Nitrogen in Minnesota Surface Waters

Conditions, trends, sources, and reductions

Minnesota Pollution Control Agency

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Lead Authors of one or more chapters: David Wall (MPCA), David Mulla (U of MN), Steve Weiss (MPCA), Dennis Wasley (MPCA), Thomas E. Pearson (MPCA), Bruce Henningsgaard (MPCA). Authors of each separate chapter are listed near the chapter headings.

Co-authors and appendix authors of one or more chapters/appendices: David Lorenz (USGS), Nick Gervino (MPCA), William Lazarus (U of MN), Karina Fabrizzi (U of MN), Pat Baskfield (MPCA), David Christopherson (MPCA), Gary Martin (USGS), Jacob Galzki (U of MN), and Ki-In Kim (U of MN).

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Contents

Executive Summary

Purpose

This study of nitrogen (N) in surface waters was conducted to better understand the N conditions in Minnesota's surface waters, along with the sources, pathways, trends and potential ways to reduce N in waters. Nitrogen is an essential component of all living things and is one of the most widely distributed elements in nature. Nitrate (NO_3), the dominant form of N in waters with high N, is commonly found in ground and surface waters throughout the country. Human activities can greatly increase nitrate, which is typically found at low levels in undisturbed landscapes.

Concern about N in Minnesota's surface waters has grown in recent decades due to: 1) increasing studies showing toxic effects of nitrate on aquatic life, 2) increasing N concentrations and loads in the Mississippi River combined with nitrogen's role in causing a large oxygen-depleted zone in the Gulf of Mexico, and 3) the discovery that some Minnesota streams exceed the 10 milligrams per liter (mg/l) standard established to protect potential drinking water sources.

Minnesota recently initiated two state-level efforts related to N in surface waters. The Minnesota Pollution Control Agency (MPCA) is developing water quality standards to protect aquatic life from the toxic effects of high nitrate concentrations. The standards development effort, which is required under a 2010 Legislative directive, draws upon recent scientific studies that identify the concentrations of nitrate harmful to fish and other aquatic life.

Also in development is a state-level Nutrient Reduction Strategy, as called for in the 2008 Gulf of Mexico Hypoxia Action Plan. Minnesota contributes the sixth highest N load to the Gulf and is one of 12 member states serving on the Mississippi River/Gulf of Mexico Watershed Nutrient Task Force. The cumulative N and phosphorus (P) contributions from several states are largely the cause of a hypoxic (low oxygen) zone in the Gulf of Mexico. This hypoxic zone affects commercial and recreational fishing and the overall health of the Gulf, since fish and other aquatic life cannot survive with low oxygen levels. Minnesota is developing a strategy which will identify how further progress can be made to reduce N and P entering both in-state and downstream waters.

The scientific foundation of information documented in this report will be useful as the MPCA and other state and federal organizations further their nitrogen-related work, and also as local government considers how high N levels might be reduced in their watersheds.

The Minnesota Department of Agriculture is completing a separate but concurrent effort to revise the state's Nitrogen Fertilizer Management Plan, as required under Minnesota's Ground Water Protection Act. The plan addresses groundwater protection from nitrate. Yet because groundwater baseflow is an important contributor to surface water nitrate, certain groundwater protection efforts will also benefit surface waters.

Approach

The general approach for conducting this study was to:

1) **Collaborate with other organizations.** This study was conducted and written by 15 authors and co-authors. The University of Minnesota led the assessment of agricultural and nonpoint sources of N.

The U.S. Geological Survey assisted with nitrate trends evaluations and certain modeling and mapping efforts. Assistance and review was provided by several other organizations including Metropolitan Council, Minnesota Department of Agriculture, Board of Water and Soil Resources, and others.

2) **Build from existing information, tools, and data**. The study incorporated:
   - Recent water N concentration results from more than 50,000 water samples collected at more than 700 stream sites in Minnesota;
   - Water N loads calculated from monitoring results at more than 75 Minnesota watersheds;
   - Monitoring results from approximately 1976 to 2010 at 50 river sampling sites in Minnesota;
   - Findings from more than 300 published studies;
   - Findings from six previously developed computer models and two newly developed models; and
   - More than 40 existing Geographic Information System (GIS) spatial data layers.
3) **Include both total nitrogen and nitrate.** The study assesses total nitrogen (TN) for understanding downstream N loads to the Gulf of Mexico and Lake Winnipeg, and also assesses the nitrate form of N (concentrations, loads, trends) due to its impact on in-state aquatic life and drinking water.
4) **Develop results for large scales**. Results were determined for large-scale areas, such as statewide, major basins, and 8-digit Hydrologic Unit Code (HUC8) watershed outlets. Minnesota has 81 HUC8 watersheds, each averaging over 1000 square miles. Results should not be applied to the small watershed scale.
5) **Verify results.** The study results were verified with alternative methods, data, and studies, so that the conclusions are supported by more than one approach.

Nitrogen conditions in surface waters

Nitrogen conditions in surface waters are usually characterized in four different ways: 1) concentration, 2) load, 3) yield, and 4) flow weighted mean concentration.

- *Concentrations* are determined by taking a sample of water and having a laboratory determine how much N mass is in a given volume of that water sample, typically reported as mg/l. Load is the amount of N passing a point on a river during a period of time, often measured as pounds of N per year.
- *Loads* are calculated by multiplying N concentrations by the amount of water flowing down the river. Nitrogen loads are influenced by watershed size, as well as land use, land management, hydrology, precipitation, and other factors.
- *Yield* is the amount (mass) of N per unit area coming out of a watershed during a given time period (i.e., pounds per acre per year). It is calculated by dividing the load by the watershed size, which then allows for comparisons of watersheds with different sizes.
- *Flow weighted mean concentration (FWMC)* is the weighted-average concentration over a period of time, giving the higher flow periods more weight and the lower flow periods less weight. The FWMC is calculated by dividing the total load for a given time period by the total flow volume during that same period, and is typically expressed as mg/l.

Nitrogen concentrations

Maximum nitrite+nitrate-N (nitrate) levels in Minnesota rivers and streams (years 2000-2010) exceeded 5 mg/l at 297 of 728 (41%) monitored sites across Minnesota, and exceeded 10 mg/l in 197 (27%) of these sites. A marked contrast exists between nitrate concentrations in the southern and northern parts of the state. In most southern Minnesota rivers and streams, nitrate concentrations at least occasionally exceed 5 mg/l (Figure 1). Most northeastern and northwestern Minnesota streams have nitrate concentrations which usually remain less than 1 and 3 mg/l, respectively.

Nitrate concentrations in southern Minnesota streams tend to fluctuate seasonally. However, seasonal variability is much less in several southeastern Minnesota streams, where groundwater baseflow provides a continuous supply of high nitrate water to streams throughout the year.

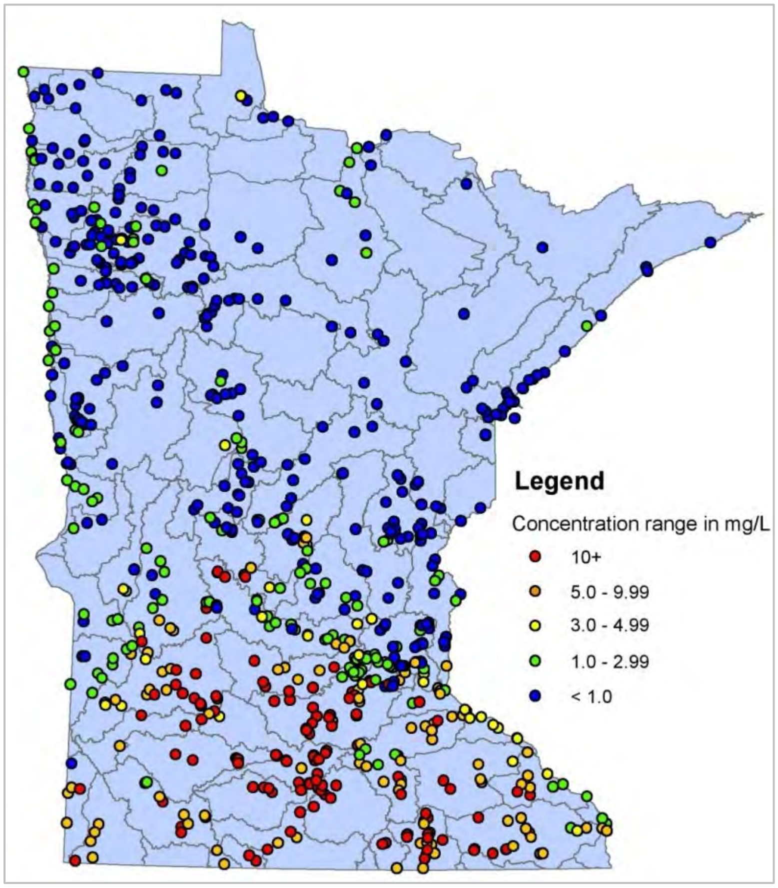


Figure 1. Nitrate concentrations at 728 river and stream sampling sites. Each colored circle shows the 90th percentile concentration from all samples taken at the site between 2000 and 2010.

Total nitrogen concentrations exhibit a similar spatial pattern across the state as nitrate, but are typically about 0.5 to 3 mg/l higher than nitrate-N, since TN also includes organic N and ammonia+ammonium (ammonium). Ammonium concentrations are less than 1 mg/l at 99% of river and stream sites in the state, and median concentrations are mostly less than 0.1 mg/l.

Mainstem river loads

Monitoring-based annual TN loads show that most of the state's TN load leaves Minnesota in the Mississippi River (Figure 2). On average, 211 million pounds of TN leaves Minnesota each year in the Mississippi River at the Minnesota-Iowa border, with just over three-fourths of this load originating in Minnesota watersheds, and the rest coming from Wisconsin, Iowa, and South Dakota. This compares to about 37 million pounds leaving the Red River at the Minnesota-Manitoba border, with about half from Minnesota and half from the Dakotas.

The highest TN-loading tributary to the Mississippi River is the Minnesota River, which adds about twice as much TN as the combined loads from the Upper Mississippi River (at Anoka) and St. Croix River (at Stillwater). The higher TN load in the Minnesota River is mostly due to much higher average TN concentrations in that river (8.2 mg/l flow-weighted mean concentration) as compared to the Upper Mississippi (2.2 mg/l) and the St. Croix River (1.0 mg/l).

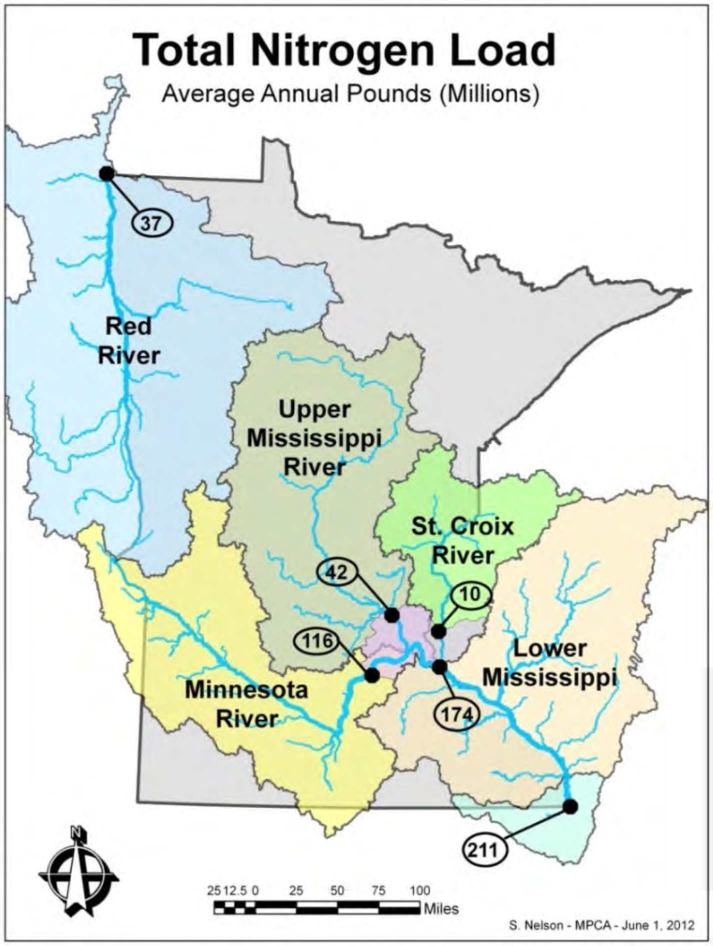


Figure 2. Long term (15-20 year) average annual TN loads at key points along mainstem rivers.

South of the Twin Cities, tributaries from Wisconsin and Minnesota contribute additional N to the Mississippi River. Only small fractions of TN are lost in the Mississippi River, except where the water is backed-up for long periods in quiescent waters, allowing nitrate to be converted to N gas through natural processes or to be used by algae. In the river stretch between the Twin Cities and Iowa, some N is lost when river flow slows in Lake Pepin and in river pools behind locks and dams. Monitoring-based loads show that an average 9% TN loss occurs in Lake Pepin. An additional 3 to 13% of the river TN is estimated to be lost in the 168 mile Mississippi River stretch between the Twin Cities and Iowa. The net effect of the TN additions and losses in the Lower Mississippi Basin is an average 37 million pound annual TN load increase between the Twin Cities and Iowa.

Year-to-year variability in TN loads and river flow can be very high. In the Minnesota River Basin, TN loads during low flow years are sometimes as low as 25% of the loads occurring during high flow years. Major river TN loads typically reach monthly maximums in April and May. About two-thirds of the annual TN load in the Mississippi River at the Iowa border occurs during the months March through July, when both river flow and TN concentrations are typically highest.

Comparing watersheds

Watershed loads, yields and FWMCs were estimated for HUC8 level watersheds throughout the state so that different parts of the state could be compared and geographic priorities established. The two methods used to compare watersheds were: 1) monitoring results from the 2007 to 2009 period, and 2) SPARROW modeling that integrated long-term water monitoring data with landscape information and in-stream losses to estimate long-term average loads.

The monitoring results from 2007-2009 and SPARROW modeling results show similar parts of the state with high and low river N loads (Figures 3 and 4). The highest N yields occur in south central Minnesota, where TN FWMCs typically exceed 10 mg/l. The second highest TN yields are found in southeastern and southwestern Minnesota watersheds, which typically have TN FWMCs in the 5 to 9 mg/l range.

The highest three TN-yielding HUC8 watersheds include the Cedar River, Blue Earth River, and Le Sueur River watersheds, each yielding over 20 pounds/acre/year, on average. The 15 highest TN loading HUC8 watersheds to the Mississippi River contribute 74% of the TN load which ultimately reaches the river. The other 30 watersheds contribute the remaining 26% of the load to the Mississippi.

Total N yield estimated from SPARROW modeling showed that the urban dominated Mississippi River Twin Cities watershed delivered TN yields comparable to many other rural southern Minnesota watersheds (Figure 4).

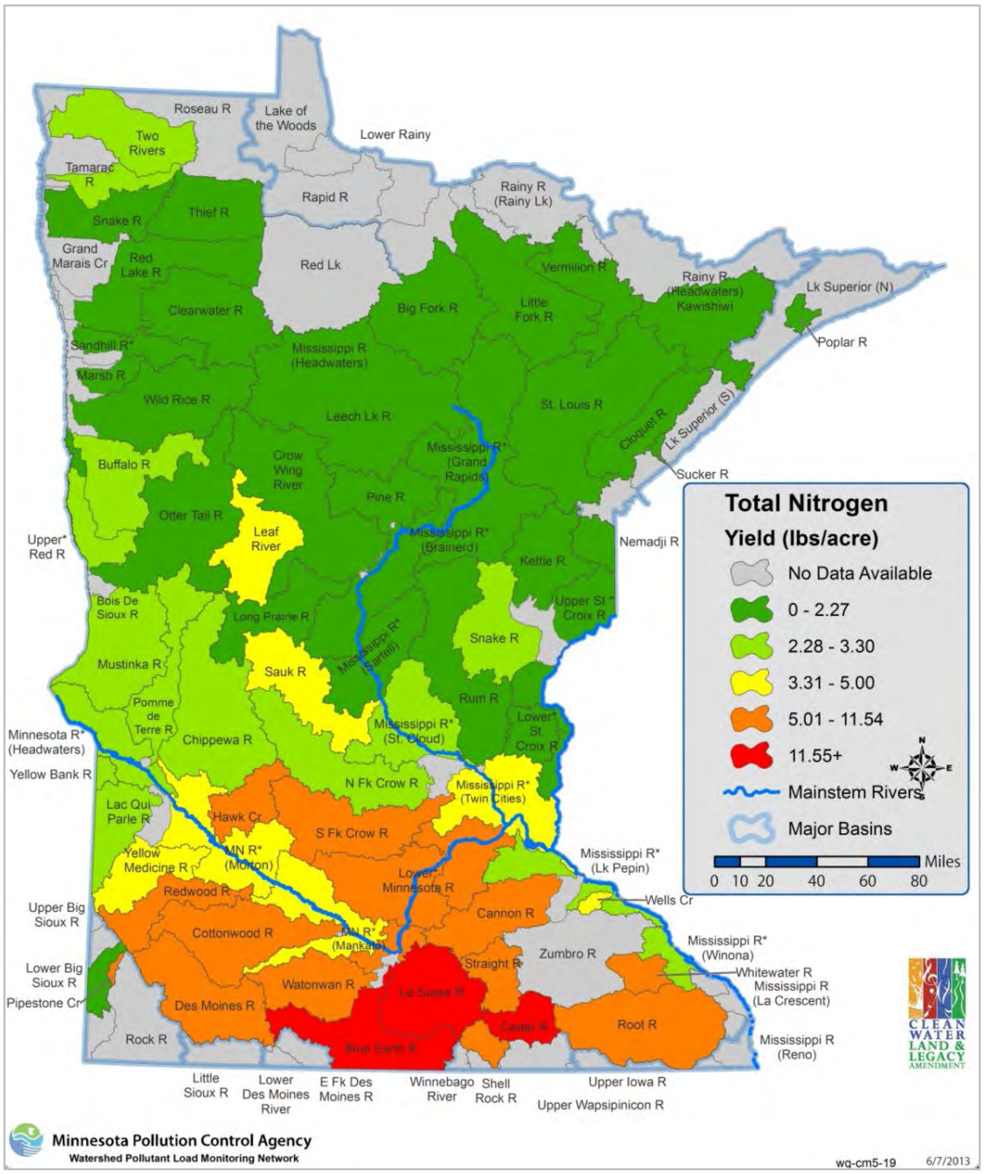


Figure 3. Monitoring-based annual TN yields near the outlet of each watershed. Average of available annual yield information between 2007 and 2009.

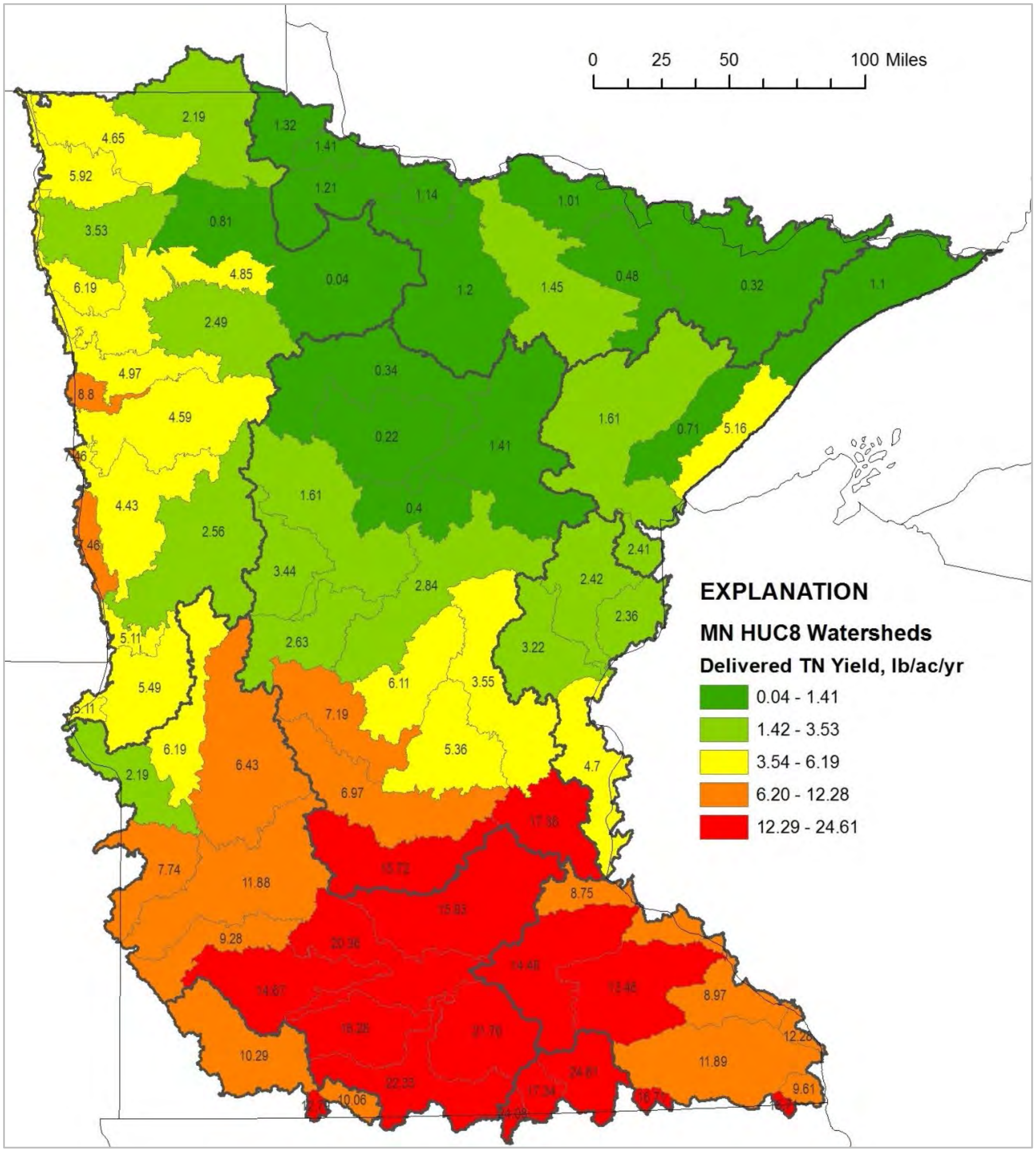


Figure 4. SPARROW model simulated incremental TN yields at the outlet of HUC8 watersheds (or state borders for watersheds cut-off by the state border).

Trends

Previous studies of N trends in Minnesota rivers and streams showed that *TN loads* increased since the 1970s and 1980s in the Red River of the North, Mississippi River, and Minnesota River. *Nitrate loads* had been found to have increased in the Mississippi and Minnesota Rivers between 1976 and 2005. Previous studies showed that *nitrate concentration*s were increasing in southeastern Minnesota streams and parts of central Minnesota, but that the downstream half of the Minnesota River generally showed no significant trend or a decrease. Previous studies also showed that river ammonium concentrations declined significantly over the 1980s and 1990s, likely in response to municipal wastewater upgrades and possibly also from feedlot and manure management improvements.

For this study, we evaluated flow-adjusted nitrite+nitrate-N (nitrate) concentration trends at 51 mainstem river and major tributary river monitoring sites throughout the state. The statistical trend analyses were performed with the QWTREND model, which was developed to evaluate periods of both increases and decreases which can occur at the same site over the period of record. River flow data was paired with nitrate monitoring results over a timeframe beginning during the mid-1970s and ending between 2008 and 2011.

Long-term (30-36 years) flow-adjusted nitrate concentration changes on the mainstem rivers are shown in Figure 5. The Mississippi River, which has very low nitrate concentrations in the north and less than 3 mg/l in the southern part of the state, showed increasing concentrations between 1976 and 2010 at most sites on the river, with overall increases ranging between 87% and 268% everywhere between Camp Ripley and LaCrosse. During recent years (i.e., 5-15 years prior to 2010), nitrate concentrations were increasing everywhere downstream of Clearwater on the Mississippi River at a rate of 1-4% per year, except that no significant trend was recently detected at Grey Cloud and Hastings in the Metro region.

Increasing nitrate concentration trends were also found in the Cedar River (113% increase over a 43-year period) and the St. Louis River in Duluth (47% increase from 1994 to 2010).

Not all locations in the state, however, are showing increasing trends. While nitrate concentrations remain very high in the downstream stretches of the Minnesota River (FWMC over 6 mg/l), two monitored sites (Jordan and Fort Snelling) showed a slight increase from 1979-2005, followed by a decreasing trend between 2005-06 and 2010-11. During recent years, all sites on the Minnesota River and most tributaries to the Minnesota River evaluated for trends have been either trending downward or have shown no trend (through 2009-11). Additionally, a few tributaries to the Mississippi River have also shown decreasing nitrate trends during the 6-8 year period prior to 2010, including the Rum, Straight, and Cannon Rivers.

Some other rivers have shown no significant trends since the mid-1970s, including the Rainy, West Fork Des Moines, and Crow Rivers. The Red River showed significant increases before 1995, but no significant trends between 1995 and 2010.

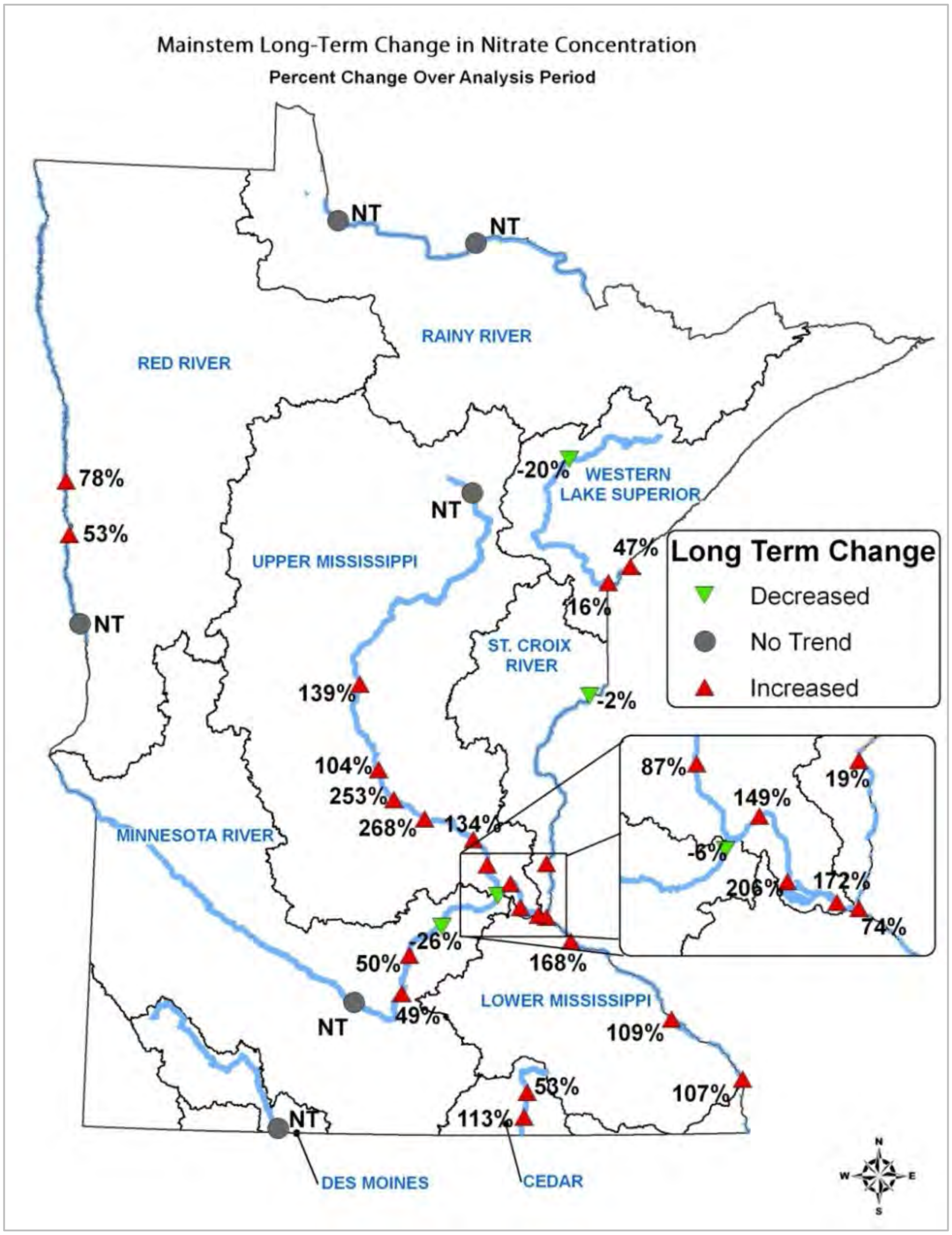


Figure 5. Long-term overall nitrate concentration trends (from mid to late 1970s until 2008-11) at mainstem river monitoring sites. Concentrations were adjusted for flow and changes are statistically significant at p<0.1.

Sources and pathways

Nitrogen source contributions to surface waters during average, wet and dry weather periods were estimated for each major basin and statewide. The estimated annual statewide TN (hereafter referred to as N) contributions reaching surface waters during an average precipitation year are shown in Figure 6. Results are intended for broader management planning decisions and should not be used in place of Total Maximum Daily Load (TMDL) studies or detailed local assessments based on site specific water quality monitoring and modeling data.

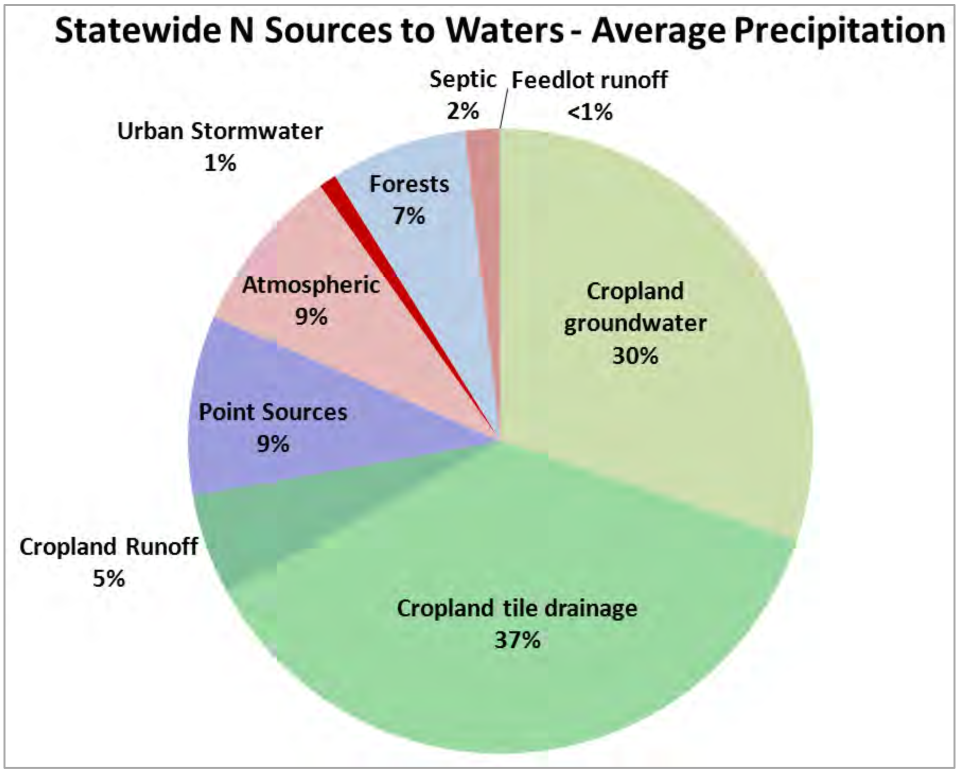


Figure 6. Estimated statewide N contributions to surface waters during an average precipitation year (rounded to whole numbers).

Cropland sources

Cropland N loads were estimated for three different pathways: surface runoff, tile-line transport, and leaching to groundwater and its subsequent underground movement to surface waters. Cropland sources were estimated by taking published field research results about N losses to water and then using GIS data-bases to extrapolate field-research results to larger scales. Cropland N source estimates were based on available site-specific data and watershed characteristics, adjusted for crops, geologic sensitivity, soils, climate, fertilizer rates, livestock manure availability, agricultural drainage, N losses within groundwater, and several other factors. The amount of N reaching surface waters from cropland varies tremendously, ranging from less than 10 pounds/acre on some cropland and more than 30 pounds/ acre on other cropland.

According to the N source assessment conducted for this study, during an average precipitation year cropland sources contribute an estimated 73% of the statewide N load to surface waters. This statewide estimate is similar to SPARROW model simulations, which indicate that 70% of statewide N loading to surface waters is from agricultural sources. The cropland fraction of N load to surface waters varies by watershed, accounting for an estimated 89 to 95% of the N load in the Minnesota portions of the Minnesota River, Missouri River, Cedar River, and Lower Mississippi River Basins, and yet contributing less than 50% of the Upper Mississippi River Basin N (refer to Figure 8 for basin locations).

The emphasis of this study was estimating N loads from specific source categories to *surface waters*. Nitrogen sources to *land* were also estimated, since these sources can provide a general framework of understanding N potentially available for entering waters. Inorganic N becomes available to statewide cropland from several added sources to the soil, including commercial fertilizers (47%), legume fixation (21%), manure (16%), and wet plus dry atmospheric deposition (15%). Soil organic matter mineralization releases an estimated annual amount of inorganic N comparable to fertilizer and manure N additions combined. Septic systems, lawn fertilizer, and municipal sludge together account for about 1% of all N added to soils statewide.

Cropland surface runoff

Cropland N moves from soil sources to surface waters through two dominant pathways: 1) tile-line transport, and 2) leaching to groundwater and subsequent underground flow into surface waters. Compared to these two pathways, cropland surface runoff adds relatively little N to waters. Surface runoff contributes only 1-4% of N loads to waters in all major basins except the Lower Mississippi River Basin and Red River Basin, where runoff from cropland contributes 9-16% of the N load, respectively.

Cropland tile drainage

Nitrogen moving through tile-lines and subsequently into ditches and streams was found to be the pathway contributing the most cropland N to surface waters. During an average precipitation year, row crop tile drainage contributes an estimated 37% of the N load to Minnesota's waters overall, and contributes 67% of the N load in the heavily-tiled Minnesota River Basin. During a wet year, the fraction of N to waters from tile drainage increases to an estimated 43% of statewide N load and 72% of the Minnesota River N load. River monitoring results affirmed the importance of tile drainage contributions, showing that the highest N-yielding watersheds in the state are those which are intensively tiled.

Cropland nitrate leaching to groundwater

Nitrogen leaching into groundwater below cropped fields, and subsequently moving underground until it reaches streams, contributes an estimated 30% of N to surface waters statewide. Groundwater N can take hours to decades to reach surface waters, depending on the rate of groundwater flow and the distance between the cropland and stream. Nitrogen leaching into groundwater is the dominant pathway to surface waters in the karst dominated landscape of the Lower Mississippi River Basin, where groundwater contributes an estimated 58% of all N. Yet in the Minnesota River Basin, dominated by clayey and tile-drained soils, cropland groundwater only contributes 16% of the N to surface waters, on average.

Wastewater point sources

Wastewater point source loads, estimated largely from MPCA discharge permit records, release an annual average 29 million pounds of TN to statewide waters, accounting for 9% of the statewide N load according to the N source assessment. This is slightly more than the 7% point source contribution estimated from SPARROW modeling.

Wastewater point source loads are dominated by municipal wastewater sources, which contribute 87% of the wastewater point source N load discharges, with the remaining 13% from industrial facilities. The 10 largest wastewater point source N loading facilities collectively contribute 67% of the point source TN load. Nearly half (49%) of the wastewater point source N discharges occur within the Twin Cities Metropolitan Area. River monitoring shows that six million pounds of N (on average) is gained in major rivers as they pass through the Twin Cities area, which equates to a 3.5% increase.

Wastewater point source N additions from large urban areas can contribute similar loads as many croplands draining from a similarly sized area. However, the wastewater N delivery to rivers is different than from cropland, as it enters waters at a few specific points as opposed to being dispersed across the watershed.

Other sources

Two other source categories, atmospheric deposition and forestland runoff, each contribute cumulative total statewide N loads comparable to wastewater point source N loads. While the N concentrations from atmospheric deposition and forest sources are much lower than wastewater discharges, the aerial extent of these two sources is vast, thereby accounting for the similar overall loads.

Nitrogen falling onto land from wet and dry atmospheric deposition was highest in the south and southeast parts of the state and lowest in the north and northeast where fewer urban and agricultural sources exist. Atmospheric deposition falling into lakes and streams was considered in the source assessment as a direct source of N into waters, contributing 9% of the statewide annual N load to waters. Correspondingly, the areas of the state with the most lakes and streams had the most atmospheric deposition directly into waters. Yet, relatively few other N sources are found in the northern Minnesota lakes regions, and a large fraction of N entering most lakes from atmospheric deposition will not leave the lake in streams. Low river N concentrations and loads are found in the northern lakes regions of the state.

Some N, typically less than three pounds/acre/year, is exported from forested watersheds. Forest N contributions are nearly negligible in localized areas and N levels in heavily forested watersheds are quite low. Yet since such a large fraction of the state is forested, the total cumulative N to waters from forested lands is estimated to be about 7% of the statewide N load.

Other statewide N sources contribute relatively small N loadings, including septic systems (2%), urban/suburban runoff (1%), feedlot runoff (0.2%) and water-fowl (<0.2%).

Source load differences among major basins

The load estimates in this study only quantify N source contributions originating in Minnesota portions of basins. Nitrogen source and pathway contributions from Minnesota portions of river basins vary considerably from one major river basin to another, as shown in Figure 7 (see also basin location map in Figure 8). For example, during an average precipitation year, cropland source contributions range between 16% and 95% of the estimated N load to the waters in each basin. Wastewater point source contributions range from 1% to 30% across the different basins, and contribute a higher fraction of the load where cropland sources are relatively low.

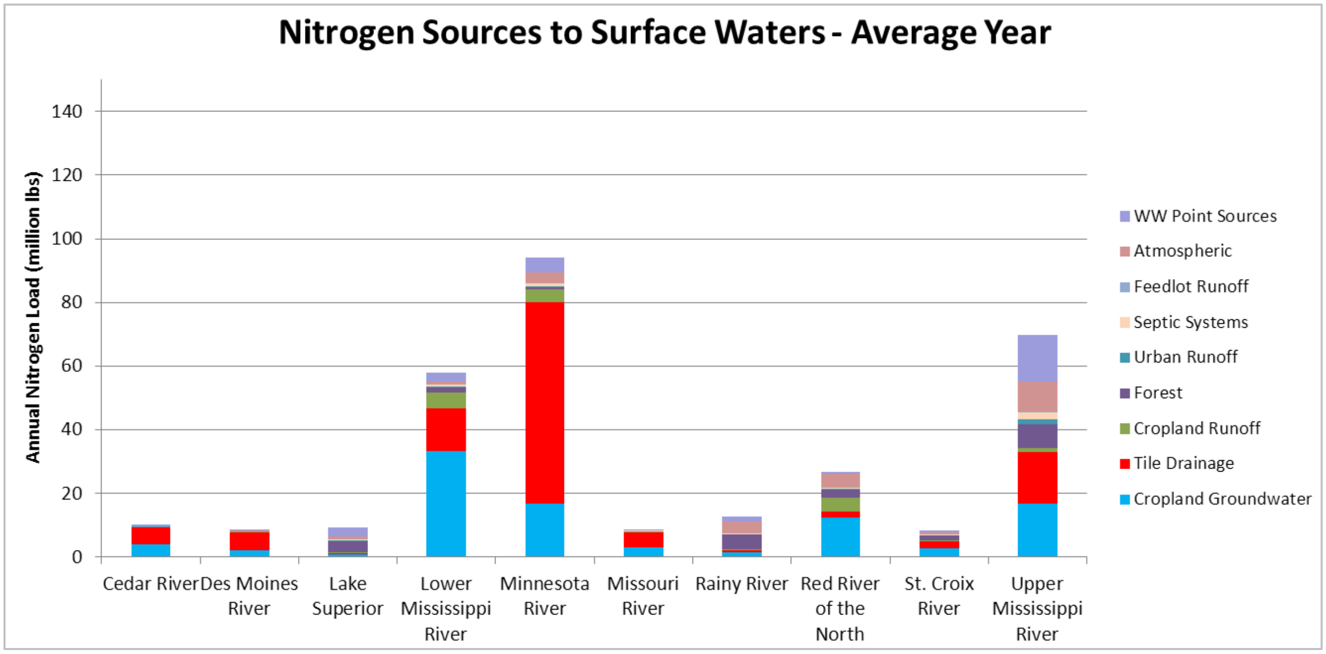


Figure 7. Estimated annual N loads to surface waters from different sources within the Minnesota portions of major basins during an average precipitation year.

Figure 8. Minnesota's major basins and watersheds.

Precipitation effects on source loads

Precipitation amounts have a pronounced effect on N loads. During a dry year, statewide N loads drop by 49% from average year loads (Figure 9). During a wet year, overall loads increase by 51%, as compared to an average year (Figure 10). The effects of precipitation are even greater in the Minnesota River Basin, where wet years have an estimated 70% greater N load, and dry years have 65% less N load.

Precipitation also affects the relative contributions from different N sources and pathways. During wet years, the cropland source contributions increase from 73% to 79% of the statewide N loads to waters. Agricultural drainage increases from 37% to 43% of the loads to surface waters during wet years, cropland runoff increases from 5% to 6%, and cropland groundwater remains at 30%. During dry years, the fraction of the load coming from wastewater point sources increases from 9% to 18%, whereas cropland sources are reduced to 54% of the estimated statewide N load.

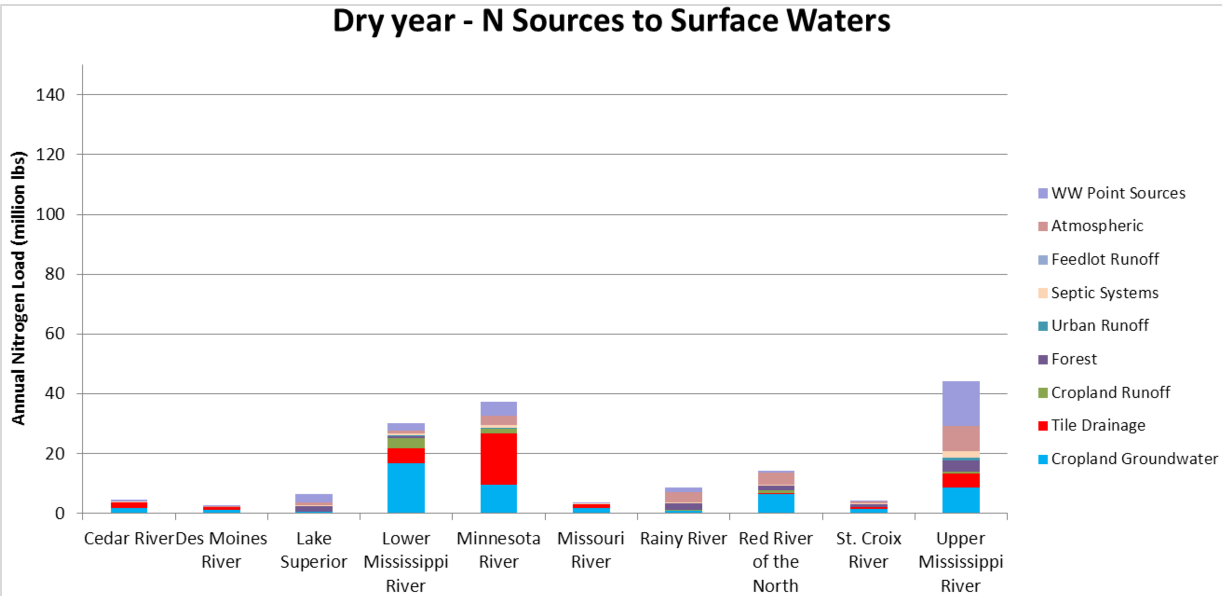


Figure 9. Estimated annual N loads to surface waters from different sources within the Minnesota portions of major basins during a dry year.

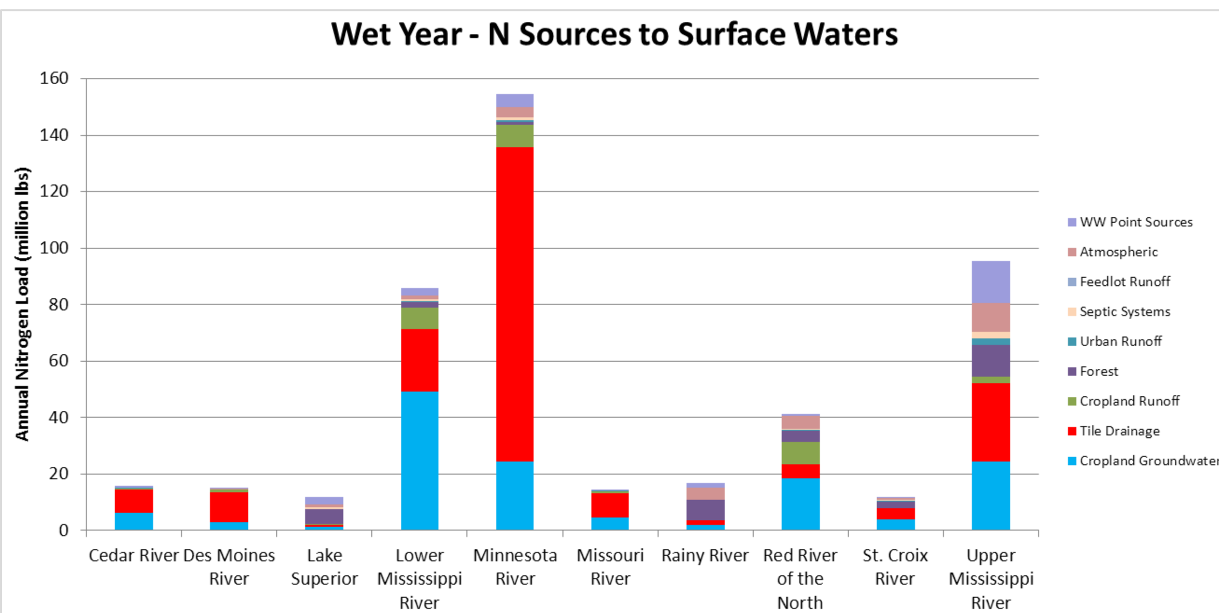
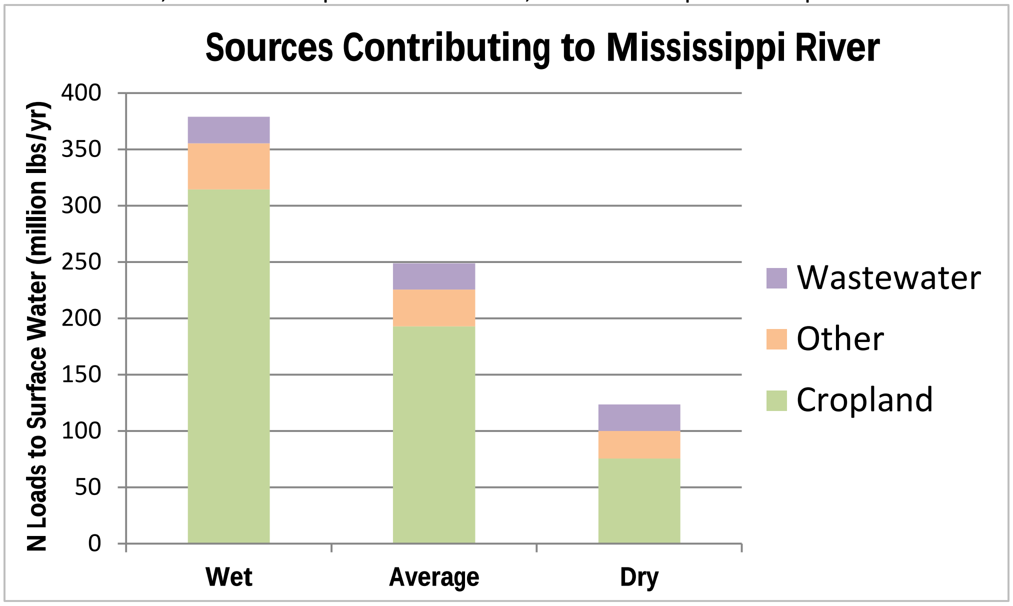


Figure 10. Estimated annual N loads to surface waters from different sources within the Minnesota portions of major basins during a wet year.

Sources to the Mississippi River

Just over 81% of the TN load to Minnesota waters is from watersheds which ultimately flow into the Mississippi River. If we look only at those Minnesota watersheds which contribute to the Mississippi River, source contributions during an average precipitation year are estimated as follows: cropland sources 78%, wastewater point sources 9%, and non-cropland nonpoint sources 13% (Figure 11).



Cropland source contributions increase to 83% for these watersheds during wet (high-flow) years, and point sources decrease to 6%. During a dry year, cropland sources represent an estimated 62% of N to waters and point sources contribute 19%.

Figure 11. Sum of N source contributions in watersheds which eventually reach the Mississippi River. The "other" category includes septic systems, atmospheric deposition directly into waters, feedlots, forested land and urban/suburban nonpoint source N. "Wastewater" includes municipal and industrial point sources.

Uncertainties and verification of sources

The source assessment conducted by the University of Minnesota and MPCA has some areas of uncertainty. All sources should be treated as large-scale approximations of actual loadings, and each source estimate could be refined with additional research. One particular area of uncertainty is the cropland groundwater component, due to: a) limited studies quantifying leaching losses under different soils, climate and management, and b) high variability in denitrification losses, which can occur as groundwater slowly flows toward rivers and streams.

Because of source assessment uncertainties, we compared the source assessment results with results from five separate approaches, as follows:

1) **Monitoring results** – HUC8 watershed and major basin scale monitoring results
2) **SPARROW modeling** – major N source categories (statewide)
3) **HSPF modeling** – Minnesota River Basin modeled estimates of sources, pathways and effects of precipitation
4) **Watershed characteristics analysis** – comparing watershed land and hydrologic characteristics with river N yields and concentrations
5) **Literature review** – existing studies in the upper-Midwest related to N sources and pathways

Mainstem river monitoring results compared reasonably well to the sum of the sources estimated by the source assessment during dry, average and wet conditions (Figures 12-14). The monitoring results were not expected to be the same as the sum of sources, since the sum of sources do not consider in-stream

N losses or lag times in groundwater N transport from sources to surface waters. Yet the fairly close agreement between the monitoring results and source load estimates provides one line of evidence that the source estimates may be reasonable.

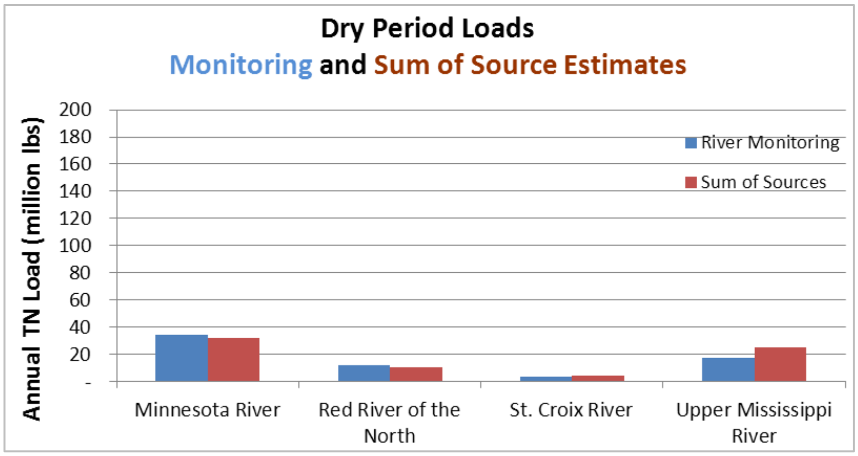


Figure 12. Dry period comparison of river monitoring average annual loads with the sum of estimated source loads.

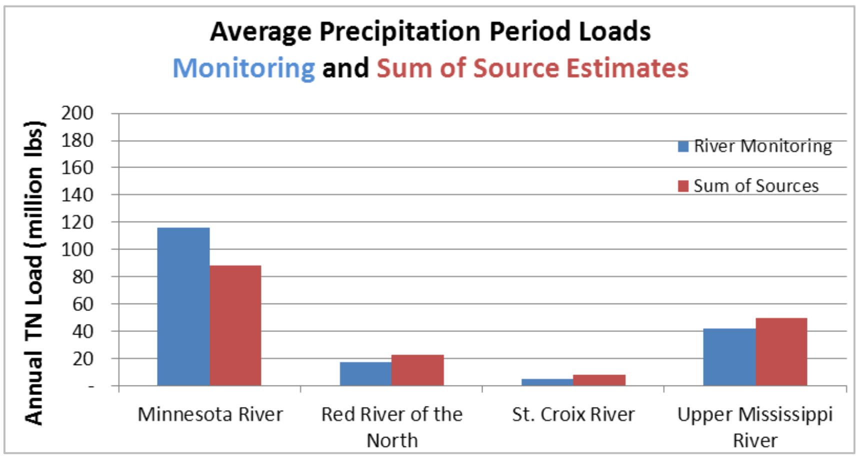


Figure 13. Average period comparison of river monitoring average annual loads with the sum of estimated

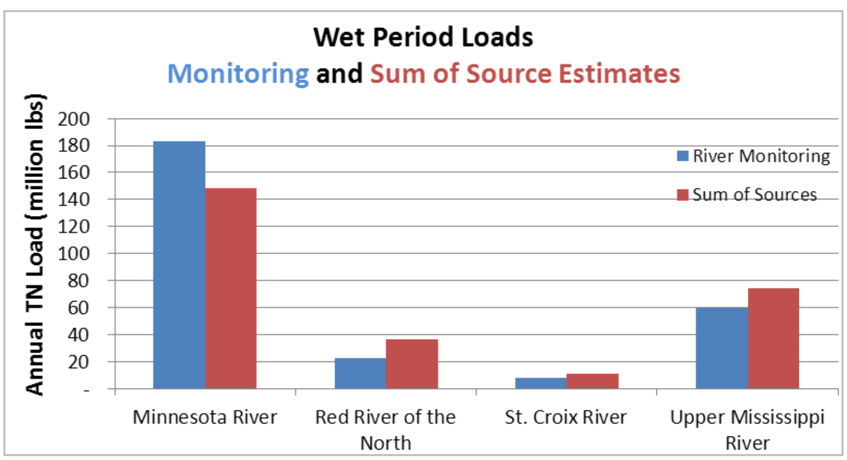


Figure 14. Wet period comparison of river monitoring average annual loads with sum of estimated source loads.

The SPARROW and HSPF model N source estimates were both consistent with the source assessment findings. SPARROW model results showed cropland sources as the dominant statewide N sources to Minnesota rivers, representing 70% of the source loads (Figure 15).

Using a markedly different modeling approach than SPARROW, the HSPF model results showed that the cropland sources represent 96.6% of the Minnesota River Basin nonpoint source inorganic N load to rivers, which was similar to a 97.6% estimate from the source assessment findings. The HSPF model results also showed similar flow pathways and wet weather effects on loads as compared to the source assessment findings.

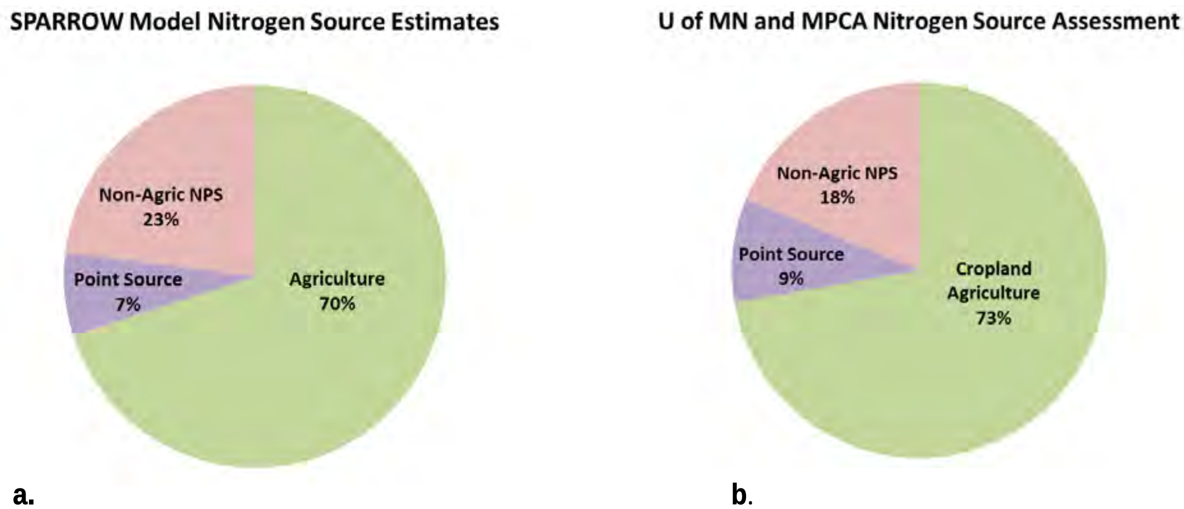


Figure 15. Comparing N source category contributions to Minnesota surface waters statewide during an average year using a) SPARROW model results, and b) N source assessment conducted for this study.

We also used statistical and non-statistical methods to compare watershed monitoring results with 18 watershed land use and hydrologic characteristics. These checks on the source assessment findings did not show inconsistencies with the source load findings, and they did show several relationships which support the source assessment findings. For example, a distinct pattern was observed between watershed nitrate levels and the percent of watershed with row crops over tile-drainage, sandy soils, and soils with a shallow depth to bedrock (Figure 16).

Statistical models of nitrate and TN concentration suggested that row crops over tile-drained soils and high groundwater recharge areas (sandy soils and/or shallow depth to bedrock) accounted for much of the nitrate concentration variability in the 28 HUC8 watersheds analyzed (r-squared exceeding 0.96). Statistical models also showed a similarly strong correlation between watershed N yields and two variables: 1) the amount of land with row crops over tile drainage, and 2) annual precipitation. For both the concentration and yield statistical models, the tile drainage variable exerted the strongest magnitude of influence, with two to five times the influence of the other explanatory variables.

All five ways of checking the findings corroborate the source assessment results and no major discrepancies were found. This increases our confidence that the source assessment is reasonably accurate and is useful for generally understanding large scale N load sources and pathways to Minnesota surface waters.

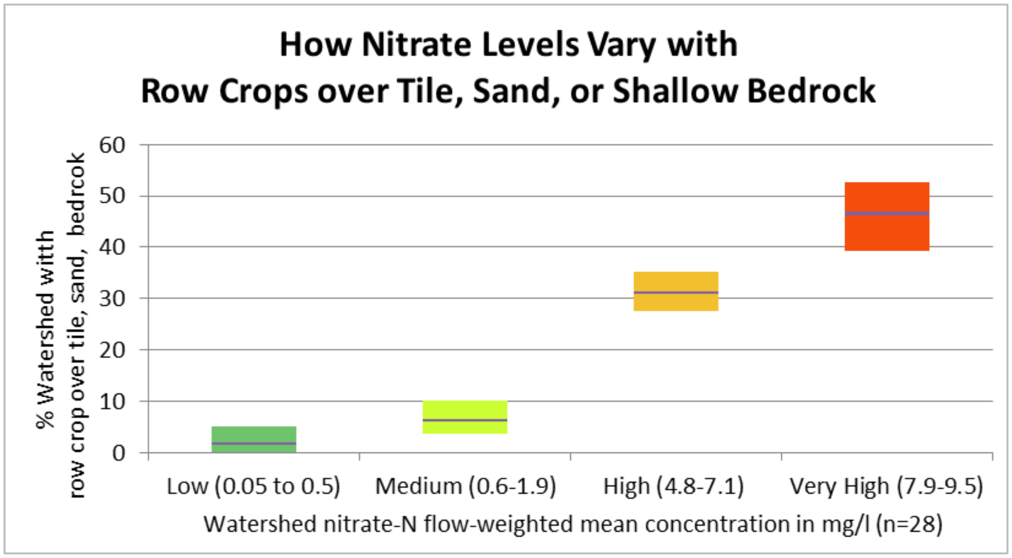


Figure 16. The range (colored bars) and average (dark line) percent of land in row crops underlain by tile-drainage (estimated), shallow bedrock or sandy subsoils. The four watershed nitrate classifications are based on river monitoring averages from two normal flow years within the period 2005-2009.

Potential ways to reduce nitrogen in surface waters

Because high N loading is pervasive over much of southern Minnesota, little cumulative large-scale progress to reduce N in surface waters will be made unless numerous large watersheds (i.e., the top 10 to 20 N loading watersheds) reduce N levels. Appreciable N reductions to major rivers and large downstream waters cannot be achieved by solely targeting individual small subwatersheds or mismanaged tracts of land. However, cumulative smaller scale changes repeated across much of the southern Minnesota landscape can make an appreciable difference in N loading.

Reducing nitrogen losses from cropland

Based on the N source assessment and the supporting literature/monitoring/modeling, meaningful regional N reductions to rivers can be achieved if Best Management Practices (BMPs) are adopted on acreages where there is a combination of: a) high N sources, b) seasonal lack of dense plant root systems, and c) rapid transport avenues to surface waters (which bypass denitrification N losses common in many groundwaters). These conditions mostly apply to row crops planted on tile-drained lands, but also include row crops in the karst region and over many sandy soils.

Further refinements in fertilizer rates and application timing can be expected to reduce river N loads and concentrations, yet more costly practices will also be needed to meet downstream N reduction goals.

BMPs for reducing N losses to waters can be grouped into three categories:

1) I*n-field nutrient management* (i.e., optimal fertilizer rates; apply fertilizer closer to timing of crop use; nitrification inhibitors; variable fertilizer rates)
2) *Tile drainage water management and treatment* (i.e. shallower depth of tile drainage; control structures that let farmers adjust water levels; constructed and restored wetlands for treatment purposes; woodchip trench bioreactors; and saturated buffers)
3) *Vegetation/landscape diversification* (i.e. cover crops; perennials planted in riparian areas or marginal cropland; extended rotations with perennials; energy crops in addition to corn)

Through this study, a tool was developed by the University of Minnesota to evaluate the expected N reductions to Minnesota waters from individual or collective BMPs adopted on lands well-suited for the practices. The tool, called "Nitrogen Best Management Practice watershed planning tool" (NBMP), enables planners to gauge the potential for reducing N loads to surface waters from watershed croplands, and to assess the potential costs (and savings) of achieving various N reduction goals. The tool also enables the user to identify which combinations of BMPs will be most cost-effective for achieving N reductions at a HUC8 watershed or statewide scale.

We used the NBMP tool to assess N reduction scenarios in Minnesota (statewide and in specific HUC8 watersheds). Results from the NBMP tool were also compared to results from an Iowa study which used different methods to assess the potential for using agricultural BMPs to achieve N load reductions to Iowa waters. Both the Minnesota and Iowa evaluations concluded that no single type of BMP is expected to achieve large-scale reductions sufficient to protect the Gulf of Mexico. However, combinations of in-field nutrient management BMPs, tile drainage water management and treatment practices, and vegetation/landscape diversification practices, can together measurably reduce N loading to surface waters.

The N reduction potential varies by watershed (Figure 17). For example, if BMPs were implemented on all land suitable for the BMPs, the NBMP tool predicts a 22% river N reduction in the Root River Watershed and a 39% reduction in the LeSueur River Watershed. The North Fork Crow River Watershed could potentially achieve a 38% N reduction; however, it would need to rely more heavily on taking marginal cropland out of row crop production and replacing with perennials. The total net cost of achieving the reductions shown in Figure 19 is estimated to range from $22 to $47 million per watershed per year. The fertilizer BMPs were projected to save money and the majority of the estimated net costs were associated with the vegetation change BMPs.

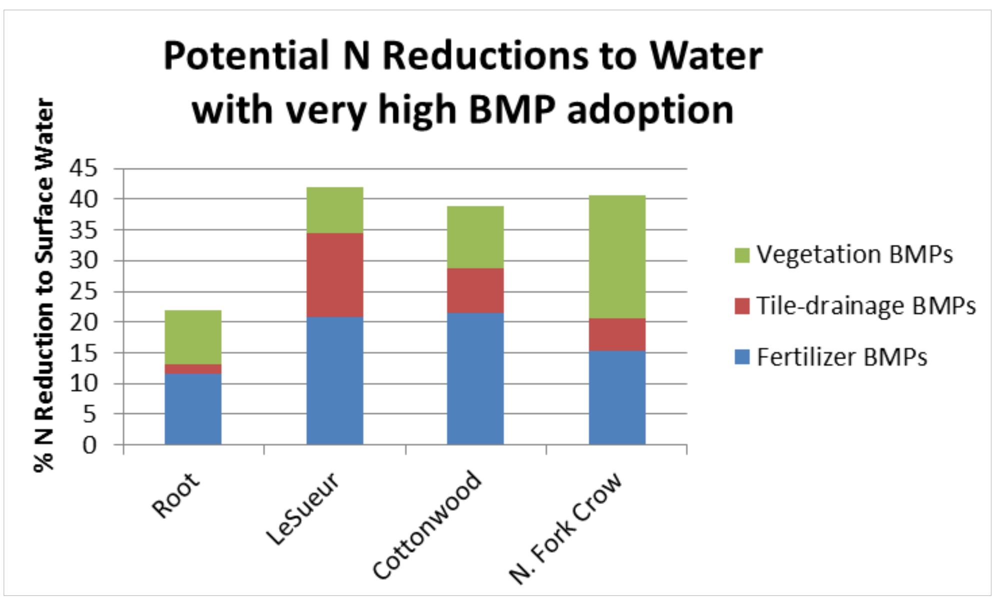


Figure 17 – Potential % N reductions to surface waters estimated with the NBMP tool when adopting BMPs on 100% of lands suitable for the following BMPs: optimal fertilizer rates and timing for corn (fertilizer BMPs), bioreactors and wetland construction/restoration and controlled drainage (tile-drainage BMPs), and plant cover crops and on marginally productive lands replace row crops with perennials (vegetation BMPs).

Statewide, river N loads can potentially be reduced by as much as 13% through widespread implementation of optimal in-field nutrient management BMPs, practices which can reduce fertilizer costs. To achieve 25% N load reductions, high adoption rates of a suite of other BMPs would need to be added to the in-field N management practices, and the net cost per pound of N reduced would increase.

The NBMP tool indicated that a 30-35% statewide reduction of cropland N losses to waters could be achieved if: over 90% of the corn land received optimal fertilizer rates applied in the spring; perennials were planted on 100 feet of either side of most streams; all tile drainage waters were treated in wetlands, bioreactors or otherwise were managed with controlled drainage structures; rye cover crops were planted each year on most row crops; and marginal cropland was retired to perennial vegetation. The projected net cost to install and manage these practices was over a billion dollars per year with recent crop prices and without further improvements in N reduction BMPs. Changes in crop economics and/or improvements to BMPs could reduce this net cost in the future.

Iowa predicted a 28% statewide nitrate reduction in water if cover crops were planted on row crops throughout the state. While Minnesota has a cooler climate, cover crops deserve further study in Minnesota due to a combination of desirable potential benefits to water quality and agriculture. If Minnesota can find ways to successfully establish and manage cover crops in row-cropped fields, and then achieve widespread use of cover crops, we could potentially reduce cropland N in Minnesota rivers by as much as 15 to 25% from this practice alone.

Tile-drainage water treatment BMPs are also part of a sequential combination of BMPs which could be employed in many areas to achieve additional N reductions to waters. Constructed wetlands and wetland restoration designed for nitrate treatment purposes remove considerable N loads from tile waters (averaging about 50%) and should be considered for certain riparian and marginal lands. Bioreactors may be an option for treating tile-line waters in upland areas where wetland treatment is less feasible, but they cost considerably more than wetlands for each pound of N reduced. If controlled drainage is used in combination with wetlands and bioreactors on lands well-suited for these BMPs, statewide N loads to streams can be reduced from these practices by an estimated 5-6%, and N loads in heavily-tiled watersheds can be reduced by an estimated 12-14%.

Perennial vegetation can greatly reduce N losses to underlying groundwater and tile drainage waters. When grasses, hay, and perennial energy crops replace row crops on marginally productive lands, N losses to surface waters are greatly reduced on the affected acreage. Under the current economic situation, the crop revenue losses when converting row crops to perennials, makes this practice less feasible on a widespread scale as compared to other practices, according to the results obtained with the NBMP tool. However, if changes occur and new markets develop for perennial crops, the economic picture could make this practice more feasible on larger acreages.

While this study largely focused on N removal BMPs, many BMPs provide additional benefits apart from reducing N. Any evaluation of recommended practices to reduce N should consider the additional costs and benefits of the BMPs. For example, BMPs such as constructed wetlands could potentially help reduce peak river flows through temporary storage of water, which could reduce flooding potential and improve water quality. Wetlands and riparian buffers also have a potential to increase wildlife habitat. Cover crops have added benefits of reducing wind and water erosion and potentially improving soil health and reducing pesticide use.

This study also focused on cost optimization of BMPs, rather than providing a full accounting of the net value of benefits from a reduced hypoxic zone in the Gulf of Mexico and other environmental benefits to Minnesota waters.

Wastewater nitrogen reduction

Wastewater point source N discharges can be reduced through two primary methods: 1) Biological Nutrient Removal (BNR), and 2) Enhanced Nutrient Removal (ENR) involving biological treatment with filtration and/or chemical additions.

BNR technologies, if adopted for all wastewater treatment facilities capable of adapting to this technology, would result in an estimated 43-44% N reduction in wastewater point source N discharges to rivers in the Upper Mississippi and Minnesota River Basins, and a 35% reduction in the Red River Basin. Because N loading from wastewater facilities is a relatively small statewide source compared to other sources, these reductions correspond with an estimated overall N reduction to waters of 9.3%, 2.2%, and 0.8% in the Upper Mississippi, Minnesota, and Red River Basins, respectively.

ENR technologies, if adopted for all wastewater treatment facilities capable of adapting to this technology, are estimated to result in a 64-65% N reduction in wastewater point source discharges to rivers in the Upper Mississippi and Minnesota River Basins, and a 51% reduction in the Red River Basin. These reductions correspond with an estimated overall N reduction to waters of 13.5%, 3.2%, and 1.2% in the Upper Mississippi, Minnesota, and Red River Basins, respectively.

In conclusion

Surface water N concentrations and loads are high throughout much of southern Minnesota, contributing to the N enriched hypoxic zone in the Gulf of Mexico, nitrate in excess of drinking water standards in certain cold water streams, and a potential to adversely affect aquatic life in a large number of Minnesota rivers and streams. Northern Minnesota has relatively low river N levels, and pollution prevention measures should be adopted in this area as landscapes and land management change.

Since the mid-1970s nitrate concentrations have continued to increase in the Mississippi River, yet they still average less than 3 mg/l (FWMC). The Minnesota River average nitrate concentrations remain high (above 6 mg/l FWMC), but were showing signs of stabilizing or decreasing in the 2005 to 2011 period. Trends are mixed in other rivers in the state, showing increases, decreases and several with no significant trend.

An estimated 73% of statewide N entering surface waters is from cropland sources and 9% is from wastewater point sources, with several other sources adding the other 18%. Most of the cropland N reaches waters through subsurface agricultural tile drainage and groundwater pathways, with a relatively small amount in overland runoff.

Reducing N levels in rivers and streams in southern Minnesota will require a concerted effort over much of the land in this region, particularly tile-drained cropland and row crops over permeable soils and shallow bedrock. Significant cumulative reductions are predicted when multiple practices are implemented over large acreages. Some progress toward reducing N losses to waters can be made by further optimizing in-field N management and temporarily retaining tile-line drainage waters in wetlands, bioreactors and behind controlled drainage structures. Cover crops and strategic establishment of perennial energy crops can greatly reduce N losses to waters, but need further development in Minnesota to make these practices more successful and adopted on more lands.

A1. Purpose and Approach

Purpose

Nitrate has long been a concern for human health when elevated levels reach drinking water supplies. The 10 mg/l nitrate-N drinking water standard established for surface and groundwater drinking water sources and for cold water streams is exceeded in numerous wells and streams. In recent decades, the concern about nitrogen (N) in surface waters has grown due to nitrogen's role in causing a large oxygen-depleted hypoxic zone in the Gulf of Mexico, and an increasing body of evidence showing toxic effects of nitrate on aquatic life.

Minnesota has initiated several state-level planning efforts to address N in waters. Effective plans and strategies should be based on an understanding of the scientific data and technical body of knowledge surrounding the issues. The purpose of this study was to provide an assessment of the science concerning N in Minnesota waters so that the results could be used for current and future planning efforts, thereby resulting in meaningful goals, priorities, and solutions.

More specifically, the purpose of this project was to characterize N loading to Minnesota's surface waters, and assess conditions, trends, sources, pathways, and potential ways to achieve nitrogen reductions in our waters. The study results will be used in developing: 1) Minnesota's state-level Nutrient Reduction Strategy, 2) responses to potential river nitrate standard exceedances, and 3) other regional watershed implementation plans for addressing N in waters. Each of these three efforts is summarized below.

The state-level Nutrient Reduction Strategy is a multi-agency effort to establish paths to achieve progress toward meaningful and achievable N and phosphorus reductions. The strategy is being designed to protect and improve Minnesota's own waters, along with reducing cumulative impacts to downstream waters such as the Gulf of Mexico and Lake Winnipeg. In 2008, Minnesota committed to the U.S. Environmental Protection Agency (EPA) and the Gulf of Mexico Hypoxia Task Force to complete the first strategy by 2013. Guidance documents for state strategy development recommend that states conduct assessment work prior to establishing quantitative targets and identifying the needed management practices/strategies. The guidance suggests that each state characterize watersheds, identify sources, prioritize geographic areas, document current loads, and estimate historical trends.

River water quality nitrate standards are being developed by the Minnesota Pollution Control Agency (MPCA) in response to a 2010 Minnesota legislative directive asking the agency to establish water quality standards for nitrate-N and total nitrogen (TN) (2010 Session Laws, Chapter 361, Article 2, Section 4, Subdivision 1). The nitrate water quality standards are being developed based on aquatic life toxicity concerns. Information in this study is not intended to influence the standard, which is established based on strict independent criteria related to toxicity testing, but rather will help us understand the extent of high nitrate water, nitrate sources, and considerations for reducing nitrate in impacted watersheds.

Watershed implementation plans and protection requirements are developed at the local level where water quality standards are exceeded or have the potential to be exceeded. At the time of this writing, 15 streams, mostly in southeastern Minnesota exceed the 10 mg/l standard for nitrate-N.

While N reduction strategies are needed in many watersheds with or without new nitrate standards addressing aquatic life toxicity, the addition of such standards will likely increase Minnesota's efforts aimed at reducing nitrate concentrations. Additionally, because groundwater is a primary pathway of N movement to streams, some of the study results may also be considered for groundwater and drinking water supply protection efforts.

To aid the above efforts, the following information needs were identified and were thus addressed in this study:

1. *Watershed nitrogen conditions* – assess how N loads, yields, and concentrations in rivers and streams vary geographically across Minnesota watersheds, and estimate how much N is lost within waters before being delivered to downstream waters.
2. *Concentration trends* – evaluate how in-stream nitrate concentrations have changed since the mid-1970s and how they have changed during more recent periods.
3. *Sources* – estimate mass loadings from different point and nonpoint land uses/sources and assess which sources most influence N loading to surface waters.
4. *Hydrologic pathways* – assess the amount of N delivered to streams by groundwater baseflow, tile drainage, surface runoff, atmospheric deposition, and other hydrologic pathways.
5. *Solutions for reducing nitrogen* – evaluate different scenarios for reducing N, considering N reduction potential and costs.

The approaches used to address these areas of study are summarized below and are more specifically described within each chapter.

Approach

The general approach for this study was to:

1. Collaborate with other organizations and MPCA divisions.

   The MPCA Watershed Division and Environmental Outcomes and Analysis Division worked together with the University of Minnesota and the U.G. Geological Survey (USGS) to complete this study. The University of Minnesota's primary area of focus was determining N contributions to water from nonpoint sources. The USGS assisted with watershed modeling (SPARROW model) and N concentration mapping and trends analyses. The Minnesota Department of Agriculture (MDA) and the Metropolitan Council provided data, assistance, and review. (See acknowledgments for specific authors, co-authors and others who provided assistance.)

2. Compile existing information, data, and results, whenever possible, taking advantage of past work from multiple organizations.

   For many years prior to this study, a tremendous amount of work has been completed by several different organizations to better understand N in Minnesota's surface waters. Our approach was to build on these other efforts, pulling together information from past studies and monitoring results, and combining this information with work conducted specifically for this project. No new monitoring was conducted for this study. Instead we analyzed existing results from the MPCA, Metropolitan Council, USGS, the MDA, and other sources. While new modeling efforts were completed for this project, the models were generally built upon previous modeling efforts by the USGS, University of Minnesota, and the MPCA.

Some of the existing information used in this study includes:

- Recent water N concentration results from over 50,000 water samples collected at over 700 stream sites in Minnesota;
- Water N loads calculated from monitoring over 20 to 30 years at 9 mainstem river sites and 1-10 years near 70 watershed outlets;
- Water chemistry sampling combined with water flow monitoring for 20 to 35 years at over 50 sites around the state (used for time-trend analysis);
- Findings from over 300 published studies;
- Six previously developed computer models (and two newly developed models); and
- More than 40 existing GIS spatial data mapping efforts.

3. Use multiple methods and information sources so that the conclusions do not hinge on one data source or model.

   Rather than relying on single models, data sets, or information sources, we used multiple approaches to validate and verify results. In most cases, we had a primary approach along with one or more secondary approaches as verification of the primary approach results. Results from models were verified with recent monitoring results.

4. Focus on the 8-digit HUC (HUC8) watershed scale and larger.

   Since the results for this study are intended mostly for helping with larger scale planning efforts, the scale of project results was designed for major watersheds (HUC8s); major basins; and statewide (Figure 1).

Figure 1. Major basins and HUC8 level watersheds in Minnesota.

This report focuses largely on TN since the forms of N which comprise TN can be transformed from one form into another. Since the nitrate form of N affects aquatic life toxicity and drinking water quality and is the dominant form which influences TN in high-yielding watersheds, trends analyses and certain other statistical evaluations were specifically done with the nitrite+nitrate form of N. In some analysis and discussion, we also include the ammonium and organic forms of N.

An overview of the methods used for each of the major study components is described below. More details about the methods are included in the body of the report within each chapter.

Nitrogen conditions

Nitrogen conditions across Minnesota were assessed by analyzing monitoring-based calculations of concentrations, loads, and yields, and additionally supplemented with SPARROW model results. All loads and yields in this report are annual loads and yields, unless specified otherwise.

Recent monitoring results at over 700 river and stream sampling sites were used to map and describe concentrations of different forms of N. The resulting maps show concentrations during low N periods (10th percentiles), average conditions (50th percentile) and high N periods (90th percentiles) during the past decade.

Monitoring-based watershed N annual loads were analyzed at two different levels: 1) major (mainstem) rivers, and 2) outlets of HUC8 watersheds. Annual loads were calculated by the MPCA and Metropolitan Council from continuous flow measurements and regular stream sampling. Because loads are largely influenced by the size of the watershed, the area-normalized loads (yields) and flow-weighted mean concentrations (load divided by flow) were mostly used when comparing N loads in watersheds around the state. Monthly loads were assessed at certain mainstem river monitoring points using data from the Metropolitan Council.

A spatial comparison of annual N loads and yields was also evaluated using modeling results from the SPARROW model. This model was developed and calibrated by the U.S. Geological Survey using monitoring-based results that are mostly independent of the other HUC8 watershed monitoring data described in this report. The model is specifically designed to spatially compare nutrient delivery from watersheds within a specific geographic area.

Because N forms transform within waters and are sometimes lost to the atmosphere, an extensive review of literature and data was conducted to evaluate how much N entering waters in one area is lost or transformed as it is transported to downstream waters.

Nitrate concentration trends

Stream nitrate concentration trends at 51 monitoring sites in the state were evaluated by the USGS and MPCA for nitrate concentration trends. Water quality monitoring data from the MPCA, USGS and Metropolitan Council was used, along with river flow data from the USGS. Long term trends (30 or more years) were assessed using the USGS QWTREND model. The QWTREND model allowed us to determine which specific periods of time within the entire record had increasing, decreasing, or stable trends. Trend results were mapped so that differences in trends could be observed across the state.

The statistical analyses were compared to several other previous trends studies conducted in Minnesota.

Sources and pathways

Total nitrogen inputs to waters from different sources and pathways were estimated as follows:

Point sources – MPCA NPDES permit records were used to estimate municipal and industrial point source N discharges directly into surface waters.

Atmospheric deposition – An EPA Model (CMAQ) was used to determine wet and dry atmospheric N deposition. The model is based on results from monitoring combined with N source information. Geographic Information System (GIS) data were used to determine amounts of atmospheric N falling directly onto lakes, streams, and land.

Cropland sources – The University of Minnesota estimated cropland losses for three different pathways: surface runoff, tile-line transport, and leaching to groundwater and its subsequent travel to surface waters. Different methods were used for each pathway, but all three assessments involved taking field research results and then using GIS databases to extrapolate the field-research results to the watershed and basin scales.

> For surface runoff, typical N concentrations in cropland runoff were multiplied by runoff volumes that varied for each part of the state.
>
> For tile drainage, field research results from the literature were extrapolated for estimating losses to tile lines under different fertilization rates and precipitation scenarios. Fertilizer rates were estimated from recent farmer surveys.
>
> For leaching to groundwater, field research results from the literature were extrapolated for estimating losses under different soils and geologic sensitivity conditions. Using GIS, the N leaching was estimated for each agro-ecoregion based on geologic sensitivity, soils, climate, fertilizer rates, etc. Recognizing that some N is lost in the groundwater via denitrification before reaching streams, denitrification loss coefficients estimated from research literature were assigned to each agroecoregion. Time lags between leaching to groundwater and delivery to surface waters were not directly accounted for.

All major cropland N inputs and outputs were evaluated in a basin-wide and state-wide N budget assessment. The budget allowed us to estimate the total fraction of cropland N inputs which is lost to waters.

Septic systems – Septic system transport was divided into direct pipe discharges and groundwater discharges. Average N generated per home was multiplied by the number of direct pipe septic systems to represent direct pipe discharges. For leachfields, N generated per home was multiplied by the number of leachfields, and then adjusted to account for denitrification losses within the soil and groundwater that would likely occur prior to N reaching surface waters.

Feedlots – Feedlot runoff N estimates were made using the Minnesota Feedlot Annualized Runoff Model (MinnFARM) and then multiplied by estimates of the size and number of non-compliant feedlots. Land application of manure was incorporated into the cropland source categories, and therefore is not included under the feedlot source category.

Forests – N loss coefficients from published studies of forest land were examined. A coefficient was selected to represent all forested land in the state. This coefficient was multiplied by the forested acreage using GIS.

Urban stormwater runoff – N loss coefficients from published studies and Twin Cities monitoring data were examined before selecting a single coefficient to represent typical urban/suburban stormwater runoff N loads. An additional amount of N was added based on a literature search, to represent urban/suburban groundwater contributions. GIS data layers were used to multiply the urban suburban lands by the loss coefficient.

Due to analysis uncertainties, the above source assessment findings were verified using five different approaches, as follows:

Monitoring results – The sum of the individual source estimates were compared with monitoring results from similar geographic areas as the source estimates. This comparison was conducted for the HUC8 and major basin scales.

Watershed land characteristics – Land characteristics in watersheds with more than one year of monitoring during normal-flow conditions were used in non-statistical and multiple regression analyses to assess relationships between the land and river N yields and concentrations. The land characteristics most associated with high and low river N levels were compared with the findings of the N source assessment.

The SPARROW model – The SPARROW model was used to estimate the relative contributions of major source categories of: agriculture, point source, and non-agricultural nonpoint sources. These statewide results were compared with similar groupings from the N source assessment.

Minnesota River Basin HSPF model – The HSPF model developed for the Minnesota River Basin was used to compare nonpoint source N delivery pathways and sources for this basin.

Literature review – Nitrogen source findings from other studies in the upper Midwest were compared to the findings from the source assessment.

Reducing nitrogen loads

The University of Minnesota and Iowa State reviewed existing literature to determine estimates of the expected N reductions which can be achieved from individual agricultural best management practices (BMPs) adopted at both the field and statewide scales. The N reduction estimates, BMP cost estimates, N loss to waters, along with limitations in the landscape for adopting each BMP, were all incorporated into a nitrogen BMP watershed planning spreadsheet (NBMP). We used the tool to estimate the N reduction effects and associated costs from different combinations of BMP adoption rates, and also compared our findings to Iowa’s results.

This part of the study was intended to provide information and results that could be used for assessing large-scale potential ways to achieve N load reductions. The results are not suited for small scale analysis or individual farmer use.

Estimates of wastewater point source reductions that could be achieved with two types of technologies were developed from existing published information.

A2. Nitrogen in Waters: Forms and Concerns

Author: Dave Wall, MPCA

Assistance from: Angela Preimesberger (MPCA) and Hillary Carpenter (MDH) on human health and drinking water; Steve Heiskary (MPCA) on lake eutrophication; and Greg Pratt (MPCA) on atmospheric issues

Introduction

Nitrogen (N) is one of the most widely distributed elements in nature and is present virtually everywhere on the earth's crust in one or more of its many chemical forms. Nitrate (NO_3), a mobile form of N, is commonly found in ground and surface waters throughout the country. Nitrate is generally the dominant form of N where total N levels are elevated. Nitrate and other forms of N in water can be from natural sources, but when N concentrations are elevated, the sources are typically associated with human activities (Dubrovski et al., 2010). Concerns about nitrate and total N in Minnesota's water resources have been increasing due to effects of nitrate on certain aquatic life and drinking water supplies, along with increasing N in the Mississippi River and its impact on Gulf of Mexico oxygen depletion. This chapter provides background information on:

- forms of N found in water
- environmental and health concerns with N in waters
- how N reaches surface waters

Concurrent to this report writing, the Minnesota Department of Agriculture (MDA) is updating the Nitrogen Fertilizer Management Plan. The MDA plan provides a wealth of background information on agricultural N in soils and water, and the reader is encouraged to refer to the plan for additional background information related to N forms, transport to groundwater, health concerns, well-water conditions, N fertilizer sales and sources, and much more:
www.mda.state.mn.us/chemicals/fertilizers/nutrient-mgmt/nitrogenplan.aspx

Additionally, more discussion of N forms and transformations from one form to another is included in Appendix B5-2.

Forms of nitrogen in water

Overview

Nitrogen enters water in numerous forms, including both inorganic and organic forms (Figure 1). The primary inorganic forms of N are ammonia, ammonium, nitrate, and nitrite. Organic-nitrogen (organic-N) is found in proteins, amino acids, urea, living or dead organisms (i.e., algae and bacteria) and decaying plant material. Organic-N is usually determined from the laboratory method called total Kjeldahl nitrogen (TKN), which measures a combination of organic N and ammonia+ammonium. Since N can transform from one form to another, it is often considered in its totality as total nitrogen (TN). This report most often refers to TN, but also at times focuses more specifically on the dominant form nitrate-N.

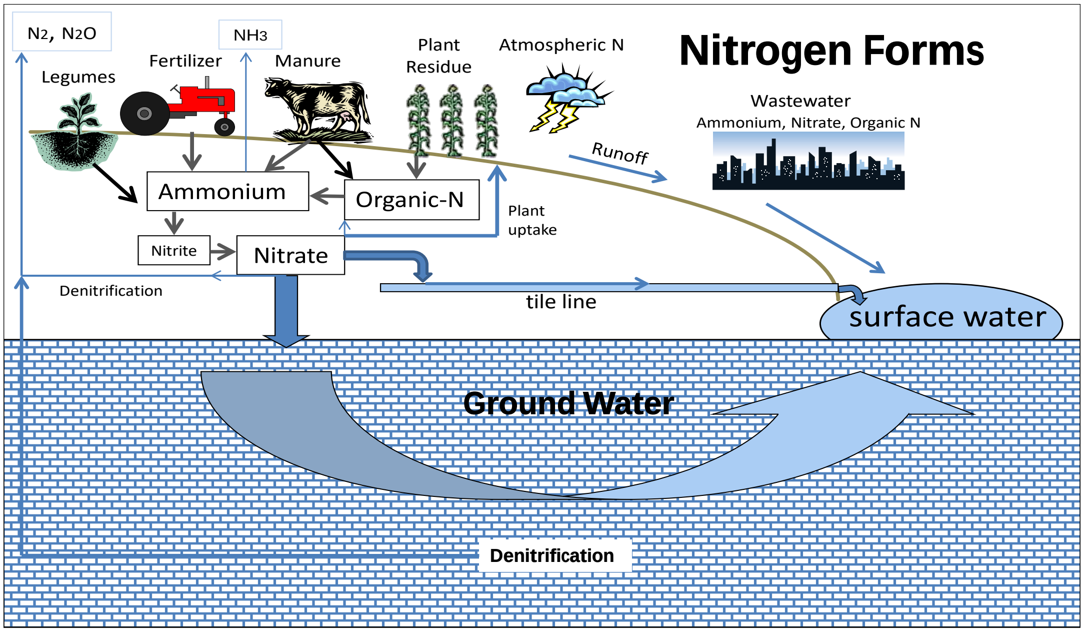
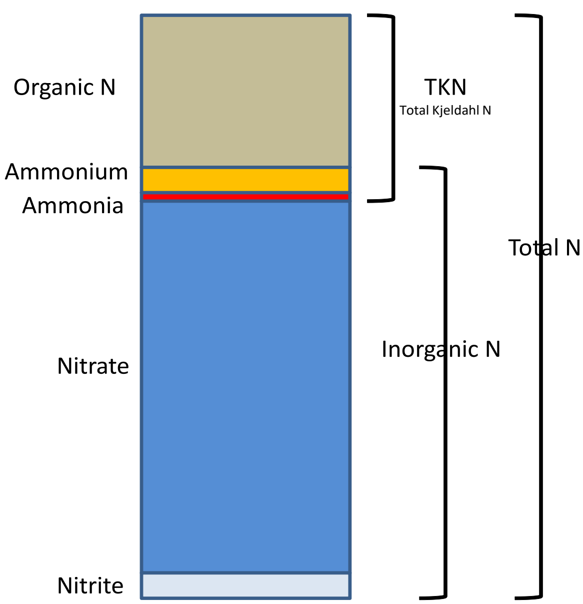


Figure 1. Nitrogen cycle, showing primary N sources, forms and routes to surface waters.

The relative amounts of the different forms of N in surface waters depends on many factors, including: proximity to point and nonpoint pollution sources; influence of groundwater baseflow discharging into the water; abundance and type of wetlands; reservoirs and lakes in the pathway of flowing streams; as well as other natural and anthropogenic factors. Temperature, oxygen levels, and bio-chemical conditions each influence the dominant forms of N found in a given soil or water body.



Types of N commonly found in surface waters are depicted in Figure 2. In most surface waters, the dominant forms of N are nitrate and organic-N. Where streams originate in areas of agricultural production, the nitrate form of N is usually substantially higher than organic N. Because nitrate is very low in forested and grassland areas, organic N is typically higher than nitrate in landscapes dominated by these more natural conditions. Ammonia and ammonium forms of N are usually only elevated near sources of human or animal waste discharges.

Figure 2. Schematic diagram of the relative amounts of different N forms commonly found in Minnesota surface waters with elevated N levels.

An overview of the N forms and their associated health and environmental concerns is provided in Table 1. Each specific form is described in more detail in subsequent sections.

Table 1. Overview of the primary forms of N found in Minnesota waters and associated concerns and standards.

Nitrogen parameter	General description	When found	Sources to surface waters	Health and environmental concerns	Minnesota standards
Nitrate-N (NO3)	Main form of N in groundwater and high-N surface waters. Dissolved in water and moves readily through soil.	Present as a common form of nitrogen, since most other N forms can transform into nitrate in N cycle.	Transformed into nitrate from other N forms found in fertilizer, soil N, atmosphere and human and animal waste.	Methemoglobinemia in infants and susceptible adults. Toxic to aquatic life, especially freshwaters Eutrophication and low oxygen (hypoxia), especially in coastal waters.	Drinking Water: 10 milligrams per Liter (mg/l) in groundwater and Class 2A cold water streams. Standards under development for aquatic life toxicity in MN surface waters.
Nitrite-N (NO2)	Low levels in waters – typically measured in lab together with nitrate	Less stable intermediary form of N found during N transforming processes	Same as nitrate.	Methemoglobinemia in infants and susceptible adults. Toxic to aquatic life.	Drinking Water: 1 mg/l in groundwater and Class 2A cold water streams. Standards under development for aquatic life toxicity in MN surface waters.
Ammonia-N (NH3)	Unionized Ammonia – low levels in most waters.	Most of NH3+NH4 is in the NH4 form. But NH3 increases with higher temps and pH (potential of Hydrogen).	Human and animal waste discharges.	Toxic to aquatic life.	0.016 mg/l in Class 2A cold water streams (trout protection) 0.040 in most other streams (Class 2B).
Ammonium-N (NH4)	Measured in lab together with ammonia – usually higher than ammonia but less toxic	Usually found at low levels compared to nitrate and organic N. Found near waste sources.	Human and animal waste discharges.	Can convert to more highly toxic ammonia in high pH and temperature waters.	
Organic-N	Main form of N in low-N surface waters (where nitrate is low).	Living and dead organisms/algae. Found naturally in waters and is supplemented by human impacts.	Algae; soil; organisms; human and animal waste.	Can convert to ammonium and ultimately nitrate under certain conditions.	
Inorganic N	Sum of Nitrite, Nitrate, Ammonia and Ammonium.			See separate parameters above	See separate parameters above
Total Kjeldahl N (TKN)	Lab measurement which includes organic-N, ammonia and ammonium.	Useful to determine organic-N when ammonia+ammonium is also determined separately and subtracted from TKN.		See separate parameters above	See separate parameters above
Total N	Sum of TKN, nitrite and nitrate.			See separate parameters above	See separate parameters above

Nitrate (NO_3) and nitrite (NO_2)

Nitrate (NO_3) is very soluble in water and is negatively charged, and therefore moves readily with soil water through the soil profile, where it can reach subsurface tile lines or groundwater. Where groundwater remains oxygenated, nitrate remains stable and can travel in the groundwater until it reaches surface waters. Similarly, nitrate can move downward into tile lines, which then route the drained water to ditches and surface waters. When nitrate encounters low oxygen/anoxic conditions in soils or groundwater it may be transformed to N gasses through a biochemical process called "denitrification." Therefore, groundwater nitrate is sometimes lost to gaseous N before the nitrate-impacted groundwater has enough time to travel to and discharge into streams. Typically a smaller fraction of nitrate reaches streams in stormwater runoff over the land surface, as compared to subsurface pathways.

Nitrite (NO_2) is typically an intermediate product when ammonium is transformed into nitrate by microscopic organisms, and is therefore seldom elevated in waters for long periods of time. Nitrite is also an intermediary product as nitrate transforms to N gas through denitrification.

Most commonly, laboratories test for a combination of nitrite plus nitrate. When analyzed separately, nitrate is usually much higher than nitrite. Nitrite can be elevated when water samples are taken near sources of organic wastes or sewage, where ammonium is being converted first to nitrite and then to nitrate. Because nitrate is usually so much higher than nitrite, the combined laboratory concentration of nitrite plus nitrate is often referred to in reports as "nitrate." In this report, we use the following terms interchangeably except where it is important to distinguish nitrite from nitrate: nitrite+nitrate-N, NO_2+NO_3-N, NOx-N and nitrate.

Common additions of nitrate in Minnesota soils and waters include: treated wastewater from municipal or industrial waste, on-site septic systems, fertilizer and precipitation. Much of this nitrate does not initially enter the soils in this form, but results from the biological breakdown of ammonium and organic sources of N which originate as manure, fertilizer and soil organic matter. In the presence of oxygen, moisture, and warm temperatures, other forms of N will tend to transform into nitrate.

Nitrate is the dominant form of N in groundwater, and is also dominant in rivers and streams with elevated TN. In Minnesota lakes, nitrate is nearly always at or below laboratory detection limits (Heiskary and Lindon, 2010). Nitrate is found in reservoirs with short residences times and high inputs of N from upstream sources.

Concerns about nitrate in our water include: human health effects when found elevated in groundwater used for drinking water supplies, aquatic life toxicity in surface waters, and increased eutrophication and correspondingly low oxygen in downstream waters such as the Gulf of Mexico.

Ammonia and ammonium

Ammonia (NH_3) is toxic to fish and other aquatic organisms. Ammonium (NH_4), the predominant form in the pH range of most natural waters, is less toxic to fish and aquatic life as compared to NH_3. As the pH increases above 8, the ammonia fraction begins to increase rapidly. In the rare situation that a natural water pH exceeds reaches 9, ammonia and ammonium would be nearly equal.

Sometimes the terms "ammonia" and "ammonium" are used interchangeably in reports and presentations to represent the laboratory-determined concentration of "ammonia plus ammonium-N." The ammonia fraction, often referred to as "unionized ammonia," can be calculated from laboratory reports of ammonia+ammonium if the water temperature and pH are also known. In most Minnesota waters, the ammonium form represents the majority of the ammonia+ammonium.

Common sources of ammonia/ammonium include human and animal wastes, as well as certain fertilizers and industrial wastes. Ammonia and ammonium most commonly enter surface waters through overland runoff or direct discharges from wastewater sources.

Ammonium is also the byproduct when organic matter in soils is mineralized to inorganic-nitrogen (inorganic-N). Once in the soil, ammonium binds onto soil particles such as clay and organic matter. For that reason, ammonium is less likely to move vertically through the soil matrix into groundwater, as compared to nitrate. Yet, ammonium can at times be found in well water at concentrations exceeding 1 mg/l (Razania, 2011). Under the right soil temperature and moisture conditions, ammonium will readily transform into the more mobile form of nitrate-N.

Inorganic-nitrogen

Inorganic-N in waters is predominantly the sum of the nitrite, nitrate, ammonia, and ammonium-N. Most inorganic N is typically in the dissolved form in waters. Where sampling or laboratory methods ensure that all of the nitrite, nitrate, ammonia and ammonium is in the dissolved forms, it is referred to as dissolved inorganic nitrogen (DIN).

Organic-nitrogen

Organic-N includes all substances in which N is bonded to carbon. It occurs in both soluble and particulate forms. Organic-N is found in proteins, amino acids, urea, living or dead organisms (i.e., dead algae and bacteria), and decaying plant material. Soluble organic-N is from wastes excreted by organisms, including livestock manure and human wastes, or from the degradation of particulate organic-N from plants and plant residues.

Some organic-N is attached to soil particles and is associated with sediment losses to water. Different soils have varying amounts of organic-N. For example, soils developed under prairies and prairie wetlands have more organic-N than soils developed in forested areas. Climate, soil particle sizes, age of the land surface, agricultural practices and soil chemistry also affect the amount of organic-N in soils.

Organic-N concentrations in water are typically not measured directly in the laboratory, but are calculated by subtracting the ammonia+ammonium-N (determined separately) from the total Kjeldahl nitrogen (TKN) laboratory analysis (TKN includes N from organic-N and ammonia+ammonium-N). Typically, the organic-N fraction of TKN in surface waters is much higher than the ammonia+ammonium-N fraction.

In nature, organic-N can be biologically transformed to the ammonium form and then to the nitrite and nitrate form. Once in the nitrate or ammonium forms, these nutrients can be used by algae and aquatic organisms and thereby convert back to organic forms of N. Heiskary et al. (2010) and Heiskary and Lindon (2010) found that in high P surface waters, where algae growth is high, TKN is also elevated. Where P and algae are low, TKN is also low. The high algae levels were not believed to be caused by the high TKN, but rather the algae were believed to comprise much of the organic-N in the TKN measurements.

Organic-N sometimes makes up a significant fraction of soluble and particulate N in natural waters, especially in forest and rangeland areas where natural sources of organic matter are found and nitrate concentrations are typically low.

Total nitrogen

Total nitrogen refers to the combination of both organic and inorganic N. While it can be measured directly in the laboratory, it is also commonly approximated by adding TKN and nitrite+nitrate-N concentrations.

Because N can transform from one form to another in water, TN is often a parameter considered when estimating potential downstream effects of N to receiving waters such as the Gulf of Mexico.

In Minnesota rivers and streams with TN concentrations less than 1.5 to 2.0 mg/l, organic-N comprises most of the TN. As TN increases above 2 mg/l, nitrate-N becomes an important component to TN. When TN concentrations exceed 3 to 4 mg/l, nitrate-N will usually be higher than the organic-N (Heiskary et al., 2010).

Environmental and health concerns

Different forms of N in the environment have led to human health and environmental health concerns. Environmental and health concerns with N can be grouped into four general categories:

1. human health
2. aquatic life toxicity
3. eutrophication (resulting in oxygen-deprived or hypoxic waters)
4. nitrogen gasses and atmospheric concerns

An examination of the suite of environmental issues together is important so that efforts to reduce N in one area of the environment do not result in unintended problems in other areas, and such that management plans consider more than one N impact at a time.

Human health concerns

The N forms of primary concern for human health are nitrite and nitrate. Nitrite is the most toxic form of N to humans, especially infants. Nitrate is of most significance, not because of direct toxicity, but when ingested is converted to nitrite. Exposure to nitrate and in some cases nitrite contaminated well water has notably contributed to methemoglobinemia or “blue baby syndrome” in infants. Cases of methemoglobinemia in infants occurring after consuming formula prepared with drinking water high in nitrate date back to before the 1940s. Early academic research and evaluations by government agencies have led to long-standing regulatory drinking water standards based on methemoglobinemia (described in the next section), with more recent studies examining the potential long-term health effects.

Clinical observations and epidemiological studies in the 1940s and 1950s on methemoglobinemia in infants identified nitrate exposure in well water as an important contributing factor, particularly when well water nitrate concentrations exceeded 10 mg/l nitrate-N (Knobeloch et al., 2000). Later studies determined that bacterial conversion of nitrate to nitrite in the gastrointestinal system was an important determinant in the development of methemoglobinemia (NRC, 1995). Nitrite is a reactive form of N that changes the state of iron in hemoglobin (red blood cells). This altered form of hemoglobin, methemoglobin, has a significantly reduced capacity to bind and transport oxygen. Low oxygen transport leads to the visual indicator of methemoglobinemia (blue-gray skin coloring) and adverse effects, such as lethargy, irritability, rapid heartbeat, and difficulty breathing. It is possible for methemoglobinemia to progress to coma and death if not treated (Knobeloch et al., 2000).

Infants under six months of age are more susceptible to methemoglobinemia than older infants and most adults because of: a) lower acidity (higher pH) levels in their stomachs, creating an environment that favors the growth of bacteria capable of reducing nitrate to nitrite; b) lower levels of an enzyme that converts methemoglobin back to hemoglobin; and c) greater consumption of drinking water (formula) per unit of body weight (Ward et al., 2005). Additional factors influence the risk of methemoglobinemia in infants ingesting high nitrates, including co-contamination of drinking water with both high nitrate and bacteria, and existing health status (medications and presence of infections or diarrhea).

Besides infants, the Minnesota Department of Health (MDH) also notes that pregnant women and people with reduced stomach acidity and certain blood disorders may also be susceptible to nitrate-induced methemoglobinemia (MDH, 2012).

Minnesota does not require clinicians to report methemoglobinemia cases, but cases are still occasionally identified in states like Wisconsin where reporting is required (Knobeloch et al., 2000). The MDH has conducted studies and extensive public outreach to citizens and medical professionals related to nitrate and bacterial contamination in private well water. Public drinking water is regulated for nitrate, nitrite, and bacterial contamination. With the existing outreach and standards, cases of infant methemoglobinemia from drinking high nitrate well water in Minnesota appear to be very limited.

The MDH and the Centers for Disease Control have also conducted studies on the occurrence of methemoglobinemia in pregnant women in Minnesota (Manassaram et al., 2010). The study did not find elevated levels of methemoglobin, but only a few participants had drinking water concentrations measured above 10 mg/l nitrate-N. In addition, many women were drinking water treated by an in-home device or bottled water. While the authors did not specifically inquire as to the reason for not drinking household tap water, the results suggested awareness by the participants of health concerns associated with potential drinking water contaminants.

Concerns about nitrate have also included possible health effects related to long-term exposure. Studies have suggested association with nitrate exposure and adverse reproductive outcomes, thyroid disruption, and cancer. Evaluations of these potential health effects in 1995 by the National Research Council (NRC) and more recently, by the World Health Organization (WHO) (2007), concluded that human epidemiological studies on nitrate toxicity provide inadequate evidence of causality with these health outcomes. When also considering additional information, such as the internal conversion process of nitrate to nitrite and direct nitrite exposure available from animal studies, risks for reproductive effects and cancer were deemed to be low at environmental concentrations.

Besides contaminated drinking water, other sources of exposure to nitrate and nitrite have been considered for evaluating potential health effects. For older infants and adults, the primary sources of exposure are from diet and internal physiological (endogenous) production. Certain vegetables, as well as cured meat, contain high levels of nitrate and nitrite, respectively. There are added benefits of co-occurring antioxidants and vitamins from vegetable consumption, which can protect against some of the negative health effects associated with nitrate intake (Ward, 2005).

Available information on nitrate and nitrite exposures and adverse health effects continues to center on methemoglobinemia in infants less than six months of age, who have consumed formula with high nitrate concentrations. Older infants, children, and adults, because of differences in both biological processes and exposure sources, are much less susceptible to health concerns. However, both the WHO (2007) and a recent draft report from Health Canada (2012) recommend keeping exposure to nitrate and nitrite concentrations in drinking water below 10 mg/l nitrate-N and 1 mg/l nitrite-N, respectively, for all populations.

Drinking water standards for nitrate and nitrite

The U.S. Environmental Protection Agency (EPA) established the Safe Drinking Water Act (SDWA) standard, known as a maximum contaminant level (MCL), for nitrate in drinking water of 10 mg/l nitrate-N (equivalent to 45 mg/l as nitrate) in 1975. The EPA adopted a nitrite MCL of 1 mg/L nitrite-N in 1991. Maximum contaminant levels are regulatory drinking water standards required to be met in finished drinking water provided by designated public drinking water facilities. Both standards were promulgated to protect infants against methemoglobinemia, based on the early case studies in the United States, including Minnesota, which found no cases of methemoglobinemia when drinking water nitrate-N levels were less than 10 mg/L (NAS, 1995). The nitrite MCL is lower than nitrate, because nitrite is the N form of greatest toxicity, and nitrate’s risk to infants is based on the level of internal conversion to nitrite. Because the impacts of methemoglobinemia can occur as quickly as a day or two of exposure, the MCLs are applied as acute standards, not to be exceeded on average in a 48-hour timeframe.

The MDH administers the SDWA program. Because nitrate and nitrite are regulated under this program, SDWA facilities must monitor for nitrate and nitrite and inform consumers if MCLs in finished drinking water are exceeded. The MDH reports that exceedances are uncommon (< 1% in 1999 to 2007), but do occur, particularly in systems that use groundwater (MDH, 2009). The MDH notes that users of private wells have more likelihood of having elevated nitrate and bacterial concentrations (MDH, 2012).

The MDH is also responsible for promulgating Health Risk Limits (HRLs) under the Minnesota Groundwater Protection Act (Minn. Stat. ch. 103H). Health Risk Limits are health-protective drinking water standards applicable to groundwater. Health Risk Limits are the principle standards used to evaluate contaminated groundwater not regulated under the SDWA, especially private well water. Health Risk Limits are meant to ensure that consumers of groundwater are not exposed to a pollutant at concentrations that can potentially lead to adverse health effects (Minn. R. ch. 4717). Currently the HRLs for nitrate and nitrite are the SDWA MCLs. The MDH continues to follow ongoing research on these common groundwater contaminants for possible future HRL updates.

Surface water standards for drinking water protection

As described, the MDH administers the Federal SDWA standards. The MPCA incorporated these same standards by reference in the State’s Water Quality Standards (Minn. R. ch. 7050). The nitrate and nitrite MCLs are applied as Class 1 Domestic Consumption standards. Class 1 standards apply in all Minnesota groundwater and in designated surface waters. Streams upstream of SDWA facilities (e.g., Mississippi River from Fort Ripley to St. Anthony Falls and Red River of the North) are protected as drinking water. Minnesota rules also designate cold-water streams and lakes, primarily trout-waters, as Class 1. Therefore, the MCLs for nitrate-N of 10 milligrams/liter (mg/L) and nitrite-N of 1 mg/L are also regulatory standards in some Minnesota surface waters.

The MPCA and MDA monitor nitrate in surface waters. The MPCA uses this data to determine if all water quality standards are being met. In 2011, 15 cold-water streams in Minnesota were listed as not meeting the nitrate water quality standards (listed as impaired). Twelve of the fifteen were located in southeastern Minnesota. These determinations are based on a limited number of monitoring locations. Surface water nitrate concentrations are discussed further in Chapter B1.

Nitrate in groundwater and drinking water: exceedance of standards

A recent national study by the United States Geological Survey (USGS) found nitrate-N concentrations above 10 mg/l in 4.4% of sampled wells (DeSimone et al., 2009). The upper Midwest was noted as one of the areas where concentrations were most commonly elevated. The percent of wells with elevated nitrate depends on the targeted land uses, well depths, well types, and hydrogeologic settings where the well samples are taken.

The MDH and the MDA conduct nitrate monitoring studies in drinking water and groundwater. The MDH Well Water Quality data base for new wells shows that about 0.5% of newly constructed wells exceeded the MCL during the past 20 years. Newly constructed wells target areas and depths where low nitrate waters are more likely to be found, and they have proper grouting and sealing to prevent surficial contamination (MPCA et al., 2012).

In a targeted study of southeastern Minnesota private well drinking water nitrate concentrations, the percent of wells exceeding 10 mg/l nitrate-N ranged between 9.3% and 14.6% during the years 2008 to 2011 (MDA, 2013).

In 1993, the MDA developed a "walk-in" style of water testing clinic with the goal of increasing public awareness of nitrates in rural drinking and livestock water supplies. While the information collected does not represent a statistically random set of data, and is likely biased toward more highly impacted wells, the results verify the broad extent of elevated nitrate in certain Minnesota well water settings. Based on over 52,000 well water samples (1995-2006), 10% of submitted well water samples exceeded the 10 mg/l nitrate-N drinking water standard (MDA, 2012).

When targeting shallow wells in agricultural areas, the national study by DeSimone et al. (2009) found nearly 25% of wells exceeded the drinking water standard for nitrate. The MDA monitoring network designed to assess shallow groundwater in agricultural areas in different regions of Minnesota found that 36% of 208 well water samples collected in 2010 had nitrate-N in excess of 10 mg/l (MDA, 2010) and that 62% of wells had average nitrate-N exceeding 10 mg/l between 2000 and 2010 (MDA, 2013).

Minnesota groundwater susceptibility to elevated nitrate

The susceptibility of groundwater to elevated nitrate levels varies tremendously across the landscape and across the state. Groundwater nitrate is more likely to be elevated in areas with a combination of a large nitrate source and more permeable soils and hydrogeologic characteristics, such as sands, shallow groundwater, or shallow soils over fractured or highly permeable bedrock.

Several statewide, regional and county mapping efforts have characterized sensitivity of groundwater to contamination in certain parts of Minnesota. The MDH, working with the counties, has developed numerous nitrate probability maps. These maps show higher and lower probability areas for nitrate reaching groundwater based on geologic sensitivity, land use and water quality results. An example of a nitrate probability map is shown below for Fillmore County (Figure 3). This map and other related maps can be found at: www.health.state.mn.us/divs/eh/water/swp/nitrate/nitratemaps.html.

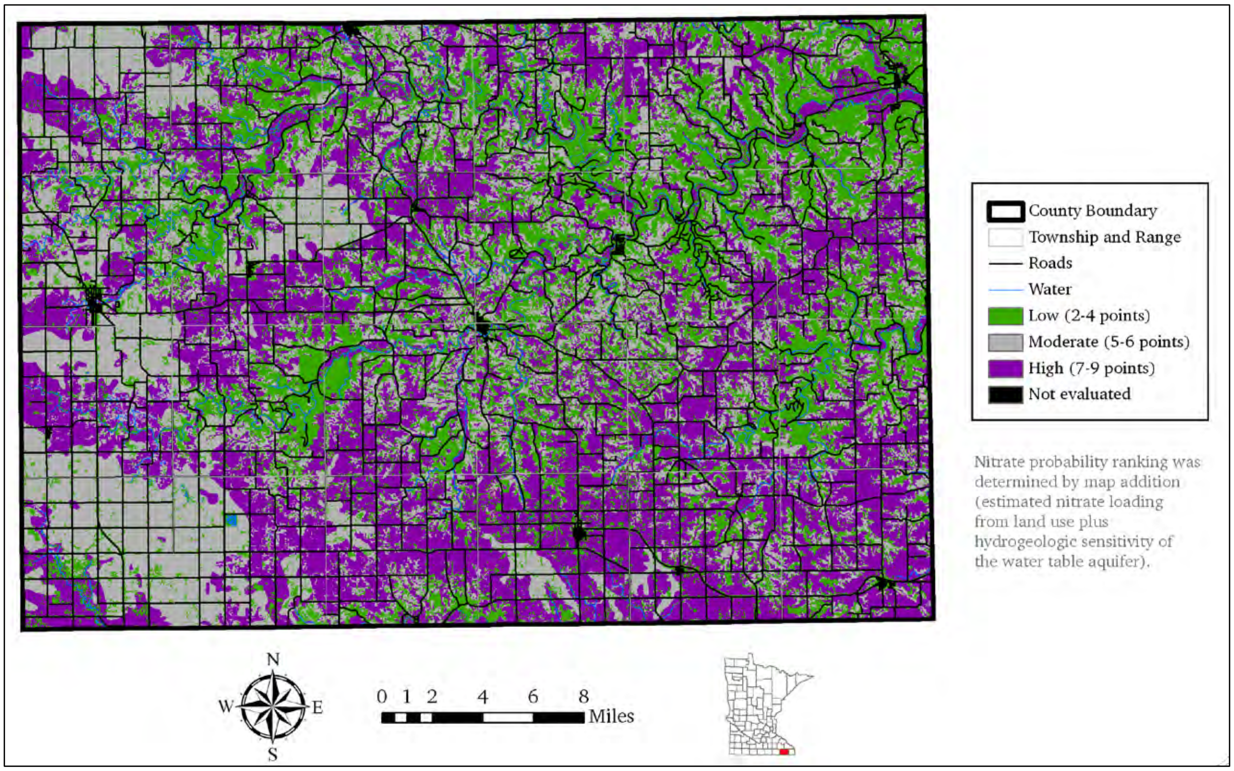


Figure 3. Fillmore County Nitrate Probability Map, showing areas with high (purple), moderate (gray) and low (green) probability of elevated nitrate in the water table aquifer (from MDH).

Ammonia toxicity to aquatic life

Among the different inorganic nitrogenous compounds (NH_4^+, NH_3, NO_2, HNO_2, NO_3) that aquatic animals may be exposed to in ambient surface waters, unionized ammonia (NH_3) is the most toxic, while in comparison, ammonium and nitrate ions are less toxic. Toxicity from unionized ammonia has long been recognized as a concern, and surface water standards are established in Minnesota to restrict point source discharges of ammonia.

Ammonia is a chemical that occurs in human and animal waste. Ammonia in water readily converts between its highly toxic form (NH_3 or un-ionized ammonia) to its less toxic form ammonium (NH4), depending on temperature and pH. The pH and temperature of water samples are required to determine the NH_3 toxicity of a specific stream environment to organisms. As pH and temperature increase, the more toxic unionized ammonia concentrations increase, and there is a corresponding decrease in ammonium. Carmargo and Alonso (2006) found published research indicating that low dissolved oxygen can also increase susceptibility to ammonia toxicity. Conversely, higher salinity and calcium was found to reduce ammonia toxicity.

Plants are more tolerant of elevated ammonia than animals, and invertebrates are generally more tolerant than fish. Toxic effects to fish include reduced blood oxygen carrying capacity, depletion of ATP in the brain, damage to the gills, liver and kidney, and increased susceptibility to bacterial and parasitic diseases (Carmargo and Alonso, 2006). These effects can lead to death and population reductions to aquatic life where concentrations are extreme.

Minnesota has a single chronic standard for ammonia (often referred to as unionized ammonia) of 16 µg/L (ppb) for Class 2A waters (primarily trout streams and lakes) adopted in Minn. R. ch. 7050. The standard for all other classes of waters (except class 7) is 40 ppb. No separate standard exists for ammonia+ammonium-N. Minnesota's 2010 inventory of impaired waters showed a total of six waters assessed as impaired and needing a TMDL for un-ionized ammonia between 1992 and 2010: two in the Minnesota River Basin; two in the Red River of the North Basin; one in the Des Moines River Basin; and one in the St Croix River Basin.

An additional 10 waters were assessed as impaired for un-ionized ammonia between 1992 and 1998, but have since been delisted (2004, 2006, 2008, and 2012 lists). Four delistings were the result of actions taken to upgrade wastewater treatment facilities (new data showed no impairment). One delisting identified septic system upgrades and feedlot/manure management improvements as reasons contributing to water quality standard attainment. The remaining five were delisted based on new and/or more comprehensive data showing no impairment.

In an assessment of water quality in 51 hydrologic systems across the nation, the USGS (Dubrovsky et al., 2010) reported that the chronic criteria for ammonia were exceeded at 4.4% of the sampled sites, a much higher percentage than in Minnesota. Nearly 14% of urban sites and 6% of sites in mixed land use settings exceeded the ammonia chronic criteria. In many cases, treated effluent from wastewater-treatment facilities was known or suspected to be the source of ammonia. Despite large inputs of fertilizer and manure, sampling at 135 agricultural sites found that only 3.7% of the sites exceeded the ammonia criteria, mostly in the western states. This suggests that ammonia from nonpoint sources is typically not reaching or persisting in streams at high concentrations. Rather, ammonia in agricultural watersheds is likely being sorbed onto soils, volatilized, converted to nitrate through the process of nitrification, and (or) rapidly removed from in waters by aquatic plants.

Nitrite and nitrate toxicity to aquatic life

Nitrite can reduce the oxygen carrying ability in aquatic animals. Hemoglobin in fish is converted into methemoglobin that is unable to release oxygen to body tissues, causing hypoxia and potentially death. Other toxic effects include: electrolyte imbalance; heart function problems; formation of compounds which can be mutagenic and carcinogenic; damage to liver cells and tissue oxygen shortage; increased vulnerability to bacterial and parasitic diseases (Camargo and Alonso, 2006). Nitrite toxicity in natural water systems is typically limited due to the rapid conversion of nitrite into nitrate.

Freshwater fish, invertebrates and amphibians have also been shown to exhibit toxicity effects from elevated nitrate (Camargo and Alonso, 2006). A precise cause of nitrate toxicity is unknown though endogenous conversion to nitrite may be a factor in toxicity to aquatic organisms.

In general, freshwater animals are less tolerant to nitrate toxicity than seawater animals, likely due to the ameliorating effect of water salinity in the seawater. The nitrate concentrations which create toxic effects to aquatic life are substantially higher than those concentrations causing problems with nitrite.

At the time of this writing, the MPCA is studying the toxicity effects of aquatic life under Minnesota conditions, so that water quality standards protective of aquatic life communities can be established in Minn. R. ch. 7050 to be. More information can be found at www.pca.state.mn.us/index.php/view-document.html?gid=14949

Eutrophication in Minnesota waters

Eutrophication is the process and condition which occurs when a body of water receives excess nutrients, thereby promoting excessive growth of plant biomass (i.e., algae). As the algae die and decompose, decomposing organisms deplete the water of available oxygen, causing harm or death to other organisms, such as fish.

In Minnesota, water quality standards have been adopted to protect lakes from eutrophication, and at the time of this writing Minnesota is drafting standards to protect against eutrophication in rivers. Since phosphorus (P) is considered to be the primary nutrient causing eutrophication in Minnesota lakes and streams and is often referred to as the "limiting" nutrient, eutrophication standards are based on P concentrations rather than N. This does not mean that reducing the supply of N to lakes and streams is unimportant, rather P supplies, relative to aquatic plant and algae requirements, are much lower than N supplies and thus further reduction of P will often lead to reduced algal growth.

When developing the eutrophication standards, monitoring data was examined and compared to responses measured in the fish/biological community. While some sensitive invertebrate populations were lower when TN was elevated in streams, no clear trend was established at that time for the role of N in the biological and eutrophication responses in Minnesota streams (Heiskary et al., 2010). One presumed reason for this is the co-variance of P and N; whereby TP and TKN (mostly organic N) are highly correlated. Also the high TN was the direct result of elevated nitrate-N. These findings and increasing concern about the role of elevated nitrate-N, has caused Minnesota, the EPA, and other states to continue to look for possible relationships between elevated nitrate-N and biological impacts in freshwater lakes and streams.

In lakes, TN to total phosphorus (TP) ratios (TN:TP) have been used as a means for estimating which nutrient may be limiting algal production. Ratios less than 10:1 (molar concentration ratio) have often been used to indicate potential for N being the controlling nutrient for algae growth; while ratios greater than 17:1 have been used as a threshold indicating P as the controlling nutrient. Ratios between 10:1 and 17:1 suggest that either P or N could be limiting. In a recent randomized study of 64 Minnesota lakes, Heiskary and Lindon (2010) noted that five lakes had TN:TP ratios of less than 10:1 (Figure 4). Heiskary (2011 personal communication) indicated that all five lakes are hypereutrophic, with TP concentrations ranging from 140 to 817 ppb. Total nitrogen concentrations in the five lakes were in the normal range of 1.2 to 2.6 mg/l, with most of the N in the organic forms and very low levels of nitrate. Therefore, the low TN:TP ratio is thought to be from the excessively high TP concentrations, rather than indicative of unusually high N levels.

Lake nitrate concentrations in the 64 lakes rarely exceeded laboratory detection limits (Table 2), whereas TN concentrations were generally comparable to stream TN concentrations. Nitrate-N is dissolved and is readily used up by bacteria and macrophytes in lakes, where some of the N may then show up as organic N in TN or TKN laboratory analyses. This is not the case for many streams where it is common to find elevated nitrate-N concentrations.

Table 2. Minnesota lake N concentrations based on 64 lakes (50 random and 14 reference lakes). From Heiskary and Lindon (2010).

Percentile	Nitrate-N (mg/l)	Ammonium-N (mg/l)	Total N (mg/l)
5th	<0.005	0.008	0.288
10th	<0.005	0.011	0.417
25th	<0.005	0.015	0.537
50th	<0.005	0.024	0.807
75th	<0.005	0.045	1.341
90th	0.012	0.182	2.435
95th	0.110	0.276	4.026

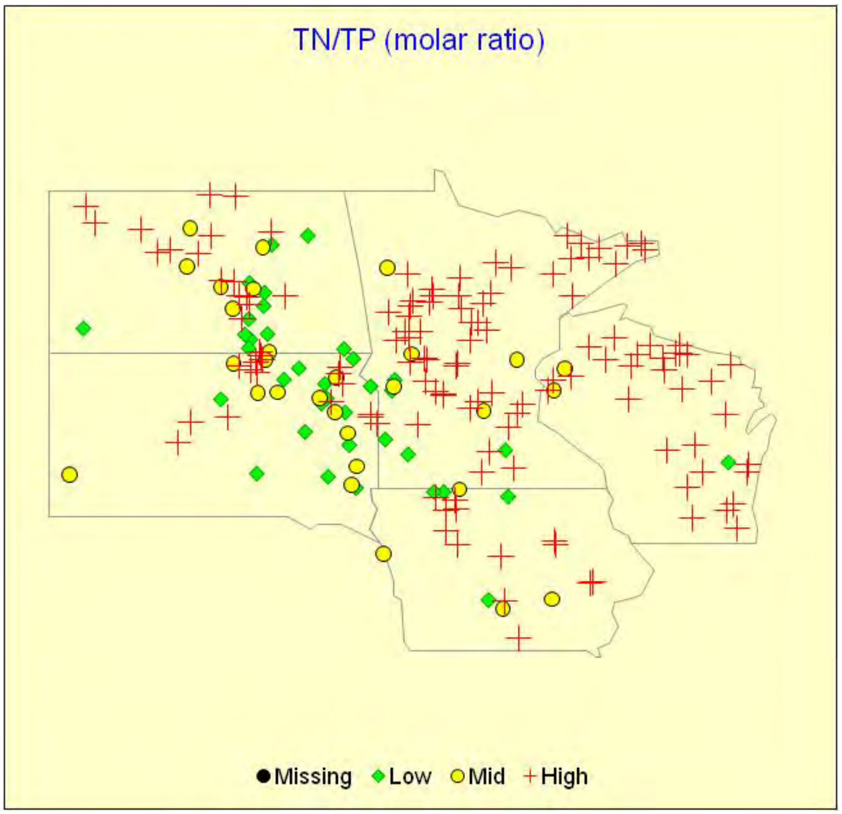


Figure 4. Total nitrogen to TP ratios in Minnesota Lakes, showing locations of "low" (<10:1), "Mid" (10:1 to 17:1) and "High" (>17:1) ratios. From Heiskary and Lindon (2010).

While N is not usually considered to be the nutrient that controls the extent of algae growth in Minnesota lakes or streams, it can contribute to eutrophication of downstream coastal waters. Symptoms of N-driven eutrophication vary, but can include: subtle increases in aquatic plant production; change in the composition of the primary producer communities; rapidly accelerating algae growth; visible discoloration or blooms; losses in water clarity; increased consumption of oxygen; dissolved oxygen depletion (hypoxia); and elimination of plant and animal habitats (EPA, 2011). The EPA reported that coastal water eutrophication is a widespread problem, with one national study showing 78% of the assessed estuarine areas having moderate to high eutrophic conditions (EPA, 2011).

Gulf of Mexico hypoxia

Nitrogen is considered a limiting nutrient in the Gulf of Mexico, the body of water where much of Minnesota's river and stream waters ultimately discharge. When nutrients in the Mississippi River originating in 31 states reach the Gulf of Mexico, a low oxygen "dead zone" known as hypoxia develops (Figure 5).

Figure 5. Watershed area which drains into the Gulf of Mexico. From Mississippi River/Gulf of Mexico Watershed Nutrient Task Force – Gulf Hypoxia Annual Report 2011.

Hypoxia, which means low oxygen, occurs when excess nutrients, primarily N and P, stimulate algal growth in the Mississippi River and gulf waters. The algae and associated zooplankton grow well beyond the natural capacity of predators or consumers to maintain the plankton at a more balanced level. As the short-lived plankton die and sink to deeper waters, bacteria decompose the phytoplankton carbon, consuming considerable oxygen in the process. Water oxygen levels plummet, forcing mobile creatures like fish, shrimp, and crab to move out of the area. Less mobile aquatic life become stressed and/or dies.

The freshwater Mississippi River is less dense and warmer compared to the more dense cooler saline waters of the gulf. This results in a stratification of the incoming river waters and the existing gulf waters, preventing the mixing of the oxygen-rich surface water with oxygen-poor water on the bottom.

Without mixing, oxygen in the bottom water is limited and the hypoxic zone remains. Hypoxia can persist for several months until there is strong mixing of the ocean waters, which can come from a hurricane or cold fronts in the fall and winter.

Hypoxic waters have dissolved oxygen concentrations of less than about 2-3 mg/l. Fish and shrimp species normally present on the ocean floor are not found when dissolved oxygen levels reduce to less than 2 mg/l. The Gulf of Mexico hypoxic zone is the largest in the United States and the second largest in the world. The maximum areal extent of this hypoxic zone was measured at 8,500 square miles during the summer of 2002. The average size of the hypoxic zone in the northern Gulf of Mexico in recent years (between 2004 and 2008) has been about 6,500 square miles, the size of Lake Ontario. The size of mid-summer gulf hypoxic zones from 1985 to 2011 are shown on Figure 6.

A multi-state Hypoxia Task Force (which includes Minnesota) released their first Action Plan in 2001. This plan was reaffirmed and updated in a 2008 Action Plan. The Hypoxia Task Force established a collaborative interim goal to reduce the 5-year running average areal extent of the Gulf of Mexico hypoxic zone to less than 5,000 square kilometers (1,931 square miles). Further information about Gulf of Mexico hypoxia can be found at: www.gulfhypoxia.net/Overview/

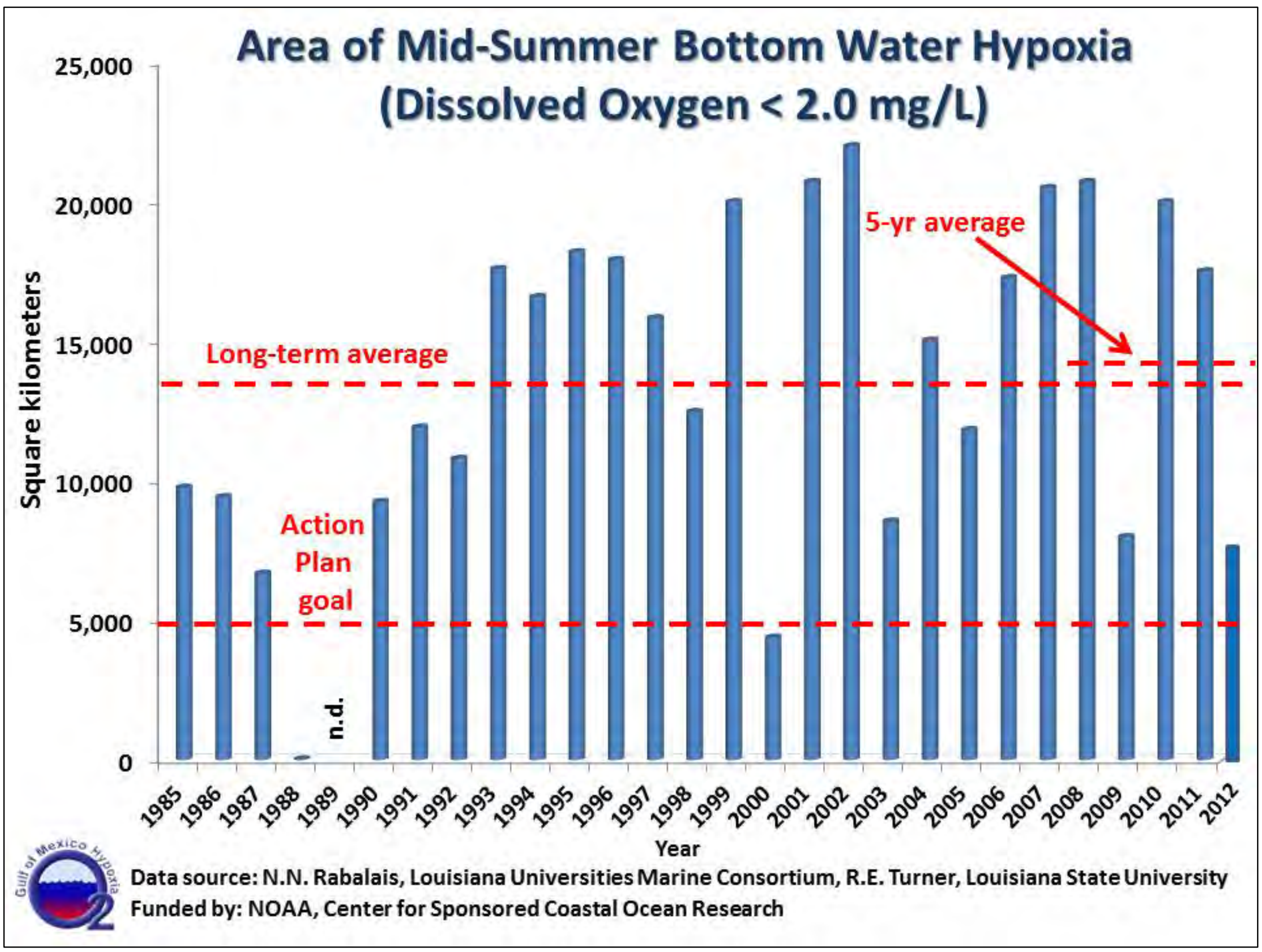


Figure 6. The size of mid-summer bottom water hypoxia areas in the Gulf of Mexico in square kilometers between 1985 and 2011.

A thorough technical discussion of the research associated with Gulf of Mexico hypoxia and possible nutrient reduction options is presented by the US EPA (2007). The report notes that P may be more influential than N in the near-shore gulf water algae growth, particularly in the spring months, when algae and phytoplankton growth are often greatest. In the transition months between spring and summer, the algae and phytoplankton growth are controlled largely by the coupling of P and N. Nitrogen typically becomes the controlling nutrient in the summer and fall months. Based on these more recent findings, emphasis has shifted to developing strategies for dual nutrient removal (P and N). The Science Advisory Board recommends a 45% reduction in riverine TP and TN loads into the Gulf of Mexico (US EPA 2007).

Minnesota's contribution to gulf hypoxia

Certain areas of Minnesota release large quantities of N and P to Minnesota streams. Much of the nutrients remain in the Mississippi River system, ultimately reaching the Gulf of Mexico. Alexander et al. (2008) used computer modeling (SPARROW) to estimate the proportion of gulf nutrients originating in different geographic areas. The model accounted for the loss of nutrients in the river, river pools, and backwaters prior to reaching the Gulf of Mexico. This modeling indicated that Minnesota contributed 3% of Gulf of Mexico N and 2% of the P. However, with more recent SPARROW modeling, Minnesota's contribution is estimated to be higher, ranking as the sixth highest state for N contributions behind Iowa, Illinois, Indiana, Ohio, and Missouri. The more recent modeling estimates indicate that Minnesota is responsible for about 6% of the N loading and 4% of the P loading into the Gulf of Mexico (Robertson, 2012 personal communication).

Recognizing that it will take a concerted effort by all states which contribute significant amounts of nutrients to the gulf, the MPCA agreed with other top nutrient contributing states to complete and implement a comprehensive N and P reduction strategy. This plan is to be completed in 2013 (Mississippi River/Gulf of Mexico Watershed Nutrient Task Force, 2008). The goal of the Action Plan is to reduce nutrients to the Gulf of Mexico while at the same time addressing in-state water protection and restoration.

Lake Winnipeg eutrophication

Environment Canada (2011) reported "the quality of Lake Winnipeg waters has deteriorated over time, with particular concern arising over the last few decades in response to the effects of accelerated nutrient enrichment. The frequency and intensity of algal blooms in the lake have increased in association with rising phosphorous and N loading from diffuse and point sources in the Lake Winnipeg watershed."

While the specific role of N in Lake Winnipeg is currently being studied, Manitoba Water Conservation and Stewardship believes there is growing evidence in the literature that N plays a role in eutrophication of many freshwater lakes (Armstrong, 2011).

Minnesota and North Dakota combine to contribute between about 22 and 30% of the N loading to Lake Winnipeg, as exported in the Red River (Environment Canada, 2011; Bourne et al., 2002).

Atmospheric concerns

The primary focus of this study is on N in waters, rather than N in our atmosphere. Yet the N cycle is complex and the connections between air, water and land are numerous. It is important to understand atmospheric issues because of the ecological and hydrological linkages between N in atmosphere and N in waters. We need to be careful that our treatment and management to protect waters from N does not create other problems related to N in our atmosphere. Environmental concerns with N in the atmosphere include: 1) atmospheric deposition of nutrients into waters; 2) acute and chronic toxicity from nitrous oxides in the atmosphere; 3) tropospheric ozone formation; 4) greenhouse gasses, 5) stratospheric ozone depletion; and 6) acid rain (Pratt, 2012).

The form of most N that returns to the atmosphere through various processes is N_2, a harmless common gas. The atmosphere is approximately 78% N_2 gas. However, relatively small amounts of other forms of N can contribute to environmental problems.

Certain forms of N can be transformed in the atmosphere to nitric acid (HNO_3), which can create acid rain and lower the pH of surface waters with little ability to buffer the acid rain. The acidification of freshwaters from nitric acid can increase concentrations of aluminum and trace metals, and can have adverse effects on aquatic organisms living in waters which have lower concentrations of calcium, sodium and potassium. In a review of the literature, Carmargo and Alonso (2006) identified numerous adverse effects to plants and animals stemming from fresh water acidification. These effects can include decreased species diversity, delayed egg hatching, disruption of insect and crustacean molting and emergence, respiratory disturbances on a variety of aquatic life, as well as other effects.

In addition to nitric acid deposition, atmospheric N can return to waters in other forms that can add to nutrient-stimulated algae growth and eutrophication. This atmospheric addition is of particular importance where large surface areas of water are found and where the algae growth is largely limited by N, such as coastal waters and estuaries. More information on atmospheric deposition of N to land and waters in Minnesota is found in Chapter D3.

Nitrous oxide (N_2O) is a potent greenhouse gas and also contributes to ozone depletion in the stratosphere. Nationally, the highest emissions of nitrous oxide are from the soil processes of nitrification and denitrification (US EPA, 2011). Denitrification mostly results in the release of harmless nitrogen gas (N_2) into the atmosphere. However, a small but important fraction of other more harmful gasses from denitrification reaches the atmosphere. The nitrification process also produces nitrous oxides. The Intergovernmental Panel on Climate Change (IPCC) estimates that 1.25% of N that enters agricultural soils and 0.75% of N that reaches rivers is converted to nitrous oxide (Mosier et al., 1998). More research is needed on the release of nitrous oxides from nitrification and denitrification processes, especially as we look at denitrification as a treatment option for nitrate polluted waters.

Lastly, ammonia emissions from such sources as livestock manure and anhydrous ammonia fertilizers combine with sulfate and nitrate to form aerosols (PM2.5), and in most locations ammonium sulfate and ammonium nitrate are the largest components of PM2.5 (Pratt, 2012). These compounds are eventually deposited back to the earth’s surface (water and land) and can cause eutrophication and acidification (Pratt, 2012).

How nitrogen reaches surface waters

Numerous potential sources of N to waters exist, including (in random order):

- livestock and poultry feedlots
- municipal sewage effluents
- industrial wastewater effluents
- mineralization of soil organic matter
- cultivation of n-fixing crop species
- use of animal manure and inorganic N fertilizers, and subsequent runoff/leaching/drainage

- runoff from standing or burned forests and grasslands
- urban and suburban runoff
- septic system leachate, and discharges from failed septic systems
- emissions to the atmosphere from volatilization of manure and fertilizers and combustion of fossil fuels, and the subsequent atmospheric (wet and dry) deposition into surface waters
- other activities that can mobilize N (from long-term storage pools) such as biomass burning, land clearing and conversion, and wetland drainage

The contributions of the main N sources and pathways in Minnesota were assessed for this study and are described in Chapters D1-D4 of this report.

Nitrogen can take several different pathways to surface waters. Nitrogen can enter waters directly, through direct discharges from municipal and industrial waste sources. Nitrogen can be dissolved in the runoff water, or attached to soil particles in the forms of ammonium-N and organic-N, and runoff during storms or snowmelt. Nitrogen can also be emitted into the atmosphere and return to land and waters in precipitation and dry deposition. The common N sources and pathways to waters are depicted in Figure 7.

The most mobile forms of N in waters are nitrite and nitrate, which easily dissolves in water and moves with the water. Since nitrate moves vertically through the soil with soil water, the primary pathways for nitrate are usually: 1) leaching into groundwater which then moves toward a stream, lake or well; and 2) leaching into tile lines which discharge into drainage ditches and surface waters.

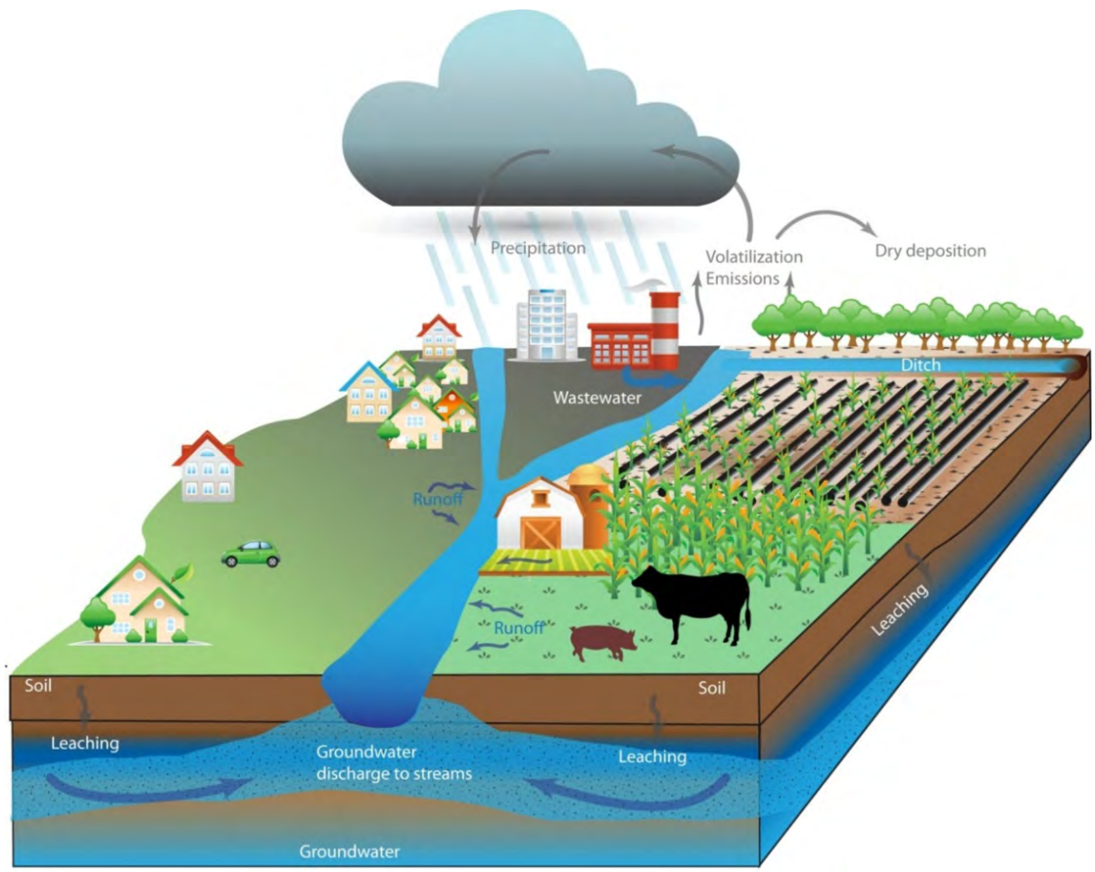


Figure 7. Nitrogen sources and pathways to streams, including direct discharges, runoff, leaching to groundwater, subsurface tile drainage to ditches, and precipitation directly into waters.

Many factors affect the transport of N from source areas to streams. Natural factors, such as soil type, geology, slope of the land, and groundwater chemistry, have a tremendous influence on how much N is transported to streams. Where N sources exist, three Minnesota geologic systems are particularly susceptible to N pollution: 1) karst and other shallow fractured bedrock; 2) unconsolidated sand and gravel aquifers; and 3) alluvial aquifers consisting of sand and gravel deposits interbedded with finer grained deposits.

Human actions, such as irrigation, artificial subsurface drainage, and creation of impervious surfaces, also govern N transport. The result can be varying concentrations of nutrients in streams, even in watersheds with similar land use settings and rates of N additions (Dubrovsky, et al., 2010).

To develop the most effective strategies for reducing N in streams, it is important to understand the combinations of sources and hydrologic pathways resulting in high N levels. That is because strategies and best management practices (BMPs) for preventing surface runoff are often different than those practices used to prevent leaching into ground water and tile waters. And where subsurface tile drainage waters are a dominant pathway, additional BMPs can be considered for treating and managing tile drainage waters.

Denitrification losses in groundwater prior to reaching surface waters

In order for N on the land to reach waters in appreciable quantities, four things must occur: 1) the presence or addition of a high N source; 2) presence of water to drive the N through or over the soil; 3) the absence of an effective way of removing soil N (such as high density of plant roots); and 4) a transport pathway which circumvents denitrification losses.

The N transport pathway greatly affects the potential for denitrification losses to occur. Where nitrate leaching is the dominant pathway, and the leached water is not intercepted by tile lines, nitrate entering low oxygen groundwater zones can be converted to N gas through a process known as denitrification. Denitrification can remove substantial amounts of N in groundwater systems where oxygen levels are low (Korom, 1992). This can occur either in upland groundwater or subsurface riparian buffer zones. The rate of nitrate losses within groundwater can greatly affect the amount of nitrate which ultimately discharges into streams. For this study, we conducted a literature review on groundwater denitrification for conditions representative of Minnesota aquifers. This review is presented in Appendix B5-1.

Denitrification losses in the subsurface are highly variable and are affected by such factors as: 1) the source and amount of N passing through the root zone; 2) the age of water since entering the subsurface; 3) oxygen state along the subsurface flow pathway; 4) riparian zone processes which potentially remove large amounts of N; and 5) rates of flow.

Most of the nitrate will persist and reach surface waters when the following set of subsurface conditions exist: water age is young (recently entered the ground), rates of flow are high, waters remain oxygenated, and riparian processes are negligible. Such conditions occur in tile-drained lands, sand and gravel aquifers, and karst geologic settings, as well as other settings. In karst, nitrate can rapidly move through the thin layers of soils and reach fractures in bedrock, where fast flow rates can transport nitrate to streams without much opportunity for denitrification losses to occur within the groundwater.

The amount of nitrate entering streams is also influenced by the types of geologic materials that the groundwater encounters on its way to becoming stream baseflow. For example, in shallow subsurface riparian zones that contain organic-rich sediments with low dissolved-oxygen concentrations, bacteria convert dissolved nitrate in groundwater to largely innocuous gaseous forms of N through the process of denitrification (Dubrovsky, 2010). Nitrogen also can be removed by plants in riparian or buffer zones.

USGS researchers concluded, "In some settings, groundwater can flow along relatively deep flow paths beneath riparian zones such that nitrate in the groundwater is unaffected by the riparian zone and can discharge directly to streams. Findings show that riparian zones are most effective for nitrogen removal in settings with thin surficial aquifers underlain by a shallow confining layer, with organic-rich soils that extend down to the confining layer. Groundwater in these types of settings tends to flow through biologically reactive parts of the aquifer, which promotes the removal of nitrate" (Dubrovsky, 2010).

Once N reaches surface waters, it can either remain in the water, be transformed to other forms of N, or be lost to the atmosphere through denitrification. These processes and the factors that affect these processes within Minnesota waters were extensively reviewed for this study, and are discussed in Chapter B5 and Appendix B5-2.

Overview of nitrogen entering surface waters

In summary, N enters surface waters through groundwater baseflow and from surface and near-surface runoff and tile line transport (Figure 8). Nitrogen can be lost in the groundwater before discharging into streams, and once in the surface waters further losses can occur before reaching downstream waters.

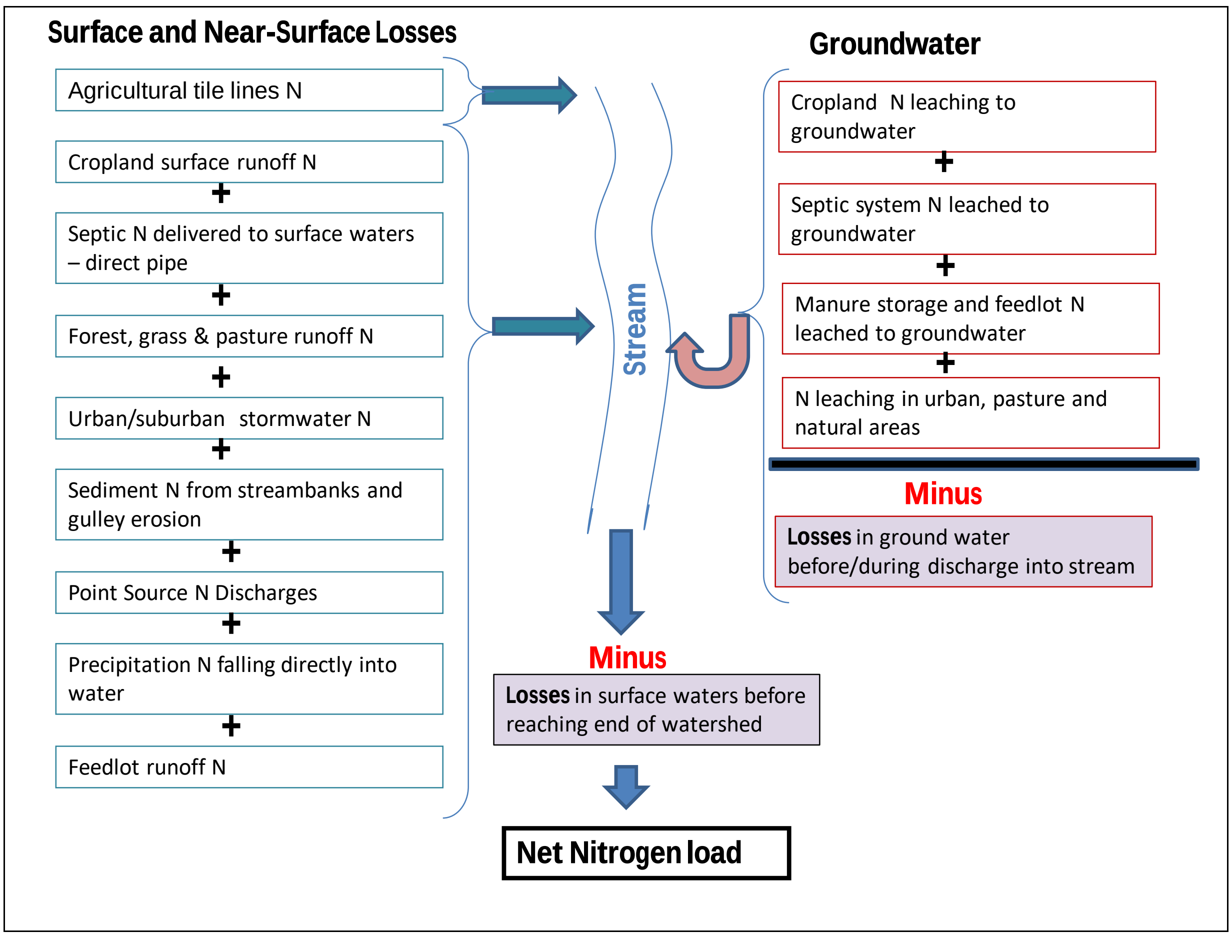


Figure 8. Conceptual diagram of potential N sources, pathways and losses which affect the net N load at the end of the watershed. Denitrification losses are represented by the shaded boxes.

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B1. Monitoring Stream Nitrogen Concentrations

Author: David Wall, MPCA

Assistance with project design, data analysis and mapping provided by: David Lorenz, Abigail Tomasek, and Chris Sanocki (U.S. Geologic Survey) and Dennis Wasley (MPCA)

Introduction

River and stream nitrogen (N) concentrations have been sampled by several different agencies during the past decade. The data were primarily collected to characterize ambient river and stream water quality conditions; yet sampling intervals and sampling purposes have varied.

Nitrogen conditions in surface waters are usually characterized in four different ways: 1) concentration, 2) load, 3) yield, and 4) flow weighted mean concentration. Concentrations are determined by taking a sample of water and having a laboratory determine how much N mass is in a given volume of that water sample, typically reported as milligrams per liter (mg/l). Load is the amount of N passing a point on a river during a period of time, often measured as pounds of N per year. Loads are calculated by multiplying N concentrations by the amount of water flowing down the river. Nitrogen loads are influenced by watershed size, as well as land use, land management, hydrology, precipitation, and other factors. Yield is the amount (mass) of N per unit area coming out of a watershed during a given time period (i.e. pounds per acre per year). It is calculated by dividing the load by the watershed size, which then allows for comparisons of watersheds with different sizes. The FWMC is the weighted-average concentration over a period of time, giving the higher flow periods more weight and the lower flow periods less weight. The FWMC is calculated by dividing the total load for a given time period by the total flow volume during that same period, and is typically expressed as mg/l.

This chapter is the first of five chapters on characterizing Minnesota river and stream nitrogen (N) conditions. In Chapter B1, we take a rather simplified look at the ambient concentrations of different forms of N in rivers and streams throughout Minnesota sampled during more recent years (2000-2010). In Chapters B2 and B3, we assess monitoring-based N loads in Minnesota's rivers and streams, with Chapter B2 examining the mainstem river loads during the past few decades and Chapter B3 assessing N loads available for recent years (2005 to 2009) near the outlets of watersheds. Chapters B2 and B3 are different from Chapter B1, since Chapters B2 and B3 incorporate river flow and runoff event-based data and are therefore limited to a smaller number of sites as compared to Chapter B1. Chapter B4 incorporates the results of river load modeling at both the major basin and watershed levels using the SPARROW model results, which were developed using monitoring-based loads throughout the Upper Midwest as adjusted to a detrended 2002 base-year. Chapter B5 examines how much N is transported downstream once it reaches a stream.

The primary objective of work completed for this chapter was simply to observe patterns of how statewide stream N concentrations vary across Minnesota, and to approximate the high, low, and mid-range concentrations of different forms of nitrogen. More complex analyses involving flow-weighted mean concentrations are discussed in Chapters B2 and B3.

The steps taken to complete the Chapter B2 simple assessment of N concentrations included:

a) Compile recent stream N concentration results from multiple agencies into a single file.
   - Nitrogen parameters included: nitrite plus nitrate-N, ammonium plus ammonia-N, total Kjeldahl nitrogen (TKN); and total nitrogen (TN). Total nitrogen was derived by summing TKN and nitrite+nitrate-N.

b) From combined data sets, calculate concentration statistics for each monitored site which met minimum criteria.
   - Basic statistics calculated include: mean, median, percentiles (10th, 25th, 75th, 90th), maximum and minimum. The 10th percentile is a low-end concentration value for a given river or stream site where 10% of the concentration results are lower and 90% of the results are higher than that value. The 90th percentile is higher-end concentration value for a given river or stream site where 90% of the concentrations are lower and 10% are higher than that value.

c) Plot the concentration statistics results on maps showing the stream sampling sites.

d) Assess magnitudes of concentration statistics and spatial trends in N concentrations across the state.

Data used

We used existing stream N monitoring data from the U.S. Geological Survey (USGS), Minnesota Pollution Control Agency, Metropolitan Council, and Minnesota Department of Agriculture data bases. Only data collected between 2000 and 2010 was considered, so that the results represent more recent conditions, rather than historical conditions.

Some stream sampling efforts are weighted toward higher flow events, whereas other efforts sample at more random times, not necessarily targeting storm/runoff event periods. To make the results more comparable among the sites, data were sorted to eliminate samples which were likely intentionally and specifically sampled during runoff event periods. For example, results were not included in the analyses when samples were taken less than five days apart from another sample at the same site. Most of the data were collected at routine intervals that would inherently include both higher and lower flow periods, and thereby represent a range of flow conditions. Thus the results in this chapter do not represent a flow-weighted analysis, but rather an ambient condition analysis of the concentrations. Flow-weighted analyses are described in subsequent chapters.

The data were sorted to eliminate sites which were not sampled frequently enough to meet minimum criteria. Only those sites sampled at least 15 times during at least two calendar years between 2000 and 2010 were used for calculating “annual” or “all season” concentration statistics. At most river and stream sites, a considerably higher numbers of samples were used than the minimum and the average number of samples per site was 68-69 (Table 1). Because the data for each of monitored stream sites were not all collected during the same months or with the same sampling regularity or methods, the reader is cautioned from drawing distinct comparisons between individual mapped site results. However, we believe that by using the minimum criteria for site selection, the data statistics are sufficient to represent the N concentrations in the broad categorical presentation of the results within this chapter.

Computations for the percentile determinations were completed using the flipped Kaplan-Meier method. Means were calculated using the ROS method (Helsel, 2005).

Four nitrite+nitrate-N concentrations maximum values were considered erroneous data entry errors since they were over 400 mg/l at sites with 90th percentile concentrations less than 3 mg/l. All four values were from sampling sites in the Upper Mississippi River Basin. One TKN maximum in this same basin had a similarly erroneous value. These maximums were not used when calculating average maximums for the Upper Mississippi River Basin.

Table 1. The number of stream sampling sites meeting minimum criteria for statistical analysis, and the average number of N chemistry analyses per stream sampling site taken between 2000 and 2010 and which were used to calculate the annual and seasonal medians, means and percentiles.

	Number of sites	Average number of samples per site	Range in number of samples per site
Annual statistics			
Ammonia+ammonium	597	69	15-439
Nitrite+nitrate	728	69	15-393
Total Kjeldahl nitrogen	637	68	15-392

Results

Statistics calculated using all months of data together is referred to as “annual” or “all season” results. The high-end annual results (90th percentile), low-end annual results (10th percentile) and mid-range annual results (medians) for each qualifying stream sampling site are described below for each N parameter.

Nitrite+nitrate-N

Nitrite+Nitrate-N concentration statistics were calculated for 728 sites meeting the 15-sample annual (all-seasons) criteria. The 90th percentile nitrite+nitrate-N concentrations exceeded 5 mg/l throughout most of southern Minnesota, and 31% of sites statewide exceeded 5 mg/l (Figure 1 and Table 2).

Table 2. Comparisons of the number of stream sites with 90th percentile and maximums exceeding 5 and 10 mg/l.

Nitrite+nitrate-N concentration	Number (and %) of stream sites with 90th percentile at or above 5 and 10 mg/l	Number (and %) of stream sites with maximums (100th percentile) at or above 5 and 10 mg/l
5 mg/l or higher	225 (31%)	297 (41%)
10 mg/l or higher	125 (17%)	197 (27%)

Nitrite+nitrate-N concentrations exceeded 10 mg/l at times throughout most of south-central Minnesota. Statewide, 17% of river and stream sites had 90th percentile concentrations exceeding 10 mg/l. A notable exception to the high southern Minnesota 90th percentile nitrate concentrations is the Mississippi River in southeastern Minnesota, which receives much of its flow from tributaries in the northern part of the state where nitrate concentrations are low, thereby diluting the higher nitrate inputs from the southern part of the state.

The northern part of Minnesota has all stream sites with 90th percentile concentrations below 5 mg/l, with most streams below 1 mg/l (Figure 1). Even the maximum concentrations over the 11-year period (as shown in Table 3) are low in northern basins such as the Rainey River (1.6 mg/l), the St. Croix River (1.3 mg/l) and Western Lake Superior (0.8 mg/l). The Red River Basin has slightly higher nitrite+nitrate concentrations compared to other northern Minnesota basins, and at many monitoring locations the 90th percentile nitrite+nitrate-N concentrations were in the 1-3 mg/l range.

Table 3. Nitrite+nitrate-N concentration statistics for monitoring sites located within various major river basins in Minnesota. Mean 10th percentile concentrations for each basin represent typical low nitrate concentrations and mean 90th percentiles and maximums represent typical high nitrate concentrations for each basin.

	10th percentile (mg/L)			Median (mg/L)			90th Percentile (mg/L)			Maximum (mg/L)		
	Mean	sd	n	Mean	sd	n	Mean	sd	n	Mean	sd	n
STATEWIDE	**0.61**	**1.32**	**728**	**2.2**	**3.5**	**728**	**4.5**	**6.6**	**728**	**7.0**	**9.1**	**724**
DES MOINES	2.00	3.95	15	8.4	9.6	15	14.9	19.1	15	19.4	21.3	15
MINNESOTA	0.55	0.94	139	4.8	4.3	139	10.2	7.2	139	15.4	11.0	139
UPPER MISSISSIPPI	0.35	0.57	199	1.1	1.8	199	2.7	5.1	199	4.2	6.2	195
MISSOURI - BIG SIOUX	1.44	0.87	10	5.5	3.8	10	8.1	4.5	10	12.9	9.6	10
RAINY RIVER	0.11	0.18	19	0.3	0.4	19	0.8	1.0	19	1.6	1.7	19
RED RIVER	0.03	0.05	168	0.1	0.2	168	0.7	0.6	168	2.1	2.9	168
ST. CROIX	0.22	0.58	42	0.4	0.8	42	0.7	1.0	42	1.3	1.6	42
LOWER MISSISSIPPI	2.40	2.15	74	4.5	2.8	74	7.4	3.8	74	10.6	5.3	74
CEDAR	2.07	1.82	25	5.0	2.1	25	12.1	3.7	25	17.0	4.3	25
WESTERN LAKE SUPERIOR	0.04	0.06	36	0.1	0.1	36	0.3	0.2	36	0.8	1.6	36

Because of the high number of stream sampling sites with nitrite+nitrate-N 90th percentiles exceeding 10 mg/l, a separate 90th percentile map was created showing multiple nitrate concentration range categories above 10 mg/l (Figure 2). Rivers and stream samples seldom had nitrite+nitrate-N exceeding 20 mg/l, and 90th percentile concentrations exceeded 20 mg/l at 15 sites (2% of all sites) statewide. Four sites had 90th percentile concentrations exceeding 26 mg/l.

The difference between the maximum nitrate concentrations and the 90th percentile concentrations shows the upper-end concentration distribution (Table 2). About 31% of stream sites had 90th percentile nitrite+nitrate-N exceeding 5 mg/l; whereas the maximums exceeded 5 mg/l at 41% of the sites. Maximum nitrite+nitrate-N concentrations exceeded 10 mg/l at 27% of sampled stream sites.

In the 125 rivers and streams where 90th percentile nitrite+nitrate-N concentrations exceed 10 mg/l, the average 90th percentile concentration was 15.9 mg/l. At these same 125 sites, the average maximum concentration was 21.1 mg/l (Table 4). Therefore, the maximum concentrations recorded between 2000 and 2010 at the highest concentration sites (those with 90th percentile concentrations over 10 mg/l) are on average about 5.2 mg/l higher than the 90th percentile concentrations in these same streams.

Table 4. A comparison of the average maximum nitrite+nitrate-N concentrations (mg/l) to the average of 90th percentile concentrations for stream site categories with very low (<1 mg/l), low (1-2.99 mg/l), medium (3-4.99 mg/l), high (5-9.99 mg/l), and very high (>10 mg/l) nitrite+nitrate-N concentrations.

	Sites with 90th percentile concentrations <1 mg/l	Sites with 90th percentile concentrations 1 – 2.99 mg/l	Sites with 90th percentile concentrations 3 – 4.99 mg/l	Sites with 90th percentile concentrations 5 – 9.99 mg/l	Sites with 90th percentile concentrations 10+ mg/l
Number of sites	315	145	43	100	125
Average of the 90th percentile concentrations	0.35	1.8	3.9	7.6	15.9
Average of the maximum concentrations	1.1	4.1	6.7	11.4	21.1

Median nitrate levels in streams throughout the state are mostly above 3 mg/l in the southern part of the state and below 1 mg/l in the northern part of the state (Figure 3). Median nitrite+nitrate-N levels exceed 10 mg/l in some streams, including streams in the Lower Minnesota River watershed, as well as some scattered sites in other parts of southern Minnesota.

Another way of viewing how nitrate concentrations vary at the same sites is to look at the how the 10th percentile map (Figure 4) compares to the median and 90th percentile maps. The times of low-nitrate concentrations as represented by 10th percentile statistics, show most of streams in the state dropping below 1 mg/l nitrite+nitrate-N. Exceptions to this are the southeast and southwest corners of the state. In southeastern Minnesota, many streams are fed continuously by groundwater with elevated nitrate, so that elevated nitrate continues to discharge into the streams even during drier periods. Table 3 shows that the 10th percentile concentrations are high (on average) in the Lower Mississippi Basin (southeastern Minnesota), followed by the Cedar and Des Moines River Basins. The relatively high 10th percentile concentrations are thought to be largely due to groundwater baseflow in these regions. Municipal wastewater point source discharges also provide a continuous supply of nitrate to rivers throughout the year and could be contributing to the higher 10th percentile concentrations at some sites. It was beyond the scope of this study to research specific sources at specific sites.

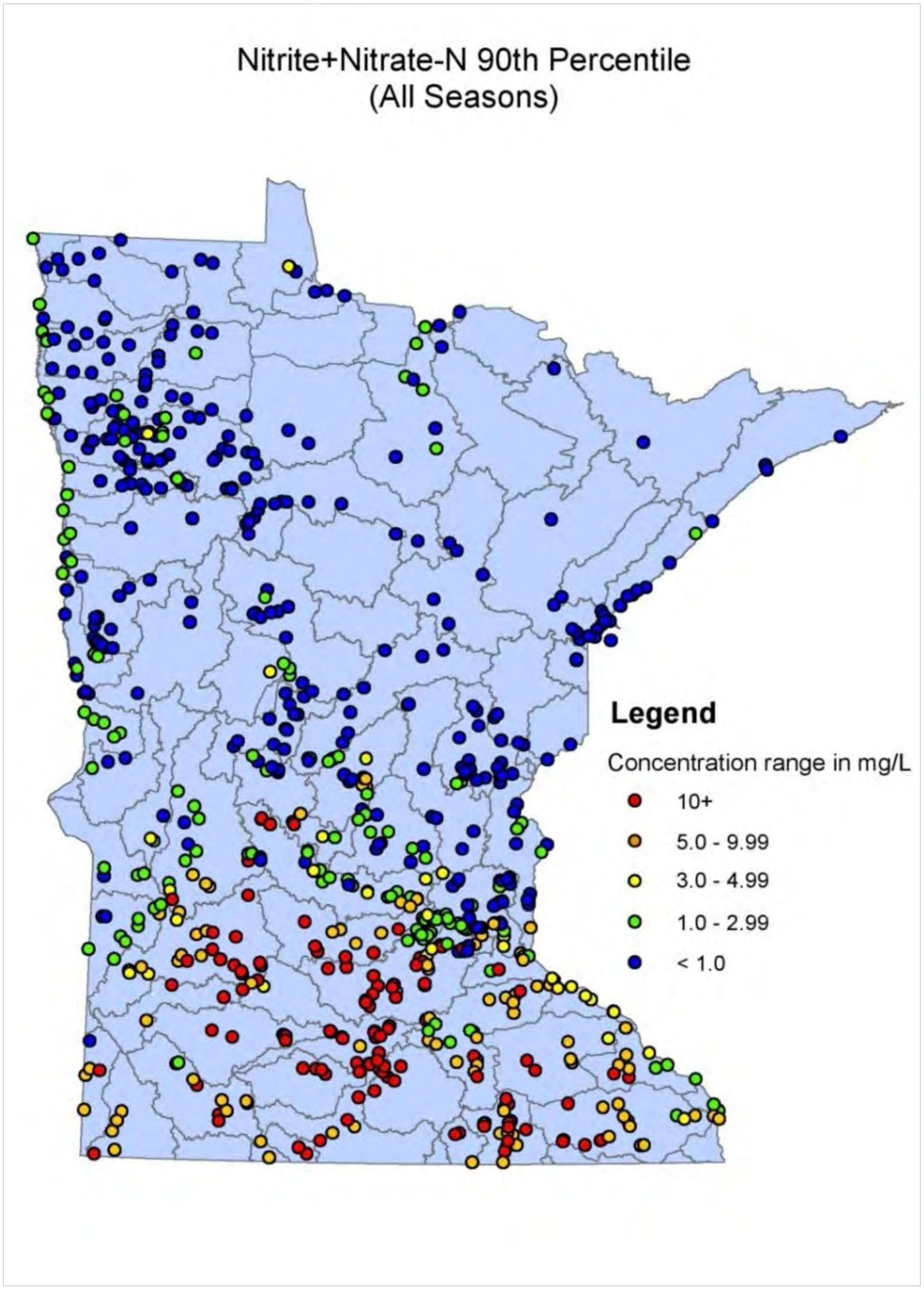

Figure 1. Nitrite+nitrate-N 90th percentile concentrations for all samples taken at each site between 2000 and 2010.

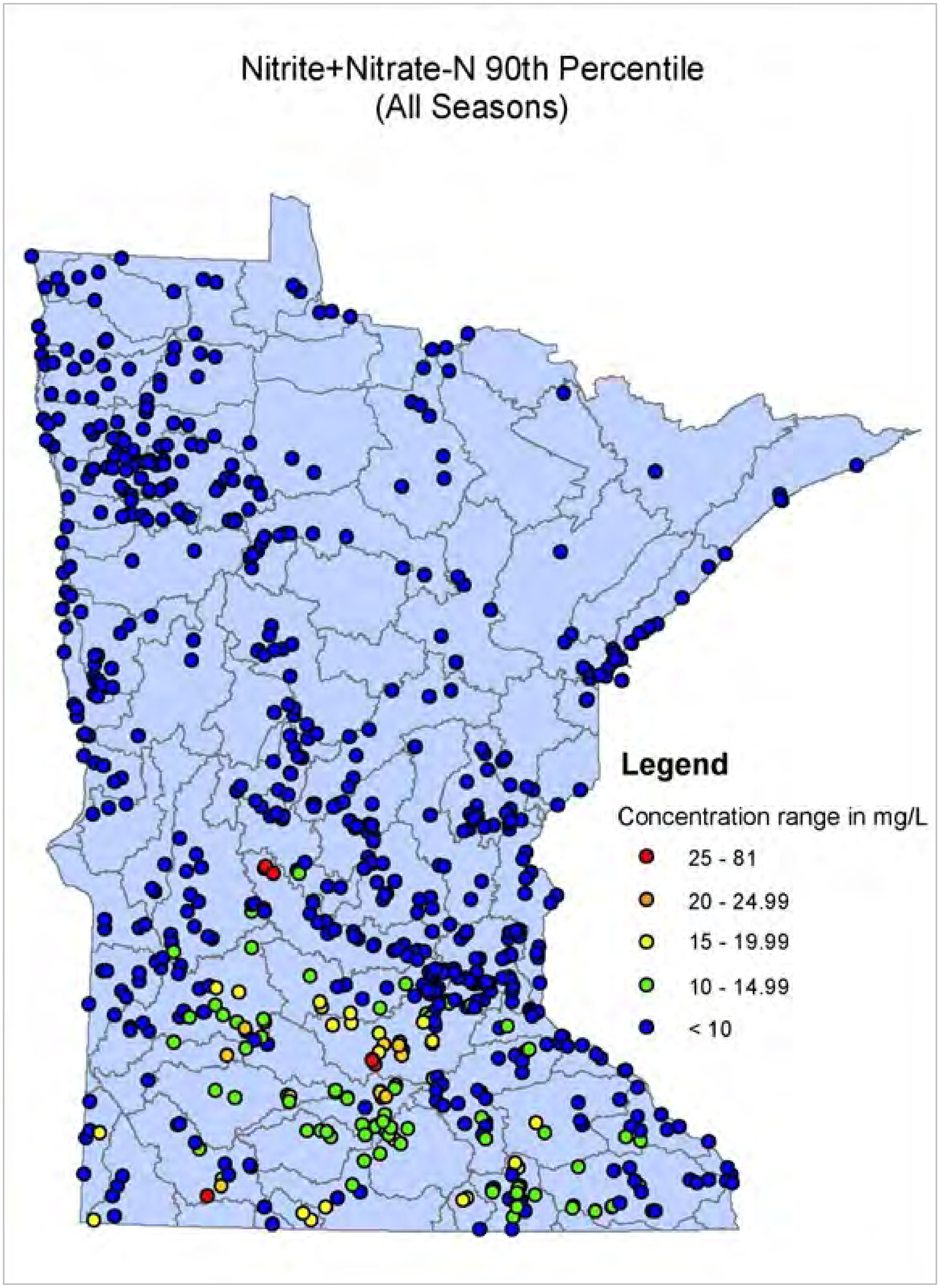

Figure 2. Nitrite+Nitrate-N 90th percentile concentrations, showing the magnitude of 90th percentile concentrations greater than 10 mg/l. This is the same figure as Figure 1, except that the concentration scale ranges are different, such that all red shaded points in Figure 1 are subdivided into four separate categories.

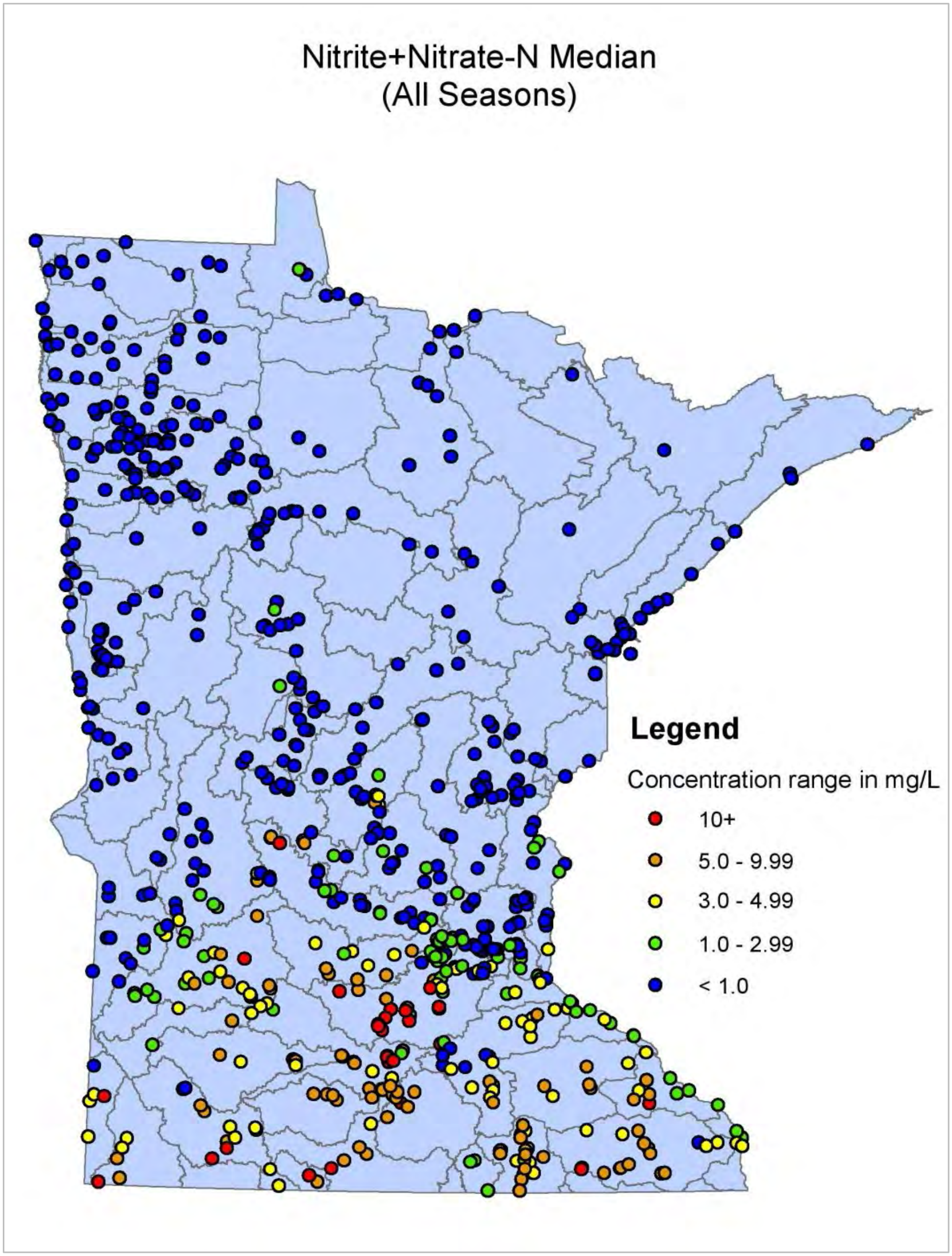

Figure 3. Median nitrite+nitrate-N concentrations for all samples taken at each site between 2000 and 2010.

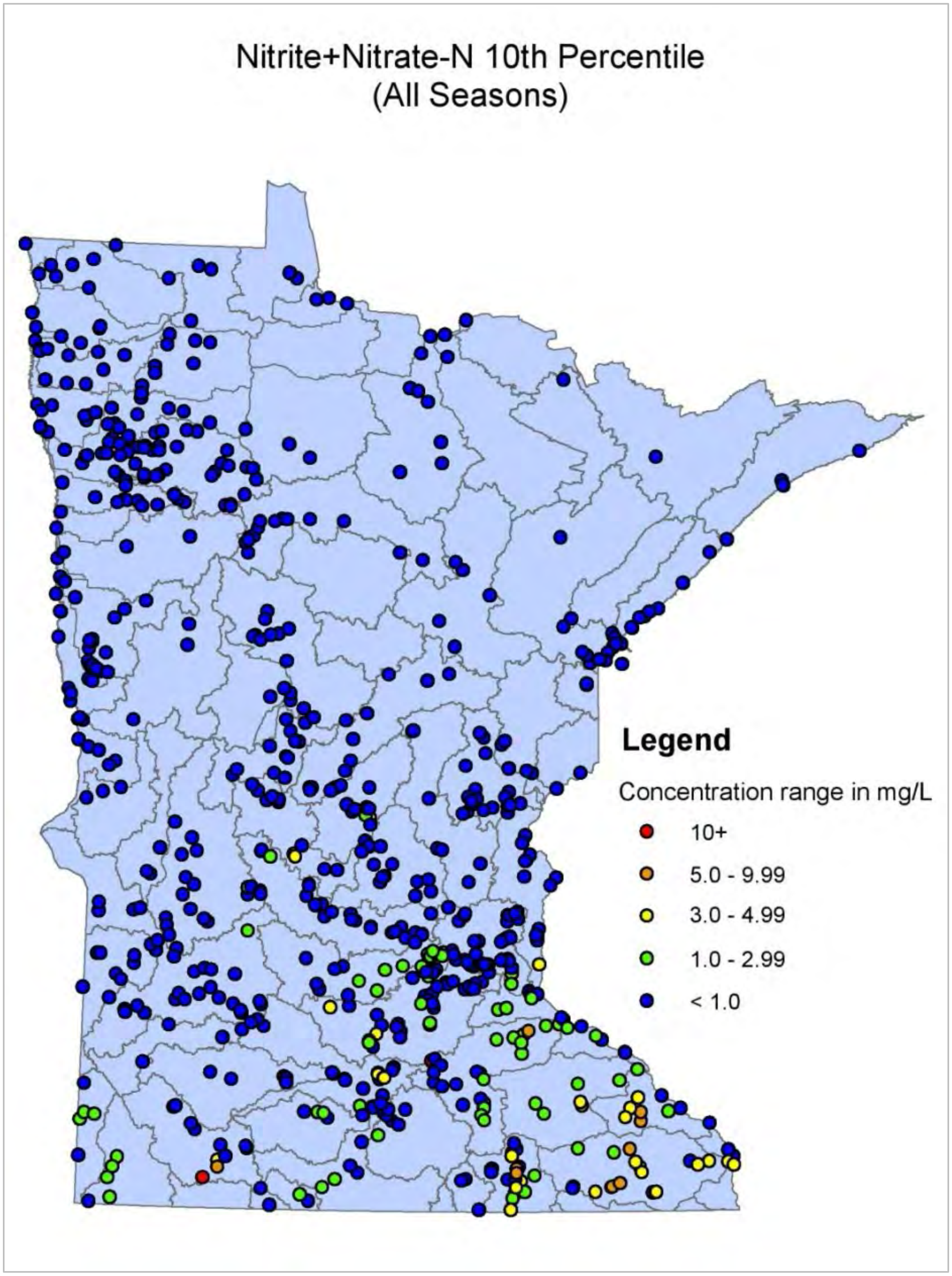

Figure 4. Nitrite+nitrate-N 10th percentile concentrations for all samples taken at each site between 2000 and 2010.

Ammonia+ammonium-N

Ammonia+ammonium-N (commonly referred to as "ammonium") concentrations are much lower than nitrate concentrations. Ammonia+ammonium-N is quickly converted to nitrite+nitrate-N via nitrification in streams, except during winter months. The 90th percentile map shows that the high-end ammonia+ammonium-N levels rarely exceed 1 mg/l (seven sites statewide), and are mostly less than 0.5 mg/l (Figure 5).

The 90th percentile concentrations at most Minnesota sites are above the national background ammonia+ammonium-N concentration of 0.025 mg/l (Dubrovsky et al., 2010), suggesting that over much of the state there are certain periods when human impacts cause ammonia+ammonium to increase. However, these impacts are not usually sustained, since median ammonia+ammonium-N levels are less than 0.1 mg/l throughout most the state (Figure 6 and Table 5).

Spatial patterns of ammonia+ammonium-N concentrations are less pronounced compared to nitrite+nitrate-N. The area of the state with predominantly low ammonia+ammonium-N concentrations (<0.1 mg/l) is north-central and northeastern Minnesota. With the exception of the Duluth area streams and two other scattered streams, all northeastern Minnesota streams had 90th percentile ammonia+ammonium-N concentrations less than 0.1 mg/l.

During typical conditions (medians) ammonia+ammonium-N concentrations are mostly less than 0.1 mg/l throughout the state. Exceptions to this include some sampling points in the Cedar River, the Twin Cities area, and a few other scattered locations.

The 10th percentile concentrations show that almost all monitoring points have less than 0.1 mg/l (Figure 7). An exception is the Cedar River, which has between 0.1 and 0.2 mg/l. The statewide 10th percentile is 0.03 mg/l (mean of all 562 sites 10th percentile concentrations see table 5), which is essentially the same as the national background concentration.

It was beyond the scope of this study to try and determine reasons why individual sites or clusters of sites had particularly high or low ammonium concentrations.

Table 5. Ammonium+ammonia-N concentration statistics for monitoring sites located within various major river basins in Minnesota. Mean 10th percentile concentrations for each basin represent typical low ammonium period concentrations and mean 90th percentiles and maximums represent typical high ammonium period concentrations for each basin.

	10th percentile (mg/L)			Median (mg/L)			90th Percentile (mg/L)			Maximum (mg/L)		
Basin	**Mean**	**sd**	**n**	**Mean**	**sd**	**n**	**Mean**	**sd**	**n**	**Mean**	**sd**	**n**
STATEWIDE	**0.03**	**0.03**	**562**	**0.05**	**0.07**	**562**	**0.26**	**0.61**	**562**	**1.0**	**1.8**	**562**
DES MOINES	0.04	0.04	15	0.05	0.04	15	0.18	0.09	15	0.8	0.7	15
MINNESOTA	0.02	0.02	104	0.05	0.06	104	0.36	0.57	104	1.5	3.1	104
UPPER MISSISSIPPI	0.03	0.02	200	0.05	0.05	200	0.23	0.22	200	1.0	1.0	200
MISSOURI - BIG SIOUX	0.04	0.02	4	0.06	0.03	4	0.23	0.14	4	1.2	1.0	4
RAINY RIVER	0.02	0.01	9	0.02	0.01	9	0.06	0.03	9	0.2	0.1	9
RED RIVER	0.03	0.03	102	0.05	0.07	102	0.20	0.15	102	0.8	1.3	102
ST. CROIX	0.03	0.01	42	0.08	0.18	42	0.44	1.68	42	1.0	2.0	42
LOWER MISSISSIPPI	0.02	0.01	46	0.04	0.02	46	0.32	0.94	46	1.1	1.7	46
CEDAR	0.12	0.06	15	0.13	0.05	15	0.22	0.11	15	0.5	0.41	15
WESTERN LAKE SUPERIOR	0.03	0.01	25	0.04	0.02	25	0.10	0.10	25	0.5	0.9	25

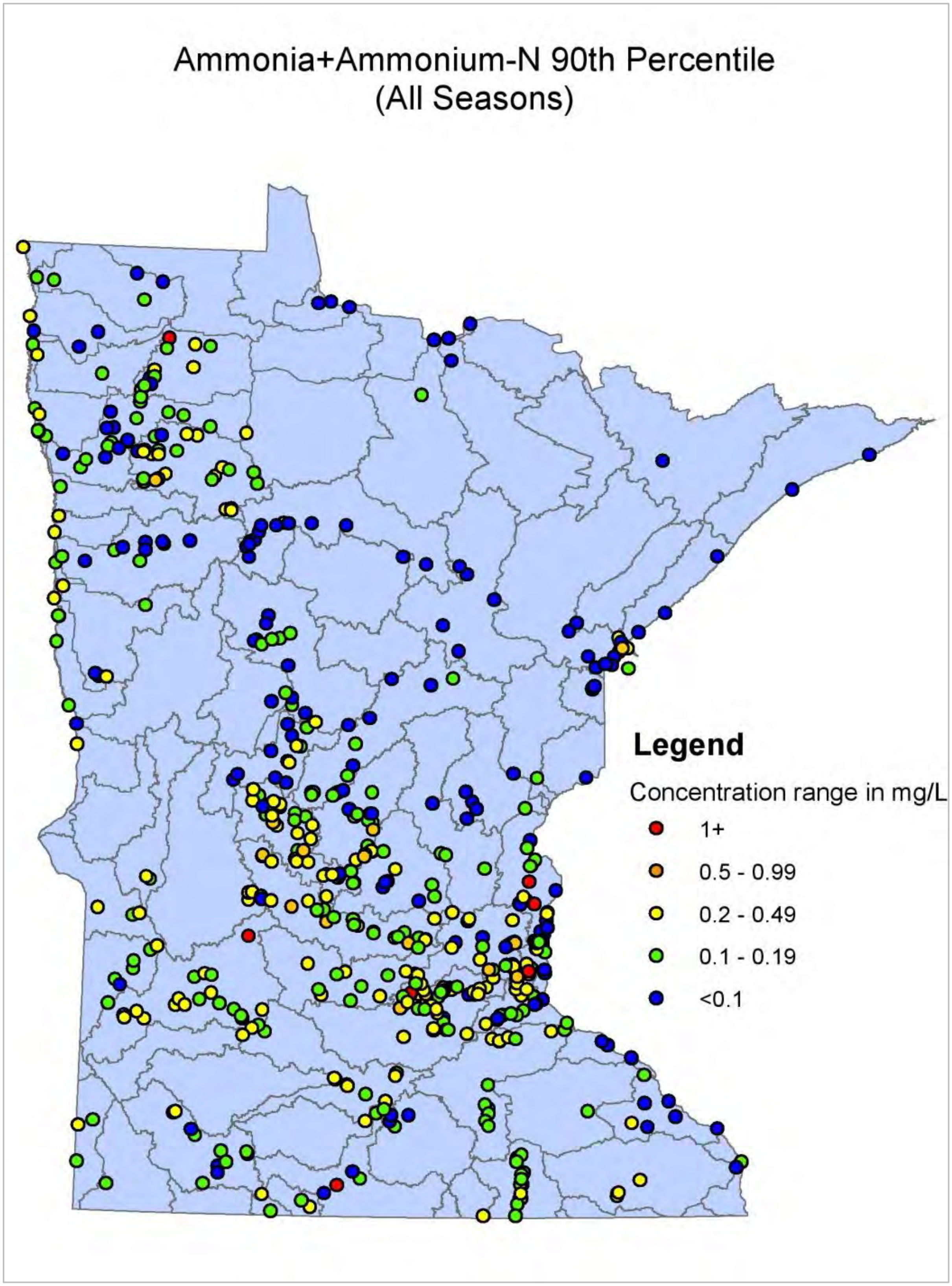

Figure 5. 90th percentile ammonia+ammonium-N concentrations for all samples taken at each site between 2000 and 2010.

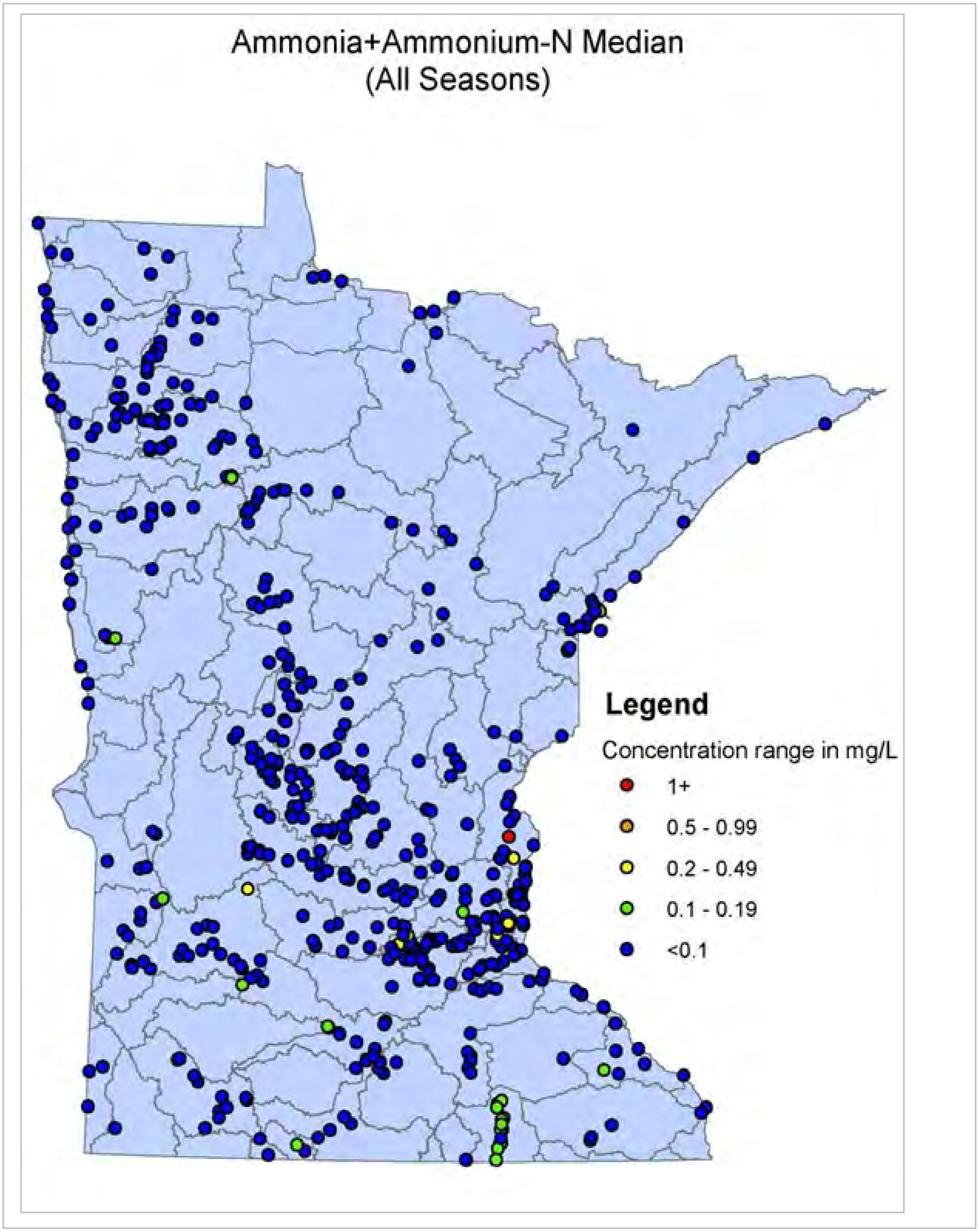

Figure 6. Median Ammonia+Ammonium-N concentrations for all samples taken at each site between 2000 and 2010.

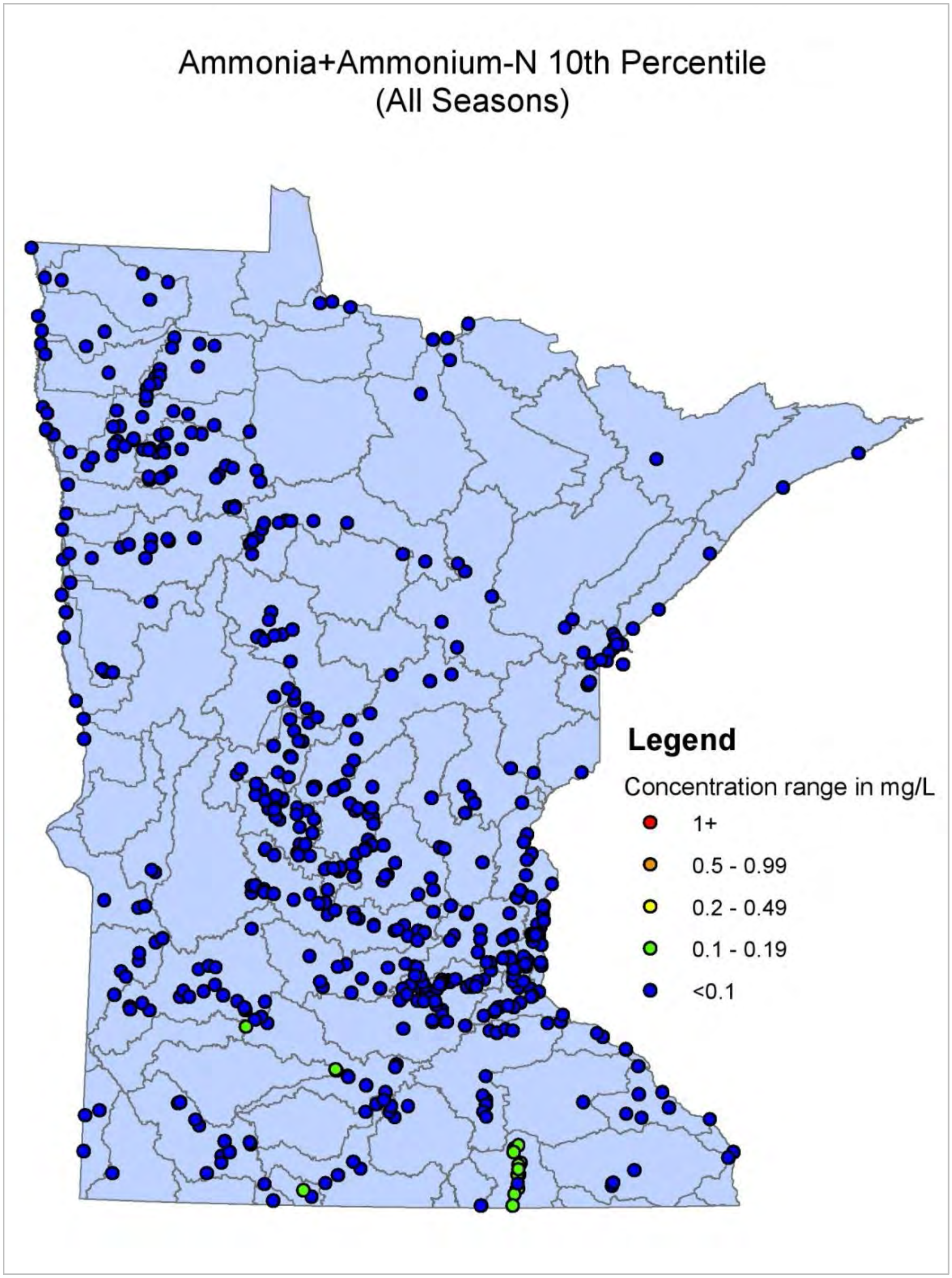

Figure 7. 10th percentile Ammonia+Ammonium-N concentrations for all samples taken at each site between 2000 and 2010.

Total Kjeldahl nitrogen

Total Kjeldahl nitrogen includes both ammonia+ammonium and organic N. Ammonia+ammonium concentrations in surface waters are typically quite low in comparison to TKN concentrations, and at most sites the majority of TKN is organic N.

Total Kjeldahl nitrogen 90th percentile concentrations are mostly in the 1-3 mg/l range throughout the state (Figure 8). Several sites in northern Minnesota and a few in southeastern Minnesota had TKN 90th percentiles less than 1 mg/l. Five main pockets of elevated TKN (90th percentiles over >3 mg/l) are located at various places in the southern half of the state, including clusters northeast and west of the Twin Cities, as well as in central and southwestern Minnesota.

Spatial patterns of TKN concentrations showed that 90th percentiles TKN remained less than 1.5 mg/l throughout most of northeastern Minnesota and was between 1.5 and over 3 mg/l in most of southern Minnesota and along the Red River. The statewide mean of all 637 sites 90th percentile concentrations is 1.9 mg/l (table 6), and means of 90th percentile values for each major river basin did not vary much for most basins of the state.

Total Kjeldahl nitrogen median concentrations did not exceed 3 mg/l at any sites, and were less than 1.5 mg/l at most sites (Figure 9). Medians exceeded 2 mg/l in the Des Moines River and Lower Minnesota River watersheds, in addition to other scattered locations. The statewide mean of all 637 site median concentrations is 1.1 mg/l (Table 6).

Total Kjeldahl nitrogen 10th percentile concentrations were mostly less than 1.5 mg/l throughout the state (Figure 10). With the exception of several streams in central and southwestern Minnesota, the 10th percentile concentrations were less than 1 mg/l. The statewide mean of all 637 sites 10th percentile concentrations is 0.7 mg/l (Table 6).

Table 6. TKN concentration statistics for monitoring sites located within various major river basins in Minnesota. Mean 10th percentile concentrations for each basin represent typical low TKN period concentrations and mean 90th percentiles and maximums represent typical high TKN period concentrations for each basin.

	10th percentile (mg/L)			Median (mg/L)			90th Percentile (mg/L)			Maximum (mg/L)		
	Mean	sd	n	Mean	sd	n	Mean	sd	n	Mean	sd	n
STATEWIDE	**0.7**	**0.3**	**637**	**1.1**	**0.5**	**637**	**1.9**	**1.0**	**637**	**4.2**	**4.6**	**636**
DES MOINES	1.4	0.3	12	2.1	0.5	12	3.3	1.1	12	5.4	3.3	12
MINNESOTA	0.8	0.4	132	1.4	0.5	132	2.5	1.1	132	5.4	2.7	132
UPPER MISSISSIPPI	0.7	0.3	241	1.1	0.4	241	1.8	0.8	241	3.6	2.7	240
MISSOURI - BIG SIOUX	0.6	0.2	5	1.0	0.1	5	1.8	0.2	5	3.6	1.3	5
MISSOURI - LITTLE SIOUX	1.2	0.1	2	1.6	0.1	2	2.3	0.1	2	3.8	0.1	2
RAINY RIVER	0.6	0.1	17	0.9	0.2	17	1.2	0.3	17	1.7	1.0	17
RED RIVER	0.7	0.2	91	1.1	0.3	91	1.6	0.5	91	3.8	7.9	91
ST. CROIX	0.5	0.3	63	0.9	0.4	63	1.9	1.7	63	4.5	6.3	63
LOWER MISSISSIPPI	0.6	0.3	49	1.0	0.5	49	1.8	0.8	49	5.3	5.8	49
CEDAR	0.6	0.2	13	1.1	0.2	13	2.1	0.3	13	3.7	1.2	13
WESTERN LAKE SUPERIOR	0.4	0.1	12	0.6	0.1	12	1.0	0.2	12	1.8	0.6	12

Many factors affect the transport of N from source areas to streams. Natural factors, such as soil type, geology, slope of the land, and groundwater chemistry, have a tremendous influence on how much N is transported to streams. Where N sources exist, three Minnesota geologic systems are particularly susceptible to N pollution: 1) karst and other shallow fractured bedrock; 2) unconsolidated sand and gravel aquifers; and 3) alluvial aquifers consisting of sand and gravel deposits interbedded with finer grained deposits.

Human actions, such as irrigation, artificial subsurface drainage, and creation of impervious surfaces, also govern N transport. The result can be varying concentrations of nutrients in streams, even in watersheds with similar land use settings and rates of N additions (Dubrovsky, et al., 2010).

To develop the most effective strategies for reducing N in streams, it is important to understand the combinations of sources and hydrologic pathways resulting in high N levels. That is because strategies and best management practices (BMPs) for preventing surface runoff are often different than those practices used to prevent leaching into ground water and tile waters. And where subsurface tile drainage waters are a dominant pathway, additional BMPs can be considered for treating and managing tile drainage waters.

Denitrification losses in groundwater prior to reaching surface waters

In order for N on the land to reach waters in appreciable quantities, four things must occur: 1) the presence or addition of a high N source; 2) presence of water to drive the N through or over the soil; 3) the absence of an effective way of removing soil N (such as high density of plant roots); and 4) a transport pathway which circumvents denitrification losses.

The N transport pathway greatly affects the potential for denitrification losses to occur. Where nitrate leaching is the dominant pathway, and the leached water is not intercepted by tile lines, nitrate entering low oxygen groundwater zones can be converted to N gas through a process known as denitrification. Denitrification can remove substantial amounts of N in groundwater systems where oxygen levels are low (Korom, 1992). This can occur either in upland groundwater or subsurface riparian buffer zones. The rate of nitrate losses within groundwater can greatly affect the amount of nitrate which ultimately discharges into streams. For this study, we conducted a literature review on groundwater denitrification for conditions representative of Minnesota aquifers. This review is presented in Appendix B5-1.

Denitrification losses in the subsurface are highly variable and are affected by such factors as: 1) the source and amount of N passing through the root zone; 2) the age of water since entering the subsurface; 3) oxygen state along the subsurface flow pathway; 4) riparian zone processes which potentially remove large amounts of N; and 5) rates of flow.

Most of the nitrate will persist and reach surface waters when the following set of subsurface conditions exist: water age is young (recently entered the ground), rates of flow are high, waters remain oxygenated, and riparian processes are negligible. Such conditions occur in tile-drained lands, sand and gravel aquifers, and karst geologic settings, as well as other settings. In karst, nitrate can rapidly move through the thin layers of soils and reach fractures in bedrock, where fast flow rates can transport nitrate to streams without much opportunity for denitrification losses to occur within the groundwater.

The amount of nitrate entering streams is also influenced by the types of geologic materials that the groundwater encounters on its way to becoming stream baseflow. For example, in shallow subsurface riparian zones that contain organic-rich sediments with low dissolved-oxygen concentrations, bacteria convert dissolved nitrate in groundwater to largely innocuous gaseous forms of N through the process of denitrification (Dubrovsky, 2010). Nitrogen also can be removed by plants in riparian or buffer zones.

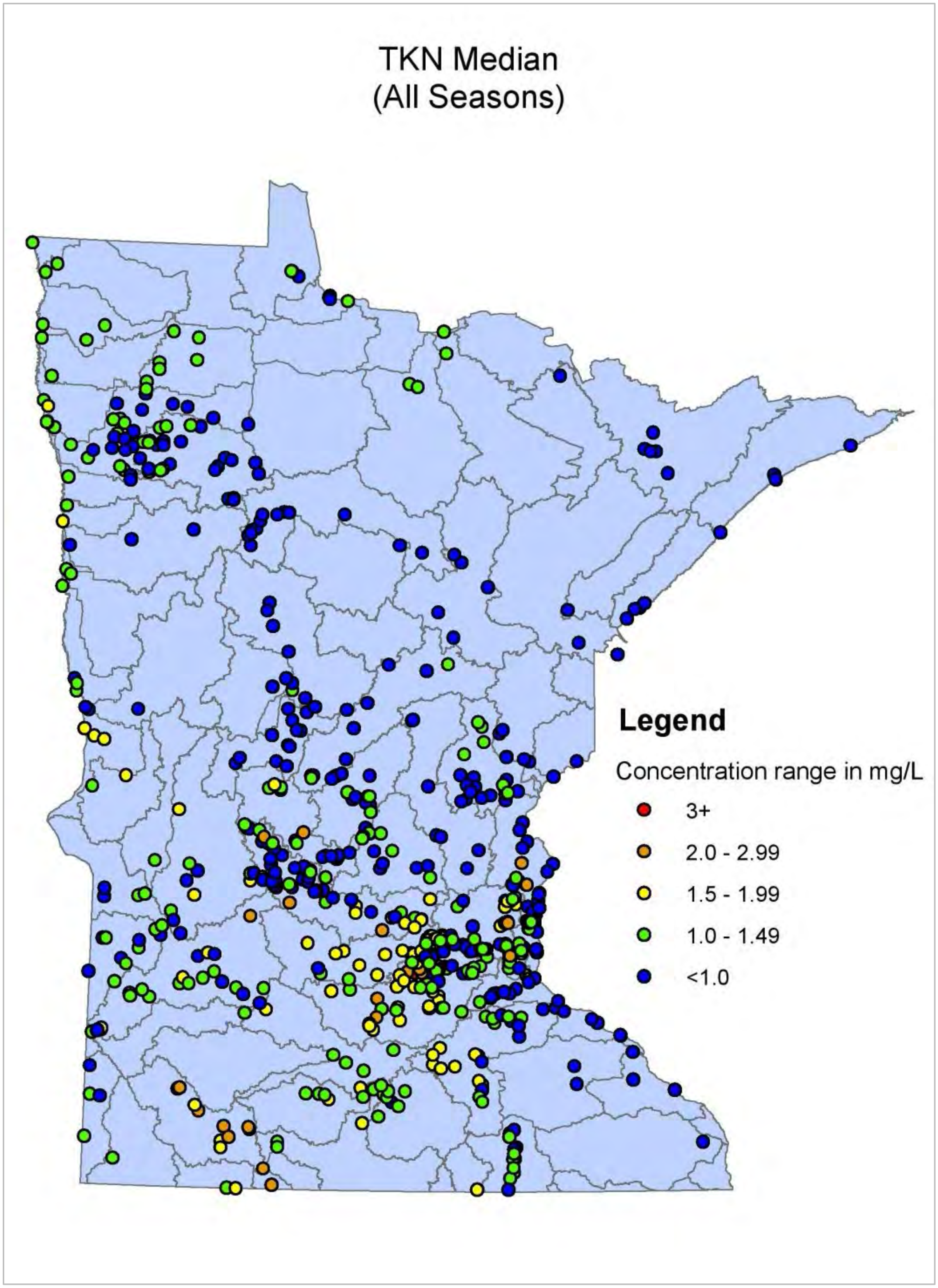

Figure 9. Median TKN concentrations for all samples taken at each site between 2000 and 2010.

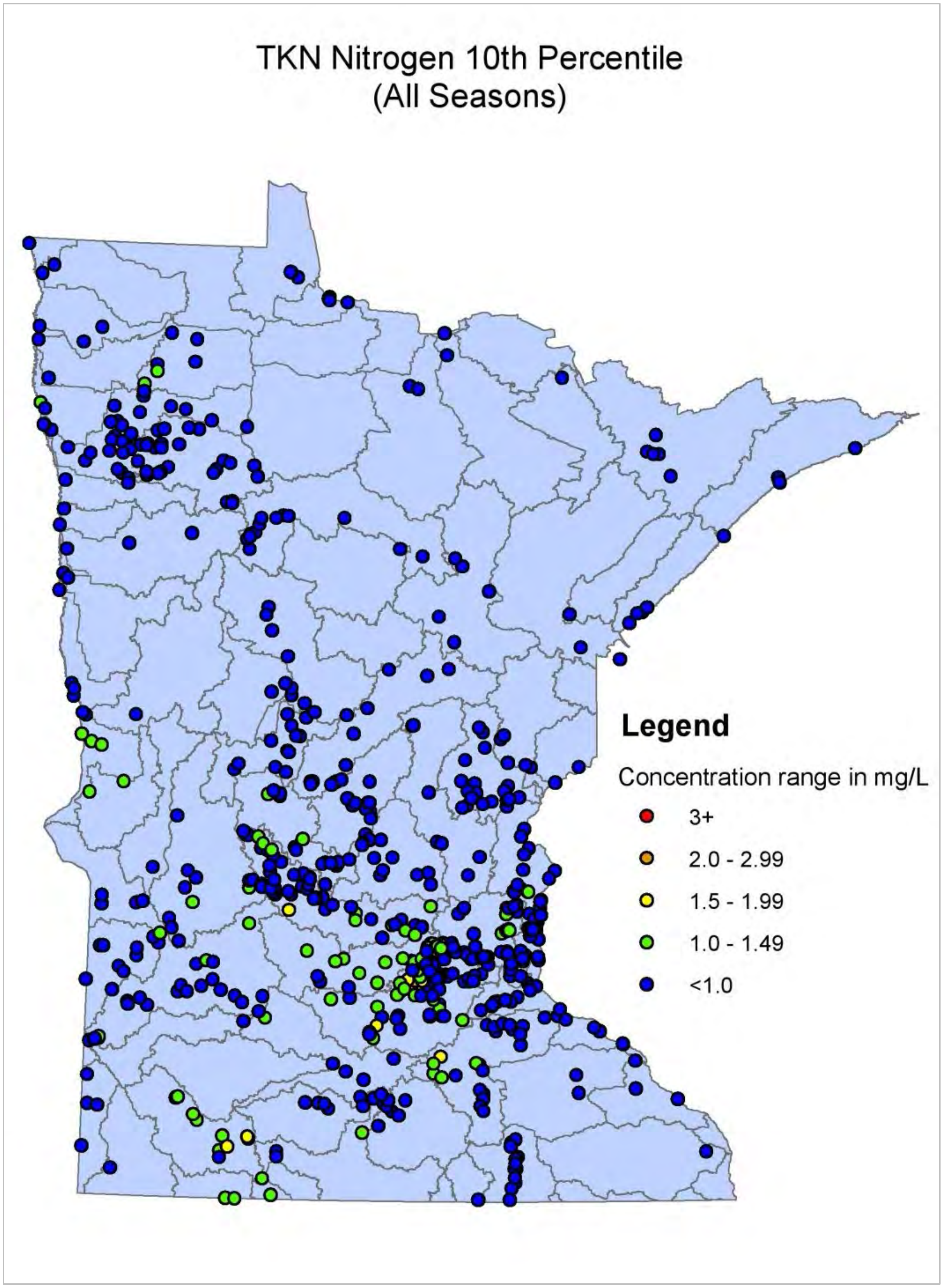

Figure 10. 10th percentile TKN concentrations for all samples taken at each site between 2000 and 2010.

Total nitrogen

Total nitrogen was calculated by summing the laboratory measurements of nitrite+nitrate-N and TKN. While the TN concentrations are slightly higher than nitrite+nitrate-N, the general patterns and concentrations are similar to the nitrite+nitrate-N concentration maps (Figures 11 to 13). The 90th percentile concentration map (Figure 10) shows concentrations mostly 1 to 3 mg/l in northern Minnesota and mostly over 5 mg/l in southern Minnesota. The 10th percentile map (Figure 13) shows substantially lower TN concentrations than the 90th percentile map, with mostly less than 1 mg/l in northern Minnesota and mostly 1-3 mg/l in southern Minnesota.

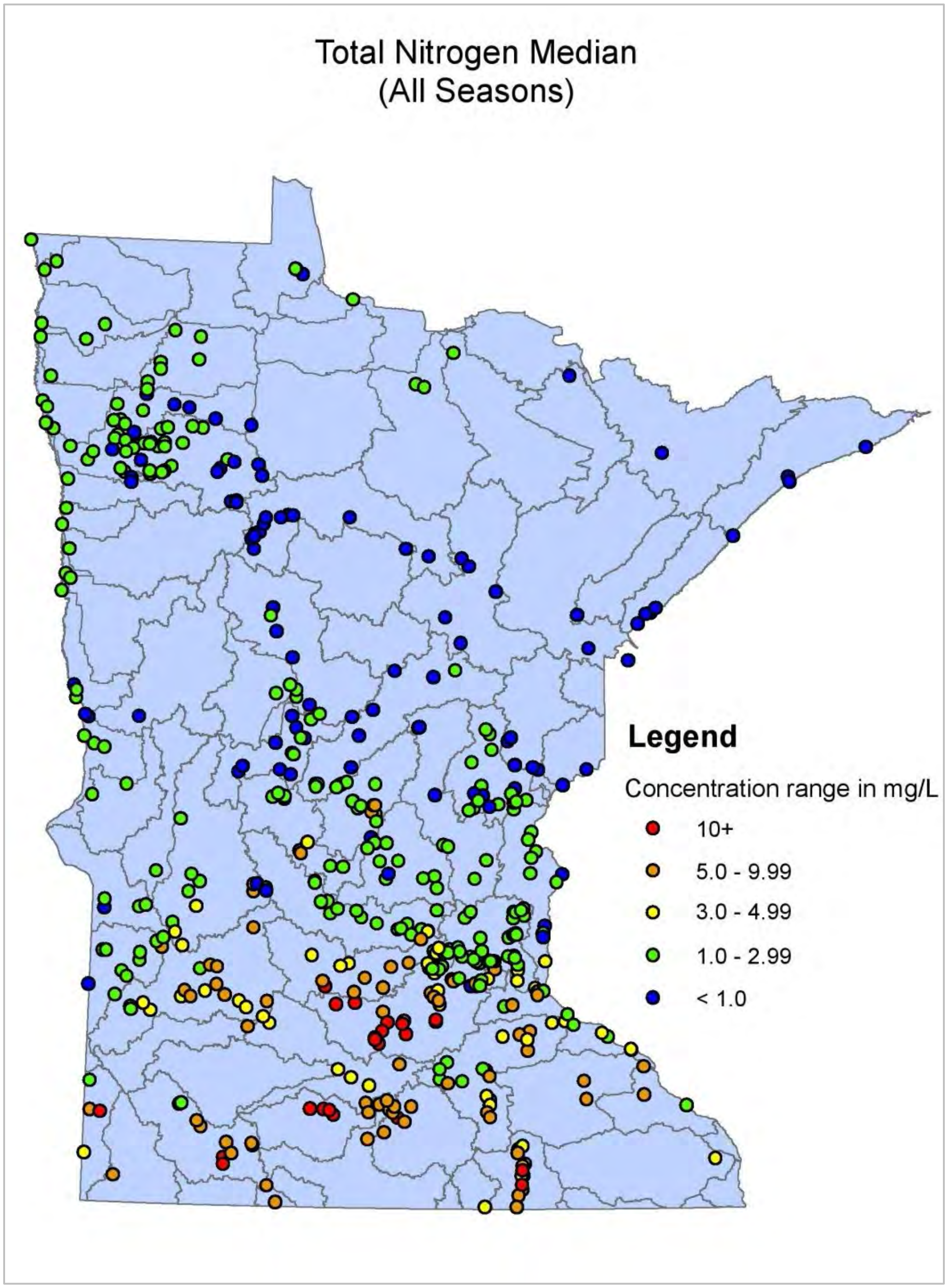

Figure 11. 90th percentile TN concentrations for all samples taken at each site between 2000 and 2010.

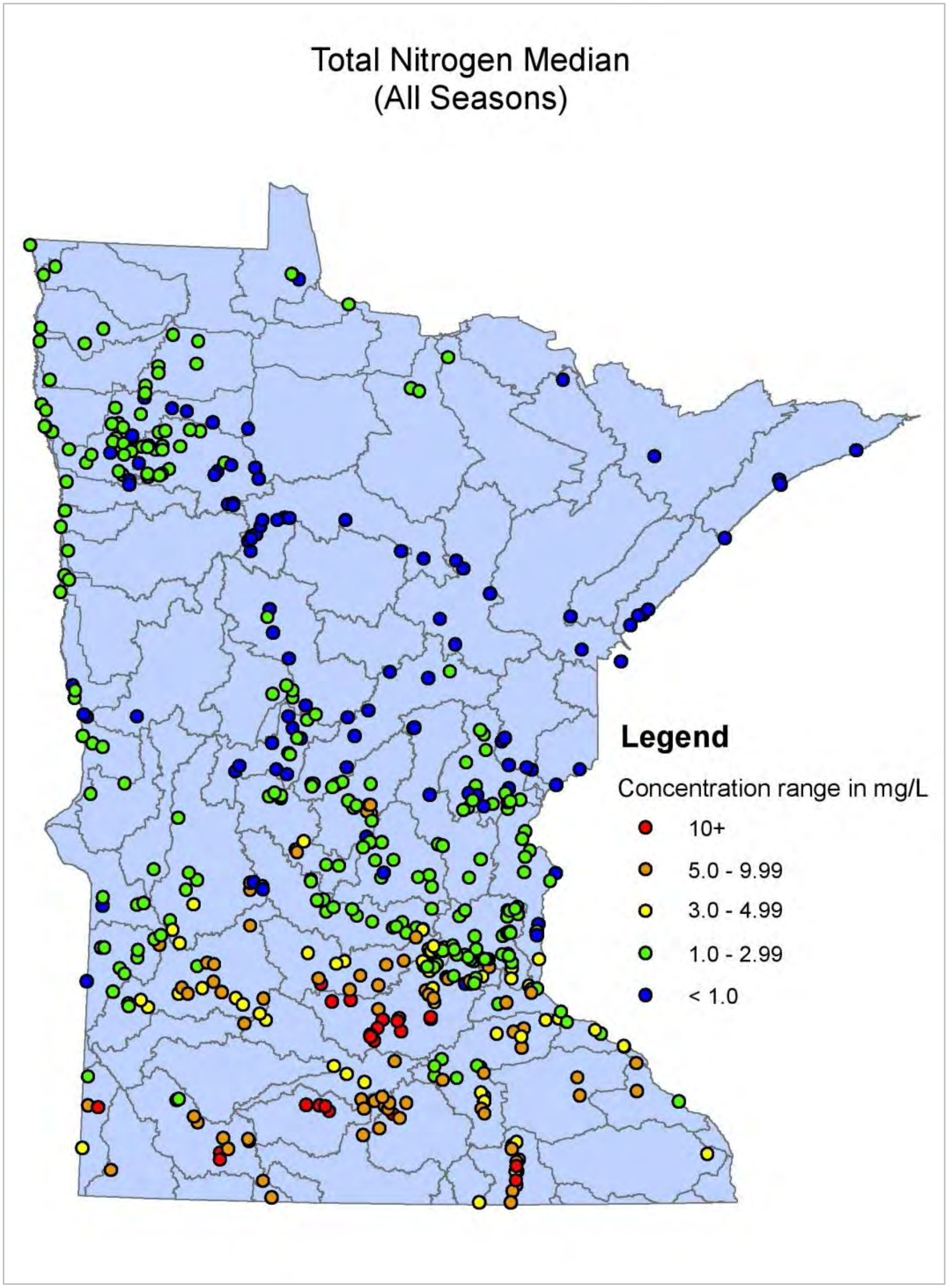

Figure 12. Median TN concentrations for all samples taken at each site between 2000 and 2010.

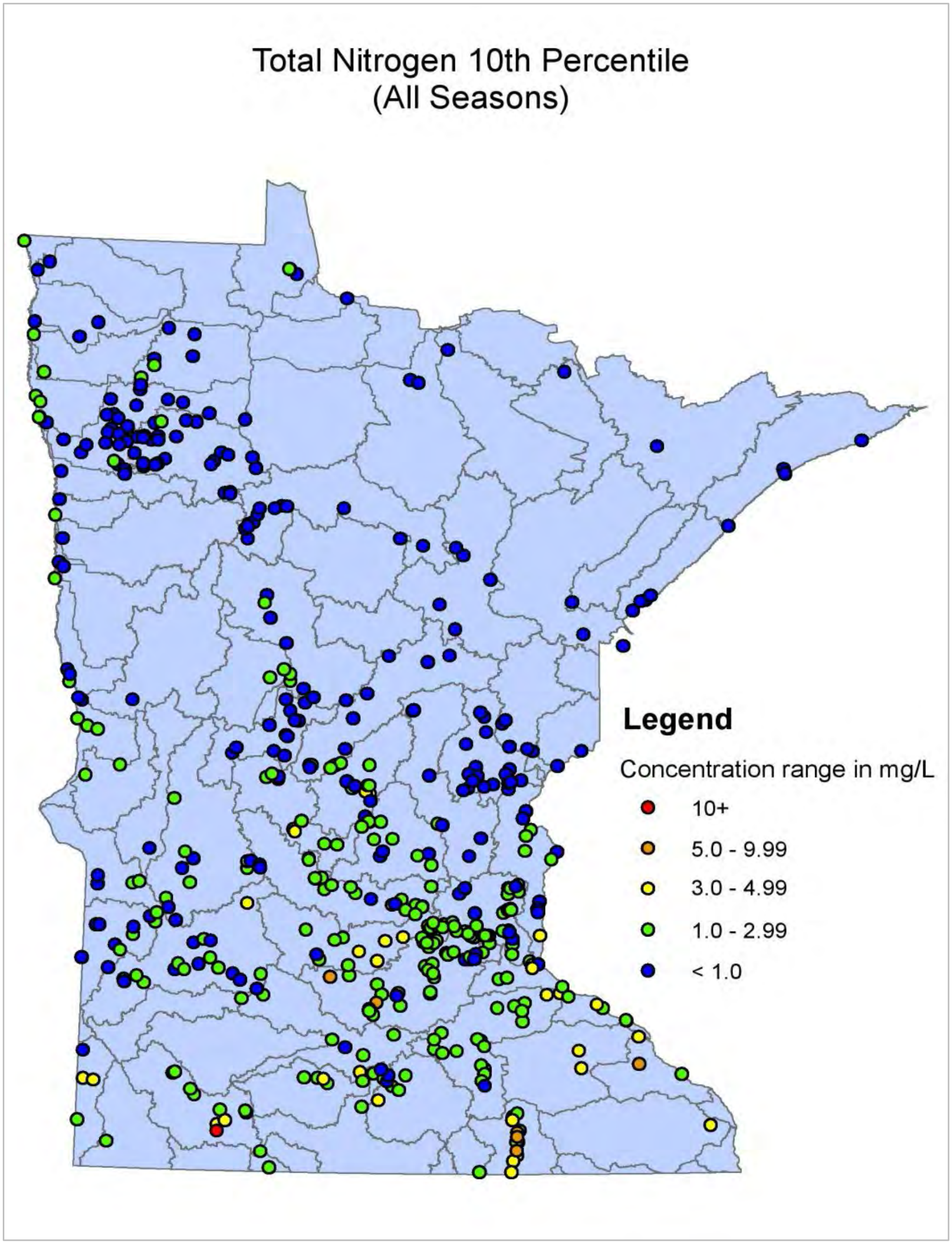

Figure 13. 10th percentile TN concentrations for all samples taken at each site between 2000 and 2010.

Seasonal nitrate concentrations

We analyzed seasonal differences in nitrite+nitrate-N medians at all sites which met a minimum criteria of 12 samples taken during that season. Seasons assessed included: spring (March-May), summer (June-August) and fall (September-November). Results were then separated by the major basin where the streams are located. The seasonal differences in the average of all stream site medians across the basins varied considerably from one basin to another (Figure 14). Streams in the Minnesota River Basin, show a strong seasonal trend of highest nitrite+nitrate-N levels in the spring and the lowest levels in the fall months. Whereas streams in the Lower Mississippi Basin, which are in an area where groundwater baseflow is highly influential, show little change from spring to fall seasons, on average.

Note that each basin has a different number of sampling sites/frequencies, and some basins are large and diverse and others are smaller with less diverse landscapes. Comparisons among basins are limited by these differences. Monthly variability in mainstem rivers are described in more detail in Chapter B3.

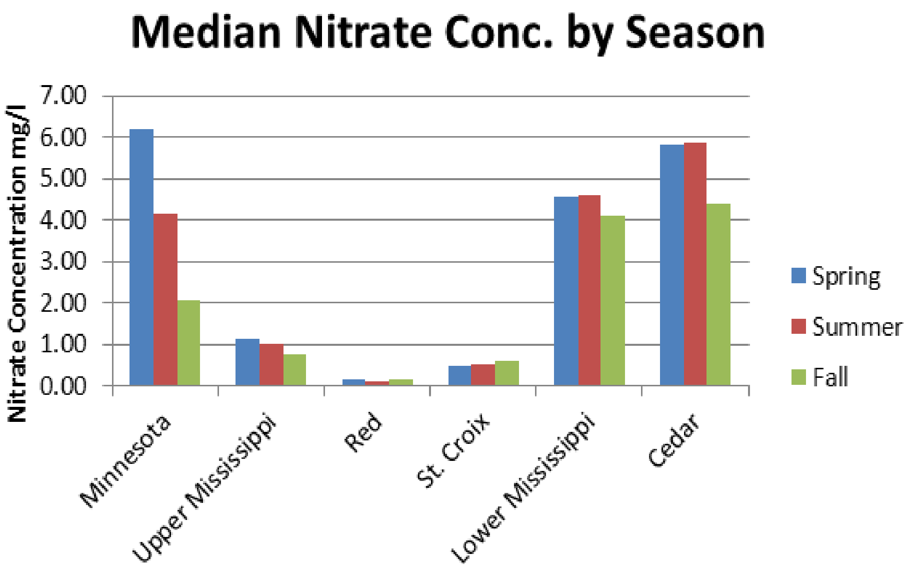

Figure 14. Seasonal nitrite+nitrate-N median concentrations averaged across major river basins in Minnesota. Spring months include March to May, summer months include June to August, and fall months include September to November.

Summary of findings

Number of monitoring sites meeting criteria

- In Minnesota, 728 river and stream sites have been frequently monitored for nitrite+nitrate-N during the period 2000 and 2010, with an average of 69 samples analyzed at each site. During this same period 637 and 597 sites were frequently sampled for TKN and ammonia+ammonium, respectively.

Nitrite+nitrate-N

- At times, nitrite+nitrate-N concentrations exceeded 5 mg/l throughout most of southern Minnesota, and 90th percentile nitrite+nitrate-N concentrations exceeded 5 mg/l at 31% of sites statewide. Nitrite+nitrate-N 90th percentile concentrations exceeded 10 mg/l throughout most of south-central Minnesota, and 17% of river and stream sites statewide had 90th percentiles exceeding 10 mg/l. Rivers and stream samples seldom had nitrite+nitrate-N exceeding 20 mg/l, and 90th percentile concentrations exceeded 20 mg/l at 15 sites (2%) statewide.

- Most northern Minnesota streams have nitrite+nitrate-N concentrations which are typically less than 1 mg/l. Yet several northern rivers and streams, particularly along the Red River, have nitrite+nitrate-N between 1 and 3 mg/l.
- The lower range nitrite+ nitrate-N concentrations (10th percentiles) are mostly less than 3 mg/l throughout the state. Exceptions to this include about 20 sites in southeastern Minnesota and scattered sites elsewhere with nitrite+nitrate-N which continued to be 3 to 10 mg/l.
- About 31% of stream sites had 90th percentile nitrite+nitrate-N exceeding 5 mg/l; whereas the maximums exceeded 5 mg/l at 41% of the sites. Maximum nitrite+nitrate-N concentrations exceeded 10 mg/l at 27% of sampled stream sites, compared to 17% of sites with 90th percentile concentrations above 10 mg/l.
- Nitrite+nitrate-N median concentrations vary by season, especially in the Minnesota River Basin, where concentrations are highest in the spring, followed by summer, and then fall.

Ammonia+ammonium-N

- The 90th percentile ammonia+ammonium-N concentrations exceeded 0.1 mg/l throughout much of the state, but only exceeded 1 mg/l at seven sites.
- Spatial patterns of ammonia+ammonium-N concentrations are less pronounced compared to nitrite+nitrate-N. Most of north-central and northeastern Minnesota have low ammonia+ammonium-N concentrations (<0.1 mg/l). With the exception of Duluth area streams and two other scattered streams, all northeastern Minnesota streams had 90th percentile ammonia+ammonium-N concentrations less than 0.1 mg/l.
- Median ammonia+ammonium-N concentrations are mostly less than 0.1 mg/l throughout the state. Exceptions to this include some sampling points in the Cedar River, the Twin Cities area, and a few other scattered locations.

TKN (mostly organic nitrogen)

- The 90th percentile TKN concentrations were between 1 and 3 mg/l throughout much of the state.
- Spatial patterns of TKN concentrations showed that during higher TKN periods, TKN remained less than 1.5 mg/l throughout most of northeastern Minnesota and was between 1.5 and over 3 mg/l throughout most of southern Minnesota and along the Red River. Five main pockets of elevated TKN (90th percentiles over >3 mg/l) are all located at various places in the southern half of the state.
- Median TKN levels are predominantly less than 1.5 mg/l throughout the state, and 10th percentile levels are predominantly less than 1 mg/l, with only about seven sites in the 1.5 to 2 mg/l range.

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B2. Monitoring Mainstem River Nitrogen Loads

Author: Dave Wall, MPCA

Load calculations:

Metropolitan Council: Joe Mulcahy, Emily Resseger, Karen Jensen, Ann Krogman
Minnesota Pollution Control Agency: Patrick Baskfield, Dennis Wasley, Andy Butzer, Jim MacArthur, Tony Dingman, Jerry Flom, Mike Walerak, Stacia Grayson, Stacia Schacht
***Manitoba Conservation and Water Stewardship and Environment Canada**:* Nicole Armstrong

Introduction

This chapter describes monitoring-based nitrogen results from many of the mainstem rivers in Minnesota, including basin and state outlets and upstream reaches of the Mississippi, Minnesota, St. Croix, and Red Rivers. The following chapter (B3) focuses on a smaller scale, examining monitoring-based results near the outlets of 8-digit Hydrologic Unit Code (HUC8) level watersheds.

Nitrogen (N) load, the amount of N passing a point on a river over a certain amount of time (i.e., pounds per year), can be estimated if river flow is monitored and water samples are collected and analyzed over a range of flow conditions and seasons. In Minnesota, we are fortunate to have numerous monitoring stations where total nitrogen (TN) and nitrite+nitrate (nitrate) loads have been calculated. The primary loads which will be described in this chapter are summarized in Table 1. In this chapter, we describe the results from these monitoring-based loads, yield, and flow-weighted mean concentrations (FWMC) for major rivers and basins.

Table 1. Monitoring programs which provided N load information for this report.

Monitoring program	Lead agency	Watershed/stream locations	Nitrogen parameter(s)	Years	Load estimation methods
Long Term Resource Monitoring Program	US Geological Survey	Mississippi River Upstream and downstream of Lake Pepin; Mississippi River near Iowa at Lock and Dam #7 and 8	Nitrite+Nitrate Total nitrogen	1991-2010	MPCA used multiple year regressions in FLUX32
Metropolitan Council Major Rivers Monitoring Program	Metropolitan Council Environmental Services	Mississippi River at Anoka and Prescott Minnesota River at Jordan St. Croix River at Stillwater	Nitrite+Nitrate TKN Total Nitrogen	1980-2010	Met Council used one-year concentration/flow data and a single year's flow to calculate loads in Flux 32.
Red River	Manitoba Conservation and Water Stewardship and Environment Canada	Emerson Manitoba	Nitrite+Nitrate TKN	1994-2007	Monthly water quality and flow data (average of daily) for full period to estimate monthly and then annual loads
Watershed Load Monitoring Program	MPCA (with support from other organizations)	Outlets of most HUC8 watersheds in Minnesota	Nitrite+Nitrate TKN Total Nitrogen	2007 - 2009	MPCA used single year regressions in FLUX32

Results overview

Three mainstem rivers (Minnesota River, Upper Mississippi River, and St. Croix River) converge in the Twin Cities Area, where their waters join and continue moving downstream in the Mississippi River along the Minnesota and Wisconsin border. Minnesota and Wisconsin tributaries from the Lower Mississippi Basin add additional N loads into the Mississippi, south of the Twin Cities. At the opposite corner of the state, the Red River flows north along the Minnesota and North Dakota state border into Manitoba.

Total nitrogen

Long term average TN loads were calculated for these mainstem rivers using monitoring results obtained reasonably close to the outlets of the basins and/or at the state borders (Table 2, Figures 1 and 2). Long-term average loads are mostly used in this chapter, since year-to-year variability can be large due to annual precipitation differences and challenges in perfectly capturing monitoring results during storm events. Averaging loads over a longer period of time reduces the effects of these single year climate influences and load calculation uncertainties.

Table 2. TN loads, yields and flow-weighted mean concentrations (FWMC) for certain major rivers in Minnesota.

	Load avg. million lbs/yr	Yield avg. lbs/acre/yr	FWMC avg. mg/l	Percent of TN in nitrite+nitrate-N form	Period which average is based on
St. Croix River, Stillwater	10	2.3	1.0	37%	1991-2010
Minnesota River, Jordan	116	11.3	8.2	84%	1991-2010
Mississippi River, Anoka (plus Rum R)*	42*	3.3*	2.2	56%	1991-2010
Mississippi River, Prescott	174	6.1	3.8	72%	1991-2010
Mississippi River, Lake Pepin Outlet	145	4.7	3.1	83%	1992-2009
Mississippi River at Minn. – Iowa border Lock and Dam #8	211	5.0	2.6	75%	1991-2010
Red River Basin at Emerson Manitoba	37	1.5	2.4	46%	1994-2008

*In this table and the rest of the chapter, loads and yields for the Mississippi River Anoka also include Rum River load averages from 2001 to 2010 calculated by Met Council, combined with the Met Council Mississippi River (Anoka) loads; so that the Mississippi River loads at Anoka include all of the Upper Mississippi River Basin N loads except for the Mississippi River Twin Cities watershed. The Rum River loads represent 6.2% of the total N average load of the Mississippi River at Anoka.

The highest loading tributary to the Mississippi River is the Minnesota River, which contributes an average of 116 million pounds of N per year (1991 to 2010). By comparison, the Upper Mississippi River and St. Croix River add lesser amounts of roughly 42 and 10 million pounds of TN per year, respectively (Figure 1). Moving downstream through the Twin Cities Metropolitan Area, TN increases by about

6 million pounds per year on average from point sources, stormwater and groundwater baseflow in the Twin Cities. Between the south part of the Twin Cities and the Iowa border, TN increases by about another 37 million pounds, with contributions from Lower Mississippi River Basin tributaries. In-stream N losses also occur in this lower stretch of the river, so that the actual additions from Lower Mississippi River Basin tributaries are more than the 37 million pound increase observed in the river loads.

The TN yields and FWMCs are substantially higher in the Minnesota River as compared to the other tributaries and sections of the Mississippi (Table 2). If 12% to 22% of N is lost in the major rivers, pools, and Lake Pepin south of the Twin Cities, then the 116 million pounds of TN measured in the Minnesota River at Jordan (upstream of the Twin Cities) will be reduced to 90 to 102 million pounds at the Iowa border, which represents 43% to 48% of the 211 million pounds of TN reaching the Minnesota/Iowa border in the Mississippi River.

The Red River TN loads at the Minnesota/Canada border are in the same general range as the Upper Mississippi Basin loads, transporting about 37 million pounds per year, on average.

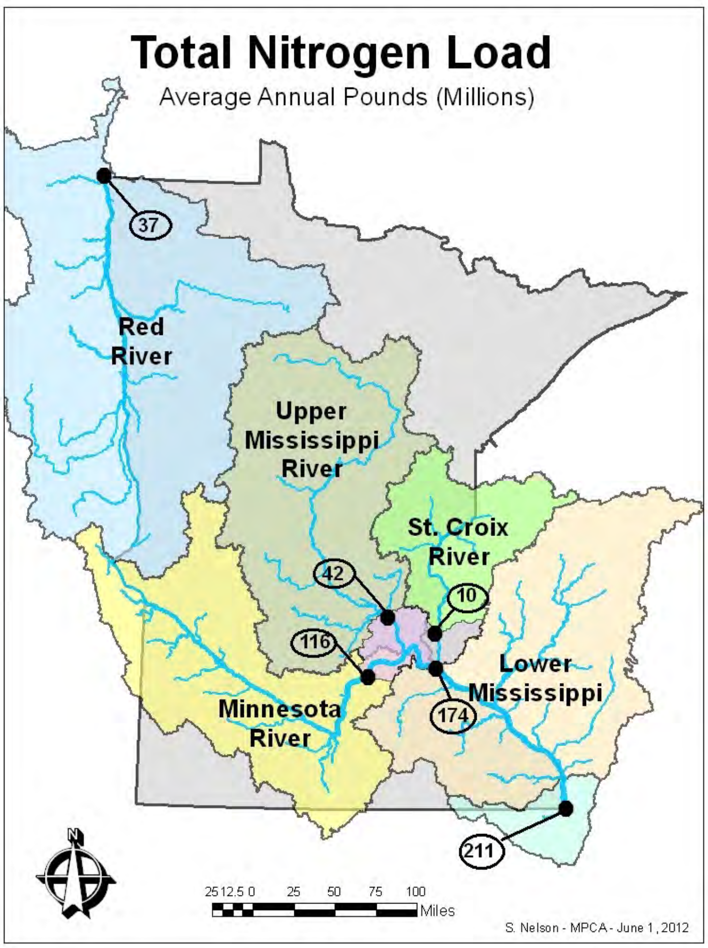

Figure 1. Long term average annual TN loads at key points along major rivers. Time period for long term averages: Red River (1994-2008); Minnesota, Upper Mississippi, and St. Croix Rivers (1991-2010); Lower Mississippi (1992-2009).

Nitrate-N

Nitrite+Nitrate-N loads are also dominated by the Minnesota River, which contributes an average 97 million pounds per year. The Upper Mississippi River, St. Croix River, Twin Cities Metropolitan Area streams, and the Lower Mississippi River Basin all add lesser amounts of 23, 4, <1 and 34 million pounds of nitrite+nitrate-N, respectively (Figure 2). The Red River nitrate loads are also low compared to the Minnesota River, transporting about 16 million pounds per year, on average.

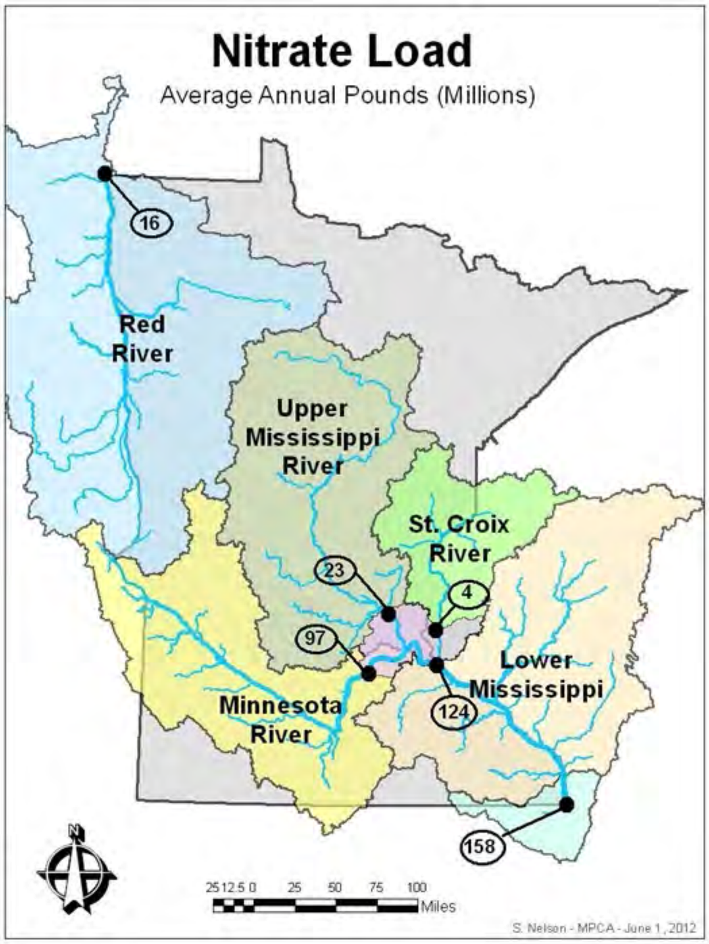

Figure 2. Long term average annual nitrite+nitrate-N loads at key points along major rivers. Time period for long term averages: Red River (1994-2008); Minnesota, Upper Mississippi, and St. Croix Rivers (1991-2010); Lower Mississippi (1992-2009).

For the remainder of this chapter, more specific results are provided for the following rivers:

- the Lower Mississippi River – Lake Pepin to Iowa
- the three mainstem rivers converging in the Twin Cities - Minnesota River, St. Croix River, Upper Mississippi River
- the Red River

Lower Mississippi River – Lake Pepin to Iowa

Mississippi River at Minnesota/Iowa border

The U.S. Geological Survey (USGS) has been taking water quality samples (every other week) since 1991 on the Mississippi River near the Minnesota and Iowa border. The U.S. Army Corps of Engineers has been measuring flow at both Lock and Dam #7 and 8 during the same time period. Two of the monitoring locations for the USGS Long Term Resource Monitoring Program (LTRMP) are located at Lock and Dam #7 and 8, near LaCrescent, Minnesota and Genoa, Wisconsin, respectively. Using USGS collected data, the Minnesota Pollution Control Agency (MPCA) calculated annual loads at Lock and Dam #7 and 8 using the FLUX32 model. The load calculations show annual mean total N loads between 1991 and 2010 of 209 and 211 million pounds at Lock and Dam #7 and 8, respectively. Because the average loads are nearly identical at these two monitoring sites, and they are located close to each other, the results and graphs below include only Lock and Dam #8, the more downstream location.

Most of the watersheds contributing water to the Mississippi River at the Minnesota/Iowa border are located in Minnesota. Overall, based on SPARROW model results, we estimate that about 77% of the TN in the Mississippi River at the Iowa border comes from loading in Minnesota catchment areas and the other 23% comes largely from Wisconsin, but also Iowa and the Dakotas. According to SPARROW model estimates, about 48% and 61% of the St. Croix and Lower Mississippi Basin TN loads are from Wisconsin, respectively. And about 4% of the Minnesota River Basin TN load is from the Dakotas and Iowa.

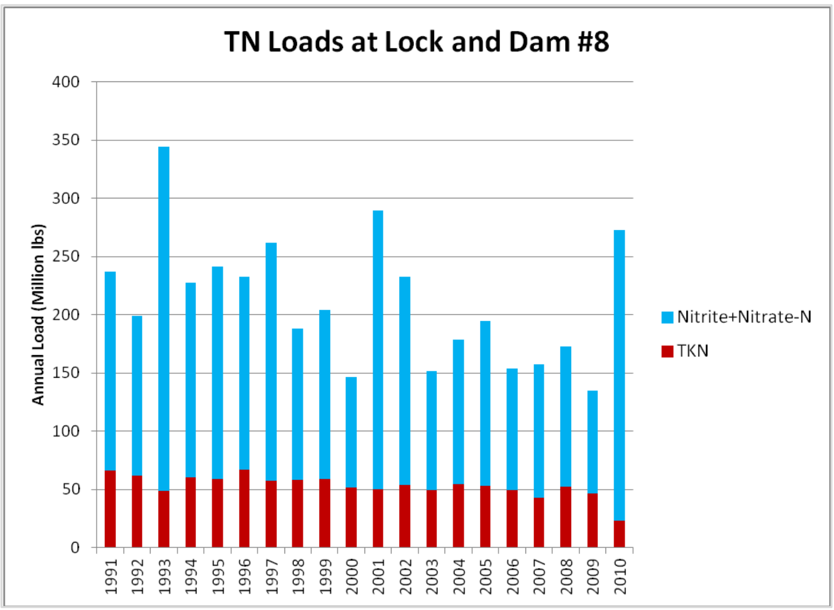

Figure 3. Annual TN loads in the Mississippi river at Lock and Dam #8 (near Iowa border), showing a) year to year variability between 1991 and 2010 and b) the proportion of TN which is in the nitrite plus nitrate and TKN (ammonium plus organic-N) form.

The annual flow-weighted mean TN concentration calculated for Lock and Dam #8 ranged from 2.4 to 3.0 mg/l between 1991 and 2010, averaging 2.6 mg/l. The annual TN loads varied more during this time period (Figure 3), due largely to year-to-year variability in precipitation and river flow. The lowest annual load occurred in 2009 (135 million pounds) and the highest load occurred in 1993 (344 million pounds). Nitrite+nitrate-N represents approximately 75% of the TN load, with Total Kjeldahl Nitrogen (organic-N + ammonium-N, abbreviated as TKN) making up the other 25% of the TN load (Figure 3).

The average TN and nitrite+nitrate loads peak in April, followed by May and then June (Figure 4). About two-thirds of the annual TN load occurs in the five months between March and July, during periods of spring runoff and early summer storms. Evapotranspiration is high in July through September when the crops are well established, and correspondingly river flow and nitrate loading decreases.

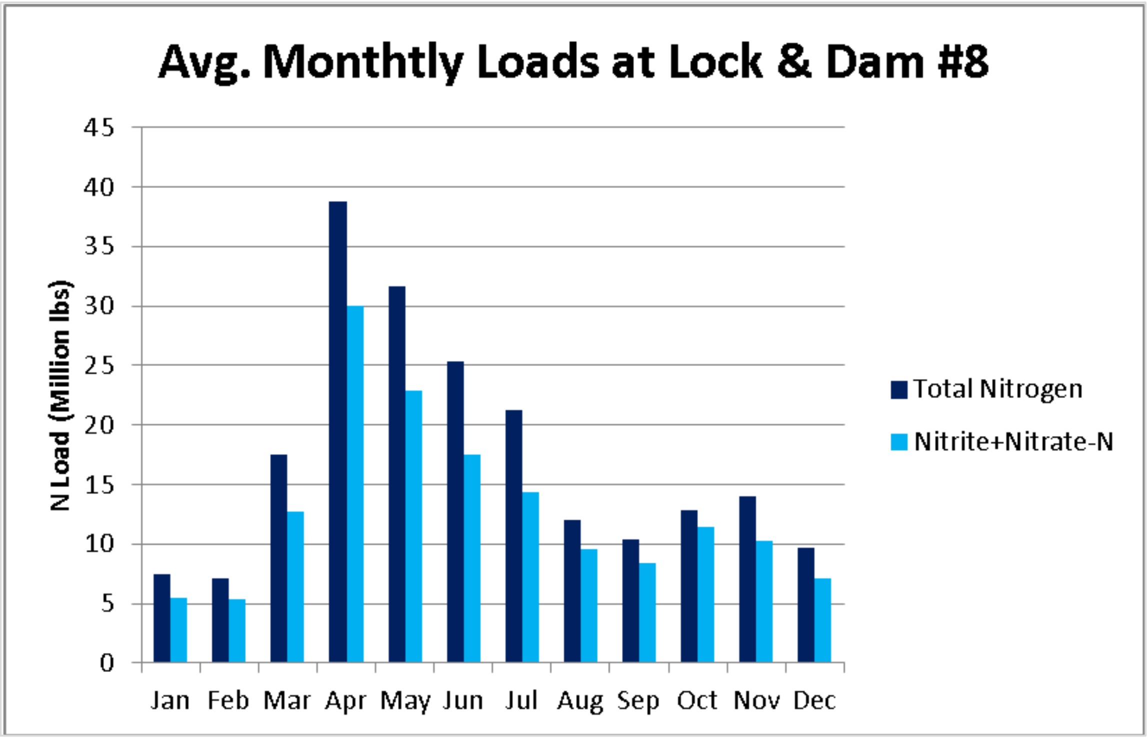

Figure 4. Monthly average (1991-2010) TN and nitrite+nitrate-N loads in the Mississippi river at Lock and Dam #8 (near Iowa border).

Mississippi River at Lake Pepin

Moving upstream on the Mississippi River to another LTRMP site at the outlet of Lake Pepin, the average TN load is 145 million pounds/year (1992-2009), which is about 66 million pounds/year lower than at Lock and Dam #8 for that same time period. During this same stretch of river, TN concentrations (flow-weighted means) drop from an average of 3.1 mg/l at the Lake Pepin outlet to 2.6 mg/l at Lock and Dam #8.

Several rivers from both Minnesota and Wisconsin enter into the Mississippi between Lake Pepin and Lock and Dam #8, including the Cannon, Zumbro, Root, Chippewa, Trempeleau, and Black River, as well as other smaller streams. The SPARROW model results indicate that 76% of the increased N load in the Mississippi River between Lake Pepin and the Iowa border is from Wisconsin tributaries and 24% is from Minnesota tributaries (see Chapter B-4). Estimates further upstream in Red Wing indicate that between Red Wing and the Iowa border in the Lower Mississippi Basin, Wisconsin tributaries contribute 61% of the TN loads and Minnesota 39%.

The average load at the Lake Pepin inlet (1992-2009) is 160 million pounds. Calculated TN loads at the inlet and outlet of Lake Pepin show that the inlet has consistently higher loads than the outlet (Figure 5). Annual N losses within the Lake Pepin section of the river averaged 8.9% per year between 1992 and 2009. The nitrite+nitrate-N fraction of TN is similar at the inlet and outlet, averaging 81.1% at the inlet and 83.4% at the outlet. The N losses within Lake Pepin and on other stretches of the Mississippi are further discussed in Chapter B5 and Appendix B5-2. Total losses in the Mississippi River dam pools and reservoirs are estimated to be between 12 and 22%.

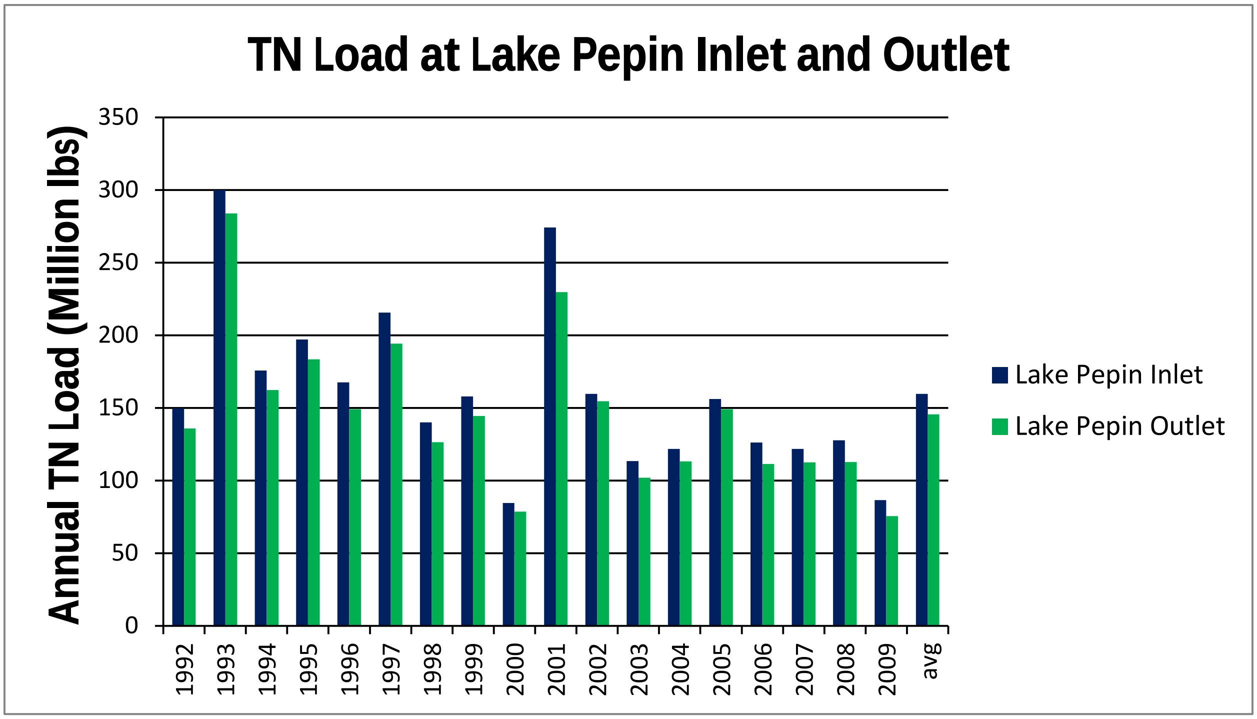

Figure 5. Average TN Loads at the inlet and outlet of Lake Pepin (1992-2009)

Mainstem rivers entering and leaving the Twin Cities

For several decades the Metropolitan Council Environmental Services (MCES) has maintained monitoring programs that routinely check water quality of the Metropolitan Area rivers, streams, and lakes. At four major river stations, samples have been taken two times per month since 1976, providing one of the best long term nutrient monitoring data sets available in Minnesota. The four monitoring station locations are shown in Figure 6, and include:

1. Minnesota River at Jordan – with a contributing watershed of 16,023 square miles from southern and southwestern Minnesota, and small portions of Iowa and South Dakota.
2. Mississippi River at Anoka – with a contributing watershed area of about 17,927 square miles of land in central and north-central Minnesota.
3. St. Croix River at Stillwater – with a contributing watershed area of about 7,069 square miles along eastern Minnesota and western Wisconsin.
4. Mississippi River at Prescott, Wisconsin Lock and Dam #3 – reflecting the combination of the above three watersheds along with contributions throughout the Twin Cities Metropolitan Area. The contributing watershed area is about 44,800 square miles.

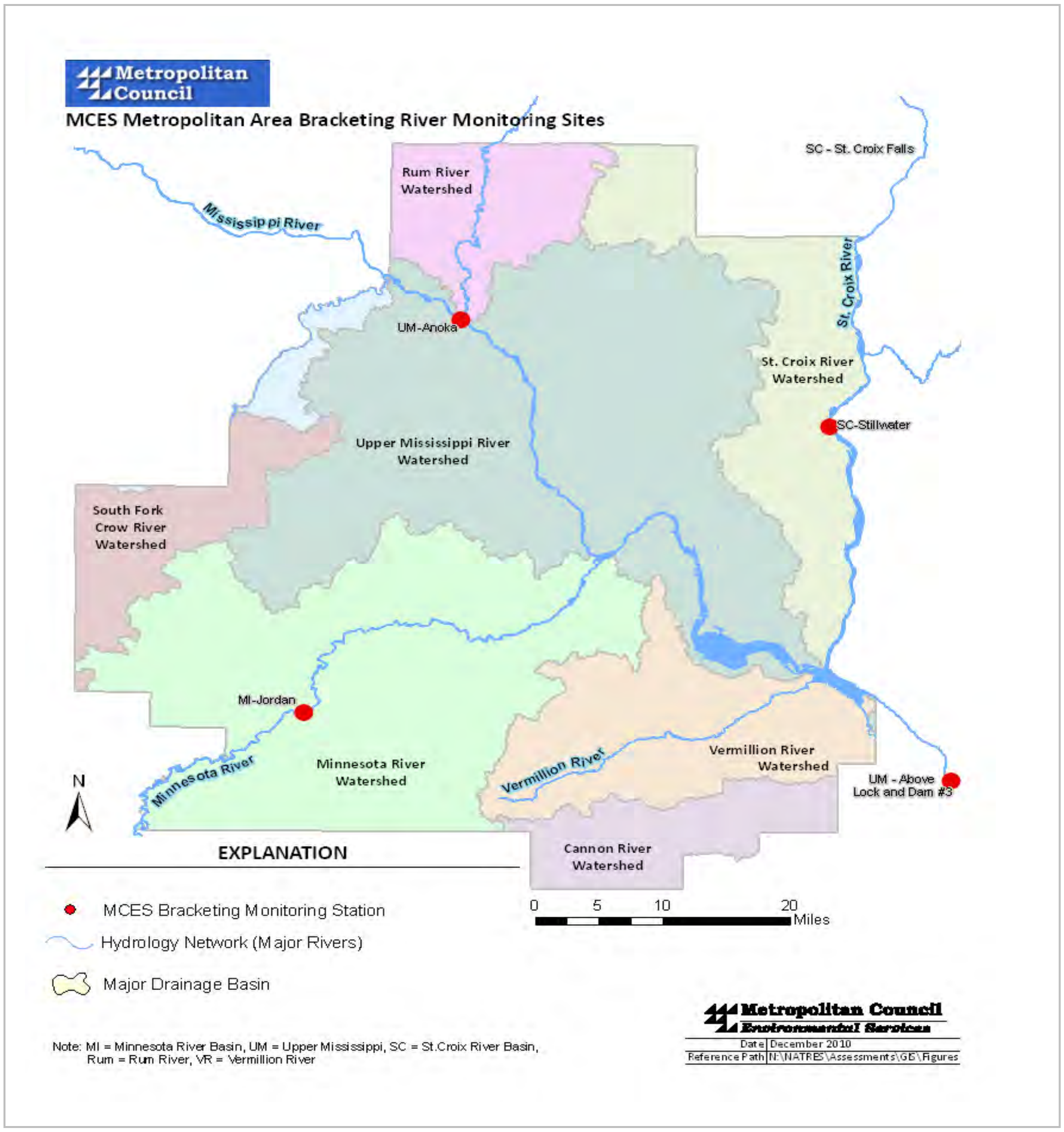

Figure 6. Locations of four major river monitoring site locations monitored by Metropolitan Council. Map developed by Met Council.

The loads at these four mainstem river monitoring stations were calculated by MCES and provided to the MPCA. The loads were calculated using the U.S. Army Corps of Engineers' software Flux32, from monitored daily average flow and grab sample chemistries taken every other week. Since flow in the four mainstem rivers responds relatively slowly to precipitation events, MCES and MPCA staff had determined, based on the MCES sampling frequency, that using a one-year record of average daily flow and grab sample water chemistry data was adequate to estimate annual loads for the mainstem rivers with acceptable uncertainty. The application of a one-year data set to define an annual river load, rather than multiple years, was viewed as acceptable since river events are typically defined as a multi-day record (three days or greater). The subtle nature of the river system hydrograph, along with consistent frequency of monitoring, allows for a strong statistical relationship when using regressions within Flux.

Loading calculations are an estimate based on monitoring results, and as such are subject to a range of variability. This variability depends on the water quality sampling frequency and regiment, as well as complexities in the watershed hydrologic responses to different runoff events. MCES calculated 95% confidence intervals around each estimated annual load. In a high-confidence year such as 2008 the 95% confidence interval ranged from 11% higher than the estimated load to 11% lower than the estimated load. Yet for certain other years the 95% confidence interval exceeded 50%. While the loads were calculated using single year analyses, in this report we use multiple year averages of those single year load estimates to represent typical loads, reducing the variability associated with single year estimates. The averages and medians were very similar in the Metropolitan Council data sets, typically differing by only 1% to 6% when looking at 20 to 30 year periods. Therefore, the results presented in this chapter would be similar whether using long-term means or medians.

Because the early and late 1980's were relatively dry, the average combined N load during the period 1980-2010 (150,731,000 pounds) is 8.6% lower compared to the 1991-2010 average (164,993,000 pounds). Except where noted, average statistics in this section use the 1991 to 2010 period instead of the complete 30-35 year record, since the 1991-2010 period: a) is more recent and will better represent current loads from more recent land uses, land management and climate, and b) the time period better matches available USGS monitoring data in the Lower Mississippi Basin.

Year to year load variability

The combined N loads from the Mississippi River (at Anoka), the Minnesota River (at Jordan), and the St. Croix River (at Stillwater) between 1980 and 2010, are represented in Figure 7. The drought years in the late 1980s had low N loads; whereas the wet period between 1991 and 1993 had high loads. The river flows show a somewhat similar, but less pronounced, year to year variability (Figure 8).

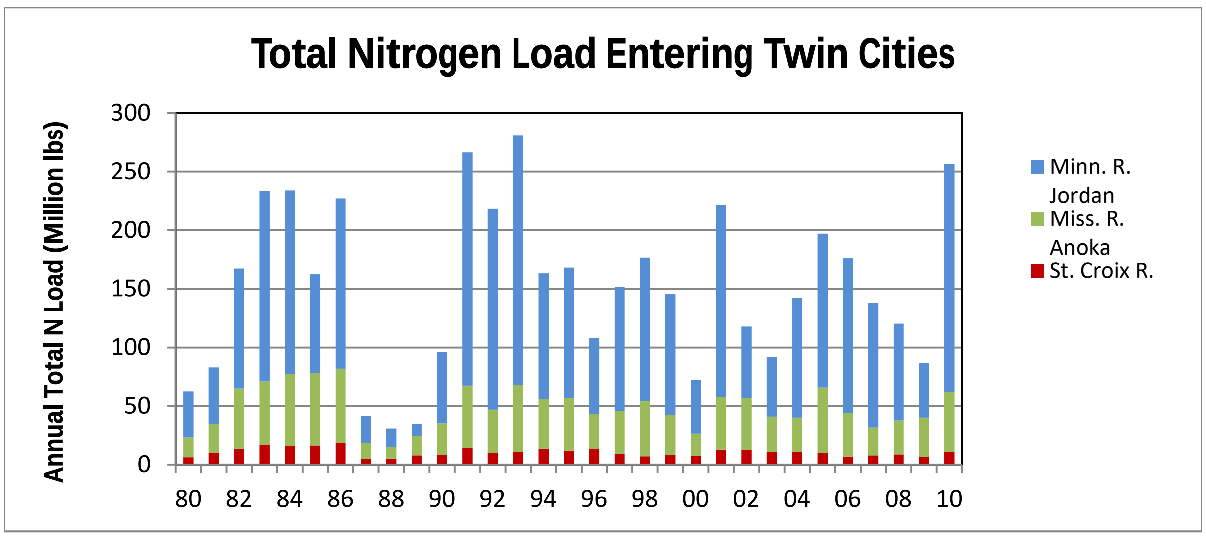

Figure 7. Annual combined total N loads from the three mainstem rivers entering the Twin Cities Area: the Mississippi River in Anoka, the St. Croix River in Stillwater, and the Minnesota River in Jordan. Time period 1980 to 2010.

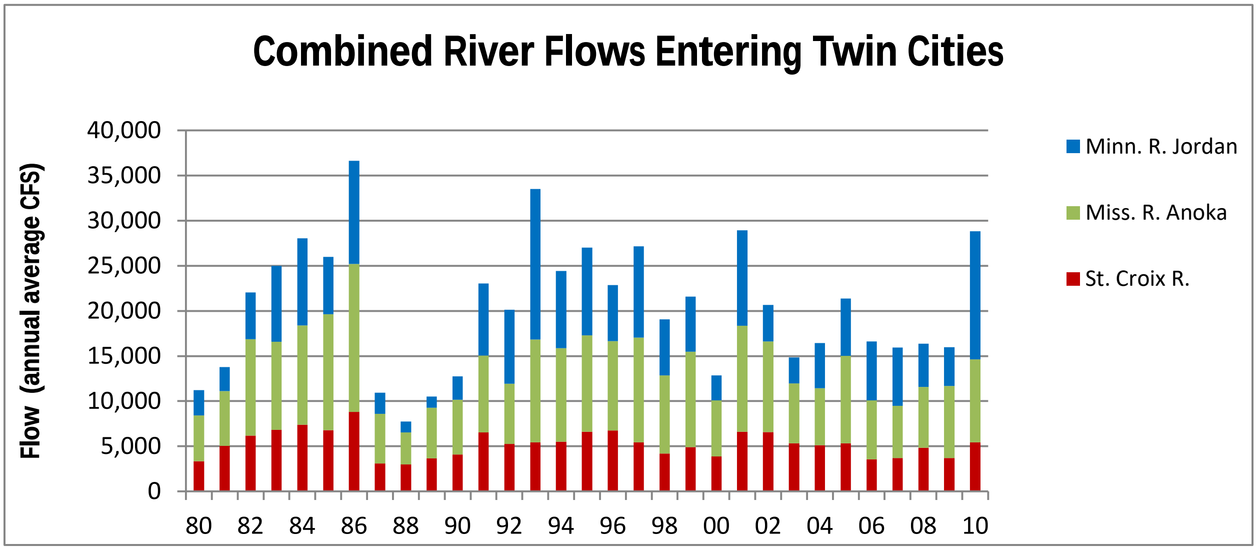

Figure 8. Annual combined TN river flow from the three major rivers entering the Twin Cities: the Mississippi River in Anoka, the St. Croix River in Stillwater, and the Minnesota River in Jordan.

The Minnesota River N loads have been much higher than the loads from the St. Croix at Stillwater and Mississippi at Anoka. The Minnesota River Basin contributes 69% of the total N loads and 78% of the nitrate loads which arrive at the Twin Cities Metropolitan Area in the three mainstem rivers, on average (Figure 9); yet represents only 38% of the total combined land area of the Minnesota, Upper Mississippi, and St. Croix River Basins.

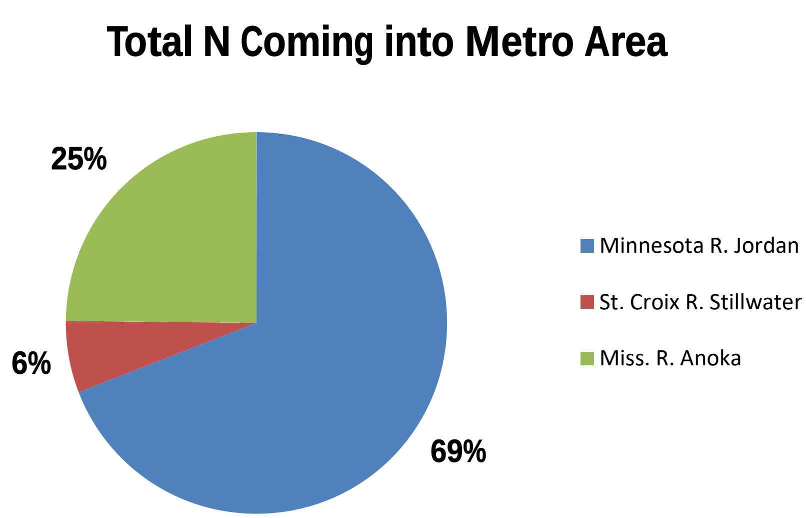

Figure 9. Proportions of TN load flowing into the Twin Cities from the three mainstem rivers, the Minnesota, St. Croix, and Mississippi (average of years 1991-2010).

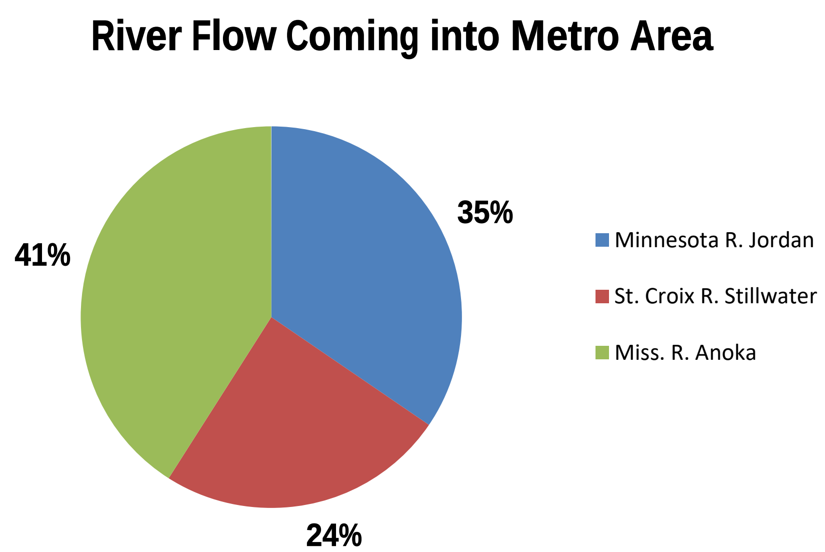

Figure 10. Average annual river flow volumes into the Twin Cities from the three major rivers, the Minnesota, St. Croix, and Mississippi (average of years 1991-2010).

The differences between the Minnesota and Upper Mississippi River N loads cannot be explained by differences in watershed areas or river flow. The catchment area for the Mississippi River at Anoka is 11.5 million acres, compared to a 10.3 million acre catchment area for the Minnesota River at Jordan. And the average flow (1991-2010) in the Mississippi (Anoka) and Minnesota (Jordan) Rivers are similar – 8,762 cubic feet per second (cfs) in the Mississippi and 7389 cfs in the Minnesota. While the flow is 16% higher in the Mississippi River (Anoka), the TN and nitrate loads are both much lower in the Mississippi (Anoka) compared to the Minnesota River (Figure 10).

Nitrogen forms in the rivers

Most of the N is in the nitrate and organic forms, together representing between 95% and 99% of the TN (Table 3). Ammonia+ammonia-N and nitrite-N tend to convert to nitrate in the presence of oxygenated waters, and concentrations are much smaller than nitrate, together constituting between 1 and 5% of the TN. Therefore, while N parameter results are often reported as nitrite+nitrate-N and TKN (ammonium+organic-N), the nitrate and organic-N forms typically represent most of the N.

The mean organic-N concentrations range from 0.57 mg/l in the St. Croix River to 1.27 mg/l in the Minnesota River. Long term average FWMC of nitrate-N varies more greatly than organic N in the three rivers, ranging from 0.35 mg/l in the St. Croix River to 6.74 mg/l in the Minnesota River (Figure 11 and Table 3).

Table 3. Annual FWMC for different forms of N averaged for years 1991-2010. Calculated from data provided by MCES. Nitrite was calculated by subtracting nitrate from the laboratory results presented as nitrite+nitrate. Organic-N was determined by subtracting NH3+NH4 from TKN.

	Nitrate-N FWMC (mg/l)	**Organic-N** FWMC (mg/l)	**Ammonia + Ammonium-N** FWMC (mg/l)	**Nitrite-N** FWMC (mg/l)	**Total N** FWMC (mg/l)
Minnesota River Jordan	6.74	1.27	0.09	0.13	8.23
St. Croix River Stillwater	0.35	0.57	0.05	0.01	0.98
Mississippi River Anoka	1.32	0.89	0.07	0.01	2.29
Mississippi River Prescott L&D #3	2.63	0.99	0.09	0.09	3.80

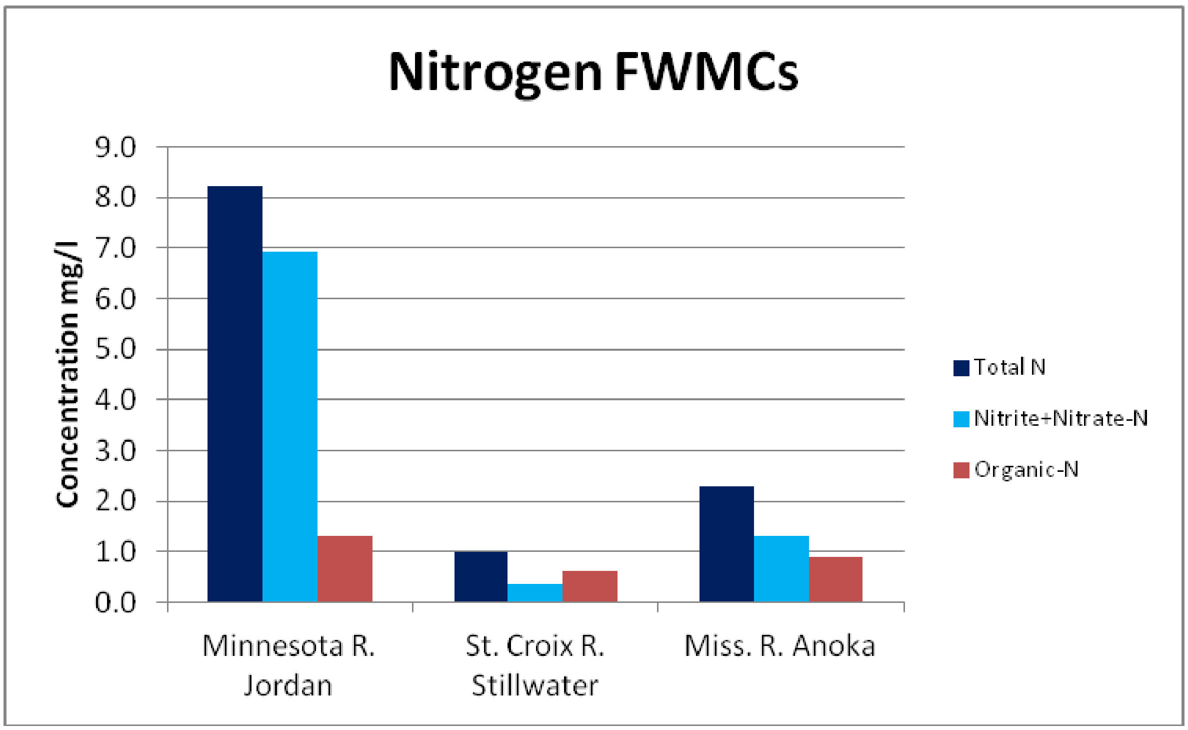

Figure 11. Flow weighted mean concentrations of total N, nitrite+nitrate-N and organic-N in the three mainstem rivers entering the Twin Cities region (average of 1991-2010).

In the Minnesota River at Jordan, nitrite+nitrate-N dominates the load, representing 84% of the TN load (Figure 12). In the lower N loading rivers of the St. Croix and Mississippi at Anoka, the nitrite+nitrate-N fraction is only 37% and 56% of the TN load, respectively.

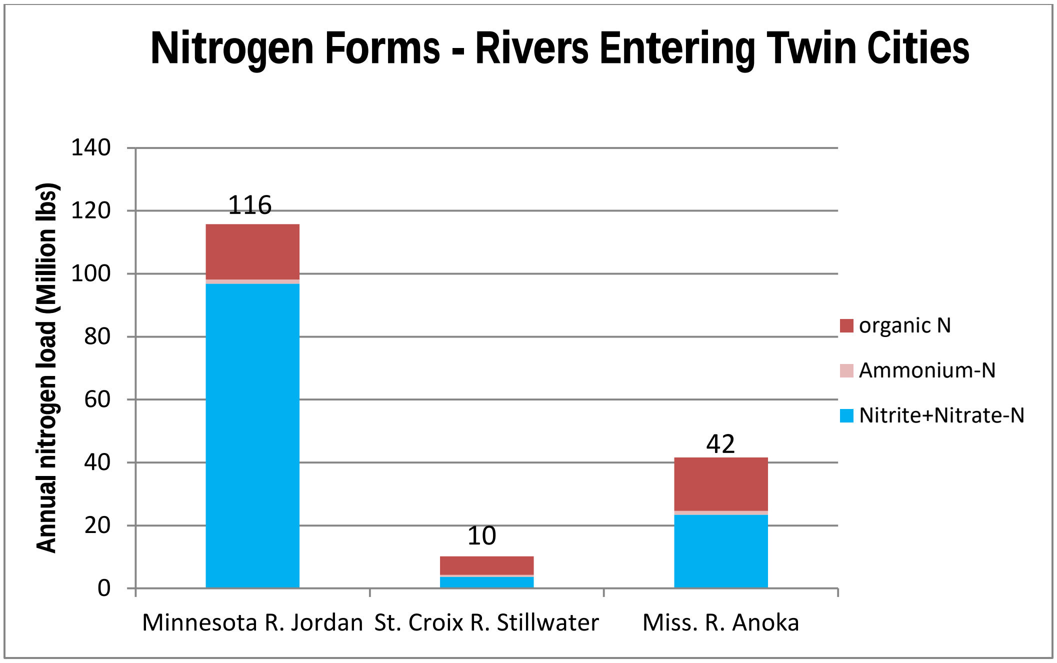

Figure 12. Average annual loads of various N forms in the Minnesota, St. Croix, and Mississippi Rivers entering the Twin Cities Area (1991-2010).

The organic N concentration is similar, but higher, in the Minnesota River as compared to the Upper Mississippi. One reason for this could be a higher amount of algae growth in the Minnesota River. A negative correlation between TKN concentration and flow in the Minnesota River (Figure 13) suggests that it is unlikely that the elevated TKN is due to the sediment in the river. During the high flow years, TKN concentrations were nearly half of the concentration during very low flow years.

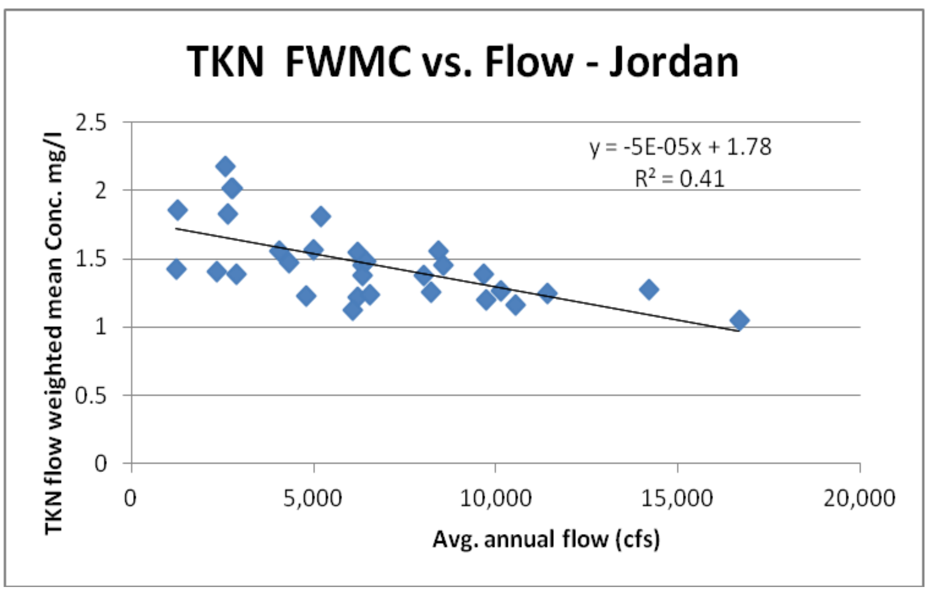

Figure 13. Relationship between long term (1991-2010) annual TKN flow-weighted mean concentrations and annual flow in the Minnesota River at Jordan.

Month to month variability

Average monthly TN and nitrite+nitrate-N loads were determined for the 20-year period 1991 to 2010. Total nitrogen and nitrate loads are highest in the spring months of April to June in the Minnesota, Mississippi, and St. Croix Rivers (Figures 14-16). The peak N loading month is April at all three rivers. Loads are relatively low from August through February.

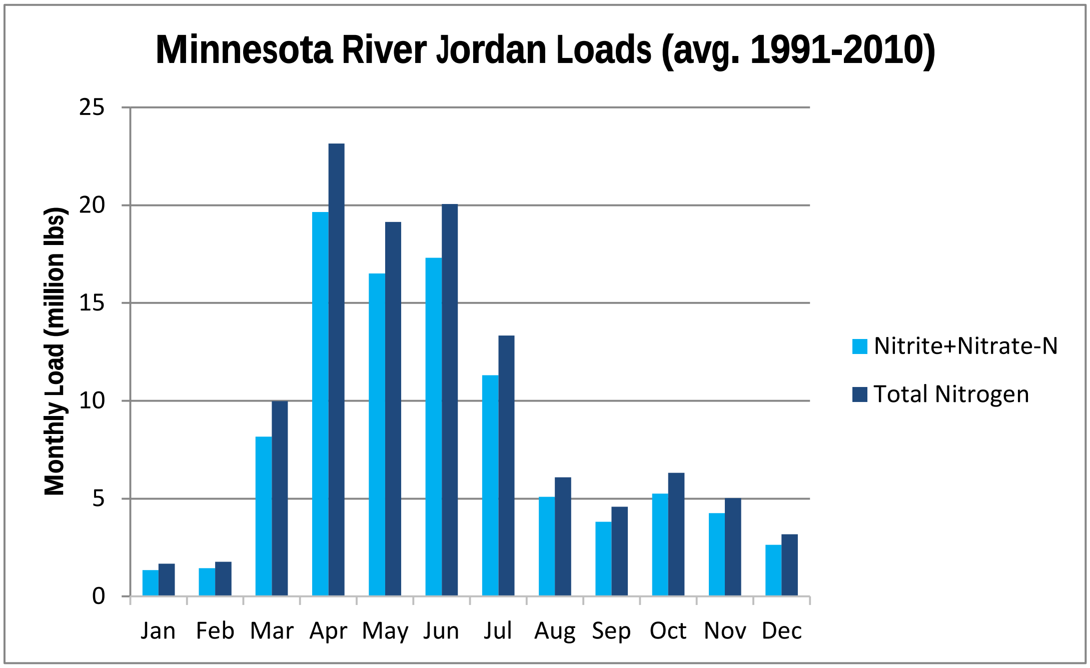

Figure 14. Long term average monthly TN and nitrite+nitrate-N loads in the Minnesota River at Jordan.

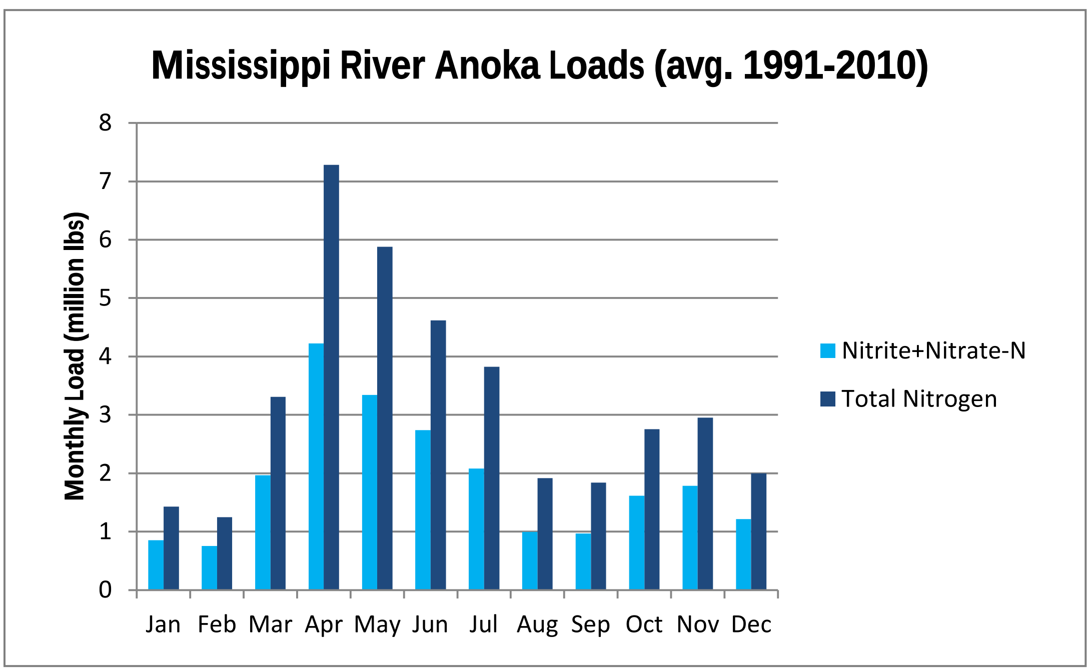

Figure 15. Long term average monthly TN and nitrite+nitrate-N loads in the Misissippi River at Anoka.

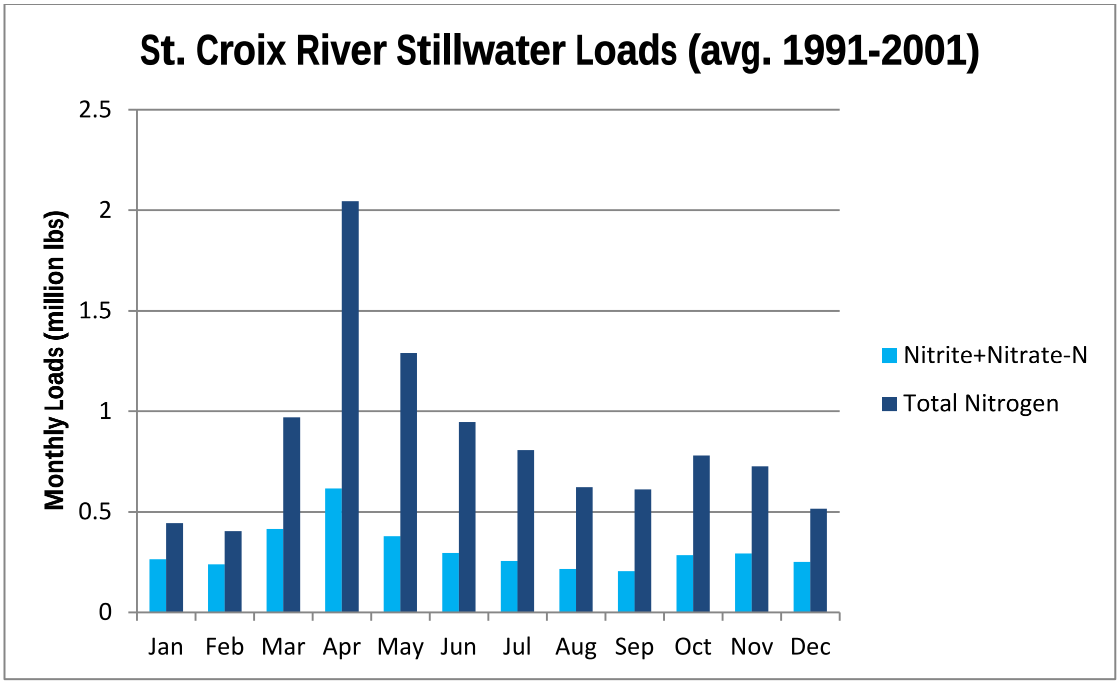

Figure 16. Long term average monthly TN and nitrite+nitrate-N loads in the St. Croix River at Stillwater.

Loads are influenced by both flow and concentration. In the spring months both flow and nitrate concentrations are elevated in the Minnesota River. In the Minnesota River (Jordan) average nitrate concentrations increase from less than 4 mg/l in the winter to about 7 mg/l in May and June (Figure 17). While much less pronounced than in the Minnesota River, an increase in both nitrate and TKN concentrations occurs in the Upper Mississippi River Basin during the spring months (Figure 18). Monthly concentrations in the St. Croix River Basin behave differently, with nitrate concentrations dropping in half during the spring and summer months and peaking in the winter months when flow is dominated by groundwater baseflow and algae production is minimal (Figure 19). In the St. Croix River summer months, organic N increases during the period when algae production increases. Yet, TKN concentrations in the St. Croix remain lower than in the Minnesota River, even during the peak months.

As the three large rivers coming into the Twin Cities Area merge into the Mississippi River south of the Twin Cities (at Lock and Dam #3 near Prescott, Wisconsin), the monthly nitrite+nitrate-N and total N concentration patterns are similar to the patterns observed in the Minnesota River (Figure 20).

The substantial differences in seasonal N concentration patterns among the three mainstem rivers might be explained, in part, by different land uses and flow pathways. The Minnesota River Basin has the highest fraction of tile-drained land. By comparison, the Upper Mississippi River Basin and the St. Croix Basin have less tile drained agricultural lands and more continuously discharging groundwater baseflow inputs (see Chapters D1 and D4).

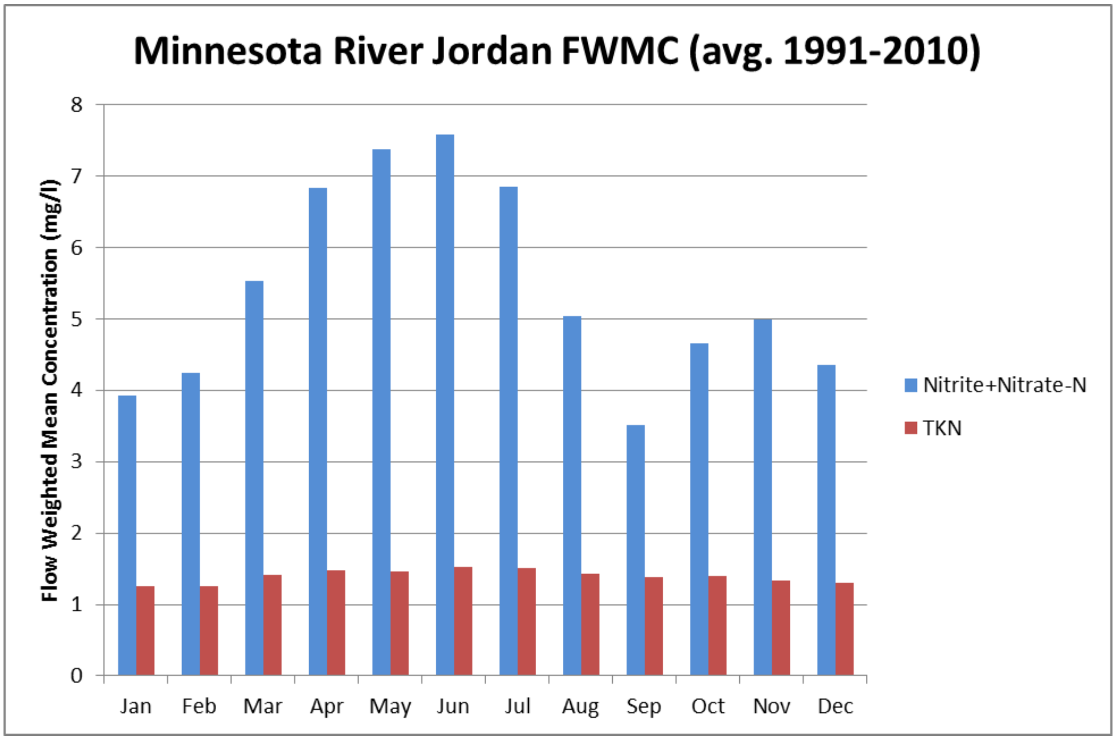

Figure 17. Long term average monthly TKN and nitrite+nitrate-N flow-weighted mean concentrations in the Minnesota River at Jordan.

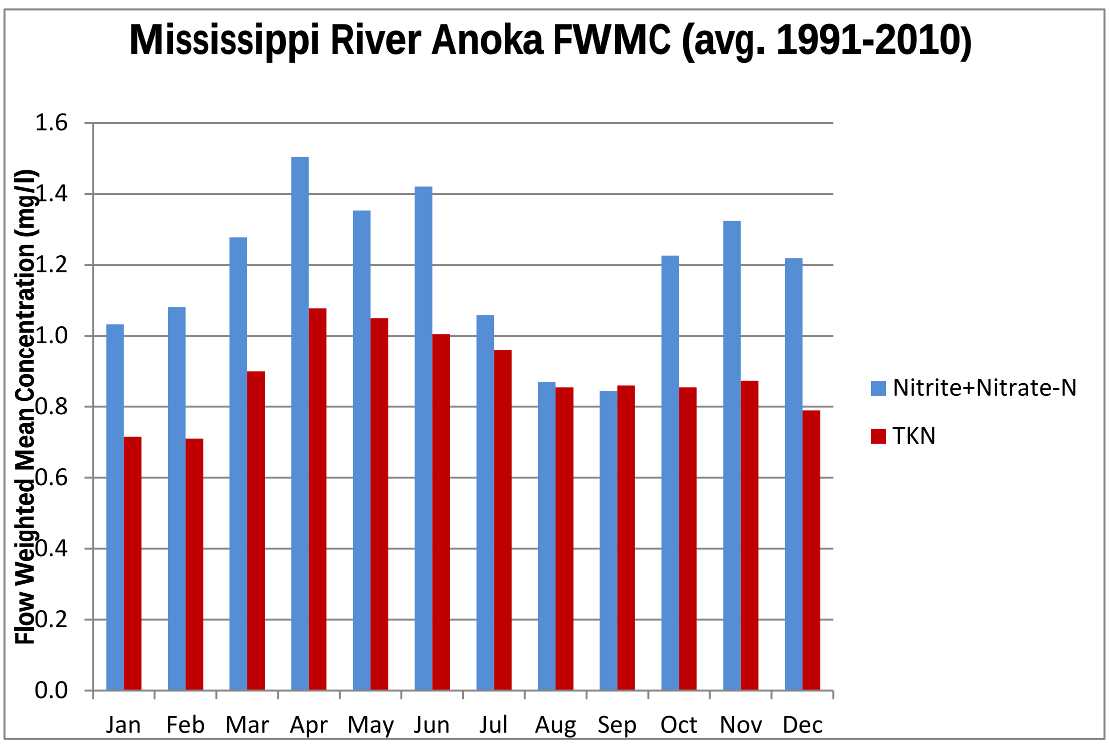

Figure 18. Long term average monthly TKN and nitrite+nitrate-N flow-weighted mean concentrations in the Mississippi River at Anoka.

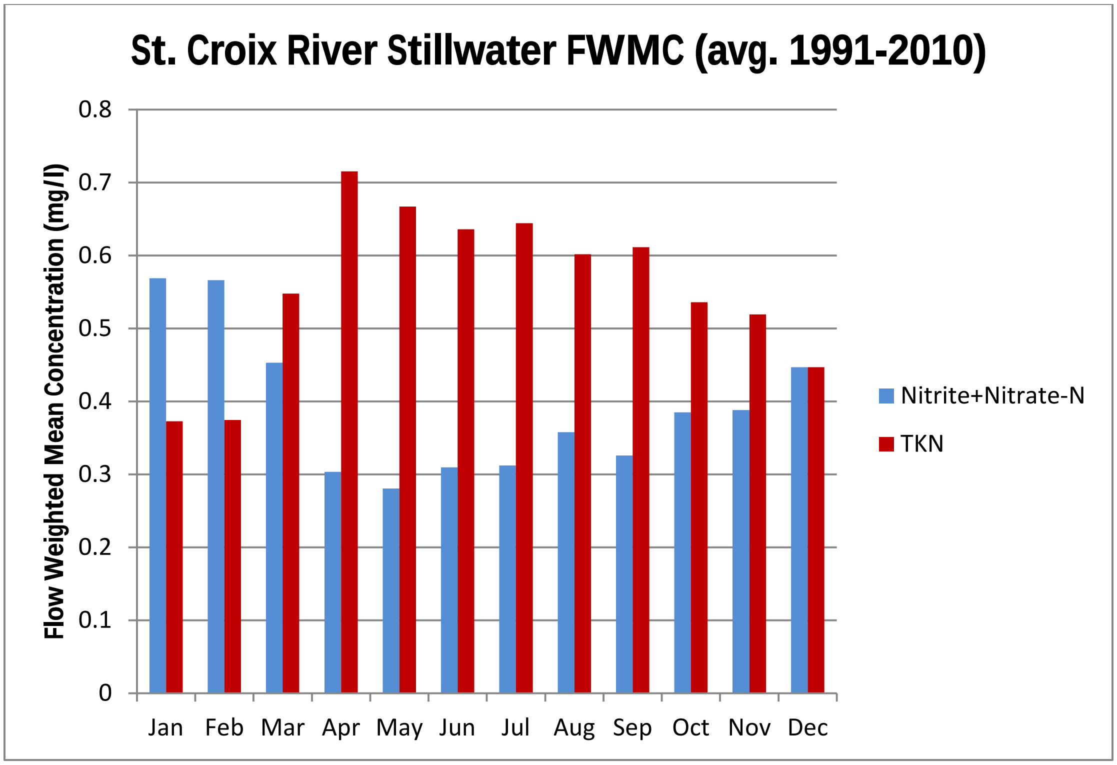

Figure 19. Long term average monthly TKN and nitrite+nitrate-N flow-weighted mean concentrations in the St. Croix River at Stillwater.

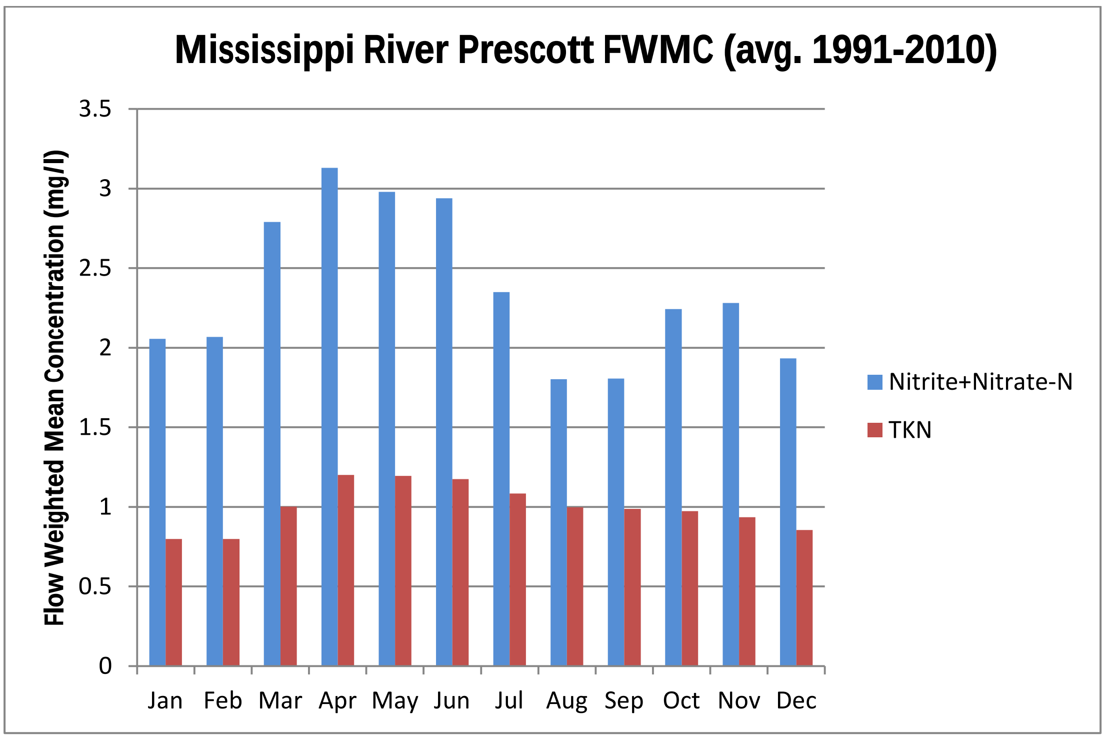

Figure 20. Long term average monthly TKN and nitrite+nitrate-N flow-weighted mean concentrations in the Mississippi River at Prescott, Wisconsin (Lock and Dam #3).

Twin Cities influence on river nitrogen

Using the 1991-2010 N loading data sets provided by the Metropolitan Council, we compared nitrate loading in the combined three mainstem river sites coming into the Twin Cities with the Mississippi River location flowing out of the Metropolitan Area at Lock and Dam #3 in Prescott, Wisconsin. Differences between the Twin Cities inputs and outputs can potentially be due to: a) uncertainty/error in the estimates; b) N losses through denitrification and other processes within the river; c) stormwater N additions from the urban, suburban, and rural areas; and d) municipal and industrial wastewater discharges in the Metropolitan region.

The 1991-2010 average annual TN was found to be 6 million pounds (3.5%) higher between the combined Jordan/Anoka/Stillwater monitoring points upstream of the Twin Cities, and the Prescott monitoring point downstream of the Twin Cities (Figure 21). This mean TN difference is similar to that found a decade earlier by Kloiber (2004), who looked at the period 1992 to 2001 and found that TN increased by 2.5% through the Twin Cities Metropolian Area. Kloiber reported that the 2.5% difference was within the potential range of uncertainty in the load calculations. Similarly, we found that with the high year-to-year variability in loads, the average 1991-2010 TN loads from rivers into the Twin Cities compared to the average loads out of the Twin Cities was not found to be statistically significant (two-sample t-test, p-value = 0.54).

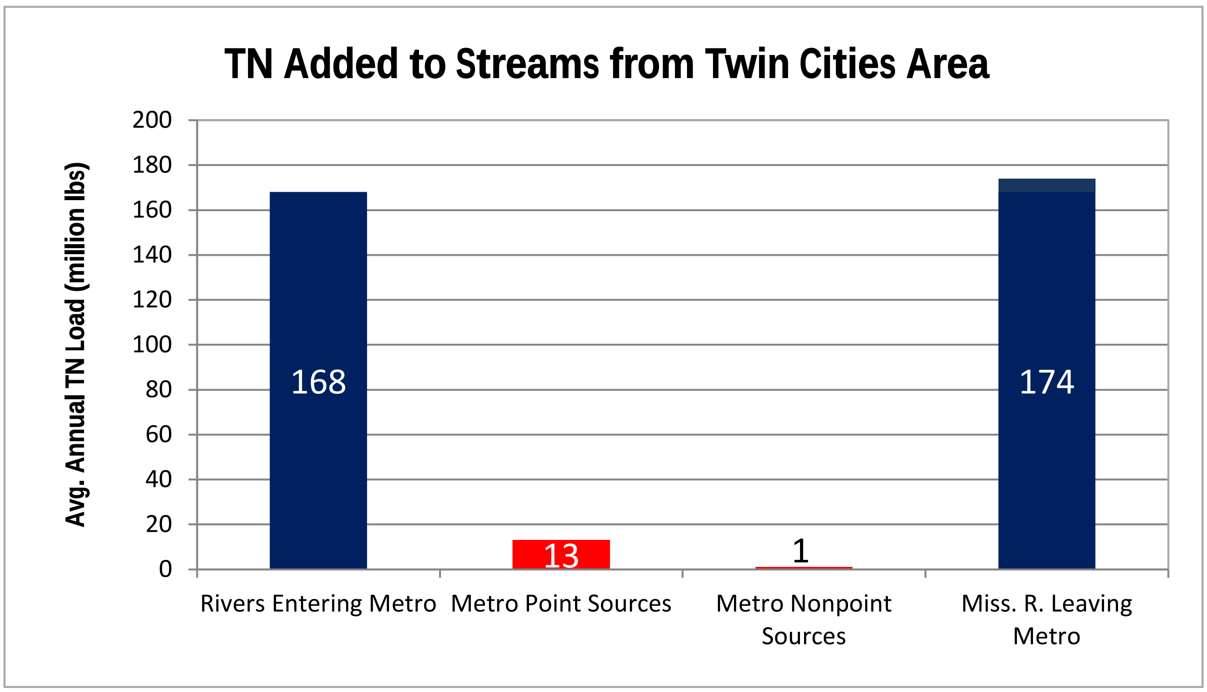

Figure 21. Average annual TN entering the Twin Cities Metropolitan Area in three mainstem rivers: the Minnesota, St. Croix, and Mississippi (average of years 1991-2010), compared to TN leaving the Metropolitan Area in the Mississippi River. The two middle bars represent the added sources of a) estimated point source TN additions to the river in the Twin Cities Area and b) the estimated nonpoint TN sources from stormwater and groundwater in the Metropolitan Area.

We know that some N additions occur in the Twin Cities Area. Point sources plus nonpoint sources add an estimated 13.8 million pounds of N in the Twin Cities Area (12.8 million pounds from point sources and 1 million pounds from stormwater runoff and groundwater contributions – see Chapters D2 and D4). A part of these additions is expected to be offset by in-stream N losses from natural processes as these rivers flow through the Twin Cities. Therefore, while the 6 million pound average increase throughout the Metropolitan Area is not statistically significant, it is within a reasonable range of expected net change considering estimated N inputs and potential N losses within the rivers.

Figure 22 shows the relative amounts of different N forms for the mainstem river inputs into the Twin Cities and the exports out of the Twin Cities. There is a disproportionately higher increase in organic N and ammonium, as compared to nitrate. This could be due to sampling uncertainties, organic N additions and/or in-stream processes where nitrate is used by algae and thereby transformed into organic N.

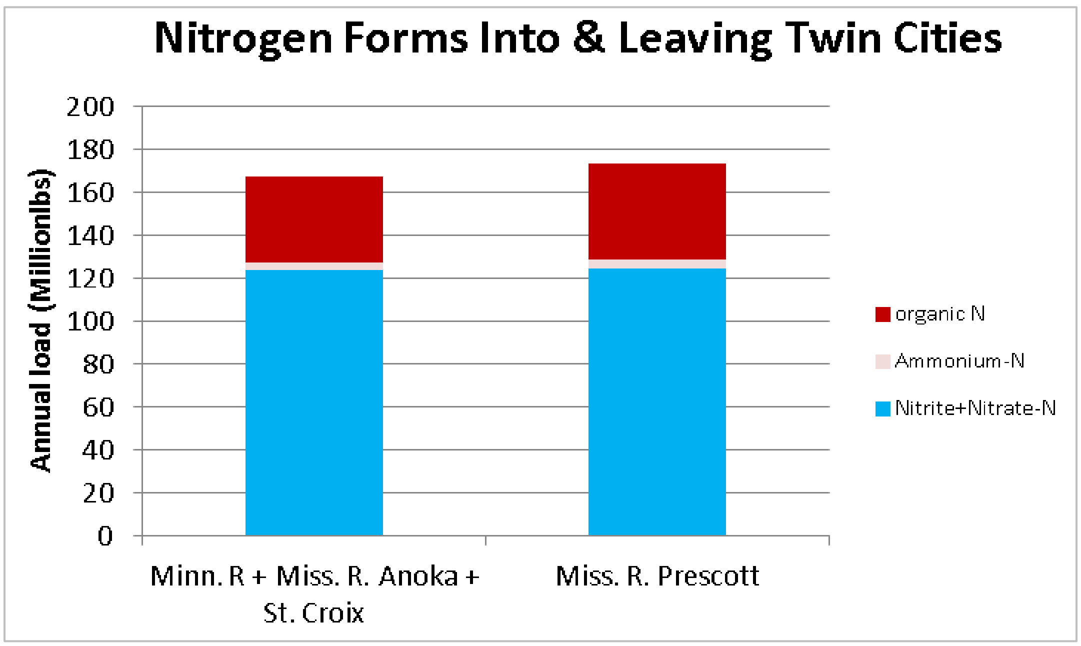

Figure 22. Annual loads of the three different forms of N comprising TN, showing the difference in N forms in the combined mainstem rivers entering the Twin Cities and N forms in the Mississippi River near Prescott downstream of the Twin Cities.

As the Mississippi River continues to flow downstream into southeastern Minnesota, TN loads decrease between Prescott, Wisconsin and the outlet of Lake Pepin. Within this stretch of the river, N inputs are minimal and in-stream losses are measurable (see Chapter B5).

Nitrogen additions in upstream reaches

Nitrogen increases along the upstream reaches of the Mississippi, Minnesota, and St. Croix Rivers were determined from monitoring results collected during 2007 to 2009. The rivers were sampled near the upstream and downstream points of the mainstem HUC8 watershed boundaries as part of the

Minnesota Watershed Pollutant Load Monitoring network, described in Chapter B3. The results for TN and nitrite+nitrate-N are shown in Figures 23 and 24 as a fraction of load measured in the Mississippi River at Lock and Dam #3 in Prescott Wisconsin, south of the Twin Cities.

The N loads remain a relatively low percentage of the Mississippi River at Prescott loads in most upstream river stretches, and show increasing loads moving downstream. The loads increase dramatically in the Minnesota River between Judson and St. Peter where TN increases from 22% of the Prescott loads to 53% of the loads and nitrite+nitrate-N increases from 23% to 59% of the Prescott loads, as the Minnesota River receives flow from the Blue Earth, Watonwan, and Le Sueur Rivers.

Toward the mouth of the Minnesota River, TN and nitrite+nitrate loads represent 63 and 74% of the loads in the Mississippi River at Prescott, Wisconsin. The Upper Mississippi and St. Croix rivers have TN and nitrite+nitrate loads which remain less than 10% of Prescott loads, except that the Upper Mississippi River loads at Anoka increase to 24% (TN) and 19% (nitrite+nitrate) of the loads in Prescott, downstream of the confluence with the Crow River.

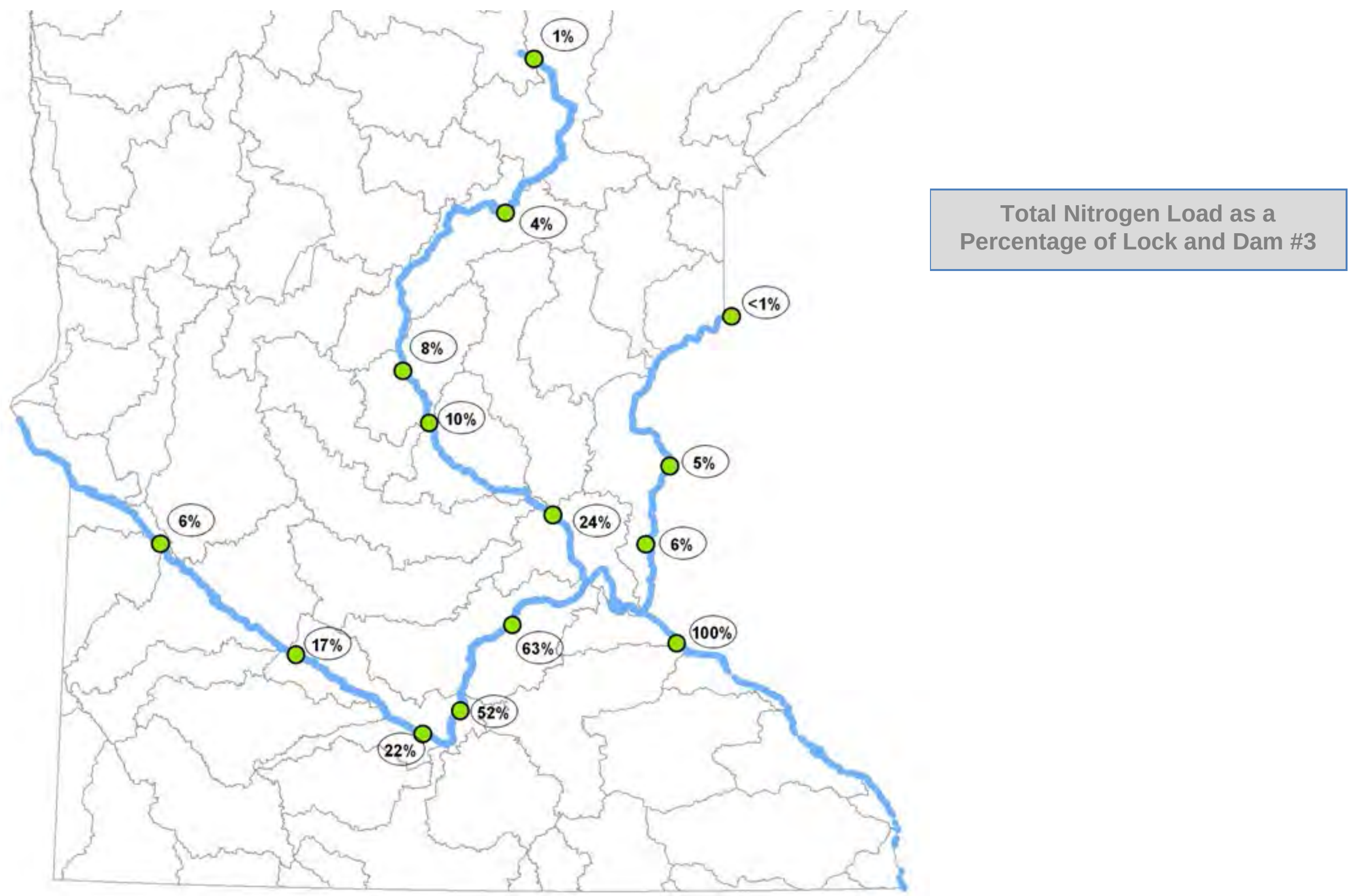

Figure 23. Average TN loads (2007-2009) at different points along the Minnesota, Mississippi and St. Croix Rivers, expressed as a percentage of the load measured at the Mississippi River Lock and Dam #3 near Prescott, Wisconsin (after the convergence of the three rivers).

Figure 24. Average nitrite+nitrate-N loads (2007-2009) at different points along the Minnesota, Mississippi, and St. Croix rivers, expressed as a percentage of the load measured at the Mississippi River Lock and Dam #3 near Prescott, Wisconsin (after the convergence of the three rivers).

Red River

The U.S. portion of the Red River Basin, depicted in Figure 25, originates mostly in Minnesota and North Dakota, with a small percentage also in South Dakota. After crossing the U.S./Canadian border, additional Manitoba watersheds flow into the Red River before it discharges into Lake Winnipeg.

Minnesota's contribution to Emerson nitrogen loads

Based on unpublished data provided by Environment Manitoba (Manitoba Water Stewardship and Environment Canada, the average Red River annual TN load between 1994 and 2008 at the Canadian border in Emerson, Manitoba was 37,326,000 pounds/year (Figure 26). Nitrate concentrations are relatively low in the Red River, and only 42% of the TN is in the nitrate form, with the remainder as TKN (organic-N and ammonia+ammonium-N). Most of the Red River load in Emerson originates in the United States, with only 5.5% coming from Canadian watersheds which flow into North Dakota before joining up with the Red River in the United States. Therefore, 94.5% of the 37 million pounds of N reaching the

Canadian border in the Red River is from Minnesota and the Dakotas. Of the United States contributions, SPARROW modeling results indicate that 48% of the United States load is from Minnesota, and 52% is from the Dakotas (see Chapter B4).

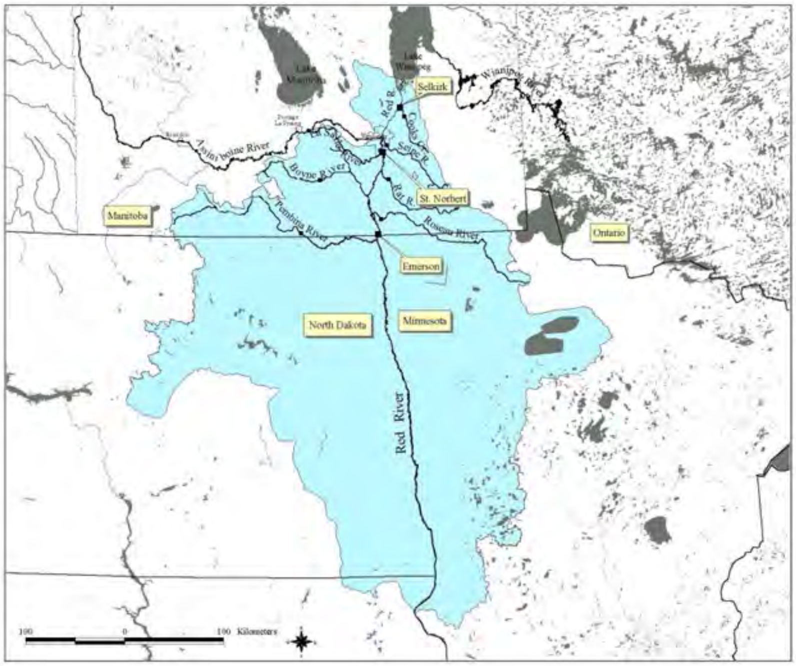

Figure 25. Red River Basin boundaries. From Bourne et al., 2002.

Therefore, if we assume 37,326,000 pounds/year of TN at Emerson, of which 94.5% is from the United States and 48% of that amount is from Minnesota, Minnesota's N contribution to the Red River is estimated as 16,931,000 pounds/year, on average.

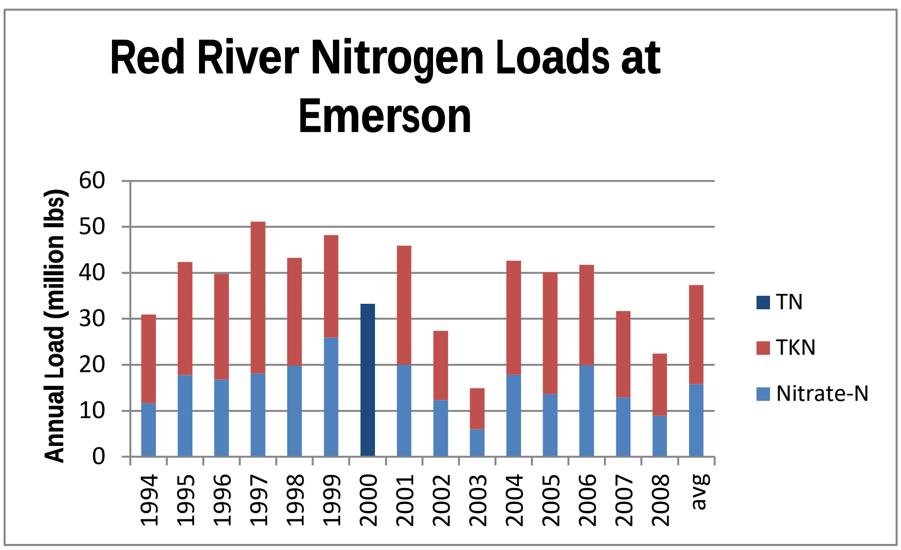

Figure 26. Red River estimated annual N Loads based on monitoring data at Emerson, Manitoba near the U.S./Canadian border. Monitoring and load calculations from Manitoba Conservation Water Stewardship and Environment Canada. Only TN was available for 2000.

United States contributions to Lake Winnipeg

Environment Canada (2011) assessed TN loads from the period 1994 to 2007, including loads from such sources as atmospheric deposition directly into Lake Winnipeg. They concluded that the Red River from the United States and Canada watersheds contributed 34% of the N load to Lake Winnipeg. In an earlier report, Bourne et al. (2002) concluded that 65% of the Red River N comes from the United States. Combining these results, we can assume that approximately 22% of the N load to Lake Winnipeg comes from watersheds in Minnesota and the Dakotas, with about 11% of the Lake Winnipeg TN load from Minnesota.

Summary points

- Long-term (15-30 years) monitoring-based loads, yields and flow-weighted mean concentrations were assessed for the Minnesota River (Jordan), Red River (Emerson), Upper Mississippi River (Anoka), St. Croix River (Stillwater), Mississippi River at Prescott, Wisconsin, Mississippi River at Lake Pepin, and Mississippi River at the Iowa border.
- The Red River is a significant contributor of N to Lake Winnipeg. The United States contributes an average of 37 million pounds of N to the Canadian border each year, and approximately 48% of that amount (16.9 million pounds) is from Minnesota. This export of N compares to 211 million pounds, leaving southern Minnesota in the Mississippi River each year, on average, of which an estimated 162 million pounds are from Minnesota watersheds.
- The Minnesota River N contributions (average 116 million pounds/year) have the greatest influence on N loads leaving Minnesota in the Mississippi River at the Iowa border. Minnesota River TN loads are about twice as high as the combined loads from the Upper Mississippi River, St. Croix River, and Twin Cities additions. The Minnesota River loads increase greatly between Judson and St. Peter, Minnesota, where the Greater Blue Earth River N loads reach the Minnesota River.
- The Mississippi River TN increases by 37 million pounds between the Twin Cities and the Iowa border. About 9% of all N reaching Lake Pepin is lost in the lake (mostly converted to N gas). An estimated 61% of the loads in the Lower Mississippi Basin tributaries are from Wisconsin and 39% from Minnesota, based on SPARROW modeling.
- Long-term average TN yields and flow-weighted mean concentrations are substantially higher in the Minnesota River, and are between 3.5 and 8 times higher than the Red, St. Croix, and Upper Mississippi Rivers.
- Year-to-year variability in TN loads and river flow can be very high, especially in river systems with lower groundwater baseflow contributions and higher tile line contributions. In the Minnesota River Basin, TN loads during low flow years are sometimes as low as 25% of the loads occurring during high flow years.
- The primary forms of N in the mainstem river systems are nitrate-N and organic-N. Nitrite-N and ammonia+ammonium-N are quite low and together comprise only 1% to 5% of the TN. Organic-N FWMCs are more consistent across the state as compared to nitrate, and range from 0.6 mg/l in the St. Croix to 1.4 mg/l in the Red River. Long-term average nitrite+nitrate-N FWMCs range from 0.3 mg/l in the St. Croix to 6.7 mg/l in the Minnesota River. While organic N is equal to or higher than nitrate in some river basins, nitrate is the parameter which most greatly affects TN loads across the state.

- Nitrite+nitrate-N loads in the Minnesota River (Jordan) are more than three times higher than the combined nitrite+nitrate-N loads from the Upper Mississippi, St. Croix, and Twin Cities tributary contributions. The Minnesota River's 97 million pounds constitutes a large fraction of the 158 million pounds leaving the state in the Mississippi River, and is much greater than the 16 million pounds leaving the state in the Red River of the North.
- Total nitrogen loads in the Minnesota, Mississippi, and St. Croix Rivers peak in April and May. About two-thirds of the annual TN load in the Mississippi River at the Iowa border occurs during the five months between March and July. This is due to both increased flow and increases in N concentrations during these months.
- The Twin Cities Metropolitan Area contributes relatively minor amounts of N to the major rivers. The Twin Cities increase river TN by 3% to 4%, on average, which was not found to be a statistically significant increase. Based on information supported in other chapters, over 90% of the added N from the Twin Cities is expected to be from point sources, mostly human wastewater, with relatively little additions from nonpoint sources such as stormwater.

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B3. Monitoring HUC8 Watershed Outlets

Authors: Dave Wall and Pat Baskfield, MPCA

Load calculations by:

Minnesota Pollution Control Agency: Patrick Baskfield, Dennis Wasley, Andy Butzer, Jim MacArthur, Tony Dingman, Kelli Nerem, Jerry Flom, Mike Walerak, Stacia Grayson, Stacia Grayson

***Metropolitan Council*:** Joe Mulcahy, Emily Resseger, Karen Jensen, and Ann Krogman

***MSU Water Resources Center*:** Scott Matteson

GIS analysis and mapping: Tom Pearson and Shawn Nelson

Introduction

In the previous chapter, monitoring-based nitrogen (N) loads along the Mississippi, Minnesota, St. Croix, and Red Rivers were described. In this chapter, we examine monitoring-based N loads at a smaller watershed scale, mostly looking at the 8-digit Hydrologic Unit Code watershed scale (HUC8 watersheds). The monitoring data analyzed in this chapter was collected between 2005 and 2009, with most of the data collected between 2007 and 2009. The first section describes all results collected through the Minnesota Pollution Control Agency (MPCA) Watershed Pollutant Load Monitoring Network between 2007 and 2009. The second section of this chapter focuses on the results in 28 watersheds which are best suited for making comparisons of watershed N yields and flow weighted mean concentrations (FWMCs) across the state.

Watershed Pollutant Load Monitoring Network

The Watershed Pollutant Load Monitoring Network (WPLMN) is a multi-agency effort led by the MPCA to measure and compare regional differences and long-term trends in water quality among Minnesota's major rivers including the Red, Rainy, St Croix, Minnesota, and Mississippi and the outlets of major HUC8 tributaries draining to these rivers. The network was established in 2007 following passage of Minnesota's Clean Water Legacy Act with subsequent funding from the Clean Water Fund of the Minnesota Clean Water, Land and Legacy Amendment. Site specific stream flow data from United States Geological Survey (USGS) and Minnesota Department of Natural Resources flow gauging stations is combined with water quality data collected by the Metropolitan Council Environmental Services, local monitoring organizations, and MPCA staff to compute annual pollutant loads at river monitoring sites across Minnesota. The WPLMN is summarized at www.pca.state.mn.us/index.php/water/water-types-and-programs/surface-water/streams-and-rivers/watershed-pollutant-load-monitoring-network.html.

The WPLMN has been collecting water quality at an increasing number of locations since 2007, reaching 79 monitoring sites by 2010. The design scale is focused toward, but not limited to, monitoring HUC8 watershed outlets within the state. Strategic major river mainstem sites are included to determine basin loads and assist with statewide mass balance calculations.

Intensive water quality sampling occurs year round at all WPLMN sites. Thirty to 35 mid-stream grab samples are collected annually at each site, with sampling frequency greatest during periods of moderate to high flow (Figure 2). Because correlations between concentration and flow exist for many of the monitored analytes, and because these relationships can shift between storms or with season, computation of accurate load estimates requires frequent sampling of all major runoff events. Low flow periods are sampled less frequently as concentrations are generally more stable when compared to periods of elevated flow. Despite discharge related differences in sample collection frequency, this staggered approach to sampling generally results in samples being well distributed over the entire range of flows. Annual water quality and daily average discharge data were coupled in the "Flux32" pollutant load model, originally developed by Dr. Bill Walker and recently upgraded by the U.S. Army Corp of Engineers and the MPCA, to create concentration/flow regression equations to estimate pollutant concentrations and loads on days when samples were not collected. Primary output includes annual and daily pollutant loads and flow weighted mean concentrations (pollutant load/total flow volume). Loads and flow weighted mean concentrations are calculated annually for total suspended solids (TSS), total phosphorus (TP), dissolved orthophosphate (DOP), nitrate plus nitrite nitrogen (NO3+NO2-N) and total Kjeldahl nitrogen (TKN). The NO3+NO2-N is added to TKN to represent total nitrogen (TN).

Normalizing the loads

Nitrogen loads are influenced by land use, land management, watershed size, hydrology, climate, and other factors. Watershed size greatly influences loads; therefore, when comparing watersheds across a region or state, it is often useful to normalize the results based on watershed size. The "yield" accomplishes this, as the yield is the mass per unit area of a constituent coming out of a watershed during a given time period (i.e., pounds/acre/year). Yield is determined by simply dividing the annual load by the watershed size. In this report all yields are reported in the unit of pounds per acre per year. If all things are equal between two watersheds except flow volume, the watershed recording twice the annual discharge volume will record twice the yield. The yield is a particularly useful parameter when watersheds are being evaluated for their effects on downstream water bodies impacted by high loads.

Another way of normalizing load data for both spatial and volumetric differences between watersheds is by assessing the FWMC. The FWMC is calculated by dividing the total load (mass) for the given time period by the total flow volume. It refers to the average concentration (mg/L) of a particular pollutant per unit volume of water. The FWMC allows for the direct comparison of water quality between watersheds regardless of watershed size or annual discharge volume.

Watershed annual N yields and FWMCs were both used in this study for making comparisons of watersheds across the state.

Results

For this report, annual loads, yields, and flow weighted mean concentrations were available for 2007, 2008, and 2009, but data from all three years were not available for all sites. Average annual TKN, TN and nitrite+nitrate-N yields and FWMCs for the period 2007 to 2009 are shown in Figures 1 to 6. The average watershed N levels in each of the Figures 1 to 6 represent a mix of results which include results from:

- one, two, or three years of monitoring
- independent HUC8 watersheds affected only by land and rivers within the HUC8, along with other HUC8s influenced by main stem rivers and other upstream rivers
- low, normal, and high flow conditions as they naturally occurred in this three year period (i.e., some watersheds include mostly dry years;, whereas, other watersheds represent an average of high precipitation years)

The resulting FWMC and yield maps for nitrite+nitrate-N and TN (Figures 1 to 4) show a strong spatial pattern of higher TN and nitrite+nitrate-N in southern Minnesota watersheds, particularly those in south-central Minnesota, and lower N in northern Minnesota watersheds. Some watersheds in southern

Minnesota do not fit the pattern of higher loads or concentrations because they are affected (diluted) by upstream lower N concentration waters (see for example Minnesota River Yellow Medicine, Minnesota River Mankato, Mississippi River Lake Pepin, and Mississippi River Winona).

Total Kjeldahl nitrogen FWMC and yield maps (Figures 5 and 6) at the outlets of all monitored HUC8 level watersheds show generally lower levels compared to nitrite+nitrate-N and are more spatially variable across the state. Sources of organic N can be natural, from human-induced sources and land alterations, or from biological processes (i.e., algae growth) which transform nitrate into organic N.

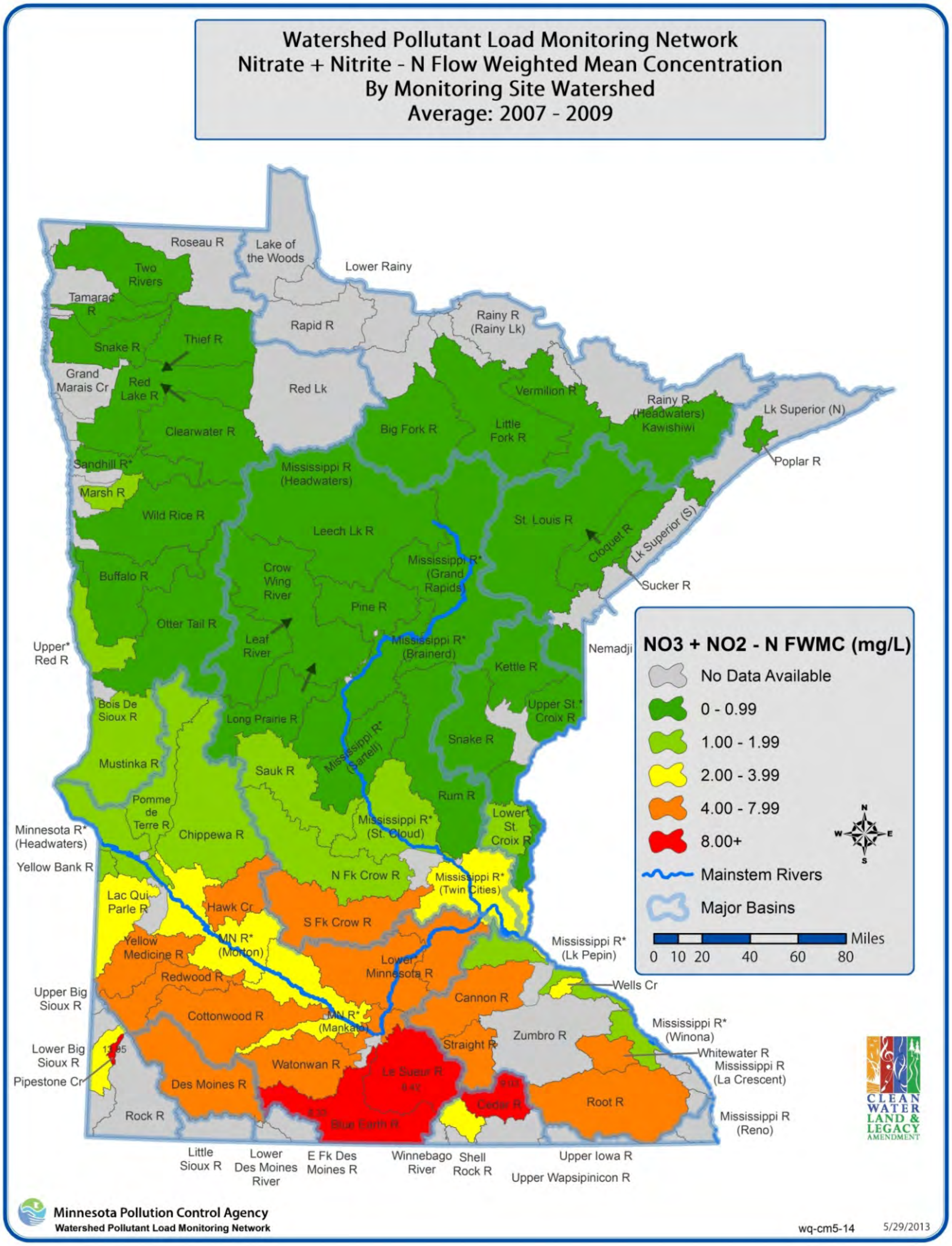

Figure 1. Nitrate+Nitrite-N flow-weighted mean concentrations near the outlet of watersheds. Average of available annual information between 2007-2009 (one to three year average for each watershed).

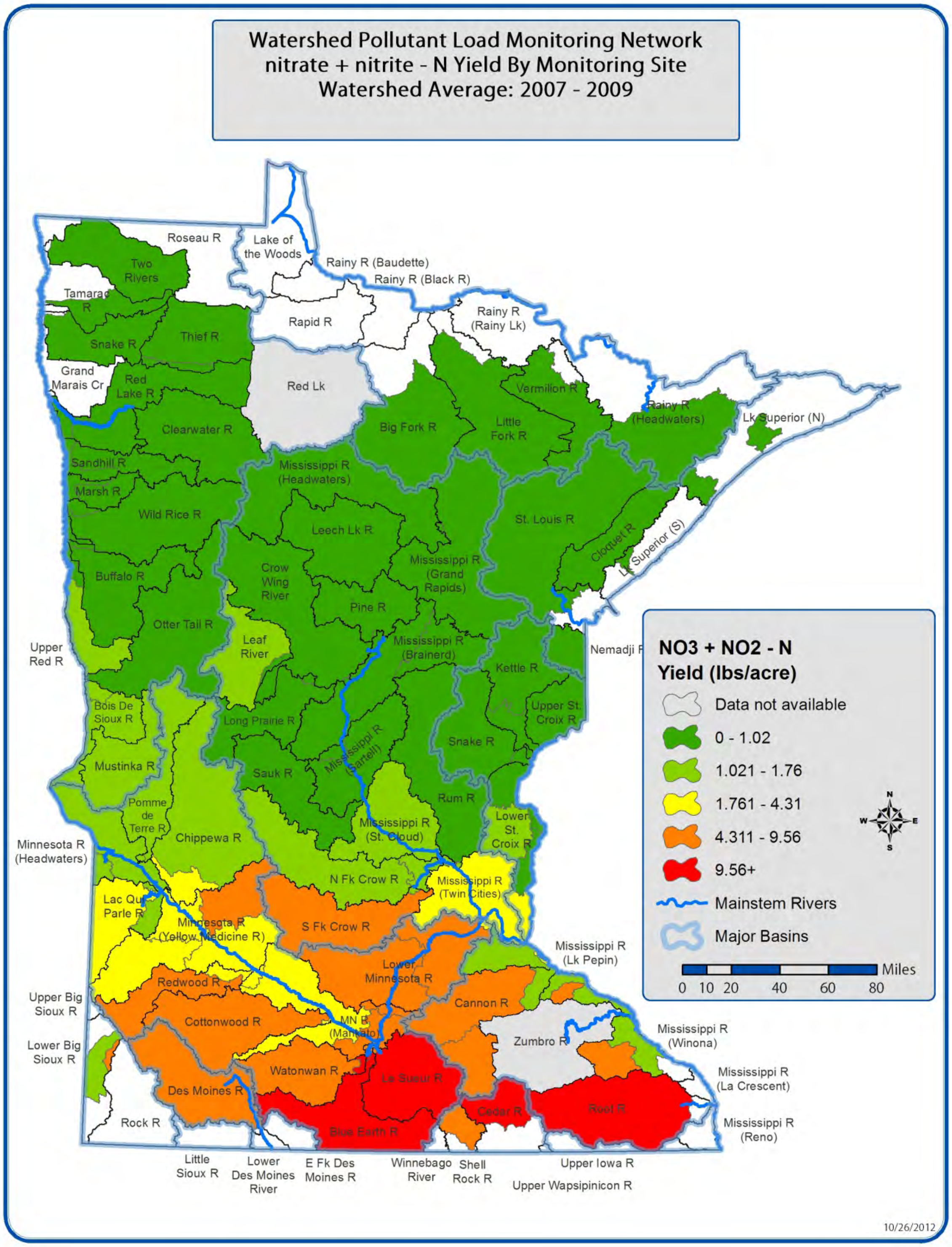

Figure 2. Nitrate+Nitrite-N yields based on monitoring near the outlet of each watershed. Average of available annual information between 2007-2009 (one to three year average for each watershed).

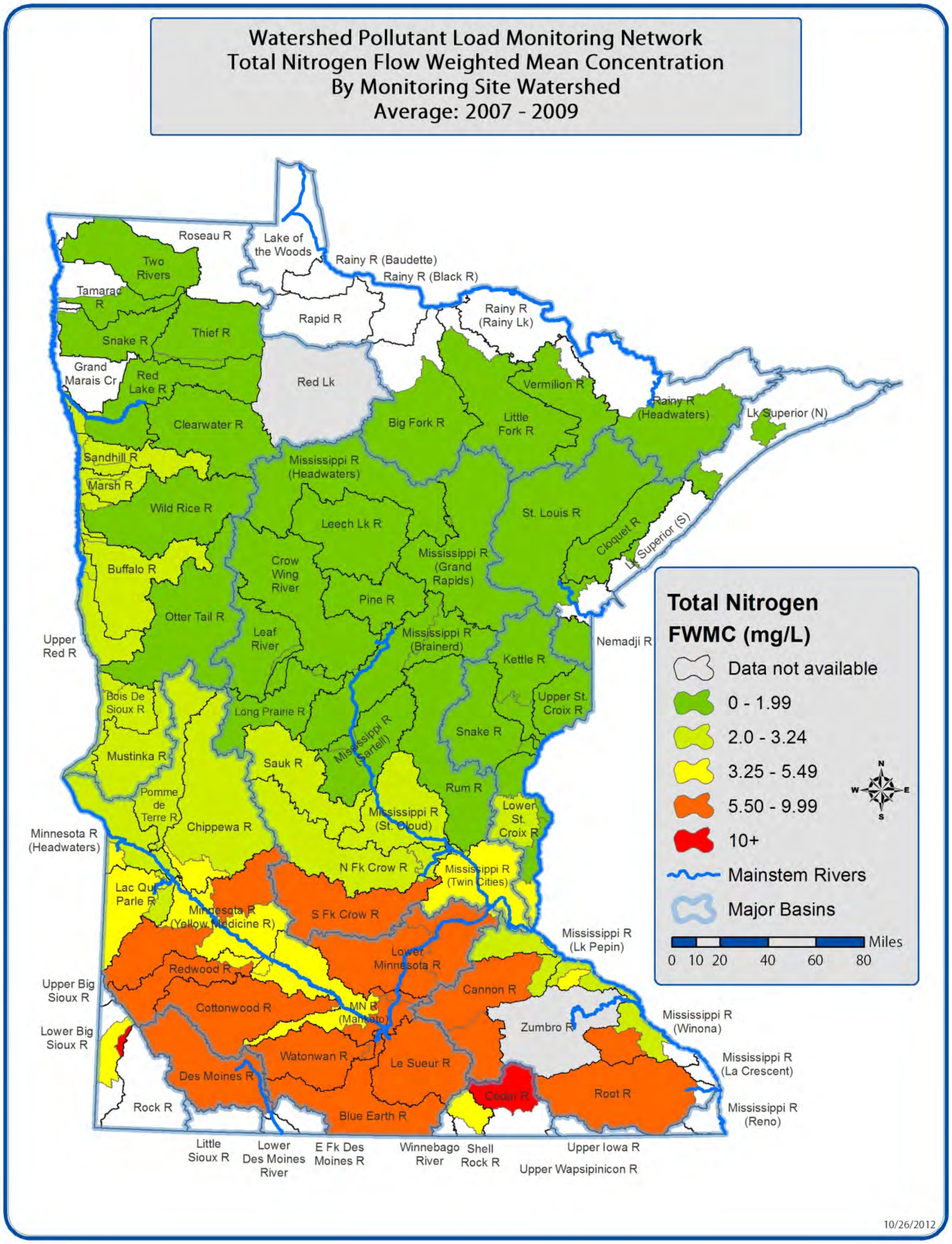

Figure 3. TN flow-weighted mean concentrations near the outlet of watersheds. Average of available annual information between 2007-2009 (one to three year average for each watershed).

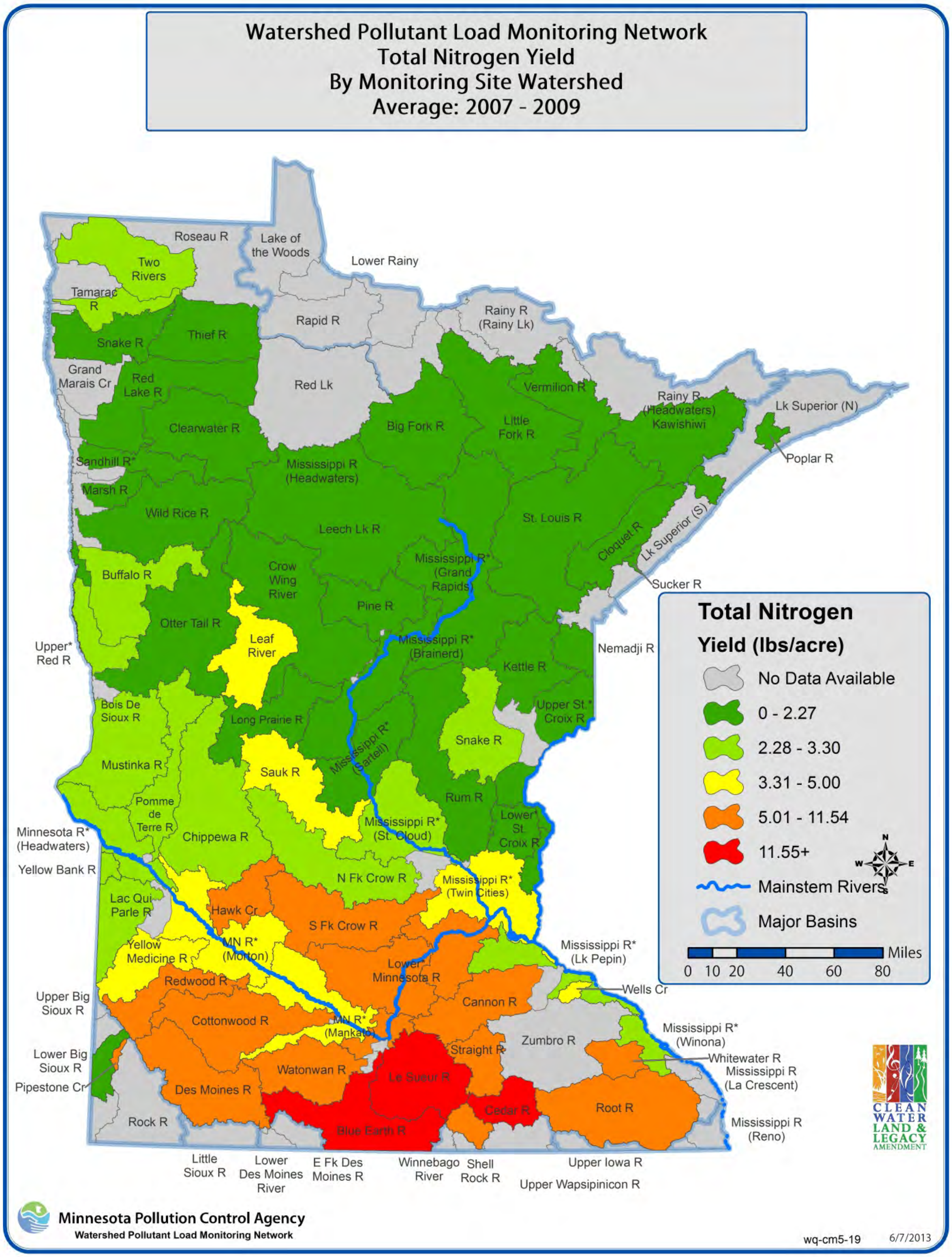

Figure 4. TN yields based on monitoring near the outlet of each watershed. Average of available annual information between 2007-2009 (one to three year average for each watershed).

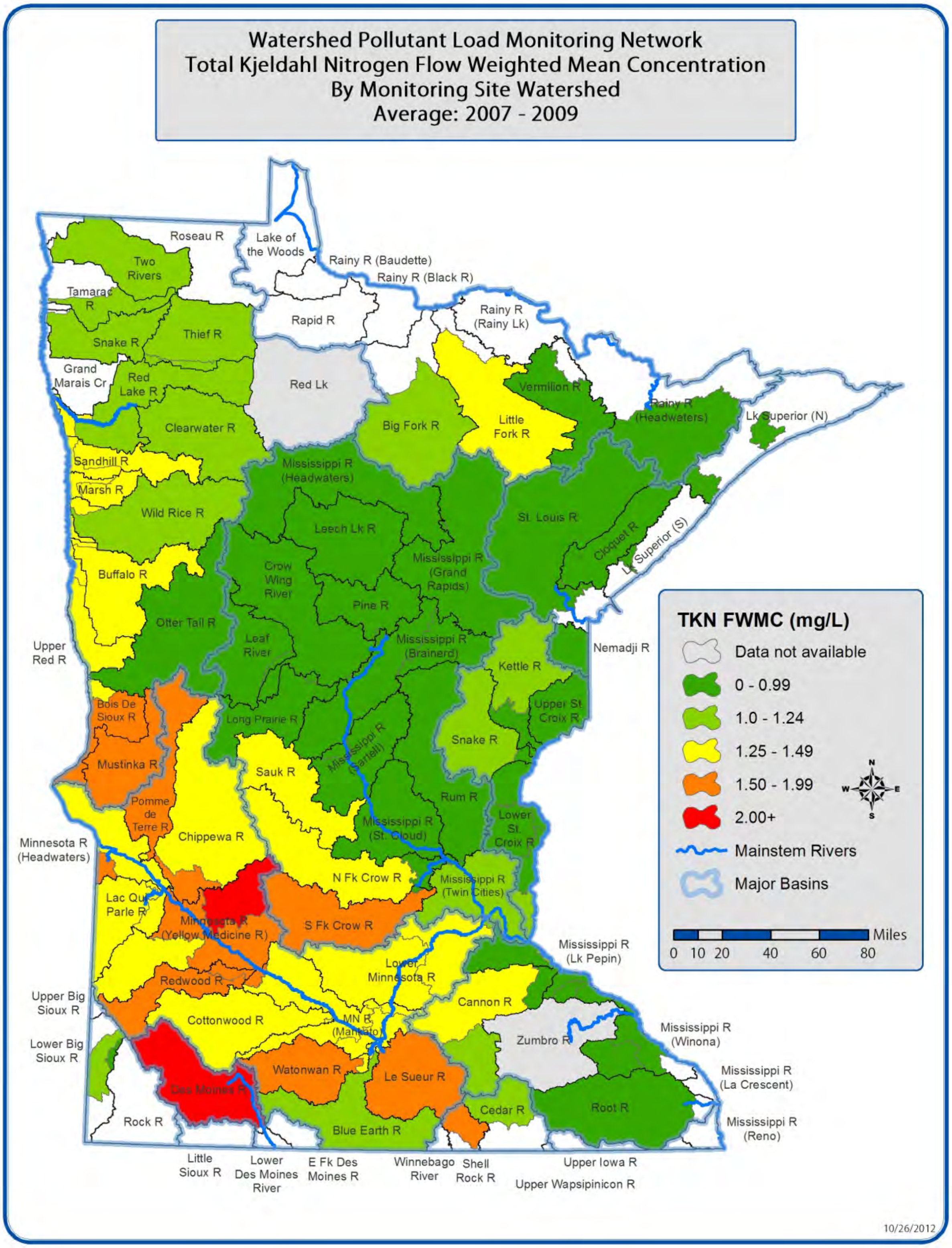

Figure 5. TKN flow-weighted mean concentrations based on monitoring near the outlet of each watershed. Average of available annual information between 2007-2009 (one to three year average for each watershed).

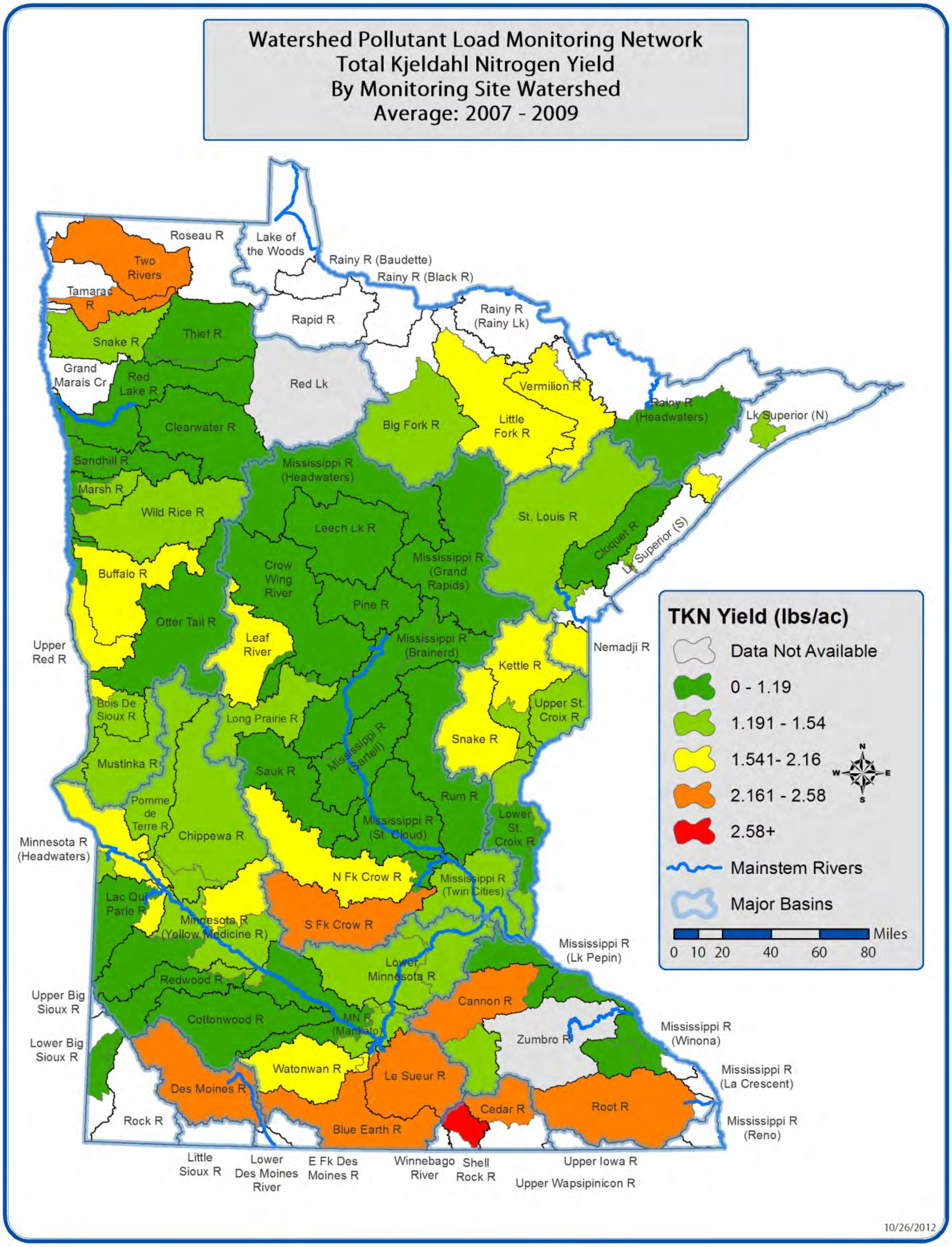

Figure 6. TKN yields based on monitoring near the outlet of each watershed. Average of available annual information between 2007-2009 (one to three year average for each watershed).

Watersheds which are intersected by a main-stem river (shown in Figure 7), such as the Minnesota River (Yellow Medicine), Minnesota River (Mankato), and Mississippi River (Twin Cities), have yields and concentrations influenced by upstream watersheds. Therefore, the results in these watersheds do not reflect N levels from only within the HUC8 watershed, but are a mix of the local inputs and upstream inputs. In many cases, the downstream watersheds along mainstem rivers are diluted by upstream incoming waters and, therefore, show a lower N level as compared to surrounding HUC8 watersheds which are not diluted by upstream waters.

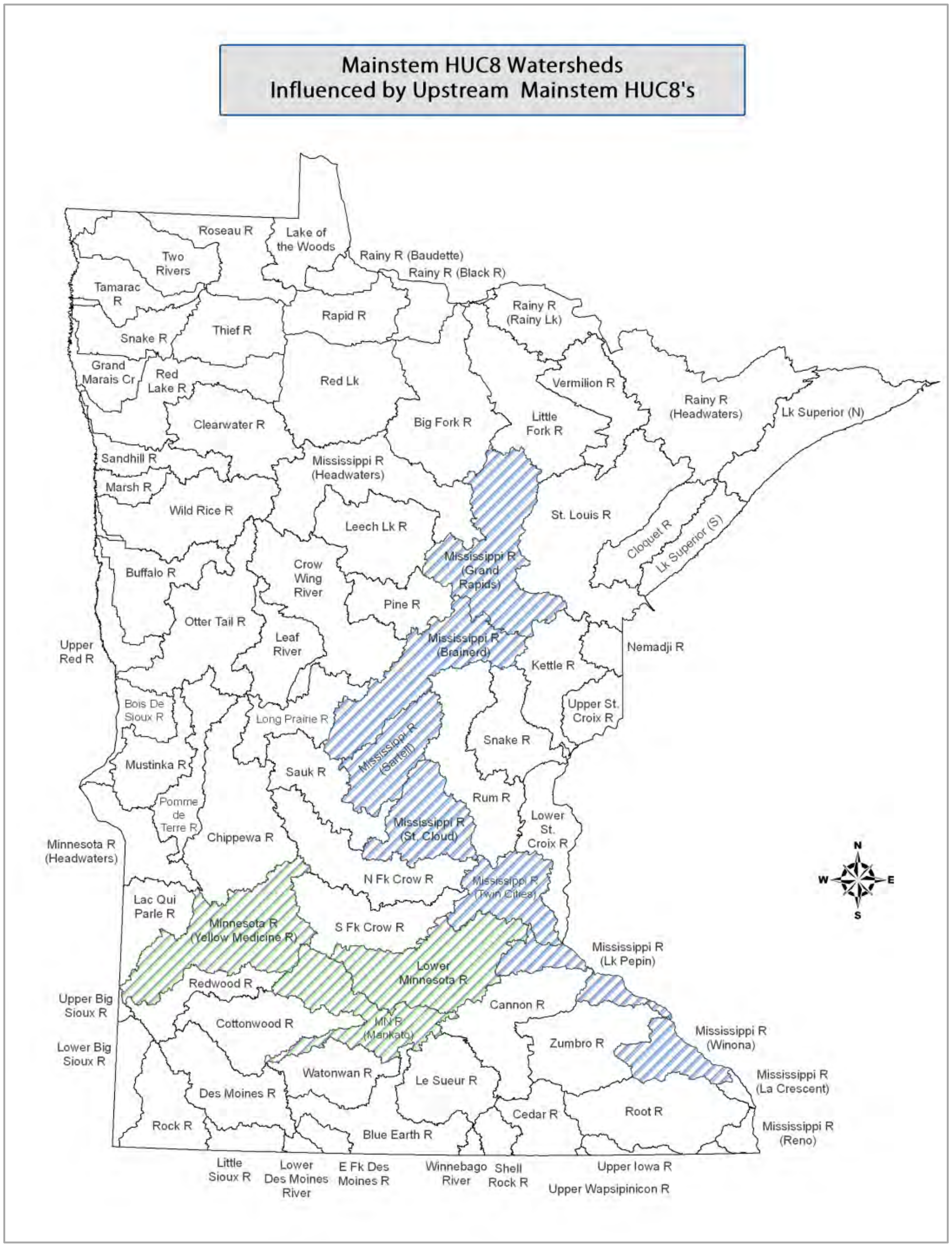

Figure 7. HUC8 Watersheds with Mississippi and Minnesota Rivers flowing through them, and are thereby influenced from land not only within the HUC8 contributing area, but also by additional upstream watersheds. HUC8 watersheds along the Mississippi watersheds and Minnesota River HUC8 watersheds are shown in blue and green, respectively.

Independent HUC8 watershed loads (mid-range flow averages)

As noted in the previous section, the yields and FWMCs for Figures 1 to 6 represent results from one to three years of monitoring depending on the availability of data from the developing WPLMN program. To enable a more uniform comparison between watersheds across the state, a subset of watersheds was selected for further analysis. The subset of watersheds was selected to remove variability due to the number of years of data and extreme climatic conditions (extreme low and high flows). The subset of watersheds also excluded HUC8 watershed monitoring sites influenced by upstream watersheds. Yields and FWMCs for this analysis were computed for independent watersheds using two years of data collected during years of mid-range flows within the 2005–2009 timeframe. Normal flows for the South Fork Crow River, Cannon River, and Root River occurred in the 2005-2006 timeframe, prior to the start of the WPLMN and, therefore, data from these three watersheds were used from Metropolitan Council and the USGS.

The years 2005-2009 had some extremely high and low river flow conditions. The year(s) when these high and low flows occurred varied for different regions of the state. When comparing watershed loads and yields measured over shorter periods of time, it is important to reduce the influence of year-to-year climate variability by comparing years with reasonably similar river flow regimes. Thus, the results described below represent monitoring-based loads, yields and flow weighted mean concentrations derived from two-year averages using recent years (2005-2009) when flow was in the normal range (between the 25^{th} and 75^{th} percentile) and avoiding years of extremes. The two-year periods representing these mid-range flows were as follows for the different regions of the state:

Northwest Minnesota: 2007 and 2008
Southwest and South Central Minnesota: 2007 and 2008
Northeast Minnesota: 2008 and 2009
Southeast Minnesota: 2005 and 2006

We also checked to see how closely the two-year average loads compared to longer term (7-18 year) load averages at 11 sites which had the additional load data available. We found that the two-year averages were closely correlated with the longer term averages, giving us greater confidence that the two-year averages provided representative loads for making geographic comparisons.

The two-year nitrite+nitrate-N and TN average annual yields and FWMCs are shown in Figures 8 to 11 for each independent HUC8 watersheds which were sampled during the two-year normal flow periods between 2005 and 2009. The results show a very similar spatial pattern across the state of high and low N watersheds as Figures 1 to 6, which were developed using one-three year averages during a wider range of river flow conditions. The highest yields and FWMCs were in the southern part of the state, particularly south-central Minnesota, whereas the northern Minnesota watersheds had consistently low N yields and concentrations.

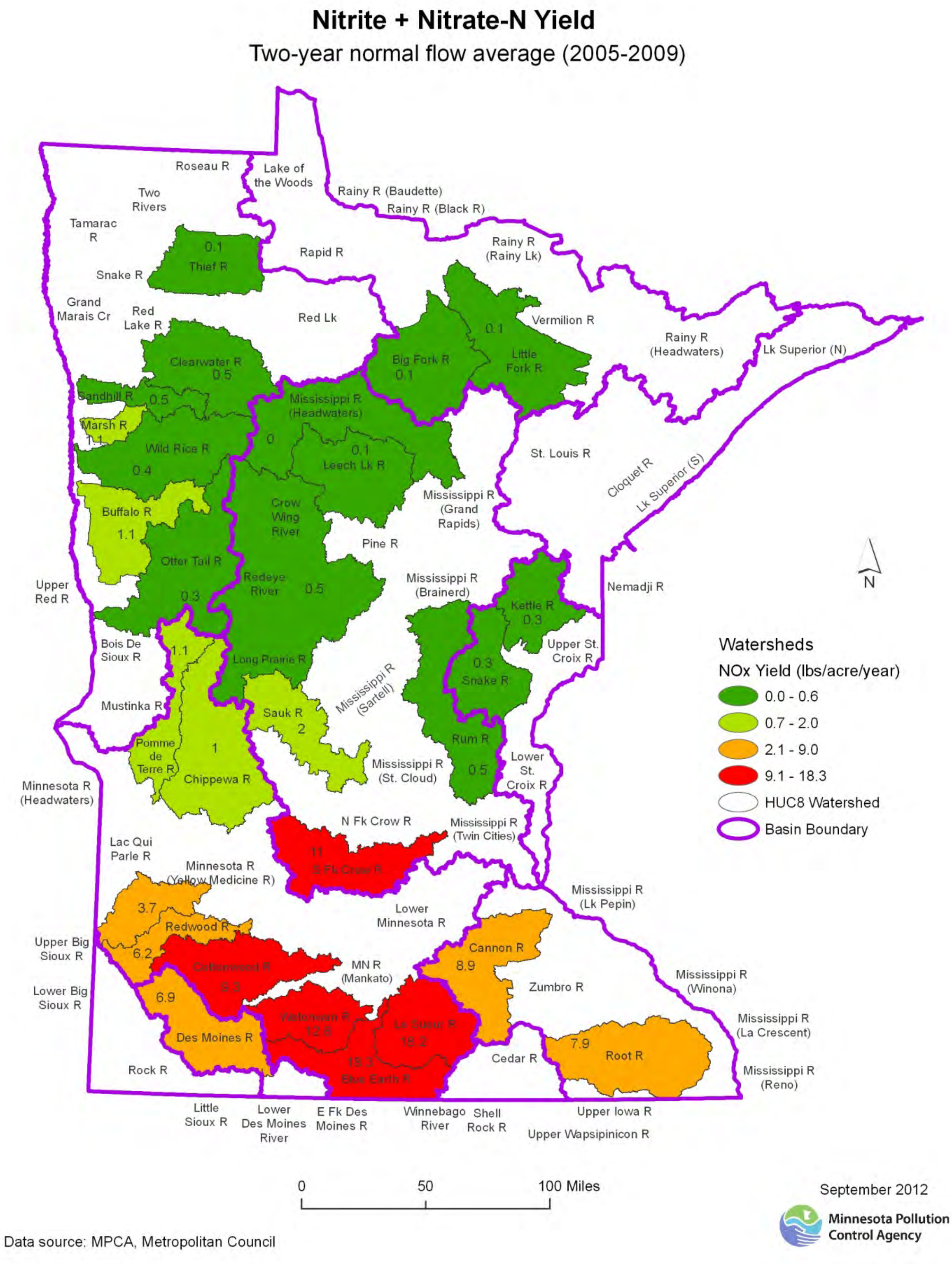

Figure 8. Two-year average Nitrite+Nitrate-N (NOx) yields during normal flow periods between 2005 and 2009.

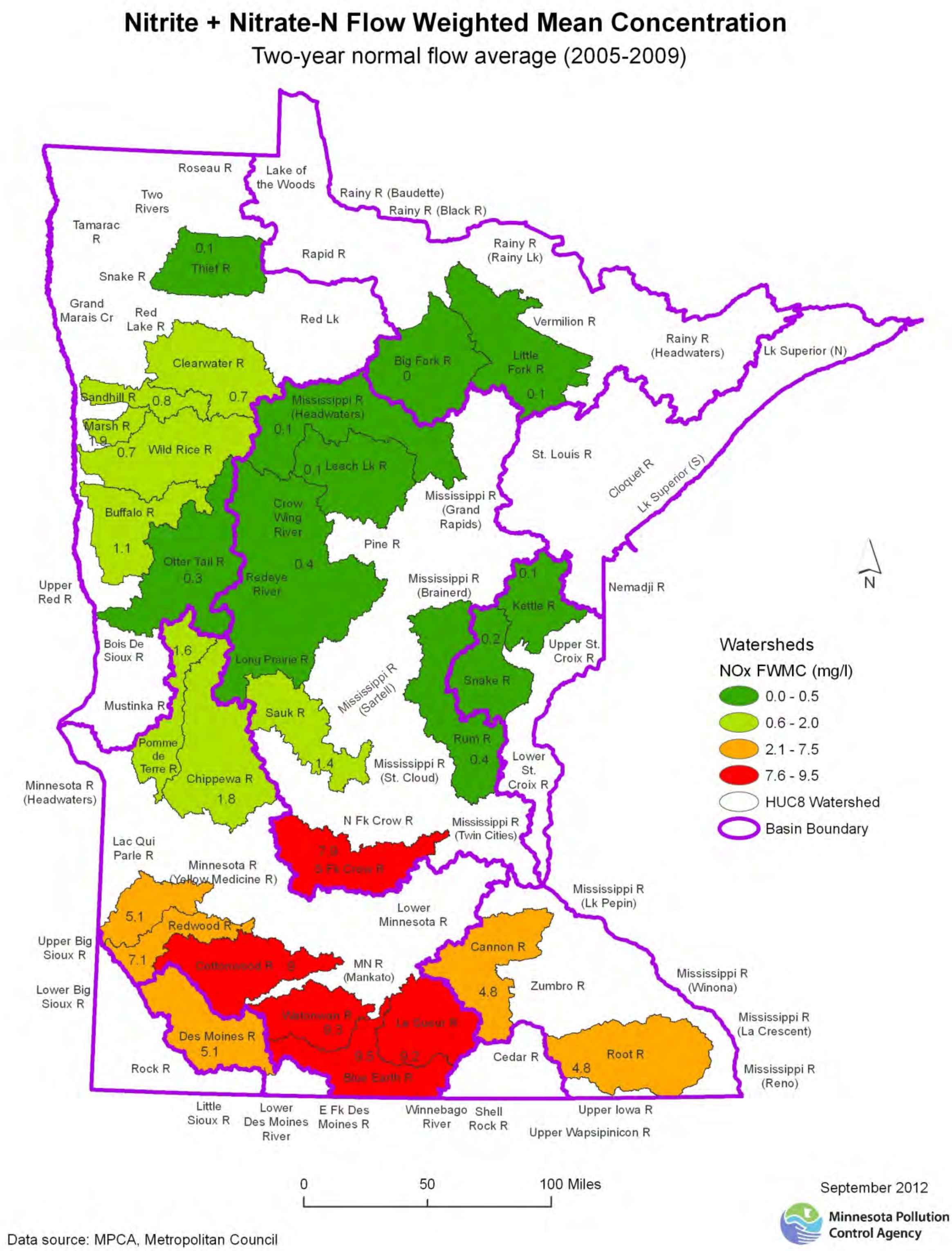

Figure 9. Two-year average Nitrite+Nitrate-N (NOx) FWMC during normal flow periods between 2005 and 2009.

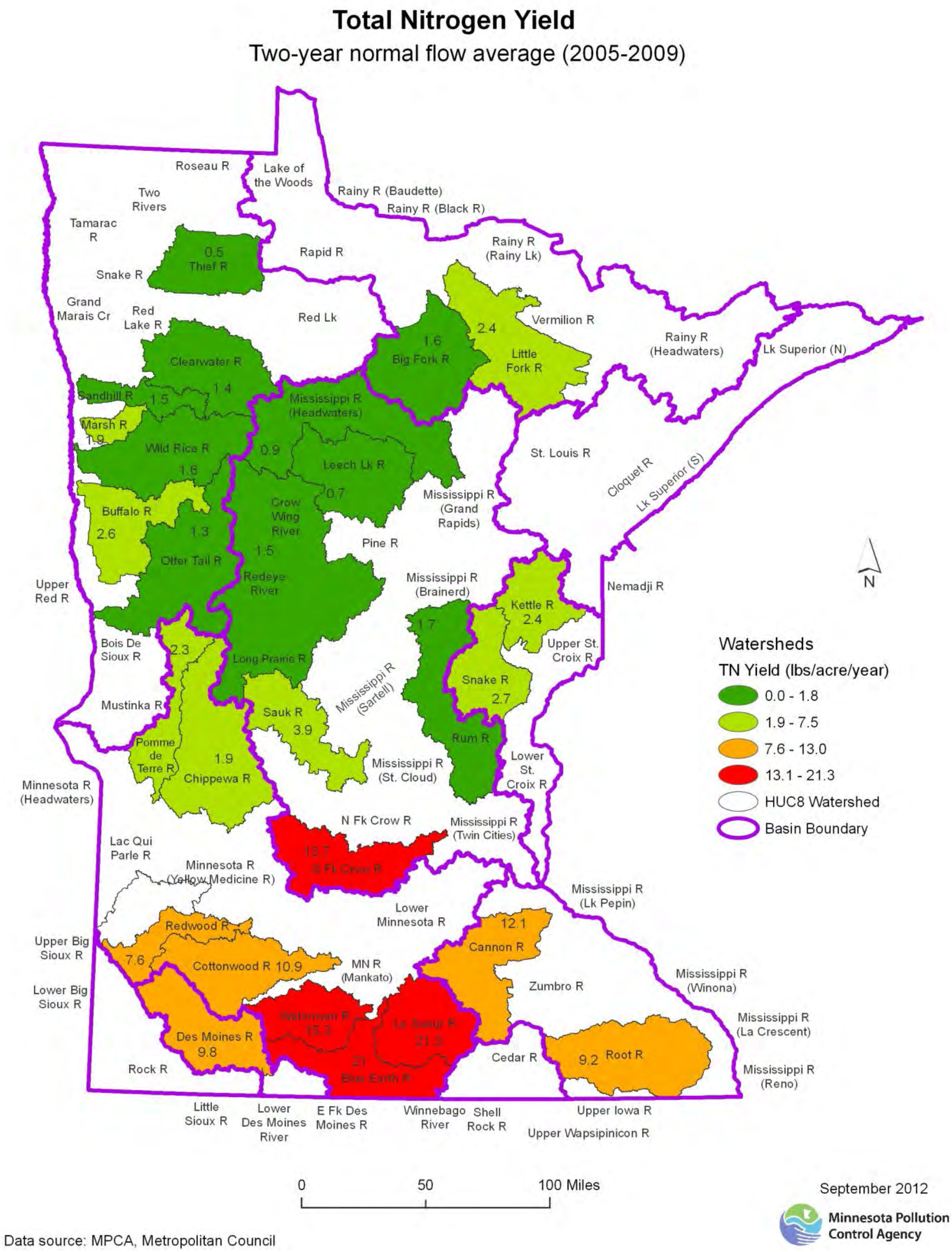

Figure 10. Two-year average TN yields during normal flow periods between 2005 and 2009.

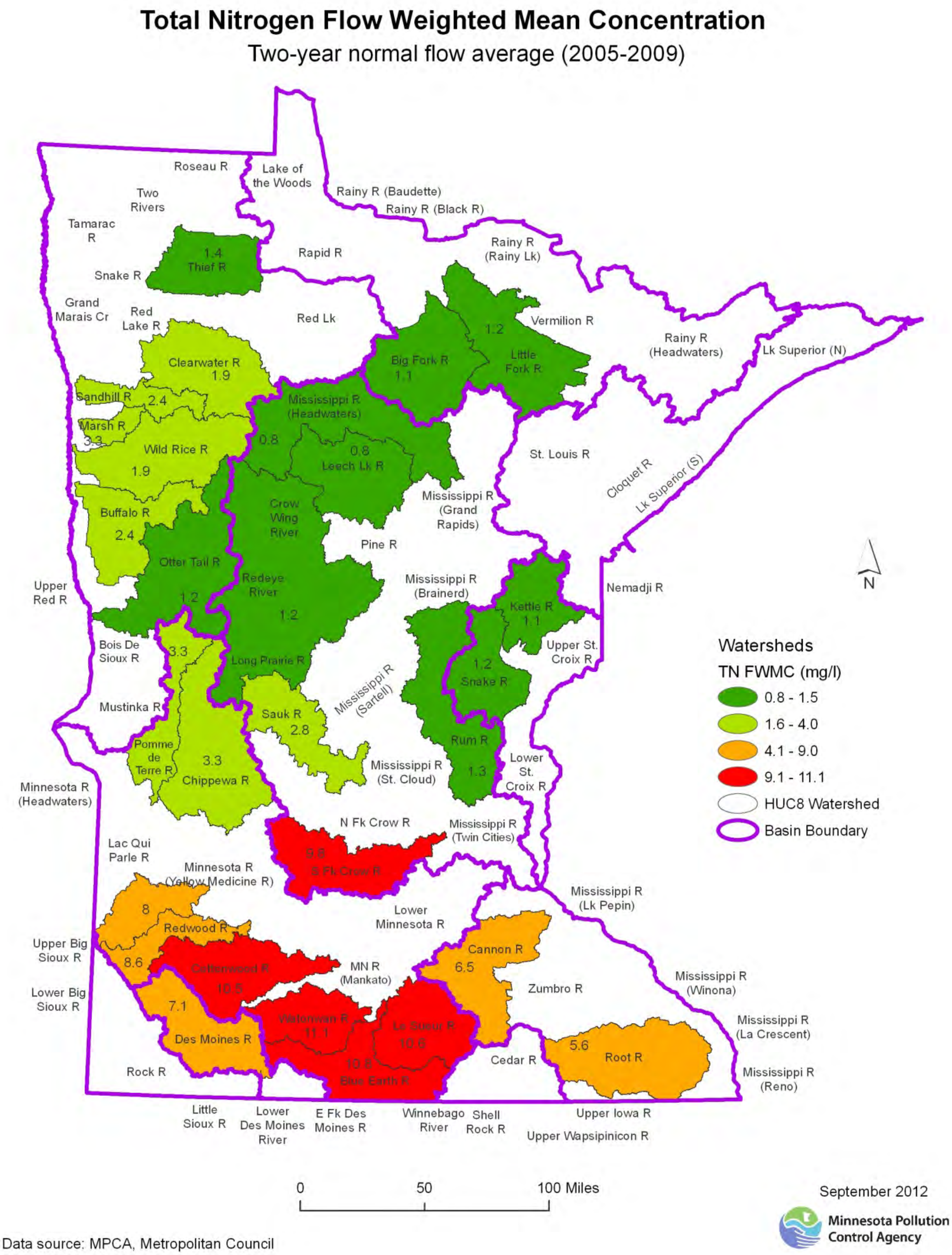

Figure 11. Two-year average TN FWMC during normal flow periods between 2005 and 2009.

Summary points

- Monitoring during recent years is showing that the highest yields and concentrations of both nitrite+nitrate-N and TN are in south central Minnesota, where TN FWMCs generally exceed 10 mg/l and yields range from about 15 to 22 pounds/acre.
- The second highest parts of the state for nitrite+nitrate-N and TN concentrations and yields is southeastern and southwestern Minnesota, which have TN FWMCs in the 5-9 mg/l range and yields ranging from about 8-13 pounds/acre.
- Watersheds north of the Twin Cities have substantially lower nitrite+nitrate-N and TN concentrations, with TN FWMCs in northeastern Minnesota less than 1.5 mg/l and yields less than 2 pounds/acre. Total nitrogen levels are higher in the northwestern part of the state as compared to the northeast, ranging from about 1.5 to 4 mg/l FWMC and 1.5 to 4 pounds/acre yield.
- Exceptions to the high nitrate and TN river concentrations in southern Minnesota occur where river N is diluted by water with lower N coming from northern reaches of the river and flowing into southern watersheds.

B4. Modeled Nitrogen Loads (SPARROW)

Authors: David Wall and Nick Gervino, MPCA

SPARROW model outputs and maps at the major basin and HUC8 watershed scales provided by: Dale M. Robertson and David A. Saad, U.S. Geological Survey, Wisconsin Water Science Center

Purpose

The SPAtially Referenced Regressions on Watershed attributes (SPARROW) model, developed and maintained by the United States Geological Survey (USGS), was used for this study to estimate Total nitrogen (TN) loads, yields, and flow-weighted mean concentrations (FWMC) in Minnesota 8-digit Hydrologic Unit Code (HUC8) watersheds and major basins. The model was also used to estimate TN contributions from different sources in Minnesota and estimate the effects of reducing specific source contributions.

While Minnesota is fortunate to have an abundance of watershed monitoring data to assess spatial trends in loads around the state, SPARROW modeling results were also included in this study for several reasons, as noted below:

Loads for all watersheds available: Monitoring results are not available for all watersheds in the state. The SPARROW model provides an estimate of loads in all watersheds, including those not directly monitored. Monitoring-based loads which were not used in the model calibration can be used to validate the model, providing greater assurance that model results for non-monitored watersheds are reasonable. By having load estimates for all watersheds, statewide watershed prioritization and spatial comparison efforts are enhanced.

Load estimates are based on many years of sampling: For some watersheds, monitoring results are available for only one or two years. The SPARROW model is developed from longer term monitoring data sets, and therefore represents typical load results for each watershed which are less subject to extreme influences introduced through climate swings or error.

Incremental loads available: The SPARROW model allows estimates of incremental river load contributions from individual watersheds, even though the watersheds have other streams flowing into or through the watershed.

Delivered loads available: The SPARROW model provides estimates of contributing loads from different watersheds to a selected downstream delivery point such as a state border or confluence with other rivers. In-stream losses are thereby accounted for.

Land use contributions: The SPARROW model provides N categorical load estimates. These results were compared to results from the N source assessment discussed in Chapters D1-D5 of this report to serve as one of several ways to verify the N source assessment results.

Overview of SPARROW model

The SPAtially Referenced Regressions on Watershed attributes (SPARROW) watershed model integrates water monitoring data with landscape information to predict long−term average constituent loads that are delivered to downstream receiving waters. The SPARROW models are designed to provide information that describes the spatial distribution of water quality throughout a regional network of stream reaches. SPARROW utilizes a mass-balance approach with a spatially detailed digital network of streams and reservoirs to track the attenuation of nutrients during their downstream transport from each source. Models are developed by statistically relating measured stream nutrient loads with geographic characteristics observed in the watershed [Preston et al., 2011a]. A geographical information system (GIS) is used to spatially describe pollutant sources and overland, stream, and reservoir transport.

The statistical calibration of SPARROW helps identify which nutrient sources and delivery factors are most strongly associated with long-term mean annual stream nutrient loads. The mass−balance framework and spatial referencing of the model provides insight to the relative importance of different contaminant sources and delivery factors. The networking and in-stream aspects of SPARROW enable the downstream loads to be apportioned to the appropriate upstream sources [Preston et al., 2011a]. SPARROW results can be used to rank sub-basins within the larger tributary watersheds and describe relative differences in the importance of nutrient sources among sub-basins.

The process for calibrating SPARROW models is designed to provide an identification of the factors affecting water quality and their relative importance through the combined use of a mechanistic model structure and statistical estimation of model coefficients.

The USGS National Water Quality Assessment program developed 12 SPARROW watershed models for six major river basins in the continental United States. Nutrient estimates for Minnesota were based upon the SPARROW Major River Basin 3 (MRB3) model developed by Robertson and Saad (2011). The MRB3 model for TN was based on data from 708 monitoring stations located throughout North Dakota, Minnesota, Wisconsin, Michigan, Iowa, Illinois, Missouri, Indiana, Ohio, Kentucky, Tennessee, West Virginia, Pennsylvania, and New York. Water quality data from 1970 to 2007 were used to estimate long-term detrended loads (to 2002) at each site. The SPARROW TN model for the Upper Midwest (Robertson and Saad, 2011) incorporates five different nutrient sources, five climatic and landscape factors that influence delivery to streams, and nutrient removal in streams and reservoirs.

More information about the SPARROW model, and specifically the MRB3 modeling effort, can be found in Robertson and Saad (2011) and in Appendix B4-1.

Delivered total nitrogen load and yield results

Major basins

Major basins in Minnesota, as represented by SPARROW model catchments, are depicted in Figure 1. A small fraction of SPARROW catchments extend into neighboring states or Canada. The portion of the Missouri River Basin in the southwestern corner of the state was not part of the MRB3 modeling effort.

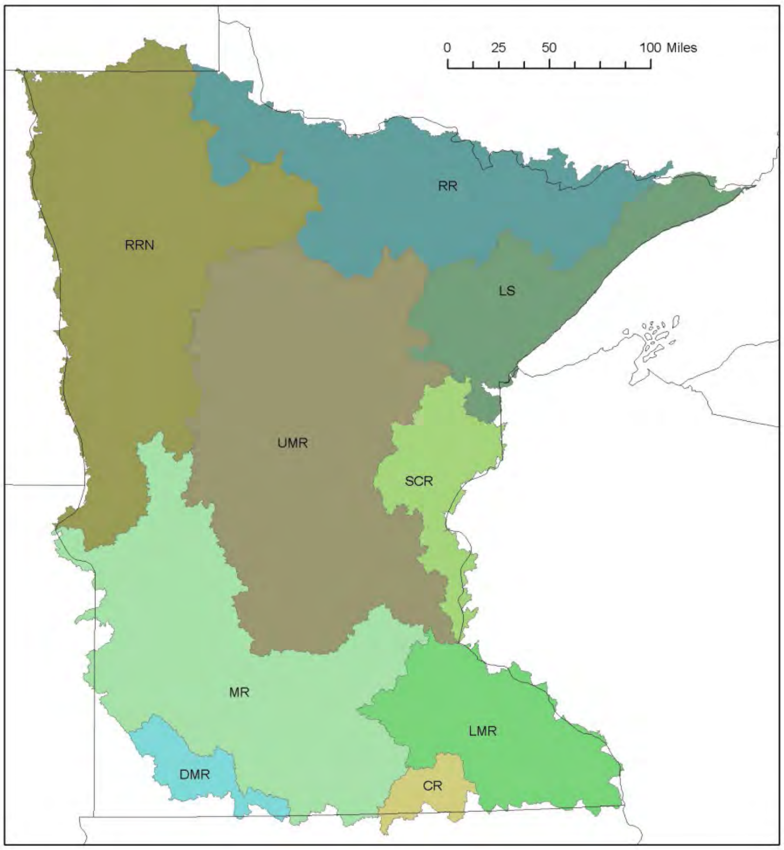

Figure 1. Minnesota Major Basins as represented by SPARROW Catchments. RRN (Red River of the North); UMR (Upper Mississippi River); RR (Rainy River); LS (Lake Superior); SCR (St. Croix River); LMR (Lower Mississippi River); MR (Minnesota River); DMR (Des Moines River); CR (Cedar River).

SPARROW model estimates of TN loads and yields delivered to the outlets of Minnesota's major basins are shown in Table 1 and Figures 2 and 3. In situations where the major river in the basin leaves the state before reaching the outlet of the basin, the SPARROW results in Table 1 and Figures 2 and 3 only include the N loads at the state boundary.

The highest N-yielding basins are the Cedar River and Minnesota River Basins, followed by the Lower Mississippi River Basin in southeastern Minnesota. The Minnesota River Basin had the highest N loads, contributing about half of Minnesota's N load into the Mississippi River. Total nitrogen yield for the entire Minnesota River Basin is 13.3 pounds/acre/year. By comparison, the low-yielding basins, such as the Rainy and Lake Superior Basins had TN loads of 0.8 and 1.8 pounds/acre/year.

Table 1. SPARROW model estimated TN loads and yields at the major basin outlets.

Basin	SPARROW **load** (lbs) at basin outlet or state border - MN contribution only (TN)	SPARROW **yield** (lbs/acre) at basin outlet or state border - MN contribution only (TN)
Lake Superior	7,153,338	1.8
Upper Mississippi River	55,451,315	4.3
Minnesota River	127,206,486	13.1
St. Croix River	7,583,476	3.3
Lower Mississippi River	47,264,258	11.7
Cedar River	14,902,044	22.7
Des Moines River	9,887,368	10.4
Red River of the North	37,216,336	3.2
Rainy River	5,737,840	0.80

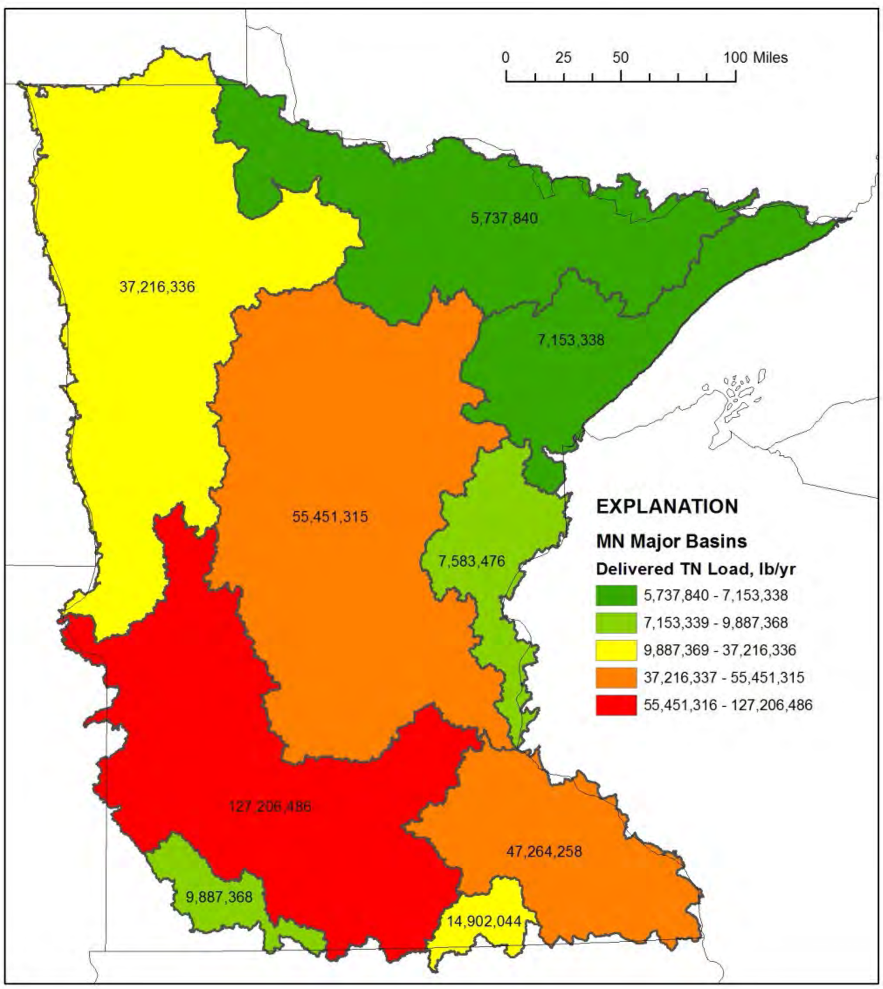

Figure 2. Total nitrogen load from each major basin in pounds/year. The basin loads represent the sum of the delivered incremental loads for each of the SPARROW (MRB3 2002) catchments, where the delivery targets are the basin outlets or state border.

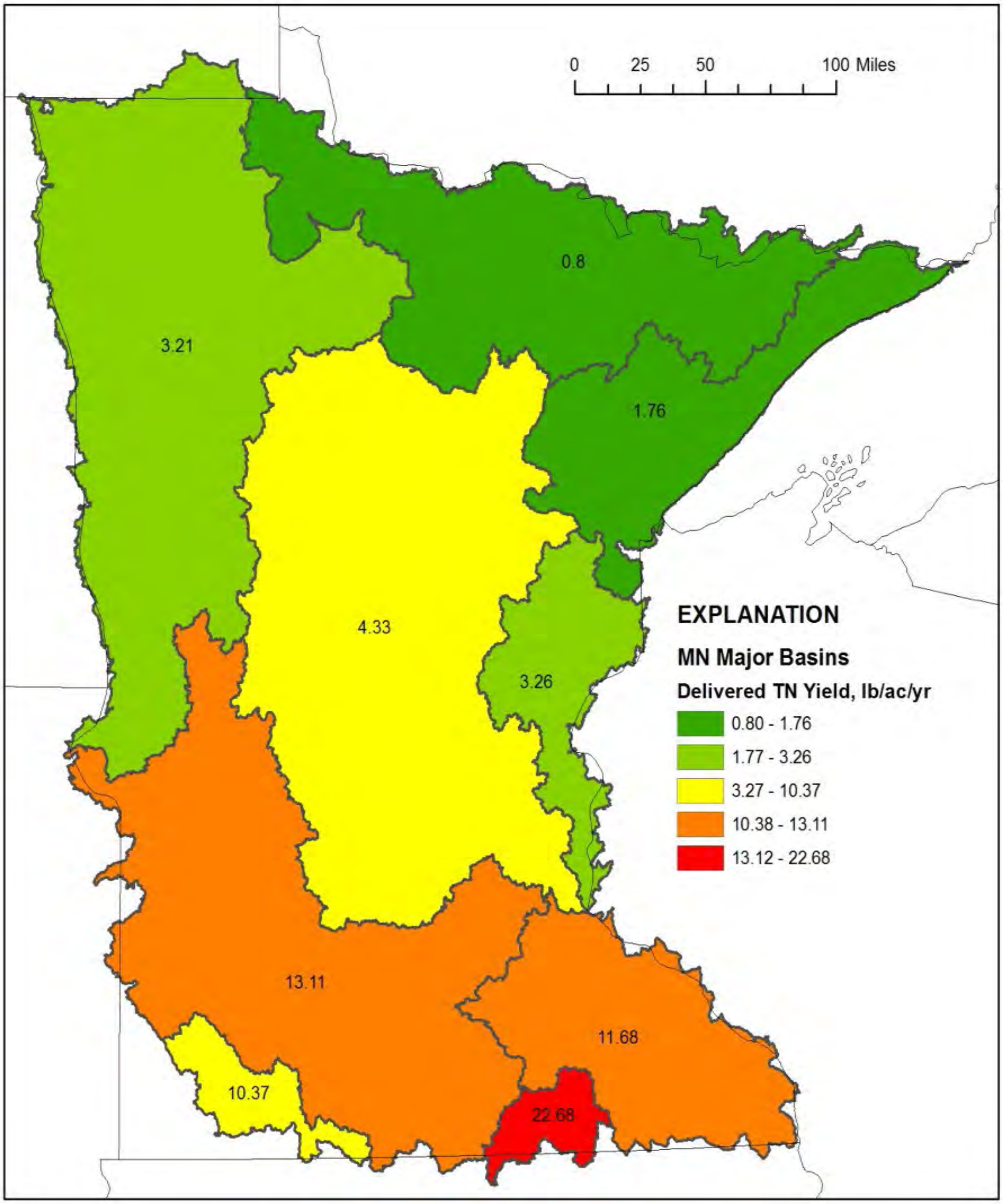

Figure 3. Annual TN yield results by major basin in pounds/acre/year. The basin yields represent the total load delivered to the basin outlet or state border divided by the sum of the SPARROW (MRB3) catchment areas.

Several of the major basins in Minnesota have large areas which extend into neighboring states or Canada. For example, nearly half of the St. Croix Basin lies in Wisconsin and over half of the Red River Basin flowing out of the United States lies in North Dakota. Loads from these areas are not reflected in the model results shown above. The SPARROW mapper tool was used by the MPCA to estimate the amount of N delivered from catchments in these neighboring states (Table 2). The results indicate that St. Croix River TN loads coming into Stillwater, Minnesota, are nearly half from Minnesota (52.2%) and nearly half from Wisconsin (47.8%).

Table 2. Estimated fraction of N coming from Minnesota and neighboring state catchments.

Basin or Watershed	Minnesota Load	Neighboring states load
Minnesota River Basin	96.0%	4.0%
Red River Basin (at Canadian Border)	47.6%	52.4%
St. Croix River Basin (at Stillwater)	52.2%	47.8%
Lower Mississippi River Basin (between Red Wing, MN and Victory, WI at the Iowa Border)	39.3%	60.7%
Blue Earth Watershed at confluence with Watonwan River	81.0%	19.0%

HUC8 watersheds

The SPARROW model was used to estimate HUC8 watershed TN loads at the delivery point of the outlet of the watershed (or near the state boundary where watershed boundaries are cut off by state boundaries). This delivery point only incorporates N losses which occur within the HUC8 watershed. Other model scenarios using different delivery points are discussed later.

The modeled load results at the HUC8 outlets (spacial scheme 1) are shown in Figure 4. The annual loads are directly related to watershed size, with larger watersheds producing higher loads than smaller watersheds with equal yields. If everything else but watershed size is equal, the larger watersheds will have higher loads than the smaller watersheds. Annual yields are a better means to describe the spatial differences in amounts of N being delivered to waters across the state. SPARROW TN yields are shown in Figure 5.

The south-central portion of the state has the highest N yields, with 15-25 pounds/acre/year. The Mississippi River Twin Cities watershed also has a high yield, with 17.4 pounds TN/acre/year delivered to the outlet of the watershed. Most northern Minnesota watersheds yield between 0.1 and 3 pounds/acre, with the exception of watersheds along the Red River, which yield 4- 6 pounds TN/acre/year.

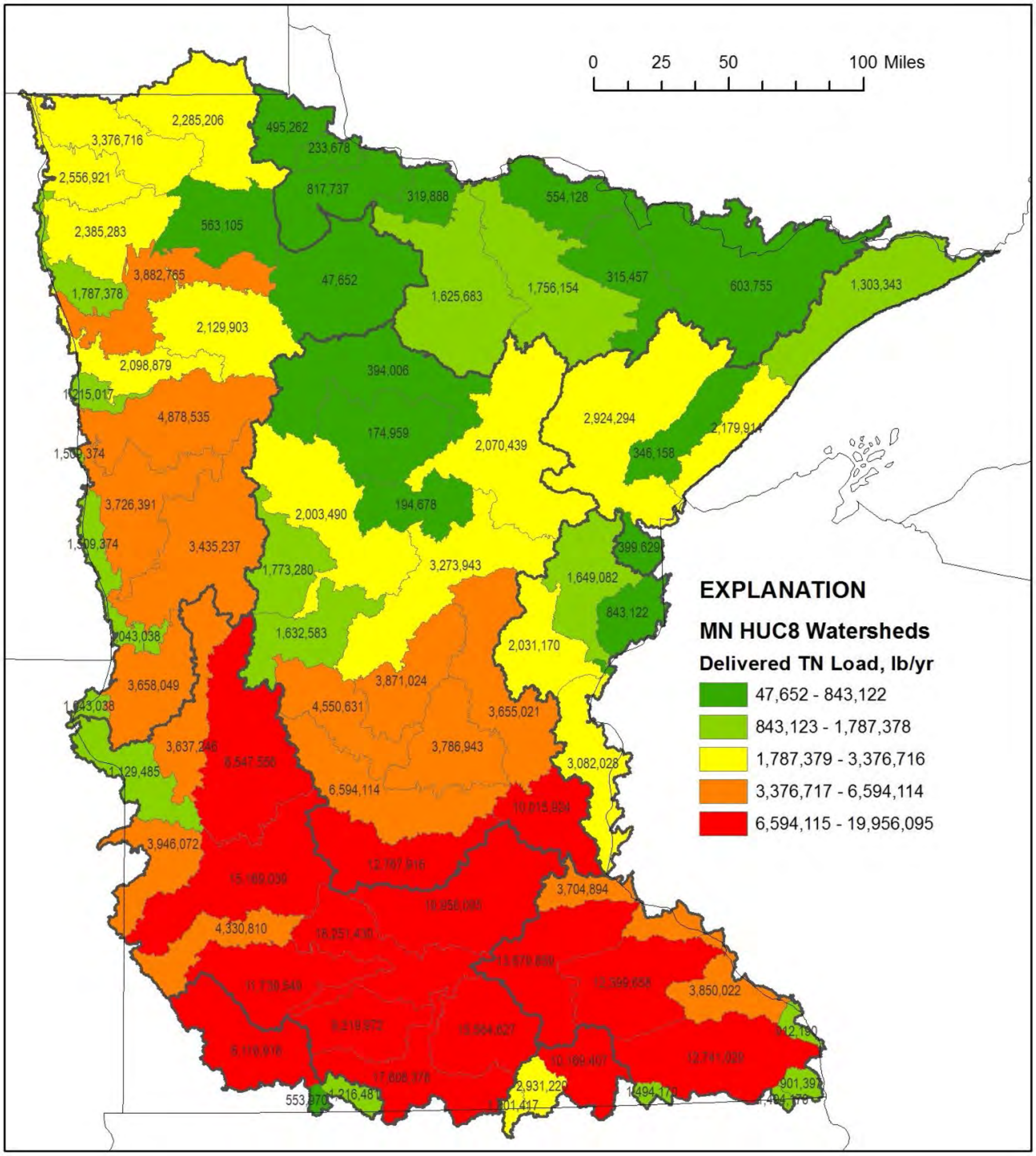

Figure 4. Simulated annual TN load results by HUC8 watershed in pounds/year. The delivery targets are the watershed outlets (or state border where watersheds are divided by a state border).

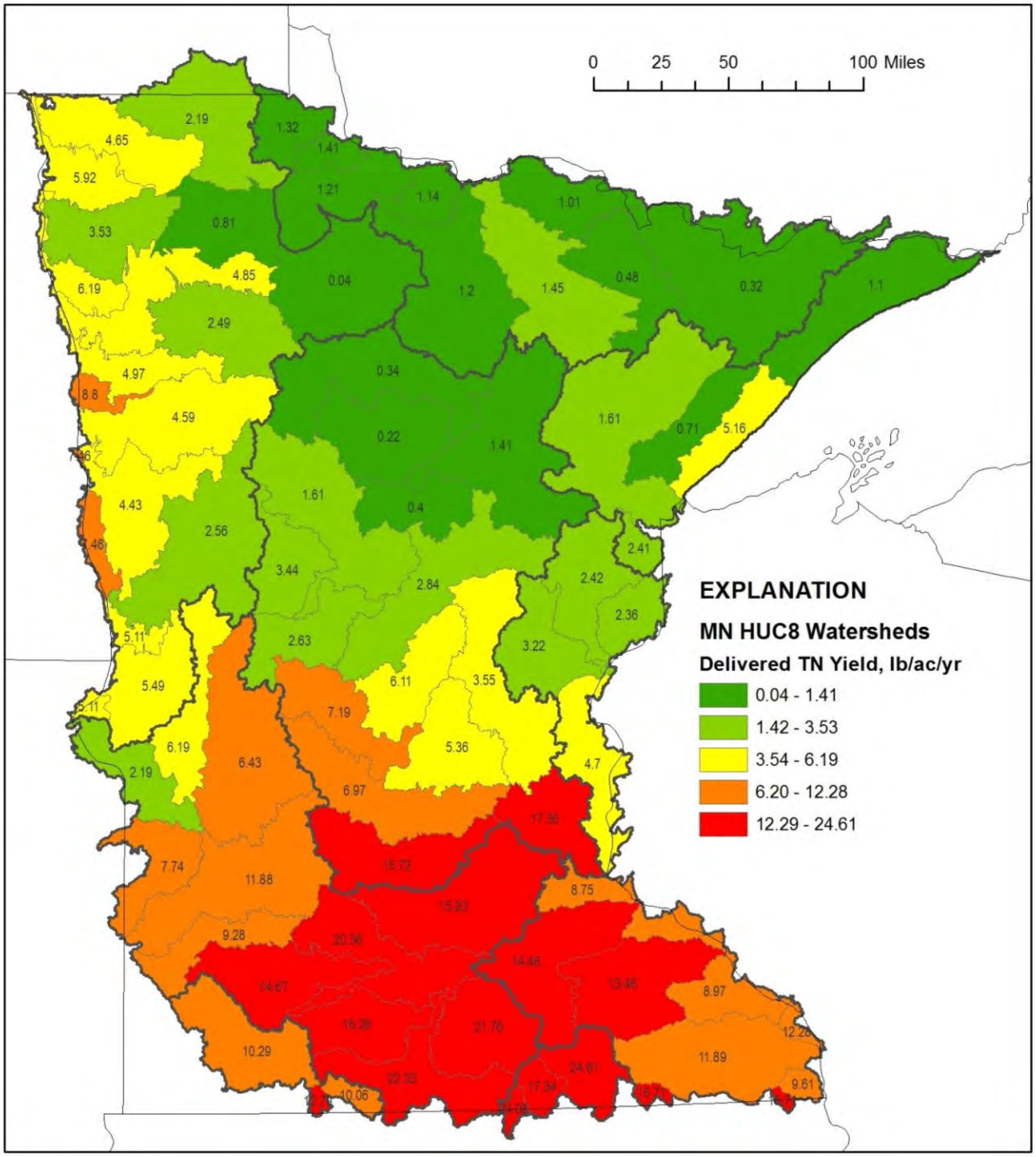

Figure 5. Simulated annual TN yield by HUC8 watershed in pounds/acre/year. Basin yields represent the total load delivered to the watershed outlet (or state border for watersheds straddling the state border) divided by the sum of the catchment area.

The flow-weighted mean TN concentrations generally had a similar pattern as the TN yield map, with the south-central watersheds having the highest concentrations (Figure 6). The FWMC represents the load/flow, whereas yield represents load/area. While the FWMC and yield maps should have many similarities, they are not expected to be identical. The SPARROW FWMC map does not show the FWMCs for the entire HUC8, but rather shows the median of FWMCs of all of the smaller subwatersheds within the HUC8. Therefore, in HUC8 watersheds, such as the Mississippi River Twin Cities, where large loads from the wastewater treatment plant discharge in a single small subwatershed, the median subwatershed FWMC does not accurately portray the true FWMC that would be measured at the HUC8 outlet.

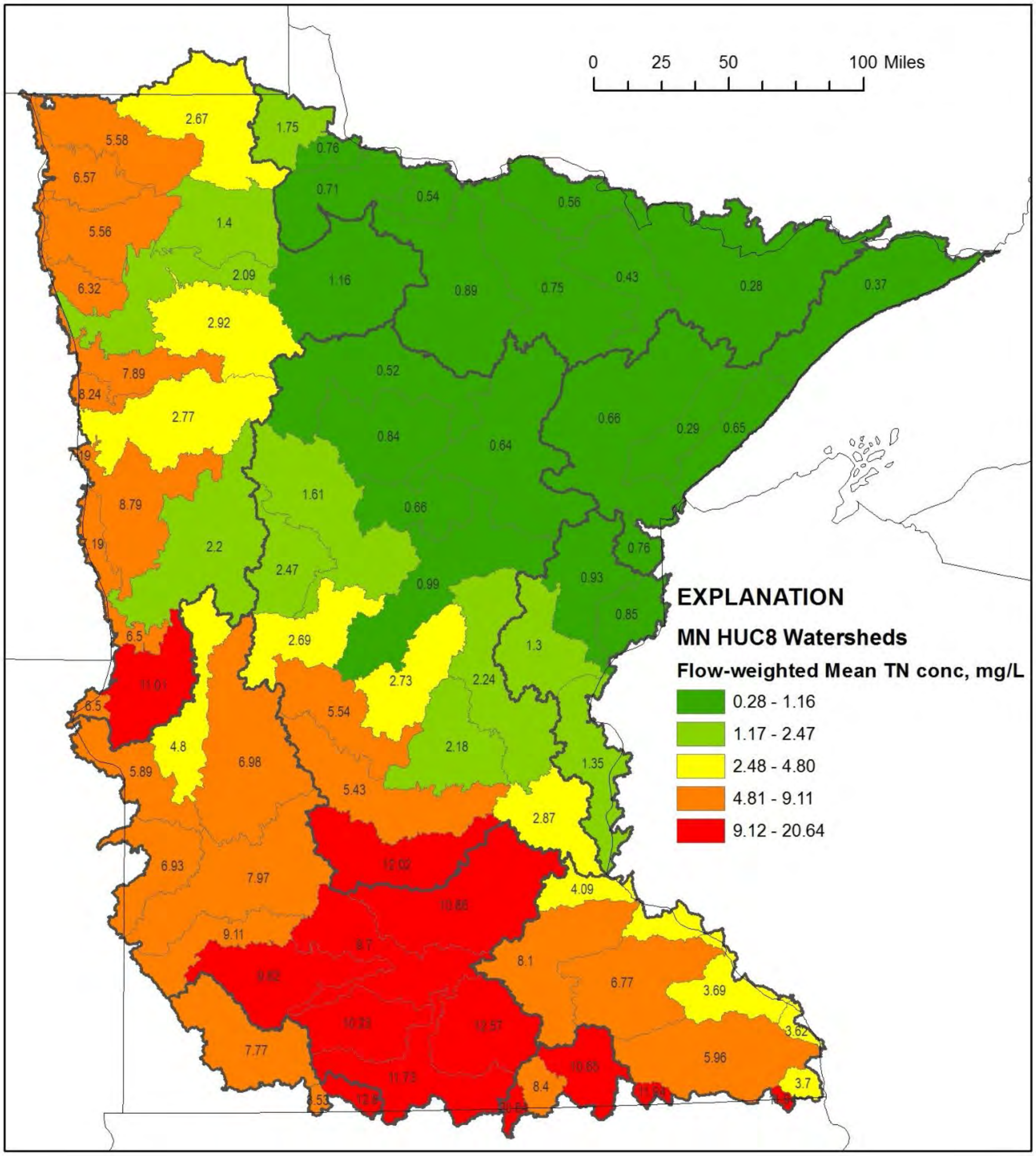

Figure 6. SPARROW flow-weighted mean TN concentration by HUC8 watersheds. The value represents the median FWMC of all subwatershed catchments within the HUC8 watersheds.

Subwatershed yields

Total nitrogen yields were also estimated for the SPARROW subwatershed outlets (Figure 7). The results indicate that there can be N yield variability within the same HUC8 watershed. Some subwatersheds stand out as being particularly high N yielding watersheds, surrounded by much lower yielding watersheds. These "islands" of high yields typically reflect metropolitan wastewater discharges from large urban areas such as the Twin Cities, Duluth, and Rochester. When the point sources are removed from the analysis, then the red and orange islands for Minneapolis, Duluth, and Rochester are not visible (Figure 8).

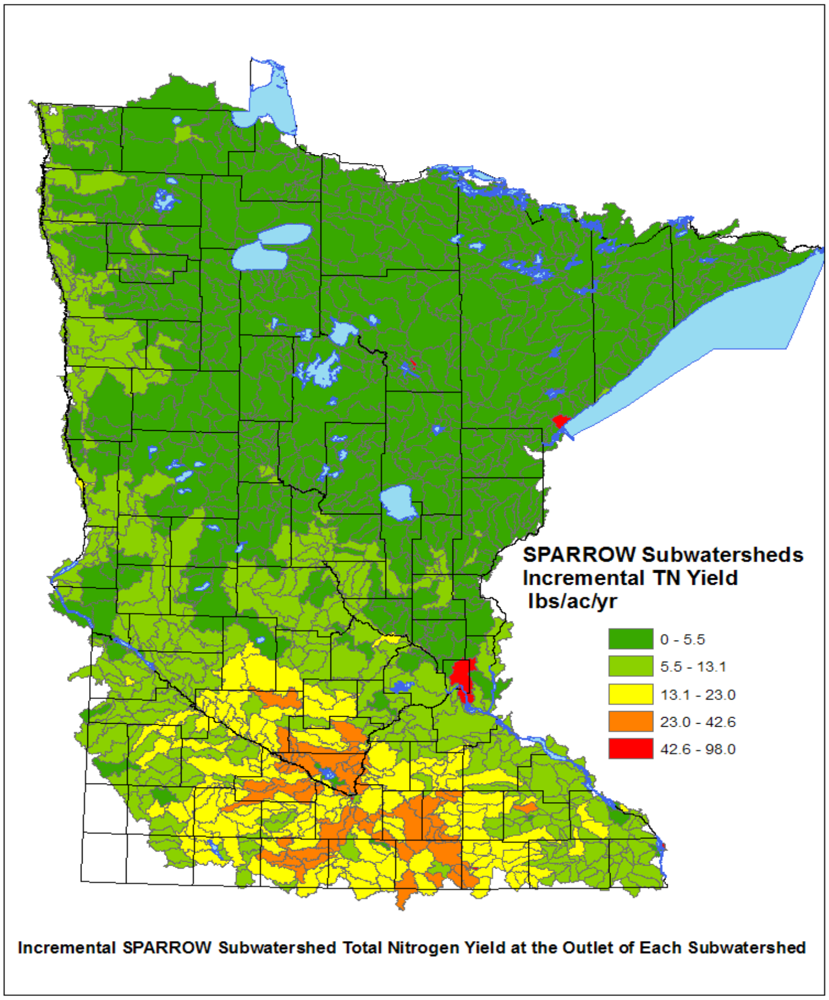

Figure 7. Total nitrogen yield for each SPARROW subwatershed, including both point and nonpoint sources of N delivered to the subwatershed outlet.

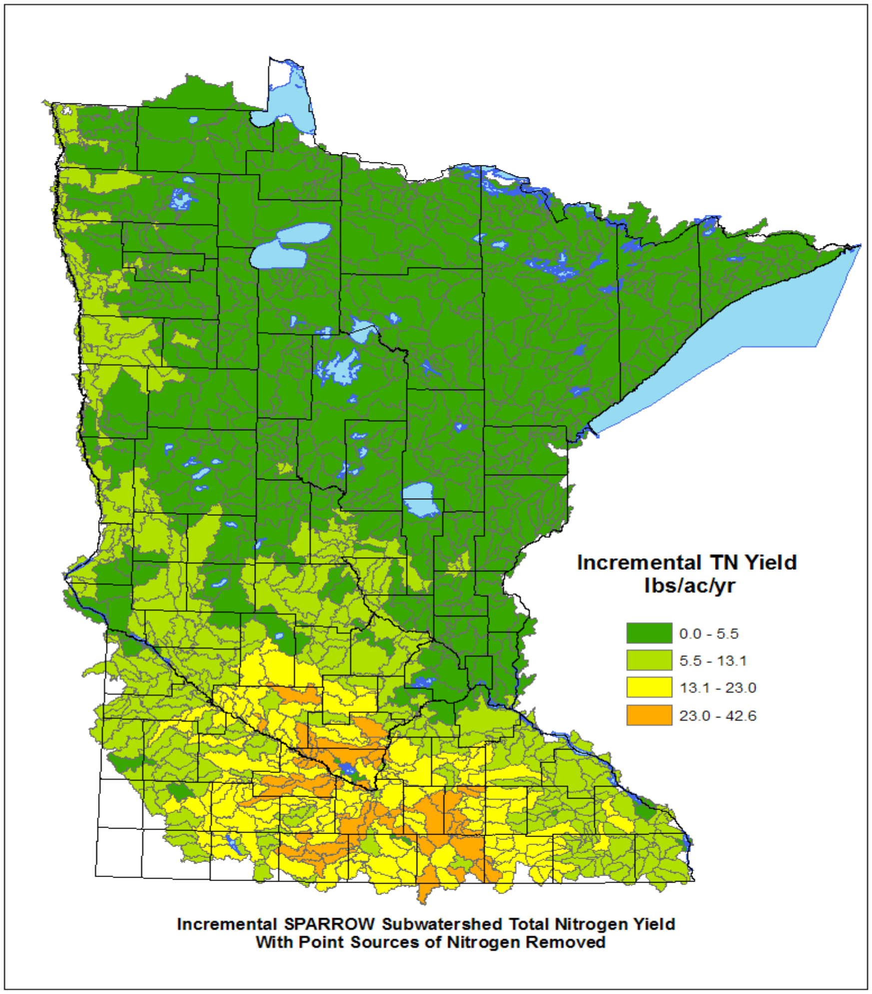

Figure 8. Total nitrogen yield for each SPARROW subwatershed watershed with urban wastewater point sources removed from the analysis. TN delivered to the subwatershed outlet.

Comparing SPARROW and recent monitoring load estimates

The SPARROW model is developed from monitoring results at numerous long-term monitoring stations, and the model is validated with independent monitoring stations. We decided to further validate the model results by comparing the SPARROW HUC8 load estimates at the watershed outlets to 29 recent monitoring-based load estimates. The monitored loads used for the comparisons were not used in the development of the SPARROW model, and thus provide an independent comparison of the general relationship between SPARROW model and short-term monitoring-based load and yield averages.

The monitoring-based estimates used for the comparisons represent two-year averages from years when flow was not high or low, with neither year in the upper or lower quartile of historical annual river flow. The years used to represent typical flows for the different regions of the state were:

- Northwest Minnesota: 2007 and 2008 (2009 was a high flow year)
- Southwest and South Central Minnesota: 2007 and 2008 (2009 was a low flow year)
- Northeast Minnesota: 2008 and 2009 (2007 was a low flow year)
- Southeast Minnesota: 2005 and 2006 (2007 was high flow; 2008 varied; 2009 low flow)

Plots of the HUC8 monitored loads verses the HUC8 SPARROW loads showed good correlation, with an R-squared of 0.85 (Figure 9). While most of the HUC8 SPARROW and monitored watersheds were in reasonably close agreement, there are a few outliers. The monitoring-based loads have a range of uncertainty largely because the monitoring-based loads represent an average of only two years of data, each year having different annual and seasonal precipitation scenarios.

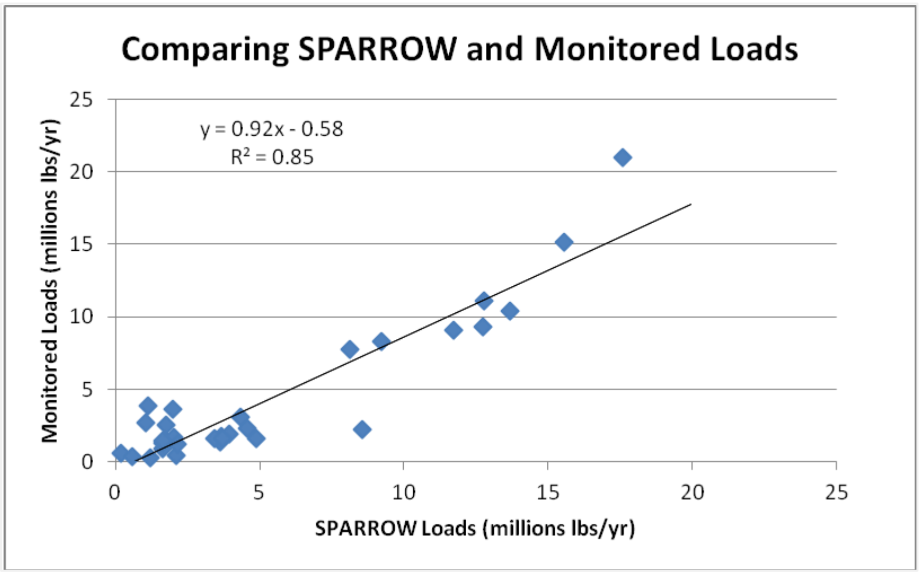

Figure 9. HUC8 watershed outlet SPARROW modeled loads plotted against monitoring-based load estimates developed from the average of two typical flow years between 2005 and 2009.

SPARROW loads were higher in the northwestern part of the Minnesota River Basin than the monitoring-based loads. The Pomme de Terre watershed SPARROW loads were 3.6 million pounds/year, compared to 1.3 million pounds/year from the 2007-08 monitoring-based average.

The Chippewa watershed SPARROW loads were 8.5 million pounds/year, whereas the 2007-08 monitoring average was 2.2 million pounds/year. The 2007-08 monitoring results are somewhat lower for the Chippewa than the estimated loads calculated over the entire period between 2000 and 2008, which averaged 3 million pounds/year. Nonetheless, the SPARROW loads for the Chippewa River remain considerably higher than the monitoring-based loads. The SPARROW model also predicted substantially higher loads in the Red River Basin, as compared to 2007-08 monitoring-based averages. The long-term average SPARROW results for the Buffalo, Wild Rice River, and Sandhill River were more than double the monitoring-based average for the two years.

A comparison of the SPARROW yields with monitoring-based yield averages shows a slightly improved correlation compared to the loading correlation, with an R-squared of 0.90 (Figure 10). The yield correlation is expected to be better than the load correlation, since the monitoring and modeled watershed catchment areas are different for many of the watersheds, and these differences are largely normalized with yields (in pounds per watershed acre per year). Overall, SPARROW yields are higher than the two year monitoring-based average yields.

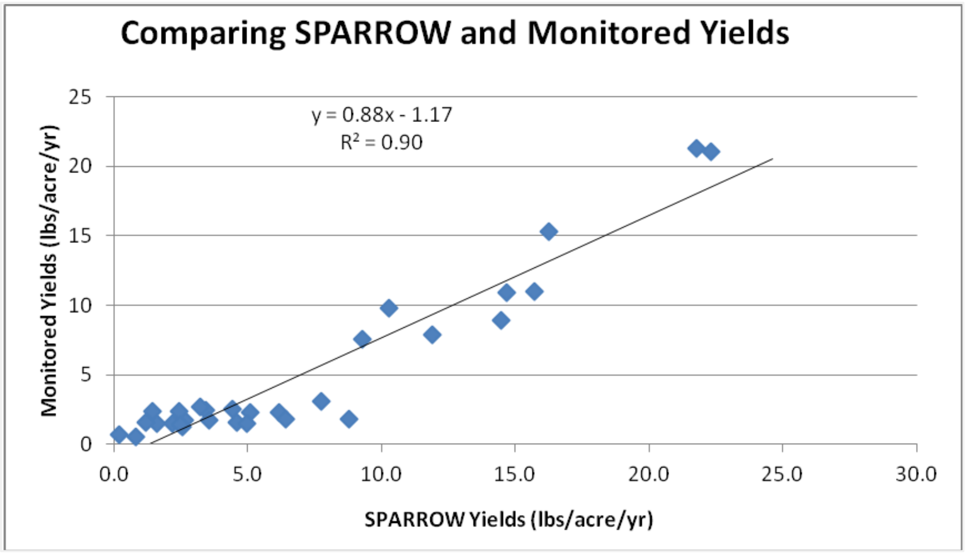

Figure 10. HUC8 watershed outlet SPARROW modeled yields plotted against monitoring-based load estimates from the average of two typical flow years between 2005 and 2009.

In summary, neither the model or two-year monitoring-based results are an exact representation of actual long term loads. However, the fact that these independently derived sources of load information correlate well gives us greater confidence that both the model results and monitoring results are providing reasonable estimates of watershed N loads in most watersheds.

Total nitrogen delivery to downstream waters

Nitrogen delivery between HUC8 watershed outlets and various downstream delivery points

In addition to examining SPARROW results at the outlet of each HUC8 watershed, the SPARROW model results were determined for two additional delivery points. These downstream points account for TN losses expected to occur as the river flows downstream. Delivery from an upstream reach to a downstream reach in the model (MRB3) is based on in-stream first–order exponential N decay, occurring as a function of three variables: travel time, streamflow (serving as a surrogate for channel depth), and the presence or absence of a reservoir. Stream N decay is not simulated for reach flow rates greater than 70 cubic feet per second. Reservoir loss is based upon the overflow rate of the reservoir (average outflow rate divided by surface area). Only reservoirs listed in the National Inventory of Dams are included in the MRB3 model, which resulted in the inclusion of 136 reservoirs in Minnesota.

The following additional schemes were examined to incorporate estimated N losses occurring after leaving the output point of the HUC8 watershed:

> Delivery Scheme 2 -Loads delivered from individual HUC8 watersheds to the state boundaries, including the Canadian border for the Red River and Roseau River, Lake Superior, and the Minnesota/Iowa border (De Soto, Iowa) for watersheds draining through Minnesota into the Mississippi River. Watersheds in the Des Moines and Cedar River Basins were not included because rivers from these areas leave Minnesota before reaching the Mississippi River. This delivery point incorporates all losses within HUC8 watersheds and all losses in rivers between the HUC8 outlets and the state borders.

Delivery Scheme 3 - Loads delivered from individual HUC8 watersheds to the Canadian border and Lake Superior in the northern part of the state and the Mississippi River in southern Iowa (Keokuk) for all watersheds draining into the Mississippi River. Keokuck, Iowa is at a point where water from the Des Moines and Cedar Rivers has entered the Mississippi River. Scheme 3 is similar to Scheme 2, but includes a delivery target which is further downstream on the Mississippi River. Since some N losses occur within the Mississippi River between De Soto, Iowa and Keokuk, Iowa, the delivered loads for Scheme 3 will be lower than Scheme 2 for all watersheds draining into the Mississippi River.

Results for all three schemes (different delivery points) are summarized in Table 3. The patterns in loads and yields for Schemes 2 and 3 are generally similar to the loads and yields at the HUC8 outlets. Nitrogen losses between the HUC8 outlet and the state border are between 10 and 16% for a majority of watersheds. Yet, in-river N loss estimates were about 34% for watersheds which have lengthy flow paths between the HUC8 watershed outlets and state border, such as in the Pomme de Terre and Lac Qui Parle in the Minnesota River Basin, and the Mississippi Headwaters and Leech Lake River in the Upper Mississippi River Basin. SPARROW results indicate that the statewide net N loss between the HUC8 outlets and the state borders is 9.7%.

If we only consider those watersheds which drain to the Mississippi River (thus excluding the Red River, Lake Superior, and Rainy River Basins), the net N loss between the outlets and the state border in De Soto, Iowa (near the Minnesota border) is 10.0%, and net loss increases to a total of 20.1% between HUC8 outlets and the Mississippi River in Southern Iowa (Keokuk). Therefore, the SPARROW model results indicate that about an additional 10% of the TN is lost in the Mississippi River along the length of the Iowa border between Minnesota and Missouri.

Table 3. SPARROW modeled delivered loads and yields for Minnesota HUC8 watersheds.

HUC8 Name	HUC8 #	SPARROW load at watershed outlet (TN lbs/yr)	Sparrow yield at watershed outlet (TN lbs/acre)	SPARROW delivered load to state border (TN lbs/yr)	SPARROW delivered load. State border in Northern MN and Keokuk, Iowa for Mississippi R. (TN lbs/yr)
Lake Superior - North	04010101	1,303,343	1.1	1,303,343	1,303,343
Lake Superior - South	04010102	2,179,914	5.2	2,179,914	2,179,914
St. Louis River	04010201	2,924,294	1.6	2,924,294	2,924,294
Cloquet River	04010202	346,158	0.7	346,158	346,158
Nemadji River	04010301	399,629	2.4	399,629	399,629
Mississippi River - Headwaters	07010101	394,006	0.3	259,163	235,807
Leech Lake River	07010102	174,959	0.2	115,082	104,710
Mississippi River - Grand Rapids	07010103	2,070,439	1.4	1,774,866	1,614,914
Mississippi River - Brainerd	07010104	3,273,943	2.8	2,875,635	2,616,481
Pine River	07010105	194,678	0.4	166,886	151,846
Crow Wing River	07010106	2,003,490	1.6	1,754,041	1,595,966
Redeye River	07010107	1,773,280	3.4	1,484,104	1,350,356
Long Prairie River	07010108	1,632,583	2.6	1,366,351	1,243,215
Mississippi River - Sartell	07010201	3,871,024	6.1	3,404,125	3,097,343
Sauk River	07010202	4,550,631	7.2	4,001,762	3,641,121

HUC8 Name	HUC8 #	SPARROW load at watershed outlet (TN lbs/yr)	Sparrow yield at watershed outlet (TN lbs/acre)	SPARROW delivered load to state border (TN lbs/yr)	SPARROW delivered load. State border in Northern MN and Keokuk, Iowa for Mississippi R. (TN lbs/yr)
Mississippi River - St. Cloud	07010203	3,786,943	5.4	3,334,766	3,034,234
North Fork Crow River	07010204	6,594,114	7.0	5,806,749	5,283,441
South Fork Crow River	07010205	12,767,916	15.7	11,243,373	10,230,112
Mississippi River - Twin Cities	07010206	10,015,924	17.4	8,995,296	8,184,634
Rum River	07010207	3,655,021	3.6	3,218,596	2,928,534
Minnesota River - Headwaters	07020001	1,129,485	2.2	997,540	907,641
Pomme de Terre River	07020002	3,637,246	6.2	2,410,134	2,192,932
Lac Qui Parle River	07020003	3,946,072	7.7	2,614,770	2,379,125
Minnesota River - Yellow Medicine River	07020004	15,169,039	11.9	13,397,022	12,189,673
Chippewa River	07020005	8,547,556	6.4	7,549,047	6,868,722
Redwood River	07020006	4,330,810	9.3	3,824,893	3,480,191
Minnesota River - Mankato	07020007	18,251,430	20.4	16,119,333	14,666,648
Cottonwood River	07020008	11,739,549	14.7	10,368,158	9,433,772
Blue Earth River	07020009	17,608,376	22.3	15,551,400	14,149,897
Watonwan River	07020010	9,219,972	16.3	8,142,913	7,409,068
Le Sueur River	07020011	15,564,627	21.8	13,746,398	12,507,563
Lower Minnesota River	07020012	19,956,095	15.9	17,624,863	16,036,499
Upper St. Croix River	07030001	843,122	2.4	753,537	685,628
Kettle River	07030003	1,649,082	2.4	1,473,861	1,341,036
Snake River	07030004	2,031,170	3.2	1,815,350	1,651,750
Lower St. Croix River	07030005	3,082,028	4.7	2,767,967	2,518,516
Mississippi River - Lake Pepin	07040001	3,704,894	8.7	3,397,700	3,091,497
Cannon River	07040002	13,679,859	14.5	12,545,584	11,414,967
Mississippi River - Winona	07040003	3,850,022	9.0	3,719,674	3,384,455
Zumbro River	07040004	12,399,658	13.5	11,774,379	10,713,264
Mississippi River - La Crescent	07040006	912,190	12.3	897,794	816,884
Root River	07040008	12,741,029	11.9	12,539,952	11,409,843
Mississippi River - Reno	07060001	901,397	9.6	901,397	820,162
Upper Iowa River	07060002	1,494,170	16.7	1,487,777	1,353,697
Cedar River	07080201	10,169,407	24.6	10,169,407	9,596,892
Shell Rock River	07080202	2,931,220	17.3	2,931,220	2,818,827
Winnebago River	07080203	1,801,417	24.1	1,801,417	1,732,345
Des Moines River - Headwaters	07100001	8,116,918	10.3	8,116,918	7,079,337
Lower Des Moines River	07100002	553,970	12.8	553,970	483,156
East Fork Des Moines River	07100003	1,216,481	10.1	1,216,481	1,065,658

HUC8 Name	HUC8 #	SPARROW load at watershed outlet (TN lbs/yr)	Sparrow yield at watershed outlet (TN lbs/acre)	SPARROW delivered load to state border (TN lbs/yr)	SPARROW delivered load. State border in Northern MN and Keokuk, Iowa for Mississippi R. (TN lbs/yr)
Bois de Sioux River	09020101	1,043,038	5.1	1,025,263	1,025,263
Mustinka River	09020102	3,658,049	5.5	629,665	629,665
Otter Tail River	09020103	3,435,237	2.6	3,376,696	3,376,696
Upper Red River of the North	09020104	1,509,374	7.5	1,491,545	1,491,545
Buffalo River	09020106	3,726,391	4.4	3,682,373	3,682,373
Red River of the North - Marsh River	09020107	1,215,017	8.8	1,204,886	1,204,886
Wild Rice River	09020108	4,878,535	4.6	4,820,908	4,820,908
Red River of the North - Sandhill River	09020301	2,098,879	5.0	2,082,969	2,082,969
Upper/Lower Red Lake	09020302	47,652	0.0	46,853	46,853
Red Lake River	09020303	3,882,765	4.8	3,836,901	3,836,901
Thief River	09020304	563,105	0.8	553,662	553,662
Clearwater River	09020305	2,129,903	2.5	2,104,744	2,104,744
Red River of the North - Grand Marais Creek	09020306	1,787,378	6.2	1,773,828	1,773,828
Snake River	09020309	2,385,283	3.5	2,367,201	2,367,201
Red River of the North - Tamarac River	09020311	2,556,921	5.9	2,556,921	2,556,921
Two Rivers	09020312	3,376,716	4.7	3,376,716	3,376,716
Roseau River	09020314	2,285,206	2.2	2,285,206	2,285,206
Rainy River - Headwaters	09030001	603,755	0.3	164,145	164,145
Vermilion River	09030002	315,457	0.5	90,610	90,610
Rainy River - Rainy Lake	09030003	554,128	1.0	234,682	234,682
Rainy River - Black River	09030004	319,888	1.1	319,888	319,888
Little Fork River	09030005	1,756,154	1.5	1,756,154	1,756,154
Big Fork River	09030006	1,625,683	1.2	1,625,683	1,625,683
Rapid River	09030007	817,737	1.2	817,737	817,737
Rainy River - Baudette	09030008	233,678	1.4	233,678	233,678
Lake of the Woods	09030009	495,262	1.3	495,262	495,262

Nitrogen delivery between subwatersheds and the Mississippi River or state borders

Further analysis was conducted to also incorporate losses in streams within the HUC8 and within the subwatersheds. The SPARROW model results indicate that over 90% of the N which leaves most subwatersheds remains in the water and is routed downstream to the Mississippi River (or state borders where subwatersheds are not a tributary to the Mississippi River) (Figure 11). Watersheds which lose more than 10% are typically those where lakes or reservoirs provide substantial N removal between the subwatershed outlet and the Mississippi River (or state border).

When we also consider SPARROW estimated losses within the subwatersheds, the fraction of N reaching the Mississippi River (or state border for non-tributaries to the Mississippi) is further reduced (Figure 12). Figure 12 illustrates the addition of the in-stream N losses occurring within the subwatersheds to the losses occurring after leaving the subwatersheds. The sum of these losses results in a 10 to 40% reduction of the delivery ratio in many of the source subwatersheds. Thus substantial N losses can occur in the smaller order streams within the subwatersheds.

A more thorough discussion of N losses within waters is included in Chapter B5 and associated appendices.

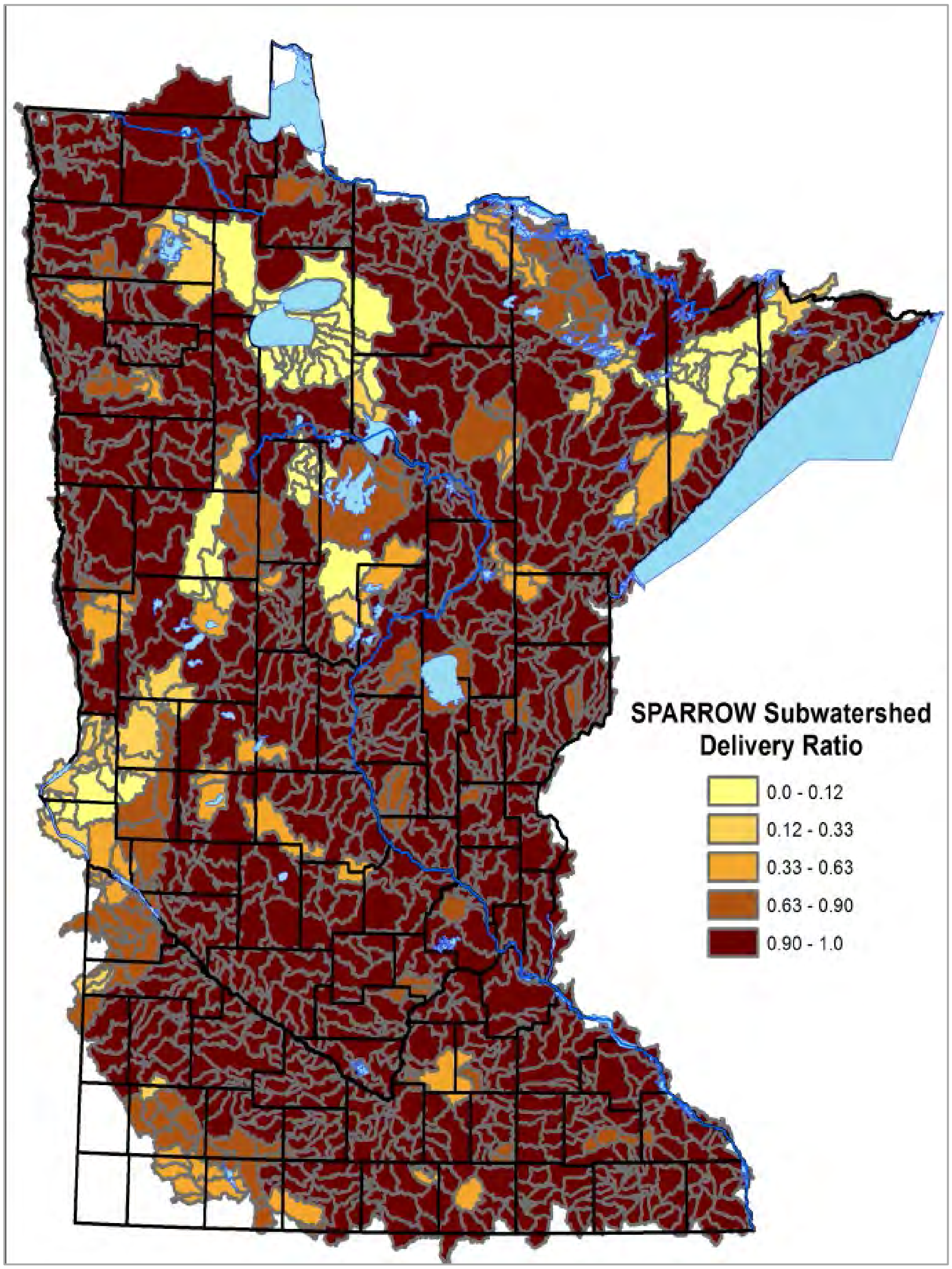

Figure 11. Ratio of N loads reaching state boundaries or the Mississippi River mainstem to N loads in waters leaving the SPARROW subwatersheds.

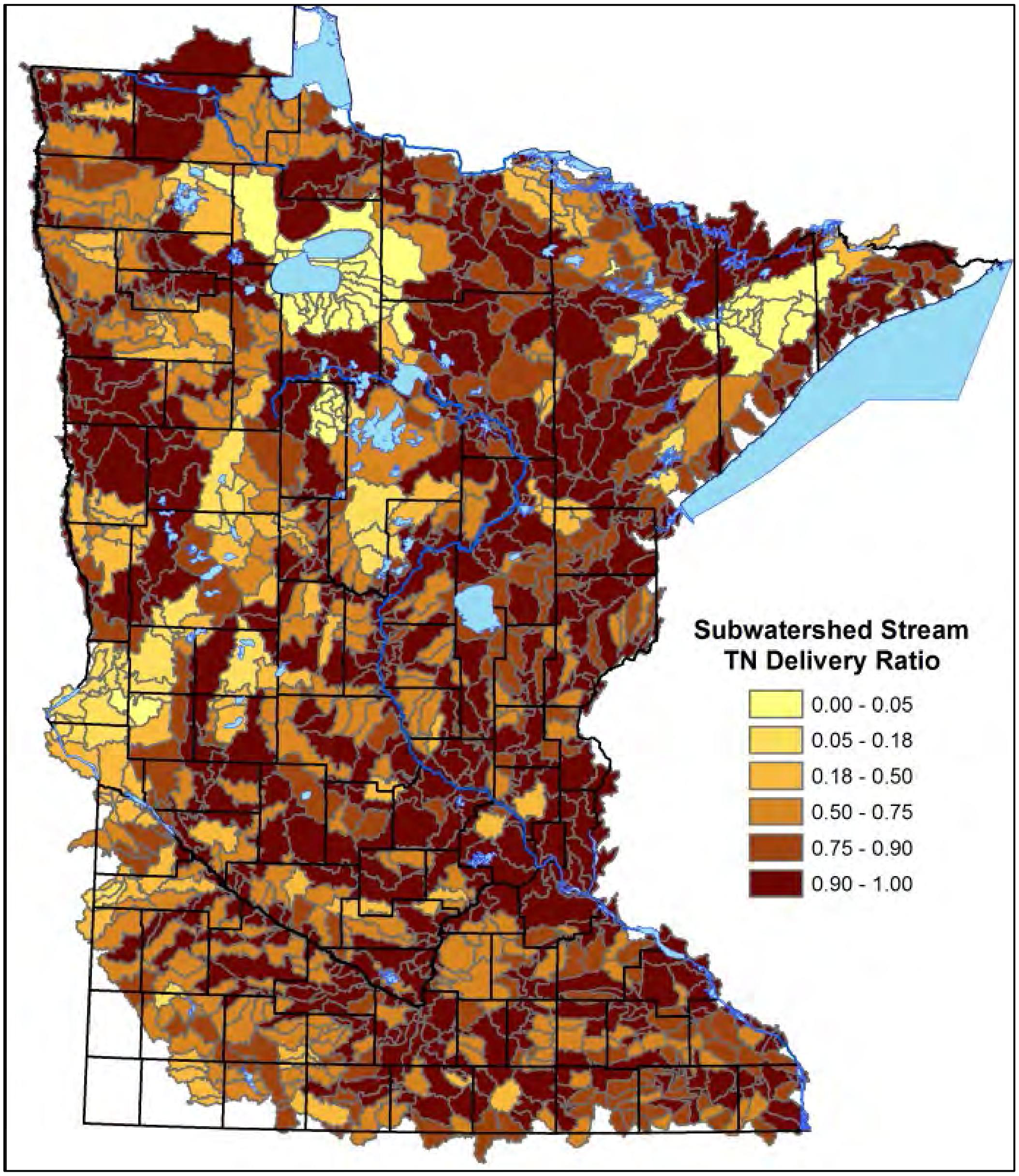

Figure 12. Ratio of N loads reaching state boundaries or the Mississippi River mainstem to N loads entering waters within the SPARROW subwatersheds. This figure includes in-stream losses within subwatersheds and within streams after leaving the subwatershed boundaries.

Highest contributing HUC8 watersheds to the Mississippi River

The TN load delivered to Keokuk, Iowa, from HUC8 Minnesota watersheds is 219,509,000 pounds/year. Fifteen of the 45 watersheds draining into the Mississippi River from Minnesota each contribute over 3% of the modeled load delivered to the Mississippi River in southern Iowa (Keokuk) (Table 4 and Figure 13). Combined, these 15 watersheds contribute 73.7% of the TN load delivered to Keokuk from Minnesota (Figure 10). The watersheds with the highest loads are mostly located in south-central and southeastern Minnesota. The other 30 watersheds each contribute between 0 and 2.4% of the total load, and are thus considered relatively minor contributors. Note that the watersheds listed in Table 4 show total load and are not the yields which are normalized based on watershed size.

Table 4. Percent contribution of the TN delivered to the Mississippi River in Keokuk, Iowa, from each of Minnesota's HUC8 Watersheds which ultimately drain into the Mississippi River.

Load ranking	WS #	Watershed name	% load contribution
1	33	Lower Minnesota River	7.3
2	28	Minnesota River - Mankato	6.7
3	30	Blue Earth River	6.4
4	32	Le Sueur River	5.7
5	25	Minnesota River - Yellow Medicine River	5.6
6	39	Cannon River	5.2
7	43	Root River	5.2
8	41	Zumbro River	4.9
9	19	South Fork Crow River	4.7
10	48	Cedar River	4.4
11	29	Cottonwood River	4.3
12	20	Mississippi River - Twin Cities	3.7
13	31	Watonwan River	3.4
14	51	Des Moines River - Headwaters	3.2
15	26	Chippewa River	3.1
16	18	North Fork Crow River	2.4
17	16	Sauk River	1.7
18	27	Redwood River	1.6
19	40	Mississippi River - Winona	1.5
20	15	Mississippi River - Sartell	1.4
21	38	Mississippi River - Lake Pepin	1.4
22	17	Mississippi River - St. Cloud	1.4
23	21	Rum River	1.3
24	49	Shell Rock River	1.3
25	10	Mississippi River - Brainerd	1.2
26	37	Lower St. Croix River	1.1
27	24	Lac Qui Parle River	1.1
28	23	Pomme de Terre River	1.0
29	50	Winnebago River	0.8
30	36	Snake River	0.8
31	9	Mississippi River - Grand Rapids	0.7
32	12	Crow Wing River	0.7
33	46	Upper Iowa River	0.6
34	13	Redeye River	0.6
35	35	Kettle River	0.6
36	14	Long Prairie River	0.6
37	53	East Fork Des Moines River	0.5
38	22	Minnesota River - Headwaters	0.4
39	44	Mississippi River - Reno	0.4
40	42	Mississippi River - La Crescent	0.4

Load ranking	WS #	Watershed name	% load contribution
41	34	Upper St. Croix River	0.3
42	52	Lower Des Moines River	0.2
43	7	Mississippi River - Headwaters	0.1
44	11	Pine River	0.1
45	8	Leech Lake River	<0.1
46	47	Upper Wapsipinicon River	<0.1

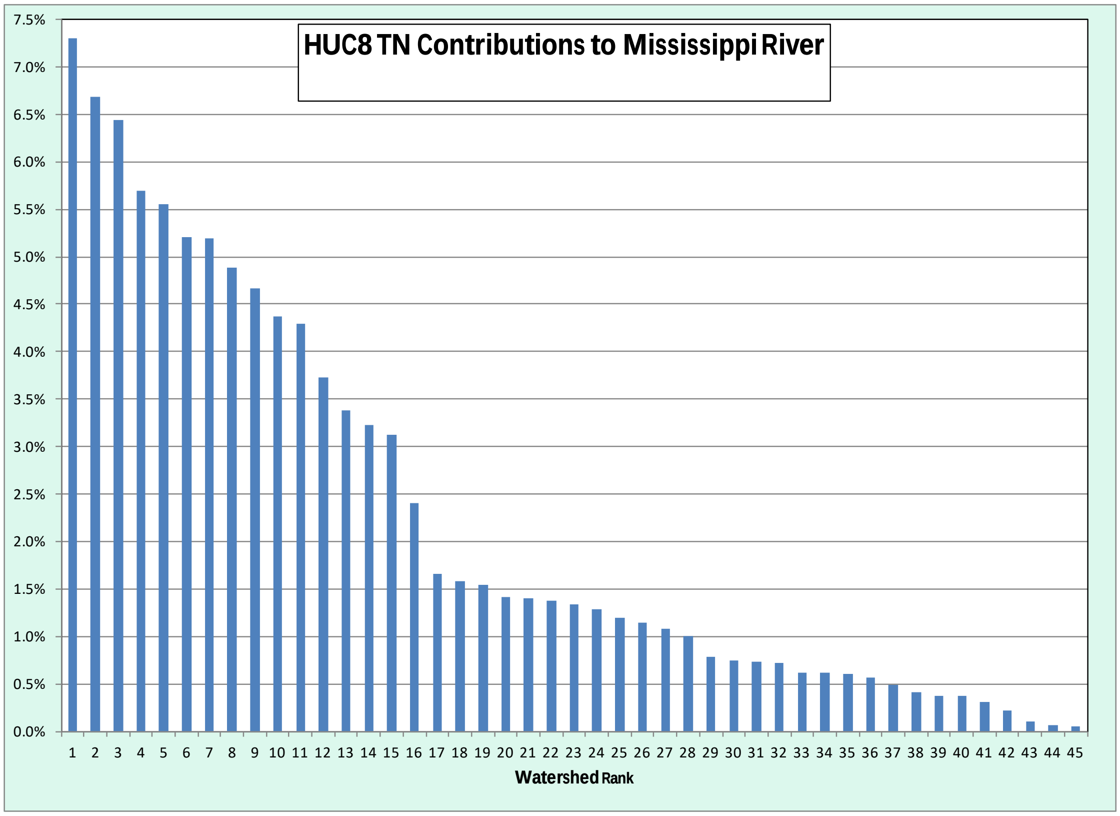

Figure 13. Ranking HUC8 watersheds based upon the contribution of N delivered to Keokuk, Iowa. Each bar represents the percentage of the TN originating from a single HUC8 watershed, from highest contributor (left) to lowest contributor (right).

Statewide, results of the SPARROW model indicate that the top 15 (of 81 total) HUC8 watersheds contribute about 63% of the total load leaving the state in all mainstem rivers (Figure 14). These results indicate that the N exports from the state cannot be solved by only making reductions in a few watersheds; yet substantial progress can be made by focusing on the top 10 to 20 contributing watersheds. The top 10 highest loading watersheds include those in the southern and eastern parts of the Minnesota River Basin and watersheds in the southeastern part of the state.

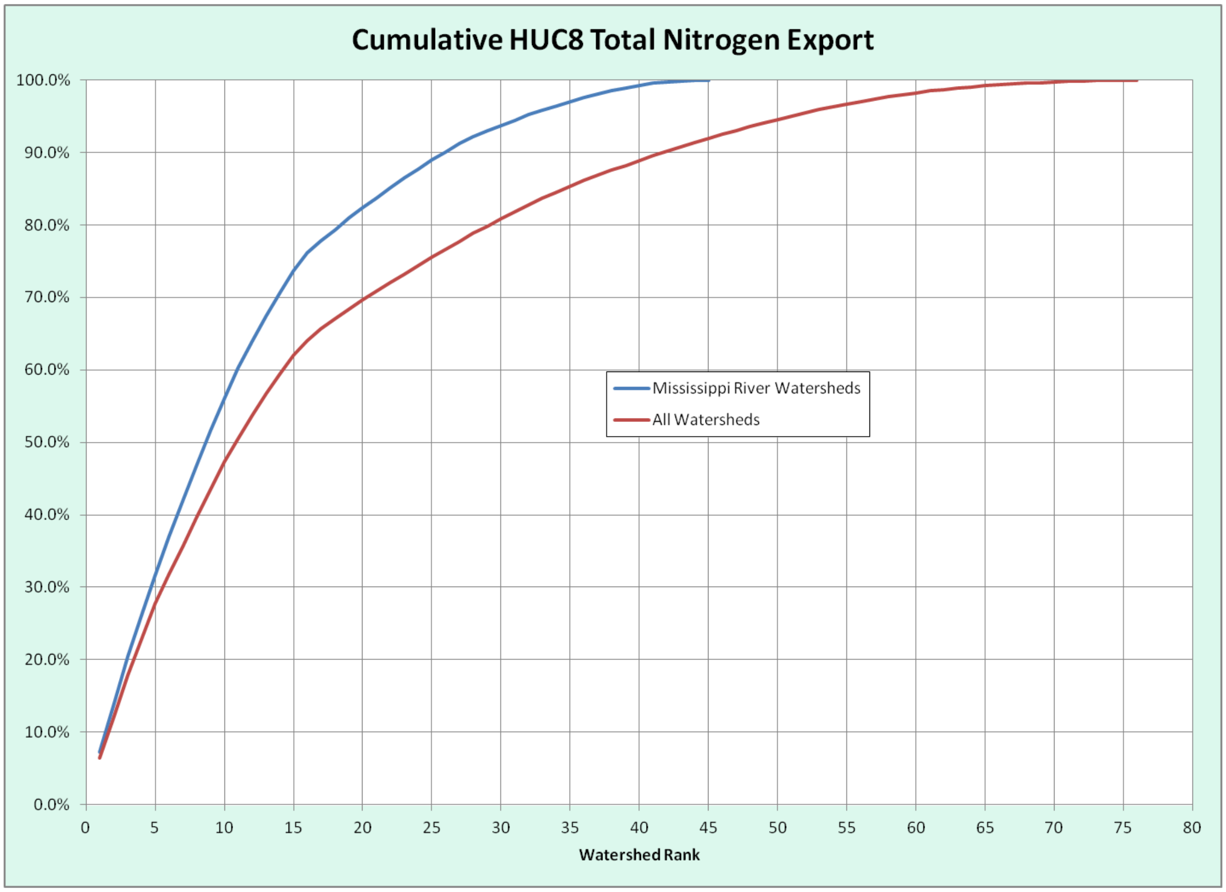

Figure 14. Cumulative TN load export by ranked HUC8 watersheds in Minnesota. Cumulative TN load delivery curves for all HUC8 watersheds in the state (blue line) and only those HUC8 watersheds draining to the Mississippi River (red line). The curves were developed by adding the watersheds in order of highest loaders (left) to lowest loaders (right).

Nitrogen sources estimated by SPARROW

The SPARROW model was not used for this study as our primary way to estimate nitrogen sources, but was instead used as a check against the source assessment described in Chapters D1 to D4, and as verified in Chapter E1. SPARROW model results were used to estimate broad source categories of contributions of N to the streams (Table 5). Model results indicate that agricultural nonpoint sources (70%), which include a combination of such sources as fertilizer, manure, soil mineralization, legumes and more, are the main contributor. If we only consider the watersheds draining into the Mississippi River, the fraction of N coming from agricultural nonpoint sources is 3% higher as compared to the entire state.

Table 5. SPARROW model estimated TN source contributions to Minnesota streams, including both statewide source estimates and sources in basins reaching the Mississippi River only

Source category	Percent contribution to statewide stream TN loads	Percent contribution to Mississippi River TN loads
Agricultural nonpoint sources	70%	73%
Wastewater and industrial point sources	7%	7%
Other nonpoint sources including atmospheric N	23%	20%

Nitrogen source reduction scenarios

The SPARROW model was used to examine how various TN concentration reduction scenarios may affect the downstream transport of N (Table 6). However, these results were not the primary method of used in the study to evaluate source reduction scenarios, but rather were used as a secondary way of assessing N reduction scenarios. The primary river nitrogen reduction analysis is included in Chapter F1.

The SPARROW modeling results indicated that reducing TN Volumetric Weighted Mean Concentrations (VWMC) in all major rivers and streams with VWMC greater than 5 mg/L down to 5 mg/l would result in a 46.8% TN load reduction in the Minnesota River, 22.9% reduction in the Lower Mississippi loads, a 37% reduction in the Des Moines loads, and a 51.7% reduction in Cedar River Loads.

Note that these scenarios do not directly correspond with the reductions necessary to achieve draft stream nitrate concentration standards. The major differences between these scenarios and scenarios for achieving nitrate toxicity-based standards being considered in Minnesota include: 1) the modeled scenarios are for TN concentrations, whereas the standards being considered are for nitrate-N concentrations; 2) modeled scenarios are for VWMC concentrations during a fairly typical year, whereas the nitrate toxicity standards are expected to be based on four-day average concentrations exceeding the standard twice or more over three years (and current Class 1B/1C water quality standard for nitrate is 10 mg/l for a 1 day average); and 3) this SPARROW model does not consider the smallest reaches of rivers which could exceed standards, even if downstream tributaries included in the model meet the standard.

Table 6. SPARROW model estimates of TN load reduction percentages that correspond with achieving annual mean TN concentrations of 3, 5, 7 and 10 mg/l. NR indicates that the modeled mean concentration is already lower than the targeted concentration.

Basin	Mean Total Nitrogen Conc (mg/L)	10	7	5	3
Cedar River	10.35	-3.4	-32.3	-51.7	-71.0
Des Moines River	7.93	NR	-11.8	-37.0	-62.2
Lower Mississippi River	6.49	NR	NR	-22.9	-53.8
Lake Superior	1.21	NR	NR	NR	NR
Minnesota River	9.39	NR	-25.5	-46.8	-68.1
Rainy River	0.72	NR	NR	NR	NR
Red River of the North	4.52	NR	NR	NR	-33.7
St. Croix River	1.21	NR	NR	NR	NR
Upper Mississippi River	2.46	NR	NR	NR	NR

The SPARROW model was also used to predict statewide delivered TN load reductions with different source reduction scenarios (Table 7). Based on these results, if 30% reductions were made to both point sources and fertilizer sources, the estimated TN load reduction at the state borders would be 11.2%. The agricultural fertilizer category does not include manure sources or any other agricultural N sources except for commercial fertilizer.

Table 7. Estimated effects of statewide reductions in the TN load in streams with source reductions in agricultural fertilizer and urban point sources by 10%, 20%, and 30% as estimated with the MRB SPARROW model.

	10% source reduction	20% source reduction	30% source reduction
Point source	-0.7% TN	-1.2% TN	-2.0% TN
Agricultural fertilizer	-3.1% TN	-6.1% TN	-9.2% TN
Total	-3.8% TN	-7.3% TN	-11.2% TN

Summary points

- Annual TN modeled yields delivered to the outlets of HUC8 watersheds range from 15 to 25 pounds/acre/year in certain south-central Minnesota watersheds and 0.1 to 3 pounds/acre for most of the northern Minnesota watersheds. Watersheds along the Red River had higher modeled yields than the rest of northern Minnesota, with yields generally ranging from 4 to 6 pounds/acre/year.
- The highest yielding watersheds included the Cedar River, Blue Earth River, Le Sueur River, and Minnesota River (Mankato) HUC8 watersheds, each yielding over 20 pounds/acre/year. Modeled yields in the urban dominated Mississippi River Twin Cities were typical of yields in other southern Minnesota watersheds, at 17.4 pounds/acre/year.
- The SPARROW yields compared similarly to monitoring-based yield calculations obtained from recent sampling (2005-2009) results that were not used when the model was calibrated, providing additional confidence in the validity of the model yield results.
- Roughly 10% of the N which leaves the HUC8 watersheds is estimated to be lost between the watershed and the state borders. An additional 10% of the N which leaves Minnesota in the Mississippi River is lost en route to Missouri.
- The highest 15 contributing HUC8 watersheds to the Mississippi River contribute 74% of the Minnesota TN load which reaches southern Iowa. The other 30 watersheds contribute the remaining 26% of the load.
- SPARROW model results indicate that agricultural nonpoint sources are the largest source category of N to the state’s rivers, contributing 73% of TN in the Mississippi River and 70% to all rivers in the state. Point sources contribute 7% of the loads to the Mississippi and statewide, according to SPARROW model estimates.
- If 30% reductions were made to TN losses into surface waters from both fertilizer and point sources, an estimated 11.2% load reduction would be achieved at the state borders.

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B5. Nitrogen Transport, Losses, and Transformations within Minnesota Waters

Author: Dennis Wasley, MPCA

Introduction

Nitrogen (N) losses and transformations can occur at each point along the flow pathway between source and final destination, including within soil, groundwater and surface water.

Nitrogen losses and transformations within the soil system were studied for Minnesota (MN) conditions as part of the agricultural N budget developed by Mulla et al., and which is included in Chapter D4 of this report.

Nitrogen losses can also occur within the groundwater and in the transition zone where groundwater moves into riparian areas and surface waters. A literature review related to denitrification losses of nitrate within groundwater, focusing on upper Midwest studies, is included in Appendix B5-1.

Once in surface waters, N can also be lost through denitrification, converted from inorganic forms (i.e., nitrate) to organic forms (i.e., algae), or transform from organic forms back into inorganic N. Because these processes within surface waters can transform large quantities of N, it is important to understand how these processes can affect N conditions in rivers and streams. For this study, N transformations and losses within surface waters were investigated, through a review of published findings and an analysis of unpublished data. These findings are summarized below and are included in their entirety in Appendix B5-2.

Summary of nitrogen transformation within Minnesota surface waters

The literature of the past two decades has greatly increased our understanding of N transport in surface waters. Generalizing the movement and transformations of total nitrogen (TN) in surface waters of MN is complicated given the wide range of aquatic systems and N loads delivered to those systems throughout the state. Nitrogen transport in surface waters is spatially and temporally variable, which also makes generalizations difficult.

Nitrogen is present in detectable amounts in most MN surface waters. In surface waters with relatively low N inputs, N is typically present in low concentrations of inorganic forms (often near detection limits), with the majority of N present in organic forms bound in various components of living and dead organisms. As N loading increases to a given surface water beyond its ability to assimilate N inputs, detectable amounts of dissolved inorganic nitrogen (DIN) are measured. In well oxygenated waters, DIN is typically present as nitrate (NO_3-N) with lesser amounts of nitrite (NO_2-N) and ammonia/ammonium. Ammonia and ammonium can also make up a portion of DIN in MN waters. It is most common in waters with low dissolved oxygen such as wetlands, the hypolimnion of stratified lakes, and during winter immediately downstream of wastewater treatment plants. Nitrification or uptake of ammonia+ammonium by organisms converts this form of N to other forms in oxygenated surface waters during the other seasons.

Many factors influence the transport of N in surface waters of MN, including N loading, residence time, temperature, nitrate concentration, discharge, depth, velocity, and land use. Some of these factors are inherently different based on the type of surface water. Wetlands and lakes are common in northeast MN along with relatively low N inputs, which both contribute to low N yields. Nitrate concentrations in streams of northeast MN are very low, often near detection limits. Yields of N from watersheds in south-central MN are much higher due to low densities of lakes and wetlands and higher inputs of N, especially during seasonally higher stream discharge. The concentration of TN in streams can drop during low flow periods in mid-late summer due to a combination of lower input loads and in-stream processing where inputs are not excessive. The reduction in mid-late summer TN concentration does not result in substantially reduced annual loads since the majority of TN is transported from late-March to mid-July when stream discharge is typically highest in MN rivers. Watersheds in southeast MN are unique to the other watersheds in the state due to the large inputs of high nitrate groundwater, which maintain elevated TN levels during low flow and, therefore, have less seasonal concentration fluctuations of TN than south-central MN.

Residence time is a key factor for N removal across all aquatic ecosystems. Residence time is basically the time it takes to replace the volume of water for a given surface water. Longer residence time allows for more interaction with biota (including bacteria) within a given aquatic resource. Streams typically have much shorter residence times compared to wetlands and lakes. Consequently, streams generally transport more N downstream than lakes and wetlands. The amount of N removed within streams generally decreases with stream size and N loading.

Special consideration was given to the Mississippi River downstream of the Minnesota River due to the unique rapidly flushed impoundments (navigational pools in the lock and dam system on the mainstem Mississippi) on this river and availability of models and monitoring data. In this river system and other rivers throughout the state, N loading is typically at its annual peak during spring and early summer when streamflow is seasonally higher. Lake Pepin, a natural riverine lake on the Mississippi River, removed only 6% to 9% of the average annual input load of TN during the past two decades. Lake Pepin has the longest residence time of all the navigational pools on the MN portion of the Mississippi River by a factor of at least 5. Upstream removal and loading reductions of N throughout the tributary watersheds is needed to substantially reduce downstream transport of N by the Mississippi River from Navigational Pools 1 to 8 during spring and early summer. Estimates of the collective impact of all the 168 miles of Mississippi River with navigational pools in MN, including Lake Pepin, range from removal of 12% to 22% of average annual input loads. Impressive N cycling has been documented in this system, but the input load simply overwhelms the capacity of the river to remove the majority TN inputs during most years.

Outputs from the SPARROW model are useful to illustrate annual downstream delivery of TN loads in MN streams and rivers. The general findings of this review and the SPARROW modeling indicate that 80% to 100% of annual TN loads to rivers are delivered to state borders unless a large reservoir with a relatively long residence time is located in the stream/river network downstream of a given headwater stream. Large headwater reservoirs such as Lake Winnibigoshish remove a larger proportion of inputs than riverine lakes such as Lake Pepin which has a much larger contributing watershed. Other approaches described in Appendix B5-2 based on mass balances estimated from monitored rivers also showed that the majority of annual TN loads to a given river reach are delivered to downstream reaches.

What is relatively clear from this review and analysis is that larger rivers with high TN loads like the Minnesota River deliver downstream most of the annual N load that reaches the river mainstem. The collective removal rate of N loading in MN's lakes, wetlands, ephemeral streams, and headwaters/streams is less certain. National models such as SPARROW can estimate the collective losses of TN for modeled rivers and streams of a given watershed (see Chapter B4).

Many factors influence the losses in smaller lotic systems (Table 1). Watersheds with extensive lakes and wetlands and modest N loading certainly remove or transform inorganic nitrogen inputs. Watersheds with extensive tile drainage and limited lakes and wetlands often transport large loads of inorganic nitrogen to watershed outlets with some removal in headwaters. The percentage of delivered load typically increases with proximity to large rivers in all watersheds. Weather and precipitation during any given year certainly influence transport dynamics within the watershed. Higher precipitation translates into greater loading and increased stream velocity, which both contribute to increased downstream transport of DIN. Drought conditions lead to reduced loading and lower stream velocities, which contribute to increased losses and transformations of inorganic nitrogen.

Table 1. Positive and negative factors that influence downstream movement of NO_X-N in MN.

Factor	Conditions that enhance N removal	Example	Conditions that generally reduce N removal	
Streamflow	Low flow	Drought	High flow	Wet periods/spring
Annual Precipitation	Low	Western MN	Moderate	Eastern MN
Depth	Shallow (inches)	Headwater streams	Deep (9 ft)	Impounded portion of Mississippi River
Carbon content of sediment	High organic content	Backwaters, impoundments, wetlands	"Clean" sand with low organic content	Main channel of large rivers
Input loads/concentration	Low	Northern MN watersheds	High	Southern MN watersheds
Season	Late summer	Low flows and high temperature	Early Spring	High flow and cool temperatures
Riparian area	Natural	Forested stream	Rock or concrete	Urban areas
Riparian wetlands	Common	Northern MN	Few	Ditches in southern MN
Temperature	Warm	Summer	Cold/cool	Winter

Lakes, including backwaters of rivers and wetlands, can remove and/or assimilate DIN inputs as long as inputs are not excessive. Long hydraulic residence times in these surface waters along with carbon rich sediments are key to removing inorganic nitrogen inputs. The overall impact of these surface waters on downstream transport of TN from MN is difficult to quantify, but it is certain that existing surface waters of these types currently reduce TN loads to downstream waters.

The comprehensive review of N losses and transformations within surface waters is found in Appendix B5-2.

C1. Nitrate Trends in Minnesota Rivers

**Authors: Dave Wall and Dave Christopherson, Minnesota Pollution Control Agency (MPCA)
Dave Lorenz and Gary Martin, U.S. Geological Survey (USGS)**

Statistical Analyses: Directed by Dave Lorenz and conducted by Dave Christopherson and Gary Martin

Objective

Regular sampling of river and stream water for nitrate began at numerous sites on Minnesota's rivers during the mid-1970s, and many of these sites continued to be monitored through 2008-2011. A few of these sites were previously assessed for nitrogen (N) load and concentration temporal trends, as is reported in Chapter C2. However, most sites have either not been assessed for nitrate trends or have been studied for trends using a shorter period of time and different statistical methods compared to this study.

The objective of this study was to assess long-term trends (30 to 35 years) of flow-adjusted concentrations of nitrite+nitrate-N (hereinafter referred to as nitrate) in a way that would allow us to discern changing trends. Recognizing that these trends are commonly different from one river to another river and from one part of the state to another, our objective was to examine as many river monitoring sites across the state as possible for which sufficient long term streamflow and concentration data were available.

The nitrate concentration parameter was chosen for trend analyses for the following reasons:

- Nitrate is the dominant form of N in most streams with elevated total nitrogen (TN) concentrations (see Chapter B2).
- Nitrate can have adverse human and aquatic-life impacts at high concentrations (see Chapter A2).
- Nitrate concentrations in Minnesota rivers and streams are mostly elevated as a result of human activities (see Chapter A2).
- The ammonia+ammonium form of N has been consistently shown in previous studies to have decreased substantially since the late 1970s (see Chapter C2), and no additional trend analysis of that N parameter was considered to be needed at this time.
- Fewer long-term data are available for TN as compared to nitrate.

Nitrate concentration trend analyses can be used to help us understand how human activities and other factors have affected stream nitrate over different time periods. One challenge, however when interpreting nitrate trend results, is a lag time that occurs between changes to the land and the corresponding change to stream N concentrations, especially where slow moving groundwater is a dominant contributor to streamflow and nitrate loads. In some areas, it can take many years for groundwater to move into surface water. In areas other areas where groundwater flow to streams is much quicker, such as tile-drained lands and karst lands, the land changes can affect stream water quality within a much shorter period of time.

Nitrate *load* trends were not assessed in this study because the monitoring frequency at most sites was insufficient for load-trend analyses, and most of the sites where load trends could be determined were already reported by Lafrancois et al. (2013) for the 1976-2005 time period (see Chapter C2).

Site selection

We targeted sites that had a long-term (pre-1980) nitrate monitoring record and associated streamflow records corresponding to the same timeframe. We avoided locations that were intentionally sited to evaluate upstream point sources. We also avoided sites where sampling was discontinued prior to 2008 or that had large gaps in the monitoring record.

The primary long-term data set available for Minnesota rivers is from sites known as "MPCA Minnesota Milestone" sites. MPCA Minnesota Milestone sites were used for 45 of the 51 sites analyzed for long-term trends (Table 1). Most of the MPCA Minnesota Milestone sites used for trend analyses had nitrate concentration data over a 30- to 35-year period. The MPCA Minnesota Milestone sites were typically sampled by MPCA staff 9-10 months per year by taking grab samples; yet occasionally the sampling frequency was reduced to 7-8 months during the year. With only a few exceptions, these sites were sampled every year for nitrate from the mid- to late-1970s until the mid-1990s, at which time the sampling frequency was reduced to two out of every five years, or 40% of the years. Sampling continued at these sites through 2008-2011 at the reduced frequency. All water quality data are stored in the Environmental Quality Information System (EQuiS).

We also conducted trend analyses on a second set of six monitoring sites. The six sites were sampled (grab samples) twice monthly every year since 1976 by the Metropolitan Council Environmental Services. In a few locations, we did not report trends at MPCA Minnesota Milestone sites that were located near the Metropolitan Council sites, but instead focused our efforts on the more robust long-term data sets obtained by the Metropolitan Council. Data are stored at the Metropolitan Council.

Our analysis of flow-adjusted trends included only those nitrate monitoring sites that could be paired with a nearby streamflow gauging station (U.S. Geological Survey, 2013) for which streamflow data were available for the same years as the nitrate data. The streamflow gauging stations were all within criteria used for other similar studies (e.g. Lorenz et al., 2009). Three sites (198, 003, 975) had nitrate monitoring data since the 1970s, but only had streamflow data since 1991-94. For those sites, our trend analyses began in the early 1990s and continued through 2010.

The location of all monitoring sites used for trend analyses is shown in Figure 1 and are listed along with the number of times each site was sampled in Table 1. The Metropolitan Council monitoring sites are denoted with an asterisk in the "Map Number" column in Table 1. The number of samples (observations) collected and used for trend analyses at the six Metropolitan Council monitoring sites range from 778 to 899 (Table 1). The number of samples is much lower for the MPCA Minnesota Milestone sites, which were typically sampled 200 to 300 times.

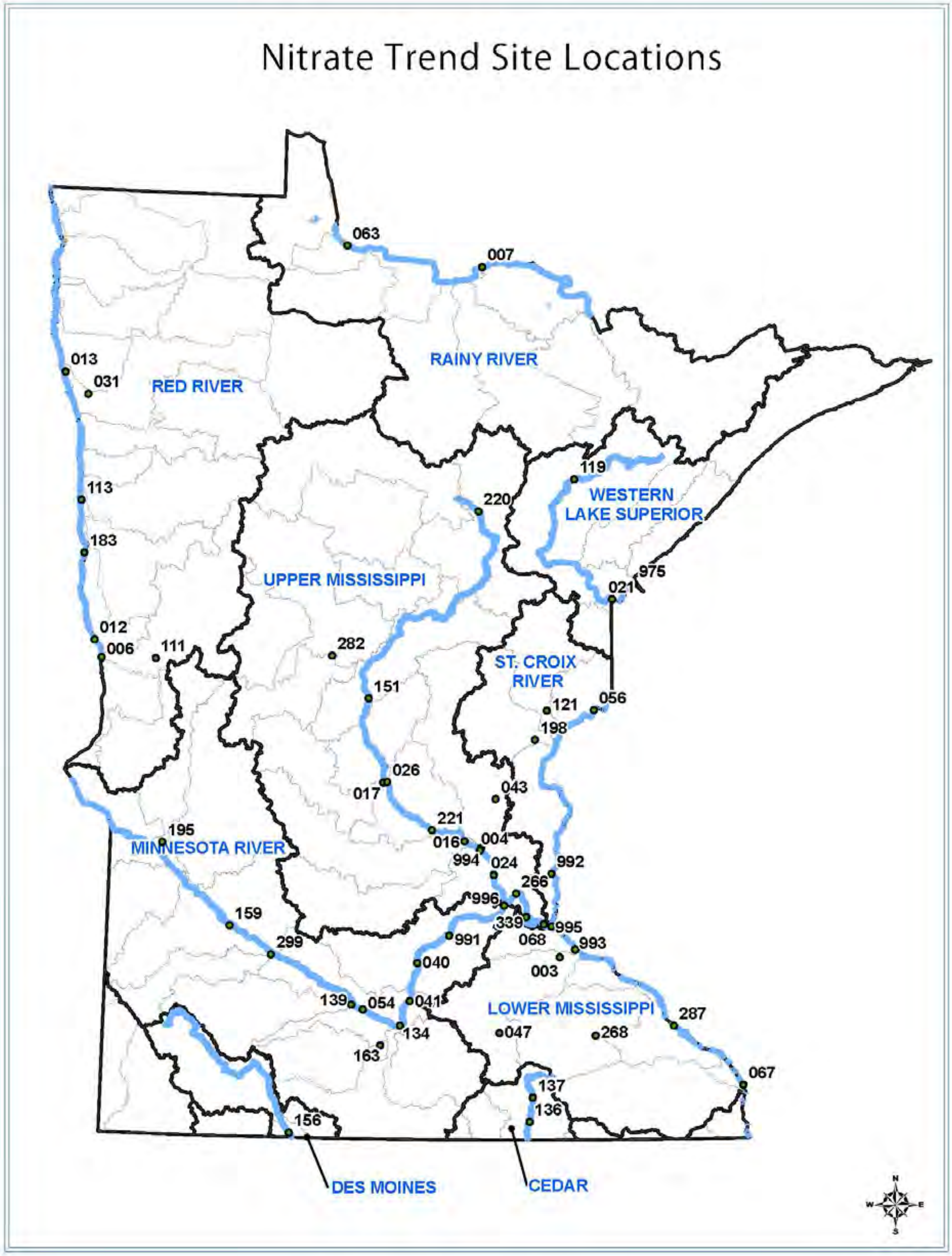


Figure 1. Site locations and associated site numbers for each of the river monitoring sites where trend analyses were completed (refer to Table 1 for more information about each site). Black lines are major basin drainage basin boundaries and blue lines are main stem rivers. Blue lettering refers to the major basin name.

Table 1. Nitrate monitoring site locations/numbers and associated number of observations (nitrate sampling events) and U.S. Geological Survey streamflow gauging station number. An asterisk indicates stations sampled by the Metropolitan Council. All other sites are MPCA Minnesota Milestone sites.

Site No. (Figure 1)	Location Code	Nitrate Monitoring Location	No. of Observations	Streamflow Gauging Station No.
Western Lake Superior Basin				
119	S000-119	St. Louis River, Forbes	223	04024000
021	S000-021	St. Louis River, Fond Du Lac	239	04024000
975	S003-975	St. Louis River Duluth	66	04024000
Red River of the North Basin				
111	S000-111	Otter Tail River, Fergus Falls	130	05046000
006	S000-006	Otter Tail River, Breckenridge	247	05046000
012	S000-012	Red River, Brushvale	348	05051000
183	S000-183	Red River, Moorhead	247	05054000
113	S000-113	Red River, Pearley	250	05064500
031	S000-031	Red Lake River, Fisher	211	05280000
013	S000-013	Red Lake River, East Grand Forks	244	05280000
Rainy River Basin				
007	S000-007	Rainy River, International Falls	250	05133500
063	S000-063	Rainy River, Baudette	254	05133500
Upper Mississippi River Basin				
220	S000-220	Mississippi River, Blackberry	288	05211000
282	S000-282	Long Prairie River, Motley	271	05245100
151	S000-151	Mississippi River, Camp Ripley	227	05267000
017	S000-017	Sauk River, Sauk Rapids	304	05270500
026	S000-026	Mississippi River, Sauk Rapids	244	05270700
221	S000-221	Mississippi River, Monticello	253	05288500
004	S000-004	Crow River, Dayton	152	05280000
994*	UM 871.6	Mississippi River, Anoka	841	05288500
043	S000-043	Rum River, Isanti	289	05286000
016	S000-016	Rum River, Anoka	112	05286000
024	S000-024	Mississippi River, Fridley	243	05288500
Minnesota River Basin				
195	S000-195	Pomme de Terre River, Appleton	316	05294000
159	S000-159	Yellow Medicine River, Granite Falls	145	05313500
299	S000-299	Redwood River, Redwood Falls	199	05316500

Site No. (Figure 1)	Location Code	Nitrate Monitoring Location	No. of Observations	Streamflow Gauging Station No.
139	S000-139	Cottonwood River, New Ulm	197	05317000
054	S000-054	Minnesota River Courtland	232	05325000
163	S000-163	Watonwan River, Garden City	282	05319500
134	S000-134	Blue Earth River, Mankato	313	05320000
041	S000-041	Minnesota River, St. Peter	226	05325000
040	S000-040	Minnesota River, Henderson	242	05330000
991*	MI 39.4	Minnesota River at Jordan	778	05330000
996*	MI 3.5	Minnesota River at Fort Snelling	915	05330000
Mississippi River between the Minnesota and St. Croix Rivers				
266	S000-266	Mississippi River, St. Paul Wabasha St.	332	05331000
339	S000-339	Mississippi River, Grey Cloud	329	05331580
068	S000-068	Mississippi River, Hastings Lock and Dam No. 2	179	05331580
St. Croix River Basin				
056	S000-056	St. Croix River, Danbury, WI	309	05333500
121	S000-121	Kettle River, Hinkley	291	05336700
198	S000-198	Snake River, Pine City	190	05338500
992*	SC 23.3	St. Croix River, Stillwater	896	05340500
995*	SC 0.3	St. Croix River, Prescott	899	05340500
Lower Mississippi River Basin				
993*	UM 796.9	Mississippi River, Prescott Lock and Dam No. 3	870	05331000
047	S000-047	Straight River, Clinton Falls	243	05353800
003	S000-003	Cannon River, Welch	107	05355200
268	S000-268	Zumbro River, South Fork, Rochester	241	05372995
287	S000-287	Mississippi River, Minneiska Lock and Dam No. 5	217	05378500
067	S000-067	Mississippi River, LaCrosse, WI	230	05378500
Cedar and Des Moines River Basins				
137	S000-137	Cedar River, Lansing	206	05457000
136	S000-136	Cedar River, Austin	300	05457000
156	S000-156	Des Moines River, West Fork, Petersburg	133	05476000

Statistical analysis methods

The long-term trends in flow-adjusted concentrations (FAC)s were assessed using the QWTREND program (Vecchia, 2003a, 2005). QWTREND was selected because it can describe long-term trends, not just monotonic trends; is insensitive to changes in the variability in streamflow; is also insensitive to unexplained variability in water quality (Lorenz et al., 2009); and it can be used to assess the relation between streamflow and water quality and sampling design. QWTREND uses a time-series model for estimating trends in FAC. The basic form of the model is:

FAC = Intercept + Time Series + Long Term + Intermediate Term + Seasonal + Trend + HFV,

where

FAC	is the log of the flow-adjusted concentration.
Intercept	is the intercept term.
Time Series	is the collection of autoregressive and moving-average time-series relations between streamflow and concentration and within the concentration data.
Long Term	is the 5-year anomaly (5-year moving average log of streamflow).
Intermediate Term	is the 1-year and seasonal (3-month) anomaly.
Seasonal	is the first- and second-order Fourier terms that describe seasonal variation.
Trend	is the user-supplied trend terms that explain long-term deviations not described by the previous terms.
HFV	is the high-frequency variability in the streamflow, which is the daily streamflow after the long- and intermediate-term anomalies have been removed.

Vecchia (2000) describes the estimation of the time-series parameters, and Vecchia (2003b) describes the computation of the anomalies.

The suggested minimum data criteria for QWTREND (Vecchia, 2000) are (1) minimum water-quality record length of 15 years, (2) average of at least 4 samples per year, (3) at least 10 samples within each quarter of the sampled years, (4) less than 10% censored data (i.e. nondetections), and (5) complete streamflow record for the water-quality record for the period of interest plus the preceding 5 years. These criteria were generally met, but exceptions were made for the preceding 5-year part of Criterion 5 when streamflow records were shorter than the water-quality record. Several sites in northern Minnesota had very low nitrate concentrations, often below detection limits, and Criterion 4 was relaxed for those sites. Aldo Vecchia (written communication, Dec 14, 2012) stated that QWTREND generally is accurate for the trend estimates with as much as 20% censored data, and possibly is accurate with as much as about 35% censored data in some cases. As the percentage of censored data increases, the trends become progressively less reliable—the magnitude of the slope is decreased and the associated probability values (p-values) become more significant. For analyses with more than 35% censored data, QWTREND should be considered only an exploratory tool (Aldo Vecchia, USGS, oral communication
December 14, 2012).

QWTREND was used to determine when changes in the trend during the analysis period (typically 1975–2010) were statistically significant. The critical p-value for a single trend was set at 0.10 compared to the no-trend model. To avoid extraneous trends, the critical p-value for a two-trend model was set at one-half the attained p-value for the single-trend model, the critical p-value for a three-trend model was set at one-third the attained p-value for the single-trend model, and so forth.

The Long Term, Intermediate Term, and High Frequency Variability (HFV) parameters of the model describe the relation between concentration and streamflow. The HFV parameter includes an average response and Fourier terms, the sine and cosine, which describe seasonal differences in the HFV response. Only the average response was included in this analysis. The Long and Intermediate Terms describe the effects of sustained long- and short-term above or below average precipitation; positive parameters indicate a flushing process, negative values indicate a dilution effect, and a value near zero indicates no effect. The HFV parameter, in general, describes the effect of rainfall or snowmelt events. Again positive parameters indicate a flushing process, negative values indicate a dilution effect, and a value near zero indicates no effect. Only sites with less than 25% censored data were used in the analysis of concentration and streamflow.

Nitrate concentration trends across the state

An overview of the results is first described for main-stem rivers across the state, including the Red River, Minnesota River, Mississippi River, St. Croix River, Cedar River, Des Moines River, and St. Louis River (within the Western Lake Superior Basin). The statewide overview is followed by a more detailed description and discussion of the results for each major basin, including results for many tributary rivers within the basins.

Statistically significant ($p < 0.1$) trends in overall flow-adjusted nitrate concentrations mostly over the time period between the mid-1970s and the 2008-2011 timeframe (typically 1976-2010) are shown in Figure 2 for Minnesota's main-stem rivers. The magnitude of change over this time period was found to vary greatly across the state. Many (22 of 32) main-stem river sites showed upward trends (increased concentrations), ranging from 7% to 268% over the entire analysis time period (30 to 35 years at most sites). Four sites showed slight overall downward trends (decreased concentrations): the two most downstream sites on the Minnesota River, the most upstream site on the St. Croix River, and the most upstream site on the St. Louis River. Six sites showed no statistically significant change.

Because the nitrate concentrations are low in the Upper Mississippi River, Rainy River, and St. Louis River, even a very small addition of nitrate over time will result in a relatively high percentage increase. The large percentage increases in the Upper Mississippi River represent a nitrate concentration increase of 0.1 to 0.4 milligrams per liter (mg/l) (see tables 2-16, ending concentration for more context on understanding the percent change over time).

A commonly asked question is how nitrate concentrations have been changing over more recent years. Results for the most recent years for each main-stem river monitoring site are shown in Figure 3. The number of years encompassing these recent trends varies greatly, and was from 5 to 9 years at seven sites, and 10 years or more at all other sites. The results for these recent periods vary from one part of the state to another. In most northern Minnesota main-stem rivers, nitrate concentrations did not have a statistically significant trend in recent years, with a few exceptions, most notably an average 2% per year increase in the St. Louis River (Duluth) over the past 17 years. Upward trends during recent periods were indicated for the Cedar River and for most of the Mississippi River sites south of Sauk Rapids, with the recent rate of change at most sites comparable to the change over the complete period of record. Downward trends during recent years were indicated for some sites on the Minnesota River.

Long-term and recent nitrate concentration trends in several major tributaries to main-stem rivers were also assessed and mapped (Figures 4 and 5). Over the entire period of analysis, 11 different tributary rivers had nitrate concentration increases, and 3 of those rivers had two monitoring sites on the same river that both indicated increases. Four tributaries had no significant trend, and 1 tributary with two sites (Cannon River Watershed) had nitrate concentration decreases (Figure 4).

For the recent trend analyses, 5 tributaries showed upward trends, 5 tributaries had downward trends, and 7 tributaries had no statistically significant trend (Figure 5). Several tributary rivers have shifted from long-term upward trends (Figure 4) to downward and non-significant trends in recent years (Figure 5).

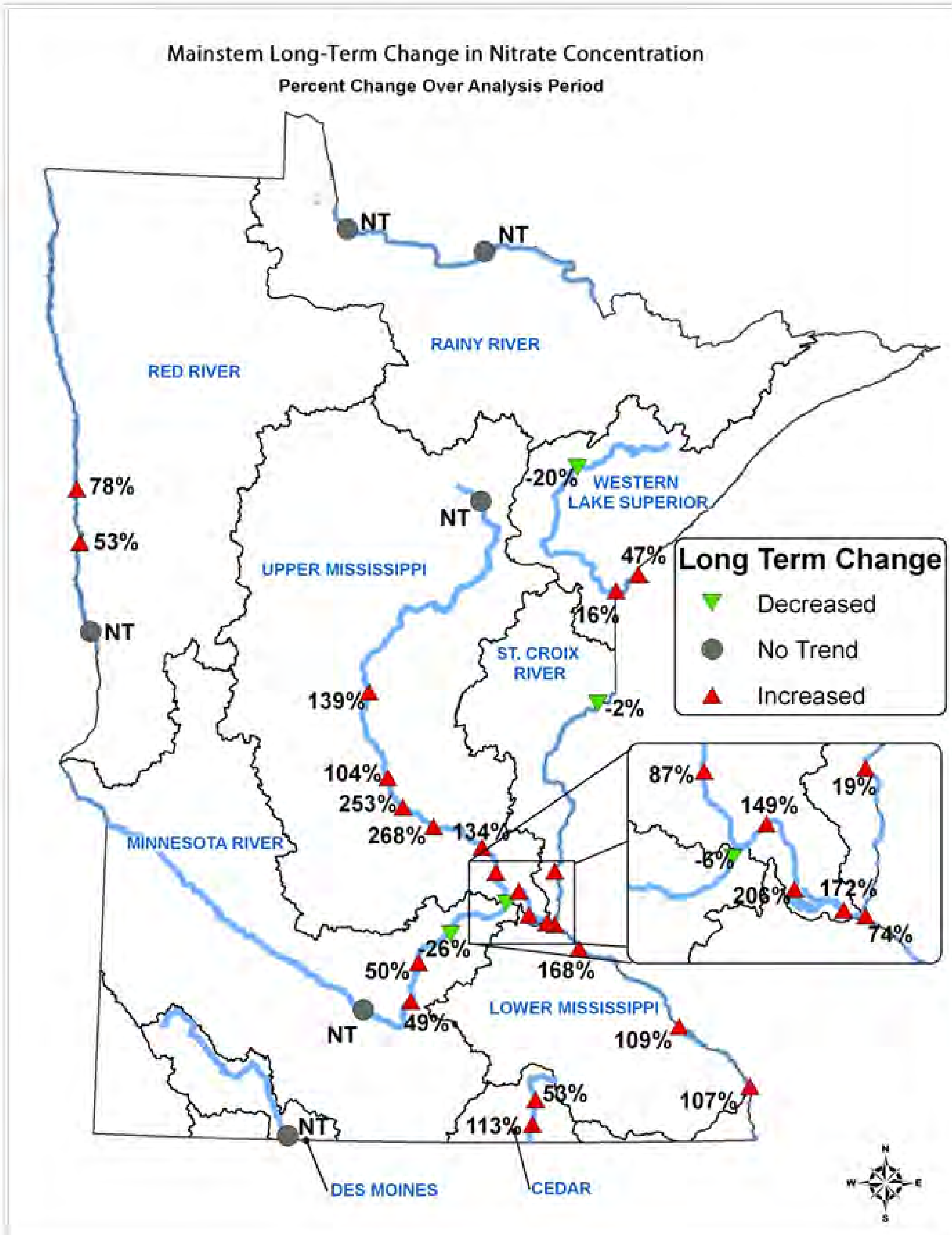


Figure 2. Mainstem river changes in nitrate concentration for main-stem rivers during the entire period of analysis, which was typically 1976 to 2010, but varied by site (see also tables 2 to 16). Values are the average percent change per year in nitrate concentrations over the analysis period. Major basins names are blue.

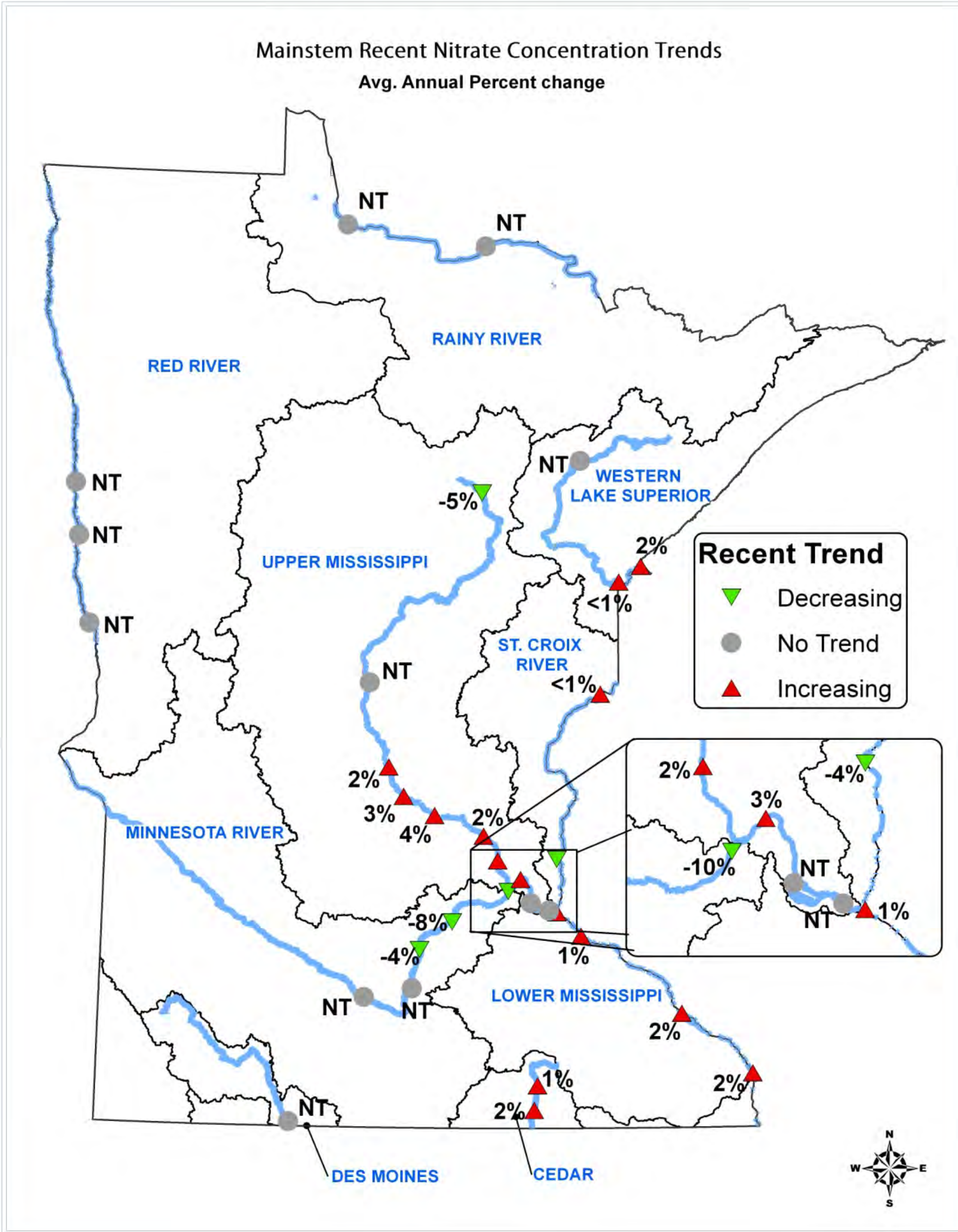


Figure 3. Trends in nitrate concentrations within past 5-15 years (ending in 2010 for most sites) for main-stem rivers. Values are the average percent change per year in nitrate concentrations during the most recent trend period. "Decreasing" indicates a downward trend and "increasing" indicates an upward trend. Major basins names are in blue lettering.

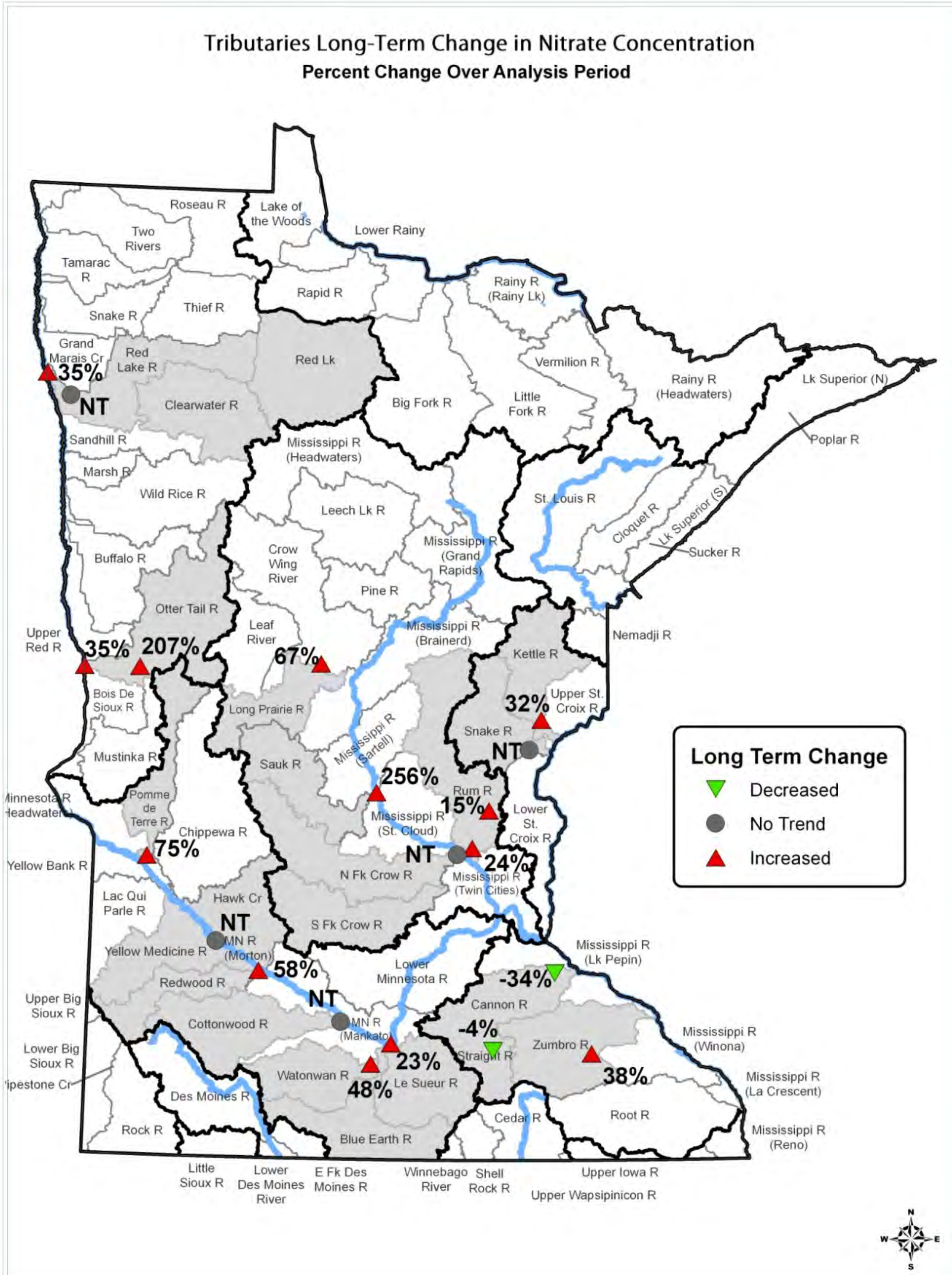


Figure 4. Percent change in nitrate concentrations in tributary rivers during the entire period of analysis (typically 1976 to 2010, but varied by site - see Tables 2 to 16). Values are the average percent change per year in nitrate concentrations over the analysis period. Watersheds associated with the trend analyses are shaded in gray.

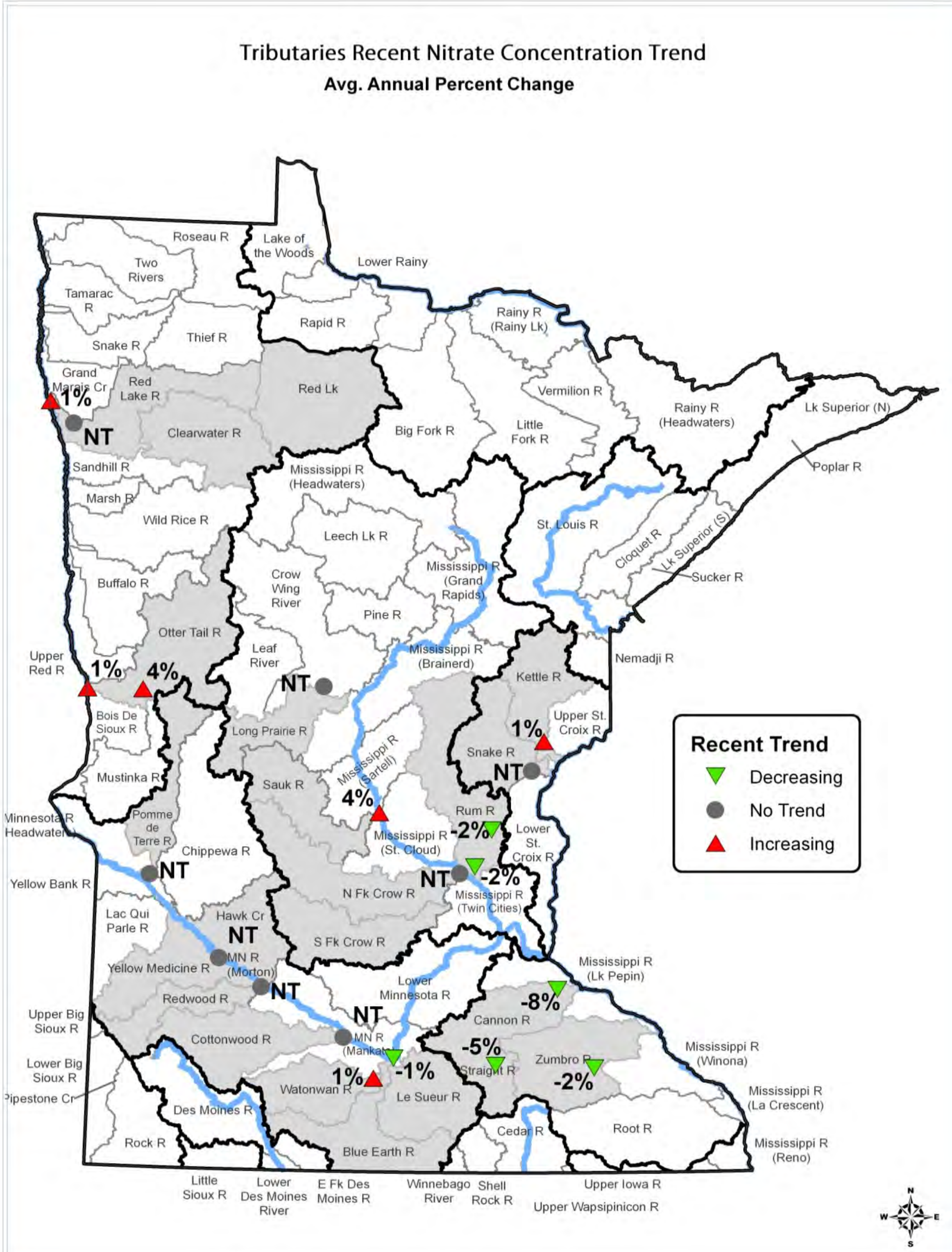


Figure 5. Trends in nitrate concentration for tributary rivers within the past 5-15 years (period ending in 2010 at most sites). Values are the percent change per year in nitrate concentrations during the most recent trend period. Watersheds associated with the trend analyses are shaded in gray. "Decreasing" indicates a downward trend and "increasing" indicates an upward trend.

At many sites, the long-term trends were not constant over the years. Some river sites had separate periods of upward, downward, or no trends. Therefore, we reported how the trends shifted throughout the 30- to 35-year period of analysis. The next section provides the results of how trends changed during the analysis period at each assessed monitoring site.

Nitrate concentration trends by basin

Trends in flow-adjusted nitrate concentrations are shown for main-stem rivers and tributaries analyzed in each major river basin (Tables 2 to 16). Note that for each site, an overall trend result is presented that represents a calculated change based on all statistically significant trends from the beginning of the trend analysis period to the end. Where trends for specific periods within the overall trend were found to be statistically significant, those specific trend segments are reported below the overall trend. A positive change represents a typical concentration at the end of the analysis period (2008-11) that is larger than the typical concentration for the site at the beginning of the analysis period, and a negative change represents a concentration that is less at the end of the analysis period than the typical concentration for the site at the beginning of the analysis period. “No trend” indicates that the trend was not statistically significant at the $p<0.1$ significance level.

Note that for two or more separate upward or downward trend segments, the sum of these segmented trends will not add up to the overall trend. This is because the percentage of increase or decrease is reported as an increase or decrease from the start of the segment, rather than the start of the entire period of analysis. For example, if a site starts with a concentration of 1 mg/l and the first decade has a 100% increase, then the concentration at the end of the first decade is 2 mg/l. If the trend during the second decade is a 25% increase, then the concentration will have increased from 2 mg/l to 2.5 mg/l. Therefore the overall increase over the two decades is 1.5 mg/l or 150% (not the sum of the 100% and 25% increases).

The “NO_3” concentrations in the graphs and the “ending concentration” in Tables 2 to 16 are annual average “nitrite+nitrate-N” concentrations during the last year of the statistical trend analysis. Because of the way the QWTREND model works, these concentrations represent an annual mean of the log of nitrite+nitrate-N concentrations, corrected for seasonal and streamflow variability, which were then translated back into a raw concentration. Therefore, for sites with a high degree of variation in nitrate concentrations from season to season, the concentrations reported in the tables and associated graphs are lower than either a flow-weighted mean concentration or an annual arithmetic mean concentration. These concentrations are therefore not comparable to concentrations reported in Section B of this report. Note also that different y-axis nitrate concentration scales are used in the trend graphics depending on the magnitude of concentrations, typically 0 to 1.0 mg/l and 0 to 10 mg/l.

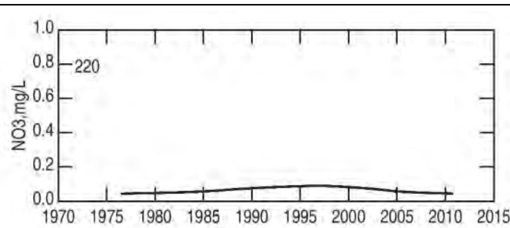
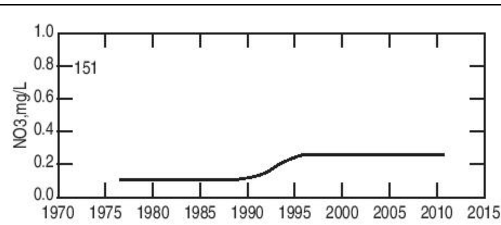
To find the location of specific site names noted below (often nearby city names), identify the associated site number in Tables 2 to 16 (left column), and refer to Figure 1. Some secondary site numbers in Tables 2 to 16 are in parentheses and indicate a Metropolitan Council monitoring site with their associated site number based on the river mile (distance upstream from the river mouth) at the sampling location.

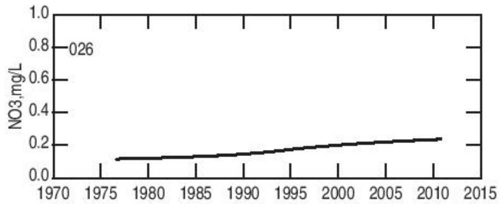
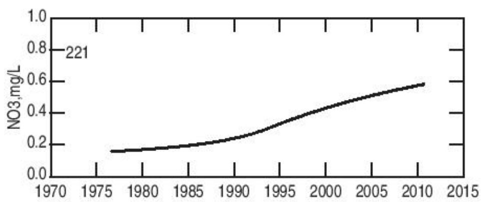
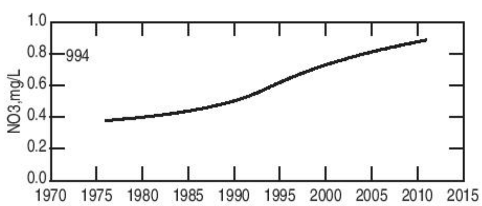
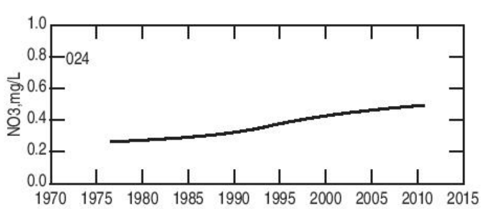
Mississippi River Basin results

Upper Mississippi River main stem (Blackberry to Fridley)

The general patterns in the Upper Mississippi River Basin are long-term increases in nitrate concentrations, with flow-adjusted concentrations often more than doubling over the three and a half decades of measurement (Table 2). The only exception to the long-term increase is the upstream-most Mississippi River site at Blackberry, which showed a decrease between 1997 and 2010. Recent period average annual increases range between 2% and 4% at all Mississippi River sites from Camp Ripley southward to Fridley. At the four most downstream sites, at Sauk Rapids, Monticello, Anoka, and Fridley, the trends were continuously upward since 1976.

Table 2. Trends in flow-adjusted nitrate concentrations in the Upper Mississippi River between the most upstream site at Blackberry to the most downstream site at Fridley. A positive change in nitrate concentration represents a statistically significant (p<0.1) upward trend, and a negative change represents a statistically significant downward trend. "NT" (no trend) indicates that the trend was not statistically significant (p<0.1). Site No. refers to site location on Figure 1 and Table 1. A 0% change is a change which rounded off to 0% overall change (the increase during the first 22 years is nearly balanced by the decrease in the last 14 years; yet the increase and decrease were each statistically significant).

Site No.	Upper Mississippi River Site Location / Trend Analysis Periods	% Change in Nitrate Concentration	Ending Concentration, mg/l
220	**Mississippi River – Blackberry**		0.05
	Overall change 1976-2010	*0%	
	1976 - 1997	+106%	
	1997 – 2010	-51%	
			
151	**Mississippi River – Camp Ripley**		0.26
	Overall change 1976-2010	+139%	
	1976-1988	NT	
	1989-1995	+139%	
	1996-2010	NT	
			

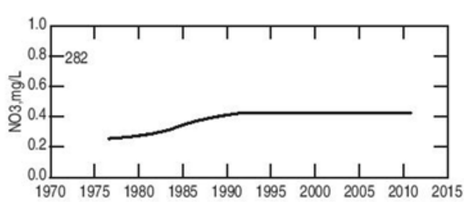
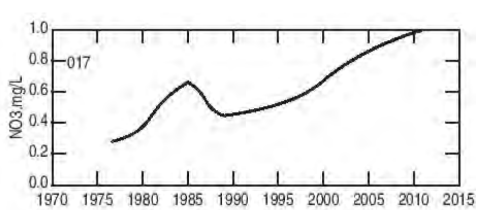
Site No.	Upper Mississippi River Site Location / Trend Analysis Periods	% Change in Nitrate Concentration	Ending Concentration, mg/l
026	**Mississippi River – Sauk Rapids**		0.23
	Overall change 1976-2010	+104%	
			
221	**Mississippi River – Monticello**		0.58
	Overall change 1976-2010	+268%	
			
994(871.6)	**Mississippi River – Anoka**		0.88
	Overall change 1976-2010	+134%	
			
024	**Mississippi River – Fridley**		0.49
	Overall change 1976-2010	+87%	
			

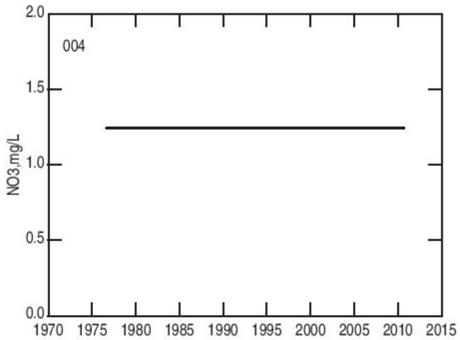
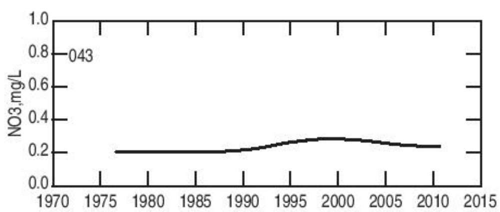
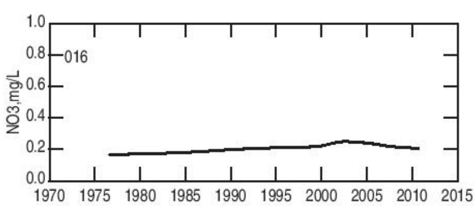
Tributaries of the Upper Mississippi River

Many tributaries flow into the Upper Mississippi River. Trends in all tributaries, along with trends in point source discharges and groundwater base flow discharging directly into the Mississippi River, affect the Mississippi River trends. Trends in four major tributaries were analyzed for this study. Three of the four tributaries showed an overall increase since 1976 and one tributary (Crow River) had no trend (Table 3). The nature of the increases was different in all three tributaries, with different magnitudes of increases (from 15 to 256%) and different periods of time when these increases occurred. During the past decade, the Long Prairie and Crow Rivers had no trend, while nitrate concentrations increased in the Sauk River and decreased in the Rum River.

The Sauk River is the only analyzed tributary that had a continuously upward trend in the past two decades, as was also found in the Mississippi River at Sauk Rapids, Monticello, Anoka, and Fridley. We were not able to assess the trend results in the many other tributaries to the upper Mississippi River due to a lack of sufficient monitoring data, and it is possible that those other tributaries also contributed to the upward trends in the Mississippi River.

Table 3. Trends in flow-adjusted nitrate concentrations in four tributaries of the Upper Mississippi River. The Rum River had two monitoring sites at different points along the river. A positive change in nitrate concentration represents a statistically significant (p<0.1) upward trend, and a negative change represents a statistically significant downward trend. "NT" (no trend) indicates that the trend was not statistically significant (p<0.1). Site No. refers to site location on Figure 1 and Table 1.

Site No.	Tributaries - Upper Mississippi River Basin Site Location / Trend Analysis Periods	% Change in Nitrate Concentration	Ending Concentration, mg/l
282	**Long Prairie River – south of Motley**		0.43
	Overall change 1976-2010	+67%	
	1976-1991	+67%	
	1992-2010	NT	
			
017	**Sauk River - Sauk Rapids**		0.98
	Overall change 1976-2010	+256%	
	1976-1984	+137%	
	1985-1988	-33%	
	1989-2010	+123	
			

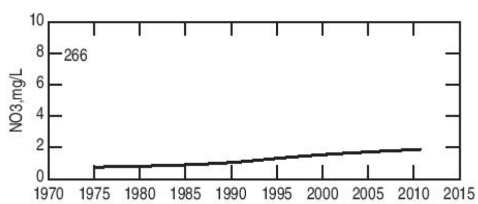
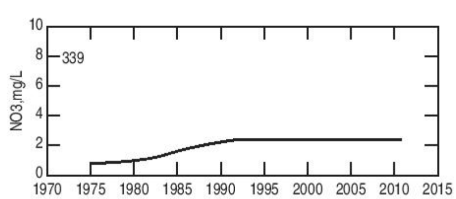
Site No.	Tributaries - Upper Mississippi River Basin Site Location / Trend Analysis Periods	% Change in Nitrate Concentration	Ending Concentration, mg/l
004	**Crow River – Dayton**		1.24
	Overall change 1976-2010	NT	
Note: y-scale 0-2 mg/l			
043	**Rum River - Isanti**		0.24
	Overall change 1976-2010	+15%	
	1976-1986	NT	
	1987-1998	+40%	
	1999-2010	-18%	
			
016	**Rum River - Anoka**		0.21
	Overall change 1976-2010	+24%	
	1976-1998	+29%	
	1999-2002	+16%	
	2002-2010	-18%	
			

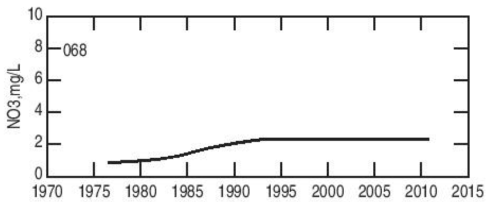
Mississippi River between the Minnesota and St. Croix Rivers

The three sites in the St. Paul area between the Upper and Lower Mississippi River Basins all had an overall increase in flow-adjusted nitrate concentrations over the entire period of record. However, the increases have largely diminished in recent years, with no apparent trend over the last two decades at the two most downstream sites (Table 4).

The Minnesota River, which merges with the Mississippi River upstream from these three sites, affects both the concentrations and trends at these three sites. The nitrate concentrations are substantially higher at these three locations on the Mississippi River, as compared to upstream Mississippi River sites at Anoka and Monticello. Another potential influence on nitrate concentrations in these segments of the Mississippi River is discharge from the Metro wastewater treatment facility between sites 266 and 339. This facility services much of the Twin Cities Metropolitan Area.

Table 4. Trends in flow-adjusted nitrate concentrations in the Mississippi River between its confluence with the Minnesota River and its confluence with the St. Croix River in the St. Paul area. A positive change in nitrate concentration represents a statistically significant (p<0.1) upward trend, and a negative change represents a statistically significant downward trend. "NT" (no trend) indicates that the trend was not statistically significant (p<0.1). Site No. refers to site location on Figure 1 and Table 1.

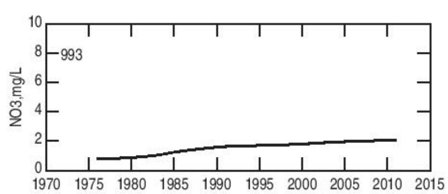
Site No.	Mississippi River – St. Paul Area Site Location / Trend Analysis Periods	% Change in Nitrate Concentrations	Ending Concentration, mg/l
266	**Mississippi River – St. Paul Wabasha St.**		1.9
	Overall change 1975-2010	+149%	
Note: Y-scale 0-10			
339	**Mississippi River – Grey Cloud Island**		2.4
	Overall change 1975-2010	+206%	
	1975-1991	+206%	
	1992-2010	NT	
			

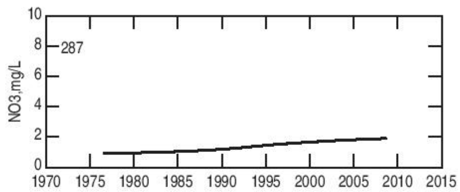
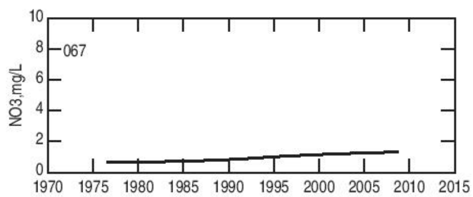
Site No.	Mississippi River – St. Paul Area Site Location / Trend Analysis Periods	% Change in Nitrate Concentrations	Ending Concentration, mg/l
068	**Mississippi River – Hastings Lock and Dam No. 2**		2.3
	Overall change 1976-2011	+172%	
	1976-1993	+172%	
	1994-2011	NT	
			

Lower Mississippi River - between Prescott (confluence with St. Croix River) and the Iowa border

In the Mississippi River between the Twin Cities and Iowa, flow-adjusted nitrate concentrations more than doubled since 1976, based on monitoring near Red Wing, Minneiska, and LaCrosse (Table 5). During the last two decades, concentrations had a reduced rate of increase at Prescott (Lock and Dam No. 3) where we have had continuous and more frequent monitoring (Table 1), but had a constant rate of increase farther downstream in Minneiska and LaCrosse.

Table 5. Trends in flow-adjusted nitrate concentrations in the Lower Mississippi River between its confluence with the St. Croix River and the Iowa border. A positive change in nitrate concentration represents a statistically significant ($p<0.1$) upward trend, and a negative change represents a statistically significant downward trend. "NT" (no trend) indicates that the trend was not statistically significant ($p<0.1$). Site No. refers to site location on Figure 1 and Table 1.

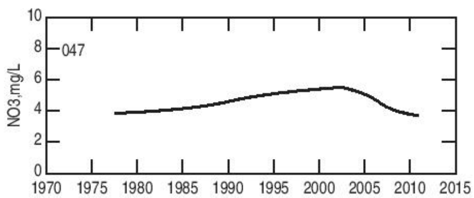
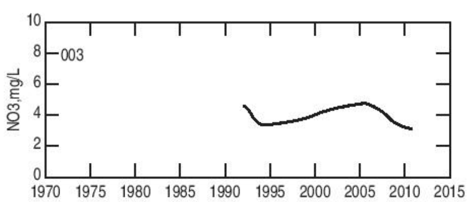
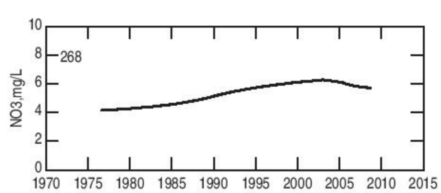
Site No.	Lower Mississippi River Site Location / Trend Analysis Periods	% Change in Nitrate Concentration	Ending Concentration, mg/l
993	**Mississippi River – Prescott Lock and Dam No. 3**		2.1
	Overall change 1976-2010	+168%	
	1976 - 1991	+117%	
	1992-2010	+24%	
			

Site No.	Lower Mississippi River Site Location / Trend Analysis Periods	% Change in Nitrate Concentration	Ending Concentration, mg/l
287	**Mississippi River – Minneiska Lock and Dam No. 5**		1.9
	Overall change 1976-2008	+109%	
			
067	**Mississippi River – LaCrosse, WI**		1.3
	Overall change 1976-2008	+107%	
			

Tributaries of the Lower Mississippi River

The three tributaries analyzed for trends in the Lower Mississippi River Basin all had downward trends in flow-adjusted nitrate concentrations between about 2003-05 and 2010 (Table 6). During the decade prior to that, all three sites had upward trends. Since 1976, the overall change in the Zumbro River has been a 38% increase. The Straight River had periods of increases and decreases, which have amounted to virtually no overall change (-4%). Many tributaries to the Lower Mississippi River from both the Minnesota and Wisconsin side of the basin were not analyzed for trends because the combination of flow and monitoring data were not available.

Table 6. Trends in flow-adjusted nitrate concentrations in four tributaries of the Lower Mississippi River. A positive change in nitrate concentration represents a statistically significant (p<0.1) upward trend, and a negative change represents a statistically significant downward trend. "NT" (no trend) indicates that the trend was not statistically significant (p<0.1). Site No. refers to site location on Figure 1 and Table 1.

Site No.	Tributaries - Lower Mississippi River Basin Site Location / Trend Analysis Periods	% Change in Nitrate Concentration	Ending Concentration, mg/l
047	**Straight River – Clinton Falls**		3.8
	Overall change 1977-2010	-4%	
	1977-2002	+43%	
	2003-2010	-33%	
			
003	**Cannon River - Welch**		3.2
	Overall change 1991-2010	-34%	
	1991-1994	-29%	
	1994-2005	+42%	
	2005-2010	-35%	
			
268	**Zumbro River - Rochester**		5.71
	Overall change 1976-2008	+38%	
	1976-2002	+51%	
	2003-2008	-9%	
			

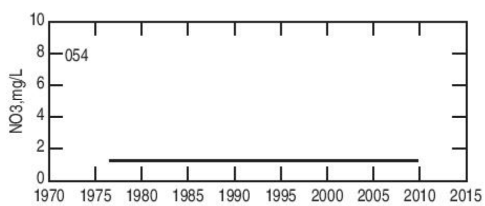
Minnesota River Basin results

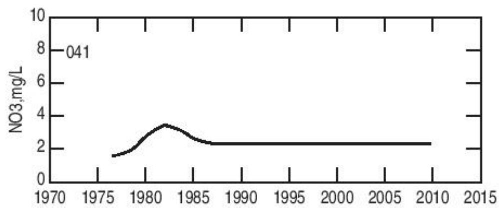
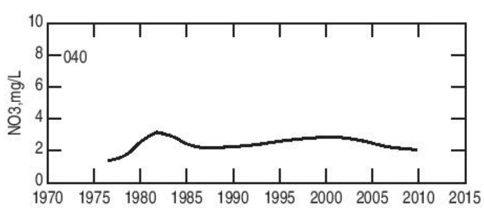
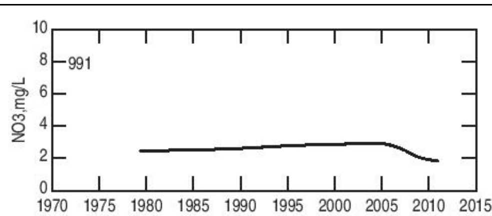
Minnesota River

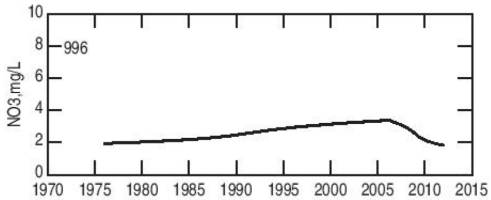
The nitrate trend analyses for Minnesota River sites indicated that flow-adjusted concentrations gradually increased in the Minnesota River for many years, but that there is evidence of amelioration in that trend in more recent years. In particular, the sites at Jordan and Fort Snelling, with the most extensive data sets (Table 1), had decreases of about 40% over the most recent six years ending in 2010 and 2011, respectively (Table 7).

Sites meeting the long-term trend analysis criteria were not available for the upper one-half of the Minnesota River main stem. The most upstream site analyzed is near Courtland, Minnesota, which is just southeast of New Ulm. At Courtland, where nitrate concentrations are still relatively low compared to downstream sites, trends in flow-adjusted nitrate concentrations were not found to be statistically significant (Table 7). Between Courtland and St. Peter, the influential tributaries of the Blue Earth, LeSueur and the Watonwan Rivers enter the Minnesota River. At St. Peter and Henderson, concentrations increased from 1976 to 1981 and then decreased from 1982 to 1986, followed by a more stable period of no significant trend at St. Peter and gradual upward and downward trends at Henderson. Farther downstream, in Jordan and Fort Snelling, the Minnesota River had upward trends from 1976 until 2004-05, followed by such large decreases that the overall change since 1976 is a slight reduction in flow-adjusted nitrate concentrations.

Table 7. Trends in flow-adjusted nitrate concentrations at five Minnesota River monitoring locations. A positive change in nitrate concentration represents a statistically significant (p<0.1) upward trend, and a negative change represents a statistically significant downward trend. "NT" (no trend) indicates that the trend was not statistically significant (p<0.1). Site No. refers to site location on Figure 1 and Table 1.

Site No.	Minnesota River Site Location / Trend Analysis Periods	% Change in Nitrate Concentration	Ending Concentration, mg/l
054	**Minnesota River - Courtland**		1.3
	Overall change 1976-2009	NT	
			

Site No.	Minnesota River Site Location / Trend Analysis Periods	% Change in Nitrate Concentration	Ending Concentration, mg/l
041	**Minnesota River – St. Peter**		2.3
	Overall change 1976-2009	+49%	
	1976-1981	+119	
	1982-1986	-32%	
	1987-2009	NT	
			
040	**Minnesota River - Henderson**		2.1
	Overall change 1976-2009	+50%	
	1976-1981	+129%	
	1982-1986	-31%	
	1987-2000	+33%	
	2001-2009	-28%	
			
991(39.4)	**Minnesota River - Jordan**		1.9
	Overall change 1979-2010	-26%	
	1979-2004	+19%	
	2005-2010	-38%	
			

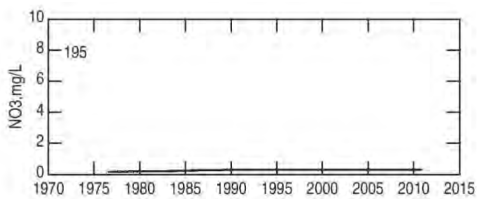
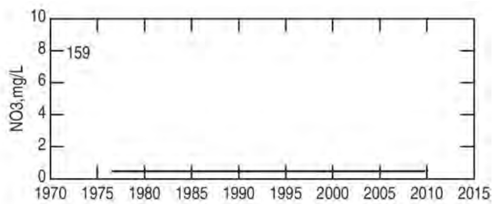
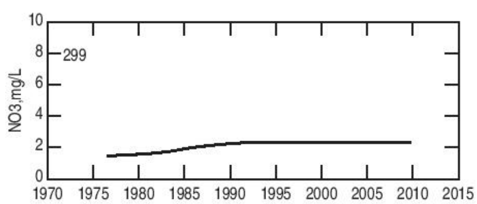
Site No.	Minnesota River Site Location / Trend Analysis Periods	% Change in Nitrate Concentration	Ending Concentration, mg/l
996(3.5)	**Minnesota River – Fort Snelling**		2.2
	Overall change 1976-2011	-6%	
	1976-2005	+74%	
	2006-2011	-46%	
			

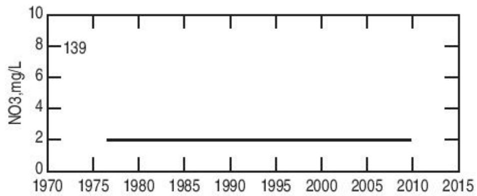
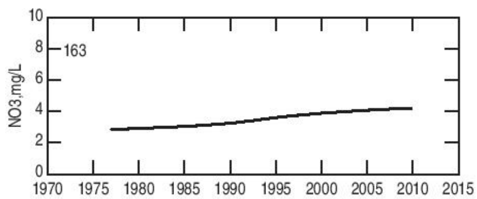
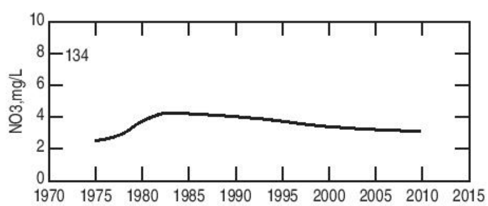
Tributaries to the Minnesota River

Trend analyses were performed for four tributaries to the Minnesota River upstream from Courtland (sites 195, 159, 299, 139). All four tributaries had gradual trends in flow-adjusted nitrate concentrations since 1993 (Table 8), and no significant trend was determined for 1993-2010 and 1992-2010 in the Pomme de Terre and Redwood Rivers. Prior to 1993, nitrate concentrations were increasing in the Pomme de Terre and Redwood Rivers and stable in the Yellow Medicine and Cottonwood Rivers.

The Blue Earth River contributes substantial quantities of nitrate to the Minnesota River and therefore has a large effect on nitrate concentrations in the Minnesota River. The Blue Earth River had an increase in nitrate concentrations from 1975 to 1982, followed by a long gradual decrease. Conversely, the Watonwan River had a long gradual increase in flow-adjusted nitrate concentrations. Neither of these trends in the Blue Earth and Watonwan mirrors the trends in the downstream segments of the Minnesota River, indicating that streamflow and nitrate inputs from additional tributaries have affected nitrate concentration trends in the lower Minnesota River.

Table 8. Trends in flow-adjusted nitrate concentrations in six tributaries of the Minnesota River. A positive change in nitrate concentration represents a statistically significant (p<0.1) upward trend, and a negative change represents a statistically significant downward trend. "NT" (no trend) indicates that the trend was not statistically significant (p<0.1). Site No. refers to site location on Figure 1 and Table 1.

Site No.	Minnesota River Tributaries Site Location / Trend Analysis Periods	% Change in Nitrate Concentration	Ending Concentration, mg/l
195	**Pomme de Terre River - Appleton**		0.3
	Overall change 1976-2010	+75%	
	1976 – 1992	+75%	
	1993 – 2010	NT	
			
159	**Yellow Medicine – Granite Falls**		0.5
	Overall change 1976-2009	NT	
			
299	**Redwood River – Redwood Falls**		2.3
	Overall change 1976-2009	+58%	
	1976-1992	+58%	
	1992-2009	NT	
			

Site No.	Minnesota River Tributaries Site Location / Trend Analysis Periods	% Change in Nitrate Concentration	Ending Concentration, mg/l
139	**Cottonwood River – New Ulm**		2.0
	Overall change 1976-2009	NT	
			
163	**Watonwan River – Garden City**		4.2
	Overall change 1976-2009	+48%	
			
134	**Blue Earth River – Mankato**		3.1
	Overall change 1976-2010	+23%	
	1975-1982	+70%	
	1982-2009	-27%	
			

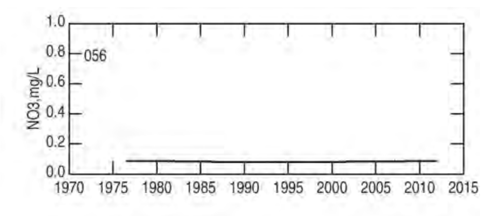
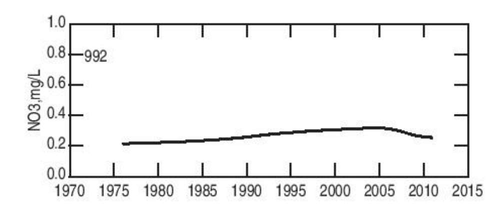
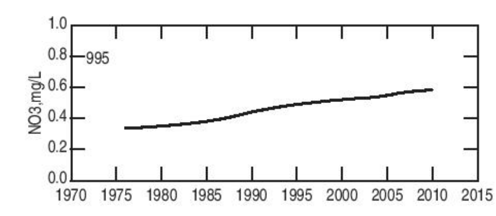
St. Croix River Basin results

St. Croix River

Changes in flow-adjusted nitrate concentrations were very minor at Danbury, Wisconsin, the upper-most monitored reach of the St. Croix River, remaining very low (less than 0.1 mg/l) throughout the period of record. Nitrate concentrations remain low throughout the St. Croix River, but are higher at Stillwater and Prescott, as compared to Danbury.

Farther downstream at Stillwater and Prescott, nitrate concentrations steadily increased from 1976 to 2005, at which time concentrations began to decrease at Stillwater and continued to increase at Prescott (Table 9).

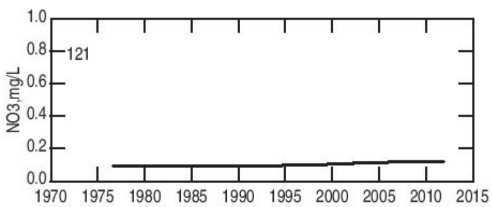
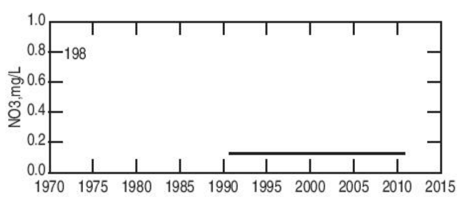
Table 9. Trends in flow-adjusted nitrate concentrations at three monitoring sites along the St. Croix River. "LS" indicates a lower strength trend. A positive change in nitrate concentration represents a statistically significant (p<0.1) upward trend, and a negative change represents a statistically significant downward trend. "NT" (no trend) indicates that the trend was not statistically significant (p<0.1). Site No. refers to site location on Figure 1 and Table 1.

Site No.	St. Croix River Site Location / Trend Analysis Periods	% Change in Nitrate Concentration	Ending Concentration, mg/l
056	**St. Croix River – Danbury, WI**		0.09
	Overall change 1975-2011	-2%	
	1976-1992	-10%	
	1993-2011	+9%	
			
992/23.3	**St. Croix River - Stillwater**		0.26
	Overall change 1976-2010	+19%	
	1976-2004	+49%	
	2005-2010	-20%	
			
995(0.3)	**St. Croix River - Prescott**		0.58
	Overall change 1976-2009	+74%	
	1976-2000	+57%	
	2001-2009	+11%	
			

Tributaries to the St. Croix River

Flow-adjusted nitrate concentrations for two tributaries in the upper reaches of the St. Croix River were analyzed for trends. Both the Snake River and Kettle River have very low nitrate concentrations, around 0.1 mg/l, similar to the concentrations in the St. Croix River at Danbury. Nitrate concentrations in the Kettle River had no trend prior to 1990 and then started to gradually increase after 1991. The Snake River had no significant trends since 1991 (Table 10). Prior to 1991, streamflow data were not available for the Snake River to allow for flow-adjusted trend analysis.

Table 10. Trends in flow-adjusted nitrate concentration in two tributaries of the St. Croix River. A positive change in nitrate concentration represents a statistically significant ($p<0.1$) upward trend. "NT" (no trend) indicates that the trend was not statistically significant ($p<0.1$). Site No. refers to site location on Figure 1 and Table 1.

Site No.	Tributaries – St. Croix River Basin Site Location / Trend Analysis Periods	% Change in Nitrate Concentration	Ending Concentration, mg/l
121	**Kettle River – Hinkley**		0.09
	Overall change 1976-2011	+32%	
	1976-1989	NT	
	1990-2011	+32%	
			
198	**Snake River – Pine City**		0.12
	Overall change 1991-2010	NT	
			

Cedar and Des Moines River results

The Cedar River has among the highest nitrate concentrations of rivers in Minnesota. Nitrate concentrations in the Cedar River have been steadily increasing since 1967 (Table 11), with increases averaging 1% per year at Lansing (1980-2010) and 2% per year at Austin (1967-2009). No statistically significant trend was found for the West Fork Des Moines River near Petersburg (Table 12).

Table 11. Trends in flow-adjusted nitrate concentrations at two sites along the Cedar River. A positive change in nitrate concentration represents a statistically significant (p<0.1) upward trend. Site No. refers to site location on Figure 1 and Table 1.

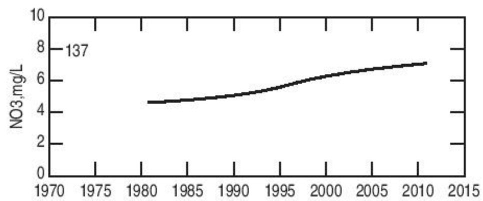
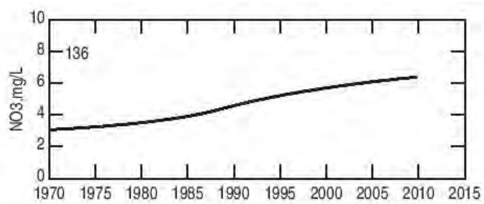
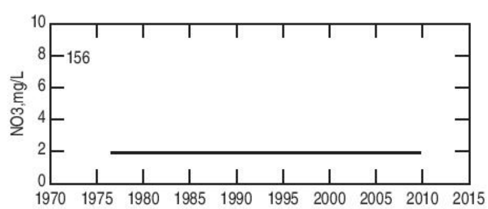
Site No.	Cedar River Site Location / Trend Analysis Periods	% Change in Nitrate Concentration	Ending Concentration, mg/l
137	**Cedar River – Lansing**		7.1
	Overall change 1980-2010	+53%	
			
136	**Cedar River - Austin**		6.4
	Overall change 1967-2009	+113%	
			

Table 12. Trends in flow-adjusted nitrate concentrations in the West Fork Des Moines River. "NT" (no trend) indicates that the trend was not statistically significant (p<0.1). Site No. refers to site location on Figure 1 and Table 1.

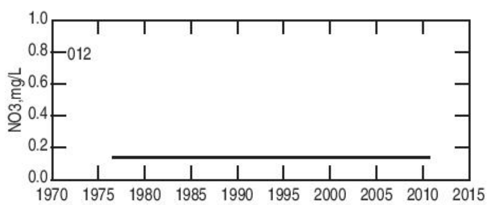
Site No.	Des Moines River Site Location / Trend Analysis Periods	% Change in Nitrate Concentration	Ending Concentration, mg/l
156	**West Fork Des Moines River – Petersburg**		1.9
	Overall change 1976-2009	NT	
			

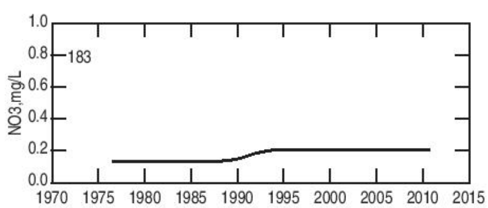
Red River of the North results

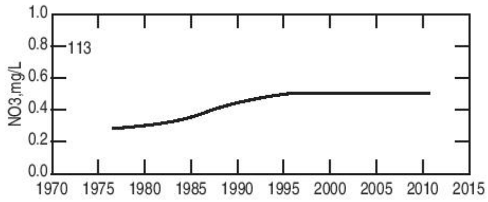
Red River of the North

Three sites on the Red River of the North were analyzed for trends in flow-adjusted nitrate concentrations. All three sites had relatively low nitrate concentrations, although the concentrations were higher at the downstream site in Perley. No trends were detected at the upper-most location at Brushvale. At Moorhead, and just downstream from Moorhead at Perley, concentrations increased prior to 1993-95, but had no significant trends after 1993 and 1995, respectively (Table 13).

Table 13. Trends in flow-adjusted nitrate concentrations at three locations along the Red River of the North. A positive change in nitrate concentration represents a statistically significant (p<0.1) upward trend. "NT" (no trend) indicates that the trend was not statistically significant (p<0.1). Site No. refers to site location on Figure 1 and Table 1.

Site No.	Red River of the North Site Location / Trend Analysis Periods	% Change in Nitrate Concentration	Ending Concentration, mg/l
012	**Red River - Brushvale**		0.14
	Overall change 1976-2010	NT	
			

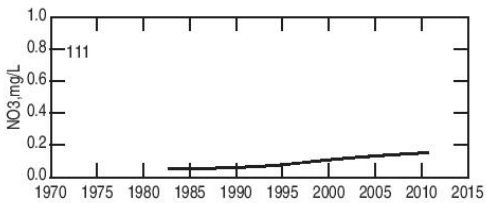
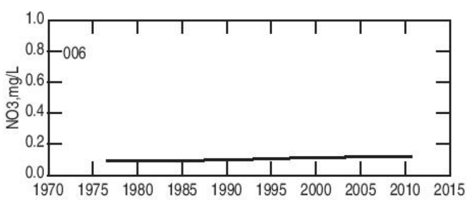
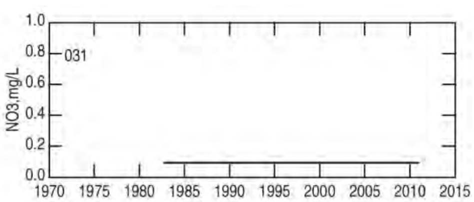
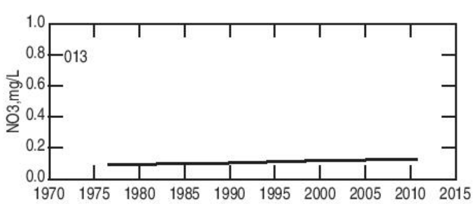
Site No.	Red River of the North Site Location / Trend Analysis Periods	% Change in Nitrate Concentration	Ending Concentration, mg/l
183	**Red River - Moorhead**		0.21
	Overall change 1976-2010	+53%	
	1976-1987	NT	
	1988-1993	+53%	
	1994-2010	NT	
			

113	**Red River - Perley**		0.51
	Overall change 1976-2010	+78%	
	1976-1995	+78%	
	1996-2010	NT	
			

Tributaries of the Red River of the North

Trends were assessed for two tributaries of the Red River of the North, the Ottertail River and the Red Lake River, each with two monitoring locations. Similar to the Red River of the North at Brushvale, nitrate concentrations were very low, mostly between 0.1 and 0.15 mg/l. At these low concentrations, the Ottertail River showed a steady increasing trend since 1982. The percentage increase was greater in Fergus Falls than at the downstream site at Breckenridge (Table 14). The Red Lake River at East Grand Forks had a trend very similar to that of the Ottertail River in Breckenridge, both with gradually increasing nitrate concentrations by 35% over the entire time of analysis. Farther upstream at Fisher, no trends were detected.

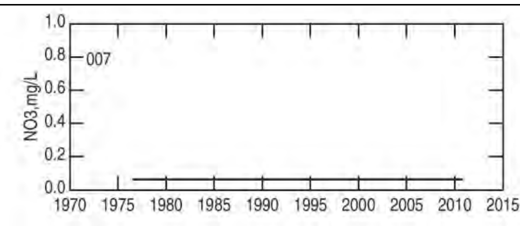
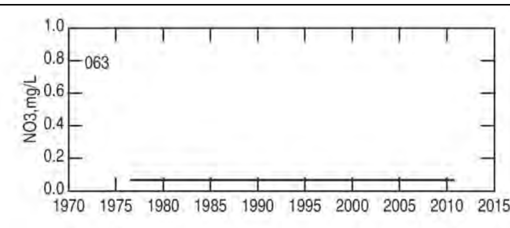
Table 14. Trends in flow-adjusted nitrate concentrations in four tributaries of the Red River of the North. A positive change in nitrate concentration represents a statistically significant (p<0.1) upward trend. "NT" (no trend) indicates that the trend was not statistically significant (p<0.1). Site No. refers to site location on Figure 1 and Table 1.

Site No.	Tributaries – Red River of the North Basin Site Location / Trend Analysis Periods	% Change in Nitrate Concentration	Ending Concentration, mg/l
111	**Ottertail River – Fergus Falls**		0.15
	Overall change 1982-2010	+207%	
			
006	**Ottertail River – Breckenridge**		0.12
	Overall change 1976-2010	+35%	
			
031	**Red Lake River - Fisher**		0.09
	Overall change 1982-2010	NT	
			
013	**Red Lake River – East Grand Forks**		0.13
	Overall change 1976-2010	+35%	
			

Rainy and Western Lake Superior basins

The Rainy River had no substantial increases or decreases in flow-adjusted nitrate concentrations over the analysis period, with a concentration change at International Falls that rounded to 0%, and no significant trend at Baudette (Table 15). Concentrations have remained very low at both sites on the Rainy River since 1976.

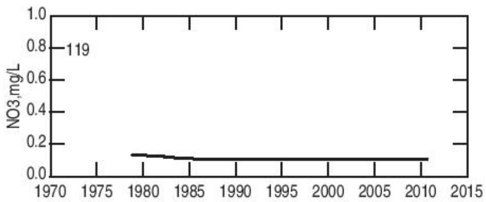
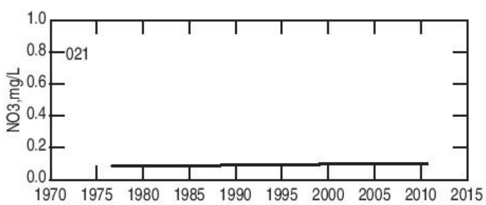
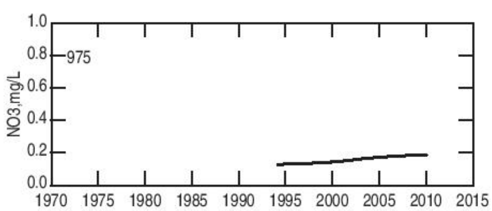
Table 15. Trends in flow-adjusted nitrate concentrations at two locations on the Rainy River. "NT" (no trend) indicates that the trend was not statistically significant (p<0.1). Site No. refers to site location on Figure 1 and Table 1.

Site No.	Rainy River Site Location / Trend Analysis Periods	% Change in Nitrate Concentration	Ending Concentration, mg/l
007	**Rainy River – International Falls**		0.06
	Overall change 1976-2010	*0%	
			
063	**Rainy River - Baudette**		0.06
	Overall change 1976-2010	NT	
			

* The trend was statistically significant, but was so small that it rounded to zero.

The St. Louis River (within the Western Lake Superior Basin), also with very low nitrate concentrations, had fairly stable trends at Forbes and Fond Du Lac, with a slight decrease in concentrations at Forbes and a slight increase at Fond Du Lac. In Duluth, nitrate concentrations in the St. Louis River increased by 47% since 1994 (Table 16).

Table 16. Trends in flow-adjusted nitrate concentrations at three locations on the St. Louis River. A positive change in nitrate concentration represents a statistically significant (p<0.1) upward trend, and a negative change represents a statistically significant downward trend. "NT" (no trend) indicates that the trend was not statistically significant (p<0.1). Site No. refers to site location on Figure 1 and Table 1.

Site No.	St. Louis River Site Location / Trend Analysis Periods	% Change in Nitrate Concentration	Ending Concentration, mg/l
119	**St. Louis River - Forbes**		0.11
	Overall change 1978-2010	-20%	
	1978-1986	-20%	
	1987-2010	NT	
			
021	**St. Louis River – Fond Du Lac**		0.10
	Overall change 1976-2010	+16%	
			
113	**St. Louis River - Duluth**		0.19
	Overall change 1994-2010	+47%	
			

Discussion

Comparison with previous studies

Results of nitrate, TN, and ammonium concentrations and load trends from previous Minnesota studies are described in Chapter C2. In this discussion, we will compare only the nitrate concentration trends from previous studies to nitrate concentration trends reported in this chapter. None of the results are directly comparable because of differences in one or more of the following: trend analysis timeframe; location on the river; and/or statistical analysis/streamflow adjustment methods. Yet, several sites from past studies were close enough in location and timeframe to allow some comparison. In general, the results in this study agreed reasonably well with previous studies where comparisons were possible, except that the magnitude of change was consistently higher in this study as compared to previous studies. Comparisons in specific rivers are described below.

Mississippi River

The 76% increase in nitrate concentrations observed by Sprague et al. (2011) in the Mississippi River between 1980 and 2008 at Clinton, Iowa, are reasonably similar to the 107 and 109% increases in the Mississippi River found in this study at the two most downstream Mississippi River sites at LaCrosse, Wisconsin, and Minneiska, Minnesota (1976 to 2008).

Lafrancois et al. (2013) found increases in the Mississippi River from Anoka to Hastings ranging from 47 to 59% between 1976 and 2006, with one of six sites having no statistically significant trend. Increases were also found in our study, yet the increases were found to be larger during the extended timeframe assessed in this study (1976 to 2010-11). We found increases of 87% to 206% at six Mississippi River sites between Anoka and Prescott.

Minnesota River

Previous trend studies for the lower part of the Minnesota River Basin showed that nitrate concentrations either had no significant trend or an overall decreasing trend, with a few exceptions. This study showed several periods of decreasing trends in the Minnesota River, yet we also found other periods of increases. In the Minnesota River at Jordan, all studies showed little overall change in nitrate concentrations in the Minnesota River from the late 1970s to the early 2000s (Table 17), although this study indicated a slight increase from 1979 to 2004 and the other studies showed either no trend or a slight decrease over slightly different timeframes. The magnitude of change shown from all studies in the Minnesota River is small considering the long period of record.

Table 17. Results of different trend studies of nitrate concentration in the Minnesota River at Jordan, along with the findings in this study. A positive change in nitrate concentration represents an upward trend, and a negative change represents a downward trend.

Timeframe	% Change in Nitrate Concentration	Author
1979-2004	+19%	This Study
1976-2006	No significant trend	Lafrancois et al. (2013)
1976-2002	-20%	Kloiber (2004)
1979-2003	-10%	Johnson (2006)

St. Croix River

Kloiber (2004) found a 17% increase in nitrate concentrations in the St. Croix River at Stillwater between 1976 and 2002. This study found an increase at this same site between 1976 and 2004, but the magnitude of the increase was higher in this study (49%).

Red River of the North

At the border between Minnesota and Manitoba, Canada, Vechia (2005) found that nitrate concentrations increased in the Red River of the North by 27% from 1982 to 1992, followed by a no-trend period from 1993 to 2001. Lorenz et al. (2009) found no trend at Grand Forks from 1999 to 2008.

The farthest downstream site on the Red River of the North evaluated for this study was at Perley, for which results were generally similar to what Vechia and Lorenz found farther downstream, with an increasing trend through 1995, and no significant trend after that (1996 to 2010).

Lag time with groundwater flow

The velocity of groundwater flow is commonly measured in terms of feet per year. It can take many years to many decades before nitrate leaching through the soil near its source will ultimately move with groundwater and discharge into a river or stream. As described in appendix B5-1, much of the nitrate can be lost during this groundwater transport process due to denitrification prior to entering surface waters.

The lag time between nitrate leaching through the soil and into groundwater and its subsequent movement to streams depends on many factors, such as soils, geology, topography, and proximity to streams. Groundwater near a stream can enter surface waters within a matter of days or weeks. Water that is farther from streams can travel to streams in timeframes ranging from days to decades to centuries, depending on the hydrogeology (see http://www.dnr.state.mn.us/waters/groundwater_section/mapping/sensitivity.html). Streams fed by shallow surficial aquifers contain a mix of waters, some of which entered the ground many years earlier and some of which recently entered the groundwater (Puckett et al., 2011).

This groundwater lag time effect can greatly affect observed trends. The nitrate concentrations observed in the river integrate the consequences of land use and management in recent years with that of land use and management occurring years to decades earlier. The complete effects of modern era commercial fertilizer use, crop genetics, and management may not yet be realized in nitrate concentrations in the river.

For example, nearly one-half of the estimated cropland N sources in the Upper Mississippi River Basin come from groundwater flow; with the rest from tile lines and surface runoff (see Chapters D1 and D4). Because of the long lag time between nitrate entering groundwater and the eventual discharge of the affected groundwater into surface waters in this basin, nitrate pollution that occurred many years to many decades ago may be a large part of the nitrate just now entering streams and rivers. Therefore, the increasing nitrate concentrations in the Mississippi River do not necessarily mean that we are currently using practices that are causing higher nitrate loads in the river than a decade or two ago.

The lag-time effect of nitrate moving from groundwater into surface waters is also expected to be a dominant process affecting trends in other basins such as the St. Croix, Red River of the North, and Lower Mississippi Basins, which each have more than one-half of the estimated cropland nitrate moving into surface waters through groundwater pathways (see Chapter D1).

In basins with a higher fraction of the nitrate moving through tile drainage, the groundwater lag time will have less of an effect on observed concentration trends in rivers. The Minnesota River Basin has about 18% of its estimated cropland N transported via groundwater (Chapters D1 and D4), and is dominated instead by the quicker-responding tile drainage flow pathway (75% of the estimated cropland N). Nitrate concentrations in the lower part of the Minnesota River were increasing until the 2001-2005 timeframe, at which time the trends reversed to show declining concentrations through 2009-11 (Table 7). The Des Moines River Basin and Cedar River Basin also have a major nitrate pathway through tile lines (55-70% of estimated cropland N). Nitrate concentration trends in the Cedar River were continuously upward (Table 11). Estimates of source pathways in Chapter D1 indicate that more N enters the Cedar River from groundwater (39%) as compared to the Minnesota River (18%). No significant trends were found in the Des Moines River (Table 12), where groundwater contributes an estimated 23% of the N.

Changes in land management and precipitation

Many factors potentially affect nitrate concentration trends, including changes in crops/vegetation; fertilizer management and N use efficiency; human population and wastewater treatment processes; livestock/poultry populations and manure management practices; climate/precipitation; soil mineralization; and flow pathways—tile drainage, groundwater, and runoff.

It was beyond the scope of this study to investigate the relation between trends in river nitrate concentrations and changes in land use and hydrologic factors expected to affect nitrate concentrations. Changes in certain variables that have the potential to affect river nitrate concentrations are summarized below. Future studies that more thoroughly explore possible reasons for changes in nitrate concentrations could be useful for understanding the most important factors affecting nitrate increases and decreases.

Fertilizer use

Minnesota N fertilizer sales have followed a similar pattern as national fertilizer sales (Figure 6). Fertilizer sales increased markedly between 1965 and 1980, followed by leveling off of sales and a gradual long-term overall increasing trend between 1980 and 2011. The average statewide N application rate per acre on corn cropland started leveling off in the early 1970s, with a gradual increasing rate from 1972 until the early 1980s (Figure 7). Fertilizer application rates per acre of corn cropland appear to have been relatively stable to slightly increasing from the late 1980s until about 2010, according to information provided by the Minnesota Department of Agriculture (MDA, 2013).

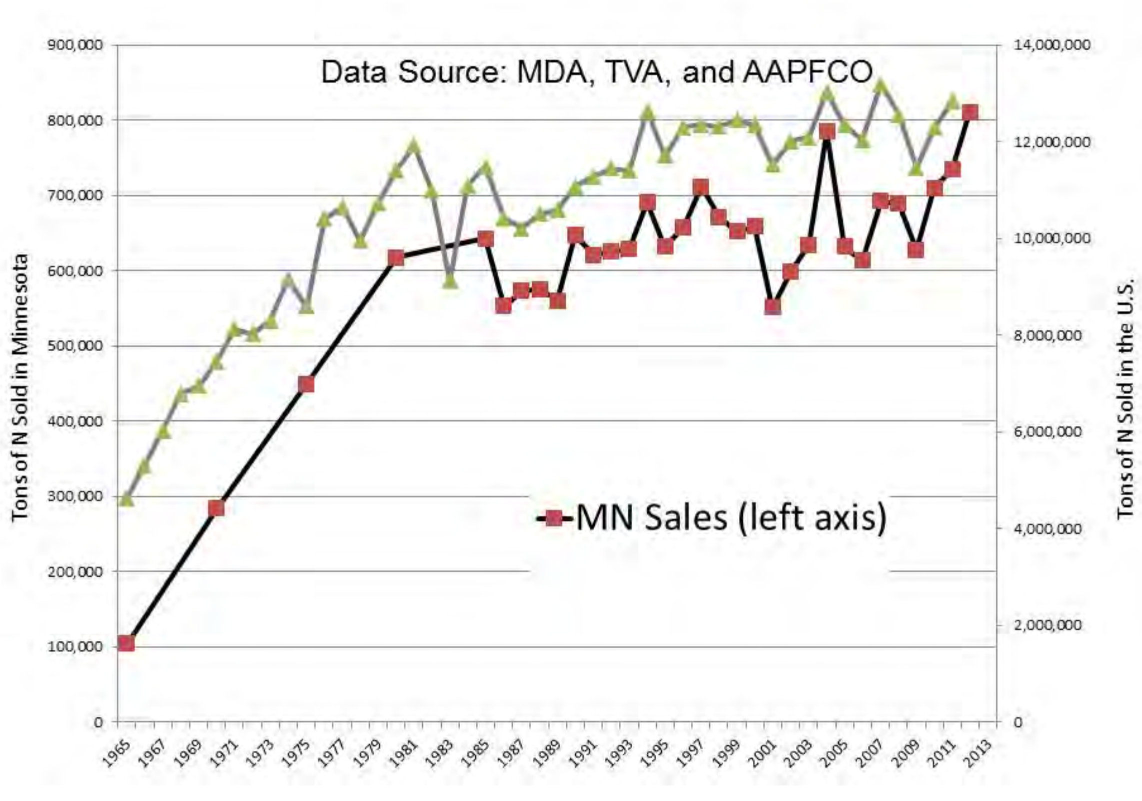


Figure 6. Commercial nitrogen (N) fertilizer sales from 1965 to 2011 in the United States (green) and in Minnesota (red). Graph from MDA (2013). Data sources are Minnesota Department of Agriculture (MDA), Tennessee Valley Authority and Association of American Plant Food Control Officials.

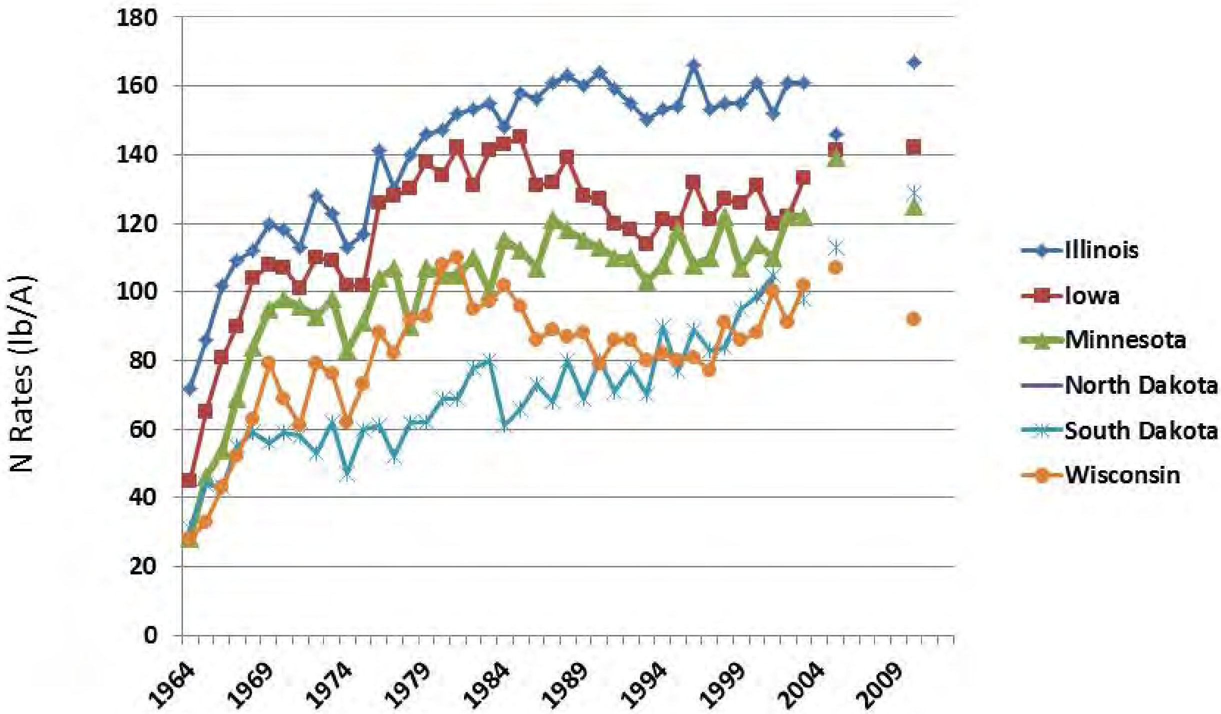


Figure 7. Midwest states' nitrogen (N) fertilizer application rates (in pounds per acre) for corn from 1964 to 2010. Graph from MDA (2013). Data sources: ERS/NASS (Economic Research Service and National Agricultural Statistics Service).

Crop nitrogen fertilizer use efficiency

An estimated 31% of statewide N outputs from agricultural lands go into the atmosphere, mostly through the three processes of senescence, denitrification in soil, and volatilization, and an estimated 6% of N outputs go into groundwater and surface waters (see Chapter D4). The remaining 63% of N from agricultural lands goes into crops and food products. As N fertilizer use becomes more efficient through plant genetics and improved management practices, more of the N goes into crops and potentially less is lost into the atmosphere and into waters. The N fertilizer use efficiency has been increasing over the past decades according to information assembled by the Minnesota Department of Agriculture. The bushels of corn produced per pound of N fertilizer input (crop N use efficiency) has increased from about 0.8 in 1992 to about 1.2 in 2011 (Figure 8; MDA, 2013). It is possible that more of the N is now used by the crop and less N may therefore be available in the soil for potential losses to the air and water for each bushel of corn produced. The potential benefits of this trend to water quality, however, may be offset somewhat as corn protein content decreases and as more corn is grown per acre. Additional study is needed of the water-quality effects from such changes.

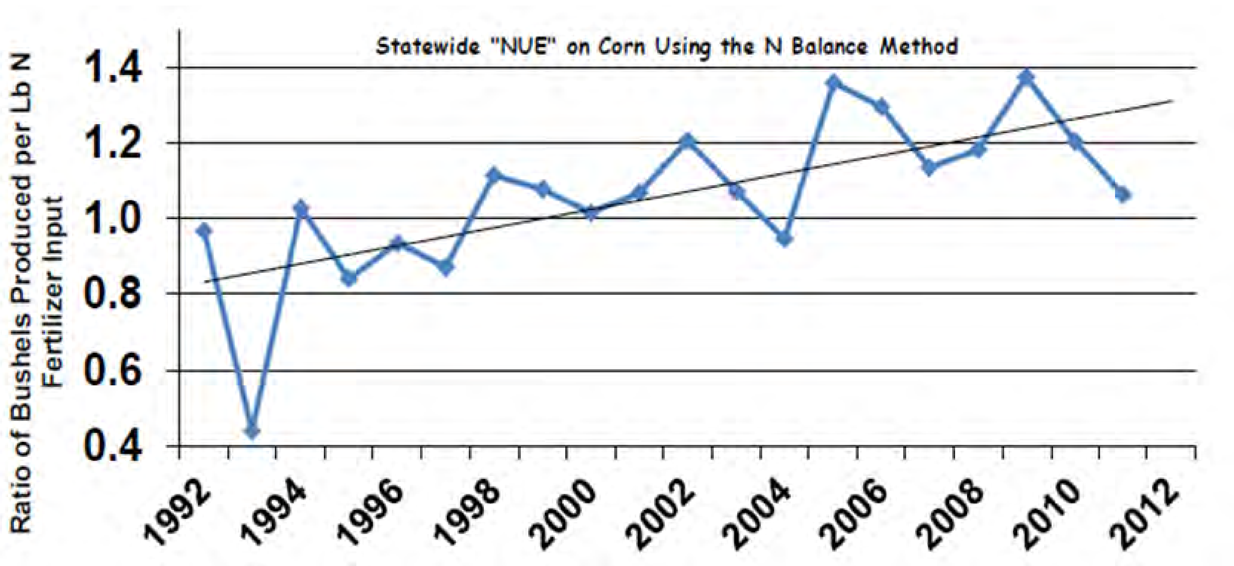


Figure 8. Bushels of corn produced per pound of N fertilizer applied to corn cropland, 1992 to 2011. Graph from MDA (2013).

Livestock/poultry manure

Based on U.S. Department of Agriculture National Agricultural Statistics Service (www.nass.usda.gov/data_and_statistics/index.asp) inventories between 1974 and 2007, Minnesota cattle and calf numbers have declined by 35% (most affected by dairy declines), while swine numbers have more than doubled and turkeys have more than tripled. The total number of animal units in the state, as animal units are defined in Minn. R. ch. 7020, has generally remained constant since 1974 (Figure 9). Decreasing cattle were offset by the increasing swine and turkey numbers.

When we multiply the animal numbers by typical manure N content for different livestock species, the estimated amount of manure N from livestock and poultry being applied onto cropland was not found to vary by more than 12% between 1974 and 2007, and estimated manure N amounts applied statewide in 2007 were only 1% more than applied in 1974. It is also possible that even though the amount of manure N being generated and applied to lands has not changed much, the amount of manure N entering waters may have changed (i.e. less manure N entering waters).

Manure management changed considerably throughout this period (1974 to 2007) as more liquid manure storage pits and basins were constructed, replacing solid manure handling systems (based on author's 16 years of experience working in the MPCA Feedlot program). Methods of application correspondingly changed, and injection of liquid manure below the ground surface became more popular. We expect that these changes may have resulted in more predictability in available N from manure for crops, and therefore improved manure management and less N losses to waters.

During 2000, Minnesota changed its feedlot regulations related to manure spreading (Minn. R. ch. 7020.2225). The effects of these regulations on N management have not been researched. It is possible that the new regulations resulted in improved N management and less N losses to waters. The rule changes affecting N management included requirements for nutrient management plan development, record-keeping of manure spreading, and laboratory testing of manure N content.

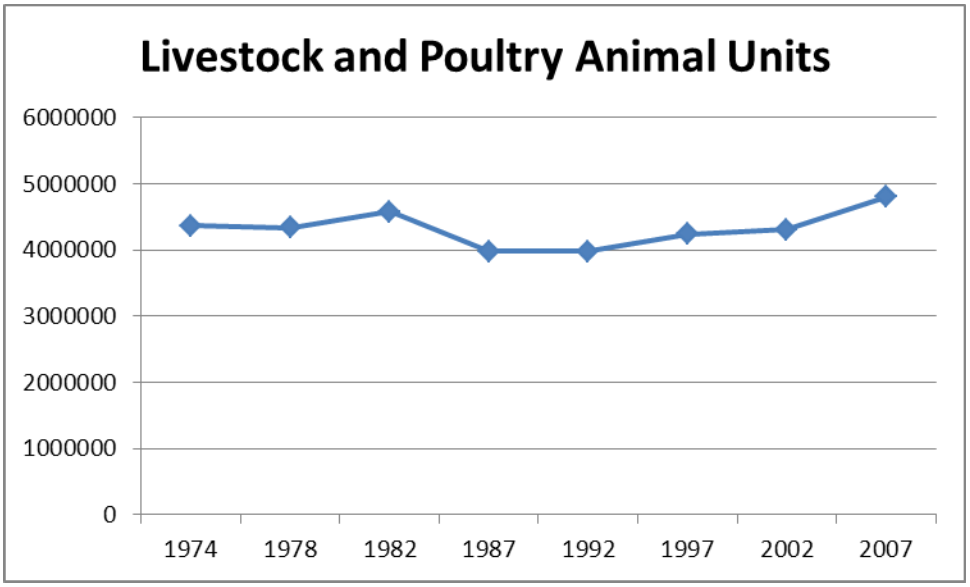


Figure 9. Trends of total animal units (AUs) in Minnesota based on USDA National Agricultural Statistics Service data (www.nass.usda.gov/) and the following conversion factors: dairy cow - 1.4 AUs; beef cow - 1 AU; other cattle and calves avg. - 0.7 AU; swine and hogs - 0.3 AU; turkeys - 0.018 AU; chickens - 0.003 AU.

Human population

The Minnesota population has been growing steadily from 4 million people in 1980 to 5.4 million in 2012 (United States Census Bureau – www.census.gov). The increased population would be expected to have a corresponding increase in human wastewater N discharges from municipalities and septic systems. Because of wastewater treatment system upgrades at approximately 110 municipal and industrial wastewater treatment facilities with ammonia limits in the 1980s and 1990s, the form of N released to waters changed from ammonia+ammonium to nitrate at these sites (Bruce Henningsgaard, MPCA, personal communication, 2013).

Cropping changes

Since the mid-1960s, row crop acreages have increased substantially in Minnesota (MDA, 2013). Corn acreage has increased by more than 30% (Figure 10) and soybean acreage has more than doubled (Figure 11). At the same time, alfalfa and clover, which contribute low levels of N to waters, have decreased by more than 40%.

Between 2006 and 2011, Minnesota's net loss of grasslands converted to corn/soybeans was 196,000 acres (Wright and Wimberly, 2013).

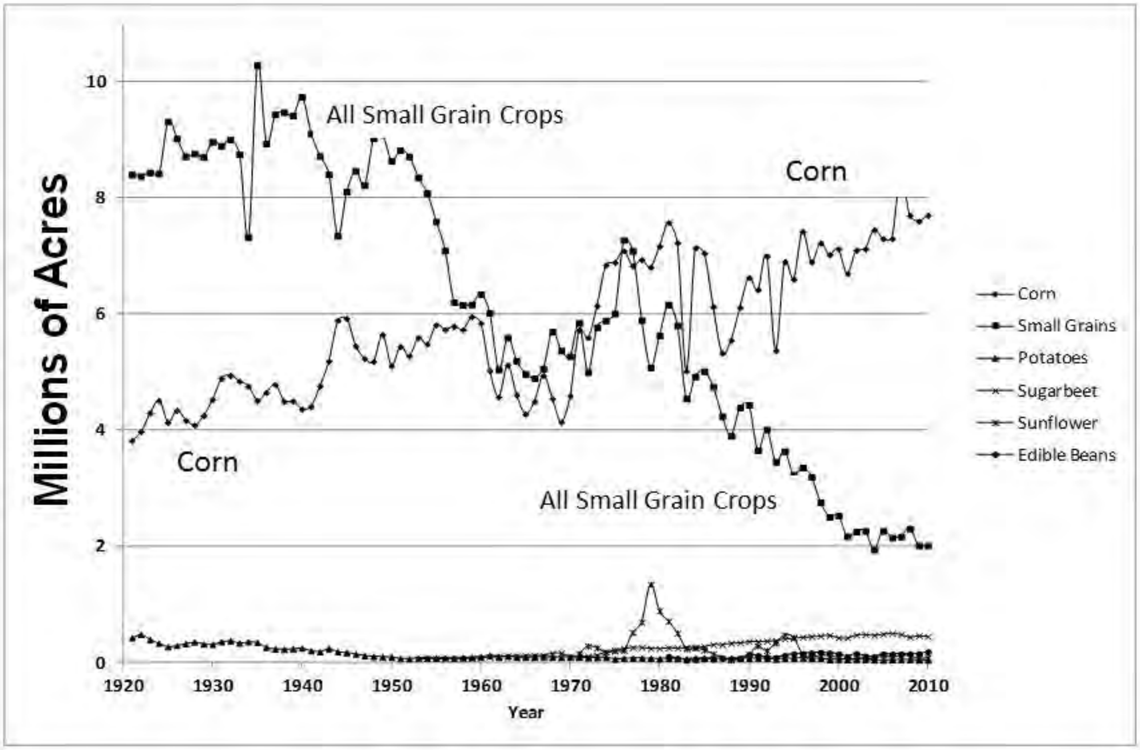


Figure 10. Trends in acreage planted to corn and small grain crops in Minnesota between 1920 and 2011. From MDA (2013).

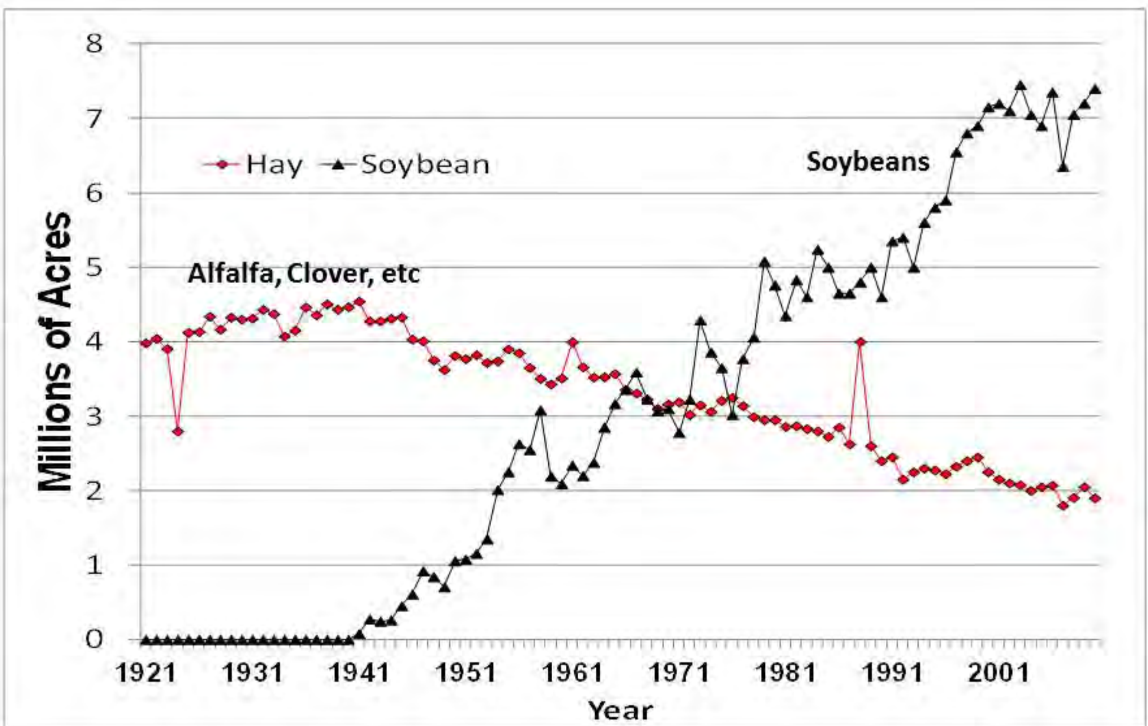


Figure 11. Trends in acreage planted to soybeans (black line) and other legumes (red line) in Minnesota between 1921 and 2011.

Tile drainage changes

Tile drains continue to be installed and replaced in Minnesota soils. The rate of increasing tile drainage is not well documented in the state and was not quantified for this study.

Precipitation changes

Between 1975 and 1995, the statewide annual average precipitation trends showed numerous wet and dry periods. Since 1995, statewide 7-year moving average precipitation has remained relatively high compared to historical levels, with a fairly stable trend compared to other times since 1890 (Figure 12).

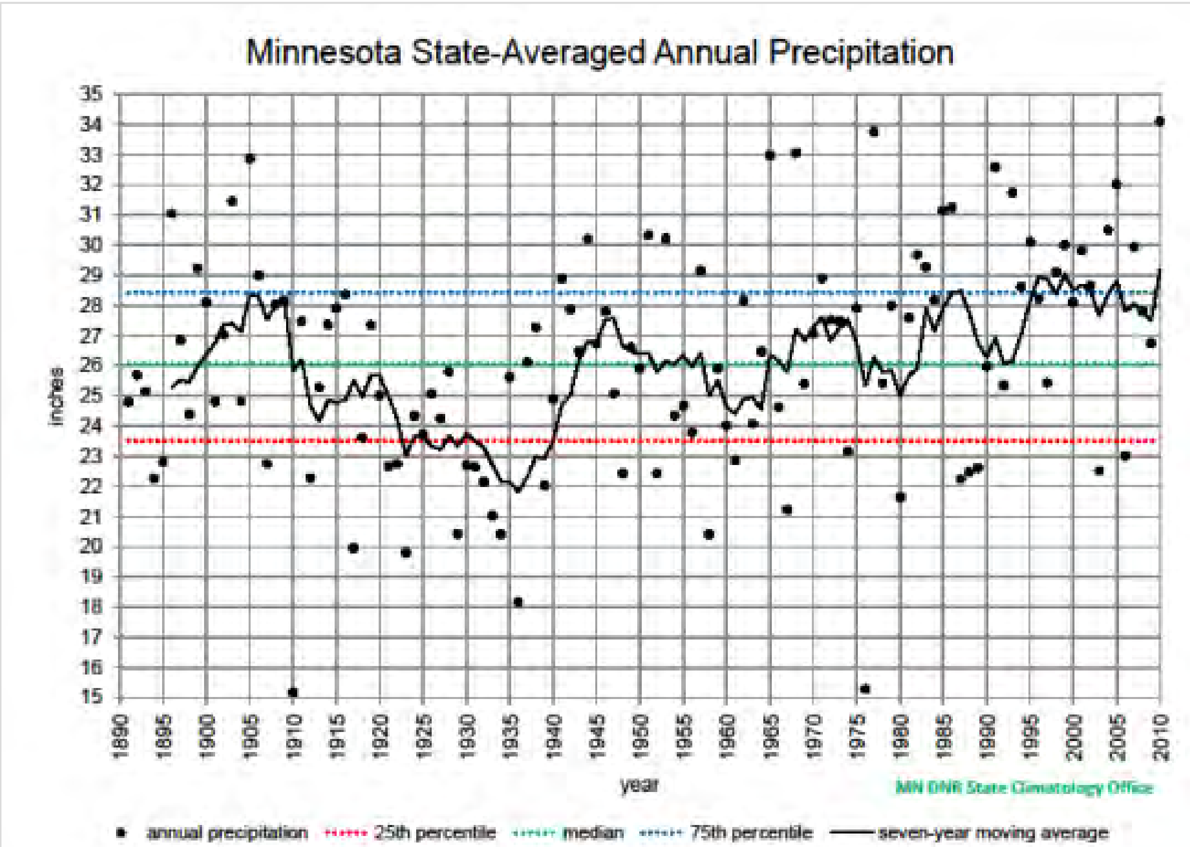


Figure 12. Long-term precipitation patterns in Minnesota since 1890. From MN DNR State Climatology Office (http://climate.umn.edu/pdf/minnesota_state_averaged_precipitation.pdf).

Figures 13 to 20 show spatial average annual precipitation amounts across several HUC8 watersheds in different regions of the state from 1980 to 2009, developed from precipitation data provided by the Minnesota Department of Natural Resources (Greg Spoden, written communication, 2011). Overall, the precipitation trends in this timeframe did not show major overall changes, although slight increases or slight decreases in annual precipitation are evident in some watersheds (Figures 13-19). A region of the state with a more consistent upward trend over this period is northwestern Minnesota in the Red River Basin (Figure 20). See Figure 4 for locations of watersheds.

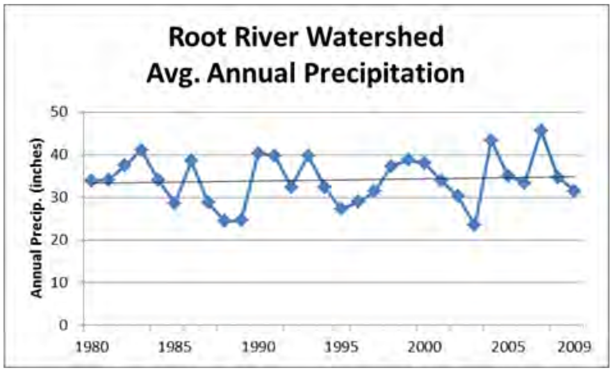


Figure 13. Spatial average annual precipitation amounts for the Root River Watershed from 1980 to 2009.

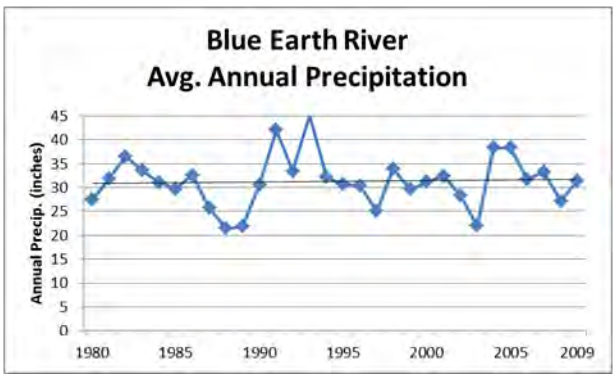


Figure 14. Spatial average annual precipitation amounts for the Blue Earth River Watershed from 1980 to 2009.

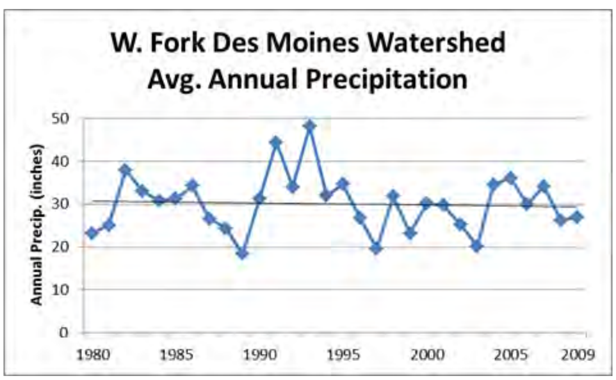


Figure 15. Spatial average annual precipitation amounts for the West Fork Des Moines River Watershed from 1980 to 2009.

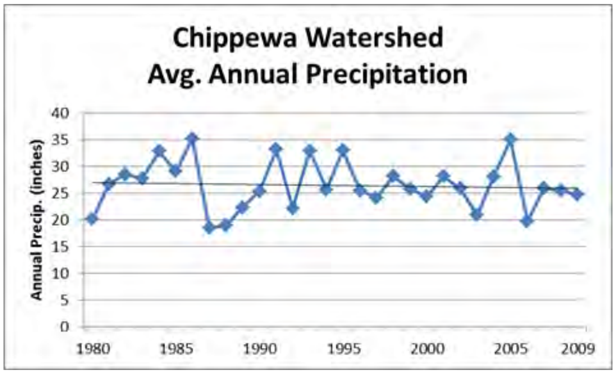


Figure 16. Spatial average annual precipitation amounts for the Chippewa Watershed from 1980 to 2009.

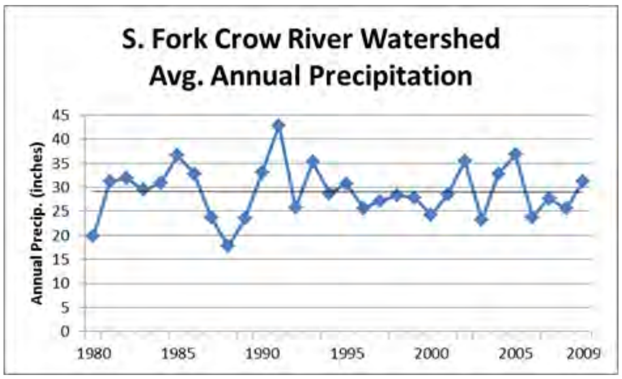


Figure 17. Spatial average annual precipitation amounts for the South Fork Crow River Watershed from 1980 to 2009.

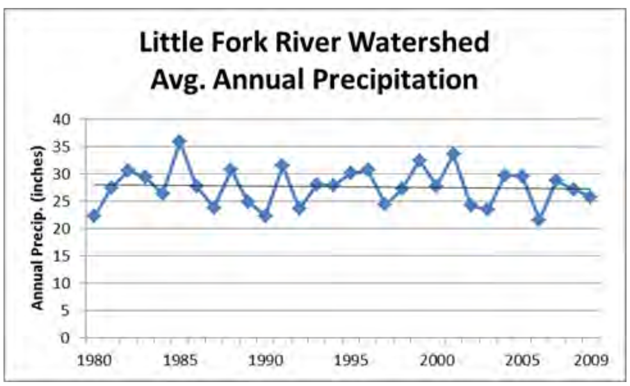


Figure 18. Spatial average annual precipitation amounts for the Little Fork River Watershed from 1980 to 2009.

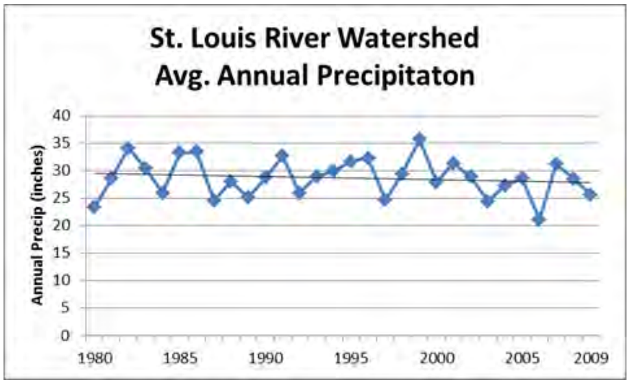


Figure 19. Spatial average annual precipitation amounts for St. Louis River Watershed from 1980 to 2009.

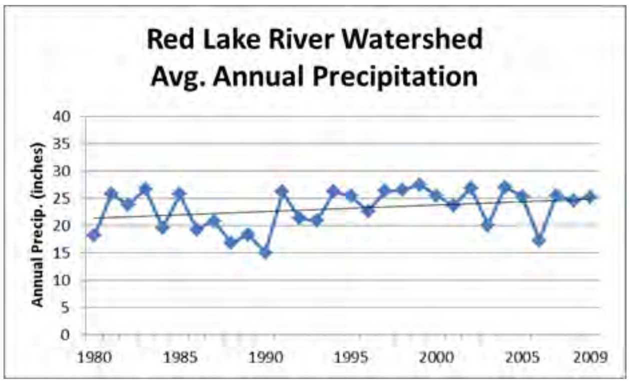


Figure 20. Spatial average annual precipitation amounts for the Red Lake River Watershed from 1980 to 2009.

Relation between streamflow and nitrate concentrations – a QWTREND analysis

The QWTREND model was used to evaluate the relation between streamflow and nitrate concentrations using four different time period assessments: (1) seasonal – 90 day periods, (2) annual, (3) 5-year, and (4) High-Frequency Variability (HFV) – short-term events. A positive streamflow anomaly coefficient indicates a direct relation between streamflow and nitrate concentrations, such that nitrate concentrations are statistically higher during high-flow periods. A negative coefficient indicates a negative relation between streamflow and nitrate concentrations. A higher magnitude coefficient represents a stronger relation, such that coefficients in the range of 0.4 to 0.8 represent a very strong relation between streamflow and nitrate concentrations.

Most of the rivers had a positive coefficient for the seasonal, annual, and HFV periods of time, indicating that the average nitrate concentrations over the 90-day, annual, and short-term event time periods are typically higher when streamflows are higher. One exception was the Rainy River, which had such low coefficients that essentially no relation was evident between streamflow and nitrate concentrations. In general, the coefficients were larger for the southern part of Minnesota than in the northern part, indicating a stronger relation between streamflow and nitrate concentrations in parts of the state where nitrate concentrations and effects of human activities on nitrate concentrations are higher.

The streamflow anomaly coefficients were larger for the 90-day and annual averages than for the 5-year average (Table 18), indicating that nitrate variation from season to season or year to year is more highly correlated to streamflow than is the 5-year average streamflow.

Analyses indicated that the Minnesota River Basin has a strong direct correlation between streamflow and nitrate concentrations for all types of time periods evaluated, but was highest for the seasonal averages. By comparison, the Upper Mississippi River Basin, which is affected more by groundwater base flow than by tile drainage, had lower coefficients and thus a weaker relation between streamflow and nitrate concentrations.

Some of the coefficients for the 5-year anomaly were negative, although the negative relations were weak at all sites (low coefficient magnitude), except for the Mississippi River between the Minnesota and the St. Croix Rivers. The negative long-term (5-year) coefficients may be at least partly attributable to the dilution of wastewater because the strongest negative signal for those coefficients was downstream from the Twin Cities.

Overall, the pattern of the coefficients indicates that surplus nitrate is flushed through the soil or off the soil by both rainfall/snowmelt events and by sustained wet periods, particularly in the agricultural areas of the state.

Table 18. Mean model coefficients for the streamflow anomalies by basin. Coefficients greater than 0.2 are highlighted in green.

Seasonal (90 day average streamflow)	Annual	5-Year	HFV (event flushing – seasonal component)
Upper Mississippi River Basin			
0.197	0.197	-0.121	0.082
Mississippi River between Minnesota and St. Croix Rivers			
0.569	0.768	-0.205	0.250
Lower Mississippi River			
0.988	0.768	-0.056	0.100
Tributaries to the Lower Mississippi River			
0.226	0.178	0.046	0.075
Minnesota River Basin			
0.703	0.649	0.453	0.269
St. Croix River Basin			
0.041	0.014	-0.008	0.002
Cedar and Des Moines River Basins			
0.521	0.521	0.240	0.233
Red River of the North Basin			
0.133	0.026	0.011	0.178
Rainy River Basin			
-0.0001	0.018	-0.075	-0.003
St. Louis River			
0.120	0.287	0.011	0.001

Summary of nitrate trends results

Flow-adjusted nitrate concentrations in the Mississippi River increased between 1976 and 2010 at most sites on the river, with overall increases in nitrate concentrations ranging from 87% to 268% everywhere except the most upstream location at Blackberry (0% change). Three of the 10 sites with increases showed a leveling off of the increase or no-trend starting in the early to late-1990s (Camp Ripley, Grey Cloud, and Hastings). The other 7 sites had a continuous increase in concentrations over the analysis period. During recent years, the annual increases everywhere downstream from Clearwater have ranged from 1% to 4% (except that no significant trend was detected at Grey Cloud and Hastings). The two most upstream sites at Blackberry and Camp Ripley have recently shown a downward trend and no trend, respectfully. Results from the small number of tributaries to the Mississippi River for which trends could be analyzed showed trends that did not always match the Mississippi River trends. For example, several tributaries, including the Rum, Straight, Cannon, and Zumbro Rivers, had downward trends in recent years.

Trends in flow-adjusted nitrate concentrations in the Minnesota River were somewhat different at different points along the river. The two most upstream sites at Courtland and St. Peter had no trend after 1987. The St. Peter and Henderson sites had an increase from 1976 to 1981, followed by a decrease between 1982 and 1986. After 1986, the Henderson site had a pattern similar to patterns at the Jordan and Fort Snelling sites. All three downstream sites (Henderson, Jordan, and Fort Snelling) showed a steady gradual increase in nitrate concentrations through 2004, followed by a decrease between 2005 and 2010. The overall long-term net changes at the three downstream sites were +50% (Henderson), -26% (Jordan), and -6% (Fort Snelling). During recent years, all sites on the Minnesota River and most tributaries to the Minnesota River had a downward trend or no trend. The only exception is the Watonwan River, which had a slight increase in concentrations of about 1% per year.

In a couple of the smaller upstream stretches of main-stem rivers originating in Minnesota, the Cedar River showed a steady increase in nitrate concentrations of 113% over a 43-year period, whereas the West Fork of the Des Moines River showed no trend.

In northern Minnesota, the major rivers showed either no trend or a slight upward trend. All of these rivers had very low nitrate concentrations throughout the period of analysis. The Red River of the North showed significant increases in nitrate concentrations before 1995, but no trends since about that time. The St. Louis River at Duluth had the most change with a 47% increase between 1994 and 2010.

Overall, the findings showed generally similar trend patterns as previous trend studies conducted at the same or nearby locations, although there were some differences. The magnitude of change was typically larger in this study as compared to previous studies. Additionally, the slight increase in nitrate concentrations at the Minnesota River Jordan site from 1976 to 2003 was different from other studies, which showed no significant trend or a downward trend.

The reasons for the nitrate concentration changes were not determined. However, we noted several concurrent statewide land-use trends during the period of analysis. Acres planted to corn and soybeans increased, while small grain and alfalfa/clover acreages decreased. Fertilizer application increased, mostly prior to 1980, and has increased at a much slower rate since 1980. Manure N generation was essentially the same in 1974 and 2007, and overall corn N use efficiency has increased steadily since 1992, resulting in more corn grown for each pound of fertilizer used. Human population has increased from 4 to 5.4 million people. No strong trends in annual precipitation were evident during recent decades, except in northwestern Minnesota where annual precipitation has been increasing.

Future studies

Studies that might add to the understanding of nitrate trends include:

- Further explore the causes of nitrate concentration trends, particularly the decreases observed in downstream parts of the Minnesota River after 2005, and several periods of increases in other rivers between 1990 and 1995.
- As more TN and nitrate load results become available, analyze trends in loads.
- Assess typical lag times between adoption of best management practices and response of nitrate concentrations in rivers for which groundwater is the dominant pathway for nitrate to rivers.
- Re-evaluate trends periodically to see if recent short-term trends continue, such as the downward trends in the Minnesota River Basin.
- Use alternative statistical trend methods to compare against QWTREND methods used in this study.
- Assess nitrate load changes over time where monitoring is sufficient and land-use changes have been made.

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C2. Nitrogen Trend Results from Previous Studies

Author: Dave Wall, MPCA

Overview

Several statistical trend analyses of Minnesota's river and stream nitrogen (N) levels have been investigated during recent decades. We reviewed the results of these previous studies to: 1) compare past results to the nitrate concentration trend analyses developed for this study and reported in Chapter C1; 2) review trends of N forms not evaluated in Chapter C1, such as ammonium and total nitrogen (TN); and 3) review river N *load* trends which are not assessed in Chapter C1. Because trend results depend on the watersheds studied, the timeframe analyzed, monitoring design, parameters assessed, and statistical procedures, the studies are not directly comparable. Yet collectively, these trends analyses provide useful information for understanding possible trends in Minnesota's rivers and streams over the past several decades.

An overview of results from previous studies is shown in Table 1. The specific studies noted in Table 1 are described in more detail in the remainder of Chapter C2.

Table 1. Summary of past trend results assessed for rivers in Minnesota. "Nitrate" refers to nitrite+nitrate and "ammonium" refers to ammonia+ammonium.

Study area	Timeframe considered	Trends results summary	Organization (author)
Mississippi River			
Mississippi River in Clinton Iowa – drainage area includes much of southern MN, NE Iowa and western Wisconsin	1980 - 2008	*Nitrate concentration* - increased 76% *Nitrate load* - increased 67%	USGS (Sprague et al., 2011)
Mississippi River in Clinton Iowa – drainage area includes much of southern MN, NE Iowa and western Wisconsin	1975-2005	Total Nitrogen flow adjusted conc. increased from 1975-82, then remained stable from 1983 to 2005.	USGS (Lorenz et al., 2008)
Mississippi River – Twin Cities Area	1976 - 2005	*Total Nitrogen conc.* – no trend at all six sites *Total Nitrogen loads* – No trends at four sites; 18-24% increase at two sites; *Nitrate-N conc.* – no trend at one site; 47-59% increases at five sites; *Nitrate-N loads* – 37 to 68% increase at all six sites *Ammonium loads and conc.* – all sites decreased by 129 - 353%	Natl. Park Service, Science Museum and Met Council (Lafrancois et al., 2013)
Mississippi River at Anoka and Red Wing	1976 – 2002	*Nitrate conc.* - increased 31% at Anoka and 12% at Red Wing *Ammonium conc.* - decreased 91% and 78%	Met Council (Kloiber, 2004)

Study area	Timeframe considered	Trends results summary	Organization (author)
Minnesota River			
Minnesota River at Jordan	1976-2005	*Total Nitrogen conc*. – No Trend *Total Nitrogen load* – Increased 18% *Nitrate conc.* – No Trend *Nitrate load* – Increased 27% *Ammonium conc.* – Decrease 221% *Ammonium load* – Decrease 142%	Lafrancois et al., 2013
Minnesota River at Jordan	1976 – 2002	*Nitrate conc.* - decreased 20% *Ammonium conc.* - decreased 72%	Met Council (Kloiber, 2004)
Minnesota River and Greater Blue Earth River	Starting in Late 1970's to mid 1980s; ending 2001-2003	*Nitrate conc*. – decreasing trends in the Minnesota River Jordan and the Greater Blue Earth River; Increasing trend in the Minnesota River at Fort Snelling	U of MN (Johnson, 2006)
Minnesota River Basin – multiple locations	1999 - 2008 (some exceptions)	*Nitrate conc.* - Western end of basin (upper parts of basin) had mostly stable and increasing trends; Eastern end of basin (lower parts of basin) had mostly stable and mixed trends, with several sites showing decreasing trends.	Minnesota State Univ. at Mankato (Sanjel et al., 2009)
St. Croix River			
St. Croix River at Stillwater	1976 – 2002	*Nitrate conc.* - Increased 17% *Ammonium conc.* - Decreased 81%	Met Council (Kloiber, 2004)
Red River of the North			
Red River at Emerson (near Canadian border) and Halstad, MN	1975 - 2001	*Nitrate conc.* increased (23-27%) from 1982 to 1992 at both sites, and had no trend before 1982 and after 1992.	USGS (Vecchia, 2005)
Red River at Canadian Border	1978 - 1999	*Total nitrogen conc.* - increased 29%	Manitoba WQ Mgmt (Jones et al., 2001)
Southeastern Minnesota			
25 rivers in SE Minnesota	1984 – 1993	*Nitrate conc*. - stable, except for slight increase in St. Croix River at Prescott *Ammonium conc.* - decreased at 24/25 sites	USGS (Kroening & Andrews, 1997)
Southeastern Minnesota Springs	Early 1990's to 2010-11	*Nitrate conc.* – increased at two springs by 15% and 100%.	MPCA (Streitz, 2012)
Mississippi River Winona Watershed	Varied 16 to 35 yrs ending 2008-11	*Nitrate conc.* – All six sites had increasing trend	Olmsted Co. Env. Res., 2012 (Crawford et al)
Twin Cities area streams	Mostly 1999 to 2010; some sites 1990-2010	*Nitrate conc.* - varied trends, with 6 sites decreasing, 3 sites increasing and 9 sites having no trend or mixed trends.	Met Council (Jensen, 2013)

Mississippi River south of the Minnesota border

The U.S. Geological Survey (USGS) has been measuring flow and nutrient concentrations in the Mississippi River at Clinton Iowa since the mid-1970s. The contributing watersheds for this site include basins primarily in Minnesota, Wisconsin, and northeastern Iowa (Figure 1). Trend results were reported in two recent USGS reports.

Using the QWTREND model, Lorenz et al. (2009) found TN flow-adjusted concentrations to increase between 1975 and 1982 from 1.60 to 2.38 mg/l. Between 1983 and 2005, the concentrations remained largely stable, decreasing slightly from 2.38 to 2.30 mg/l (Figure 2). Total nitrogen *loads* also increased in the 1975 to 1982 time period, and then generally remained stable between 1983 and 2004.

Figure 1. Location of the Clinton, Iowa USGS monitoring site and the contributing drainage area (from USGS).

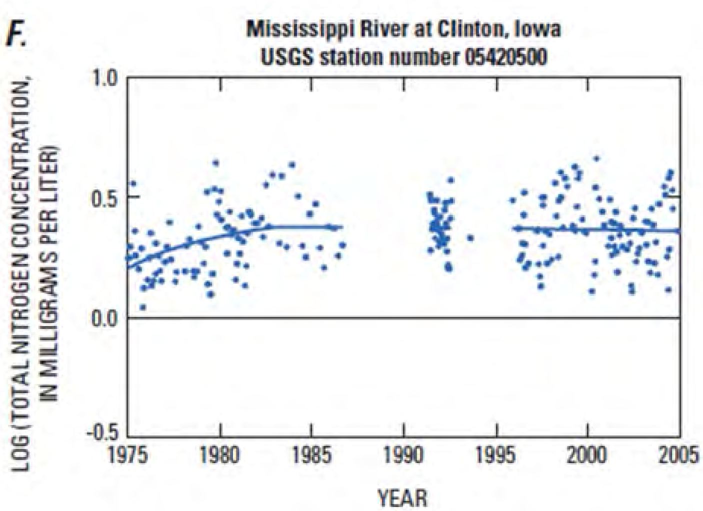

Figure 2. Flow adjusted TN concentration at the Mississippi River from 1975 to 2005. (from Lorenz et al., 2009).

Sprague et al. used the WRTDS model to evaluate nitrite+nitrate (nitrate) concentration changes at the Mississippi River Clinton, Iowa site (Sprague et al., 2011). The period of trends analysis began in 1980 and ended in 2008. Concentrations were normalized to remove variation due to random streamflow differences from one period of time to another. Results showed a nitrate increase, with the annual flow-normalized mean concentration increasing from 1.13 mg/l in 1980 to 1.99 mg/l in 2008. The increases were found at all categories of streamflow, but were largest during high and moderate streamflows at this monitoring location. Annual flow-normalized nitrate loads increased 67% during this same time period. The year-to-year load increases were found to be generally consistent, whether evaluated just for the spring months or for the entire year. One of the reasons for the difference in findings between the Lorenz et al. (2009) study and the Sprague et al. (2011) study was the assessed timeframe. Nitrate levels spiked in 2008, a year that was included in the Sprague study, but was after the Lorenz analysis period. Different statistical methods and different parameters (TN vs. nitrate) may also explain the differences in findings. Both studies showed fairly level concentrations between 1983 and 2005.

Minnesota, Mississippi, and St. Croix Rivers near the Twin Cities

Nitrogen concentration trends 1976-2005

Using data collected every other week from 1976 to 2002, the Metropolitan Council (Kloiber, 2004) assessed temporal trends at four large river monitoring sites, including the: 1) Minnesota River at Jordan; 2) St. Croix River at Stillwater; 3) Mississippi River at Anoka; and 4) Mississippi River at Red Wing (Figure 3). Using a flow-adjusted Seasonal Kendall Trend test, Kloiber found that ammonium concentrations decreased between 72 and 91% during the 1976 to 2002 timeframe at the four monitoring points. This decrease was thought to be due to improvements in point source controls which occurred during this same period. Total Kjeldahl nitrogen (TKN) decreased between 20 and 34% at the three monitored sites. Nitrate was found to have increased in the St. Croix River (+17%) and Mississippi River Anoka (+31%). Nitrate concentrations at the Minnesota River monitoring site near Jordan decreased by 20% (Table 2).

Figure 3. Location of Metropolitan Council major river load monitoring stations (from Met Council)

Table 2. Nitrogen parameter concentration medians, means and trends as determined by Metropolitan Council at their major river monitoring sites between 1976 and 2002. From Kloiber 2004.

	Median nitrate-N mg/l	Mean nitrate-N mg/l	Trend nitrate-N	Median NH4-N mg/l	Mean NH4-N mg/l	Trend NH4-N	Median TKN mg/l	Mean TKN mg/l	Trend TKN
MN River at Jordan	4.4	4.9	Decrease 20%	0.05	0.12	Decrease 72%	1.4	1.4	Decrease 20%
St. Croix River at Stillwater	0.3	0.4	Increase 17%	0.05	0.08	Decrease 81%	0.6	0.6	Decrease 33%
Mississippi River at Anoka	0.6	0.8	Increase 31%	0.05	0.11	Decrease 78%	0.9	0.9	NM
Mississippi River at Red Wing	2.2	1.4	Increase 12%	0.13	0.26	Decrease 91%	1.2	1.1	Decrease 34%

Loads and concentration trends 1976-2005

The National Park Service, working together with the Science Museum of Minnesota and Metropolitan Council Environmental Services, recently assessed flow-adjusted load and concentration trends at six Mississippi River locations between Anoka and Hastings, along with the Minnesota River near Fort Snelling. Using the Seasonal Kendall Trend test and Sen's slope estimator, long-term trends were determined for three N parameters analyzed at least twice monthly throughout each year of the 1976 to 2005 timeframe (Lafrancois et al., 2013). Percent changes over the 1976-2005 period are shown in Table 3.

Table 3. Percent increases (+) or decreases (-) in three N parameters measured at least twice monthly between 1976 and 2005. Red indicates increasing trends; blue indicates decreasing trends and white "n.s." boxes indicate no statistically significant trend. From Lafrancois et al. (2013).

Sites	TN conc.	TN load	NO2+NO3-N conc.	NO2+NO3-N load	NH3+NH4-N conc.	NH3+NH4-N load
Miss R. UM872 (Anoka)	n.s.	+22%	+49%	+62%	-214%	-129%
Miss R. UM 848 (Mpls)	n.s.	+24%	+58%	+68%	-234%	-133%
Miss R. UM839 (St. Paul)	n.s.	n.s.	n.s.	+37%	-230%	-182%
Miss R. UM831 (S. St. Paul)	n.s.	n.s.	+59%	+53%	-303%	-238%
Miss R. UM827 (Inver Grove Heights)	n.s.	n.s.	+53%	+55%	-284%	-251%
Miss R. UM816 (Hastings)	n.s.	n.s.	+47%	+51%	-353%	-271%
Minn. R. MI4 (Fort Snelling)	n.s.	+18%	n.s.	+27%	-221%	-142%

In summary, this study showed that ammonium concentrations decreased dramatically between 1976 and 2005, while nitrate concentrations increased at most Mississippi River sites. Total nitrogen concentrations did not have a statistically significant trend at any of the sites. Total nitrogen loads increased slightly (18-24%) in the north Metro part of the Mississippi River and Minnesota River Fort Snelling, and were not significant at the four Mississippi River sites downstream of Minneapolis. Nitrate loads increased by 27 to 68% at all sites.

Minnesota River Basin

Multiple sites 1998 - 2008

Nitrate concentration trends over a 10-year period (1999-2008) were evaluated in the Minnesota River Basin by Sanjel et al. (2009). For this relatively short period of time, the Seasonal Kendall test method generally showed that watersheds in the western part of the basin had either no statistically significant trend (seven sites) or an increasing trend (four sites). Watersheds in the eastern (lower) part of the basin had sufficient data to use the more robust QWTREND model. All three tributaries in the southeast part of the Basin had decreasing trends, and the Minnesota River had a decreasing trend at Judson and no statistically significant trend at St. Peter.

Of the nine sites evaluated in the Cottonwood River and eastward, the results were mixed. With the Seasonal Kendall test, six sites showed no trend, one site showed a decreasing trend (Little Cobb River), and two sites showed increasing trends (Cottonwood River and Minnesota River at Judson). The two most downstream sites (Minnesota River at St. Peter and at Jordan) showed no statistically significant trend.

Fort Snelling, Jordan, and Greater Blue Earth - various timeframes between 1976 and 2003

Nitrate-N flow-adjusted concentration trends were evaluated by Johnson (2006) for two Minnesota River sampling locations (Fort Snelling and Jordan) and the Greater Blue Earth River, which is the largest tributary to the Minnesota River. The trend results, which extended for at least 10 years and ended between 2001 and 2003, are shown in Table 4. Both the Minnesota River Jordan and Greater Blue Earth River had decreasing trends during this timeframe. However, the Minnesota River Fort Snelling site showed an increasing trend between 1976 and 2003 with the QWTREND method. A direct comparison over this same timeframe using the Seasonal Kendall method at Fort Snelling was not performed, yet the Seasonal Kendall test showed a 63% increase in the relatively short interval from 1995 to 2003.

Table 4. Flow-adjusted nitrate concentration trends during varying time periods and statistical methods (from Johnson, 2006).

	Nitrate-N mg/l QWTREND	Nitrate-N mg/l Seasonal Kendall
MN River at Jordan		
1979-2003	-10%	-28%
MN River at Fort Snelling		
1976-2003	+89%	
Greater Blue Earth River		
1986-2001	-17%	
1990-2001		-40%

Southeastern Minnesota

Twenty-five sites in the southern half of the Mississippi River Basin, and the Cannon, Vermillion, and St. Croix River watersheds 1984 - 1993

Using data collected between 1984 and 1993, the USGS conducted an in-depth study of stream nutrients in large parts of Minnesota, including the southern half of the Mississippi River Basin, the Cannon and Vermillion River watersheds, and the St. Croix River Basin in Minnesota and Wisconsin (Kroening and Andrews, 1997).

Seasonal Kendall tests were conducted to determine temporal trends for water years 1984 to 1993. Most stream sites outside of the Twin Cities Metropolitan Area showed no increases in nitrate or TN during the 10-year period. The only site showing a slight increase in nitrate concentrations was the St. Croix River near Prescott, Wisconsin. In the Metro Area, nitrate increased, which was thought to be due to the modified wastewater treatment systems, converting ammonium into nitrate. Many upgrades to municipal wastewater treatment facilities were made during the 10-year analysis period (131 upgrades out of 292 municipal systems). Additionally, most of the combined sanitary and storm sewers in Minneapolis and St. Paul were separated. Correspondingly, ammonium concentrations decreased at 24 of 25 stream sites, based on available data from water years 1984 to 1993.

Southeastern Minnesota springs

Nitrate trends assessed in two springs feeding fish hatcheries in southeastern Minnesota's Root River watershed both showed statistically significant (p=0.001) increasing trends over the past two decades (Streitz, 2012). The springs were monitored approximately monthly at Peterson and every other month at Lanesboro by the Minnesota Department of Natural Resources (DNR). Average annual nitrate-N concentrations in the Lanesboro spring increased from about 5.2 mg/l to 6 mg/l between 1991 and 2010 (Figure 4). Nitrate increased by a larger amount in the spring at the Peterson, Minnesota, fish hatchery, with average annual concentrations rising from less than 2 mg/l in 1989 to 4 mg/l in 2011 (Figure 5).

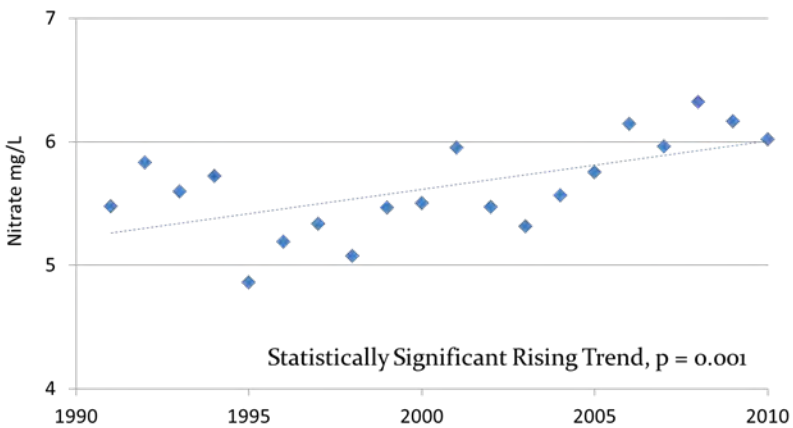

Figure 4. Lanesboro spring (DNR Fish Hatchery) average annual nitrite+nitrate-N concentrations from 1991 to 2010 (Streitz, 2012)

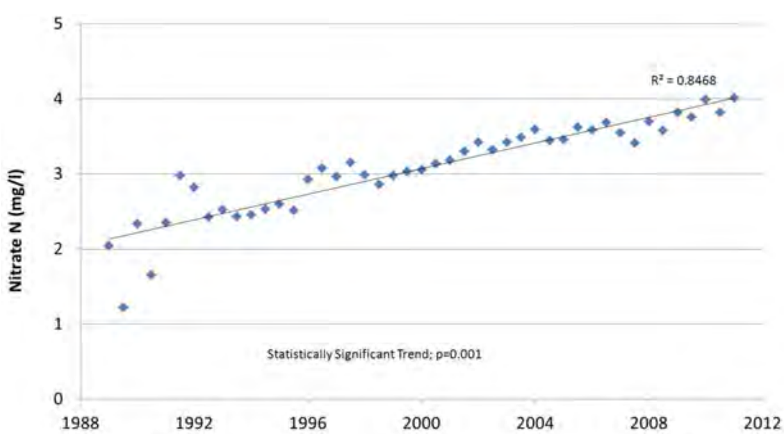

Figure 5. Peterson spring (DNR Fish Hatchery) average semi-annual nitrite+nitrate-N concentrations from 1989 to 2011 (Streitz, 2012)

Mississippi River – Winona Watershed

Nitrate concentration trends were assessed by Olmsted County Environmental Resources (2012) at six sites for periods of analysis ranging from 16 to 35 years at five sites on various branches of the Whitewater River and one site on Garvin Brook. Nitrate concentrations were not adjusted for flow; however, little relationship was found between flow and nitrate concentrations at these highly groundwater influenced streams. All six sites showed an increasing trend. The South Fork Whitewater Watershed near Utica increased from 4.2 to 11 mg/l between 1974 and 2011. The North Fork Whitewater River near Elba increased from <1 mg/l in 1967 to 6 mg/l in 2010.

Twin Cities area stream trends

The Metropolitan Council has been regularly sampling 18 stream and river sites in and around the Twin Cities Metro Area. The starting year for sampling varied between sites, ranging from 1989 to 1999. Nitrate concentration trends analyses were conducted by the Metropolitan Council from the starting year through 2010 using QWTREND (Jensen, 2013). The results provided to the MPCA showed no consistent patterns in trends. More streams showed decreases as compared to increasing trends (6 vs. 3). Four streams had no trends, and five streams had trends that were significantly increasing during certain time periods and significantly decreasing during other periods.

Summary

Nitrogen trends have varied across the state, depending on the N parameter, the location, and timeframe assessed. Ammonia+ammonium-N concentrations have consistently decreased between the mid-1970s and early 2000s, and also decreased during the shorter interval between 1984 and 1993. Improvements to both municipal wastewater treatment plants and feedlots occurred during this same time period.

Total nitrogen *concentrations* have shown few significant trends from the mid-1970s through 2005, although one study showed a few decreasing trends between 1976 and 2002. However, TN *load* trends have shown increases at some sites, with non-significant trends at other sites.

Nitrite concentrations and loads were generally increasing in the Mississippi River from the time beginning around 1976-1980 and ending 2002-2008. The St. Croix River also showed some evidence of nitrate increases. The Minnesota River showed either decreasing or non-significant nitrate concentration trends during these years at most sites, with a possible increase at Fort Snelling, as shown in one study. Nitrate *loads* in the Minnesota River at Jordan showed a slight increasing trend from 1976-2005, at the same time that nitrate concentration trends were stable or decreasing.

In the Red River, nitrate concentrations increased between 1982 and 1992, and then remained stable for the subsequent decade.

Other various rivers and stream sites sampled for nitrate showed some sites with increasing concentration trends, but several others with stable, decreasing, or mixed trends.

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D1. Sources of Nitrogen – Results Overview

Author: Dave Wall (MPCA), incorporating results from Chapters D4 by David J. Mulla et al. (UMN), Chapter D2 by Steve Weiss (MPCA), and Chapter D3 by Dave Wall and Thomas Pearson (MPCA)

Introduction

The previous chapters focused on river monitoring results and nitrogen (N) transport within waters. In this chapter and the other chapters in Section D, we assess sources and pathways of N entering Minnesota surface waters. Section D is divided into four chapters: D1) all N source results overview, D2) wastewater point sources, D3) atmospheric deposition and D4) nonpoint sources. This chapter incorporates results from Chapters D2, D3, and D4, so that the point sources, nonpoint sources and atmospheric deposition sources can be compared together. All source estimates should be viewed as large-scale approximations of actual loadings.

In this chapter, N sources were categorized as:

1. Sources to the land
2. Sources to surface waters

The emphasis of this study was estimating N loads from specific sources to *surface waters*. Nitrogen sources to *land* are also estimated, since these sources can provide a general understanding of N potentially available for being transported to waters. A certain fraction of all N to land will enter surface waters. However, the N additions to land/soils cannot be proportionally attributed to delivery into waters, as many factors affect transport of soil N from the land into waters. These factors include: timing of the additions, form of N, climate and soils where N is introduced, potential for plant uptake and removal, potential for denitrification, along with several other variables.

Sources to the land

Statewide estimated amounts of inorganic N from primary sources added to the land and from biological processes within soils are shown below (Table 1 and Figure 1).

When considering the N additions to all soils statewide apart from mineralization, cropland commercial fertilizers account for 47% of the added N, followed by cropland legume fixation (21%), manure (16%), and wet +dry atmospheric deposition (15%). Atmospheric deposition contributes nearly the same fraction of statewide N to cropland and non-cropland soils. The combination of septic systems, lawn fertilizer, and municipal sludge account for about 1% of all N added to soils statewide.

Soil organic matter mineralization also contributes a large amount of annual inorganic N to soils, yet the precise amount is more difficult to determine than other sources. Estimates of net mineralization from Mulla et al. reported in Chapter D4 suggest that average cropland soil mineralization releases an annual amount of inorganic N that is comparable to inorganic N from fertilizer and manure additions combined. Mineralization is a complex process affected by climate, soil type and conditions, fertilization, cropping, soil tillage practices and more.

The soil N mineralization estimates were not used to calculate N transport to waters in this study. However, the N transport to waters (as discussed in the next section) accounts for differences in soil types around the state, while additionally considering fertilizer rates, precipitation, crop types, and other variables described in Chapter D4.

Table 1. Estimated annual inorganic N amounts 1) added to land (including legume N fixation), and 2) released from soil organic matter mineralization.

	Inorganic nitrogen (million pounds)	**Notes and sources:**
1. Added to land		
Commercial fertilizer to cropland	1359	From Chapter D-4 by Mulla et al. Derived from farmer surveys and GIS crop information. Average state fertilizer sales from 2005-2010 are similar (1321 million lbs), as reported by MDA.
Manure application to cropland	446	Crop available N during 1st and 2nd year after application. From Chapter D-4 by Mulla et al. Derived from MDA and MPCA data, and Midwest Plan Service and Univ. of MN N availability information.
Atmospheric deposition statewide	427	See Chapter D-3. Includes all wet and dry deposition onto all land and marshes/wetlands.
Lawn Fertilizer	12	MDA 2007 Report to the Minnesota Legislature "Effectiveness of the Minnesota Phosphorus Lawn Fertilizer Law"
Septic system drain fields	9	See Chapter D-4. Includes runoff from failing systems and leaching to groundwater from all drainfields.
Municipal sludge	2	From MPCA permit reports of acreages/crops in 2009 and 2010 cropping years, multiplied by N rates.
Cropland legume fixation	612	From Chapter D-4 by Mulla et al.
Total additions	**2867**	
2. Soil mineralization		
Cropland soil mineralization	*1728	Net mineralization from Chapter D-4 by Mulla et al. 2013
Forest soil mineralization	*830	Assumed 51 lbs/acre, based on ranges of mineralization amounts in Reich et al. (1997) and 16.3 million acres of forest.
Total mineralization	**2558**	
Total of all sources	**5425**	

*More uncertainty exists with estimates of soil mineralization N as compared to other sources to soils.

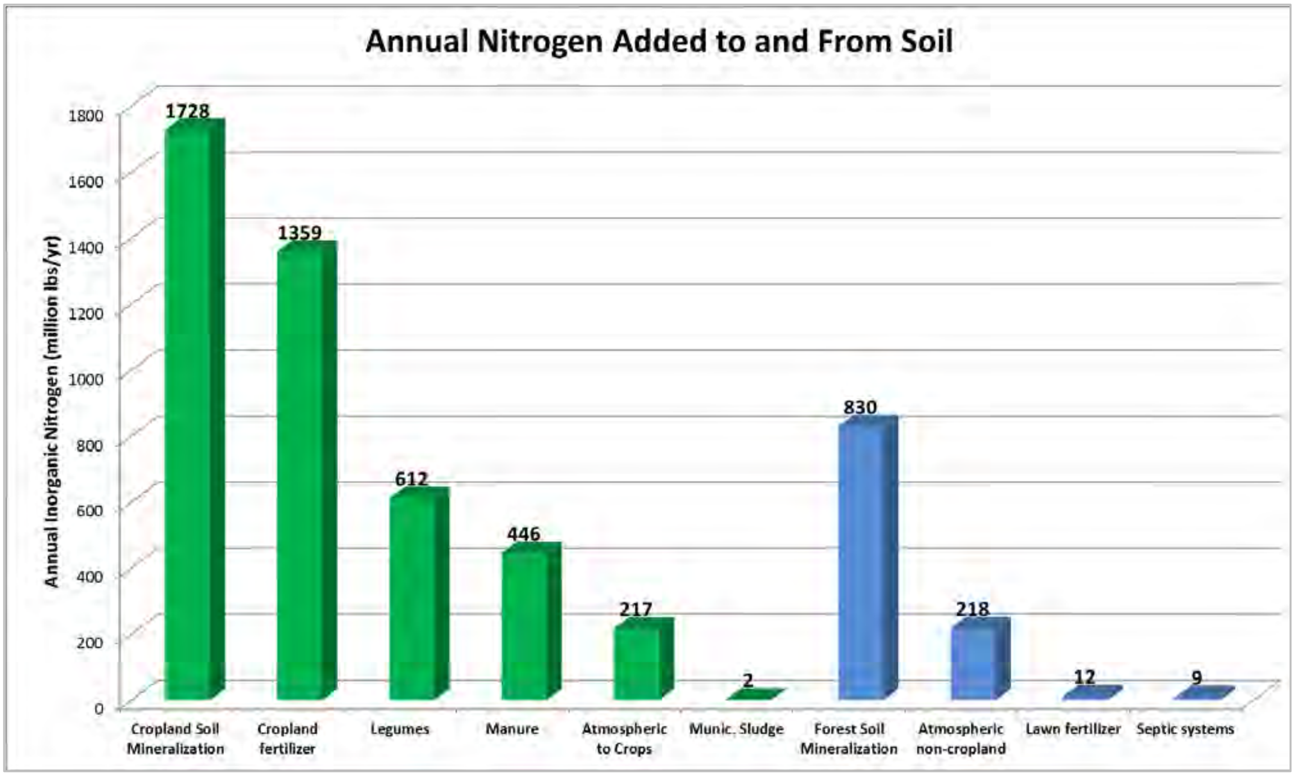

Figure 1. Estimated annual amount of inorganic N to and from cropland soils (green) and non-cropland soils (blue), in millions of pounds per year. Note: these amounts only reflect soil N and they are not proportionately delivered to surface or ground waters from each source.

Sources to surface waters: statewide

A fraction of the N added to soils reaches surface waters. Most of the soil N is either taken up by the crops or lost to the atmosphere through senescence, volatilization, or denitrification. Yet, because the N inputs and mineralization are high in many regions of the state, even a small percentage of these inputs lost to waters can cause concerns for in-state and downstream waters, as described in previous chapters.

The percentage of soil N lost to waters is expected to vary greatly from one region to another, depending on soils, climate, geology, cropping practices and other factors. In Chapter D4, Mulla et al. calculated the *statewide* fraction of cropland soil N lost to waters as a percentage of all added and mineralized N estimates. They estimated that about 6% of all cropland N additions/sources reach waters during an average precipitation year. If the N losses to surface waters are calculated as a fraction of only the added N (not including the mineralized N), then the *statewide* fraction of added cropland soil N reaching surface waters is about 8%. These estimates should not be applied at the local or regional scale, as N delivery to waters varies considerably by region.

The rest of the discussion in this chapter focuses on N source contributions to surface waters, rather than additions to soil/land. Different N source categories are used to represent contributions to *surface waters* as compared to source categories of *soil* N because: a) the pool of N sources get mixed in the soil and distinct N sources of fertilizer, manure, mineralization or atmospheric deposition to cropland were not differentiated in groundwater or tile-line drainage waters in this study , and b) some sources to waters never reach the soil but instead go directly into water (i.e. wastewater point sources and atmospheric deposition directly into lakes and streams).

The estimated annual amounts of N which reach surface waters from primary source categories are shown in Table 2 and Figure 2, and are described in more detail in chapters D2, D3, and D4 of this report. Cropland sources are estimated to contribute 72.9% of the statewide N load to streams and lakes during an average year, increasing to 78.9% during wet years when N exports to the Gulf of Mexico are highest. The cropland estimates are divided into three transport pathways: 1) surface runoff, 2) tile drainage, and 3) leaching to groundwater and subsequent travel to surface waters through groundwater baseflow. Surface runoff contributes relatively little N compared to the other pathways. Tile drainage is the largest pathway, contributing an estimated 37% of the statewide N load from all sources during an average year, and 43% during a wet year. Tile drainage contributions vary tremendously from one area of the state to another, being negligible in several basins and yet contributing about 67% of all N load in the Minnesota River Basin. Cropland leaching to groundwater and its subsequent transport to surface waters is also a major source/pathway, although it can take a long time to reach surface waters after initially entering the groundwater.

Wastewater point sources represent an estimated 9% of the N load during an average year, 6% during a wet year, and 18% of the load contribution during a dry year. Direct atmospheric deposition into lakes and streams contributes a comparable amount of statewide N load as point sources, but has a different geographic distribution compared to point sources. All forested lands together contribute an estimated 7% of the statewide N load.

Urban stormwater/groundwater, combined with septic systems and feedlot runoff contribute to less than 3% of the statewide N load to surface waters during an average precipitation year. Other sources with contributions less than an estimated 0.2% of statewide loads to surface waters are not included. An example of a very low N contributor is duck and geese excrement, which add an approximate 0.1% of the statewide N load to waters (assuming bird numbers from U.S. Fish and Wildlife Service waterfowl population reports (2012), all droppings directly enter waters, and loadings of roughly 0.4, 0.3 and 1.2 pounds N/year/bird for mallards, other ducks and geese, respectively).

Table 2. Estimated statewide annual amounts of N reaching surface waters (from chapters D2-D4). Wet years represent the 90th percentile annual precipitation years and dry years represent the 10th percentile years.

	N reaching surface waters (million pounds per year)		
	Avg. precip. year	**Wet year**	**Dry year**
1. Cropland nonpoint sources			
Leaching to groundwater*	93.3*	137.6*	49.2*
Tile drainage	113.9	199.6	31.9
Runoff from cropland	16.2	28.7	7.3
Total	223.4	365.9	88.4
	72.9%	**78.9%**	**56.5%**
2. Non-cropland nonpoint sources			
Atmospheric deposition to lakes and streams	23.8	26.2	21.4
Urban/suburban runoff and leaching**	2.8	4.3	1.4
Forests runoff/leaching	21.8	32.8	10.9
Septic system runoff/leaching	5.5	5.5	5.5
Feedlot runoff (barnyards)	0.2	0.27	0.13
Total	54.1	69.1	39.3
	17.7%	**14.9%**	**25.1%**
3. Point sources			
Municipal Point Sources	24.9	24.9	24.9
Industrial Point Sources	3.9	3.9	3.9
Total	28.8	28.8	28.8
	9.4%	**6.2%**	**18.4%**
Grand total	**306.3**	**463.8**	**156.5**
	100%	**100%**	**100%**

*This number represents the N amount which reaches surface waters from cropland ground water sources. It is substantially lower than the amount which initially reaches groundwater, since this number subtracts assumed denitrification losses which occur along the course of groundwater flow between the field and discharge into streams.

**Urban and suburban nitrogen amounts reaching waters include both stormwater and snowmelt runoff, and a relatively small amount which also leaches to groundwater and is transported to surface waters via groundwater (also accounting for denitrification losses within groundwater).

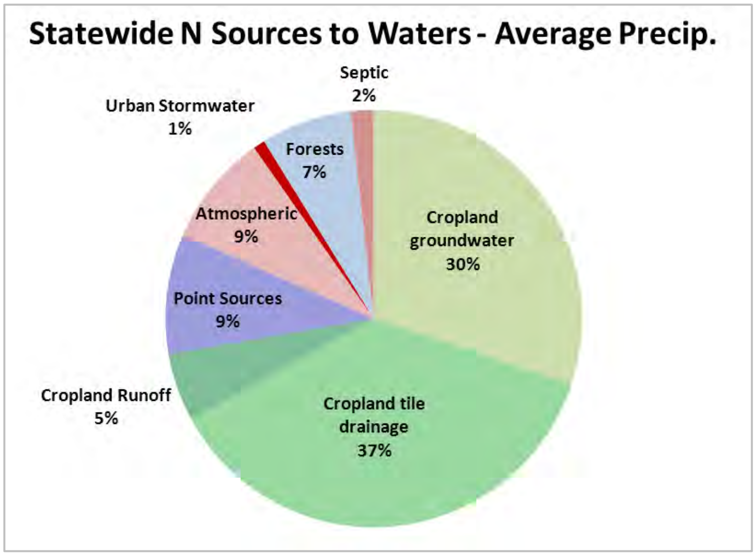

Figure 2. Estimated statewide N contributions to surface waters during an average precipitation year (rounded to the nearest percent).

Annual precipitation has a pronounced effect on N loads. During a wet year, overall estimated loads increase by 51%, as compared to an average year. During a dry year, N loads drop by 49% from average year loads. The effects of precipitation are even greater in certain basins, such as the Minnesota River Basin. In the Minnesota River Basin, wet years have 70% more N load, and dry years have 65% less N load, as compared to average years.

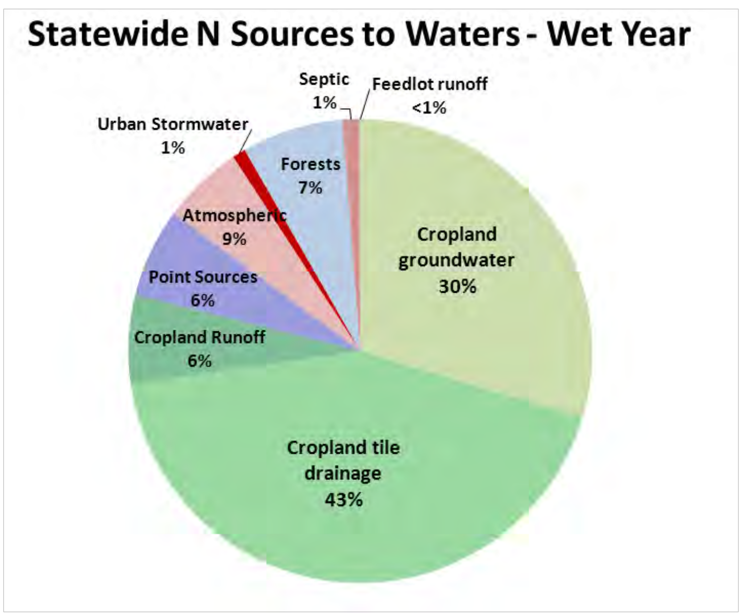

Figure 3. Estimated statewide N contributions to surface waters during a wet year.

High precipitation periods are of particular interest, since higher precipitation increases the N load transport to downstream waters such as the Gulf of Mexico. In addition to overall increasing loads, climate influences the relative source contributions from different sources and pathways. During wet years (Figure 3), the cropland sources increase to 79% of the estimated N loads to waters statewide.

Agricultural drainage increases to 43% of the loads to surface waters during wet years, cropland runoff increases to 6%, and cropland groundwater remains at 30%. The absolute loading of wastewater point source contributions remain unchanged during wet and dry years, but their relative contribution changes as the overall total annual load from all sources increases or decreases.

Sources to surface waters: by major basins

Nitrogen source contributions vary considerably from one major basin to another (Figures 5-17 and Tables 3-5). For example, during an average precipitation year, the estimated cropland sources (cropland groundwater, cropland tile drainage and cropland runoff) contribute between 89% and 95% of the load in several basins, including the Minnesota parts of the Minnesota River, Missouri River, Cedar River, and Lower Mississippi River Basins. Cropland contributes a much lower percentage of N to waters (49%) in the Upper Mississippi River Basin, and even less in the Red River (see Figure 4 for major basin locations). Point source contributions range from 1% to 30% across the different basins, generally representing a higher fraction of the load where cropland sources are relatively low and where major metropolitan areas are found (i.e. Twin Cities are largely in the Upper Minnesota River Basin). In the lower N yielding basins dominated by forests and lakes, such as in the Rainy River and Lake Superior Basins, forest and atmospheric sources contribute a higher fraction of the N.

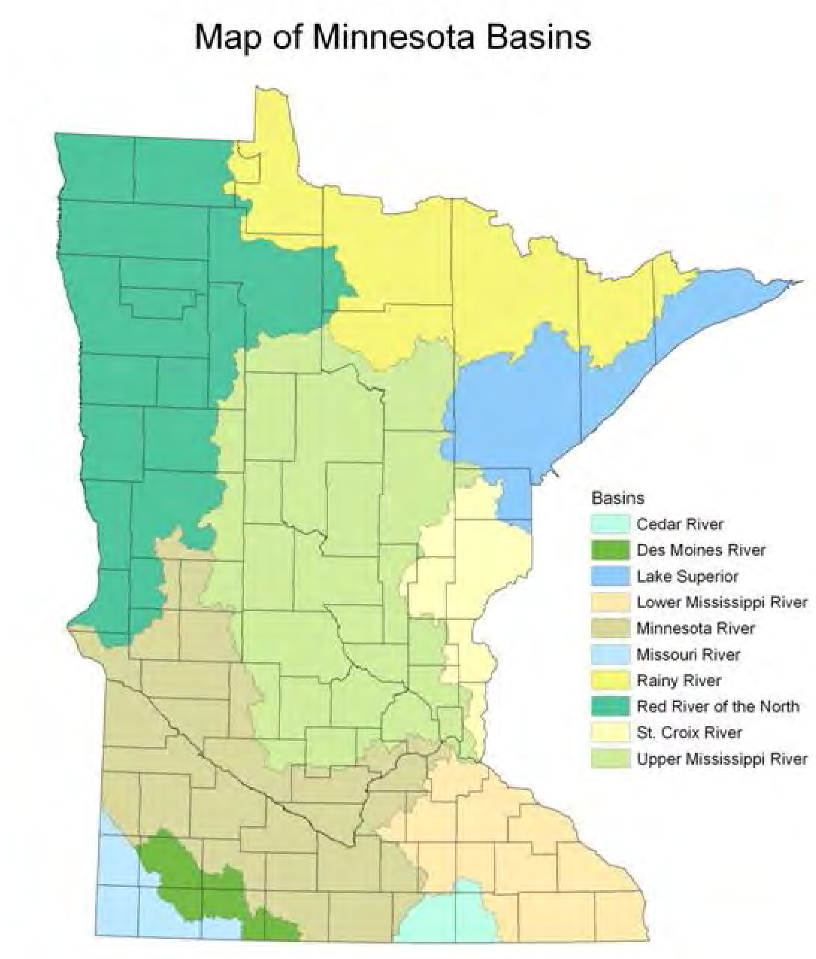

Figure 4. Location of major river basins in Minnesota.

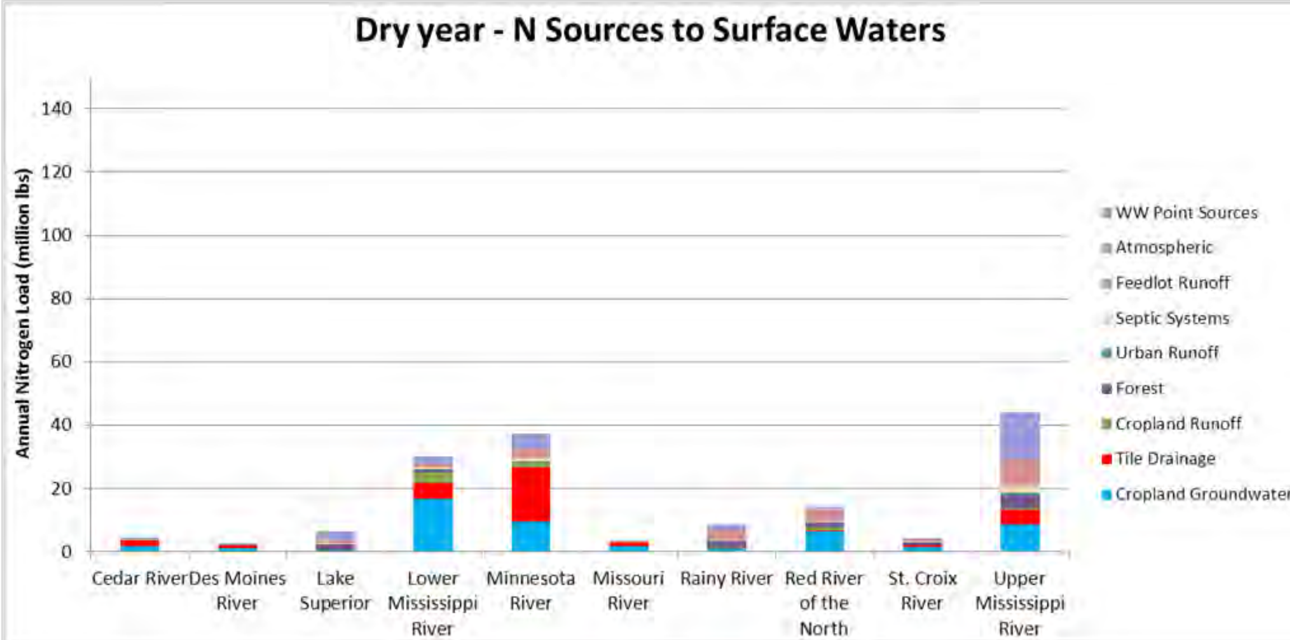

Figure 5. Estimated N loads to surface waters from different sources within the Minnesota portions of major basins during a dry year (10th percentile precipitation year).

Table 3. Estimated N loads to surface waters from different sources within the Minnesota portions of major basins during a dry year (10th percentile precipitation year).

Basin	Cropland Groundwater	Cropland Drainage	Cropland Runoff	Forest	Urban NPS	Septic	Feedlot	Atmospheric	Point Sources	Total
Cedar River	1,838,932	1,870,122	94,791	10,705	19,508	87,875	5,240	125,081	635,348	**4,687,602**
Des Moines River	1,173,366	888,502	76,405	11,038	5,971	69,203	3,368	299,546	284,353	**2,811,752**
Lake Superior	448,753	115,893	126,699	1,762,240	57,197	382,620	8	818,578	2,870,456	**6,582,444**
Lower Mississippi River	16,875,018	4,744,251	3,657,868	664,031	171,895	520,672	70,456	910,326	2,643,750	**30,258,267**
Minnesota River	9,587,169	17,172,963	1,410,743	285,815	281,171	888,027	41,709	2,874,636	4,717,144	**37,259,377**
Missouri River	1,695,077	1,387,158	62,703	8,535	9,643	84,618	6,586	175,796	98,436	**3,528,552**
Rainy River	772,685	238,187	107,451	2,346,796	13,525	141,823	58	3,447,922	1,689,520	**8,757,967**
Red River of the North	6,593,744	169,422	1,044,099	1,357,406	63,190	479,149	8,638	3,873,237	617,872	**14,206,757**
St. Croix River	1,396,201	732,743	60,944	764,478	53,368	434,357	766	499,943	441,629	**4,384,429**
Upper Mississippi River	8,795,966	4,555,276	705,877	3,711,788	744,258	2,392,008	48,354	8,420,932	14,817,420	**44,191,879**
Grand Total	**49,176,911**	**31,874,517**	**7,347,580**	**10,922,832**	**1,419,726**	**5,480,352**	**185,183**	**21,445,997**	**28,815,928**	**156,669,026**

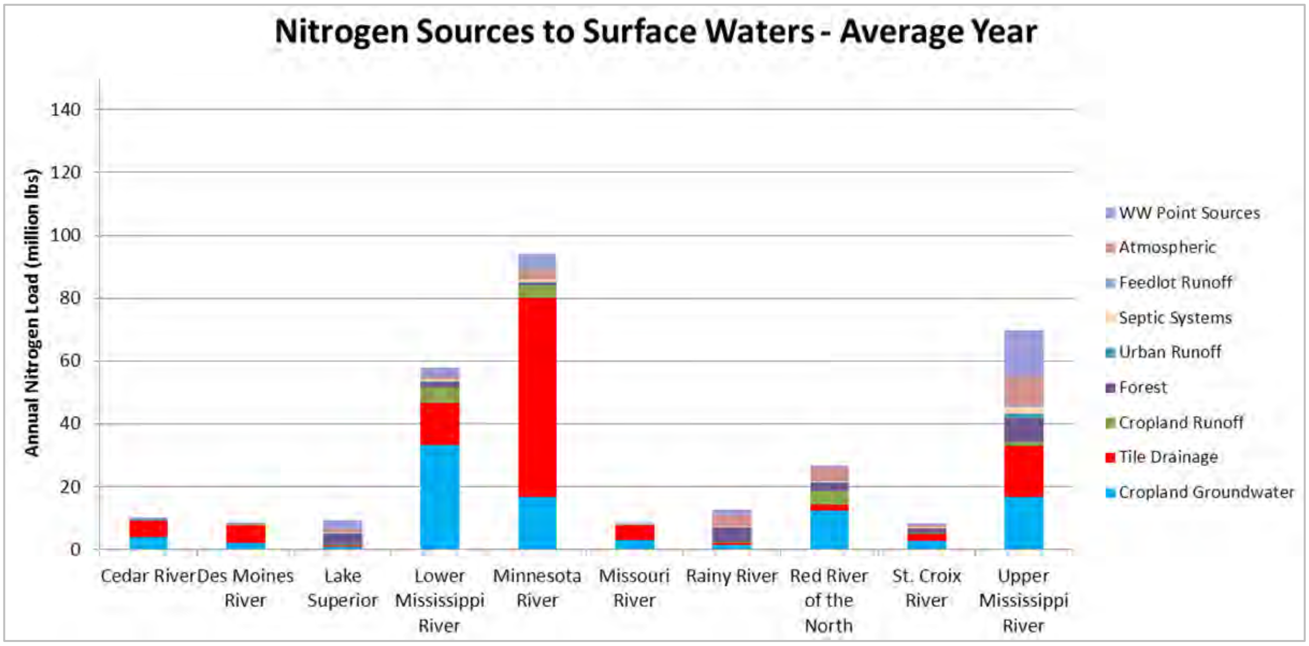

Figure 6. Estimated N loads to surface waters from different sources within the Minnesota portions of major basins during an average precipitation year.

Table 4. Estimated N loads to surface waters from different sources within the Minnesota portions of major basins during an average precipitation year.

Basin	Cropland Groundwater	Cropland Drainage	Cropland Runoff	Forest	Urban NPS	Septic	Feedlot	Atmospheric	Point Sources	Total
Cedar River	3,998,333	5,246,863	170,842	21,410	39,013	87,875	6,239	138,979	635,348	**10,344,902**
Des Moines River	2,034,489	5,672,975	355,036	22,076	11,943	69,203	4,009	332,829	284,353	**8,786,913**
Lake Superior	813,293	446,889	224,736	3,524,480	114,394	382,620	9	909,531	2,870,456	**9,286,408**
Lower Mississippi River	33,190,774	13,496,944	5,160,896	1,328,062	343,788	520,672	83,876	1,011,473	2,643,750	**57,780,235**
Minnesota River	16,875,469	63,106,270	4,034,140	571,629	562,341	888,027	49,653	3,194,040	4,717,144	**93,998,713**
Missouri River	3,095,517	4,642,270	358,054	17,068	19,285	84,618	7,840	195,329	98,436	**8,518,417**
Rainy River	1,379,430	876,724	191,282	4,693,593	27,053	141,823	69	3,831,024	1,689,520	**12,830,518**
Red River	12,427,316	1,945,435	4,156,273	2,714,812	126,383	479,149	10,285	4,303,597	617,872	**26,781,122**
St. Croix River	2,734,879	2,340,243	112,083	1,528,955	106,737	434,357	912	555,492	441,629	**8,255,287**
Upper Mississippi River	16,717,357	16,145,270	1,415,241	7,423,577	1,488,515	2,392,008	57,563	9,356,591	14,817,420	**69,813,542**
Grand Total	**93,266,857**	**113,919,883**	**16,178,583**	**21,845,662**	**2,839,452**	**5,480,352**	**220,455**	**23,828,885**	**28,815,928**	**306,396,057**

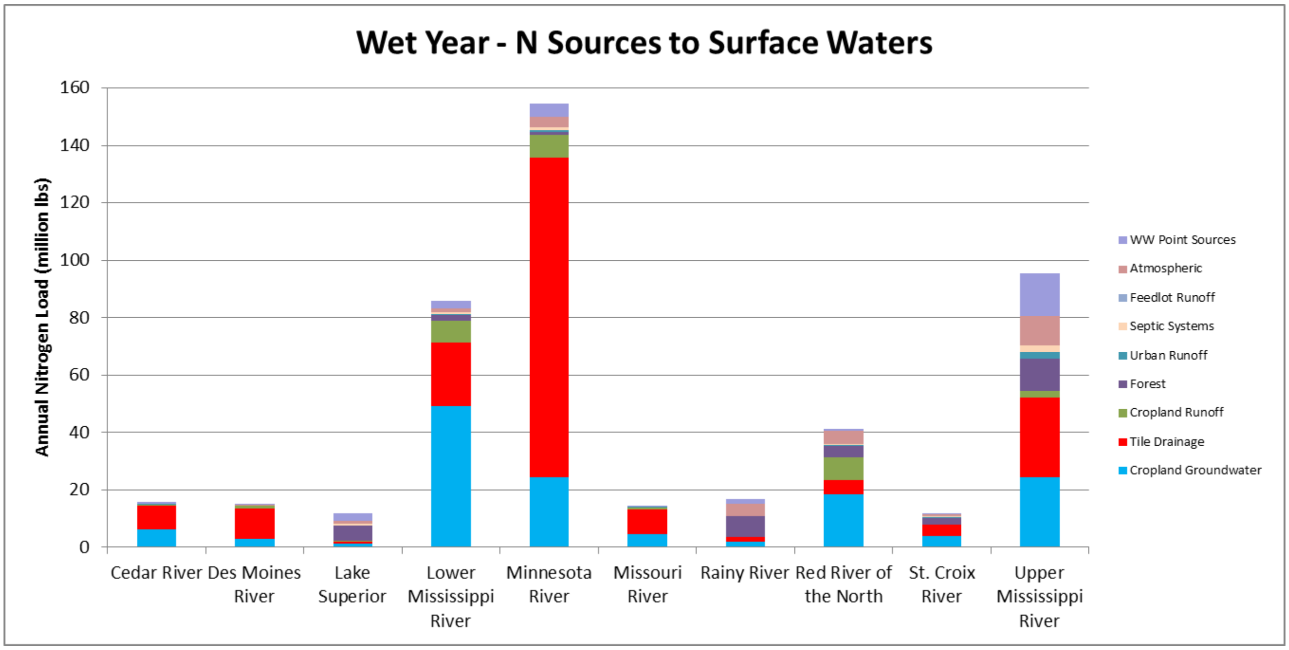

Figure 7. Estimated N loads to surface waters from different sources within the Minnesota portions of major basins during a wet year (90th percentile precipitation year).

Table 5. Estimated N loads to surface waters from different sources within the Minnesota portions of major basins during a wet year (90th percentile precipitation year).

Basin	Cropland Groundwater	Cropland Drainage	Cropland Runoff	Forest	Urban NPS	Septic	Feedlot	Atmospheric	Point Sources	Total
Cedar River	6,123,057	8,535,764	295,660	32,116	58,521	87,875	7,611	152,877	635,348	**15,928,829**
Des Moines River	2,896,958	10,657,787	828,794	33,115	17,914	69,203	4,892	366,112	284,353	**15,159,128**
Lake Superior	1,180,848	769,625	329,261	5,286,720	171,591	382,620	12	1,000,484	2,870,456	**11,991,617**
Lower Mississippi River	49,356,821	21,943,782	7,559,105	1,992,091	515,683	520,672	102,330	1,112,620	2,643,750	**85,746,854**
Minnesota River	24,393,974	111,213,311	8,199,383	857,443	843,513	888,027	60,576	3,513,444	4,717,144	**154,686,815**
Missouri River	4,497,544	8,621,258	872,115	25,604	28,928	84,618	9,565	214,862	98,436	**14,452,930**
Rainy River	1,987,456	1,496,321	282,240	7,040,390	40,580	141,823	85	4,214,126	1,689,520	**16,892,541**
Red River of the North	18,553,349	4,907,556	7,829,840	4,072,215	189,569	479,149	12,547	4,733,957	617,872	**41,396,054**
St. Croix River	4,048,735	3,787,514	168,774	2,293,431	160,106	434,357	1,112	611,041	441,629	**11,946,699**
Upper Mississippi River	24,544,775	27,685,025	2,305,990	11,135,361	2,232,772	2,392,008	70,230	10,292,250	14,817,420	**95,475,831**
Grand Total	**137,583,517**	**199,617,943**	**28,671,162**	**32,768,486**	**4,259,177**	**5,480,352**	**268,960**	**26,211,774**	**28,815,928**	**463,677,299**

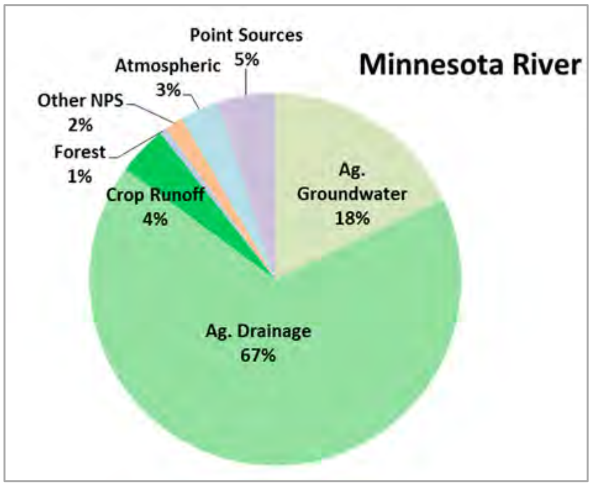

Figure 8. Estimated N sources to surface waters from the Minnesota contributing areas of the Minnesota River Basin (average precipitation year).

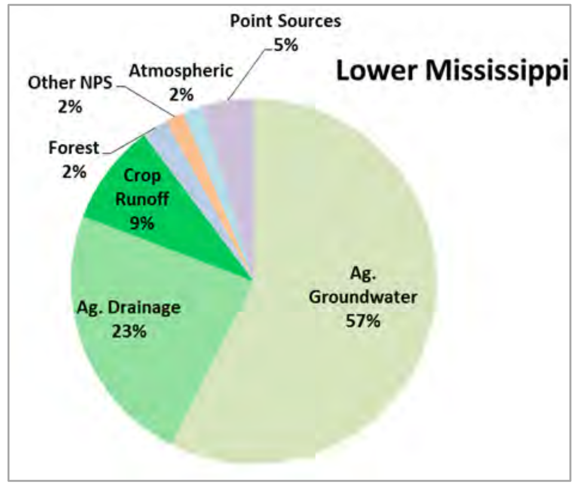

Figure 9. Estimated nitrogen sources to surface waters from the Minnesota contributing areas of the Lower Mississippi River Basin (average precipitation year).

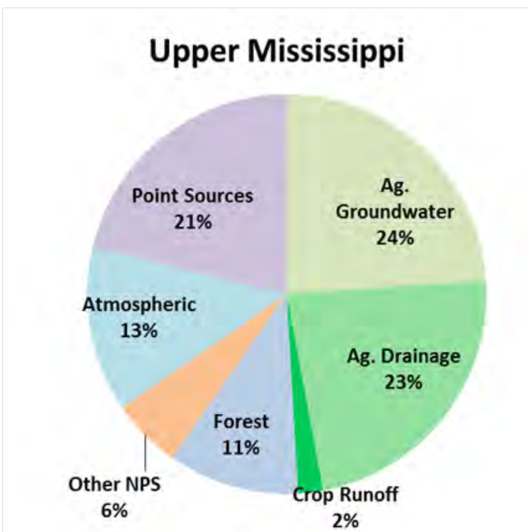

Figure 10. Estimated N sources to surface waters from the Upper Mississippi River Basin (average precipitation year).

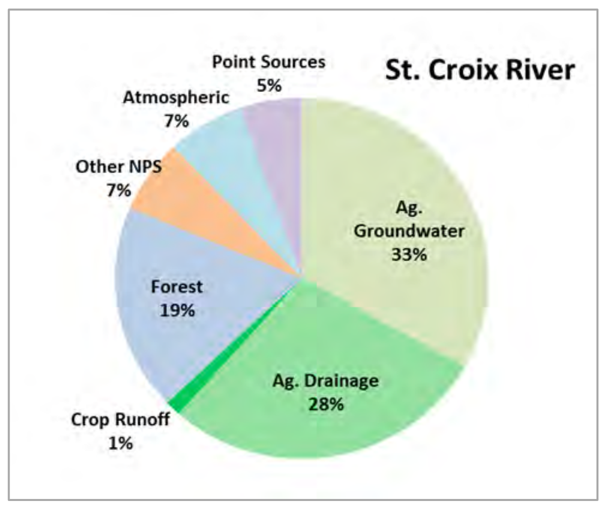

Figure 11. Estimated N sources to surface waters from the Minnesota contributing areas of the St. Croix River Basin (average precipitation year).

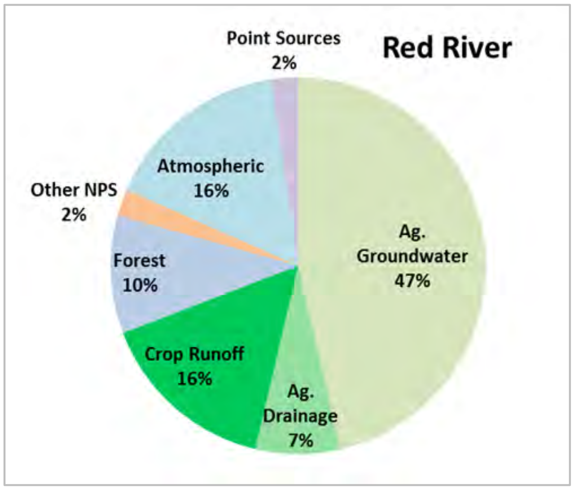

Figure 12. Estimated N sources to surface waters from the Minnesota contributing areas of the Red River Basin (average precipitation year).

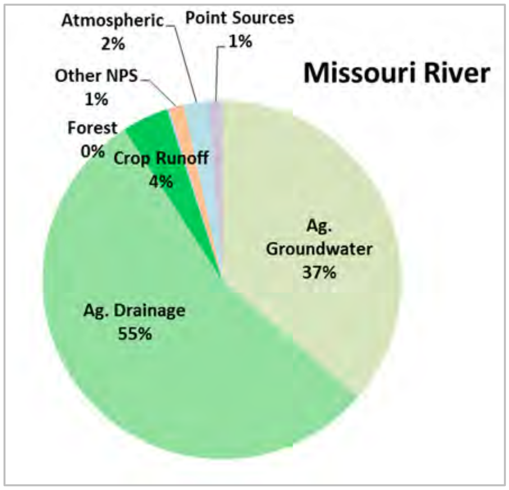

Figure 13. Estimated N sources to surface waters from the Minnesota contributing areas of the Missouri River Basin (average precipitation year).

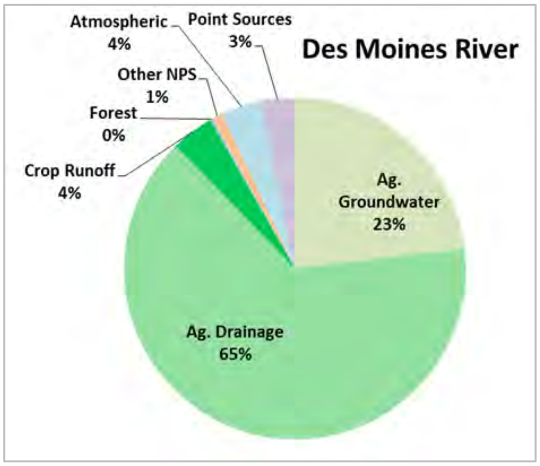

Figure 14. Estimated N sources to surface waters from the Minnesota contributing areas of the Des Moines River Basin (average precipitation year).

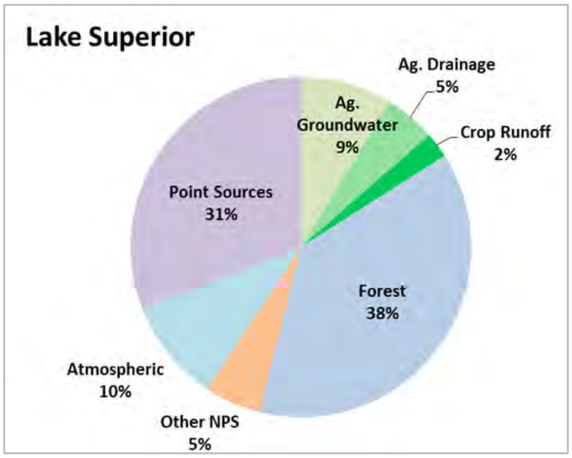

Figure 15. Estimated N sources to surface waters from the Minnesota contributing areas of the Lake Superior Basin (average precipitation year).

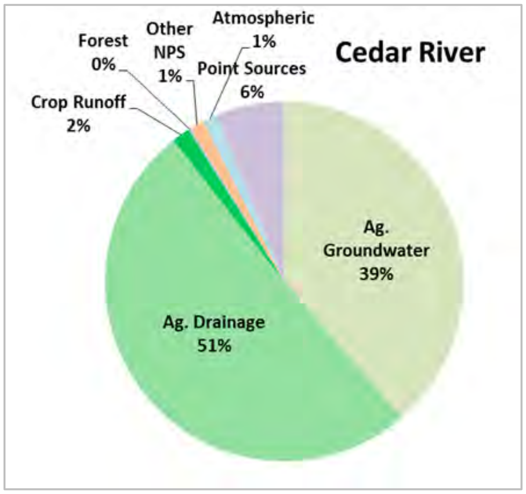

Figure 16. Estimated N sources to surface waters from the Minnesota contributing areas of the Minnesota River Basin (average precipitation year).

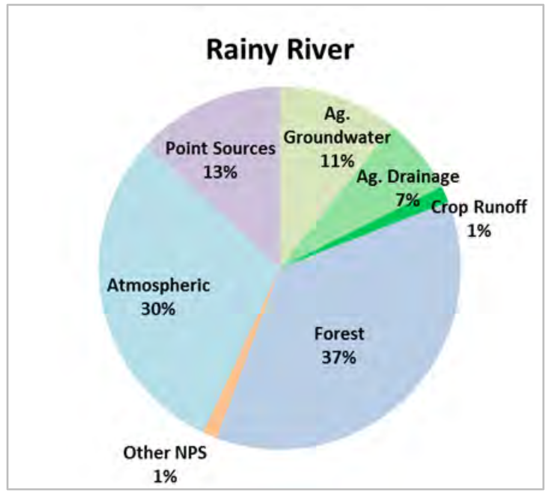

Figure 17. Estimated N sources to surface waters from the Minnesota contributing areas of the Rainy River Basin (average precipitation year).

Contributions to the Mississippi River

Because of the goal to reduce N loads going to the Gulf of Mexico in the Mississippi River, we also assessed the loads going just to the Mississippi River. About 81% of the total N load to Minnesota waters is from basins which end up flowing into the Mississippi River (including all basins except the Lake Superior, Rainy, and Red). If we look only at those Minnesota watersheds which contribute to the Mississippi River, source contributions during an average precipitation year are estimated as follows: cropland sources 78%, point sources 9%, and non-cropland nonpoint sources 13% (Figure 18). Cropland source contributions increase to 83% for these watersheds during wet (high-flow) years, while point sources decrease to 6% during wet years. During a dry year, cropland sources represent an estimated 62% of N to waters headed toward the Mississippi River and point sources contribute 19%.

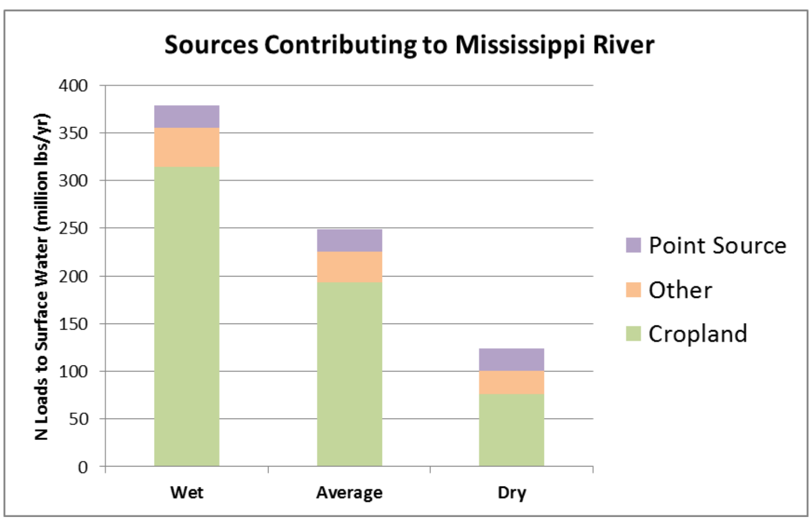

Figure 18. Sum of N source contributions in watersheds which eventually reach the Mississippi River. The "other" category includes septic systems, atmospheric deposition directly into waters, feedlots, forested land and urban/suburban nonpoint source N.

Source contributions to waters on a per-acre basis

Some sources contribute elevated N to waters on a per acre basis, but they do not represent enough cumulative acres to create an environmental threat at the statewide or regional level. Thus, sources that are relatively minor at the state-level scale can sometimes still contribute significantly to N loads at the local-level.

One way of comparing contributions from different land uses and understanding the potential for affecting local water bodies is to consider the yield, represented in pounds per acre per year delivered to surface waters. Yields from source categories are shown in Table 6 and Figure 18, for average precipitation conditions. The estimates are presented as a range, showing both the lower and higher ends of estimated yields for each source category.

Note that the yield within a single field can be larger than the yield ranges in Table 6 and Figure 18, which are based on averages across larger areas, such as subwatersheds, agroecoregions, and other monitored areas. Also, it is important to note that some source contributions to waters are not dispersed throughout the land, but enter waters at specific locations. For example, wastewater point sources from an urban area enter waters at specific points, and can therefore have a more noticeable impact in the immediate area of discharge as compared to more dispersed sources spread out over the same size area. Even though the overall loads and yields can be the same, the point source nature of discharges can affect localized water resources in different ways than more dispersed nonpoint source discharges.

The yield ranges show that N is relatively low on a per-acre basis from the following source categories: forests, urban stormwater, atmospheric deposition, and mixed crops in less geologically sensitive non-tiled regions. Row crops in sensitive areas (tile-drained, sandy, karst) have the highest yields. Point sources are a relatively small N source statewide compared to cropland sources, yet they can potentially impact localized stretches of rivers. High densities of septic systems in geologically sensitive areas can also potentially contribute moderately high N yields to surface waters, yet most areas with septic systems have yields to surface waters comparable to the lower yielding sources.

Table 6. Total nitrogen yields from various N source categories (average precipitation conditions). The estimates are presented as a range, showing both the lower and higher-end estimated yields for each source category.

Source category	Low-end lbs/ac/yr	High-end lbs/ac/yr	Assumptions and sources for yields
Row crops in sensitive areas (i.e. tiled, sandy soils, or karst regions)	20	37	Average precip cropland losses to waters based on Mulla et al. (2013) analyses presented in Chapter D4 for the following Agro-ecoregions: Rochester Plateau 37; Anoka Sand Plain 35; Level plains 33; Blufflands 20.
Mostly row crops in less sensitive areas	15	23	Average precip cropland losses to waters based on Mulla et al. (2013) analyses presented in Chapter D4 for the following Agro-ecoregions: Undulating Plains 23; Wetter clays and silts 19; Rolling moraine 15.4.
Mixed crops in less sensitive areas	5	10	Average precip cropland losses to waters based on Mulla et al. (2013) analyses presented in Chapter D4 for the following Agro-ecoregions: Cotoeu and Inner Coteau 9; Central Till 8; Steep Dryer Moraine 7; Drumlins 6
Municipal and Industrial Point Sources	8	20	From Point Source Chapter D2 by Weiss (2013). The lower density development in the Blue Lake wastewater treatment sewershed had an average of 7.8 lbs/acre/yr from both municipal and industrial wastewater, and the higher density development within the Metro sewershed had 19.7 lbs/acre/yr. Note: this N is not released in a diffuse manner – so the immediate impact to waters will be most noticeable near the points of discharge.
Urban/suburban stormwater + groundwater	2	10	Metropolitan Council monitoring of Bassett Creek and Battle Creek yielded approx. 2.5 lbs/acre/yr (from data provided by Karen Jensen); Hennepin County Three Rivers Park monitoring of subwatersheds showed industrial areas averaging 3.7 lbs/acre/yr; residential 1.9; mixed 3.9 (from data provided by Brian Vlach); Minneapolis Park Board average watershed yields in 2002-04 was 5.6 lbs/acre/yr and in different Mpls. watersheds averaged 9.7 lbs/acre/yr between 2005-2010 (data provided by Mike Perniel). All literature review results as referenced in chapter D-4 fall within these ranges, mostly averaging between 2.5 and 6 lbs/acre/yr.
Septic Systems	4	17	Low end assumes 4 person households, 7 lbs per person per year, on 3.5 acre lots, and half of N lost in groundwater through denitrification. High end assumes 4.5 person households, 8 lbs per person, on 1.5 acre lots, and 30% N lost in groundwater through denitrification.
Atmospheric	4	14	Wet plus dry deposition as shown in Chapter D-3 by Wall and Pearson (2013). Low end are estimated loads from northeastern Minnesota watershed spatial averages and High end estimates are from southeastern Minnesota watershed spatial avgs.
Forest	0.4	5	See Chapter D4. Wisconsin forested watersheds yielded 3.1 and 3.6 lbs/acre (from Clesceri, et al. (1986). USGS report showed forested watershed N yields of 0.41 lbs/acre in Namekogen and 0.25 lbs/acre in the St. Croix River (Graczyk, 1986).

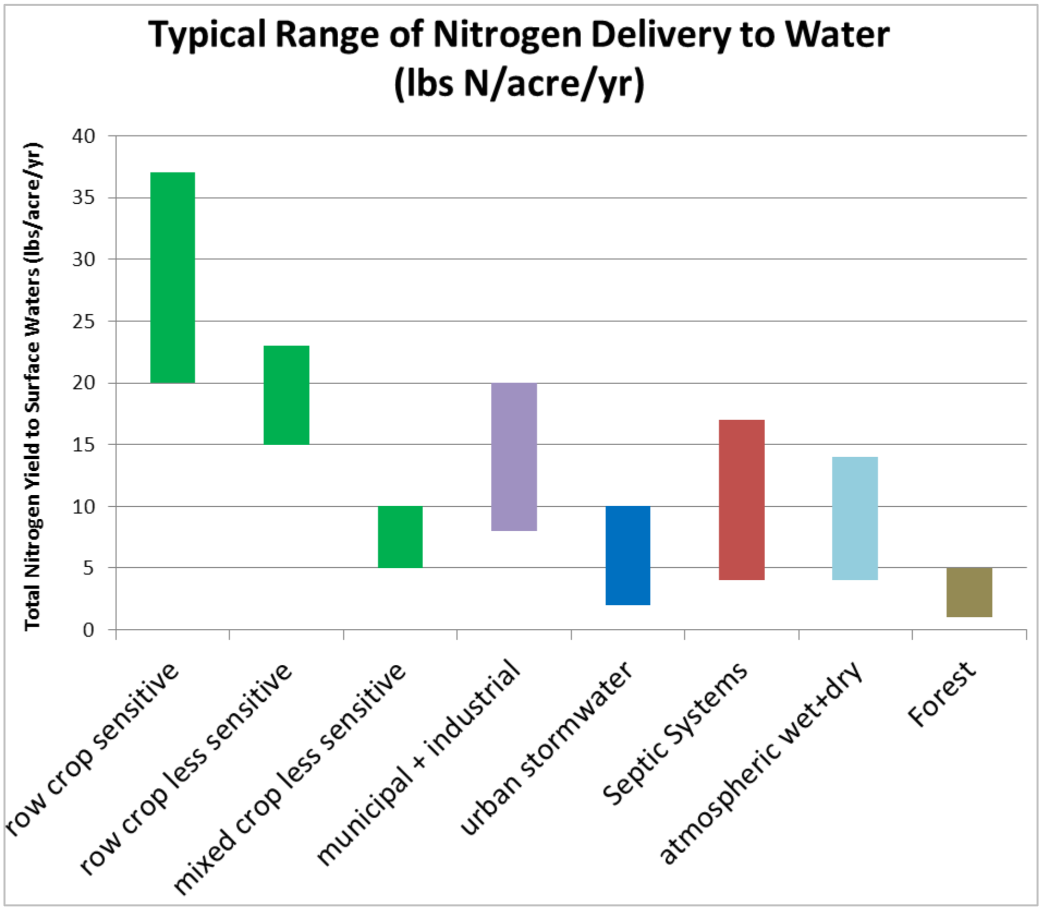

Figure 19. Graphical depiction of the source yield ranges from Table 6. Average precipitation year.

Flow pathways from all sources combined

The dominant N flow pathways between all sources and receiving surface waters vary from basin to basin and sometimes with climate. Four categories of flow pathways were estimated based on the following categorizations and assumptions:

Groundwater: The groundwater flow pathway was calculated from the source assessment information by adding 100% of the cropland groundwater that reaches surface waters, 80% of septic system N reaching surface waters, 20% of the urban/suburban nonpoint N, and 50% of forest N.

Surface runoff: The surface runoff flow pathway was calculated from the source assessment information by adding 100% of the cropland surface runoff, 20% of the septic system N reaching surface waters (direct pipe losses), 80% of the urban/suburban nonpoint N, 50% of forest N, and 100% of feedlot runoff N.

Tile line drainage: The tile drainage includes all cropland tile line drainage N.

Direct Discharge: The direct discharge pathway was calculated by adding 100% of point source discharge N and 100% of direct wet+dry atmospheric deposition into lakes and streams.

The estimated statewide N load from each N transport pathway to surface waters for average and high precipitation periods are depicted in Figures 20 and 21. Tile line and groundwater are the two dominant

N pathways to surface waters statewide. The influence of tile lines increases from 37% of the load to surface waters during and average precipitation year to 43% of the N load to surface waters during the highest loading years (wet years). The groundwater pathway is the second largest pathway in both average and wet years, representing just over one-third of the load.

The fraction of forest N delivered to surface waters via surface runoff and groundwater flow pathways was not found in the literature, and the above results assume that half is transported in surface runoff and the other half through groundwater. Because forestland only contributes an estimated 7% of the statewide N load, errors in pathway assumptions for forestland will not have an appreciable effect on the statewide pathway characterization in Figures 20 and 21.

While all the sources/pathways represent annual estimated N loads, the arrival time to surface waters varies considerably depending on the travel pathway. Much of the N from the groundwater pathway will take many years to reach surface waters. Other pathways have much shorter travel time to waters. Therefore, in areas where groundwater is an important pathway, the N concentrations in surface waters may not completely represent modern land uses and management. The N source assessment in this study attempted to account for estimated denitrification losses within the groundwater flow pathway, but did not address the time lag for groundwater flow. In other words, while the source assessment is the best estimate of source contributions to surface waters, the point in time when these sources actually reach surface waters will vary from source to source and from basin to basin, depending on how much of the N load is coming from groundwater sources and the rate at which groundwater flows.

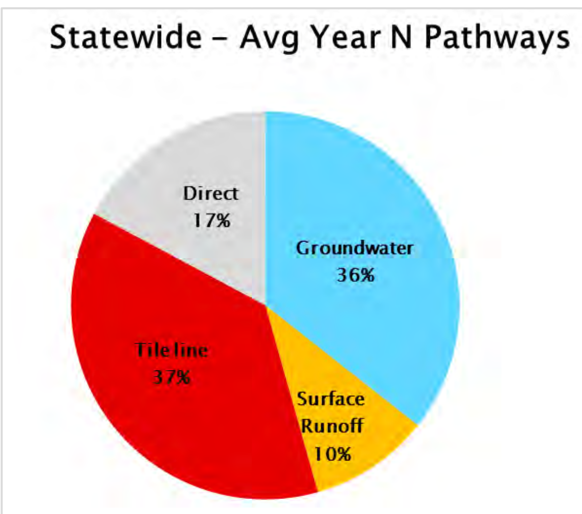

Figure 20. Statewide N pathways to surface waters during an average precipitation year, as estimated by UMN/MPCA. Direct includes both point sources and atmospheric deposition into waters.

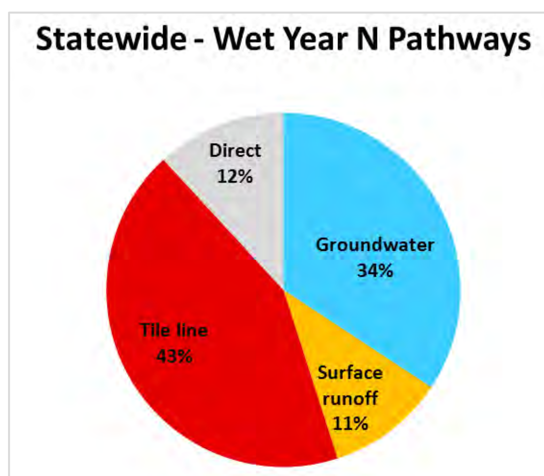

Figure 21. Statewide N pathways to surface waters during a wet year, as estimated from UMN/MPCA.

Nitrogen pathways vary by basin (Figure 22). Groundwater is a dominant pathway in the Lower Mississippi, Upper Mississippi, and St. Croix River Basins; whereas tile line flow is the dominant pathway in the Minnesota River Basin.

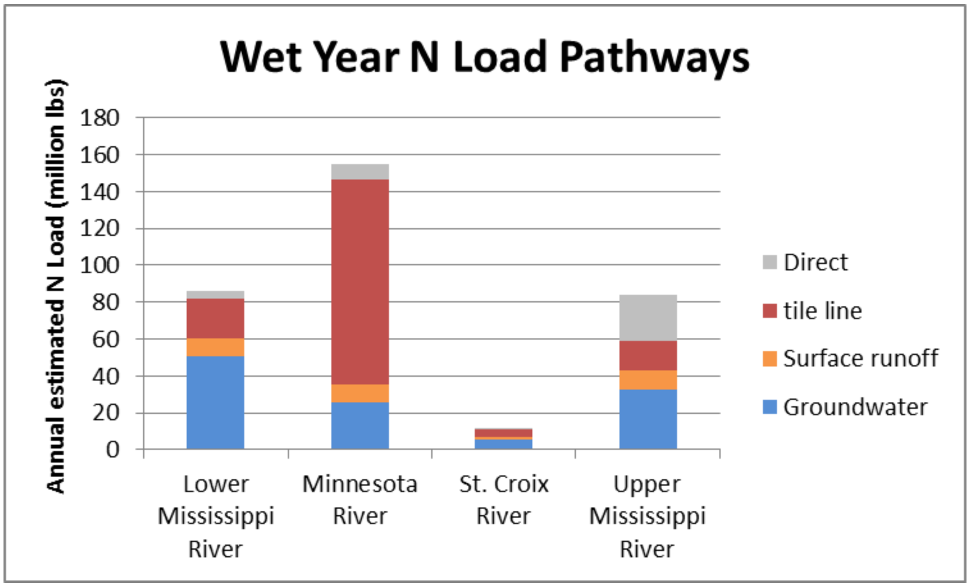

Figure 22. Basin N pathways to surface waters during a wet year for each of the four largest basins which drain into the Mississippi River system. Results are only for Minnesota land within the basins.

Uncertainty

The source contributions *to surface waters* conducted by the University of Minnesota and MPCA (UMN/MPCA) as described in Chapters D1 to D4 have areas of uncertainty. One particular area of uncertainty is the cropland groundwater component due to: a) limited studies quantifying leaching losses under different soils, climate and management, and b) high variability in denitrification losses which can occur as groundwater slowly flows toward rivers and streams.

Because of source assessment uncertainties, we compared the source assessment results with other related findings, using five different methods. These verification methods, as reported in Chapters E1 to E3, showed results which generally support the source assessment findings. However, all sources should be treated as large-scale approximations of actual loadings, and each source estimate could be refined with additional research.

Summary

Soil N comes from a variety of sources. Of the added sources, cropland fertilizer represents the largest source. Manure, legumes, and atmospheric deposition are also significant sources, and when added together provide similar N amounts as the fertilizer additions. Soil organic matter mineralization releases large quantities N annually, which were estimated to contribute about the same amount of N as cropland fertilizers and manure combined. Septic systems, lawn fertilizers and municipal sludge add comparatively small amounts of N to soils statewide (less than 1% of added N).

Cropland agricultural sources contribute an estimated 73% of the N load to Minnesota surface waters during a normal precipitation year, with the rest contributed mostly by wastewater point sources, atmospheric deposition and forestland. Feedlot runoff, urban stormwater and septic systems combined contribute less than 3% of the N load to surface waters. The sources and loads vary considerably from one major river basin to another.

The dominant pathway to surface waters is through the subsurface, with about 73% of the N load from all sources entering surface waters on an average year through groundwater pathways combined with cropland tile drainage. Surface runoff from all sources combined contributes a relatively small amount (10%) of the N loading to surface waters, and direct deposits into waters (point source discharges and atmospheric deposition) represent 17% of N to surface waters during an average year. During the highest loading years (wet weather), the tile drainage pathway contributions increase to 43% of the estimated N load, and all cropland pathways combined contribute an estimated 79% of the N load.

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Graczyk, D.J.. 1986. Water Quality in the St. Croix National Scenic Riverway, Wisconsin. Water Resources Investigations Report 85-4319. 48 pp.

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D2. Wastewater Point Source Nitrogen Loads

Author: Steve Weiss, MPCA

Introduction

Nitrogen, in its various forms, functions as both a nutrient with the potential to contribute to eutrophication (i.e. in coastal waters), and as a toxic pollutant with the potential to affect aquatic life and human health. In circumstances where excess nitrogen (N) loading may preclude the attainment of designated uses, loading from point sources is of particular importance because it can be controlled with nutrient removal technology through permit limits. This chapter provides estimates of N loading from municipal and industrial point source dischargers with National Pollution Discharge Elimination System (NPDES) permits; hereafter referred to as point sources. Load sources not covered in this chapter include: permitted industrial or municipal stormwater, concentrated animal feeding operations, large subsurface treatment systems, individual subsurface treatment systems, spray irrigation facilities where measured drain tile flow data are unavailable, and the land application of wastewater treatment biosolids. Significant sources from this list are generally covered in other chapters. Loads from individual point sources are aggregated and presented by basin and major watershed. Seasonal patterns, yield per unit area, yield per capita, and the distribution of load between municipal and industrial sources are examined in greater detail. Although this chapter primarily focuses on total nitrogen (TN), estimates of ammonia (NHx), total kjeldahl nitrogen (TKN), and nitrite and nitrate nitrogen (NOx) are also presented in various tables and appendices.

Project results are presented first, followed by a discussion of the methods used to determine the estimated point source loads.

Statewide totals

Currently, Minnesota has over 900 wastewater point sources that actively discharge to surface waters. Of these point sources, 64% are domestic wastewater treatment plants (WWTPs) and 36% are industrial facilities (Appendix D2-1). In total, it is estimated that wastewater point sources discharge an average annual TN load of 28,671,429 pounds statewide (Table 1). Most of this load is from municipal dischargers (24,929,970 pounds/year TN, 87%); the remainder is from industrial facilities (3,741,459 pounds/year TN, 13%). Within most basins, municipal facilities account for over 90% of the point source load (Table 1). The few exceptions include basins like the Rainy River and St. Croix River which have large, water-using industrial facilities.

Despite the large number of individual permits in Minnesota, the majority of wastewater point source TN loading comes from a small number of large facilities. The 10 largest point sources, as measured by average annual TN load, collectively amount to 67% of the point source TN load. The single largest facility is the Metropolitan Council Environmental Service (MCES) Metro WWTP which discharges an annual average TN load of 10,363,151 pounds/year. The Metro WWTP, by itself, amounts to 36% of the overall point source TN load. The remaining MCES facilities within the top 10 include the Blue Lake, Seneca and Empire WWTPs which collectively discharge 12% of the point source TN load. Other notable large municipal TN load sources include the Western Lake Sewer and Sanitary District (WLSSD) WWTP in Duluth, Rochester WWTP and St. Cloud, which are estimated to discharge 7%, 3%, and 2% of the overall municipal TN load, respectively. Following the 10 largest dischargers, no single facility amounts to over 1% of the state wide point source TN load. It should be noted that the industrial load only includes estimates from industrial facilities that have individual NPDES permit and not facilities considered significant industrial users (SIUs), which discharge to municipal WWTPs for further treatment. Insufficient data are available from which to estimate SIU flow and loading to municipal WWTPs statewide.

Table 1. Estimated wastewater point source TN loading per basin from industrial and municipal dischargers (2005-2009).

	Industrial		Municipal		Total
Basin	Load (lbs/yr)	%	Load (lbs/yr)	%	Load (lbs/yr)
Upper Mississippi River	1,132,842	8%	13,609,734	92%	14,742,576
Minnesota River	273,539	6%	4,443,605	94%	4,717,144
Lake Superior	256,035	9%	2,614,346	91%	2,870,381
Lower Mississippi River	257,372	10%	2,386,378	90%	2,643,750
Rainy River	1,576,132	93%	113,388	7%	1,689,520
Cedar River	14,219	2%	621,129	98%	635,348
Red River of the North	63,066	10%	554,806	90%	617,872
St. Croix River	84,148	23%	287,900	77%	372,049
Des Moines River	84,062	30%	200,291	70%	284,353
Missouri River	44	0%	98,392	100%	98,436
Total	**3,741,459**	**13%**	**24,929,970**	**87%**	**28,671,429**

Major basin wastewater point source loads

Upper Mississippi River Basin

On average, more TN is discharged annually by wastewater point sources in the Upper Mississippi River Basin (UMR) than in all other basins state-wide (14,742,576 pounds/year, 51%, Figures 1 and 3). Although there are numerous domestic and industrial dischargers within this basin, (142 and 118, respectively) the majority of the flow and loading is discharged by a few large municipal sources in the Twin Cities Metropolitan Area (TCMA). Industrial point source loading is generally estimated to be small (8%) as compared to municipal (92%). The few exceptions include high protein industries like food, rendering, and paper, the latter of which adds nutrients to feed bacteria and thereby reduce biological oxygen demand (BOD). Within the UMR, the two highest loading major watersheds are the Mississippi River Twin Cities and St. Cloud which generate annual TN loads of 10,972,760 and 864,231 pounds, respectively (Figure 2, 4, Appendix D2-2). Municipal wastewater accounts for the majority of point source loading within these watersheds (Figure 3).

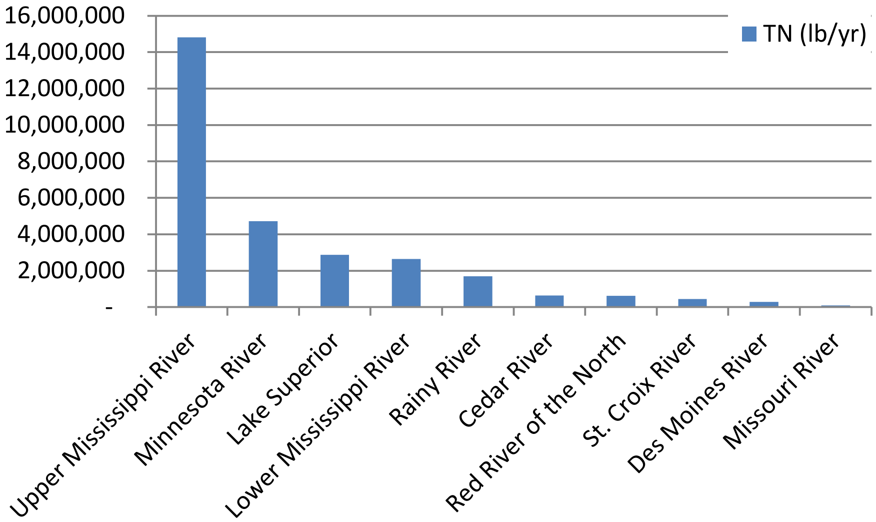

Figure 1. Comparison of watershed basin annual TN load estimates from permitted point sources.

Minnesota River Basin

The Minnesota River Basin (MRB) is estimated to have the second highest annual wastewater point source TN load (4,717,144 pounds). This equates to 16% of the total statewide point source TN load. Unlike the UMR, loading in the MRB is more evenly distributed among its 155 municipal and 81 industrial facilities in most sub basins. The Minnesota River (Shakopee) has the highest point source TN load within the MRB (3,170,968 pounds/year) and is the second highest loading major watershed in the state. Point source TN loading in the MRB Shakopee primarily comes from larger municipal facilities.

Lake Superior, Lower Mississippi, and Rainy River Basins

The Lake Superior, Lower Mississippi River, and Rainy River Basins have the third, fourth, and fifth highest annual wastewater point source TN loads at 2,870,381 pounds, 2,643,750 pounds, and 1,689,520 pounds, respectively. Like other basins, the point source TN loading in the Lake Superior and Lower Mississippi River Basins is primarily from municipal sources. Point source TN in the Rainy River, however, is estimated to be mostly from one large paper manufacturer. Industrial TN loading is estimated to be 93% of the total point source load. Paper facilities typically have a carbon rich pulp influent which requires that nutrients (i.e. phosphorus and N) be added to feed bacteria and thereby reduce BOD. Given the tremendous flow from the paper industry, moderate to high effluent TN concentrations can result in large loads.

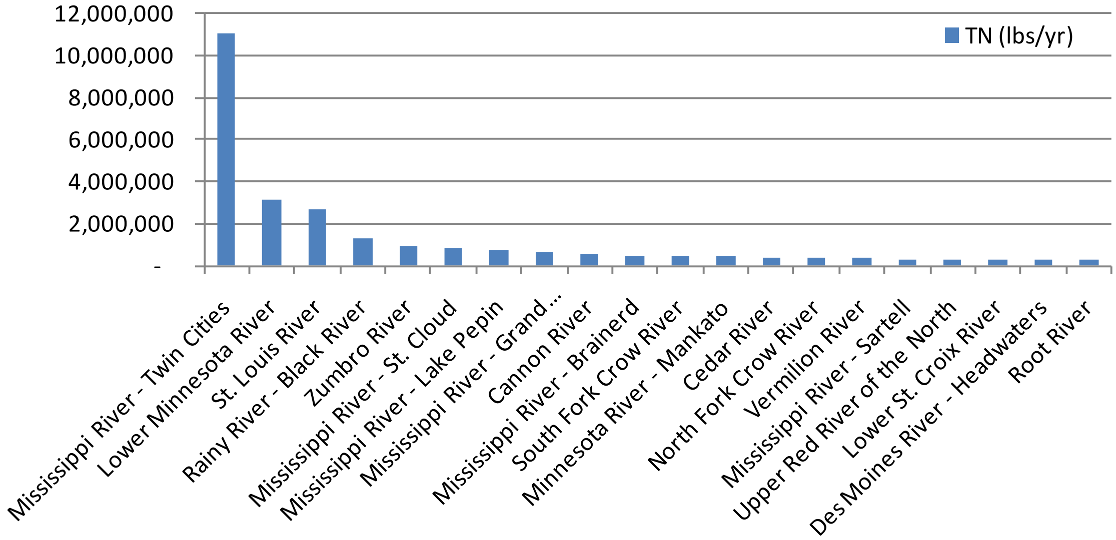

Figure 2. Annual N load estimates from permitted point source dischargers within the top 20 major watersheds in Minnesota.

Cedar, Red, St. Croix, Des Moines, and Missouri River Basins

The remaining basins of the state, including the Cedar River, Red River, St. Croix River, Des Moines River, and Missouri River, are estimated to collectively generate less than 7% of the wastewater point source TN load. The major watersheds within these basins generate annual TN point source loads in the range of less than 100 pounds to roughly 400,000 pounds.

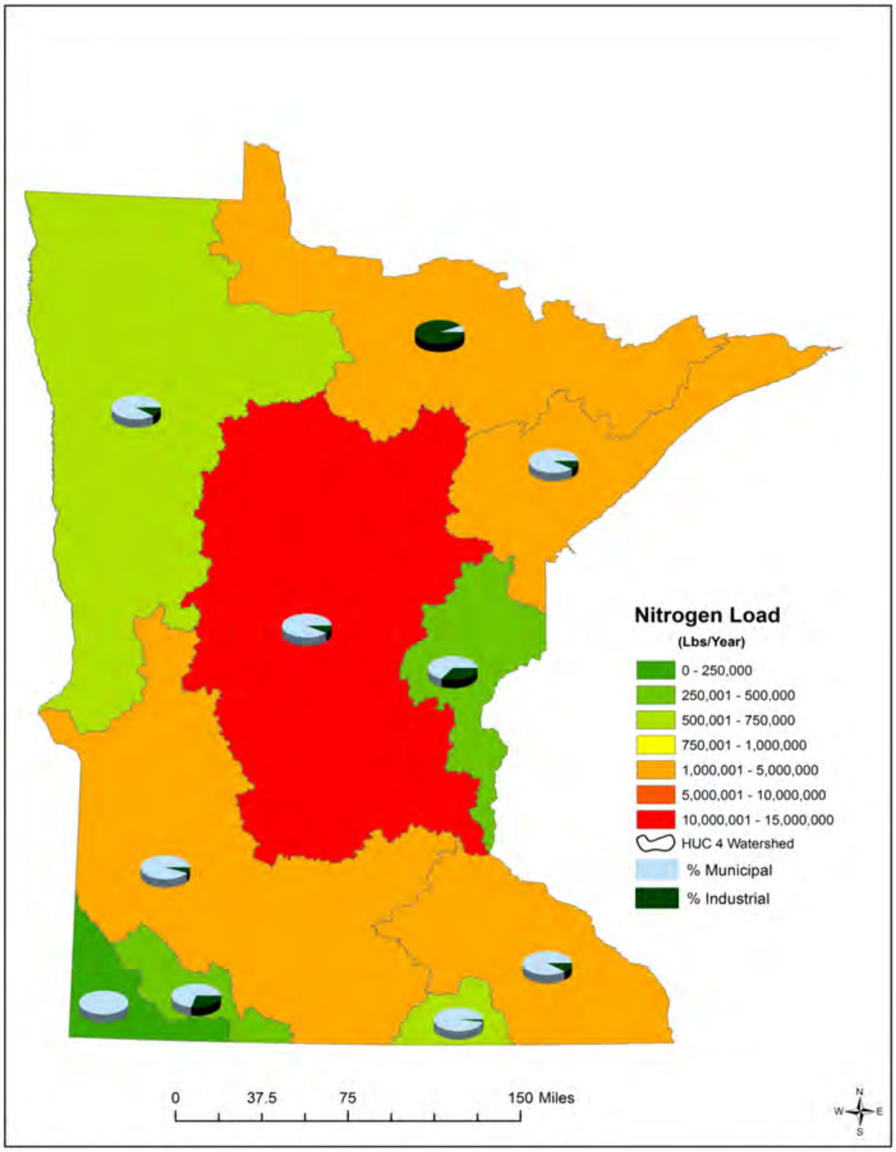

Figure 3. Total nitrogen load by basin from municipal and industrial NPDES point sources (2005-2009). Pie charts represent the percent load distribution among municipal and industrial facilities within each basin.

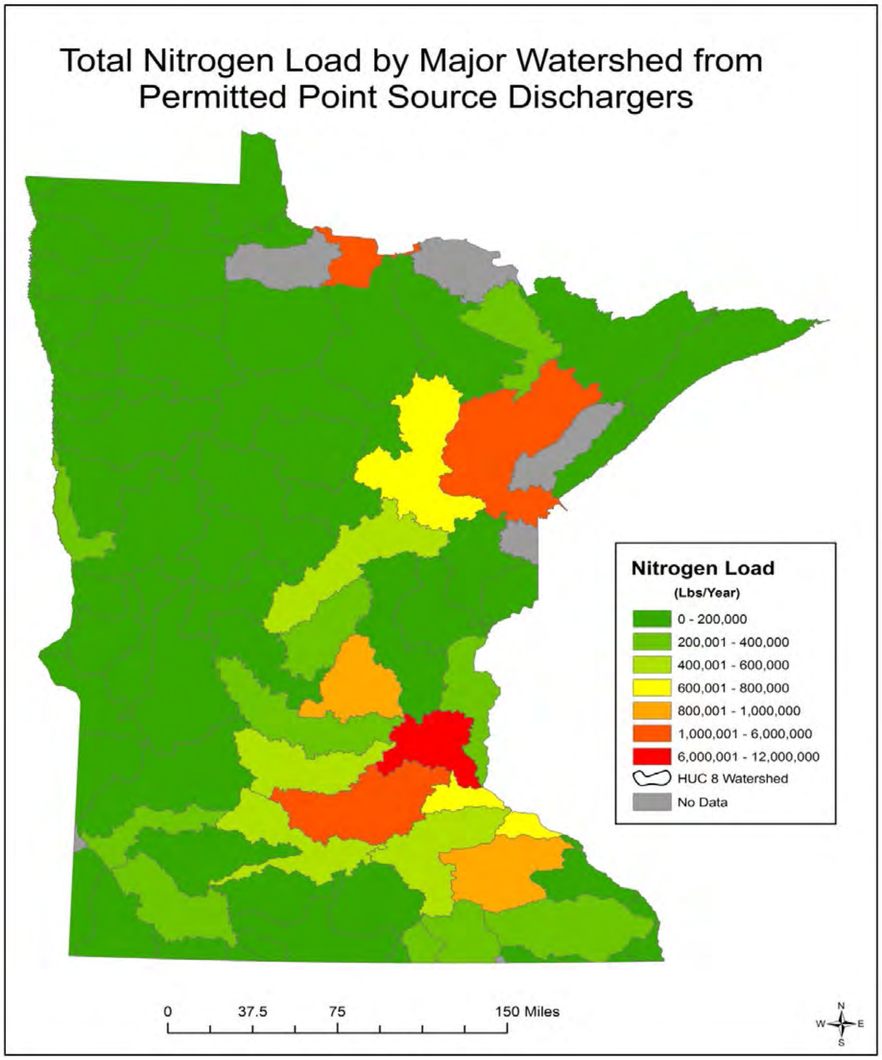

Figure 4: Total nitrogen annual load by major watershed from municipal and industrial NPDES point sources (2005-2009).

Wastewater point source yield

Nonpoint pollutant load sources are commonly assessed by a yield or per unit area basis. For means of comparison, TN point source yield values were also calculated for basins (Appendix D2-1), major watersheds (Figure 5, Appendix D2-1(B)), and in a few select cases by the land area contributing to a specific wastewater treatment facility (sewershed) (Figure 6, Table 2). Wastewater point source yields are intended to represent the TN loading potential from low to high density residential landcover. Basin and watershed yields might best be used to rank or compare watersheds or basins with each other. In contrast, sewershed yields are a more direct measure of urban point source load potential because the land area directly represents the extent of the collection system area. Yield on a per capita basis was also examined for a few select urban watersheds where sufficient user data were available (Table 2). Note that the nature of yields from wastewater point sources is different than yields from nonpoint sources, since all of the load from point source contributing areas is released at specific points in the rivers, instead of being a more diffuse discharge occurring over a larger geographic area. Yield comparisons between point and nonpoint sources are more appropriate for assessing the relative effects on downstream waters. However, the localized effects from point and nonpoint source discharges can potentially be different from similarly N yielding areas.

Basins and major watersheds

The Mississippi River Twin Cities major watershed has, by far, the highest wastewater point source TN yield (17.0 pounds/acre, Figure 5, Appendix D2-1(B)). Other major watersheds with notable yields include the Rainy River – Manitou (3.8 pounds/acre), the Minnesota River – Shakopee (2.7 pounds/acre) and the Mississippi River – Lake Pepin (1.9 pounds/acre). High point source yields typically result from a large volume of wastewater discharged within a given area. However, in some cases like the Cedar River Basin, the comparatively high point source yield is the result of a small overall basin area. Major watershed yields, especially in the Metro Area, may be distorted due to sewersheds that overlap defined watershed boundaries (Figure 6). For Example, the Metro WWTP receives wastewater from developments within the Lower Minnesota River; this amplifies the overall yield within the Mississippi River - Twin Cities watershed. Conversely, the Blue Lake WWTP serves developments within the Mississippi River – Twin Cities watershed. It is difficult to predict the difference in volume and pollutant loading received from sewersheds that extend beyond the watersheds that they discharge within.

Sewersheds

Sewershed yield was examined for seven metro area WWTPs to better understand the range in sewershed nitrogen yield. The Twin Cities metro area was selected for yield analysis because of the good availability of wastewater data, its dominance statewide in wastewater treatment volume, and the wide range of population densities within the sewersheds. Three primary aspects were analyzed; 1) point source yield per sewershed area, 2) sewershed population density, and 3) yield per capita (Table 2). Sewersheds are defined as the estimated perimeter surrounding a collection system of interest (Figure 6). It should be noted that sewersheds inevitably contain features such as parks, wetlands, and lakes which may not be characteristic of urban land cover or significantly contribute to TN loading. Area-based yields were calculated in consideration of both municipal and industrial point source loading. Industrial yield contributions included those industries with outfalls either located within or directly adjacent to sewershed boundaries. Finally, population density, yield per capita, and their relationship to area-based yield were also examined.

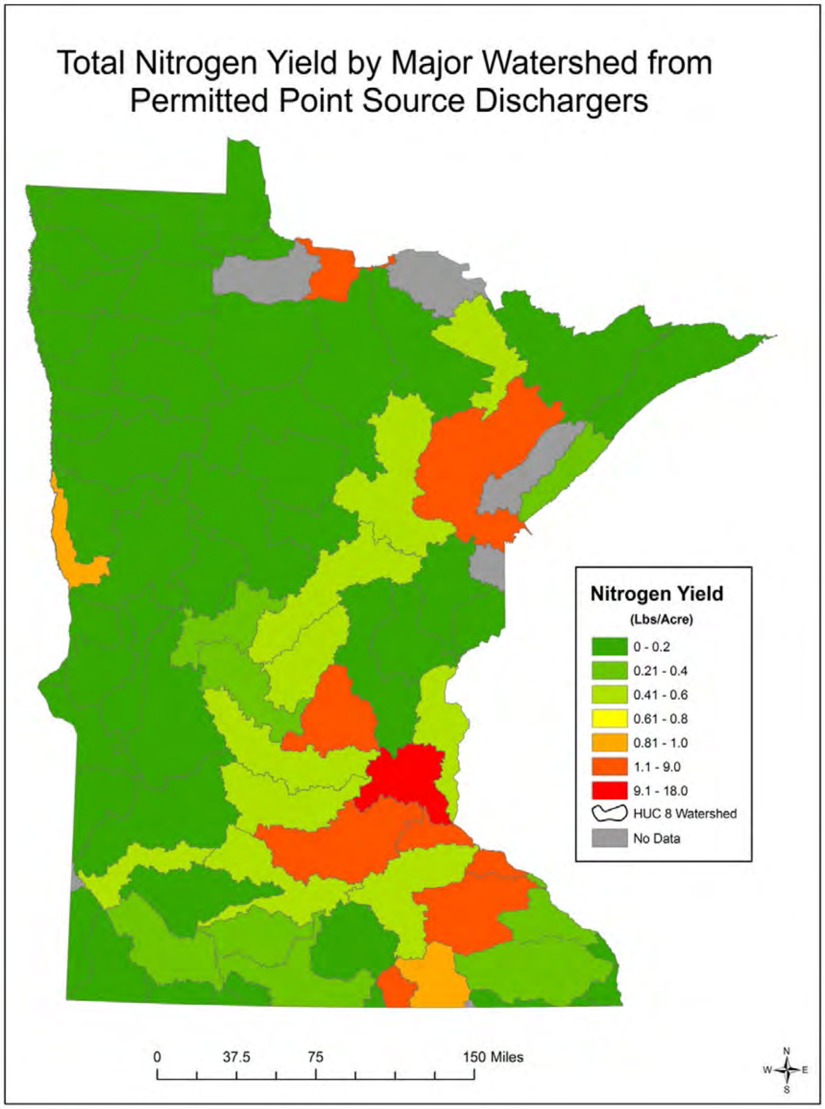

Figure 5. Total nitrogen yield by major watershed from municipal and industrial NPDES point sources (2005-2009).

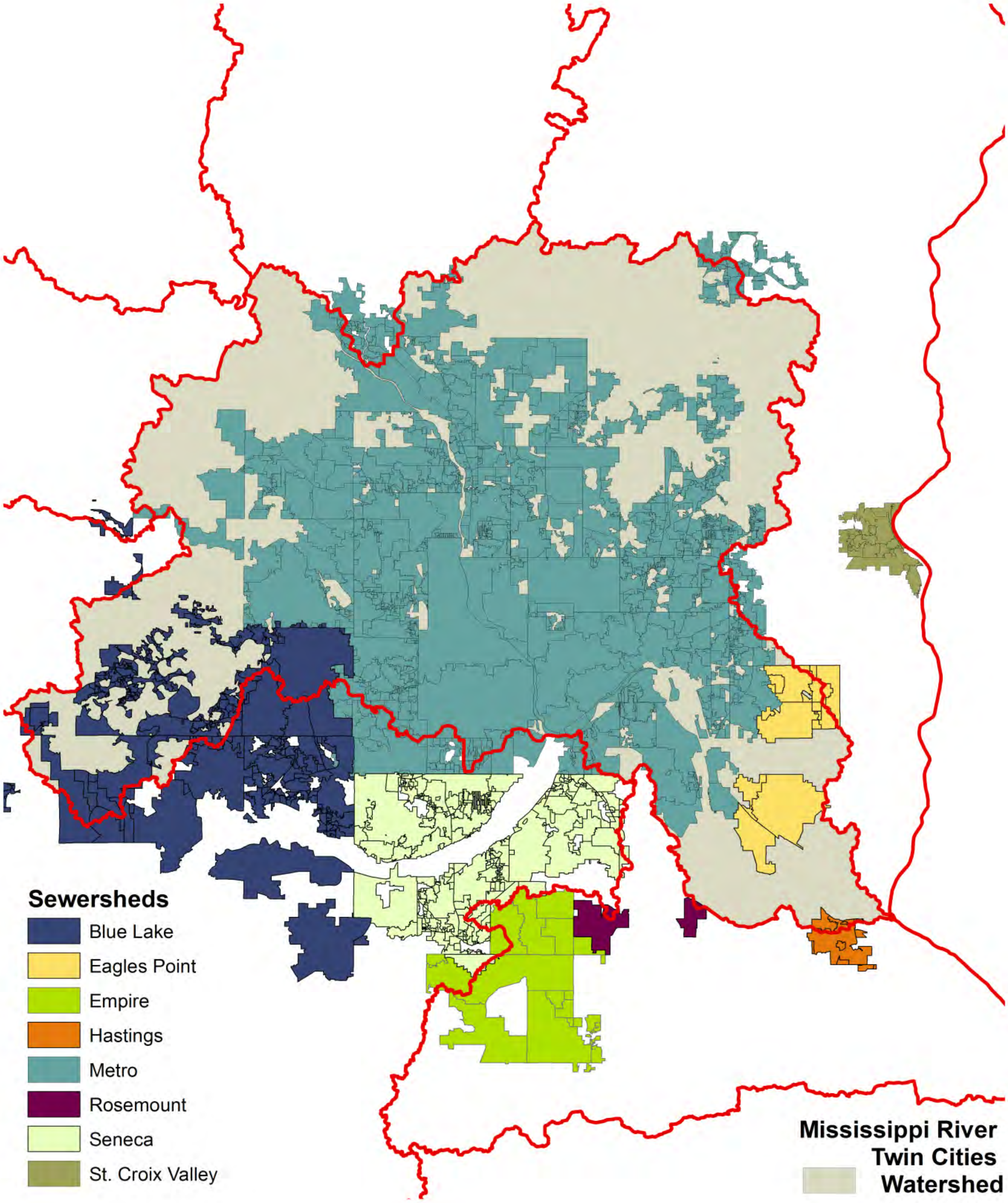

Figure 6. Municipal sewer drainage areas (sewersheds) within the TCMA in relationship with major watershed boundaries. It should be noted that effluent discharged in one watershed may contain drainage from adjacent watersheds given that sewershed and watershed boundaries overlap.

Table 2. Total nitrogen wastewater point source yield data from seven sewersheds (2005-2009).

	Area and Population			Average Annual Load			Average Annual Yield			
Sewershed	Area[1] acres	Population[2]	Population Density persons/ acre	Municipal pounds/ year	Industrial pounds/ year	Total pounds/ year	Municipal pounds/ acre	Industrial pounds/ acre	Total pounds/ acre	Per Capita pounds/ person
Metro	512,941	1,846,185	3.6	9,971,974	115,180	10,087,154	19.4	0.2	19.7	5.5
Blue Lake	174,126	285,162	1.6	1,308,553	50,248	1,358,801	7.5	0.3	7.8	4.8
Seneca	79,569	244,996	3.1	1,270,979	42,828	1,313,807	16.0	0.5	16.5	5.4
Empire	95,999	149,509	1.6	656,614	101	656,715	6.8	0.0	6.8	4.4
Eagles Point	25,140	71,741	2.9	270,448		270,448	10.8	0.0	10.8	3.8
Stillwater	13,070	27,787	2.1	164,470	33,331	197,801	12.6	2.6	15.1	7.1
Hastings	5,079	20,572	4.1	103,254		103,254	20.3	0.0	20.3	5.0
Average	129,418	377,993	2.7	1,963,756	48,338	1,998,283	13.3	0.5	13.9	5.1

[1]WWTP service areas are derived from the Metropolitan Council sewersheds GIS layer.
[2]Population data derived from the Metropolitan Council Research Group's draft 2010 population data, which is based on 2010 census data.
Note: Sewershed area and population data provided by Metropolitan Council (pers. comm. K. Jensen, E. Resseger, 3/16/2012)

The estimated sewershed area ranges from 5,079 acres (Hastings) to 512,941 acres (Metro) and averages 129,418 acres (Table 2). Overall, sewershed population ranges from 20,572 to 1,846,185 people. The population density of these sewersheds ranges from 1.6 (Blue Lake and Seneca) to 3.6 capita per acre. Of note, the smallest sewershed, Hastings, had the second highest population density. As such, sewershed size does not correlate well with population density.

Wastewater point source TN loading in select sewersheds ranged from approximately 100,000 pounds/year to nearly 10,000,000 pounds/year, most of which was estimated to be from municipal sources (Table 2). The range of loading closely relates to both the size and population of a given sewershed. Total sewershed yield per unit area ranged from 6.8 to 20.3 pounds/acre with an average of 13.9. In most sewersheds the industrial component was minor (0-4%). However, in Stillwater, estimated TN loading from a power plant amounted to 17% of the total area-based sewershed load. Given that the power users extend far beyond the boundaries of the Stillwater sewershed, addition of this industrial load results in an elevated area-based yield that may not accurately depict the urban activity of that particular sewershed area. Nonetheless, the average municipal area-based yield (13.3 pounds/acre) closely resembles that of the average total area-based yield (13.9 pounds/acre), which includes individually permitted industrial dischargers.

Sewershed per capita yield and population density are also important components to consider. TN yield per capita ranges from a minimum of 3.8 pounds/capita (Eagles Point) to a maximum of 7.1 pounds/capita (Stillwater) with an average of 5.1 pounds/capita (Table 2). There were no strong relationships between per capita yield and either total area-based yield (R^2 = 0.21, Figure 7) or municipal area-based yield. This is due, in some part, to Stillwater's high per-capita yield yet moderate area-based yield. In contrast, strong relationships were observed between population density and both total area-based yield (R^2 = 0.80, Figure 8) and municipal area-based yield (R^2 = 0.89, Figure 9).

Sewershed areas may not be readily available for many urban communities, and yet population density data often is. One may estimate municipal area-based yield with population density data of the desired scale. The linear relationship between population density and municipal area-based yield is defined below (Figure 9):

Equation 1:

$$y = 5.3164x - 1.0084$$

Where:
y = municipal point source average annual TN yield (pounds/acre), and
x = population density (capita/acre)

For example, if a community served by a municipal wastewater treatment plant had a population density of 1.9 capita/acre (roughly equivalent to that of the state of New Jersey; U.S. Census Bureau, 2010), the estimated municipal point source annual TN yield equates to 8.9 pounds/acre (Equation 1). Additional industrial load, not serviced by the WWTP could be included as a yield if the total population of concern were known. It is important that the user carefully evaluate the scale of the sewered population that one wishes to represent.

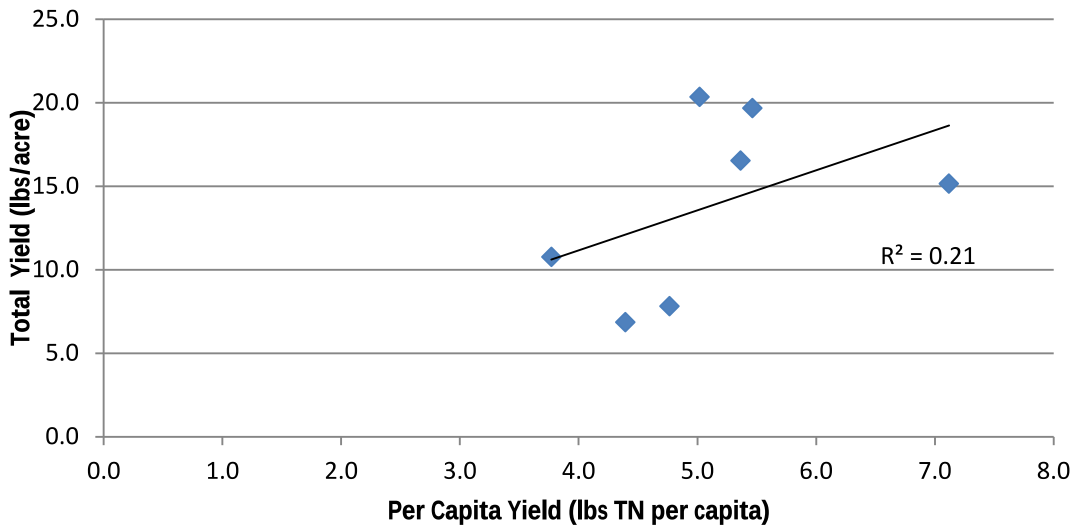

Figure 7. Sewershed point source TN per capita yield versus total area based yield. The total yield includes estimates of both municipal and industrial point source yields calculated from estimated discharges.

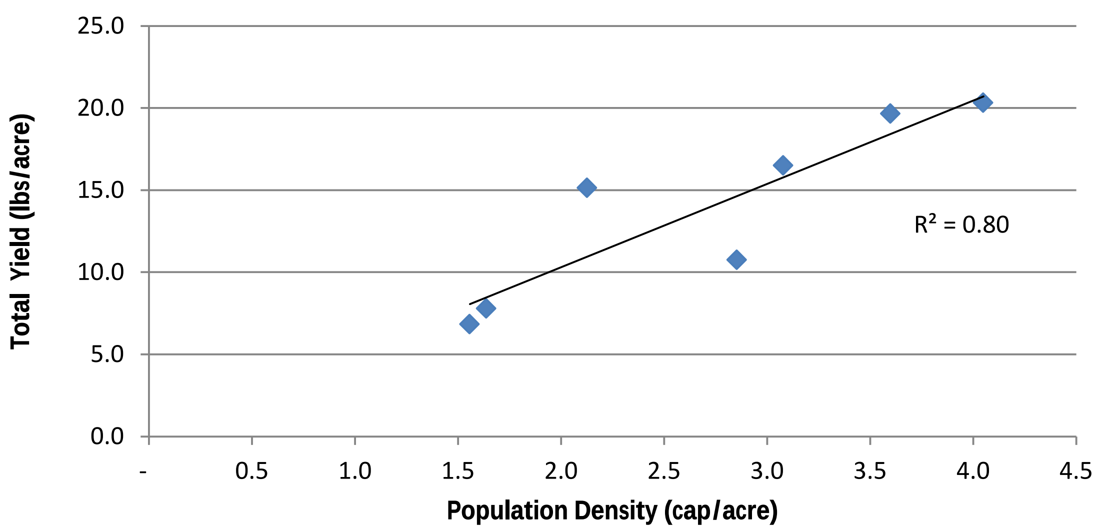

Figure 8. Sewershed population density (cap/acre) versus point source TN area based yield. Total yield includes values from individually permitted municipal and industrial point sources.

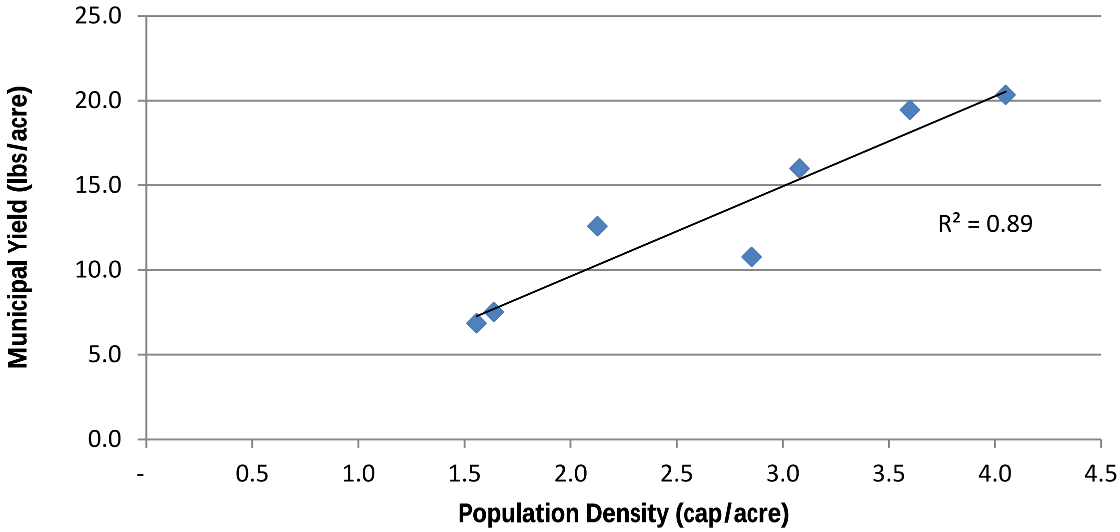

Figure 9. Sewershed population density (cap/acre) versus municipal point source TN area based yield. Municipal yield does not contain values from individually permitted industrial point sources.

Seasonal patterns

Pollutant loading from wastewater point sources is typically assumed to be constant as compared to nonpoint sources. In this section, seasonal patterns of point source TN loading within the Minnesota River Basin (MRB) are examined in greater detail. Although the MRB has a large number of small individual facilities, the mix of facility type and size makes these patterns suitable to be applied to other basins.

In total there are 236 active point sources within the MRB. This equates to 26% of all active dischargers statewide. Together, they discharge an average annual TN load of 4,717,144 pounds/year. Within the MRB 66% (155) of point sources are domestic and 34% (81) are industrial; primarily cooling water discharges. Furthermore, 37% (87) of all active point sources are municipal stabilization ponds. Ponds are often used by smaller communities. Unlike other treatment systems, ponds do not discharge continuously, but rather, store wastewater for extended periods of time and discharge for a few days to weeks within a regulated time slot. In southern Minnesota, including all of the MRB, the acceptable discharge period is in the spring from March 1 through June 15 and in the fall from September 15th to December 31st. In the north, acceptable discharge periods are less restrictive and range from March 1 through June 30 in the spring and September 1 through December 31 in the fall.

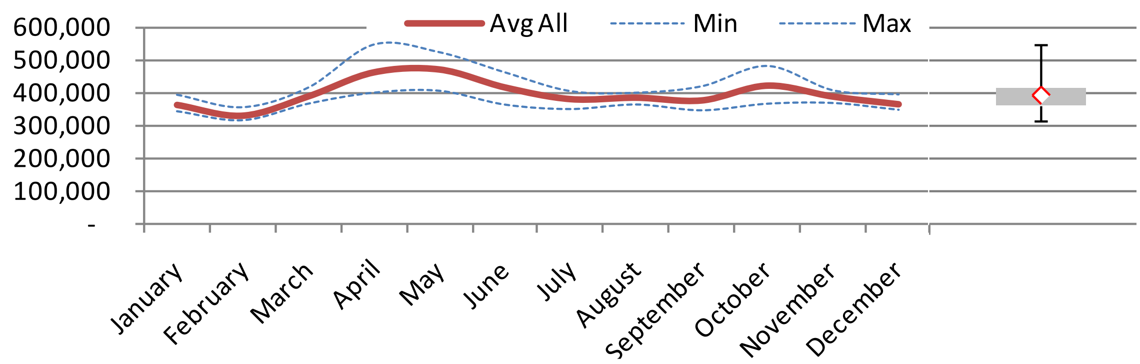

Figure 10. Monthly average point source TN effluent load (lbs) in the Minnesota River Basin (2005-2009). The adjacent box and whisker plot shows the distribution of all monthly values. The grey box indicates the 25th and 75th percentile range. The red diamond represents the mean value; whiskers represent minimum and maximum values.

Five years of monthly average TN data from all active point sources demonstrates a slight seasonal swell in mean loading and an increase in variability (Figures 10 and 11). The median monthly load is 382,265 pounds with a 12% coefficient of variation (Figure 10). The discernible rise in spring (April, May) and fall (October, November) loading coincides with annual precipitation patterns and the pond discharge window. Despite the fact that 37% of point source permits in the MRB are ponds, they only account for 3% of the annual load (Figure 11).

The overall flow volume from these facilities tends to be small. Limited effluent data suggests that the extended detention time in ponds facilitates denitrification. At peak, ponds are estimated to account for 8% (35,529 pounds/month) of monthly load in May and 7% (27,933 pounds/month) in October. This contribution drops to zero from January through March and July through August. In lieu of actual effluent concentration data, ponds are assumed to discharge 6 mg/L TN as compared to larger mechanical facilities which are assumed to discharge between 17 and 19 mg/L. When pond loading is removed from the total, a seasonal load swell is still observed due to increased flow and load from continuous facilities. Therefore, pond effluent only explains a fraction of the seasonal variation; the remainder can be attributed to seasonal precipitation patterns (Figure 11).

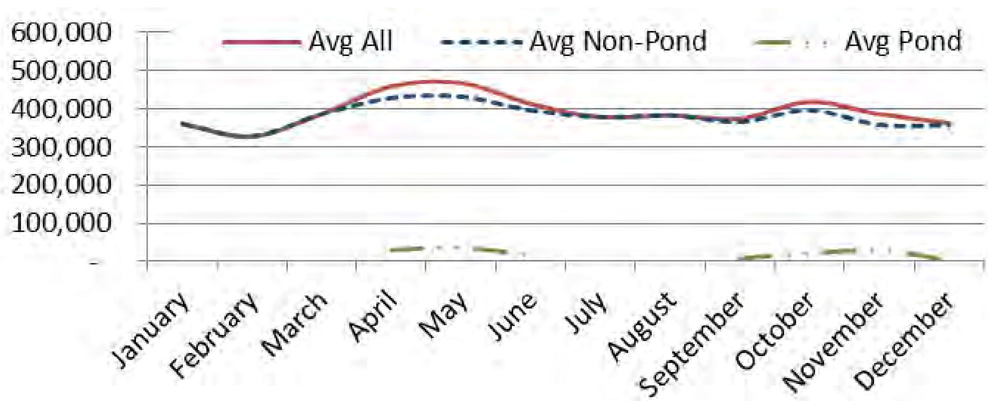

Figure 11. Monthly average point source TN effluent load (lbs) in the Minnesota River Basin (2005-2009). Municipal stabilization pond loads (green dashed), and non-pond loads (blue dashed) are disaggregated from the total monthly load (red solid).

Inflow and infiltration (I/I) of groundwater into municipal collection systems typically increases during storm events and wet seasons. Although many municipal treatment systems were built in the mid twentieth century, the collection systems often date back to the early twentieth century (MPCA 1991). Given the cost and inconvenience associated with maintenance, many of these systems are in need of repair. The remainder of the seasonal load swell, after pond loading is removed, is likely to be due to an increase in I/I. Despite the seasonal change in flow, I/I is generally assumed to have a low TN concentration, thereby resulting in a relatively constant seasonal loading rate. A review of five years of NOx data from over 350 Ohio WWTPs shows an average monthly NOx concentration change of only 3.6 mg/L (Figure 12). In spring, concentrations from all facilities averaged about 9 mg/L NOx, whereas in fall this increased to 12 mg/L. Overall, these data suggest that NOx concentrations remains relatively constant throughout the year. The Ohio data, generally, validate the constant load assumptions made for these load estimates. Effluent data currently being collected by Minnesota dischargers will better inform future analysis.

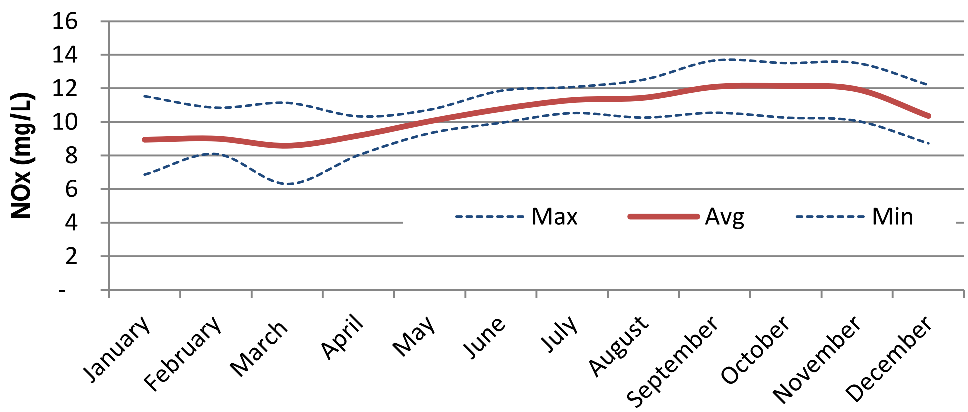

Figure 12. Monthly average NOx from over 350 Ohio WWTPs (2005-2009). Variability is greatest during spring and fall months. The average concentration rises from roughly 9 mg/L in spring to 12mg/L in fall.

Assumptions and methods

Overview

Load estimates were based on five years of discharge monitoring report (DMR) data from 2005 through 2009. At the time of analysis, only a partial year of 2010 data were available, and therefore, these data were not included. Wastewater point source N effluent data in Minnesota are somewhat sparse and coincide with the historical implementation of numeric standards. Ammonia effluent data are, by far, the most abundant. Limits and reporting requirements became more prevalent in the early 1980s. Facilities with ammonia limits generally discharge to low dilution streams or receive waste streams from high protein industries. The direct impact of ammonia from point sources is seasonal and localized. In the summer the combination of ammonia and biological oxygen demand (BOD) can cause a dissolved oxygen (DO) sag that typically occurs 2 to 5 miles downstream of a discharger in an affected stream. In winter, the DO sag typically occurs from between 20 and 30 miles downstream, at which point ammonia and BOD levels return to headwater conditions (MPCA scientist G. Rott, personal correspondence, 6/24/11).

Facilities that report TN, or NO_x either discharge upstream of a biotic life impairment, in which a form of N has been identified as a stressor, or they were found to contribute to a violation of the nitrate drinking water standard (10 mg/L NO_3). Biannual effluent monitoring for TN or NO_x is now being required for all municipal major facilities, which includes municipal point sources with average wet weather design flows (AWWDFs) greater than 1.0 million gallons per day (mgd). Future load monitoring data can be used to refine load estimates and will provide a better understanding of the variability of treatment. It is anticipated that more frequent TN and NO_x monitoring will be required if nitrate toxicity standards are developed for surface waters in Minnesota.

It would have been impractical to estimate facility loads one at a time given the large number of point sources, a five year time frame (2005-2009), and the wealth of flow, and to a lesser extent, concentration data. As such, a database system was designed to select appropriate flow and concentration records based on predetermined conditions and to calculate monthly loads (Figure 13). All DMR records for flow and the four N parameters of concern (TN, NOx, NHx, and TKN) were downloaded from the Delta database, an MCPA repository for regulatory data. No single facility is required to monitor for all four pollutant parameters of interest, so it was necessary to splice in other concentration estimates for each flow record of concern when DMR concentration data were unavailable. Concentration assumptions were either applied to specific facilities identified by permit number, or they could have been applied to a larger category of similar facilities. The success of such a system is based on two factors including: 1) database architecture, and 2) the accuracy of the concentration assumptions and actual data. Additional WWTP effluent data supplied by the Metropolitan Council Environmental Services (MCES) made it possible to test both factors.

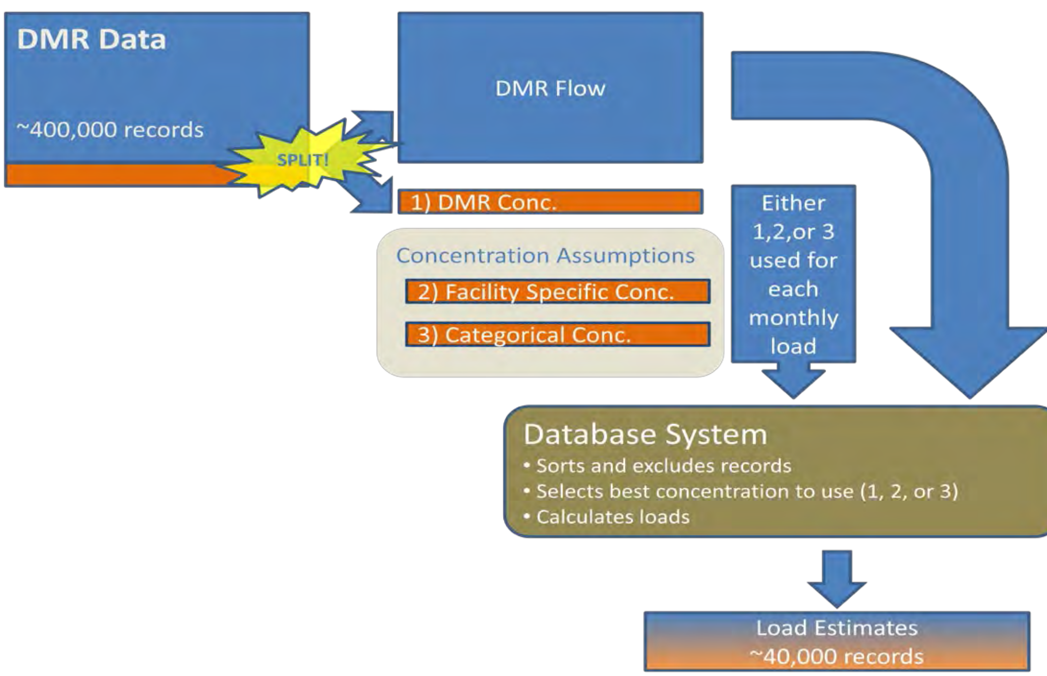

Figure 13. Overview of point source N load estimation process.

Database architecture validation

Database architecture refers to the sequence of conditional statements programmed into the database system used to select desired records and calculate loads. In total, there were nearly 400,000 flow and concentration records statewide. From this larger data dump, only approximately 40,000 records (10%) were used in this study. The remaining records were typically duplicitous and had undesired units, periods of records, or limit types (i.e. maximum, minimum etc.). Mistakes associated with faulty database architecture often result in undesired records selected, and more often, multiple loads calculated for the same time period. When errors of this sort occur, results are often distorted by a factor of two or more.

The MCES Metro facility is currently required to submit monthly average NOx concentration data as part of their DMRs which were, in turn, used to calculate loads within the database system, hereafter referred to as MPCA loads. In order to generate monthly average values, MCES collects sub-monthly NOx concentration samples. Sub-monthly values were used independently by MCES to calculate annual NOx loads, hereafter referred to as MCES loads. By comparing MPCA and MCES loads for the same facility, one can verify that the database architecture functions correctly. In this situation, long term annual average MCES and MPCA loads were only 0.1% different. Results demonstrate that the database architecture is capable of calculating loads correctly for the Metro facility, one of the largest and more complex facilities statewide. Therefore, it is reasonable to conclude that the database system is capable of deriving accurate loads for the hundreds of other point sources given the accuracy of the data and assumptions provided.

Data and assumption validation

Of the eight MCES facilities that discharged between 2005 and 2009, only Metro was required to submit NOx data. Nonetheless, MCES collected NOx samples from the remaining seven facilities for their own records and provided annual NOx loads to MPCA for this study. Long term average annual MPCA NOx loads, derived by the database from concentration assumptions, were only 5% different than MCES loads. It should be noted that these facilities are among the largest point sources in Minnesota. Results demonstrate that the concentration assumptions used in this study, and the resulting load estimates, are reasonable. In the end, MCPA loads were used in this study because they provided a finer resolution monthly estimate which could be used to analyze seasonal load patterns. In summary, point source loads were derived from actual flow and a combination of actual and assumed concentration values. Based on the comparison between MCPA and MCES loads, it is reasonable to conclude that long term average NOx and TN load estimates are within a confidence interval of 5 to 10%.

Concentration assumptions for TKN and NHx are based on a much larger body of DMR data but cannot be validated in the same manner as TN and NOx because the large majority of facilities required to report also have limits. Those without limits have the capacity to discharge at higher concentrations, the magnitude of which is somewhat difficult to estimate without effluent data.

Concentration assumptions

Categorical concentration assumptions were used to estimate most point source N loads (Table 2). Concentration assumptions were based on several sources including: limited DMR data from Minnesota and Wisconsin, additional data from MCES, and a larger database from Ohio. Following a review of available data, facilities and individual outfalls were categorized. Concentration assumptions were then used to calculate loads (Table 2). A review of over 350 WWTPs in Ohio demonstrates that seasonal concentration patterns are limited (Figure 12). Therefore, no seasonal adaptations were built into categorical concentration estimates where actual data were unavailable. The Ohio dataset also demonstrates high variability among pollutant parameters (Figure 14). With the information available, individual Ohio facilities could not be classified into categories for direct comparison with Minnesota facilities. Nonetheless, Ohio data provided another line of evidence for the evaluation concentration assumptions.

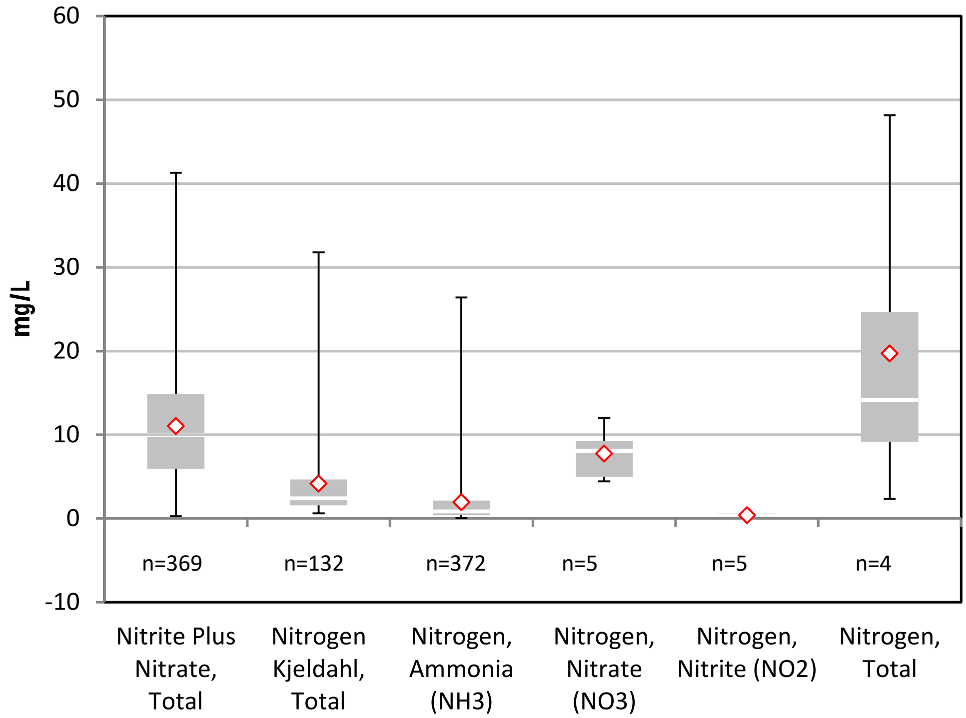

Figure 14.Distribution of effluent concentration data (2005-2009) from over 350 municipal wastewater treatment plants in Ohio. Whiskers represent minimum and maximum values. Boxes represent the interquartile range (25th to 75th percentile). Red squares and white lines represent median and mean values, respectively. Sample size (n) varies considerably among constituent.

Municipal wastewater treatment facilities were divided into four categories, A through D, which were based primarily upon design capacity and also the treatment components. Constituents like NOx have a discernible pattern among municipal categories (Figure 15). Class A larger facilities generally have higher NOx values. This may reflect a higher incidence of N-rich industrial users or possibly a lower proportion of I/I flow as a result of more recent waste collection system improvements. In contrast, smaller facilities (Class B – D) which serve incrementally smaller communities may have a higher percentage of low concentration I/I flow. In addition, most Class D and some Class C facilities are stabilization ponds which have sufficient retention time to facilitate denitrification. The available data suggests that wastewater effluent from stabilization pond dischargers often has NOx values less than 5 mg/L. Nonetheless, effluent variability from all facility classes appears to be high.

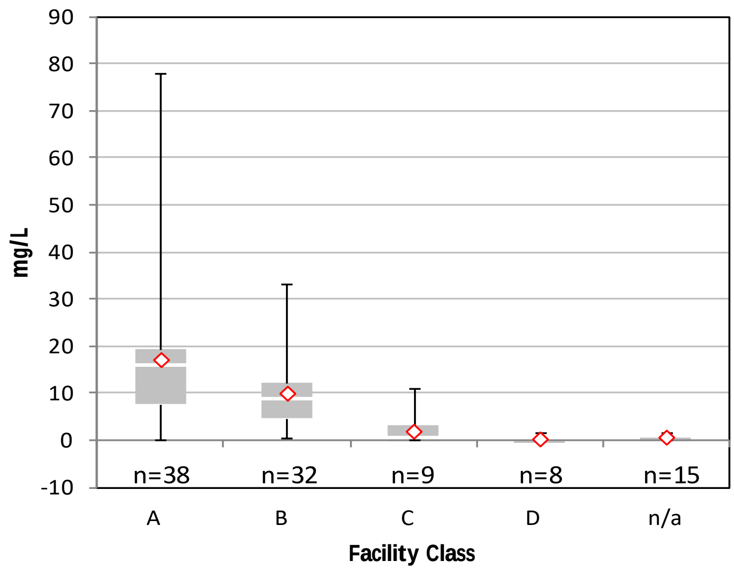

Figure 15. NOx data from municipal wastewater treatement plants in Minnesota (2005-2009). Sample size (n) varies considerably among facility classes.

Categorical concentrations for TKN and NHx were primarily derived from DMR effluent data. In addition, the difference between TN and NOx was also used to estimate TKN categorical concentrations. Class A facilities without DMR data were assumed to have TKN and NHx values of 4 and 3 mg/L, which was based upon existing data from similar classed facilities. For Class B facilities, it appeared that, on average, there was a 7 mg/L difference between TN and NOx, and therefore, it was assumed that TKN was 7 mg/L. Class B NHx was assumed to be 4 mg/L, a bit higher than other groups, due to the wide range of observed effluent data (2-70 mg/L). Class C and D municipals were assumed to have TKN of 3 mg/L and NHx of 1 mg/L. These assumptions were more closely tied to DMR data.

Industrial effluent load estimates were calculated using more facility or industry specific assumptions. As compared to municipal discharges, industrial concentrations were assumed to be moderate to low. In a few cases, two or more categories have identical concentration assumptions. In the event that future data allows for refinements of the assumptions, statewide limits can be quickly recalculated.

Industrial concentration assumptions are generally divided into two categories, high concentration and moderate to low concentration. Four categories of high concentration industrial effluents were identified; paper (P), tile lines (T), peat (PEAT), and other (O). These discharges were assumed to have TN, NOx, TKN, and NHx values of 10, 7, 3, and 2 mg/L, respectively. Paper industry assumptions were based upon data collected at one facility. Pulp rich effluent requires that nutrients, both phosphorus and N, be added to promote bacterial growth and subsequently reduce BOD. Facilities reporting tile line flow are typically draining land on which nutrient rich effluent was spray irrigated. In some cases it may be possible that these tiles are also partially draining adjacent agricultural lands. Assumptions for tile lines to surface water (T) are consistent with United States Geological Survey agricultural research in Iowa and southern Minnesota (Kalkhoff, 2000). Similarly, peat mines typically drain wetlands with the potential to be nutrient rich. As such, assumptions for PEAT were equivalent to those of tile. Assumptions for PEAT can be refined in the future when effluent data become available. The “other” category includes contact cooling water effluent with the potential for contact with N rich sources.

Table 2. Categorical concentration assumptions (mg/L)

Category	General Description	TN	NOx	TKN	NHx
A	Class A municipal - large mechanical	19	15	4	3
B	Class B municipal - medium mechanical	17	10	7	4
C	Class C municipal - small mechanical/pond mix	10	7	3	1
D	Class D municipal - mostly small ponds	6	3	3	1
O	Other - generally very low volume effluent	10	7	3	2
PEAT	Peat mining facility – pump out/drainage from peat	10	7	3	2
T	Tile Line to Surface Discharge	10	7	3	3
P	Paper industry	10	7	3	2
NCCW	Non contact cooling water	4	1	3	2
POWER	Power Industry	4	1	3	2
WTP	Water treatment plant	4	3	1	1
GRAV	Gravel mining wash water	2	1	1	1
GW	Industrial facilities, primarily private ground water well	0.25	0.25	0	0
MN00xxxx	Other individual facility assumptions based on limited data and applied per NPDES preferred ID number	Na	Na	Na	Na

Industrial categories with moderate effluent concentrations include non-contact cooling water, and the power industry (POWER). Both were assumed to use ammonia based additives, and therefore, were assigned categorical TN and NHx values of 4 and 3 mg/L respectively. There are additional challenges when estimating the load from the power industry. Most of the water used is collected from a lake or river, passed through a cooling system once without additional additives, and discharged back to the receiving water resulting in no net load increase. Most facilities use a small amount of groundwater, to which they apply ammonia-containing additives. In order to not overestimate POWER loading, categorical concentrations were only applied to a fraction of total effluent flow corresponding to the volume of groundwater which receives additives, typically 1% of total effluent flow (J. Bodensteiner at Xcel Energy, personal communication, February 3, 2011).

Industrial categories with low effluent concentrations include mine pump out and gravel mine wash water (GRAV) and industrial facilities that primarily use private well water (GW). A review of private well data determined that 75% of commercial industrial wells contained nitrate concentrations of 0.5 mg/L or lower (Kroening, 2011). Only 10% of these wells contained nitrate N concentrations greater than 2.4 mg/L.

Concentration assumptions for a short list of individual facilities, including four fish hatcheries and one small industrial facility, were based upon short-term data collected and stored outside of the MPCA Delta database. The aforementioned industry manufactures explosives, presumably with ammonium nitrate, resulting in NHx concentrations in excess of 40 mg/L. Mining activities that use explosives containing ammonium nitrate may contribute higher TN loads than what was assumed in this study (Environment Canada, 2003). Unfortunately, N effluent data and more detailed information regarding specific mining activities were not available for this study but may be a consideration for future load estimate refinements.

In summary, there is a high degree of confidence in municipal Class A load estimates. Class A facilities have the largest pool of actual concentration data for direct load calculations and from which to base concentration assumptions. In addition, Class A municipals discharge more water than all other groups

(49%, Figure 16). Loads from other categories, particularly industrials, have a lower degree of confidence. However, these lesser categories also typically discharge lower volumes of water, resulting in somewhat insignificant estimated loads on a statewide basis (Figure 16, 17). As more N concentration data become available, load estimates will be more accurate. However, given that we currently have the highest confidence in the largest point source group, additional data in the near future is not likely to significantly change either the magnitude or degree of confidence in load estimates statewide.

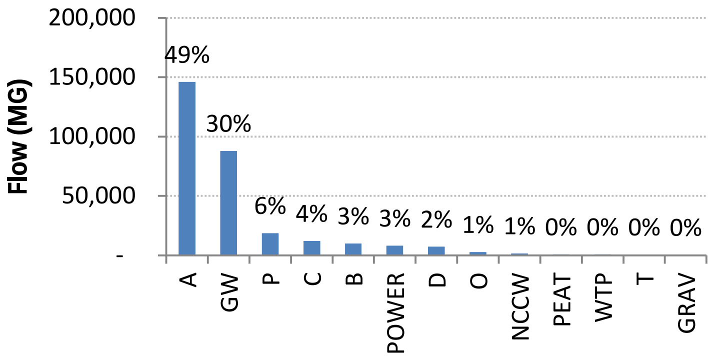

Figure 16. Flow in million gallons (MG) from various groups of point source dischargers statewide.

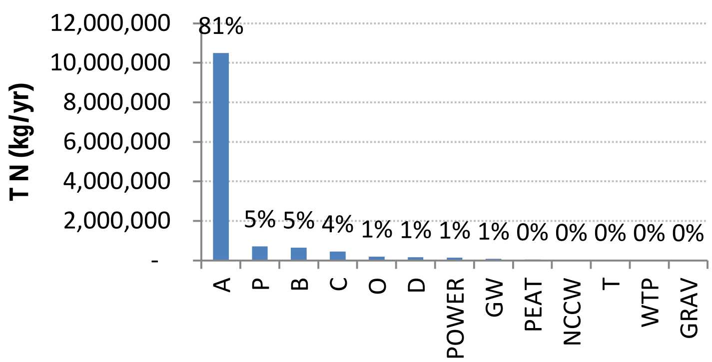

Figure 17. Total nitrogen (TN) loading in kilograms per year (kg/yr) from various groups of point source dischargers statewide.

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D3. Atmospheric Deposition of Nitrogen in Minnesota Watersheds

Authors: Dave Wall and Thomas E. Pearson, MPCA

Background

Emission sources

Atmospheric nitrogen from natural and human sources can fall on to land and waters through both wet weather deposition in rainfall and snow, or through dry weather deposition when particles and vapor are deposited without precipitation. Sources of nitrogen (N) to the atmosphere include, but are not limited to, automobiles, power plants, livestock manure, fertilizers, and lightning.

Providing a national perspective on sources of reactive N to the environment, the U. S. Environmental Protection Agency's (EPA) Science Advisory Board developed N flux estimates from various sources (Table 1). Each area of the country will have different percentages coming from these sources. Cities will have more combustion sources (mostly NOx) and rural areas will often have more livestock and fertilizer sources (mostly NHx).

Table 1. United States N inputs to the atmospheric environmental system in 2002. (EPA, 2011)

Emission inputs	billion lbs N/yr	%
NOX-N emissions*	13.7	61
Fossil fuel combustion – transportation	7.7	
Fossil fuel combustion – utility & industry	4.2	
Other combustion	0.9	
Biogenic from soils	0.7	
Miscellaneous	0.4	
NHx-N emissions*	6.8	31
Agriculture: livestock NH3-N	3.5	
Agriculture: fertilizer NH3-N	2.0	
Agriculture: other NH3-N	0.2	
Fossil fuel combustion – transportation	0.4	
Fossil fuel combustion – utility & industry	0.06	
Other combustion	0.6	
Miscellaneous	0.2	
N2O-N emissions	1.8	8
Agriculture: soil management N2O-N (nitrification and denitrification processes)	1.1	
Agriculture: livestock (manure) N2O-N	0.06	
Agriculture: field burning agricultural residues	0.002	
Fossil fuel combustion – transportation	0.2	
Miscellaneous	0.2	

*NOX-N emissions include nitrate (NO3) and nitrite (NO2), but also include NO, N2O5, HONO, HNO3, PAN and other organo-nitrates. NHx emissions mostly include ammonia (NH3) and ammonium (NH4) (EPA, 2011).

Objective

Our objective was to estimate typical wet and dry atmospheric inorganic N deposition for each of the 8-digit Hydrologic Unit Code (HUC8) watersheds in Minnesota. Our goal was to develop atmospheric deposition estimates for nitrogen falling directly onto a) land, and b) waters. Our objective was not to determine relative amounts of atmospheric N from specific sources, but rather to estimate the combined N deposition from all sources.

It was beyond the scope of this study to estimate how much of the N deposited in Minnesota originates from Minnesota vs. other states/provinces, nor was it within the scope to estimate how much atmospheric N from Minnesota sources is deposited in other states/provinces. We also did not intend to evaluate all of the environmental effects associated with atmospheric N deposition. A brief summary of environmental concerns related to atmospheric N is included in Chapter A2.

Approach

The primary approach was to use results from atmospheric deposition modeling conducted by the EPA, and cross-check these results using wet weather monitoring results from the National Atmospheric Deposition Program.

Modeling results for wet and dry N deposition were provided by EPA (Dennis, 2010). The model used by EPA was the Community Multiscale Air Quality (CMAQ) modeling system, which is described in Byun and Schere (2006). The model includes components for meteorological atmospheric states and motions, emissions from natural and man-made sources, and chemical transformation and fate after being injected into the atmosphere. The CMAQ model uses precipitation monitoring results from the National Atmospheric Deposition Program (NADP), and then adds N source information to improve spatial estimates of wet deposition and to model dry deposition amounts.

The modeled results provided by EPA for this study included wet and dry deposition of both oxidized (mostly nitrate and nitrite, but also include NO, N_2O_5, HONO, HNO_3, PAN and other organo-nitrates) and unoxidized (mostly ammonia and ammonium) forms of N. The N source estimates are from a 2002 base year inventory. The dry deposition is not expected to vary appreciably from year to year, unless major new sources are added or removed, and wet weather deposition can be expected to vary linearly with increases or decreases in precipitation (Dennis, 2011).

Atmospheric nitrogen deposition (per acre)

Statewide and major basin average nitrogen deposition

Basin and statewide averages of modeled dry and wet weather deposition are shown in Table 2. On average across the state, wet weather deposition accounted for 52% of the total atmospheric N deposition, and dry deposition accounted for 48% of the total. The unoxidized fraction represented 62% of the wet plus dry N, with 38% in the oxidized form. The statewide average inorganic N deposition (wet plus dry) is 8.4 pounds/acre/year.

Table 2. Minnesota basin and statewide spatially weighted averages of wet and dry atmospheric N deposition in pounds/acre based on CMAQ model results for the 2002 base year. Low and high precipitation represent 10th and 90th percentile annual precipitation amounts.

Basin	Oxidized wet	Unoxidized wet	Oxidized dry	Unoxidized dry	Avg. precip. yr total N wet + dry	Low precip. yr Total N wet + dry	High precip. yr total N wet + dry
Lake Superior	1.30	1.97	1.80	0.48	5.55	5.03	6.21
Upper Mississippi River	1.72	2.97	1.71	2.28	8.67	7.92	9.61
Minnesota River	1.86	3.31	1.59	4.38	11.14	10.31	12.17
St. Croix River	2.15	3.45	2.02	1.37	9.00	8.10	10.12
Lower Mississippi River	2.68	4.12	2.15	4.25	13.20	12.12	14.57
Cedar River	2.23	3.51	2.02	4.67	12.44	11.52	13.58
Des Moines River	1.77	3.17	1.57	4.81	11.32	10.53	12.31
Red River of the North	1.09	2.10	1.19	2.06	6.44	5.93	7.08
Rainy River	1.04	1.70	1.43	0.57	4.75	4.31	5.29
Missouri River	1.63	3.04	1.55	5.25	11.47	10.72	12.40
MN - Statewide	1.59	2.72	1.59	2.49	8.40	7.71	9.26

Watershed deposition amounts

Because there is substantial spatial variability across the state in atmospheric N deposition, modeled results for each HUC8 watershed were individually calculated based on a spatial average across each watershed (Appendix D3-1 - Table 1). The pattern of deposition shows higher deposition rates in the southern part of the state, where agriculture, urban, and other human sources are more common (Figures 1, 2, and 3). Inorganic N amounts varied from over 14 pounds/acre in the southern part of the state to just over 4 pounds/acre in the northeastern region, during years of average precipitation.

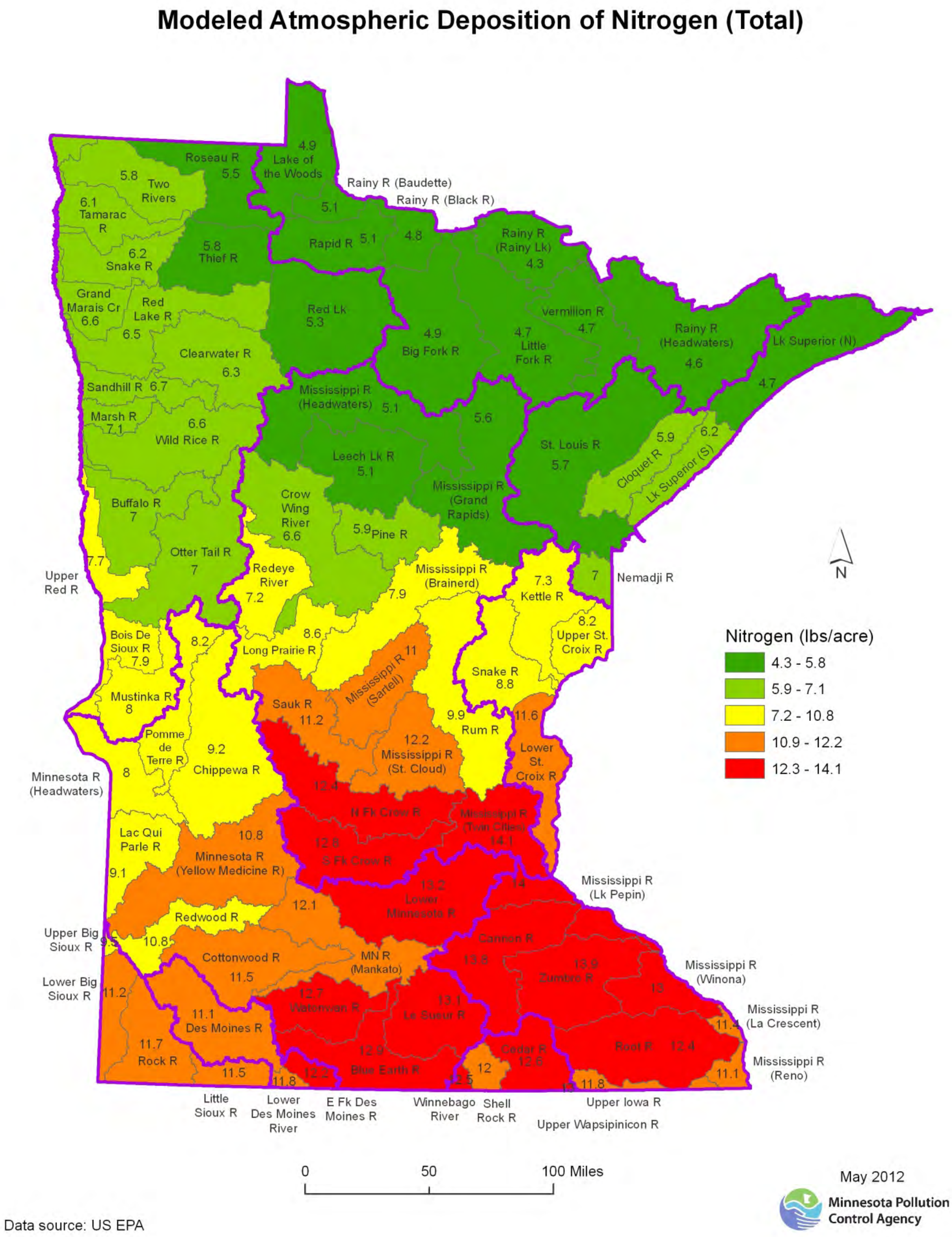

Figure 1. Total annual inorganic N deposition estimated by the CMAQ model, including both wet and dry deposition.

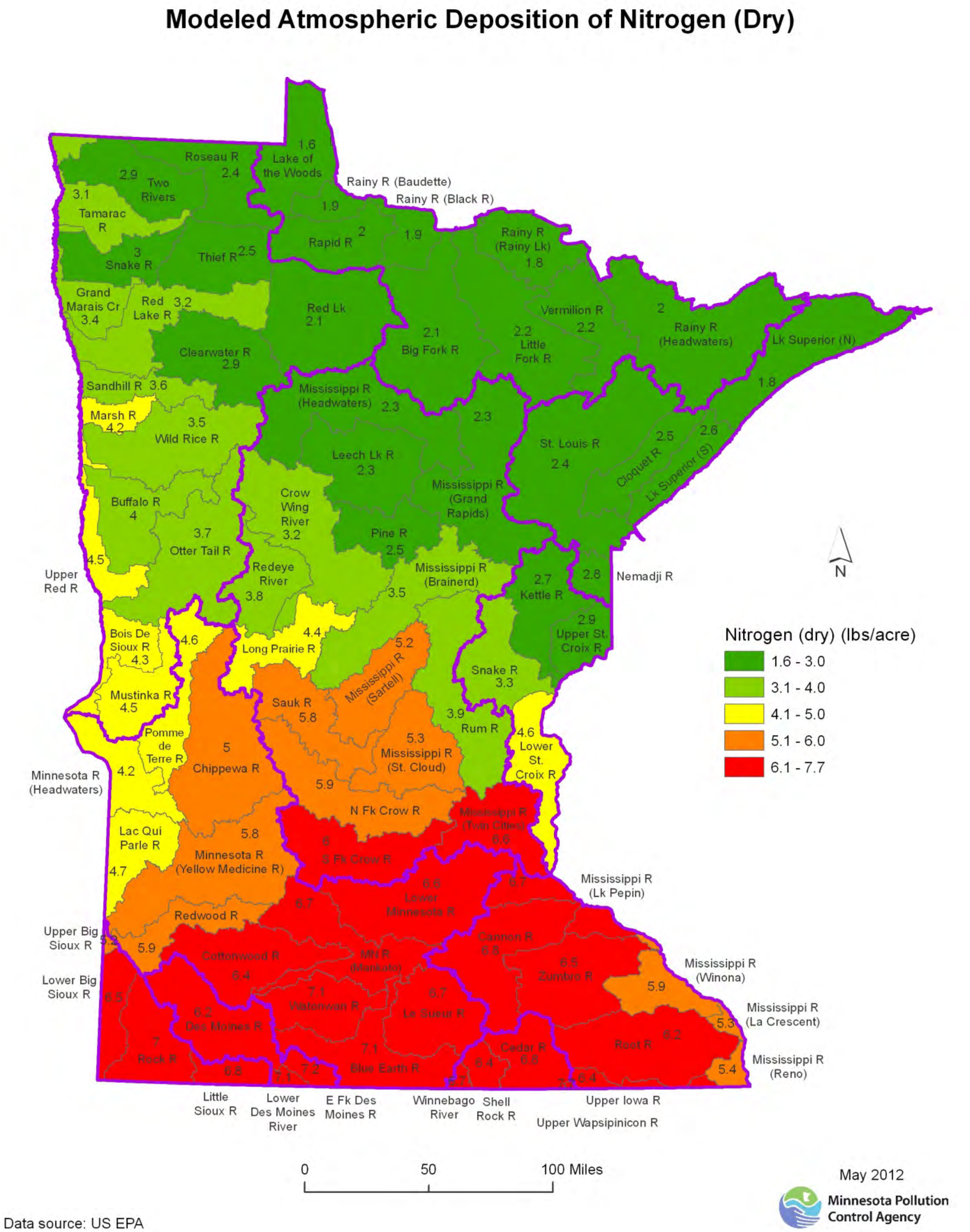

Figure 2. Total annual inorganic N *DRY* deposition estimated by the CMAQ model, and spatially averaged across the HUC8 watersheds.

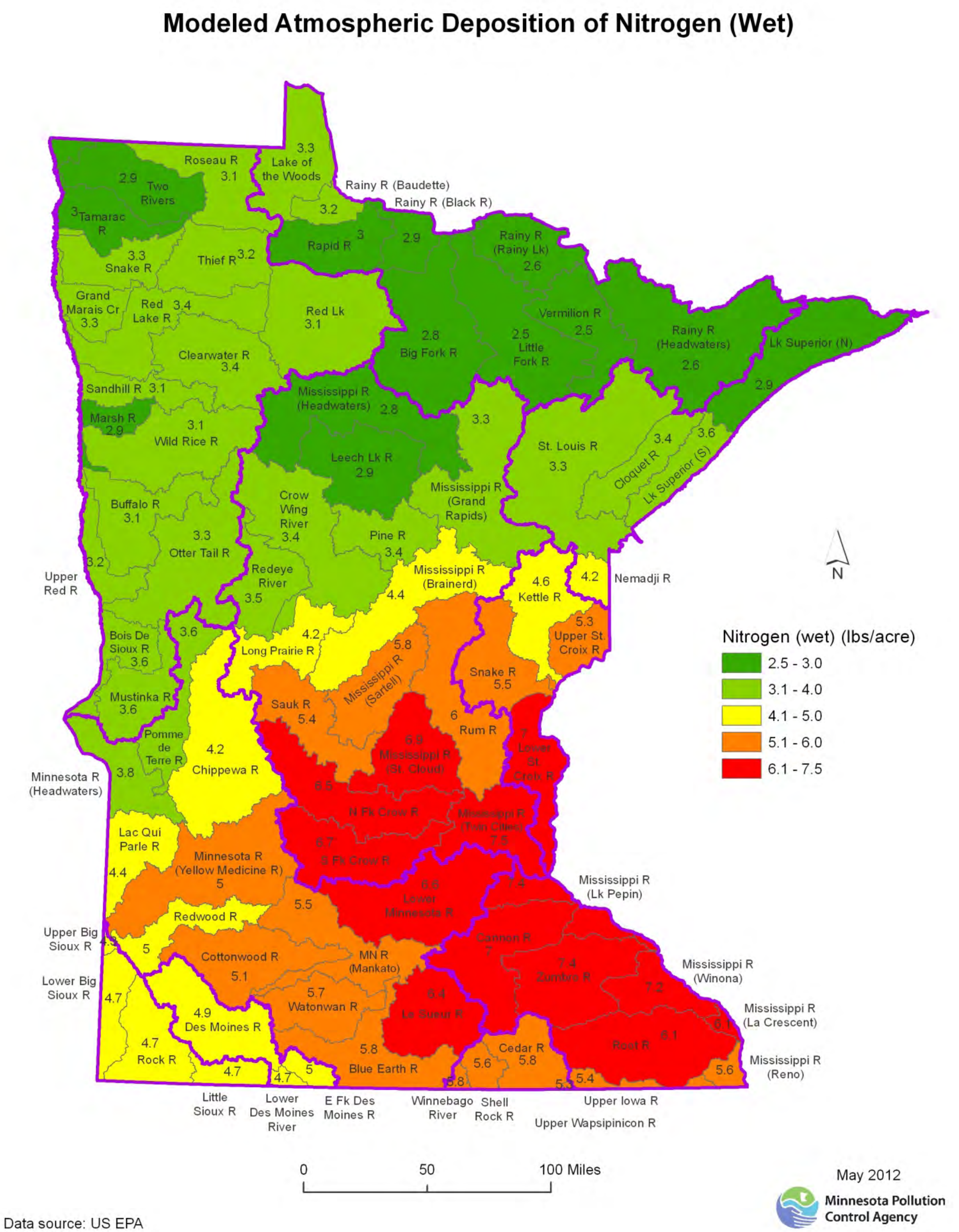

Figure 3. Total annual inorganic N *WET* deposition estimated by the CMAQ model, and spatially averaged across the HUC8 watersheds.

Direct deposition into waters

Most of the atmospheric deposition of N falls on land, where it mixes with the soil to be a source of N for vegetation, or in some situations becomes part of the surface runoff nutrient losses. Yet some falls directly into waters. We used spatial data layers and GIS software, along with CMAQ modeled results, to estimate the amount of N which falls during average precipitation years onto a) dry land, b) wetlands and marshes, c) lakes, and d) rivers and streams.

Calculation of surface water area

To calculate the surface area for rivers, we used three classes of streams within the high resolution 1:24,000 scale National Hydrography Dataset (NHD) including stream/river, canal/ditch, and connector. We then ran the intersect command in ArcGIS 10 (ESRI, 2010) using the NHD and the Minnesota Department of Natural Resources (DNR) HUC8 watershed data layer. We used the summarize command in ArcGIS to sum the total stream length for each watershed. We then multiplied the total stream length values by the average estimated width value of seven meters to obtain a final estimate of stream surface area.

For lake surface area calculations, we considered using the high resolution NHD but found numerous errors in the dataset, and we felt that the medium resolution 1:100,000 scale NHD would provide a more accurate assessment. We calculated surface area for lakes using two classes of water bodies within the medium resolution NHD including lake/pond and reservoir. We ran the intersect command in ArcGIS using the NHD and the DNR HUC8 watershed data layer. We then used the summarize command in ArcGIS to sum the total lake area for each watershed.

To calculate surface area for wetlands, we considered using the high-resolution NHD, but the primary wetland class, swamp/marsh was not populated for this data layer. We also considered using the National Wetlands Inventory (NWI), however this dataset for Minnesota is dated, it was developed circa 1980, and it is our understanding that the accuracy of wetlands in the medium resolution NHD is better than the NWI. Therefore, we calculated surface area for wetlands using the swamp/marsh class in the medium resolution NHD. We ran the intersect command in ArcGIS using the NHD and the DNR HUC8 watershed data layer. We then used the summarize command in ArcGIS to sum the total wetland area for each watershed.

Results – into waters

Based on this assessment, 374 million pounds (82.5%) of inorganic N falls onto land in Minnesota and 79 million pounds (17.5%) falls directly into lakes, marshes, wetlands and rivers. For wet and dry years, these amounts would be expected to average about 10% lower and higher, respectively, across the state. Of the N falling directly into waters, over 97% falls into lakes and marshes, which have a high capacity for assimilating and reducing N levels (see Appendix B5-2). About 2.1 million pounds, or 2.5% of the total falling into waters, falls directly into rivers, streams, and creeks. Specific annual estimated amounts falling directly into waters in different basins and HUC8 watersheds are included in Table 4 and Table 2 in Appendix D3-1.

For the statewide source assessment comparison of N into lakes and streams from major sources (Chapter D1), we used the atmospheric deposition into rivers and lakes and did not include deposition into wetlands and marshes. Wetlands can remove large quantities of nitrogen (see Appendix B5-2), and most atmospheric deposition falling into wetlands is not expected to leave the wetlands and move into streams, rivers or lakes.

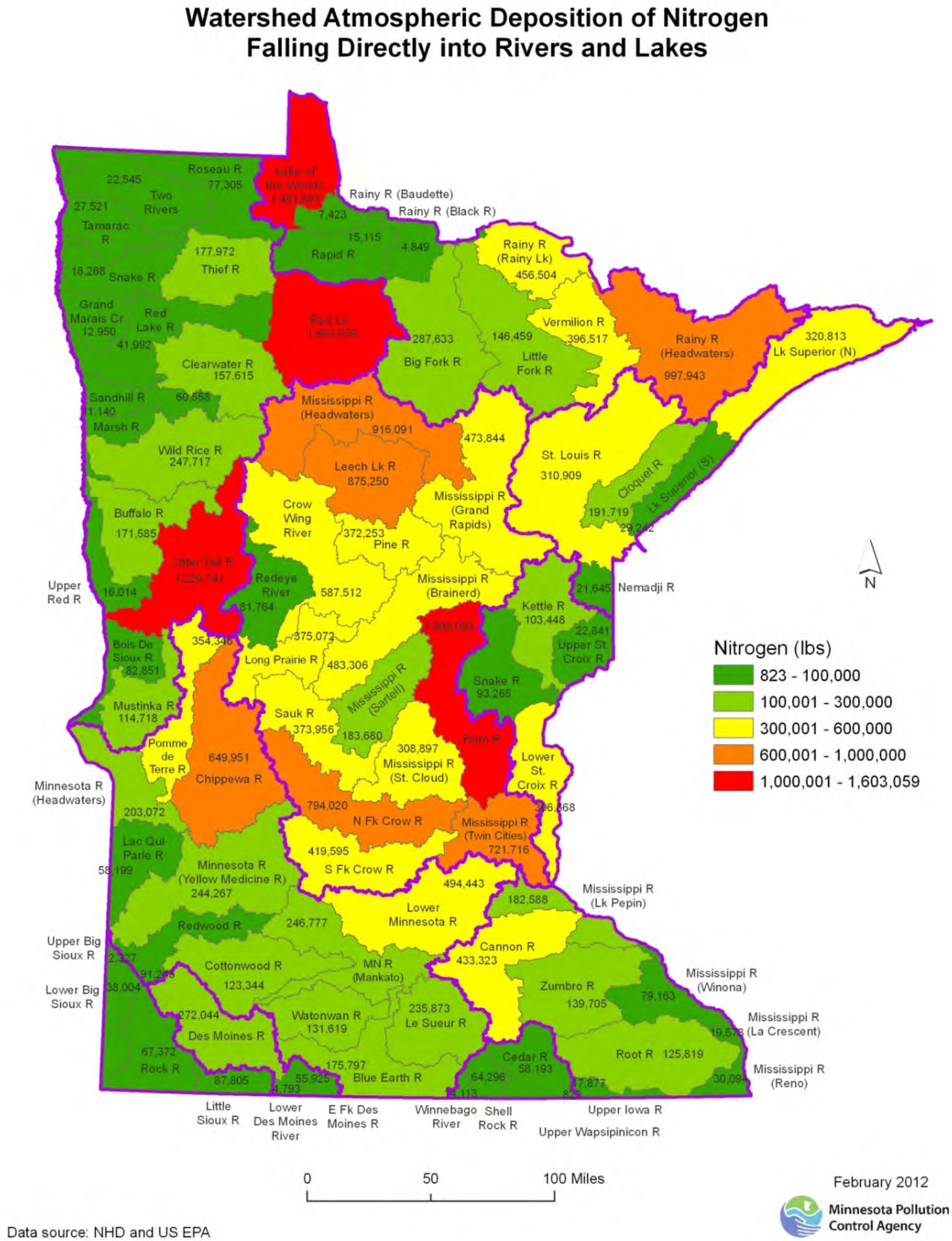

Figure 4. Estimated annual amount of wet plus dry oxidized and unoxidized inorganic N falling directly into rivers and lakes in each HUC8 watershed (note that this does not include wetland deposition).

Table 4. Atmospheric deposition estimates of wet+dry inorganic N falling directly into rivers and streams, marshes/wetlands, lakes, dry-land, and the total onto all land and waters. Results are shown for each of the major basins in the state.

Basin	Rivers	Marsh	Lake	Land	Total
Lake Superior	97,525	4,761,219	812,006	16,166,410	21,837,160
Upper Mississippi River	401,053	12,780,788	8,955,538	89,432,276	111,569,654
Minnesota River	553,936	757,661	2,640,104	102,810,198	106,761,900
St. Croix River	80,860	2,913,266	474,632	16,777,994	20,246,753
Lower Mississippi River	435,344	345,523	576,129	51,859,283	53,216,278
Cedar River	44,561	47,015	94,418	8,091,877	8,277,871
Des Moines River	57,190	36,554	275,639	10,770,989	11,140,371
Red River of the North	328,772	7,720,136	3,974,825	60,896,642	72,920,375
Rainy River	108,812	10,834,347	3,722,212	19,651,106	34,316,476
Missouri River	112,501	7,413	82,828	12,881,475	13,084,217
MN - Statewide	**2,220, 553**	**40,203,921**	**21,608,332**	**389,338,250**	**453,371,055**

Comparing modeled results with wet deposition measurements

Wet weather deposition data from the NADP were compared to CMAQ-modeled results. We accessed the NADP on-line data base nadp.sws.uiuc.edu/ to obtain inorganic N (nitrate+nitrite-N plus ammonium-N) deposition information for sites in and near Minnesota. Our search was limited to those sites for which deposition information was available for each year between 1999 and 2009. Eight Minnesota locations met these criteria. We combined the Minnesota results along with information from monitoring locations in Iowa, Wisconsin, South Dakota, and North Dakota.

We used data from 24 monitoring sites in Minnesota and neighboring states together with a kriging method in ArcGIS to create an interpolated spatial data layer of mean annual wet weather inorganic N deposition amounts (1999 to 2009). We then used this interpolated data layer together with a zonal statistics method in ArcGIS to calculate the average annual deposition amount, in pounds per acre, for each HUC8 watershed in Minnesota. Results from this process are shown in Figure 5, which shows the average wet weather inorganic N deposition from Minnesota based on the interpolated NADP data.

The pattern of deposition determined from precipitation monitoring is very similar to modeled results using CMAQ (Figure 5), with higher amounts in the southern part of the state and lowest amounts in the north. The CMAQ results estimate slightly higher wet weather deposition in the southeast and central Minnesota and slightly lower deposition in the northeast, as compared to the NADP-based estimates. However, the results are similar enough to provide assurance in the reasonableness of CMAQ results provided by the EPA.

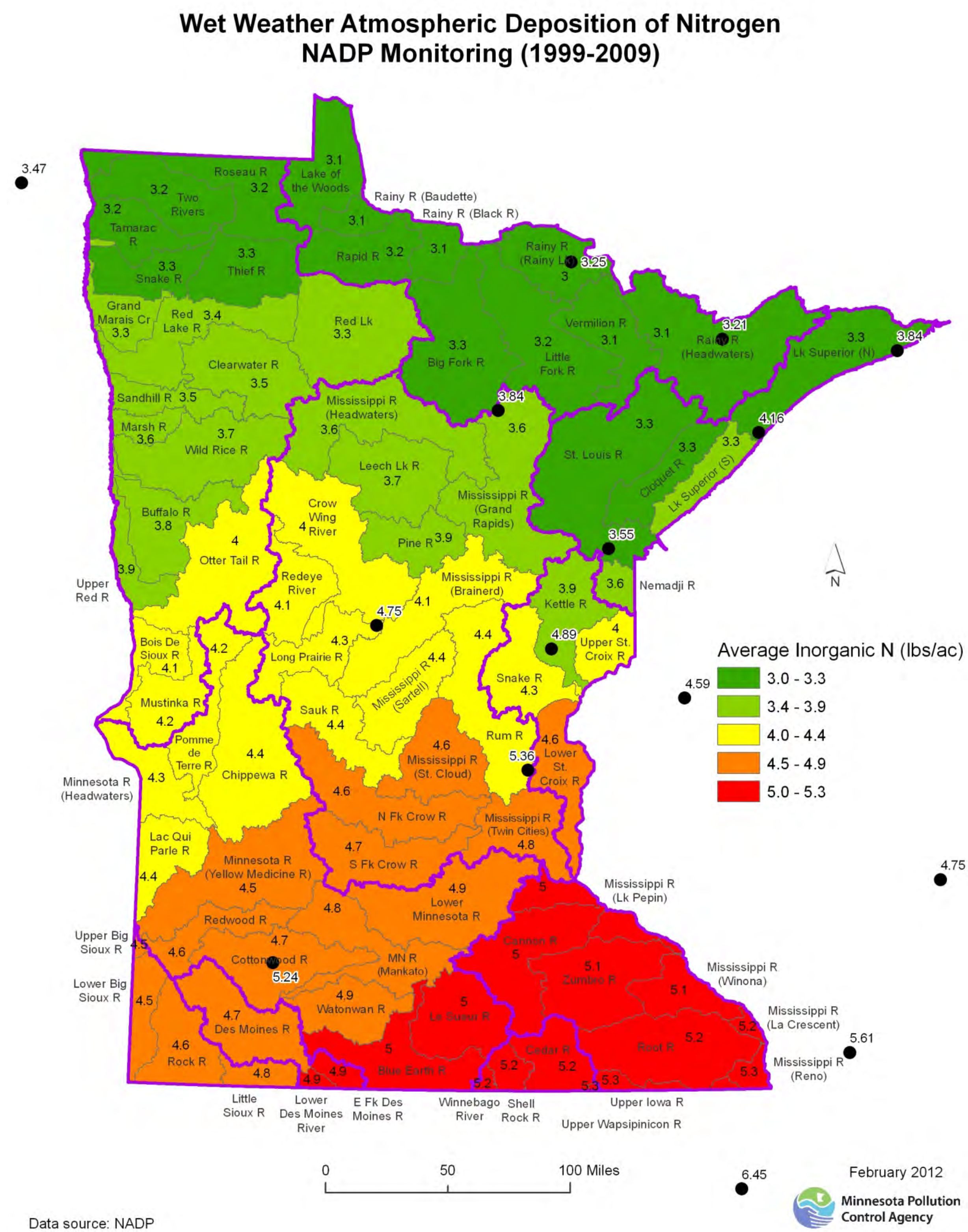

Figure 5. Inorganic N monitored from wet weather deposition (average between 1999 and 2009). Data source NADP. Amounts between monitoring points (triangles) were interpolated.

Organic nitrogen

Organic N deposition is not included in the CMAQ modeled results. Organic N deposition is likely to contribute to atmospheric deposition total nitrogen inputs, although the magnitude of the deposition rate is highly uncertain. Goolsby et al. (1999) noted that if the fraction of organic N/total N in wet deposition measured in a 1998 study by Scudlark is assumed to be similar to the fraction that occurs in the Mississippi Basin, wet deposition of organic N in the Mississippi Basin can be estimated as 25% of the total wet deposition. The EPA concluded from the literature that organic N can be about 10% as much as the NOx from atmospheric deposition, but could be as much as 30% (EPA, 2011). This would mean that the organic N deposition likely represents an additional 4% to 13% of the total wet and dry inorganic atmospheric deposition.

With limited information and no modeled results, along with the relatively small expected contribution from organic N, we did not include an organic N amount in the predicted atmospheric deposition for this study.

Summary

Based on the Community Multiscale Air Quality-modeled results provided by the EPA, wet plus dry atmospheric inorganic N deposition contributes between 4 and 14 pounds annually per acre to Minnesota soil and water, averaging 8.4 pounds/acre/year across the state. Atmospheric deposition is highest in the south and southeast parts of the state and lowest in the north and northeast where fewer urban and agricultural sources exist. The annual wet and dry deposition amounts are nearly equal, on average, across the state. The inorganic N in wet plus dry deposition is about 62% unoxidized (NHx – mostly ammonia and ammonium) and 38% oxidized (N0x - nitrite, nitrate, other). Approximately 82.5% of total statewide inorganic N deposition falls onto land (374 million pounds), and 17.5% (79 million pounds) falls directly into lakes, marshes, wetlands, and flowing waters. Of the N falling directly into waters, 97.5% falls into lakes and marshes, and about 2.5% (2.1 million pounds) falls directly into rivers, streams, and creeks.

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D4. Nonpoint Source Nitrogen Loading, Sources, and Pathways for Minnesota Surface Waters

Authors: David J. Mulla, Jacob Galzki, Karina Fabrizzi, and Ki-In Kim, University of Minnesota, and Dave Wall (MPCA)

Introduction

Nonpoint source nitrogen (N) loading to Minnesota Surface Waters was estimated for the primary N sources, including cropland, urban/suburban nonpoint sources, forested areas, and feedlots. Pathways for cropland sources were divided into three parts: 1) cropland runoff, 2) tile drainage, and 3) leaching to groundwater which subsequently flows into surface waters. Nitrogen from these sources was estimated for average, wet, and dry precipitation years at the watershed, major basin, and statewide scales.

A cropland soil N balance was also conducted as a separate and distinct element of this study. The cropland balance provided estimates of the N inputs and outputs to the cropland soil. The balance was not used to calculate cropland N sources or delivery to surface waters. Yet certain elements of the N balance, such as fertilizer and manure additions, were also used to estimate N losses to surface waters.

Project goals

- Assess soil N budgets (N additions to soil and losses from soils) for combinations of soils, climates and land uses representative of the most common Minnesota conditions.
- Assess N contributions to Minnesota rivers from each of: a) the primary land use sources (excluding point source municipal and industrial), and b) the primary hydrologic pathways.

Materials and methods

Study area

Minnesota has diverse climatic factors, land use, land cover, soil and geologic materials, and landscapes. In addition, the density of permanent streams, drainage ditches, and lakes varies across the state. This diversity affects water quality and water quantity. It also affects the types of crop and animal production systems and their associated suite of management practices. Mean annual precipitation varies from less than 20 inches in the northwestern part of the state to over 34 inches in the southeastern part of the state. Soil parent material and geologic materials at the land surface include alluvial, outwash, peat, glacial moraine, glacial till, and lacustrine materials. The soils and their associated landscapes range from flat to steep in slope, and from poorly drained to well drained. This combination helps determine the potential for runoff, leaching and the likelihood of artificial drainage and losses of nitrate-N to surface waters.

The diverse range in Minnesota climate, soil and landscapes, and land use/land cover can be broadly described using the concept of agroecoregions (Figure 1), which is defined further in Brezonic et al. (1999). Agroecoregions are units having relatively homogeneous climate, soil and landscapes, and land use/land cover. Agroecoregions can be associated with a specific set of soil and water resource concerns, and with a specific set of management practices to minimize the impact of land use activities on soil and water resource quality.

Land use in Minnesota includes urban areas, forest, forested wetlands, wetlands, agriculture, and barren rock. Land use associations include agriculture, forest, agriculture-forest, forest-wetlands-agriculture, forest-wetlands, and urban-agriculture. Agricultural uses include both crop and animal production. Crop production is diverse, major crops considered for the study include corn, soybeans, wheat, hay, potatoes, sugar beets, oats, and barley. The main cropping production systems include corn-soybeans, corn-soybeans-hay, corn-hay, wheat-hay-mixed, wheat-soybeans-mixed, and hay. Animal production systems include cattle-hogs, cattle-hogs-turkeys-chickens, cattle-poultry, and hogs-cattle, and cattle. If not properly managed, N contained in the manure produced by these animals may pollute the atmosphere, or surface and groundwaters.

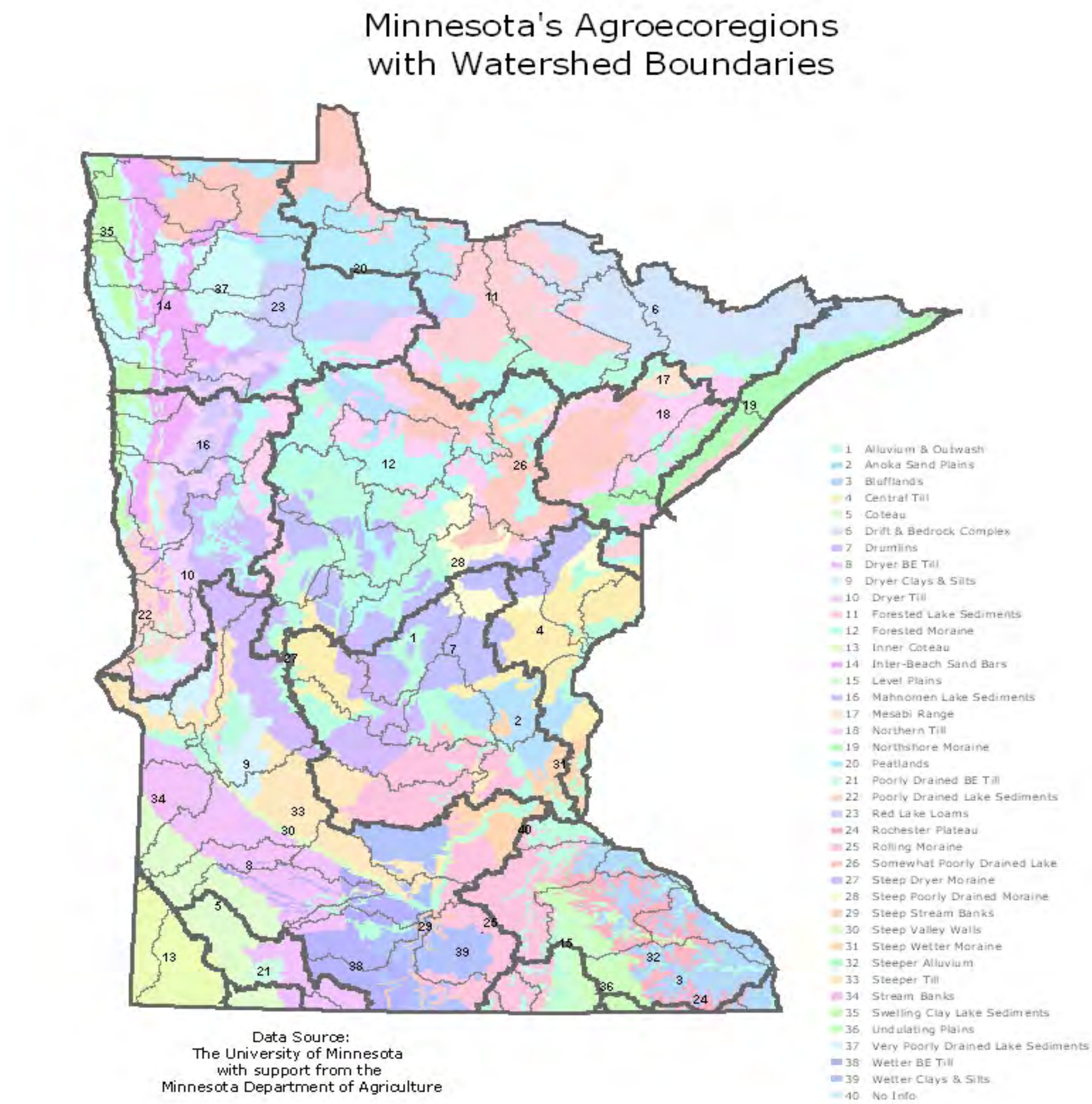


Figure 1. Minnesota's agroecoregions with basin and major watershed boundaries.

Methods overview

Two separate methods were used for two distinct purposes within the scope of this project. First, a statewide cropland N budget (or balance) was developed so that specific inputs and outputs to the cropping system could be estimated. Since inputs should roughly equal outputs, comparing the sum of the inputs with the sum of the outputs provides one way to check the estimates. One of the N outputs is an estimate of the amount of cropland N inputs which reach surface waters. This output was determined through the second project objective, and then was also used to complete the N balance.

The second objective was to determine the amount of N that reaches surface waters from all nonpoint sources, including cropland, urban/suburban, septic systems, and forest. The goal was to also break down cropland sources to waters into the three major pathways, tile drainage, groundwater and surface runoff. While some of the information from the cropland N budget was used for the nonpoint sources estimates, most of the information came from information sources separate from the N balance study. The specific methods for each of these two project objectives are described below.

1: Cropland nitrogen balance methods

The approach used to carry out this mass-balance of the state of Minnesota was to compile the information necessary for each component to the balance individually, and then assemble all of these components in a format that would be both easy to interpret, as well as accessible, for changes in the future when updated information becomes available. The fluxes included were chosen based on their implicit importance within the boundaries of the study area, as well as the availability of sufficient information and methods to confidently include them.

An N balance was estimated for the cultivated cropland component of this study. Forest, urban/suburban and septic system inputs and outputs were not considered in the N balance, but N export to surface waters for these sources was considered separately. Ideally, N inputs and outputs should be equal in the N balance. The inputs represented in this balance include mineralization minus immobilization (net mineralization), symbiotic and non-symbiotic fixation, inorganic fertilizer, atmospheric deposition, animal feed, and planted seeds. The outputs include tile drainage and runoff, denitrification, leaching to groundwater, crop senescence, fertilizer volatilization, crop removal, milk, eggs, and animal slaughter. The two fluxes considered internal to this balance are a portion of the harvested crops that are fed to livestock and the livestock manure that is returned to the fields (Figure 2).

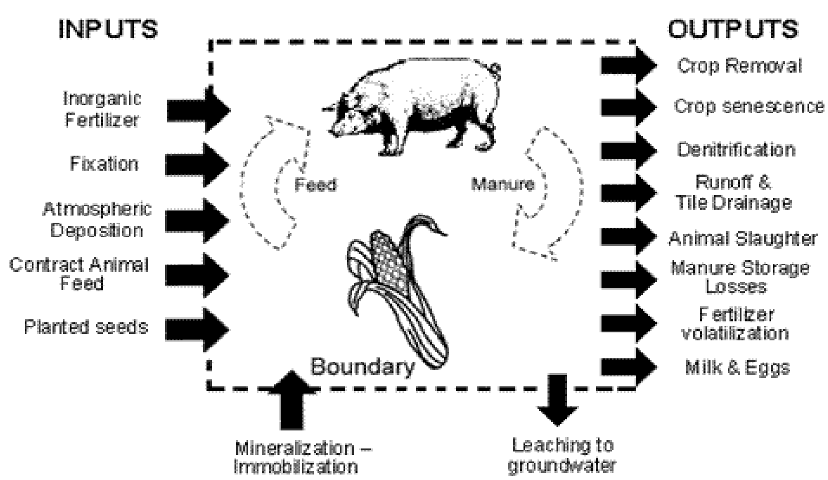


Figure 2. Nitrogen balance used to evaluate the N use efficiency in the state of Minnesota (extracted from Stuewe, 2006).

Area in various land uses (forest, urban) and major crops were determined for each agroecoregion based on 2006 National Land Cover Database land use coverages. (NLCD, 2006).

Harvested crop area for each agroecoregion was determined using a five year average (2005-2009) of data from the National Agricultural Statistics Service (USDA-NASS, 2011) for the following crops: corn, soybeans, spring wheat, barley, oats, sugarbeet, potatoes, alfalfa. For corn silage and other hay, a weighted average was reported (USDA-NASS-CDL, 2009). Total cultivated area was the sum of all harvested crop area.

Nitrogen inputs

The estimated N balance and specific inputs and outputs were not used to estimate nitrogen loads to surface waters, except that fertilizer and manure inputs were used for certain elements of the cropland source pathway estimates. The balance provides a framework for understanding the cropland soil N sources and processes, but is not used to attribute N contributions to surface waters.

Planted seeds

Corn and soybean growers in the Midwest annually purchased seeds from seed dealers. This annual purchase represents an input of N into the system that needs to be estimated and included in the N balance. It was assumed that 0.34 kg N ha^{-1} and 4.5 kg N ha^{-1} (0.3 lb N ac^{-1} and 4.0 lb N ac^{-1}) are contained in the seeds planted for corn and soybeans, respectively (Meisinger and Randall, 1991). For barley, oats, spring wheat and potatoes, planted N seed (lb) was calculated as following:

N seeds (lbs N/ac) = seeding rate/ac * N content (%) in the seed

Planted seeding rates were 80, 80 and 133 lb ac^{-1} for barley, oat and spring wheat (MAES, 2006). Nitrogen content was 1.86%, 3.5% and 2.6% for barley, oat, and spring wheat (Sims et al. 2002, Pan and Hopkins, 1991, Hofstetter, 1988). Thus, the estimated planted N seed was 2, 2.3 and 3.9 pounds ac^{-1} for barley, oat, and spring wheat respectively. Nitrogen content in the potatoes was estimated at 23.4 pounds N ac^{-1}, using N content of 1.608% and 1.648% for tubers and vines (Rosen et al. 1999). Estimates of the N contained in alfalfa seeds, other hay and sugar beets were not included. Total planted N seed was calculated as:

Planted N seed (lb) = Σ(harvested crop area (ac) * N seeds (lb ac^{-1})

Atmospheric deposition

Atmospheric N deposition comprises both wet and dry depositional processes, and includes all oxidized and reduced forms of N, including NO_3 and NH_4. Total atmospheric deposition rate was area-weighted for each agroecoregion (EPA, 2011; Byun and Schere, 2006), as described in more detail in MPCA, 2012. Atmospheric deposition represents an average over many climatic years.

Symbiotic nitrogen fixation

Symbiotic and non-symbiotic fixations were included in this balance. In symbiotic fixation, specialized root-nodule bacteria attached to leguminous plants and converts N_2-N from the atmosphere into N compounds that are taken up by the plant (Graham, 1998). Non-symbiotic fixation is essentially the same process, but the soil bacteria carrying out the process are free living and unattached to a leguminous host plant (Meisinger and Randall, 1991).

The symbiotic fixation rates used in this balance are reported in Table 1. The total land area over which these fixation rates were applied includes the harvested acres of soybean, alfalfa, and grass/legume crops (USDA-NASS, 2011, USDA-NASS-CDL, 2009).

The non-symbiotic N fixation estimates made for this balance are based on Meisinger and Randall (1991) and a rate of 2.2 kg N ha^{-1} (2 lb N ac^{-1}) was applied to all of the harvested cropland area.

Table 1. Symbiotic fixation rates estimated for soybean, alfalfa and grass/legume.

Crop	Symbiotic fixation rates	
Soybean‡	60.5 kg N ha^{-1} yr^{-1}	50 lb N ac^{-1} yr^{-1}
Alfalfa†	22.86 kg N ton^{-1}	50.4 lb N ton^{-1} yr^{-1}
Grass/legume†	19.7 kg N ton^{-1}	43.5 lb N ton^{-1} yr^{-1}

†Source: Plants Database, USDA (http://npk.nrcs.usda.gov) reported by MDA, 2005: Reports, publications and fact sheets.
‡Russelle, M (pers. comm.)

Mineralization

Mineralizable N was estimated using the same approach presented by Burkart and James (1999a), and reported by Stuewe (2006), with a small modification in the soil elemental N content (from 3.0% to 3.2%). The following equation was used:

$$Nm = 1000\, Db * Om/100 * Vs * Ne * Np$$

where:

Nm = Mineralizable nitrogen (lb ac^{-1})
Db = Bulk density of specific soil (Mg/m^3) (constant=1.471 Mg m^{-3})
Om = Organic matter content of soil (%)
Vs = Volume of 30 cm thick soil in one hectare (constant = 3,000 m^3 ha^{-1})
Ne = Elemental nitrogen fraction of soil organic matter (constant = 3.2%)
Np = Annual mineralizable portion of soil organic nitrogen (constant = 2%)

The percent organic matter used in these calculations is from SSURGO mapping unit values (USDA NRCS, 1995). Percent organic matter was estimated only in cultivated lands (NLCD, 2006). High anomalous values were removed to maintain data integrity (eg. Anoka Sand Plain average went from 8.4% with anomalous values to 2.02%, a much more appropriate value based on Delin et al. 1994). The bulk density assumed across the entire study area is the commonly used estimate of 1.471 Mg m-3 (2,000,000 pounds ac-1-6 inches deep). The volume of soils considered was the top 30 cm (11.8 inches) of soil, equivalent to 3,000 m3 ha-1 (Burkart and James, 1999a). The annual mineralizable portion of the soil organic N used was 2% (Schepers and Mosier, 1991).

Immobilization

The amount of immobilized N (converted from inorganic N to organic N by micro-organisms or plants) was estimated after all volatilization losses were accounted for both the inorganic fertilizer and the manure applied in the study area. This amount of N immobilized should not be considered a complete loss from the system, and should be viewed as N held in the soil organic matter pool, unavailable for immediate plant uptake during the first year of application, but possibly available in subsequent years (Burkart and James, 1999b).

The immobilization rate for all forms of inorganic fertilizer was assumed to be 40% (Burkart and James, 1999a). The immobilization rates for each type of livestock manure are presented in Table 2 (Burkart and James, 1999b, adapted from Elliot and Swanson, 1976; Schepers and Mosier, 1991; reported by Stuewe, 2006).

Table 2. The N immobilization rates assumed for each type of livestock manure applied to cropland (reported by Stuewe, 2006).

Animal type	% N immobilized
Beef Cows	70%
Milk Cows	60%
Hogs	10%
Chickens (broilers)	25%
Turkeys	25%

Inorganic fertilizer

The total amount of inorganic N fertilizer considered in this balance was calculated based on the N fertilizer rate and the cultivated area of each crop.

For crops other than corn, a constant rate was used for all agroecoregions (Table 3). Soybean fertilizer rates were adjusted from 20 to 3 pounds ac^{-1} since only 15% of soybeans fields are fertilized (NASS, 2002-2004-2006-2008).

Fertilizer N rates for corn in each agroecoregion were determined based on county-level farmer surveys (Figure 3) (Bierman et al., 2011). Nitrogen rates for corn were based on non-manure fields; however rates were adjusted according to manure credit calculations. The Minnesota Pollution Control Agency (MPCA) feedlot registration database was used to determine animal units of different species. These registration numbers are often reported on the high-end of an operation’s potential animal capacity so as to not limit the operation. Since actual animal numbers are often less than reported in this database, animal numbers were corrected downward based on surveyed values from the Minnesota Department of Agriculture (MDA). National Agricultural Statistics Service (NASS) animal statistics were used to cross check this method, and confirm that it accurately represented animal numbers.

Using these adjusted feedlot numbers, available N from manure was calculated using two different methods (Midwest Plan Service MWPS-18 2004; University of Minnesota Extension Service 2001). It was assumed that 50% to 70% of calculated first year N credits would be taken, with no second year credits considered in this calculation, and also 59% of poultry manure would be burned.

Total amounts of N fertilizer were initially estimated as the product of fertilizer N rate times area of each crop planted based on remote sensing data collected for the 2009 CDL. This amount was compared with statewide estimates of N fertilizer sales, excluding sales in urban areas, and found to be slightly low. Initial estimates of corn acres planted were then adjusted upwards based on improved estimates of corn acreage using statistical survey data from NASS. The improved corn acres planted estimate was then multiplied by the surveyed N rates applied to corn (Bierman et al., 2011) and credits for land applied manure were then subtracted to obtain the total amounts of N fertilizer applied to corn.

Table 3. Nitrogen fertilizer rates for each crop

Crop	Fertilizer N rate
	lbs ac^{-1}
Soybeans	3
Spring wheat	107[1]
Barley	66[2]
Oats	48[3]
Sugarbeet	83[4]
Potatoes	195[5]
Alfalfa	10[6]
Other Hay	10[6]

[1] MDA
[2] NASS, 2003
[3] NASS, 2005
[4] NASS, 2001 and U of MN recommendations
[5] Weighted average based on U of MN recommendations for irrigated and non-irrigated potatoes
[6] U of MN recommendations

Nitrogen outputs

Crop harvest (grain nitrogen removal)

The total amount of N removed with harvested crops was calculated based on 5- year average yield data and N content in the grain. Average yield data (2005-2009) for the following crops: corn, soybeans, spring wheat, barley, oats, and sugar beets were obtained from USDA-NASS (2011). Potato yield data were provided by Carl Rosen (pers. comm. March 2011). Weighted yield average was used for corn silage and other hay to estimate grain N removal (USDA-NASS-CDL, 2009). The percentage of N in grain and stover for each crop is presented in Table 4.

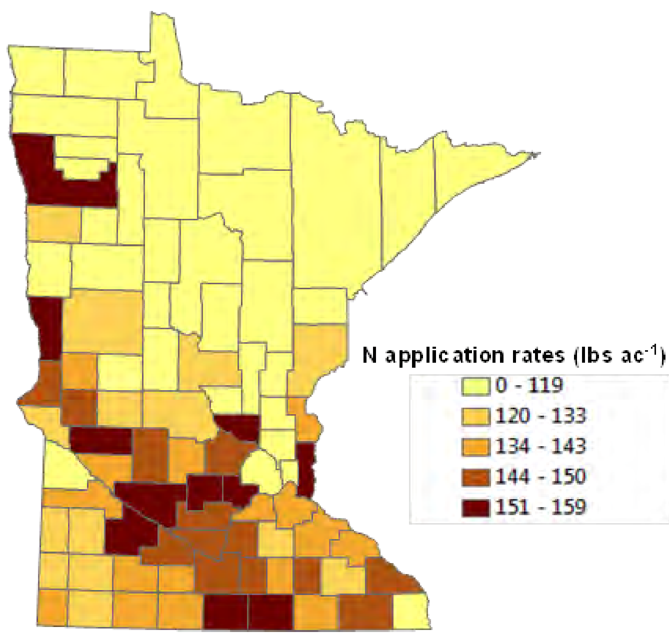


Figure 3. County N application rates for corn obtained from farmer surveys (Bierman et al. 2011).

Table 4. Percentage of N in grain and stover for each crop used to estimate the grain and stover N removal.

Crop	N grain	N stover
	%	
Corn [1]	1.2 [1]	0.70[1]
Corn silage [2]		1.18[2]
Soybeans	6.34 [3]	1.21 [3]
Spring wheat	2.62[5]	0.55[4]
Barley	1.86[6]	0.36[6]
Oats	3.5[7]	0.36 [6]
Sugarbeet	0.5[8]	2.28
Potatoes	1.61[9]	1.65[9]
Alfalfa		3.1[10]
Other Hay		2.34[11]

[1]Randall and Vetsch (2005)
[2] Sheaffer et al. (2011)
[3] Salvagotti et al (2008)
[4] Mullen and Lentz (2007)
[5] Sims et al. 2002
[6] Pan and Hopkins (1991)
[7] Hoftstetter, 1988,
[8] Kumar et al. 2009a
[9]Rosen et al. 1999
[10] Rosen et al. 1995
[11] Roger (2003)

The total amount of grain and N removal was calculated as follows:

Total amount of grain N removal (lb)= N removal rate (lb ac-1)* Number of acres for each crop

Total amount of stover removal (lb)= N removal rate (lb ac-1)* Number of acres for corn silage

Alfalfa and other hay

A proportion of the N in harvested crops is subsequently fed to livestock within the study area; the remainder is in grain that is sold for human consumption. Livestock feed N from harvested crops (estimated using methods described below) was subtracted from the total amount of harvested crop N, this remainder is a N output in the mass balance. It was assumed that all of the independently grown livestock in the study area are fed crops grown in Minnesota.

Crop senescence

During senescence, plants will volatilize N into the atmosphere, primarily as NH_3, from the maturing vegetation (Wetselaar and Farquhar, 1980). The rates of N senescence for corn, soybean, alfalfa, and small grains used in this balance are presented in Table 5.

Table 5. Crop N senescence rates estimated for major crops grown within the study area (Burkart and James, 1999a, reported by Stuewe, 2006).

Crop	Senescence rate	
	kg N ha^{-1} yr^{-1}	lb N ac^{-1} yr^{-1}
Corn	50	44.6
Soybeans	45	40.1
Alfalfa	22	19.63
Small grains†	35	31.2

† Small grains include spring wheat, barley and oats (Burkart and James, 1999a).

Volatilization of stored manure

Volatilization of stored manure decreases the amount of N subsequently available for land application. Manure N volatilization rates during storage for each animal species estimated for this study are presented in Table 6 (Purdue, 2001).

Table 6. Manure N volatilization rates during storage used in this balance.

Fertilizer type	% N loss
Beef	35%
Dairy	20%
Swine	20%
Chickens	25%
Turkeys	25%

Volatilization of land applied fertilizer and manure

Volatilization losses of N from organic and inorganic fertilizers primarily occur as NH3 during application (Burkart and James, 1999a; Mosier et al., 1998). In this balance, different volatilization rates were assumed to each type of inorganic fertilizer and animal manure applied.

Nitrogen volatilization losses during the application of synthetic fertilizers are based on the estimates described by Stuewe (2006) (Table 7).

Table 7. Percentage of total sales and N volatilization rates for each inorganic fertilizer applied in the study area.

Fertilizer type	% of total sold†	% N loss‡
Anhydrous Ammonia (82-0-0)	45.9%	2%
Urea (46-0-0)	44.8%	5%
UAN (28-0-0 & 32-0-0)	4.9%	5%
Custom Blends (all other blends)	4.4%	4%

†Bierman et al. 2011. ‡ Stuewe (2006)

Volatilized N losses during the application of livestock manure were estimated for each type of animal manure (Table 8). The manure N considered available for volatilization losses during application is the amount remaining after all storage and burned losses were accounted.

Table 8. Nitrogen volatilization rates during manure application to cropland in the study area used in this balance (Reported by Stuewe, 2006).

Fertilizer type	% N loss	Source
Beef	21%	Schmitt, 1999
Dairy	10%	Written comm. w/ Dr. Gyles Randal & verbal confirmation by Dr. David Mulla (2005)
Swine	10%	Written comm. w/ Dr. Gyles Randal & verbal confirmation by Dr. David Mulla (2005)
Chickens	18%	Schmitt, 1999
Turkeys	18%	Schmitt, 1999

Denitrification

Soil denitrification rates were assigned according to soil drainage and other soil characteristics in each agroecoregion. Denitrification rates for each agroecoregion with the described soil characteristics are presented in Table 9. Most tile drained lands were assumed to have half the rate of denitrification of untiled lands in each agroecoregion (Table 9).

Table 9. Denitrification percentages estimated for applied and in situ forms of soil N used in the N balance.

	No-Tile	Tile
	% of inorganic N denitrified	
Excessive to well drained (sandy, loam, muck)[1]	3	1
Somewhat poorly drained (loam)[2]	20	10
Poorly and very poorly drained [2]	30	15

[1] Percentage estimated from Venterea (2011)
[2] Percentage estimated from Meisinger and Randall (1991), reported by Stuewe (2006)

Total denitrification

Denitrification rates were calculated separately for the amount of N in land applied livestock manure and inorganic fertilizer, in N deposition and in the mineralizable N from soil organic matter. The amount of N in applied manure and inorganic fertilizer available for denitrification is the amount remaining after all volatilization and immobilization losses have been considered. The calculations carried out for each of these sources were combined to come up with an overall estimate of the N escaping from the study area through denitrification. For the N balance, denitrification occurs only at the field scale. To estimate N loadings from groundwater discharge, an additional denitrification factor was applied as discussed below in the section 2 “Methods: Nonpoint Source Nitrogen Loadings to Surface Waters”.

Cropland nitrogen leaching losses

A literature review was conducted to determine the N leaching rate for each agroecoregion. Details of estimated N leaching rates are presented in Section 2. Total nitrogen leaching as an output in the agricultural N balance does not account for denitrification losses that occur beyond the edge of field as groundwater travels towards and is discharged to streams.

Cropland nitrogen losses in tile drainage

Total N losses in tile drainage were calculated for dry, average and wet conditions based on growing season precipitation data and N rate applied. Details of tile drainage calculations are presented in Section 2.

Cropland nitrogen losses in surface runoff

Nitrogen losses in surface runoff were calculated as a function of runoff volume and N concentration for each agroecoregion. Details of calculations are presented in Section 2.

Nitrogen exported in milk

Nitrogen exported in milk is based on an assumed average crude protein content of 3.1% and the assumption that 16% of crude protein is N (Ferguson, 2001, reported by Stuewe, 2006). Considering these assumptions, the N content in the milk used in this balance was 0.496%. The quantity of milk considered in these applications is the total amount of milk reported to have been produced within each of agroecoregion (USDA-NASS, 2011, NASS county data weighted average 2005-2009).

Nitrogen exported in eggs

The N content assumed for each egg is 1.00 gram, based on information from the Human Nutrition Information Service (USDA, 1989). The amount of eggs produced in each agroecoregion was estimated assuming 230 eggs per year per layer (NASS, 2010). For this balance, it was assumed that all eggs produced within the study areas (agroecoregions) are sold to customers outside of this area.

Nitrogen exported in meat

The percentage of livestock slaughtered for each agroecoregion was estimated based on the total slaughter counts for the state of Minnesota (Table 10). Total slaughter counts were determined based on the MPCA feedlot registration data developed from 2006 to 2010, which represents the maximum livestock numbers in the feedlot during that time period. Data were adjusted for over-reporting feedlot data using a correction factor of 90% for dairy and swine, 70% for beef, 80% for turkey and 85% for chicken (Wayne Cords, personal communication with D. Wall, MPCA).

The slaughter-weights were estimated for each type of livestock based on the percentage of slaughter count for each agroecoregion and the total slaughter weight for the state of Minnesota (Table 11) (NASS, 2011a, b). Estimates of the live weight percentage of N in each animal type sent to be slaughtered are presented in Table 1.10 (Powers and Van Horn, 2001, reported by Stuewe, 2006). The amount of N contained in livestock sent to be slaughtered is calculated based on the live weight percentage of N and the slaughter-weights for each type of animal.

Table 10. The total slaughter-weights and counts used to estimate the total amount of N removed from the state of Minnesota within slaughtered animals.

Animal Type	State-Total Slaughter Count	State-Total Slaughter Weight
	#	lb
Cattle [1](average of dairy & beef)	2530243.4	1270655000
Hogs [1]	938839.9	2691772000
Chicken [2] (typical 9wk broiler)	13010263.2	248966000
Turkey [2] (2002 12 month average)	21177624.8	1127139000

[1] For total slaughter count: MPCA Feedlot registration data (2006-2010) with corrections for over-reporting of feedlot data
For total slaughter weight: NASS, 2011a. Livestock slaughter 2010 Summary.
[2] For total slaughter count: MPCA Feedlot registration data (2006-2010) with corrections for over-reporting of feedlot data
For total slaughter weight: NASS, 2011b. Poultry slaughter 2010 Summary.

Table 11. Whole body live weight percent N content used to estimate the N in livestock sent to be slaughtered (Powers and Van Horn, 2001; reported by Stuewe, 2006).

Animal Type	Whole Body % N
Cattle (average of dairy & beef)	1.40%
Hogs	2.32%
Chicken (average of hens & broilers)	2.40%
Turkey	2.10%

Nitrogen cycling between crop and animal agriculture

Animal manure

The manure N production rates applied in this balance are shown in Table 12. The amount of manure produced for each animal category was calculated using:

Livestock manure production (lb yr^{-1}) = # of slaughter livestock * manure N rate production (lb day^{-1}) * 365 days $year^{-1}$

Approximately 59% of chicken and turkey manure is assumed to be burned each year based on MPCA and Fibrominn records (personal communication with J. Jones, 2010), and only 41% will be available for land application.

Manure N volatilization rates during storage for each animal species were reported in Table 6. Volatilized N losses during the application of livestock manure were presented in Table 8. The manure N considered available for volatilization losses during application is the amount remaining after all storage and incineration losses were accounted for.

The available N in manure after land application is affected by soil processes, such us immobilization by soil microorganisms. For this balance, it was assumed that 50% (for beef, chicken and turkey), 55% (dairy), and 70% (hogs) of N will be available in the first year, and 25% in the second year after the initial manure application.

Table 12. Livestock manure N production rates and animal counts for each animal category used to estimate the manure N produced by the livestock in this balance

Animal Type	State total ‡ Animal counts #	N rates± lb N day $^{-1}$
Beef		
Bull	1213657	0.350
Cow	787172	0.350
Calf finish	225953	0.270
Calf	414801	0.270
Dairy		
Cow-lactating	1084383	0.720
Cow-dry		0.300
Calf	343690	0.060
Heifer/steer	468707	0.230
Hog		
Hogboar	156883	0.04
Sow-farrow finish	1246290	0.09
Farrow feed	417560	0.02
Chicken		
Broiler big	6035232	0.002
Broiler little	17036814	0.0011†
Layer big	343039	0.003
Layer little	25839825	0.0013†
Turkey		
Big	23073859	0.009
Little	13754302	0.0047

†Data not available. These values are half of the big broiler and big layer N production rates.
‡MPCA Feedlot registration data with corrections for over-reporting of feedlot data.
± MWPS (1993).

Harvested crop used for animal feed

Corn and soybean grain are used for animal feed in beef, cattle, swine, and poultry production. Also, corn silage, alfalfa and other hay are fed mainly to beef and dairy cows. Coefficients for harvested corn and soybean use in Minnesota were obtained from the Department of Agriculture (Ye, 2010; Ye, 2009a; Ye, 2009b; MDA, 2010) and are reported in Table 13.

Table 13. Percentage of corn and soybean uses in Minnesota.

Crop	Use
	%
Corn	
Export	42
Ethanol use	34
Feed use	17
Residual use	7
Soybean	
Export	40
Crush for feed	56
Seed and Residual	4

In summary, 17% and 56% of the harvested corn and soybean are being used for feeding animals in Minnesota, respectively. Approximately 25% of the soybean meal from crush is used for feed (75% is exported). The percentages used for each animal are presented in Table 14.

Ethanol production comprised 34% of the harvested corn (Table 13). During ethanol production, starch is extracted from corn grain, and the remaining nutrients are converted to by-products that can be used for animal feed, including Dried Distiller Grains (DDGs). For the N balance, it was assumed that 14.5 pounds of DDGs were produced for each bushel of corn used in the ethanol process with a crude protein (CP) content of 30% and 16% N in CP. Also, 50% of DDGs were exported out of state.

Table 14. Percentage of feed use from corn and soybean for different animal categories in Minnesota.

	Feed use
	%
Corn	
Beef	15
Hogs	46
Dairy	21
Poultry	17
Others	1
Soybean	
Beef cattle	9
Hogs and pigs	41
Dairy (milk cows)	15
Poultry	35
Others	0.4

Livestock feed

Feed N intake for each category of livestock was determined based on recommended nutrient requirements for each livestock species. All the assumptions used to estimate N consumption rate for each animal species are presented in detail in Stuewe (2006). Feed N intake was summed over all species and categories of animals in order to determine whether or not enough harvested crop used for animal feed was available to meet livestock nutritional requirements. The result of this analysis was that harvested crop used for animal feed was sufficient, and consequently, no additional nutritional supplements were added to the overall N balance.

The animal population numbers used for these estimates were obtained from the MPCA.

Swine feed

The population estimates used for swine in these calculations were reported in two categories, “hogs” and “nursery hogs. The consumption rates and crude protein requirements used for both the “hogs” and “nursery hogs” are presented in Table 15 (NAS, 1998, reported by Stuewe, 2006). The N consumption rate was calculated as follows:

N consumption (lbs yr^{-1}) = (Nº Hogs + Nº nursery hogs)* N consumption rate*365

Table 15. Feed consumption rates and crude protein requirements for "hogs" and "nursery hogs" used to estimate the feed N consumed annually by these animals (NAS, 1998, cited by Stuewe, 2006).

Livestock	Feed Consumption Rate	Crude Protein (CP)	Nitrogen in CP	N Consumption Rate	N Consumption Rate
	(kg feed day^{-1})	%	%	(kg N day^{-1})	(lb N day^{-1})
"Hogs"	2.502	15.6%	16%	0.063	0.139
"Nursery Hogs"	0.750	22.3%	16%	0.027	0.060

Beef cattle

The population estimates acquired for beef cattle within the study area were reported in four categories, including “beef heifers”, “feedlot beef”, “calf finish”, and “beef calves”. The consumption rates and crude protein requirements used for each category are presented in Table 16 (NAS, 1998, NAS, 2000; reported by Stuewe, 2006).

Table 16. Feed consumption rates and metabolizable protein requirements for "beef heifers”, “feedlot beef”, “calf finish”, and “beef calves” used to estimate the feed N consumed annually by these animals (NAS, 1998, cited by Stuewe, 2006).

Livestock	MP Consumption Rate	Conversion Factor to CP	Nitrogen in CP	N Consumption Rate	N Consumption Rate
	kg MP day^{-1}		**%**	**kg N day^{-1}**	**lbs N day^{-1}**
"Beef Heifers"	0.624	divided by 0.67	16%	0.149	0.328
"Feedlot Beef"	0.665	divided by 0.67	16%	0.159	0.351
"Calf finish"				0.159	0.351
"Beef Calves"				0.027	0.060

Dairy cattle

The population estimates obtained for dairy cattle within the study area were reported in four categories including “lactating dairy”, “dry dairy”, “young dairy steers”, and “dairy calves”. The consumption rates and crude protein requirements used for each category are presented in Table 17 (Linn, 2004; MWPS, 2003; NAS, 2001; reported by Stuewe, 2006).

Table 17. Feed consumption rates and crude protein requirements for "lactating dairy", “dry dairy”, “young dairy steers”, and “dairy calves” used to estimate the feed N consumed annually by these animals (Linn, 2004; MWPS, 2003; NAS, 2001, cited by Stuewe, 2006).

Livestock	Feed Consumption Rate	CP in Feed	Nitrogen in CP	N Consumption Rate	N Consumption Rate
	kg day^{-1}	%	%	kg N day^{-1}	lbs N day^{-1}
"Lactating Dairy"	20.4	16%	16%	0.523	1.153
"Dry Dairy"	13.6	13%	16%	0.283	0.624
"Young Dairy Steers"	8.8	14.2%	16%	0.200	0.441
"Dairy Calves"	4.2	16.9%	16%	0.114	0.251

Poultry

The population estimates for turkeys within the study area are reported in only one category, “turkeys”. The population estimates reported for chickens within the study area are reported in two categories: “broilers” and “layers”. Nitrogen consumption rate for turkeys and chickens are presented in Table 18 (NAS, 1994; reported by Stuewe, 2006).

Table 18. Feed consumption rates and crude protein requirements for "turkeys" and "chickens" used to estimate the feed N consumed annually by this poultry (NAS, 1994, cited by Stuewe).

Livestock	Feed Consumption Rate	Crude Protein (CP)	N in CP	N Consumption Rate	N Consumption Rate
	kg feed day^{-1}	%	%	kg N day^{-1}	lbs N day^{-1}
"Turkeys"	0.300	22.3%	16%	0.011	0.024
"Chickens Broiler"	0.117	20.3%	16%	0.004	0.008
“Layer Chickens”				0.002	0.004

2: Methods: nonpoint source nitrogen loadings to surface waters

Cropland losses of nitrogen via groundwater discharge to surface waters

N leaching losses

“N leaching” here refers only to that N which leaches to shallow groundwater, where it will over time either be denitrified in the groundwater, or discharge into surface waters. Discharge into well waters was not considered. N leaching into tile drainage waters is a separate study component, and is not considered in the category of “N leaching losses.” However, N leaching that moves vertically on tile-drained land and does not move into tile lines is considered in the “N leaching losses” component.

Total cropland N leaching was determined based on the amount of leaching on undrained soils in: 1) fertilized crops (corn, corn silage, wheat, barley, oats, sugarbeet, potato, 2) non-fertilized crops (soybean and alfalfa), and 3) leaching losses from all crops on drained soils.

Cropland area in each agroecoregion was classified as either drained or un-drained according to soil hydrologic class for soils with slope steepness between 0-3% (SSURGO classification, USDA- NRCS, 2006b).

A literature review was conducted to determine the N leaching rate for each agroecoregion. Most of the research related to N leaching in Minnesota has been conducted in the Sand Plains area (Venterea et al., 2011, Wilson et al., 2010, Wilson et al., 2008, Errebhi et al., 1998, Sexton et al., 1996, Delin et al., 1995, Rosen et al., 2010, Rosen, pers. comm.).

Using existing data for Minnesota, statistical algorithms were developed for N leaching losses based on the applied N rate in dry and wet years. For average climatic years, the N leaching algorithm was based on a mean of the algorithms in dry and wet years. Dry years occurred when precipitation was lower than the average using a 30-year climatic record for each Minnesota location in a particular research study. Wet years occurred when precipitation was greater than the average using a 30-year climatic record for each Minnesota location studied.

Algorithms for N leaching losses to groundwater with fertilized crops in undrained areas of Region 4 (Figure 4) were, thus, a function of the N application rate (N fertilizer +N manure):

N losses= N rate * 0.0602 + 22.245, R^2=0.0871 for dry conditions

N losses= N rate * 0.2945 + 37.6, R^2= 0.459 for wet conditions

Leaching is greatly reduced during dry conditions, regardless of the fertilizer rate, and thus the relationship between rate of application and nitrogen leaching during dry years was rather weak and the slope was low compared to the wet years. The poor statistical relationship during the dry years is expected. This relationship does not have much influence on the leaching loss estimates, given the narrow range of average fertilizer rates which are applied in different agroecoregions and the low leaching rates during dry years. Even if the dry years slope in figure 4 was zero, the N leaching load estimates would remain largely unaffected.

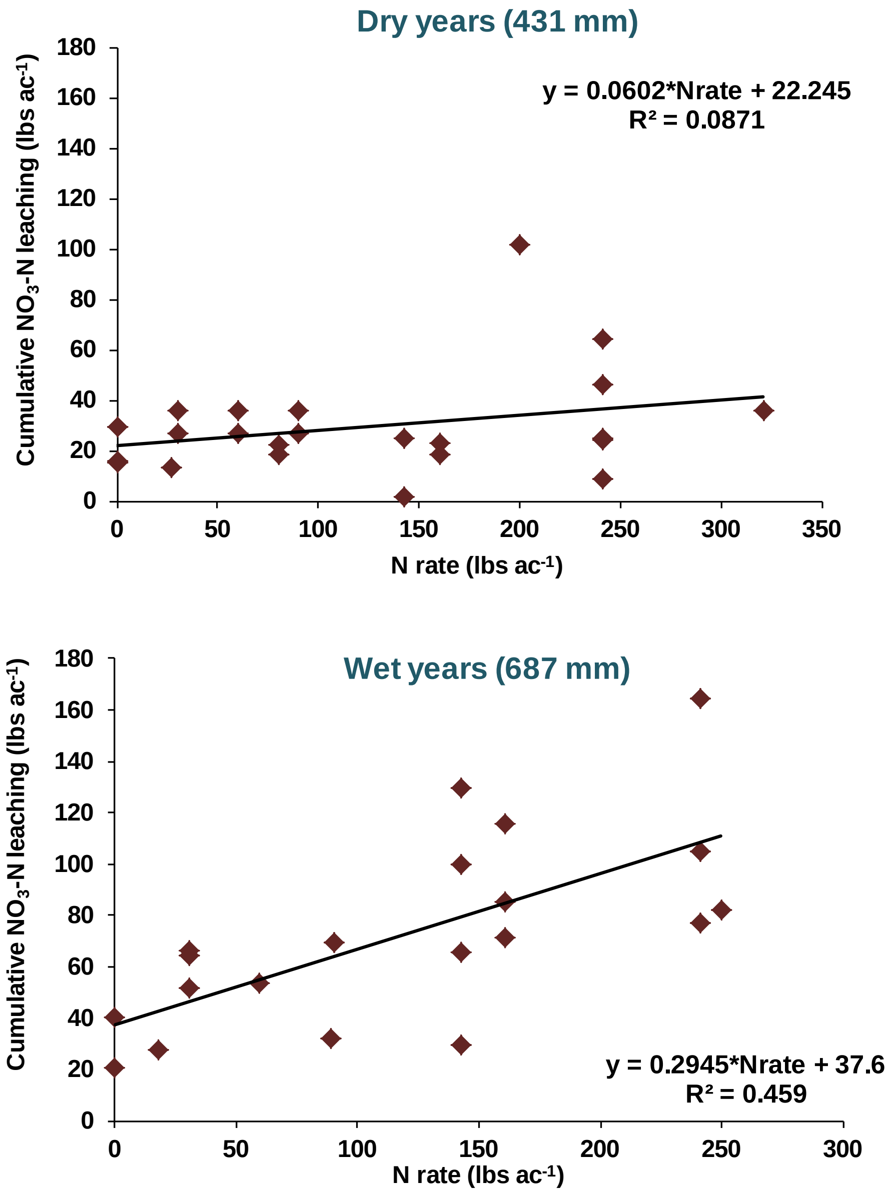


Figure 4. Cumulative NO_3-N leaching as a function of N rate for the Sand Plain area (Region 4) in Minnesota.

Each agroecoregion was assigned to one of four groundwater leaching regions according to groundwater contamination susceptibility in Minnesota. Assignment into each region was based on the measured occurrence of nitrate-N in drinking water wells from a database of 40,000 wells monitored by MDH, MPCA, USGS, and MDA. Regions were also based on results from the DRASTIC model (Depth, Recharge, Aquifer, Soil, Topography, Impact, and Conductivity).

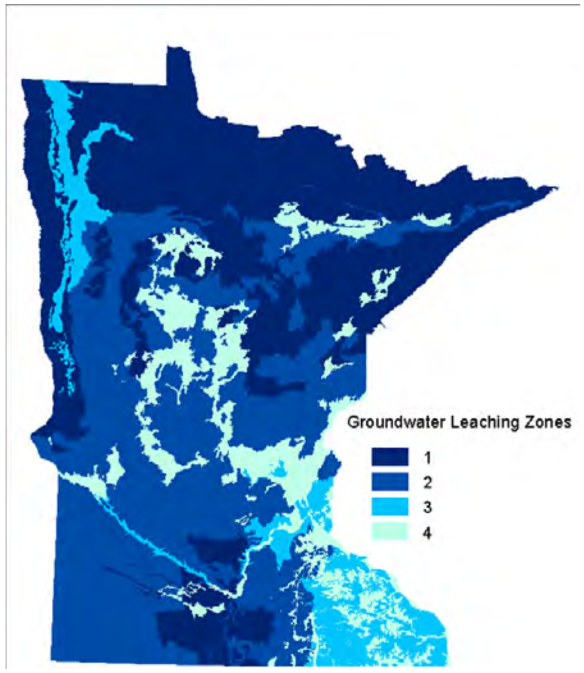


Figure 5. Nitrogen groundwater contamination vulnerability regions in Minnesota.

Table 19. Groundwater contamination vulnerability regions, and associated agroecoregions and coefficients to adjust the N leaching rate in undrained fertilized cropland for each region.

Region	Agroecoregion	Coefficient
1	Drift & Bedrock Complex, Forested Lake Sediments, Mahnomen Lake Sediments, Northern Till, Northshore Moraine, Peatlands, Poorly Drained Lake Sediments, Red Lake Loams, Somewhat Poorly Drained Lake, Steep Poorly Drained Moraine, Swelling Clay Lake Sediments, Very Poorly Drained Lake Sediments,Wetter BE Till, Wetter Clays & Silts	0.007
2	Central Till, Coteau, Drumlins, Dryer BE Till, Dryer Clays &Silts, Dryer Till, Forested Moraine, Inner Coteau, Mesabi Range, Poorly Drained BE =Till, Rolling Moraine, Steep Dryer Moraine, Steep Stream Banks, Steeper Till, Stream Banks	0.25
3	Bufflands, Inter-Beach Sand Bars, Level Plains, Steep Valley Walls, Steep Wetter Moraine, Steeper Alluvium, Undulating Plains	0.50
4	Alluvium & Outwash, Anoka Sand Plains, Rochester Plateau	1

Leaching coefficients to adjust N leaching rate in Regions 1 and 2 were determined based on SWAT model information, and coefficients for Region 3 were assumed to be halfway between the coefficients for Regions 2 and 4, since no data were available (Table 19). No adjustment was needed in Region 4, because this is where experimental data on N leaching losses were abundant. Even though the geology differs in the Anoka Sand Plains region and Rochester Plateau (karst region) of southeastern Minnesota, it was justifiable to combine them into the same groundwater contamination vulnerability region. Each has roughly the same probability of groundwater contamination.

For non-fertilized soybean on undrained land, N leaching rates were assumed equal to N leaching rates for soybean under tile drainage. These N leaching rates were adjusted using the coefficients in Table 19 for Regions 1 and 2. For alfalfa, N leaching rates were assumed to be 1.56 pounds ac^{-1} (Chung et al.2001) for dry, average, and wet years.

Leaching losses on drained cropland were calculated assuming N rate loss of 3 pounds ac^{-1} for dry, average, and wet years.

Denitrification of groundwater

The main form of N in groundwater baseflow is nitrate, which moves with water and ultimately can reach surface waters. However, nitrate can be lost before discharging to surface water through a biological process called denitrification.

Denitrification can occur within the unsaturated soil zone, within saturated soils, in the aquifer, and/or in the riparian zone. Levels of oxygen in groundwater < 0.5 mg L^{-1} can promote denitrification, since bacteria will use nitrate to oxidize organic carbon sources, and as a result, nitrate contributions from low-oxygen baseflow will be negligible or minimal. However if these conditions are not present, then all the nitrate that moves through the soil into groundwater will eventually emerge in streams via groundwater baseflow.

The amount of groundwater N discharging to surface waters was calculated by multiplying the N leaching losses by a denitrification factor. The denitrification factor was determined based on a literature review which summarizes possible nitrate losses in the groundwater for different types of soils (Böhlke et al., 2002; Dubrowvsky et al., 2010; Duff et al., 2007; Duff et al., 2008; Gentry et al., 2009; Goolsby et al., 1999; Hill, 1996; Korom, 2010; Korom et al., 2005; Masarik et al., 2007. McCallum et al., 2008; MPCA, 1998; Patch and Padmanabhan, 1994; Puckett, 2004. Puckett and Cowdery, 2002; Puckett et al., 1999; Puckett et al., 2008; Rodvang and Simpkins, 2001; Sauer et al., 2001; Schilling, 2002; Schilling and Helmers, 2008; Schilling and Libra, 2000; SCWRS, 2003; Sogbedji et al., 2000; Spahr et al., 2010; Tesoriero et al., 2009; Triska et al., 2007; and Trojan et al., 2002). The actual losses within groundwater prior to discharge into surface waters is highly variable, and will depend on the subsurface and groundwater chemistry, residence time in aquifers, and the types of sediments it moves through in the riparian zone. Based on the available information, denitrification losses within the groundwater itself were assumed to be 25% for Karst agroecoregions, 40% for Sand Plain and Alluvial agroecoregions, 60% for finer textured soil agroecoregions , and 50% for all other agroecoregions (Table 20).

Considerable lag time can occur between the time of leaching into groundwater and the point of discharge into surface waters. Land management changes that affect leaching losses can take from weeks to centuries before the changes are reflected in surface waters. This lag time was not directly accounted for in this study. Estimates of discharge into surface waters are independent of travel time, except that denitrification coefficients were adjusted based on the hydrologic conditions within the agroecoregion. The estimates of N reaching surface waters through leaching losses will not necessarily be reflected in the stream monitoring for a single year, or even a single decade.

Table 20. Groundwater denitrification factor assigned to different agroecoregions.

Agroecoregion	Denitrification factor
Blufflands, Rochester Plateau	0.25
Anoka Sand Plains, Alluvium and Outwash, Inter-Beach Sand Bars, Steep Valley Walls, Steeper Alluvium.	0.40
Forested Lake Sediments, Mahnomen Lake Sediments, Poorly Drained BE Till, Poorly Drained Lake Sediments, Red Lake Loams, Somewhat Poorly Drained Lake, Swelling Clay Lake Sediments, Very Poorly Drained Lake Sediments	0.60
Other agroecoregions	0.50
Drained soils	0.60

Cropland nitrogen losses to surface waters in tile drainage discharge

Annual tile drainage N losses are difficult to estimate, since several factors influenced N export through tile drainage. In Minnesota, extensive research has been developed on N losses in tile drainage (Chung et al., 2001, Randall et al., 1997, Huggins et al., 2001, Nangia et al., 2008, Randall and Iragavarapu, 1995, Randall and Vetsch, 2005, Randall et al., 2003, Sands et al., 2008, Randall et al. 2000, Gast et al., 1978).

Total N losses in tile drainage were determined based on the amount of N losses in croplands under: 1) fertilized crops (corn, corn silage, wheat, barley, oats, sugar beet, potato), 2) and non-fertilized crops (soybean and alfalfa).

Based on the available information, two algorithms were developed for corn and soybean crops (Figure 6). Algorithms were a function of growing season precipitation and N rate (N fertilizer + N manure) for fertilized crops, and only growing season precipitation for non-fertilized crop (soybean) in each agroecoregion:

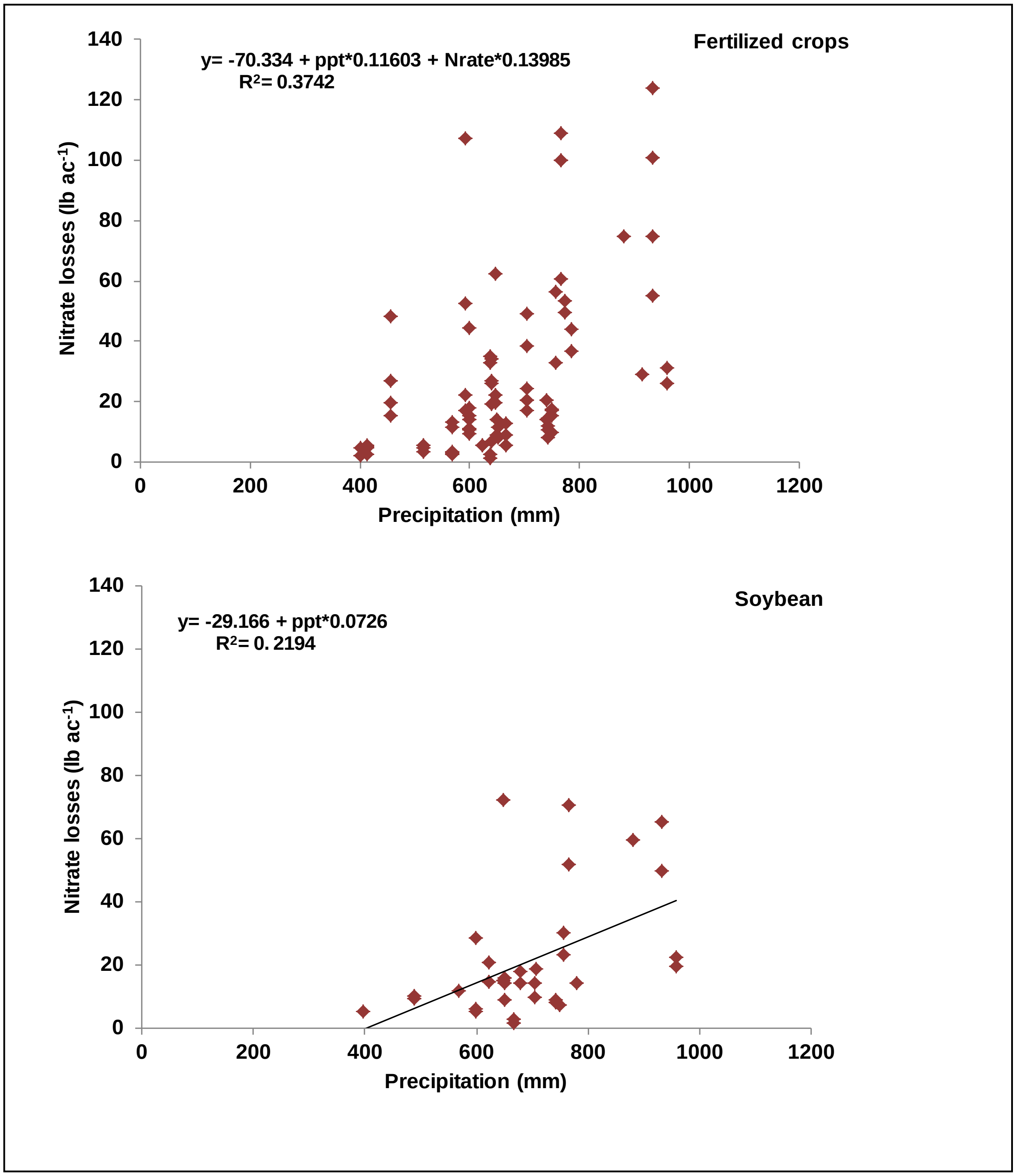


Figure 6. Nitrate losses through tile drainage as a function of precipitation for corn and soybean. The regression equation for corn is based on both precipitation and N rate.

Algorithms for N losses to surface waters through tile drainage took the form:

NO_3-N losses (fertilized crops) = -70.334 + Precipitation*0.11603 + N rate * 0.13985

NO_3-N losses (soybean) = -29.166 + Precipitation*0.0726

For alfalfa forage, an N leaching rate of 1.56 lb ac^{-1} was estimated based on N leaching research in Minnesota (Chung et al., 2001).

Total N losses were calculated for dry, average, and wet climatic conditions based on growing season precipitation data (MPCA HUC8 precipitation data 1980-2010, MN DNR, 2010).

Tile drainage N losses estimated using the algorithms above were inflated an additional 12% to account for contributions of TKN (organic N forms) based on studies conducted in Minnesota (Dave Wall, personal communication with S. Matteson, Nov. 2011).

Cropland nitrogen losses in runoff

Nitrogen in surface runoff was calculated as a function of runoff volume and N concentration for each agroecoregion.

Thirty years of precipitation data were analyzed at the basin scale, and wet, average, and dry years were determined based on the statistical 90th, 50th, and 10th percentiles, respectfully. Discharge volume from USGS monitoring was determined using average, low and high flow discharge data for these same years in each agroecoregion.

Runoff as a percent of discharge was determined based on available data from SWAT modeling for the agroecoregions cited in Table 21. For the remaining agroecoregions runoff percentages were calculated based on a water budget approach for each agroecoregion.

Table 21. Runoff (percent of discharge) from SWAT modeling.

Area	Agroecoregion	Runoff (%)
7 Mile Creek	Wetter Clays and Silts	22
Root River	Undulating Plains	16
Karst	Blufflands, Rochester Plateau	24
Red River	Swelling Clay lake sediments, Very poorly drained lake sediments	71
Sunrise	Central till, Anoka Sand Plains, Alluvium and Outwash	6

Similar to the approach used to estimate cropland N losses through leaching and groundwater discharge, each agroecoregion was assigned a runoff category according to their susceptibility to surface runoff in Minnesota (Table 22). For Blufflands and Rochester Plateau, runoff was assigned an N concentration of 10 mg L^{-1} based on data reported by Peterson and Vondracek (2006) for the Karst region.

Table 22. Nitrogen concentration in cropland runoff for each Agroecoregion.

Region	Agroecoregion	N concentration (mg L^{-1})
1	Drift & Bedrock Complex, Forested Lake Sediments, Mahnomen Lake Sediments, Northern Till, Northshore Moraine, Peatlands, Poorly Drained Lake Sediments, Red Lake Loams, Somewhat Poorly Drained Lake, Steep Poorly Drained Moraine, Swelling Clay Lake Sediments, Very Poorly Drained Lake Sediments, Wetter BE Till, Wetter Clays & Silts	3.5[1]
2	Central Till, Coteau, Drumlins, Dryer BE Till, Dryer Clays &Silts, Dryer Till, Forested Moraine, Inner Coteau, Mesabi Range, Poorly Drained BE =Till, Rolling Moraine, Steep Dryer Moraine, Steep Stream Banks, Steeper Till, Stream Banks	1.8[2]
3	Blufflands, Inter-Beach Sand Bars, Level Plains, Steep Valley Walls, Steep Wetter Moraine, Steeper Alluvium, Undulating Plains	0.7[3]
4	Alluvium & Outwash, Anoka Sand Plains, Rochester Plateau	0.24[4]

[1] Kumar et al. 2009 (East Grand Forks, MN), Ginting et al. 2000 (southern Minnesota River Basin)
[2] Thoma et al. 2005 (Lamberton, MN)
[3] No research data were available for zone 3 (assumed intermediate values)
[4] Delin and Landon (2002) (Sand Plain-Princeton)

Forest export of nitrogen to surface waters

Total acres of forest (deciduous, coniferous, and mixed forest) were obtained from the National Land Cover Database (NLCD, 2006). Approximately 11 million acres are under forest statewide. Nitrogen export coefficients for dry, average and wet conditions are presented in Table 23. Estimation of these coefficients was based on available information for forested lands in Minnesota, Wisconsin, and eastern Unites States regions (Mulla et al. 1999, Gold et al., 1990, Timmons et al., 1977, Verry and Timmons, 1982, Clark et al., 2000, Clesceri et al., 1986, Boyer et al., 2002, Campbell et al., 2004, Beaulac and Reckhow, 1982, Reckhow et al., 1980, Cooke and Prepas, 1998, Rast and Lee, 1978, Lin, 2004, Loerh et al., 1989, McFarland and Hauck, 2001,Dodd et al., 1992, Groffman et al., 2004).

Table 23. Nitrogen export coefficients for forested lands in Minnesota.

Conditions	N export (lbs N ac^{-1})
Dry	1
Average	2
Wet	3

Nonpoint source nitrogen export in urban/suburban regions

Based on information from National Land Cover Database (NLCD, 2006), the total acres of developed land use (open space, light, medium, and heavy developed) was approximately 1 million acres statewide.

Nitrogen export coefficients used to calculate total nonpoint source N export in urban/suburban areas of Minnesota are presented in Table 24. Nitrogen export coefficients were estimated based on available information sources (Weiss et al., 2008, Dodd et al., 1992, McFarland and Hauck, 2001, Rast and Lee, 1983, Frink, 1991, Lin, 2004, Reckhow et al., 1980, Peterson and Vondracek, 2006,Brezonik and Stadelmann, 2002, Mulla et al. 1999, Groffman et al., 2004, Horner et al., 1994, Wollheim et al., 2005, Deacon et al., 2006, Lerner, 2000, Trojan et al., 2003, Shields et al., 2008, Evans, 2008, Brian Vlach, (pers. Comm. 2010), Mike Trojan, (pers. Comm. 2011), Mike Perniel, (pers. Comm. 2011.).

Table 24. Nonpoint source N export coefficients for urban/suburban lands in Minnesota.

Conditions	N export (lbs N ac^{-1})
Dry	2
Average	4
Wet	6

Nitrogen export from septic systems

Nitrogen losses from septic systems were based on county data from MPCA (2011). Losses were estimated for septic systems that are Imminent Public Health Threats (IPHT) and for those that are not IPHT as follows:

> Septic N to Groundwater = [(# Septics per county) *(Persons per household by county)* ({9.1 pounds N per person}*{85% for denitrification losses})] *(% NOT Imminent Public Health Threat (IPHT))

> Septic N to Surface Water = [(# Septics per county) *(Persons per household by county) *(9.1 pounds N per person)] * (% Imminent Public Health Threat (IPHT))

Information to determine the number of people per household by county was obtained from U.S. Census (2010). The per capita N coming out of septic systems was assumed to be 9.1 pounds N per person (Information provided by Mark Wespetal, MPCA). Denitrification was assumed to remove 15% of the septic system N within the soil prior to reaching groundwater. Once in the groundwater, the same groundwater denitrification loss coefficients for cropland (Table 20) were assigned to septic system N. All non-metropolitan population data were classified using 2008 ZIP code populations to improve spatial accuracy of county data.

Feedlot nitrogen losses in runoff

The number of out of compliance feedlots for open runoff was determined from an MPCA survey of counties in 2010 (pers. comm. Don Hauge, MPCA). Some counties had missing information for the number of feedlots out of compliance, and numbers had to be estimated using results from similar counties.

Feedlot N runoff was estimated using the Minnesota Feedlot Annualized Runoff Model (MinnFarm model). MinnFarm model (version 2.3) was run for a 75 AU beef/dairy operation to represent feedlots in the 50-100 AU category, a 150 AU beef/dairy to represent feedlots in the 100-300 AU category, and a 300 AU beef/dairy to represent feedlots in the >300AU category, recognizing that not all animals at the farm typically have access to the noncompliant lots.

The MinnFARM model assumed 200 square feet per animal on the lot and over 100% animal unit density - all soil covered with some manure in the lot. Also the model considered a small buffer downslope of the lot, which reduced the N losses by half. This is equivalent to about a 25 foot length meadow or 75 feet of fair pasture.

These estimates do not account for runoff from non-registered feedlots, feedlots in counties with minimal animal agriculture and small amounts of N from compliant feedlots using vegetation to treat runoff.

Methods for assessing sensitivity and uncertainty in cropland nitrogen balance

Due to uncertainty in the estimation of the variables that affect the agricultural N balance, a sensitivity analysis was conducted to determine how changing these variables would affect the overall agricultural N balance. In the sensitivity analysis, each source or coefficient was varied in increments of plus or minus 5, 10, 15, 25, or 50% of its baseline value. For each of these changes, we computed the resulting percentage change in the overall agricultural N balance relative to its baseline value.

Also, a sensitivity analysis was conducted for the main N pathways to surface water (runoff, leaching, tile drainage).

Conversion of agroecoregion based nitrogen loadings to watershed based nitrogen loadings

The majority of N inputs and outputs were calculated based on agroecoregion boundaries because of how inherent similarities in soil type and parent material largely influence the amount of N stored or delivered. To convert these N loadings into data representing major watershed boundaries, they were area-weighted. Agroecoregion data totals were converted to pounds per acre N yield raster data sets. Zonal statistics were then used to calculate an area-weighted average N yield for HUC8 watershed polygons. This average N yield value was converted back to a total delivery in pounds based on watershed areas.

Some rounding errors may introduce small discrepancies between the agroecoregion based and watershed based data, but this is the best representation of the original data. When possible (i.e. urban N deliveries, forest N deliveries), data were calculated for each watershed based on 30 m landuse rasters. In other words, area-weighting was avoided when data resolution could be better represented with direct landuse calculations.

Finally, the area-weighting process introduced a high amount of tile drainage N delivery from the Mississippi Twin Cities major watershed, a watershed having little to no tile drained cropland. For this specific case, the Mississippi Twin Cities watershed was determined to have zero tile drainage, and the amount removed from this watershed was “de-weighted” or assigned back to the watersheds associated with the influencing agroecoregion.

Results

Minnesota cropland nitrogen balance

Physical description of study area

Minnesota has 54,000,000 acres of land in total and nearly 36,000,000 acres of cropland, forest and urban landuses (Figure 7). Cropland accounts for 44% of the total area in Minnesota, while forest accounts for 20%, and urban landuse accounts for 1%. There are another 18 million acres (33% by area) of lakes, rivers, shrub and grasslands, and wetlands not considered in this study. Cropland accounts for 67% of the area (36,000,000 acres) represented in this study of nonpoint source N pollution, forest accounts for 31% and urban-suburban land accounts for 2% (Figure 8). Cropland includes land in corn, soybean, small grains, sugar beet, potato, alfalfa and hay. The three largest Basins in Minnesota (Minnesota River, Red River of the North, and Upper Mississippi River) account for nearly 60% of the area in the state. The largest concentration of cropland is in the Minnesota River, Red River of the North, and Upper and Lower Mississippi River Basins (Figure 9). Cropland accounts for 74% of the area in the Minnesota River Basin, 51% of the area in the Red River of the North, and only 21% of the area in the Upper Mississippi River Basin (Figure 10). The Lower Mississippi River Basin has 47% of its area in cropland. The Rainy River and Lake Superior Basins, by contrast, have only 1.2% and 0.2% of their areas in cropland.

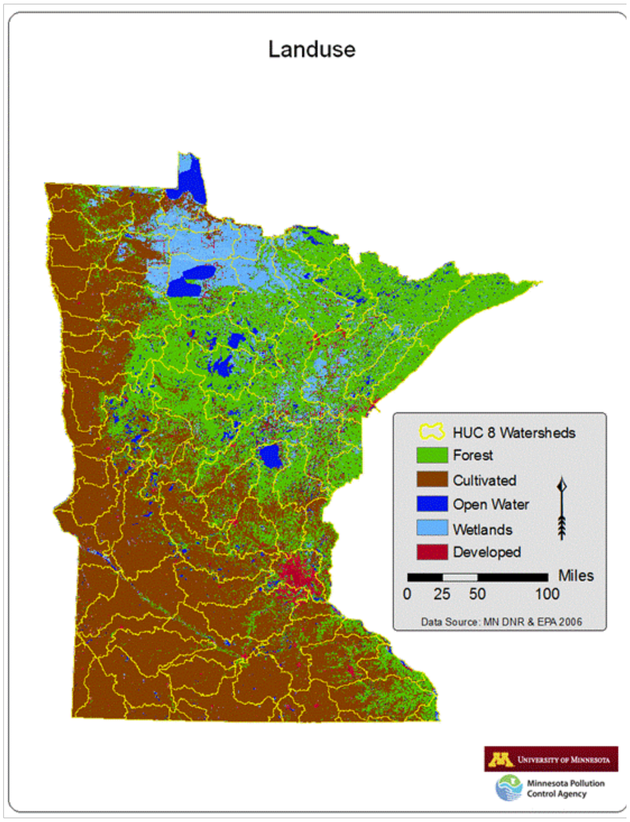


Figure 7. Minnesota landuse categories for this study

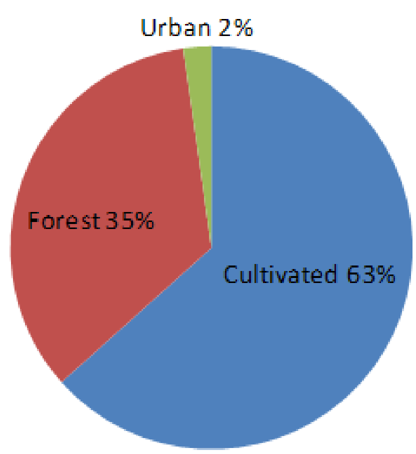


Figure 8. Landuse percentages for this study

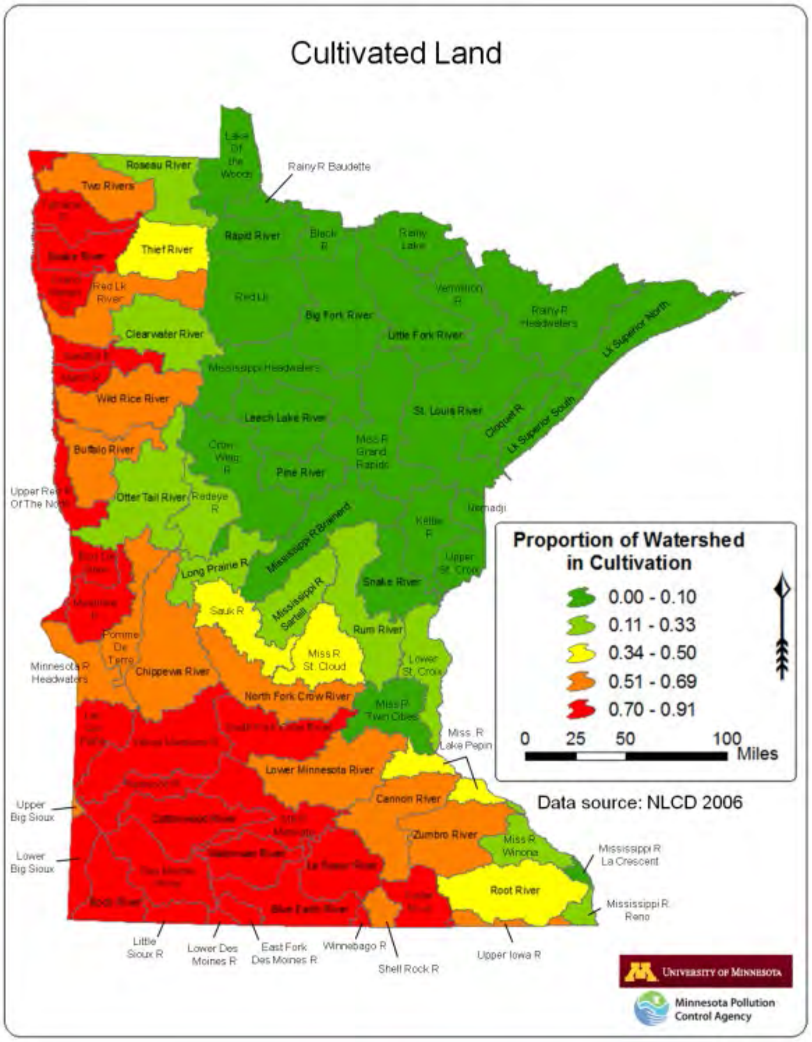


Figure 9. Cultivated cropland (ac) in Minnesota.

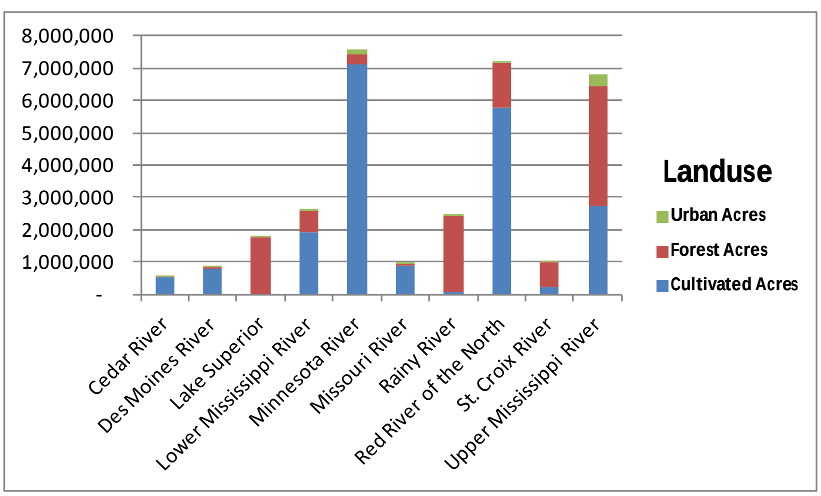
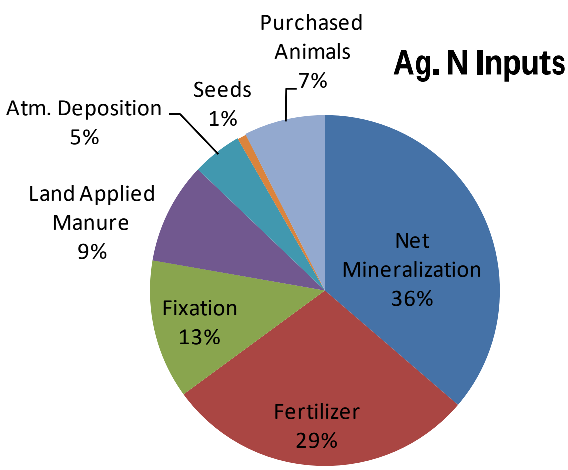


Figure 10. Landuse distributions (ac) by river basin.

Agricultural nitrogen inputs

Agricultural N inputs to cropland include soil mineralization, N fertilizer; N fixation by legumes, atmospheric deposition, planted seeds, and purchased animals. Land applied animal manure can also be compared with agricultural N inputs, though technically it is an internally recycled nutrient, and should not be explicitly considered. When land applied animal manure is included, agricultural N inputs total about 4.8 billion pounds of N. Mineralization accounts for 36% (1.73 billion pounds) of the N inputs to cropland (Figure 11a, b), while N fertilizer accounts for 29% (1.36 billion pounds). Nitrogen fixation by legumes (0.61 billion pounds) accounts for 13% of the N inputs. Land applied manure (0.45 billion pounds), atmospheric deposition (0.22 billion pounds), and purchased animals (0.36 billion pounds) each account for roughly 5-9% of the N inputs to cropland. Purchased seeds account for less than 1%. Not surprisingly, because of relatively large areas of cropland, the largest agricultural N inputs to cropland (Figure 12) occur in the Minnesota River Basin (1.7 billion pounds), followed by the Red River of the North Basin (1.0 billion pounds) and the Upper Mississippi River Basin (0.71 billion pounds). The Lower Mississippi River Basin receives roughly 0.52 billion pounds of N annually. A majority of the N inputs for these four basins arises from soil mineralization and N fertilizer.



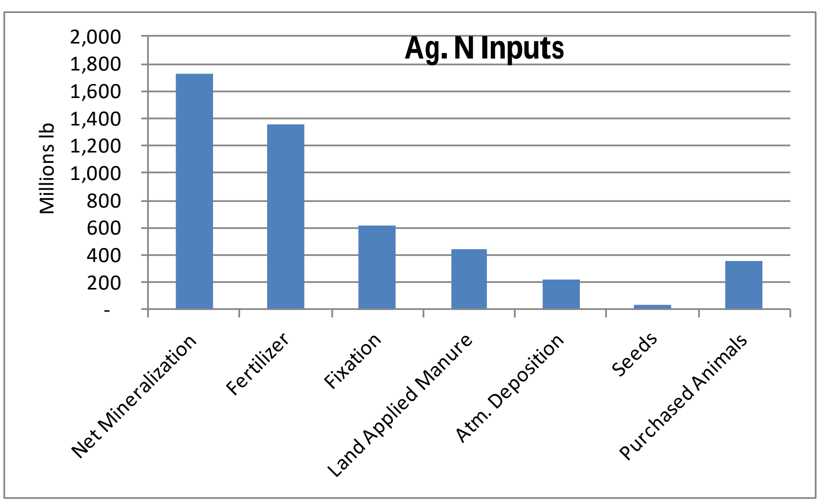


Figure. 11a, b. Agricultural inputs (% or lb) by source to the N balance.

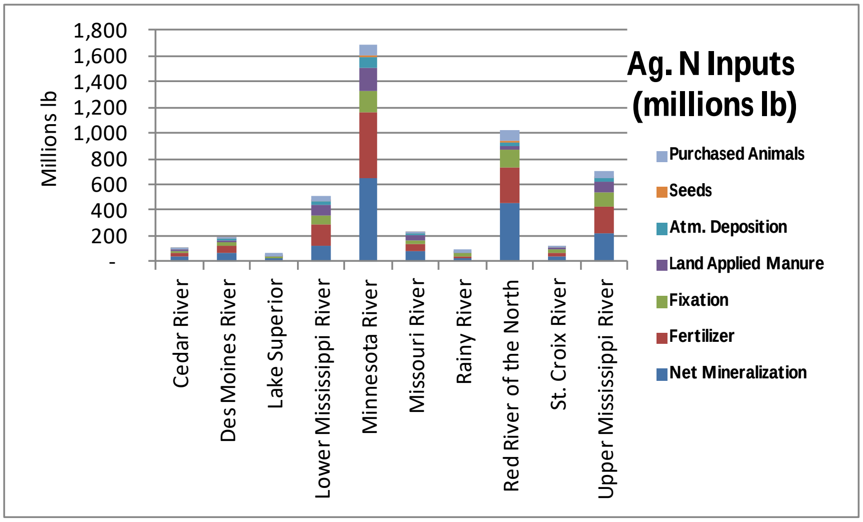


Figure 12: Agricultural N inputs (lb) by source and river basin.

When normalized by total watershed area, the largest N inputs to cropland from a single source occur with soil mineralization (Figure 13) in the Minnesota River, Missouri River, and Des Moines River Basins (54-75 pounds/acre). Mineralization of cropland soils is relatively insignificant (4-5 pounds/acre) in the Rainy River and Lake Superior Basins. The second largest source of N inputs is fertilizer (Figure 14). Fertilizer applications account for 48 to 57 pounds/acre annually in the Minnesota River, Missouri River, and Des Moines River Basins when averaged over the total watershed area (including non-cropland acres). When averaging only for cultivated acres (including unfertilized and fertilized crops, fertilizer application rates in these same basins are approximately 70 pounds/acre. Fertilizer rates range between 2.2 and 2.9 pounds/acre annually in the Rainy River and Lake Superior Basins.

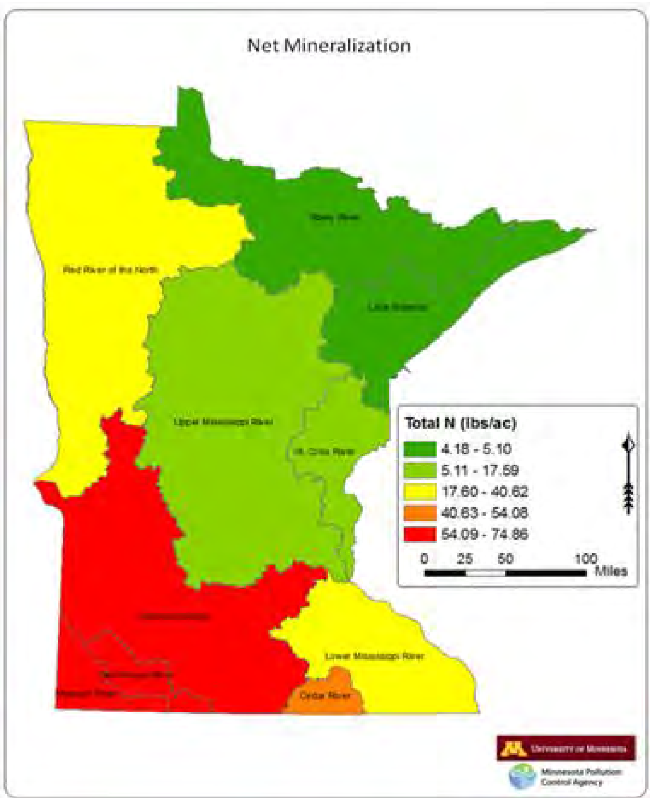


Figure 13. Net mineralization (lb/ac) by basin.

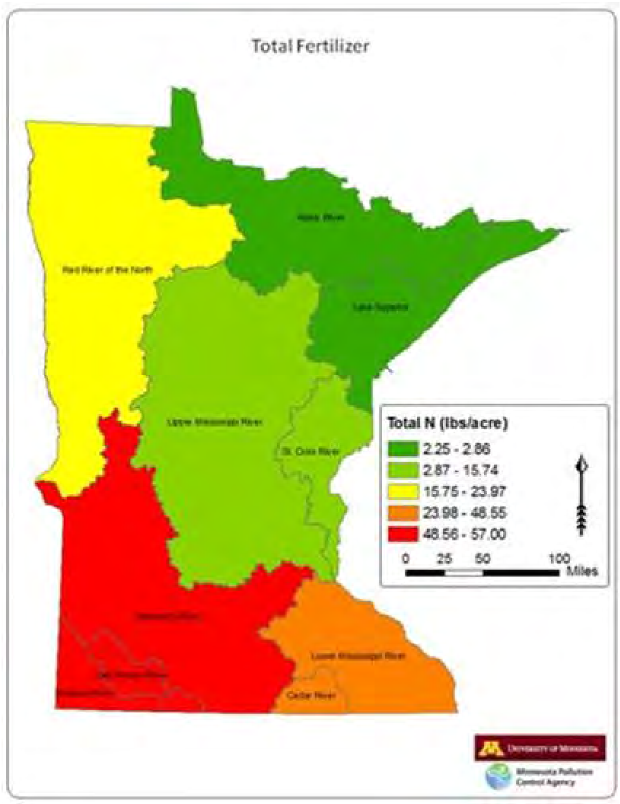


Figure 14. Fertilizer N (lb/ac) by basin

Most of the fertilizer is applied to land used for growing corn, with some also applied to land used for growing other crops, including wheat, potatoes, edible beans, etc. Rates of N fertilizer applied to cropland used for growing corn generally range from 136-152 pounds/acre across a wide area covering the Minnesota River and Lower Mississippi River Basins, as well as the southern portions of the Upper Mississippi River Basin (Figure 15).

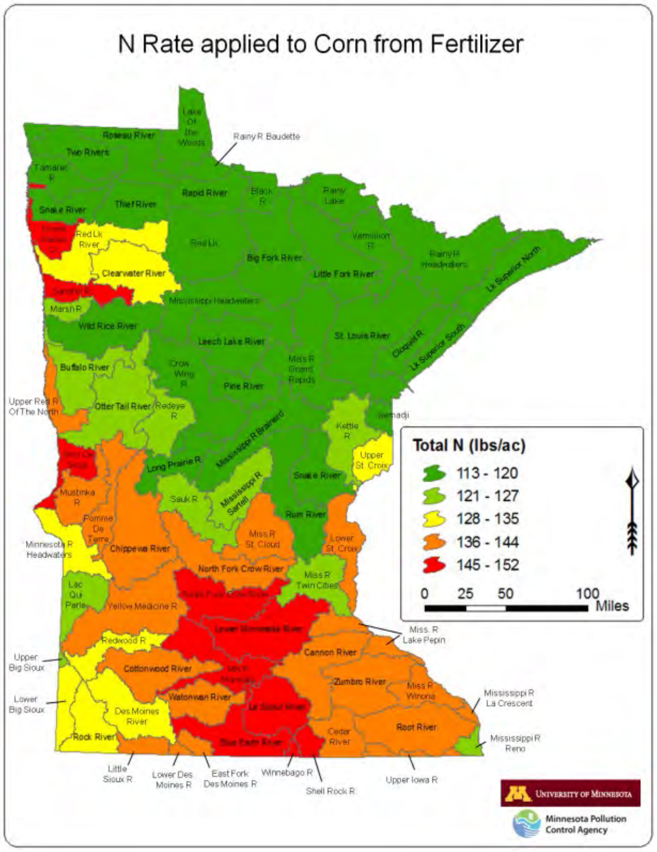


Figure 15. Fertilizer N rates (lb/ac) applied to corn.

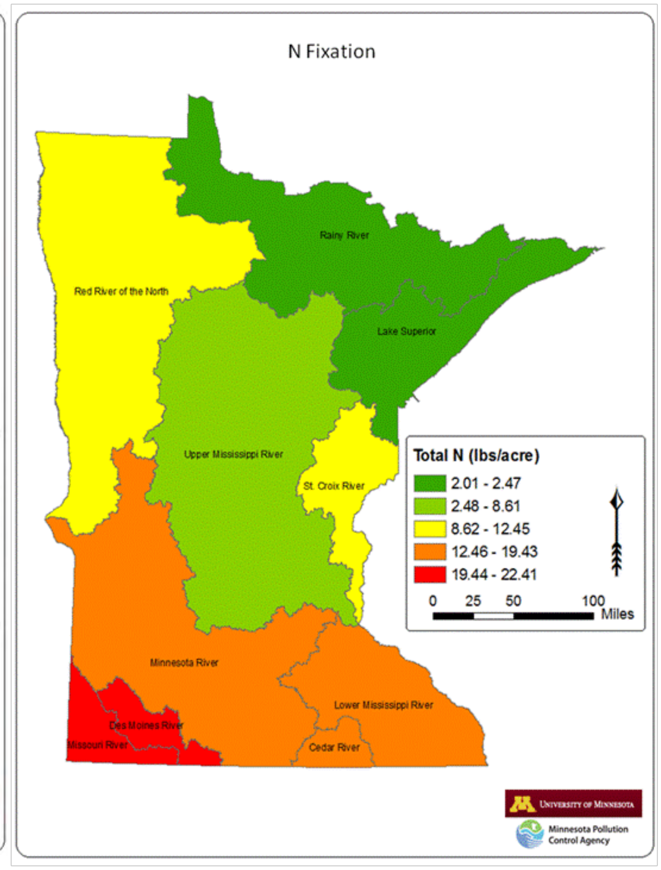
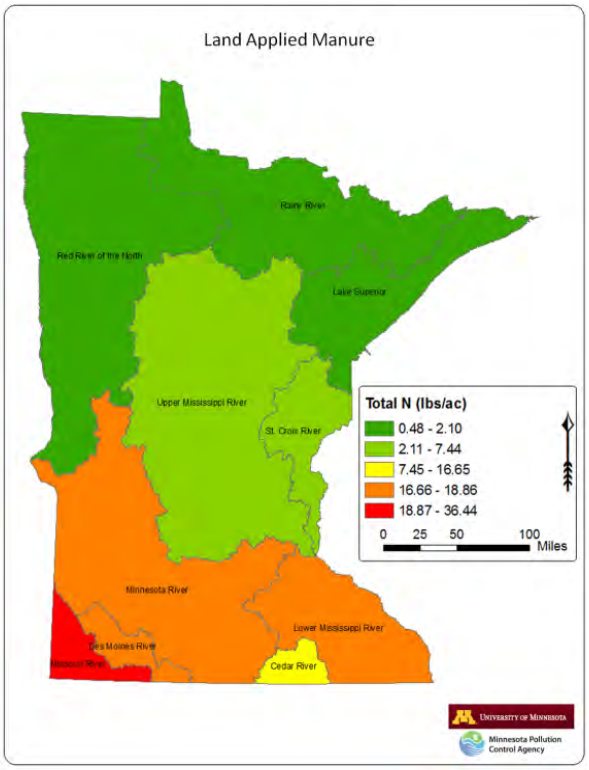


Figure 16. N fixation (lb/ac) by basin.

Nitrogen fixation ranges between 12 and 22 pounds/acre annually in the Minnesota River, Missouri River, Des Moines River, and Lower Mississippi River Basins (Figure 11). Land applied manure ranges between 17 and 36 pounds/acre (normalized to total watershed area) in the Lower Mississippi River, Minnesota River, Des Moines River and Missouri River Basins (Figure 17). Not surprisingly, the heaviest concentration of farm animals (Figure 18) occurs in a broad swath covering the Minnesota River and Lower Mississippi River Basins.

Total N inputs (excluding land applied manure) normalized to watershed area are greatest for the Minnesota River, Missouri River, and Des Moines River Basins, ranging from 155-174 pounds/acre annually (Figure 19). Total N inputs range between 11 and 15 pounds/acre in the Rainy River and Lake Superior Basins.

Total N inputs (excluding land applied manure) are greatest for the Minnesota River Basin (1.5 billion pounds annually) and Red River of the North Basin (1.0 billion pounds) (Figure 20). The Upper Mississippi River Basin (0.63 billion pounds) and Lower Mississippi River Basin (0.44 billion pounds) have moderate amounts of total N inputs. Nitrogen inputs are less than 0.07 billion pounds in the Lake Superior Basin.



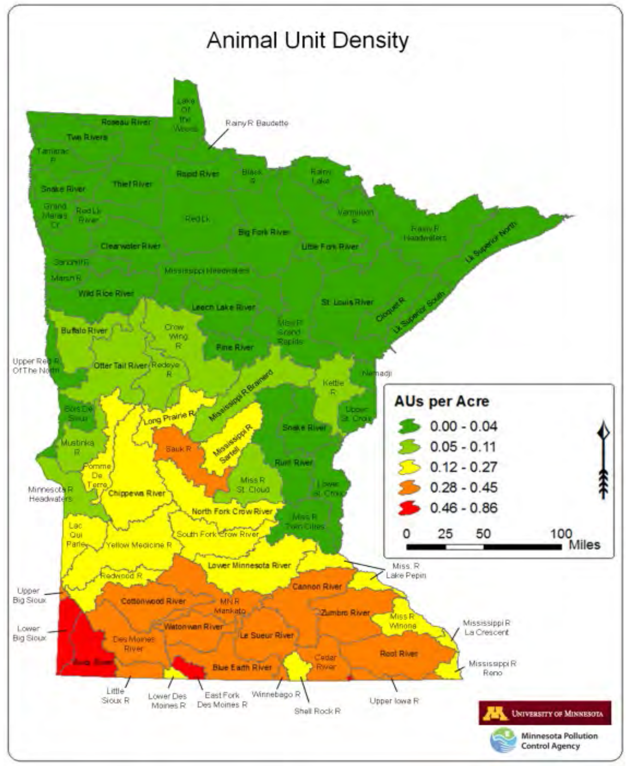
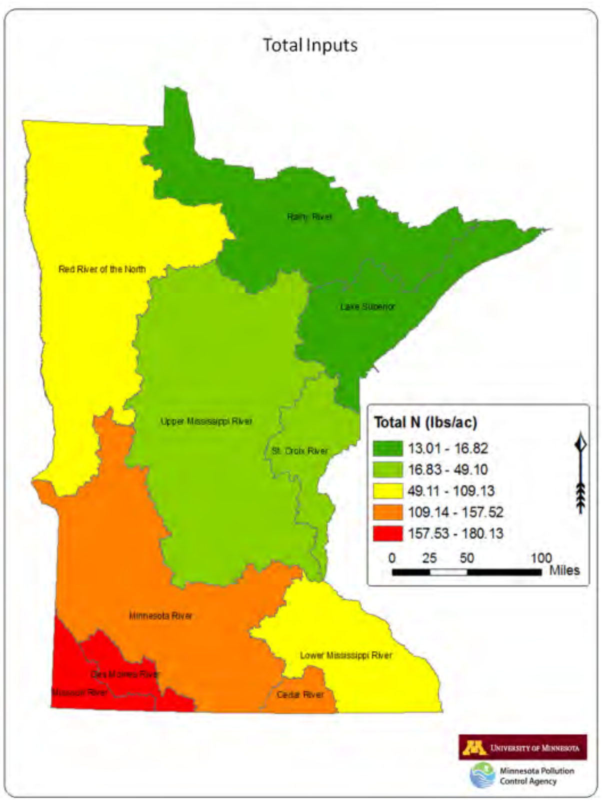


Figure 17. Land applied manure (lb/ac) by basin.

Figure 18. Animal units by major watershed.



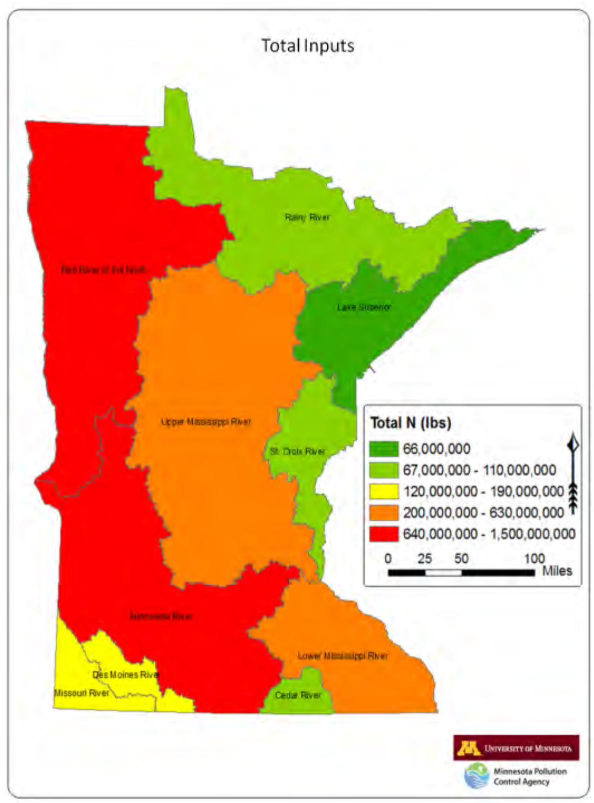


Figure 19. Total inputs of agricultural N (lb/ac) by basin.

Figure 20. Total inputs of ag. N (lb) by basin.

Agricultural nitrogen outputs

Agricultural N outputs to cropland include crop removal (harvest), senescence, denitrification, animals sold, volatilization of fertilizer and manure, incinerated animal manure, milk and eggs sold, and N losses to the surface and groundwater by drainage, leaching and runoff. Animal feed (harvested crop fed to animals) can be compared with agricultural outputs, though technically it is an internally cycled nutrient, and should not be explicitly considered. Agricultural N outputs (including animal feed) total roughly 5.0 billion pounds annually. Crop removal (harvest) accounts for 45% (2.2 billion pounds) of the total N outputs, by far the largest pathway (Figs. 21-22). Harvested crop used for animal feed accounts for another 15% (0.75 billion pounds). Senescence and denitrification account for 14% (0.72 billion pounds) and 10% (0.48 billion pounds), respectively, of the N outputs. Volatilization of fertilizer and manure together account for 6% (0.27 billion pounds). Sales of meat, milk and eggs also account for about 3% (0.16 billion pounds). Losses to the environment by agricultural drainage, leaching and runoff together account for about 6% (0.29 billion pounds) of the total N outputs.

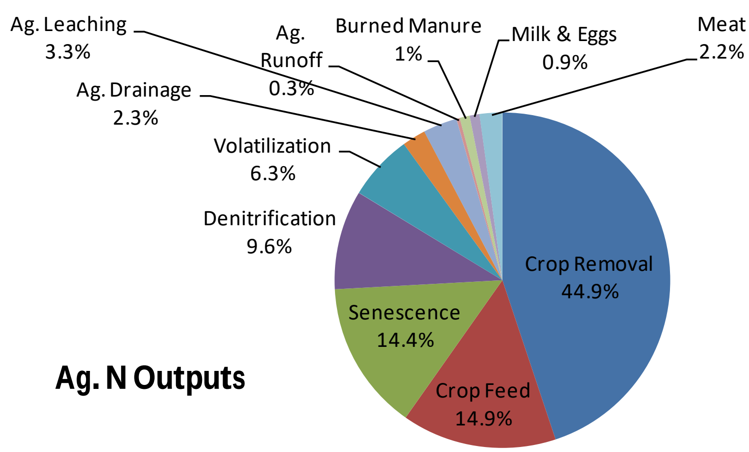


Figure 21. Agricultural N outputs by source (%). Crop removal is crops harvested for sale, export or ethanol production. Animal feed is crops harvested for livestock feeding in Minnesota, plus distiller dry grains from ethanol production that are fed to Minnesota livestock.

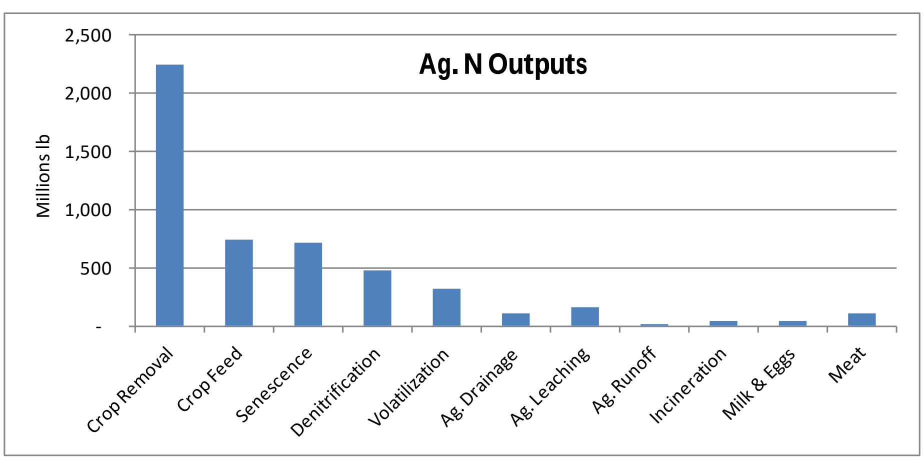


Figure 22. Agricultural N outputs by source (lb). Note that denitrification only refers to soil denitrification, and not subsequent denitrification in the underlying groundwater.

The four basins with the largest agricultural N outputs are the Minnesota River (1.5 billion pounds), Red River of the North (0.85 billion pounds), Upper Mississippi River (0.61 billion pounds), and Lower Mississippi River (0.56 billion pounds) Basins (Figure 23). A majority of the N outputs from each of these Basins arises from crop removal (harvest) and senescence plus denitrification. When normalized by watershed area, crop removal (Figure 24) is largest in the Missouri River and Des Moines River Basins (82-104 pounds/acre). Crop removal averages roughly 75-82 pounds/acre in the Minnesota River and Cedar River Basins. Crop removal accounts for 41-75 pounds/acre in the Lower Mississippi River. Crop removal averages only 3-5 pounds/acre in the Rainy River and Lake Superior Basins. Senescence is largest in the Missouri River and Des Moines River Basins (27-33 pounds/acre). Rates of senescence (Figure 25) average 14-27 pounds/acre in the Lower Mississippi River, Cedar River and Minnesota River Basins. Senescence averages 1-1.5 pounds/acre in the Rainy River and Lake Superior Basins.

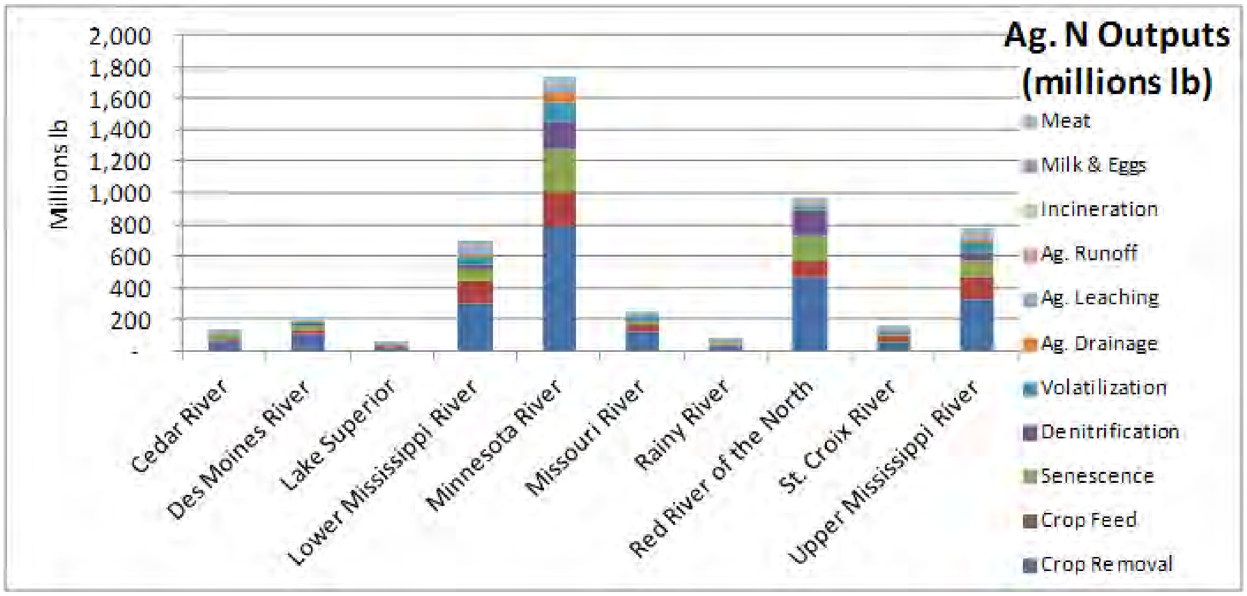


Figure 23. Agricultural N outputs by source (lbs) and river basin.

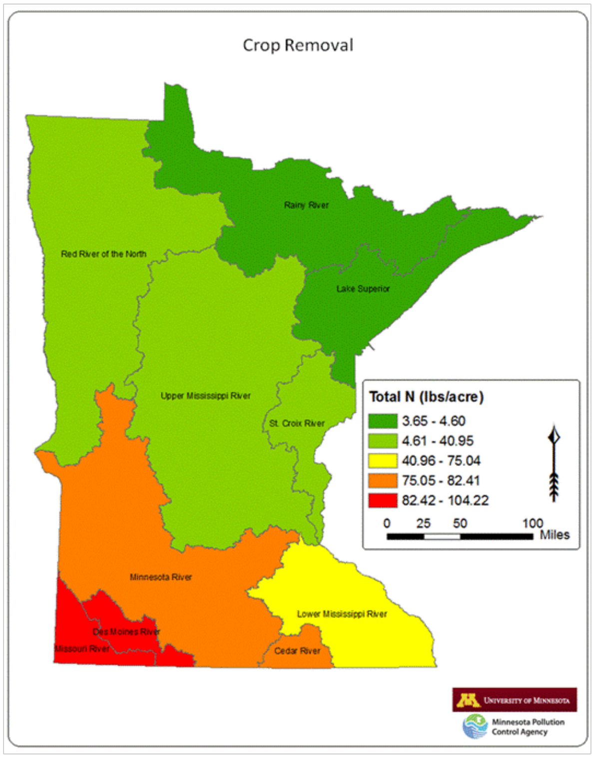


Figure 24. Crop removal (lb/ac, minus animal feed) by basin.

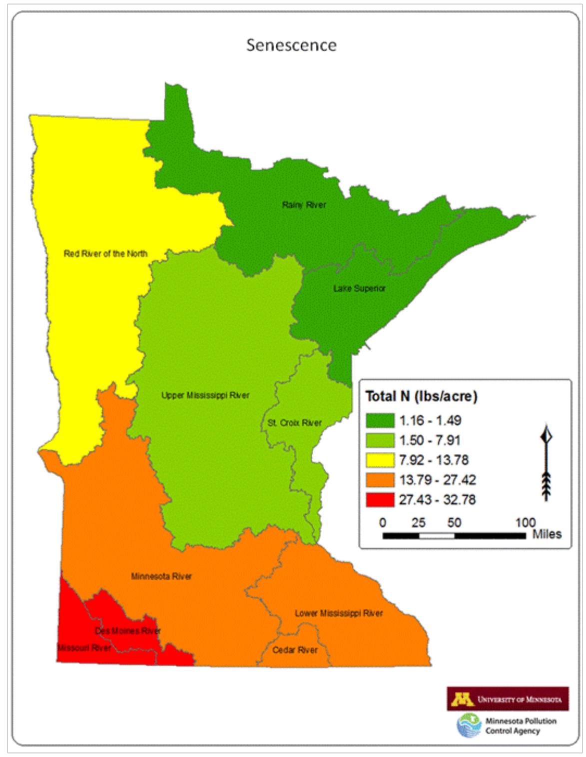


Figure 25. Crop senescence (lb/ac) by basin.

Denitrification is largest in the Minnesota River and Des Moines River (14-20 pounds/acre) Basins (Figure 26). It is moderately large in the Red River of the North and Cedar River (7-14 pounds/acre) Basins. Denitrification is elevated in all four of these Basins relative to the other Basins as a result of a large proportion of land that is poorly drained. Much of this cropland, particularly in the Minnesota River Basin, has been improved by installation of artificial drainage to make growing annual crops more economically profitable or feasible (Figure 27).

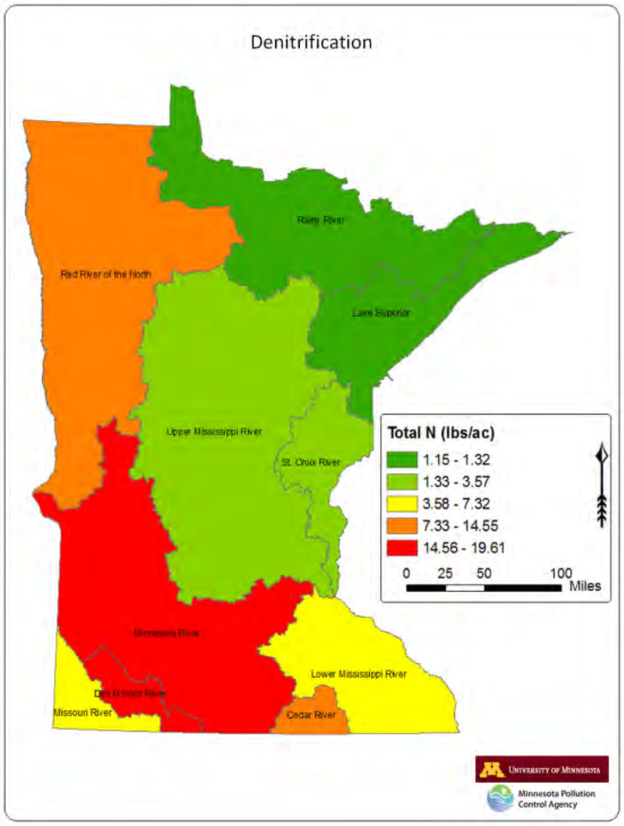


Figure 26. Denitrification (lb/ac) by basin.

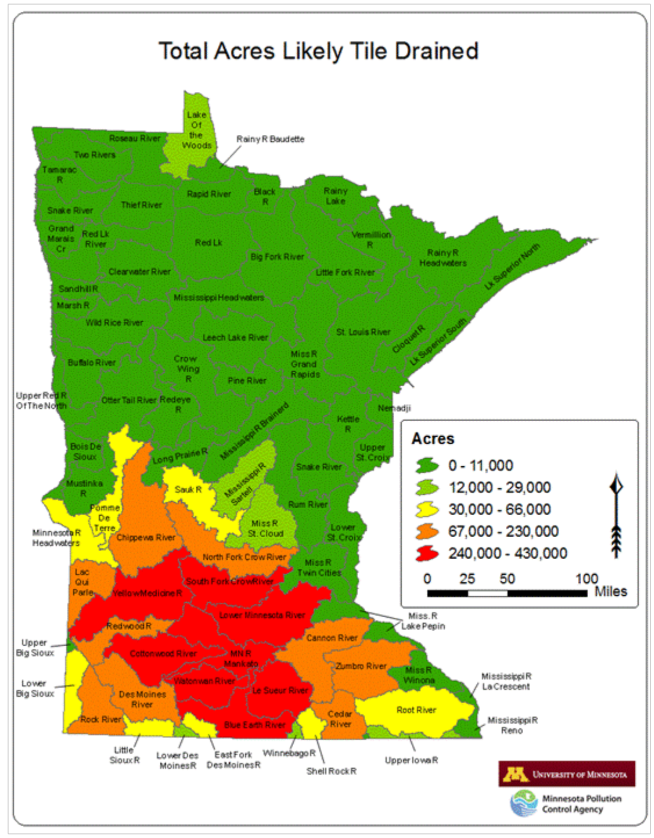


Figure 27. Tile drained acres by major watershed.

Total N outputs (excluding crop harvested for animal feed) normalized to watershed area (Figure 28) are greatest for the Missouri River and Des Moines River Basins, ranging from 179-181 pounds/acre annually. Nitrogen outputs are also significant in the Minnesota River and Cedar River Basins (158 pounds/acre) and the Lower Mississippi River Basin (138 pounds/acre). Total N outputs range between 7 and 9 pounds/acre in the Rainy River and Lake Superior Basins.

Total N outputs (excluding crop harvested for animal feed) are greatest (Figure 29) for the Minnesota River Basin (1.5 billion pounds annually). Total N outputs for the Red River of the North Basin are next highest at 0.85 billion pounds. The Upper Mississippi River Basin (0.61 billion pounds) and Lower Mississippi River Basin (0.56 billion pounds) have moderate amounts of total N outputs. N outputs are less than 0.06 billion pounds in both the Rainy River and Lake Superior Basins.

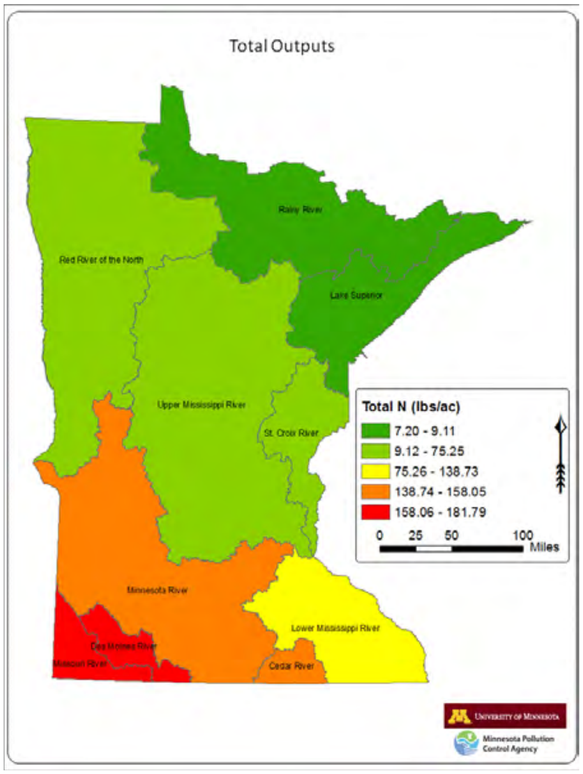


Figure 28. Total ag. N outputs (lb/ac) by basin

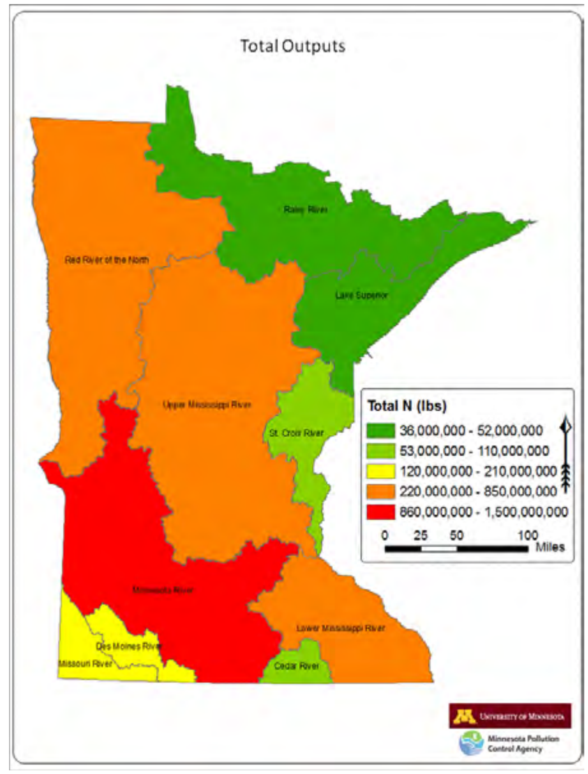
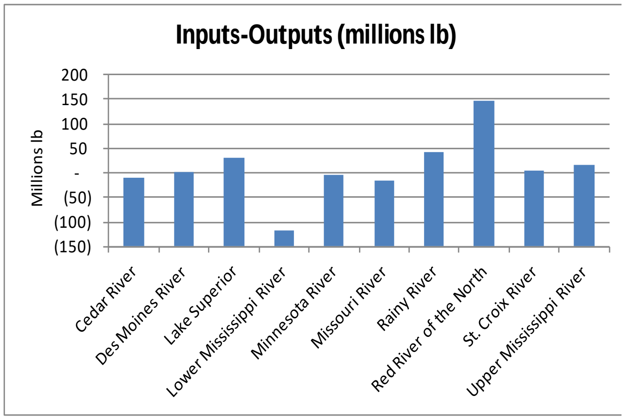


Figure 29. Total ag. N outputs (lb) by basin

Overall nitrogen balance

The overall N balance is obtained by subtracting total N outputs (4.3 billion pounds) from total N inputs (4.2 billion pounds). The inputs and outputs do not include internally recycled N from the harvested crops which are fed to livestock and then later returned to the soil as manure. Results of this give 0.09 billion pounds of N (outputs exceed inputs), about 2.1% of the inputs or outputs. This result shows that the overall N balance is excellent. Individual N balances (Figs. 30a, b) are excellent for the Cedar, Des Moines, Lake Superior, Minnesota, Missouri, Rainy, St. Croix, and Upper Mississippi River Basins (errors less than 1% of total inputs). The errors in the N balance arise primarily from the Lower Mississippi River and Red River of the North Basins. The N balance in the Red River of the North Basin is overestimated by about 3.4% or 0.15 billion pounds (inputs exceed outputs by 13 pounds/acre), while the N balance is underestimated by about 2.8% or 0.12 billion pounds (outputs exceed inputs by 29 pounds/acre) in the Lower Mississippi River Basin (Figs. 31-32).



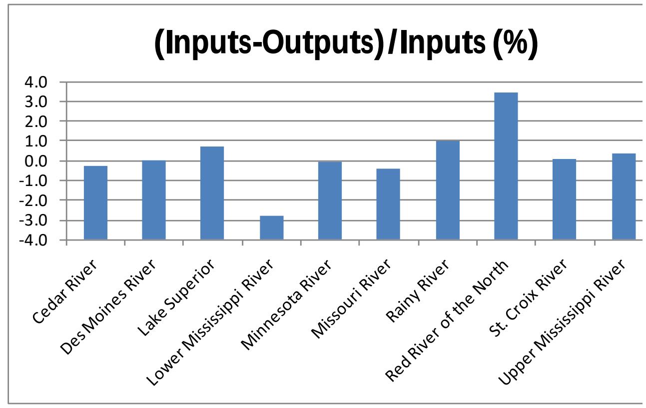


Figure 30a, b. Agricultural N inputs minus outputs (lb or %) by basin.

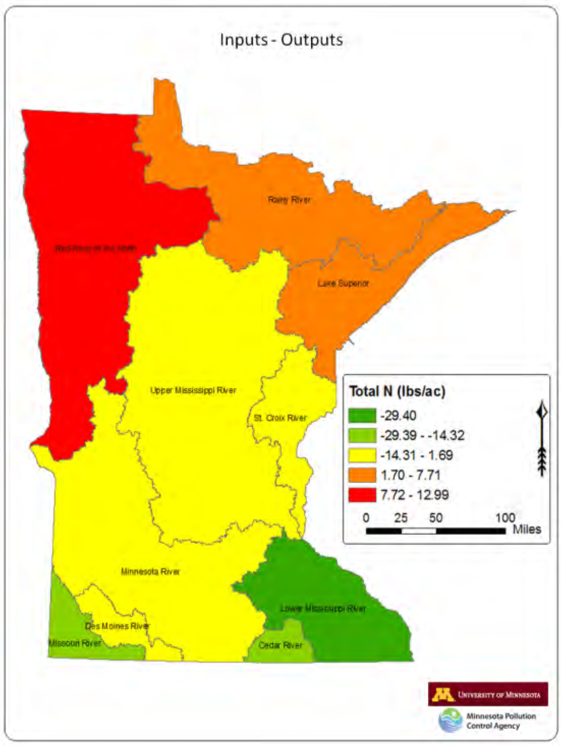


Figure 31. Ag. N inputs minus outputs (lb/ac) by basin

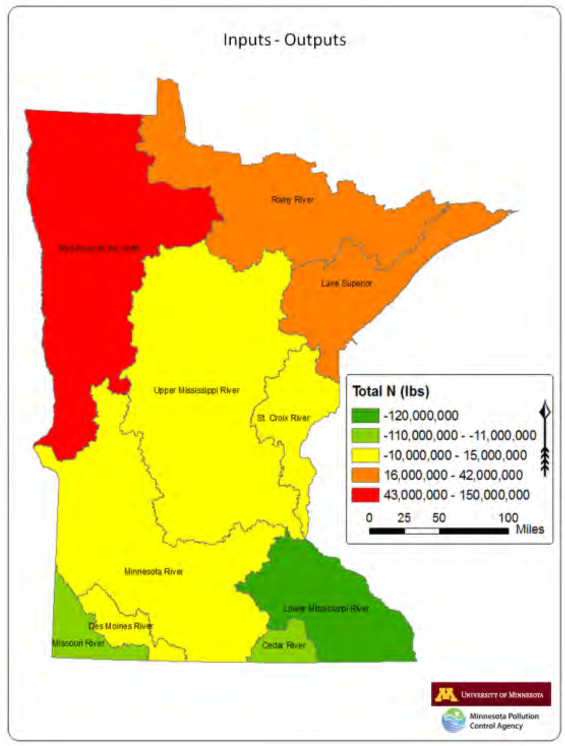


Figure 32. Ag. N inputs minus outputs (lb) by basin.

Agricultural nitrogen balance sensitivity analysis and uncertainty

The agricultural N balance is dependent on many sources of N, each of which itself depends on various coefficients. Development of the agricultural N balance was based on the principle that each source and coefficient should independently be estimated based on the best available data or scientific research relevant to site-specific conditions in Minnesota. As such, there was little to no calibration of sources or coefficients.

There is a certain level of uncertainty inherent with each source and coefficient used in the agricultural N balance. A sensitivity analysis was conducted to determine how varying certain key sources or coefficients would affect the overall agricultural N balance. In the sensitivity analysis, each source or coefficient was varied in increments of plus or minus 5, 10, 15, 25, or 50% of its baseline value. For each of these changes, we computed the resulting percentage change in the overall agricultural N balance relative to its baseline value.

The agricultural N balance was most sensitive to changes in three factors (Figure 33), namely; crop removal (excluding crop harvested for animal feed), net mineralization and amount of applied N fertilizer. Changing any of these three factors by plus or minus 50% would cause the overall balance to change by plus or minus 17-28%.

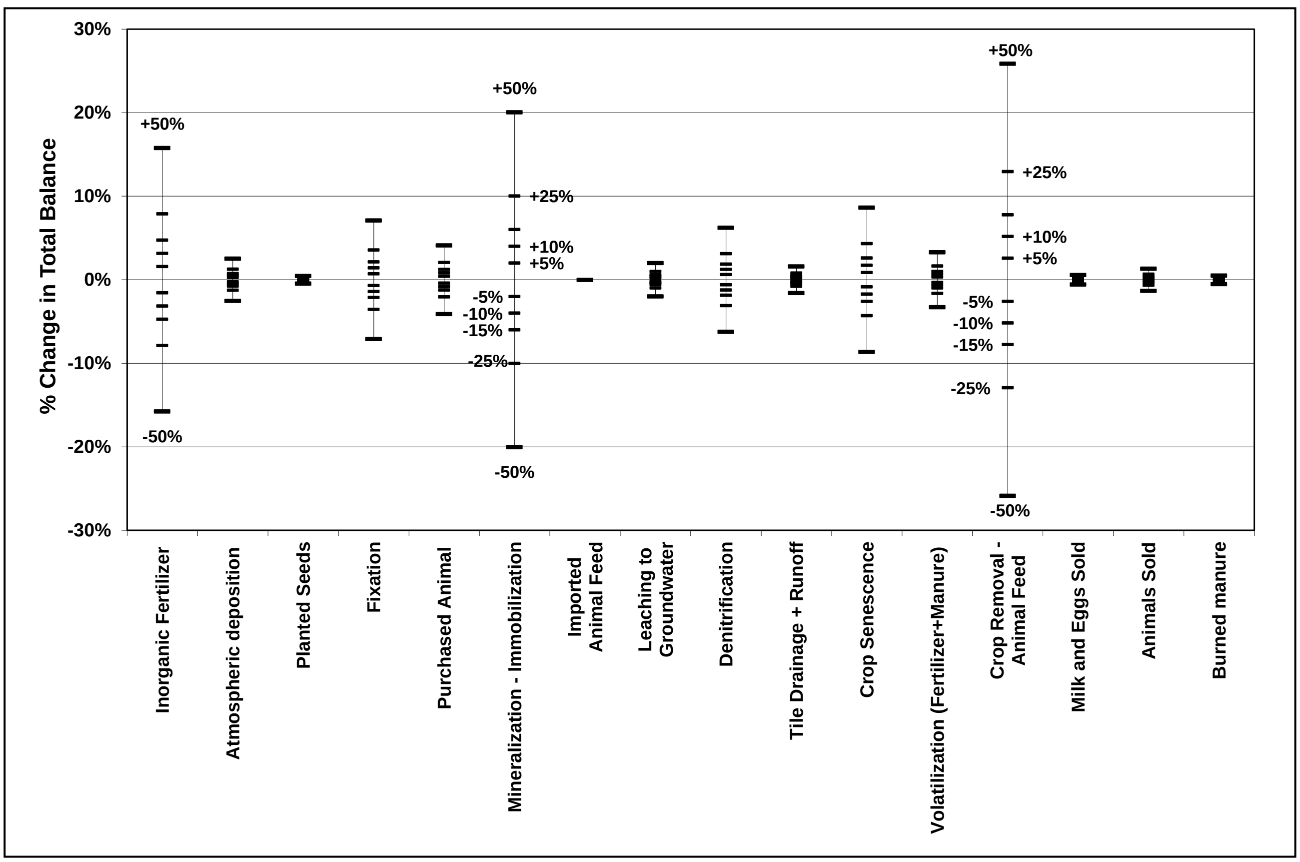


Figure 33. Sensitivity analysis of N input factors on agricultural N balance.

There is a difference, however, between sensitivity and uncertainty. While a change in applied N fertilizer of 50% would cause the N balance to increase by about 17%, the uncertainty in the amount of basin wide N fertilizer application rates is believed to be relatively small. The amount of N fertilizer applied in Minnesota is accurately known compared to other inputs due to good data collection and survey methods to track fertilizer sales and application rates. Similarly, there is a low uncertainty in the amount of N removal by crops, because the amount harvested is accurately known.

In contrast, the amount of net mineralization is moderately uncertain. Net mineralization fluctuates from year to year and place to place based on variations in soil moisture and temperature. Our estimates of net mineralization are based on state-wide average soil moisture and temperature conditions. It is likely that these estimates of net mineralization have an uncertainty of plus or minus 10-25%. With these levels of uncertainty in net mineralization, the N balance would change by up to plus or minus 10% (equivalent to up to 0.4 billion pounds of N). Future research should address the impacts of variations in soil moisture and temperature on net mineralization.

As stated in the previous section, the N balance in the Red River of the North Basin is overestimated by about 0.15 billion pounds, while the N balance in the Lower Mississippi River Basin is underestimated by about 0.12 billion pounds. These differences could be a result of poor estimates of net mineralization in each Basin. The Red River of the North Basin tends to have soils which are cooler and drier than soils in many of the other Basins. This would cause net mineralization to be reduced relative to rates in other Basins. A decrease in net mineralization of 10% in the Red River Basin would be able to correct for the overestimation of N inputs in that Basin. In contrast, soils in the Lower Mississippi River Basin tend to be warmer and wetter than soils in many of the other Basins. This would cause net mineralization to be increased relative to rates in other basins. An increase in net mineralization of 10% in the Lower Mississippi River Basin would be able to correct for the underestimation of N inputs in that basin.

The agricultural N balance was moderately sensitive to three factors, namely; senescence, denitrification, and N fixation. All three of these factors are known to be rather uncertain as a result of variations in climate and soil type. Yet, changing any one of these three factors by as much as plus or minus 50% would only cause the N balance to change by plus or minus 6-9%. Therefore, while we are uncertain about the values of senescence, denitrification or N fixation, errors in estimating them would not cause large changes in the N balance.

Uncertainty in any of the remaining factors (atmospheric deposition, planted seeds, purchased animals, N losses to groundwater, N losses in runoff or tile drainage, volatilization of fertilizer or manure or sales of milk, eggs or meat) would have only minor impacts on the agricultural N balance. Changing any one of these factors would change the agricultural N balance by at most a few percent.

Results: Minnesota nonpoint source N loadings to surface waters

Total nonpoint source N loadings to Minnesota surface waters are estimated at 254 million pounds during an average climatic year. Sources of N loadings to surface waters included cropland drainage (114 million pounds in an average year), cropland runoff (16 million pounds) and cropland leaching (93 million pounds); forest export of N (22 million pounds); urban/suburban export of nonpoint source N (3 million pounds); feedlot runoff (0.2 million pounds), and individual septic treatment system losses (5 million pounds).

The spatial distribution of modeled (estimated through this study) total nonpoint source N loadings to Minnesota surface waters during an average climatic year is shown in Figure 34. These modeled results compare well with water quality monitoring data as shown below (Figure 35). Predicted N loadings are highest for the Zumbro and Root Rivers of southeastern Minnesota, where N loadings from groundwater, drainage and runoff are all high. Predicted N loadings are next highest in a cluster of major watersheds centered in the Minnesota River Basin, where N losses in drainage are high, but groundwater and runoff losses are smaller than in southeastern Minnesota. These 15 major watersheds in southeastern, southern, and west central Minnesota contribute 140.6 million pounds of nonpoint source N loadings to surface waters. This is 55% of estimated N loadings in the entire state of Minnesota. On a per acre basis, the highest loadings occur in 8 watersheds located in southern Minnesota (Figure 34). Loadings per acre are generally highest in the Minnesota River and Lower Mississippi River Basins.

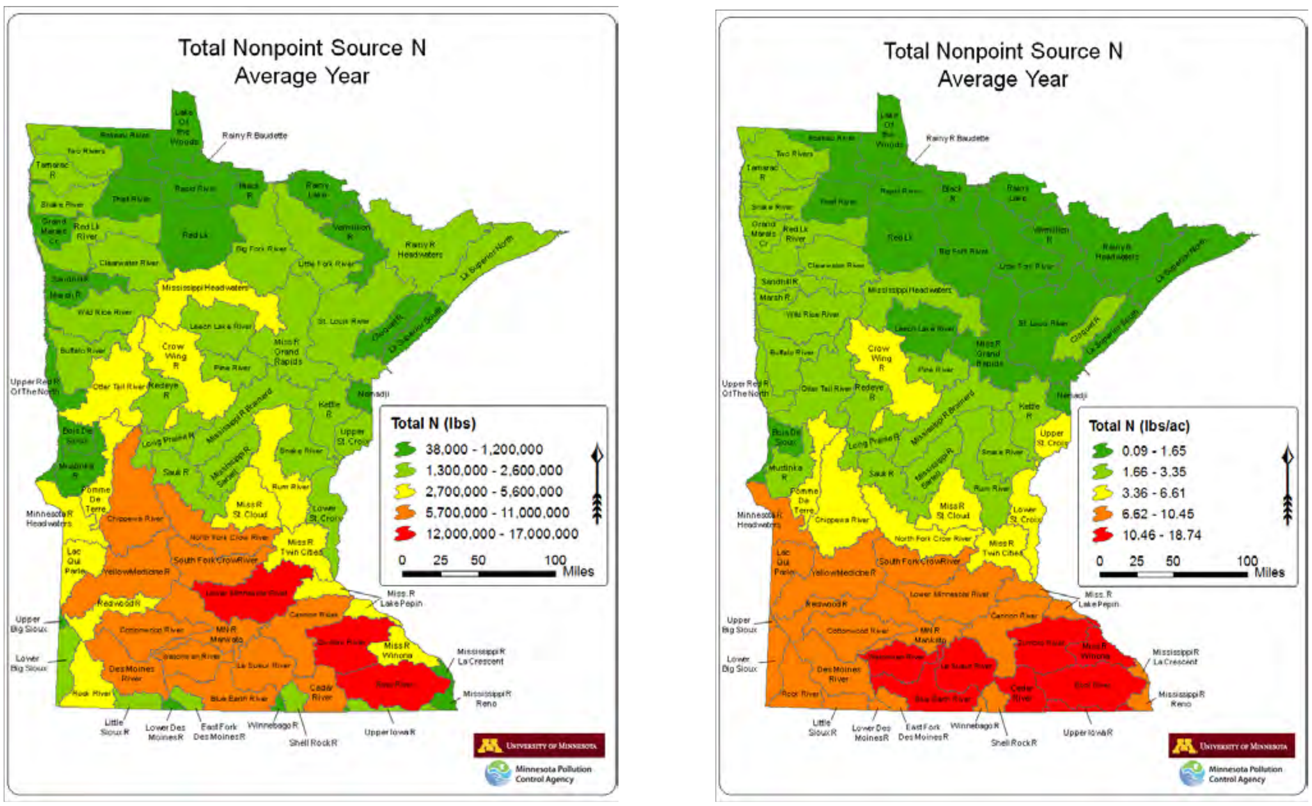


Figure 34. Modeled average N loading to major watersheds, in lb (left) or lb/ac (right).

Comparison between modeled and monitored nitrogen loadings

A comparison between the combined-source modeled nonpoint source N loadings to Minnesota surface waters (in an average climatic year) and monitored N loadings (average of two typical years) was conducted for 33 MPCA monitored major watersheds across Minnesota. Monitored N loadings were not used to calibrate the modeled nonpoint source N loadings, as the modeled N loadings were estimated independently, without calibration. Linear regression between modeled and MPCA monitored N loads (Figure 35) was very good ($y = 1.33x – 631,920$; $R^2 = 0.69$). Modeled N loadings across all monitored watersheds were 10% higher than monitored N loads. It should be noted that modeled nonpoint source loadings are estimated before in-stream and channel losses would take place (these are reflected in observed monitoring results). Thus, it is not surprising that modeled N loads are larger than monitored N loads. Other differences could arise because monitoring results include effects of point sources, whereas modeled results do not.

Further analyses comparing river monitoring results and estimated total N delivered to waters from all sources (point sources, nonpoint sources and atmospheric deposition directly into waters) are described in Chapter E1.

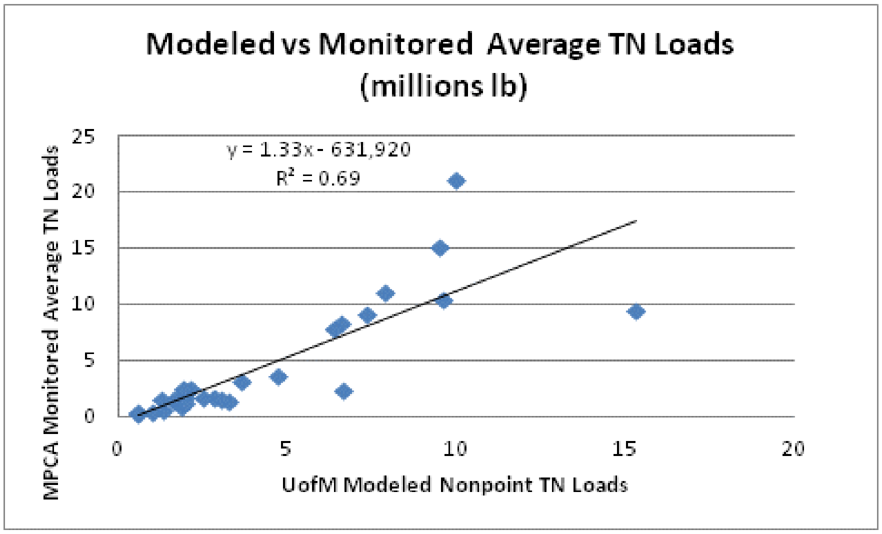


Figure 35. Modeled versus monitored major watershed N loads. Each point represents one HUC8 watershed average TN load obtained between 2007 and 2009.

The Lake Superior Basin consists of 5 major watersheds, 3 of which have one year of water quality monitoring data. Modeled nonpoint N loads in the Cloquet River are comparable in magnitude to average monitored total N loads (Figure 36). Modeled nonpoint N loads are lower than monitored loads in the St. Louis River watershed.

The Rainy River Basin consists of 9 major watersheds, 3 of which each have three years of water quality monitoring data. Modeled nonpoint N loads in the Vermillion, Little Fork, and Big Fork River watersheds are comparable in magnitude to average monitored total N loads (Figure 37). Modeled nonpoint loads are slightly lower than monitored loads in the Little Fork watershed.

The Red River of the North Basin consists of 17 major watersheds. Eleven of these have one to three years of water quality monitoring data. Modeled nonpoint source N loads in the Otter Tail, Buffalo, Marsh, Wild Rice, Sandhill, Thief, Clearwater, Snake, and Tamarac River watersheds are higher than average water quality monitoring results (Figure 38). This is reasonable, given the fact that modeled N loads do not account for in-water denitrification beyond the edge of field. Modeled nonpoint source N loads in the Two Rivers watershed are lower than monitored N loads.

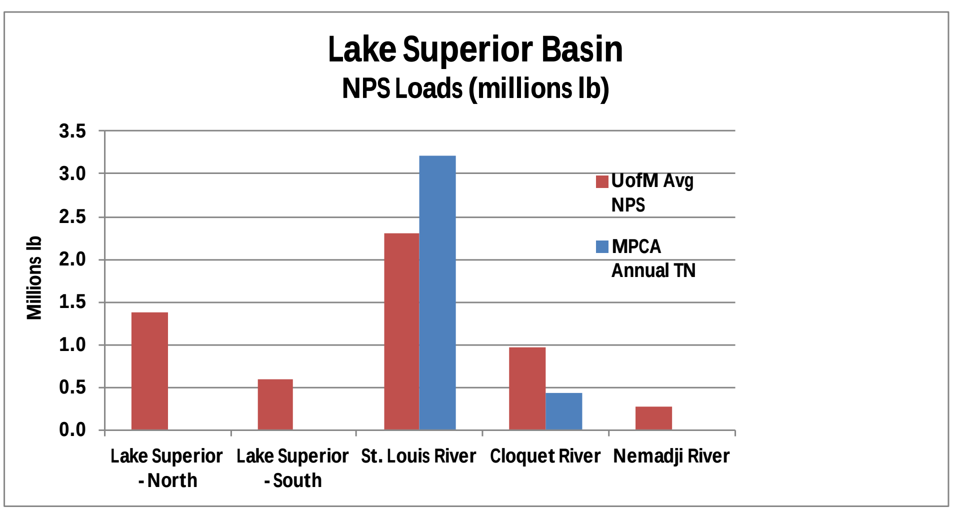


Figure 36. Modeled versus monitored N loads Lake Superior Basin.

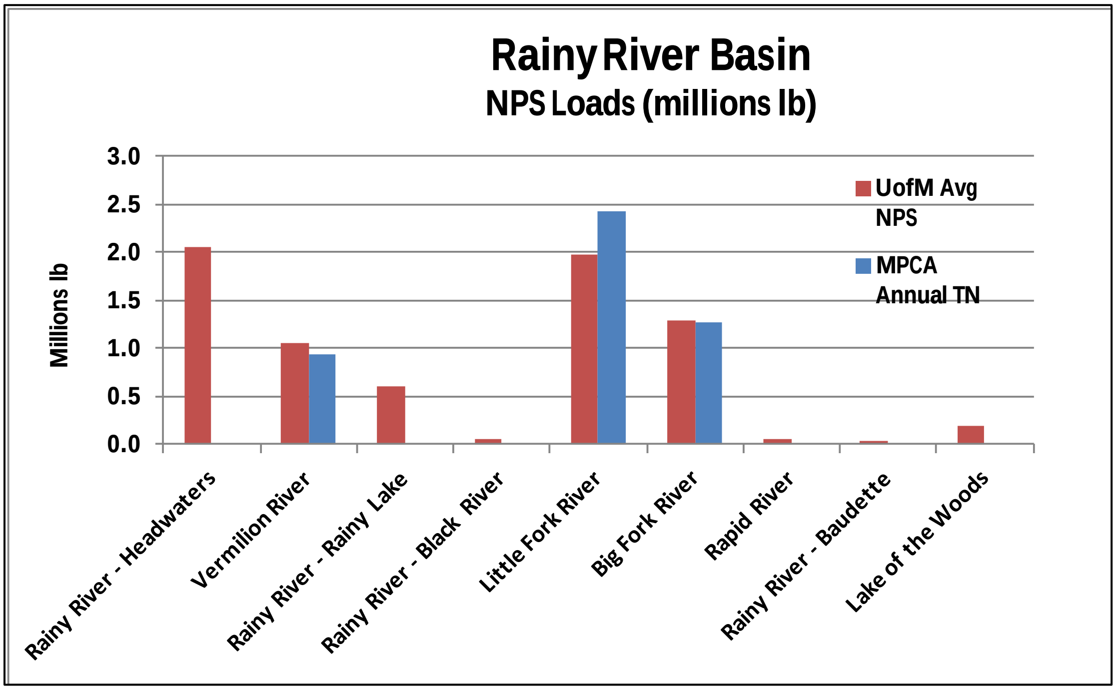


Figure 37. Modeled versus monitored N loads Rainy River Basin.

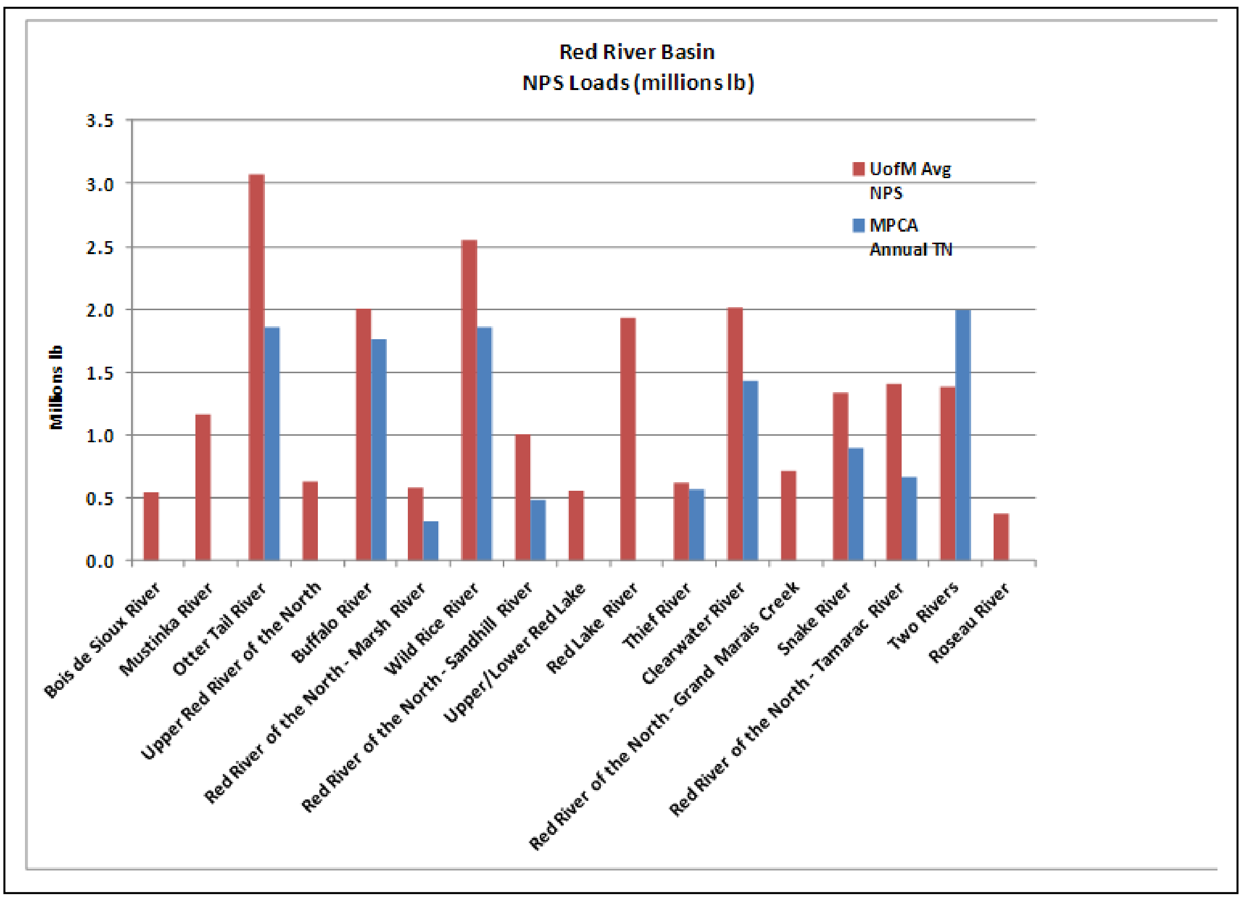


Figure 38. Modeled versus monitored N loads Red River of the North Basin.

There are 15 major watersheds in the Upper Mississippi River Basin. Nine watersheds have from one to three years of water quality monitoring data. Modeled nonpoint source N loads are higher than average water quality monitoring results in the Leech Lake, Pine, Crow Wing, Red Eye, Long Prairie, and Rum River watersheds (Figure 39). This is to be expected, since modeled N loads do not account for denitrification or biological uptake that occurs beyond the edge of field. Modeled N loads are quite a bit higher than measured loads in the North Fork of the Crow River watershed. The South Fork of the Crow River watershed has about 0.5 million pounds of N from point sources that are not included in modeled results. Modeled N loads in the Upper Mississippi River Twin Cities watershed also do not include about 11 million pounds of point sources.

The St. Croix River Basin includes 4 major watersheds, of which 2 have each been monitored for three years of water quality data. Modeled nonpoint source N loads are very comparable to (although somewhat higher than) average monitored water quality data in the Kettle and Snake River watersheds (Figure 40).

The Lower Mississippi River Basin includes 7 major watersheds. The Cannon and Root River watersheds have been monitored for water quality during the last 17 to 18 years. Modeled nonpoint source N loads are slightly larger than average water quality monitoring data in both the Cannon and Root River watersheds (Figure 41). Thus, modeled and monitored N loads agree quite well in the Lower Mississippi River Basin.

The Minnesota River Basin includes 12 major watersheds. Nine of these watersheds have been monitored for one to three years by the MPCA. Modeled nonpoint source N loads are somewhat larger than, or comparable in magnitude to average water quality monitoring data in the Pomme de Terre, Chippewa, Redwood, and Watonwan River watersheds (Figure 42). Modeled N loads are significantly higher than measured loads in the Cottonwood River watershed. Modeled N loads are significantly lower than measured N loads in the Le Sueur and Blue Earth River watersheds.

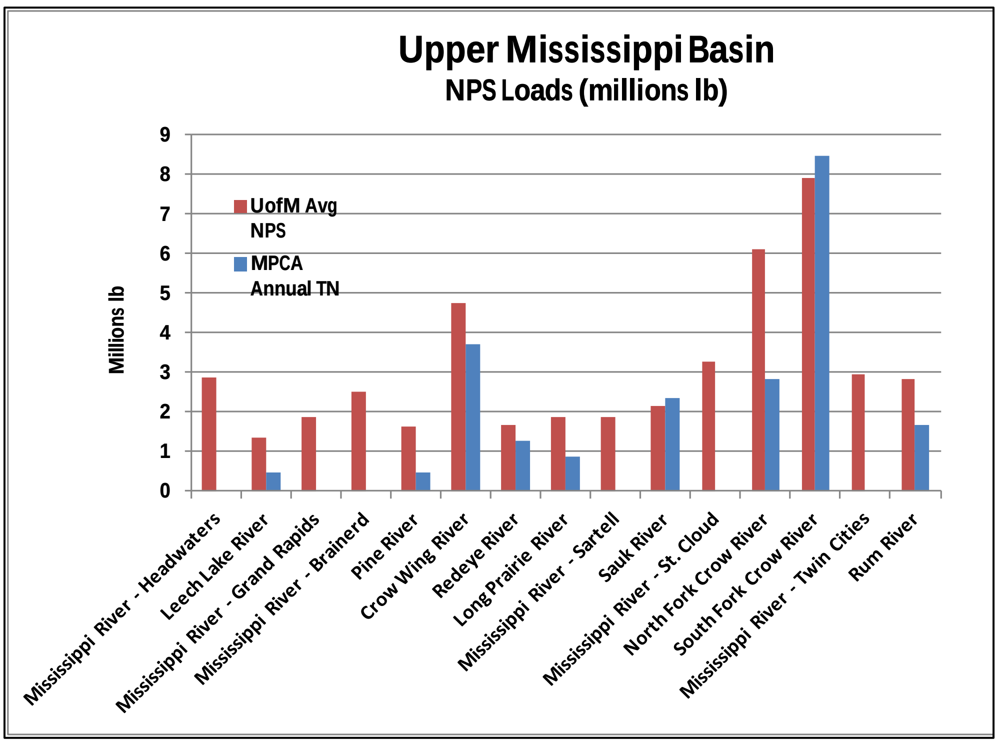


Figure 39. Modeled versus monitored N loads in the Upper Mississippi River Basin

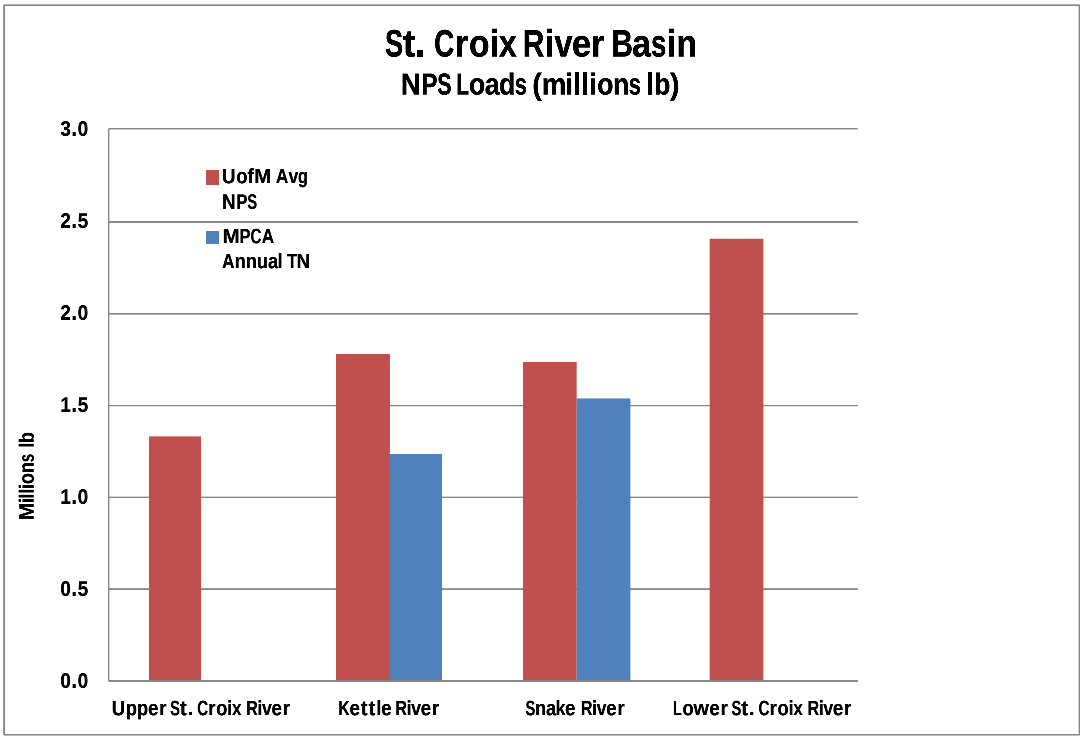


Figure 40. Modeled versus monitored N loads in the St. Croix River Basin.

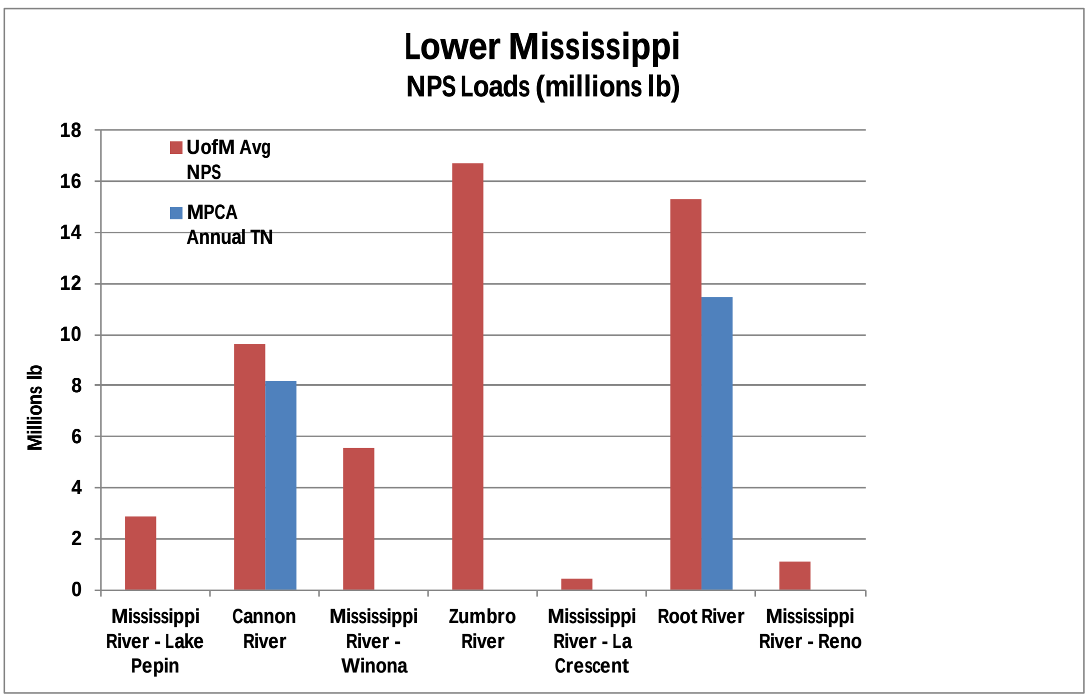


Figure 41. Modeled versus monitored N loads in the Lower Mississippi River Basin.

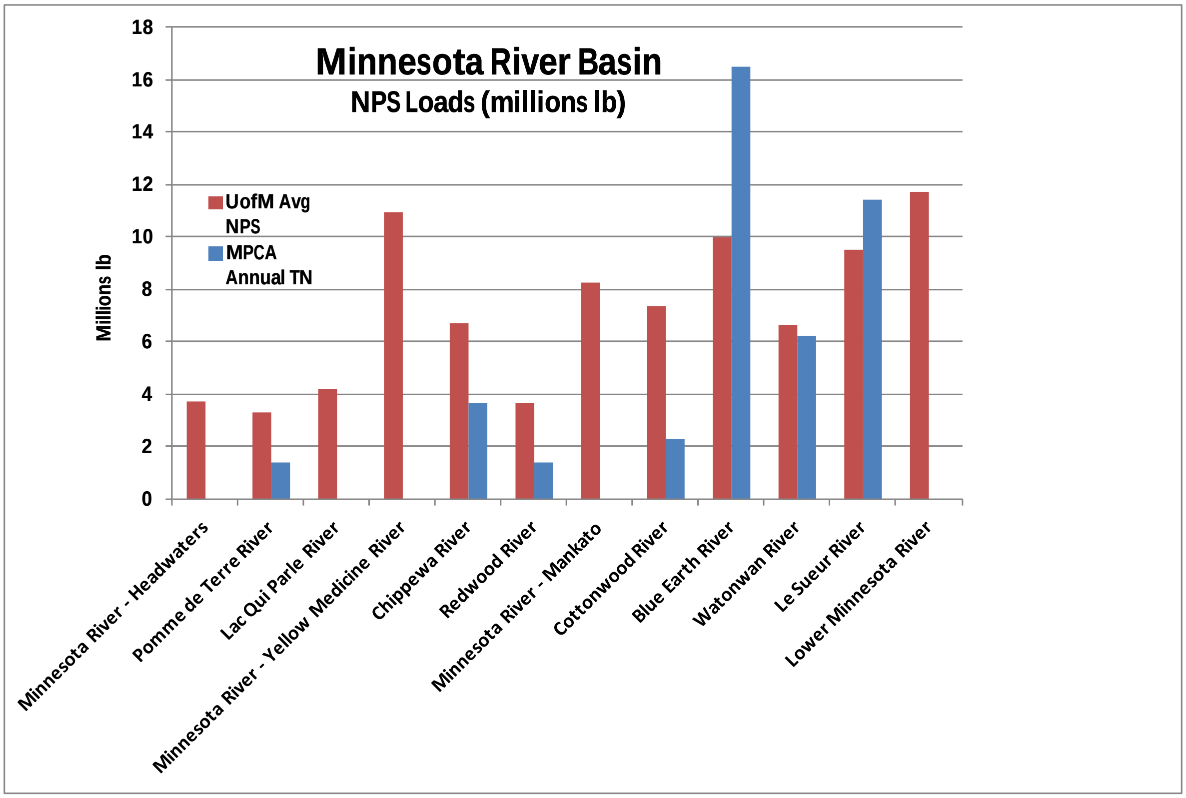


Figure 42. Modeled versus monitored N loads in the Minnesota River Basin.

Several possible reasons could be invoked to explain the difference between modeled and monitored N loads in the Blue Earth and Le Sueur River watersheds. These watersheds have large areas of lacustrine soils and are intensively tile-drained. The modeled tile drainage losses may be underestimated in these watersheds, due to underestimates of tile-drained lands and/or underestimating losses from tile-drained fields. Second, the Blue Earth and Le Sueur River watersheds have some very deeply incised river channels and there is significant seepage along the bluff faces. This seepage of groundwater could be a source of additional N that is not accounted for in the modeled results.

Uncertainties in nitrogen loadings

The three primary pathways for N loadings in agricultural regions were by drainage, leaching, and runoff. There are uncertainties in the factors and coefficients used to estimate N loadings via each pathway. Losses of N in agricultural drainage are primarily dependent on three factors, namely; the areal extent of tile drainage, growing season precipitation, and the amount of N applied to cropland from fertilizer and manure. A sensitivity analysis was conducted to determine how changes in each of these factors affected the losses of N in agricultural drainage (Figure 43). Nitrogen losses in agricultural drainage were very sensitive to growing season precipitation. Increasing or decreasing growing season precipitation by 50% caused N losses in agricultural drainage to increase or decrease by 150%. This has important implications for comparisons between modeled nonpoint source N losses and monitored N losses in tile drained regions. If the period when water quality monitoring data were collected is wetter or dryer than average, modeled N losses will be smaller than or larger than monitored N losses, respectively. Nitrogen losses in drainage were much less sensitive to changes in tile drained area or applied N rates. Changes in either factor of up to plus or minus 50% would change the modeled N losses in drainage by less than plus or minus 50%. As mentioned previously, there is little relative uncertainty in applied N rates. The areal extent of tile drained lands may be larger than the area estimated for this study if landscapes steeper than 3% slope or soils with hydrologic group B have subsurface tile drainage.

Underestimation of tile drained acreages was limited to less than 10% in the small Beauford Watershed located in the Le Sueur major watershed. If the underestimation of tile drainage is limited to 10% or less, then the resulting uncertainty in drainage N losses would be less than 10%. The extent of tile drainage is likely underestimated in the Minnesota River Basin. Adjusting for this would increase N loadings in tile drained regions of the Minnesota River Basin.

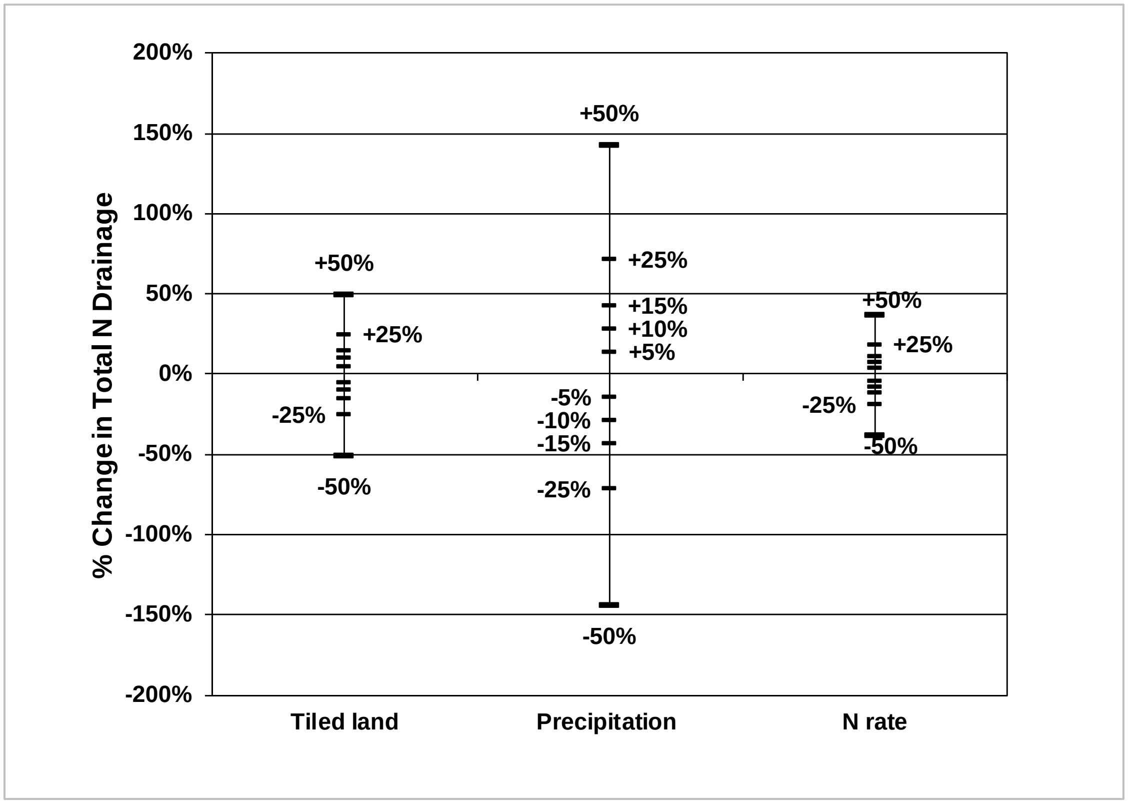


Figure 43. Sensitivity analysis for N losses in agricultural drainage.

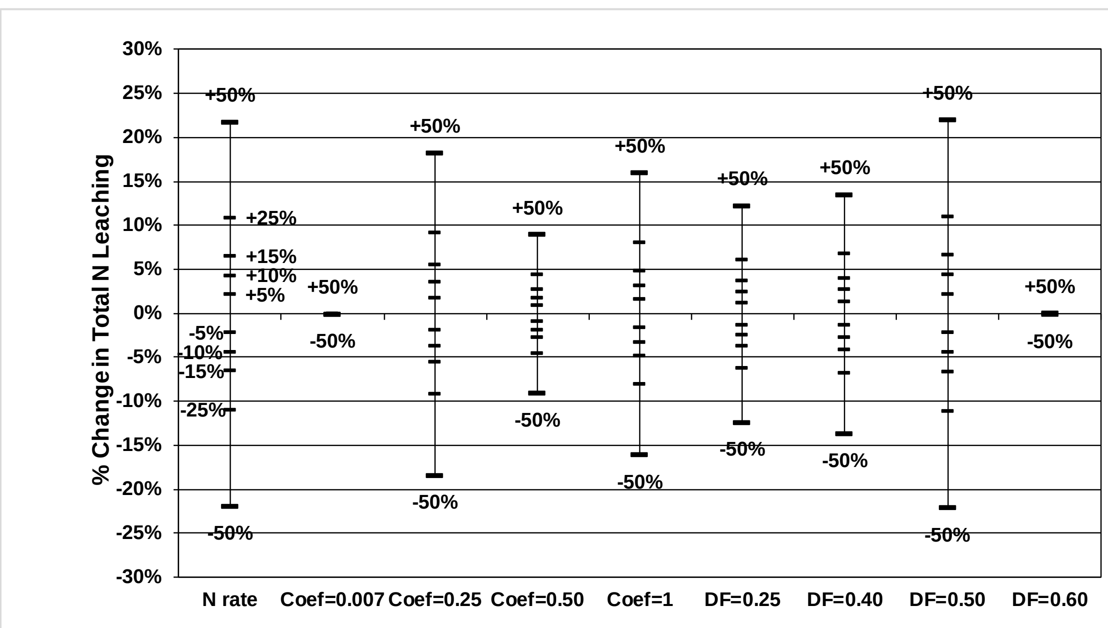


Figure 44. Sensitivity analysis for agricultural leaching contributions to surface water N loads.

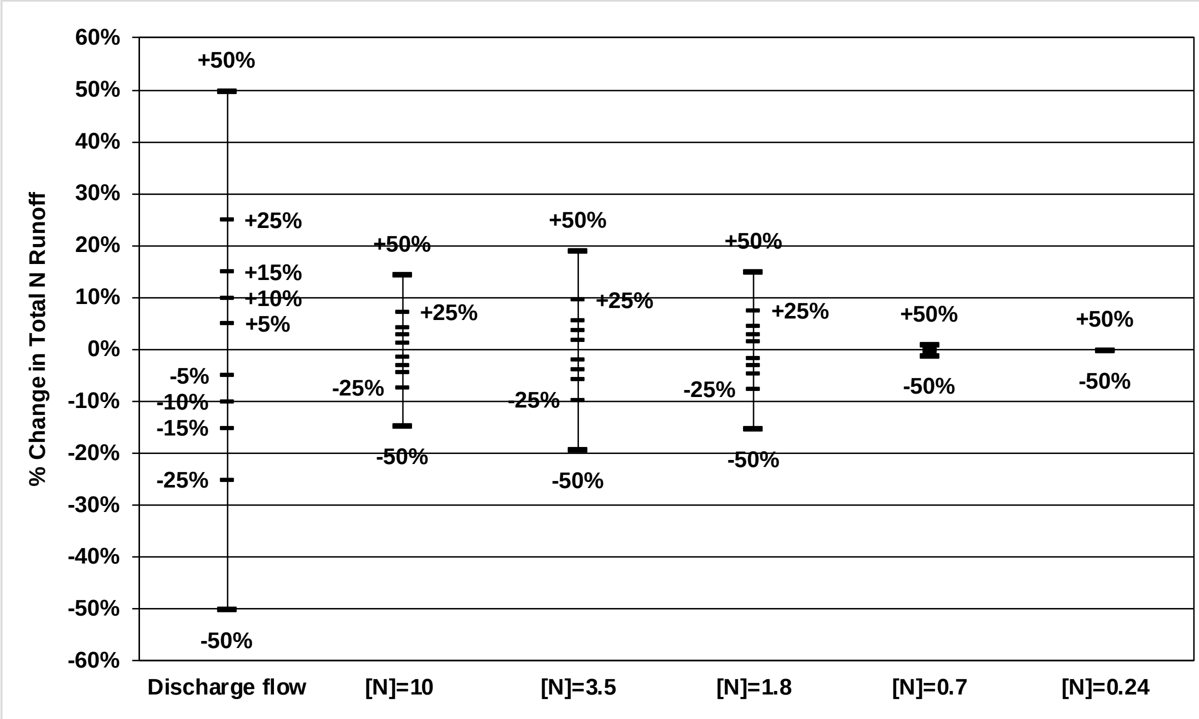


Figure 45. Sensitivity analysis for N losses in agricultural runoff.

Losses of N in agricultural leaching, with subsequent discharge of groundwater to surface waters, are estimated using algorithms that depend on applied N rate and precipitation. Modeled losses of N for a given precipitation or irrigation regime are primarily affected by four coefficients along with the rate of applied N (Figure 44). As discussed previously, there is little uncertainty in the rate of applied N. The four coefficients determine by how much the leaching algorithm is adjusted for each region of the state. Changing coefficient one would have an insignificant impact on N losses by leaching. Changing any one of coefficients two-four by plus or minus 50% would change the modeled N losses by leaching by plus or minus 9-18%. Because of limited leaching quantification studies, uncertainty exists in the four leaching coefficients, especially coefficients for regions 2 and 3. More important, and more uncertain, are values of groundwater denitrification prior to surface water discharge. Changing the first three denitrification coefficients by plus or minus 50% would increase or decrease groundwater discharge of N to surface water by 17-22%.

Losses of N in agricultural runoff are estimated based on amounts of river discharge contributed by runoff and by concentrations of N in runoff. There are five values used for concentration of N in runoff (ranging from 0.24 to 10 mg/L), which vary region by region across the state. In general, results of the sensitivity analysis showed that as N concentration in runoff increased, the sensitivity of the modeled N losses in runoff also increased (Figure 45). In regions where N concentration in runoff is between 1.8 and 10 mg/L, changing N concentrations in runoff by 50% would change modeled N losses in runoff by up to plus or minus 25%. In regions where N concentration in runoff is between 0.24 and 0.7 mg/L, changing N concentration in runoff by 50% would have little impact on modeled N losses in runoff. Of greater importance is the sensitivity of the model to river discharge, which is sensitive to precipitation. Changing discharge by plus or minus 50% would change modeled N losses in runoff by plus or minus 50%.

Fortunately, river discharges are well known for dry, average and wet climatic conditions for various regions across the state. Hence, there is little uncertainty in river discharge for these three climatic regimes.

Variation in nitrogen loads for dry, average and wet climatic years

Climate has a significant effect on nonpoint source N loadings to surface waters in Minnesota. Total loadings of N to surface waters modeled for dry, average and wet years are roughly 106, 254, and 409 million pounds, respectively (Figure 46). Nitrogen losses by cropland leaching to groundwater and tile drainage are particularly sensitive to an increasingly wetter climate.

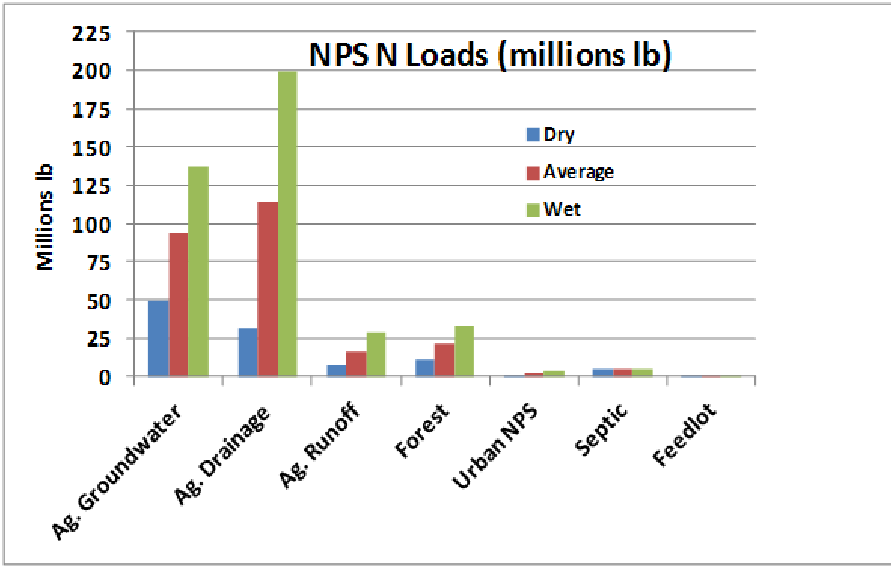


Figure 46. Statewide nonpoint source N loads (lbs) for various sources in dry, average and wet years.

During a dry year (10th percentile precipitation years), the majority (46%) of nonpoint source N losses to surface waters arises from groundwater discharge (Figure 47). Losses from tile drainage (30%) and runoff (7%) on cropland are much smaller in comparison during a dry year. Losses from forested regions account for 10% of the total nonpoint source losses to surface waters. Septic system losses account for 5%. Losses of nonpoint source N from urban areas and feedlots are very small.

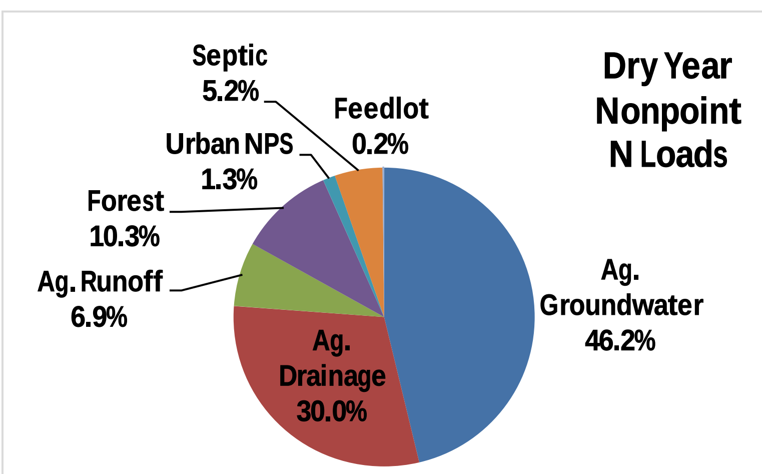


Figure 47. Statewide nonpoint source N loads (%) for various sources in a dry year.

Losses of nonpoint source N during a dry year are largest for the Minnesota River watershed (30 million pounds), followed by the Lower Mississippi River watershed (27 million pounds) and the Upper Mississippi River watershed, with 21 million pounds of losses (Figure 48). Losses in the Red River of the North are about 10 million pounds. The other basins all have very small losses of nonpoint source N during a dry year.

During an average year (Figure 49), the nonpoint source losses from agricultural drainage (45%) increase relative to the losses from agricultural groundwater discharge (37%) in comparison with the losses during a dry year. Forest export of N accounts for 9% of the nonpoint source N losses during an average year, while agricultural runoff accounts for 6%. Septic system and urban losses account for only 2% and 1% of the total nonpoint sources, respectively. Losses from feedlots are insignificant.

During an average year, the Minnesota River Basin (34% or 86 million pounds of total nonpoint source N loadings) contributes more nonpoint source N losses than any other basin (Figs. 50-51). The Lower Mississippi River Basin (21% or 54 million pounds) contributes less than the Minnesota River Basin during an average year, in contrast to their relative contributions in a dry year. Modeled losses of nonpoint source N in the Upper Mississippi River are 18% or 46 million pounds. Losses from the Red River of the North are about 9% or 22 million pounds. The other basins contribute small nonpoint source N losses in comparison to the Minnesota, and Lower and Upper Mississippi River Basins.

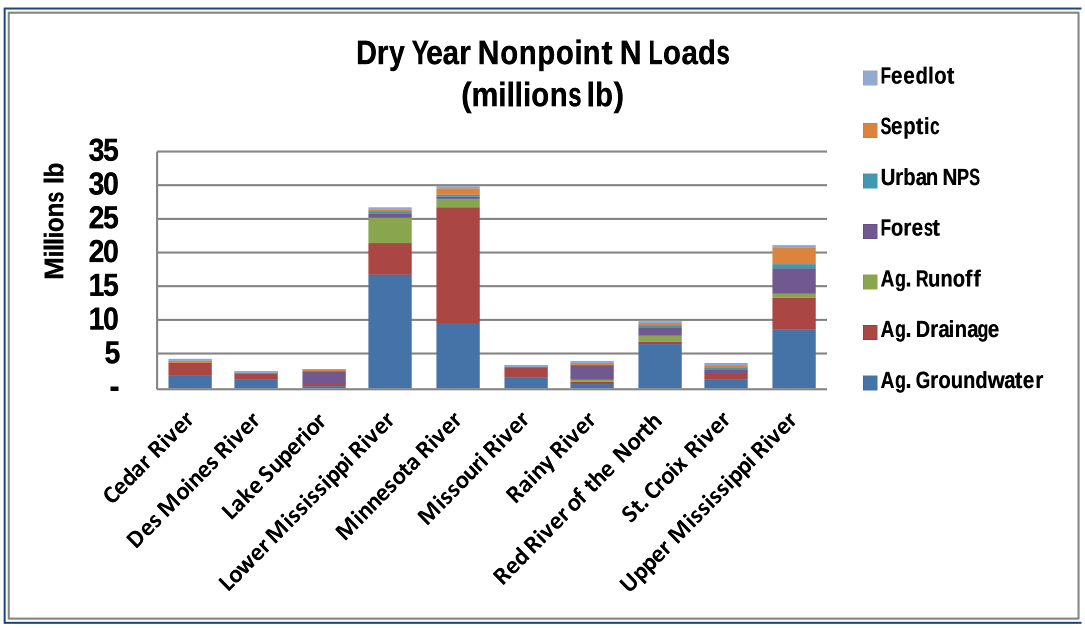


Figure 48. Nonpoint source N loads (lb) for various sources by river basin in a dry year.

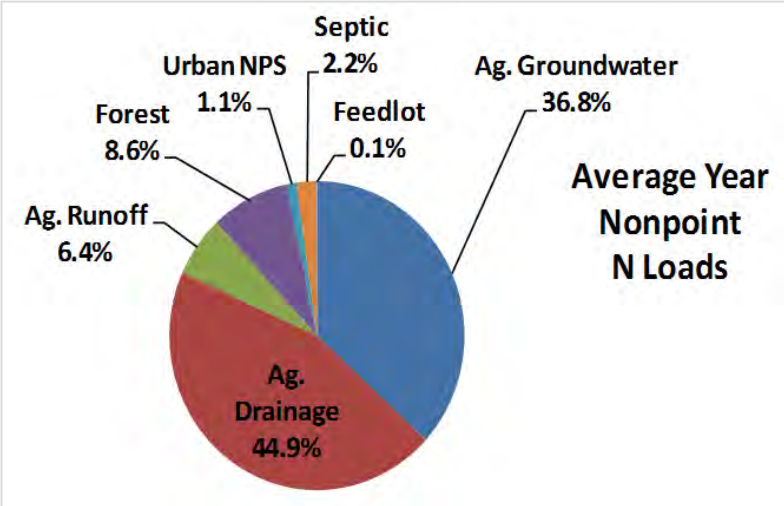


Figure 49. Statewide nonpoint source N loads (%) for various sources in an average year.

During a wet year (90th percentile precipitation year), the majority of nonpoint source N losses statewide (Fig. 52) arise from agricultural drainage (49%). Discharge of groundwater from agricultural regions contributes another 34%. Forested regions generate 8%, and agricultural runoff generates 7% of the statewide nonpoint source N losses during a wet year. Other sources are relatively small in comparison.

The largest nonpoint source N losses in a wet year (Figure 53) occur in the Minnesota River Basin (146 million pounds). The Lower and Upper Mississippi River Basins generate 82 and 70 million pounds, respectively, of nonpoint source N during a wet year. The Red River of the North generates 36 million pounds. Other basins generate less than 15 million pounds each of nonpoint source N during a wet year.

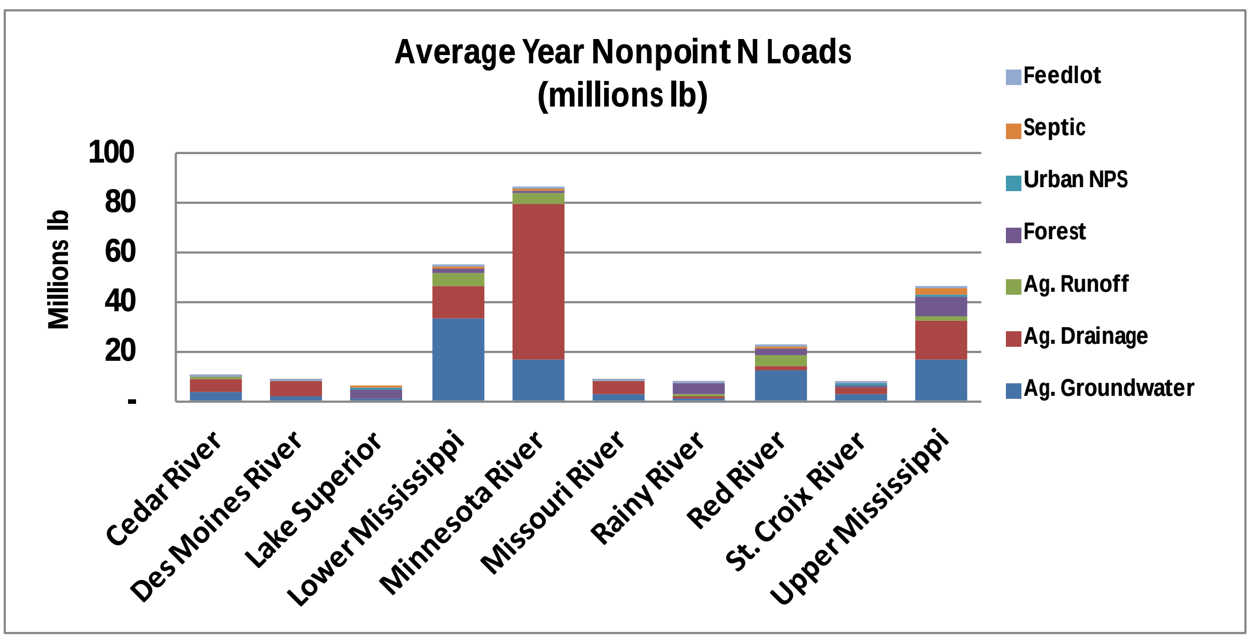


Figure 50. Nonpoint source N loads (lb) for various sources by river basin in an average year.

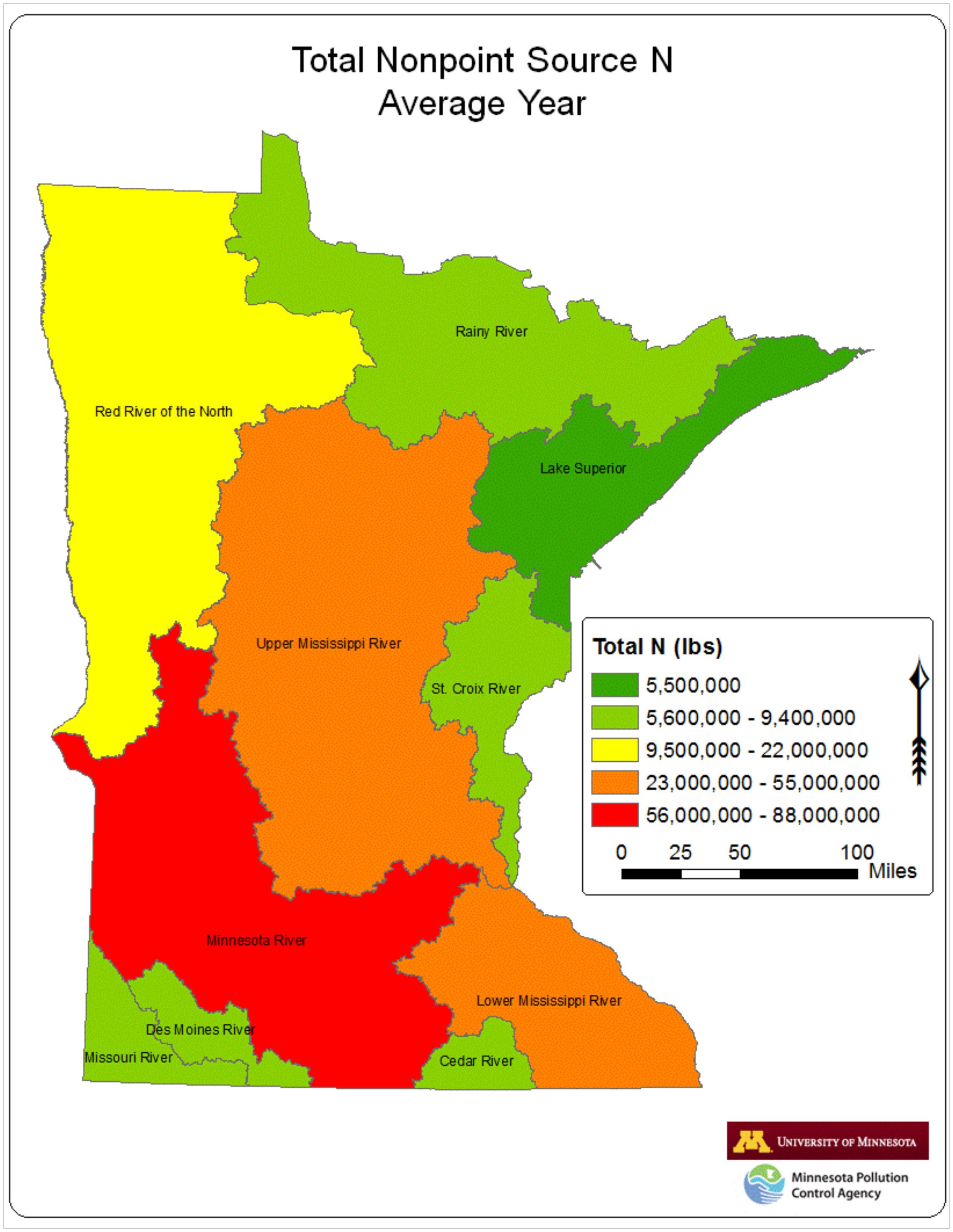


Figure 51. Nonpoint source N loads (lb) for Minnesota in an average year.

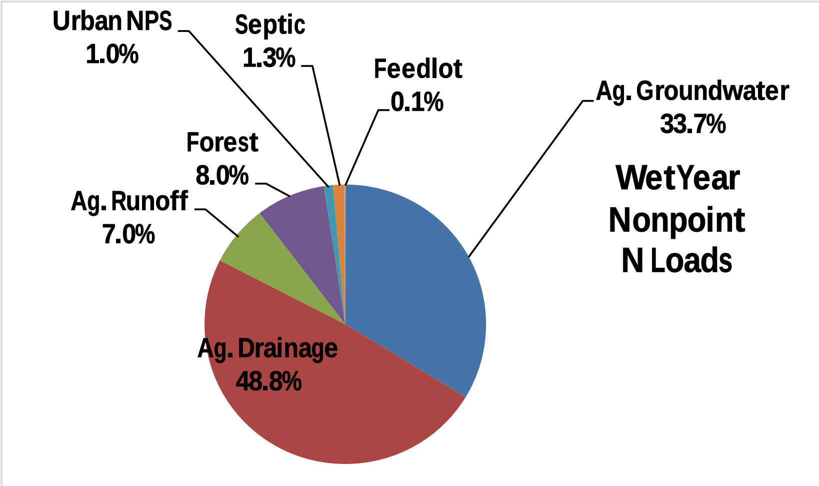


Figure 52. Statewide nonpoint source N loads (%) for various sources in a wet year.

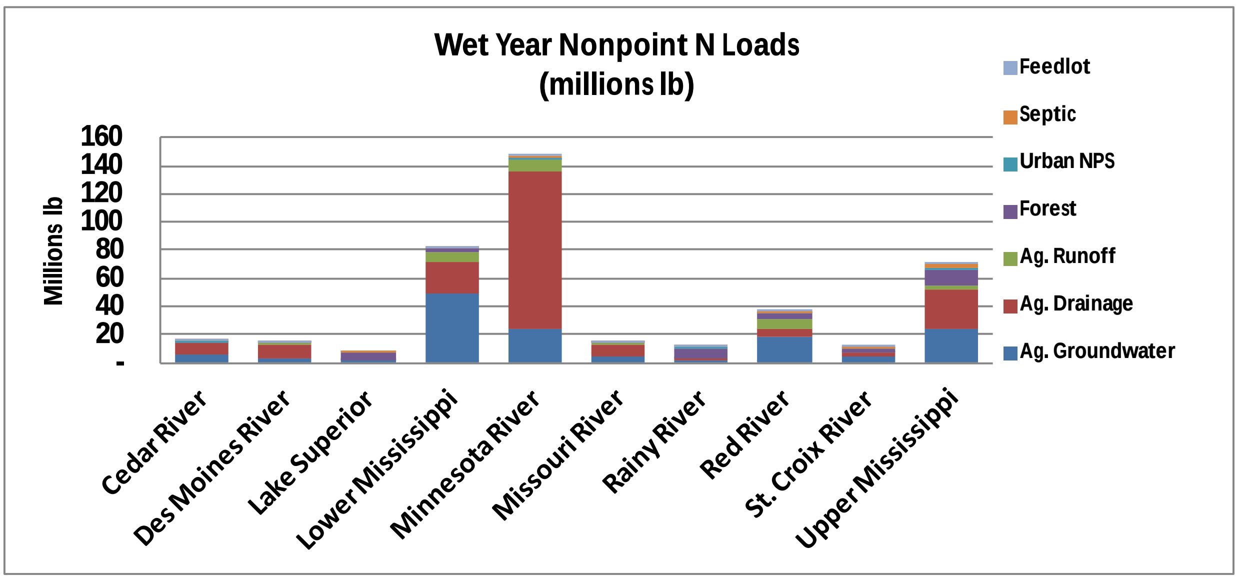


Figure 53. Nonpoint source N loads (lb) for various sources by river basin in a wet year.

Comparison between modeled and monitored N loads (including effects of point sources)

Data for point source N loads were provided by MPCA in the Minnesota, Red River of the North, St. Croix, and Upper Mississippi River Basins. These N loads were added to the modeled basin wide nonpoint source N loads described in previous sections. The basin total modeled plus point source N loads were compared with water quality monitoring data in each of the four river basins for dry, average, and wet climatic conditions. The monitoring data only represent the Minnesota contributions to the rivers.

In dry years (Figure 54), there was excellent agreement between monitoring data and modeled plus point source N loads in the Minnesota River Basin (32 million pounds), Red River of the North (10.3 million pounds), and St. Croix River (3.9 million pounds). In the Upper Mississippi River Basin monitored N loads were less than modeled plus point source N loads by about 7.3 million pounds, but this is not unexpected. Watersheds upstream of Sartell in the Upper Mississippi River Basin have from 10-40% of their area covered by wetlands. Nitrogen loads leaving fields and forest and entering these wetlands would be subject to further losses that are not reflected in modeled N loads. This could partially explain why modeled N loads are larger than monitored N loads in the Upper Mississippi River Basin. Additionally, because of the importance of the groundwater pathway in this region and the slow movement of groundwater, some of the nitrate from past decades has not yet reached the river and therefore would not be included in the monitoring data.

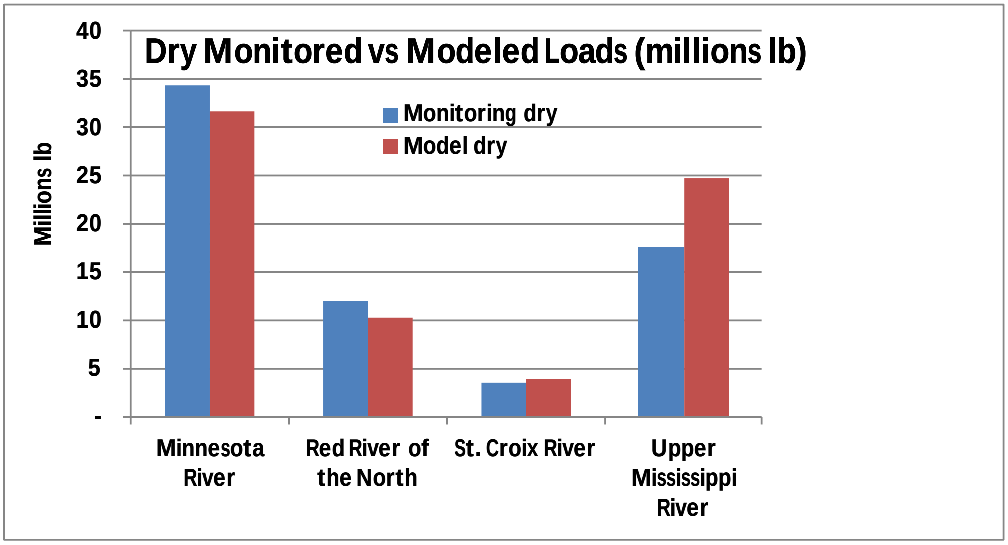


Figure 54. Comparison of modeled + point source N loads with monitored N loads in a dry year.

During average climatic years (Figure 55), there was excellent agreement between monitoring data and modeled plus point source N loads in the Red River of the North (22.5 million pounds), St. Croix River (7.7 million pounds), and Upper Mississippi River (49.5 million pounds) Basins. Modeled loads underestimated monitored loads by about 28 million pounds in the Minnesota River Basin. It appears that there may be other sources of N (such as additional groundwater discharge and/or more tiled land than assumed) in the Minnesota River Basin that are not adequately accounted for in the modeled results.

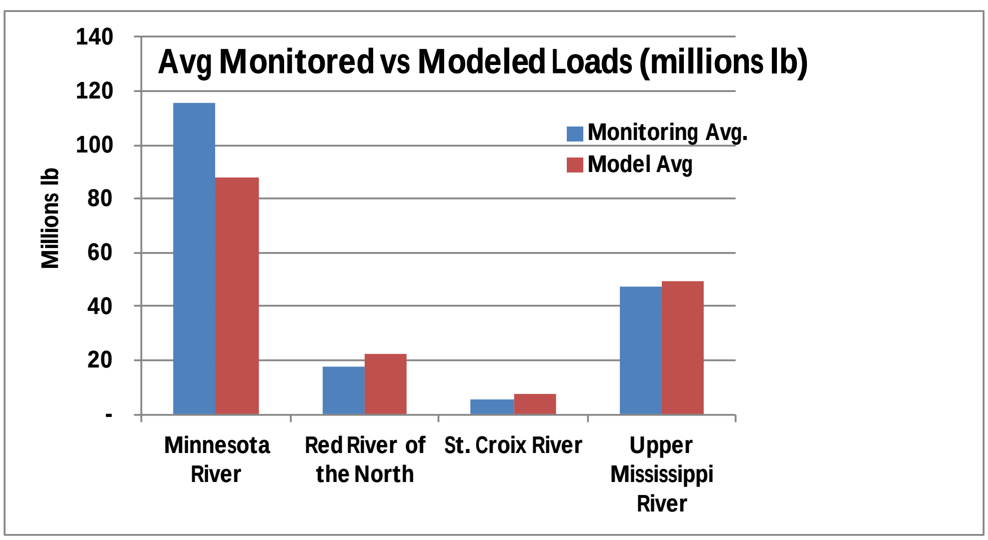


Figure 55. Comparison of modeled + point source N loads with monitored N loads in an average year.

During wet climatic years (Figure 56), there was reasonably good agreement between monitoring data and modeled plus point source N loads in the Minnesota River (148.5 million pounds), Red River of the North (36.7 million pounds), St. Croix River (11.3 million pounds), and Upper Mississippi River (74.2 million pounds) Basins. As with average years, N loadings to the Upper Mississippi River were overestimated (by 14.6 million pounds), probably because as a result of denitrification losses occurring in wetlands and slow movement of groundwater. Monitored N loads in the Minnesota River Basin were underpredicted by about 34.5 million pounds. This is an underprediction of monitored loads by about 18%. Again, this indicates that there may be underestimated or other sources of N in the Minnesota River Basin not accounted for by modeled results.

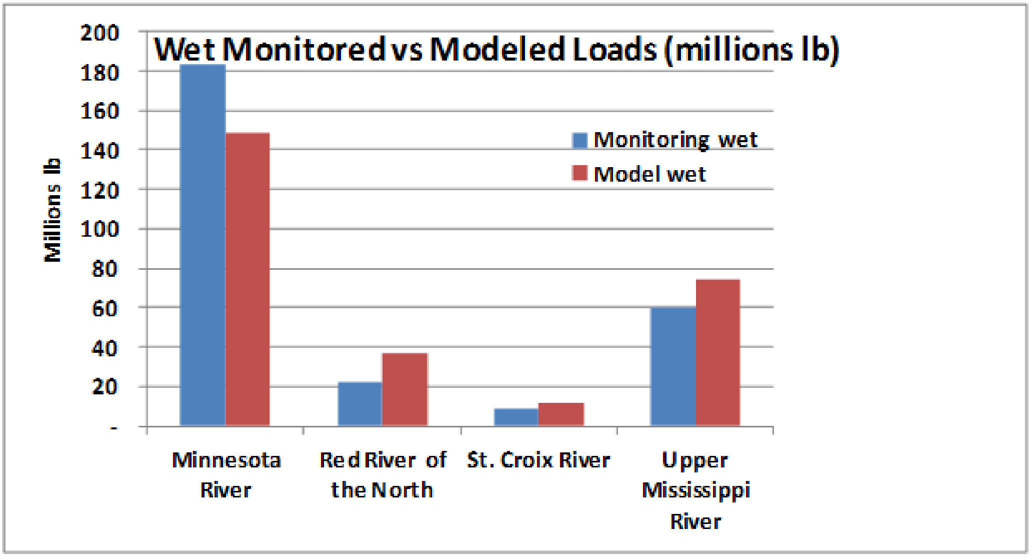


Figure 56. Comparison of modeled + point source N loads with monitored N loads in a wet year.

Conclusions

An N budget was estimated for Minnesota's agricultural land as a separate and distinct analysis from the efforts to determine sources to surface waters. Inputs included mineralization (1.7 billion pounds), N fertilizer (1.36 billion pounds), N fixation by legumes (0.61 billion pounds), and several other smaller sources. The largest inputs occurred in the Minnesota River Basin. Outputs included crop removal (2.2 billion pounds), senescence (0.72 billion pounds), and denitrification (0.48 billion pounds), and several other smaller sources. The overall statewide N balance (inputs-outputs) was very good, with a difference of only 0.09 billion pounds (or 2.1% of the total inputs). This difference suggests that today's high biomass crops may be mining N from the soil, however, small increases in rates of soil mineralization assumed for the study could easily bring the system into balance.

Total nonpoint source N loadings to Minnesota surface waters were estimated at 254 million pounds during an average climatic year. This is about 6% of the total inputs of N on all Minnesota cropland (including soil mineralization). Sources of N loadings included cropland drainage (114 million pounds), cropland leaching (93 million pounds), forest N export (22 million pounds), cropland runoff (16 million pounds), individual septic treatment systems (5 million pounds), urban/suburban nonpoint source N (3 million pounds), and feedlot runoff (0.2 million pounds). During an average year, the Minnesota River Basin contributes more nonpoint source N loading to surface water (86 million pounds) than any other basin. The Lower Mississippi River Basin contributes (54 million pounds), the Upper Mississippi River Basin contributes 46 million pounds, and the Red River of the North contributes 22 million pounds. At the major watershed scale, modeled nonpoint source N loadings were highest for the Zumbro and Root Rivers of southeastern Minnesota, which are large watersheds where N loadings from groundwater discharge, drainage and runoff are all significant. N loadings were next highest in a cluster of major watersheds in the Minnesota River Basin, where N losses in drainage are high. These major watersheds include the Lower Minnesota, Blue Earth, and Le Sueur River watersheds.

A comparison between the modeled nonpoint source N loadings to Minnesota surface waters (in an average climatic year) and monitored N loadings (average of two typical years) was conducted for 33 MPCA monitored major watersheds across Minnesota. Monitored N loadings were not used to calibrate the modeled nonpoint source N loadings, as the modeled N loadings were estimated independently, without calibration. Linear regression between modeled and MPCA monitored N loads was very good, with an R^2 value of 0.69. However, the modeled N loads were lower than monitored loads for several watersheds in south-central Minnesota. Modeled N loadings across all monitored watersheds were 10% higher than monitored N loads, which is not surprising given that additional losses in predicted N loadings may occur as nitrate travels downstream to the mouth of the watershed.

Climate has a significant effect on nonpoint source N loadings to Minnesota surface waters. Total statewide nonpoint source N loadings to surface waters for dry, average and wet years were predicted to be 106, 254, and 409 million pounds, respectively. During a dry year, the majority (46%) of nonpoint source N losses to surface waters arises from groundwater discharge. Losses from tile drainage (30%) and runoff (7%) on cropland are much smaller in comparison during a dry year. Losses from forested regions account for 10% of the total nonpoint source losses to surface waters. During an average year, the nonpoint source losses from agricultural drainage (45%) increase relative to the losses from agricultural groundwater discharge (37%) in comparison with the losses during a dry year. Forest export of N accounts for 9% of the nonpoint source N losses during an average year, while agricultural runoff accounts for 6%. During a wet year, the majority of nonpoint source N losses statewide arise from agricultural drainage (49%). Discharge of groundwater from agricultural regions contributes another 34%. Forested regions generate 8%, and agricultural runoff generates 7% of the statewide nonpoint source N losses during a wet year.

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E1. Comparing Source Assessment with Monitoring and Modeling Results

Author: Dave Wall, MPCA

Modeling contributors:
SPARROW modeling: Dale Robertson (USGS) and David Saad (USGS)
HSPF modeling: Chuck Regan (MPCA), Jon Butcher (Tetra Tech)
HSPF model output analysis: Travis Wojciechowski, Lee Ganske, and Jenny Brude (MPCA)

The source assessment of Nitrogen (N) delivery to surface waters, as conducted by the University of Minnesota and the Minnesota Pollution Control Agency (UMN/MPCA) and described in Chapters D1 to D4, have areas of uncertainty. For example, one area of uncertainty is the quantity of N reaching surface waters from the cropland groundwater component. This uncertainty stems largely from: a) limited studies quantifying leaching losses under different soils, climate and management; and b) extreme variability in denitrification losses, which can occur as groundwater slowly flows toward rivers and streams. Another area of uncertainty is the tile drainage acreages, which were estimated based on soils, slopes and crops, and which have been increasing at during the previous few years.

Because of these and other source assessment uncertainties, we compared the N source assessment results with other related findings, using five different ways to check the findings as follows:

1) **Monitoring results** – Comparing HUC8 watershed and major basin scale monitoring results with loads estimated by summing the source estimates (Chapter E1).
2) **SPARROW model** – comparing modeled estimates of major source categories to source assessment findings (Chapter E1).
3) **HSPF model** – Comparing Minnesota River Basin HSPF modeled estimates of sources, pathways and effects of precipitation with the source assessment findings (Chapter E1).
4) **Watershed characteristics analysis** – Comparing watershed and land use characteristics with river monitoring-based concentrations and yields (Chapter E2).
5) **Literature review** – Comparing findings of studies in the upper-Midwest related to N sources and pathways with source assessment findings (Chapter E3).

In this chapter, N source estimates reported in Chapters D1 to D4 are compared with the first three approaches noted above, including: 1) monitoring-based load calculations; 2) SPARROW modeling source category results; and 3) HSPF modeling of the Minnesota River Basin. Subsequent chapters include the Watershed Characteristics Analysis (Chapter E2) and Literature Review (Chapter E3).

Monitoring results comparison with sum of source loads

Monitoring results obtained near major basin outlets (1991-2010) and near HUC8 watershed outlets (2005-09) were compared with the sum of individual source load estimates documented in Chapters D1-D4. The purpose was to see how closely the sum of individual source loads compared to loads calculated from major river and watershed monitoring. With the exception of urban nonpoint source and forest N loss coefficients, which were based on small scale watershed monitoring, the source estimates were determined from methods that did not involve watershed monitoring. Since the monitoring data used in this comparison was not used to derive any of the source load estimates, it represents an independent check of the source assessments.

It is important to note that there are three important limitations associated with this comparison. First, the source estimates in Chapters D1-D4 do not consider N losses within streams, rivers or reservoirs. The source estimates are expected delivery to the stream; not delivery within the streams. Losses within streams can be minimal to substantial, depending on the hydrologic conditions. For example, reservoirs with a long residence time can result in large decreases of N from algal uptake and subsequent settling to the reservoir bottom, and to denitification. Due to this issue, the sum of the estimated source loads by the UMN/MPCA would be expected to be higher than the monitoring-based loads, if everything else was equal.

Second, the source estimates do not consider the time lag between when nitrate leaches below the root zone in the soil to the time that it moves into and through groundwater and ultimately discharges into the stream. This lag time is particularly important with the groundwater flow pathway below cropland, and could cause monitoring results to be lower than the source assessment results in watersheds which are largely influenced by groundwater transport, such as in karst and sand plain regions.

The third limitation in comparing the source estimates with monitoring results is the challenge of obtaining representative monitoring-based load results. Nitrogen loads can vary tremendously from year to year due to climatic differences. Additionally, load calculations from monitoring information have uncertainty because samples are not collected continuously. The effect of this third limitation was minimized by using long-term average loads for the major basins analysis. For the HUC8 watershed load analysis, we used two-year averages from years without extremely low or high annual flow volumes, and limited the watersheds to those which had two years of monitoring-based load calculations during “normal” flow years between 2005 and 2009, as described in Chapter B3.

While recognizing these anticipated differences between watershed source assessments and watershed monitoring results, the comparison of findings from watershed monitoring with estimated loads from cumulative source estimates can still be useful as an indication of whether the source estimates are generally reflecting actual watershed loading conditions. This validation at larger scale watersheds is important since the source assessment was conducted by using mostly smaller field-scale research/monitoring and expanding the results to larger scales through the use of statewide geographical spatial data.

The source assessment results would need to be questioned if the monitoring results and the sum of the source assessment results were markedly different in watersheds without: a) large reservoirs or other identified N transformation processes; b) extreme climatic conditions during monitoring years; or c) some other scientific explanation. If, on the other hand, the monitoring results and the sum of the source assessment results are reasonably close, then we can have a greater level of confidence in the source assessment results. A reasonably close comparison does not prove the complete validity of the source assessment results, but provides one line of evidence that the source assessment may be providing reasonably accurate estimates.

Basin level comparison with monitoring

Monitoring of Minnesota’s major rivers is described in Chapter B2. The total nitrogen (TN) loads based on monitoring of major rivers were compared to the sum of N sources to waters in those same basins for average, wet, and dry years (Figures 1 to 3).

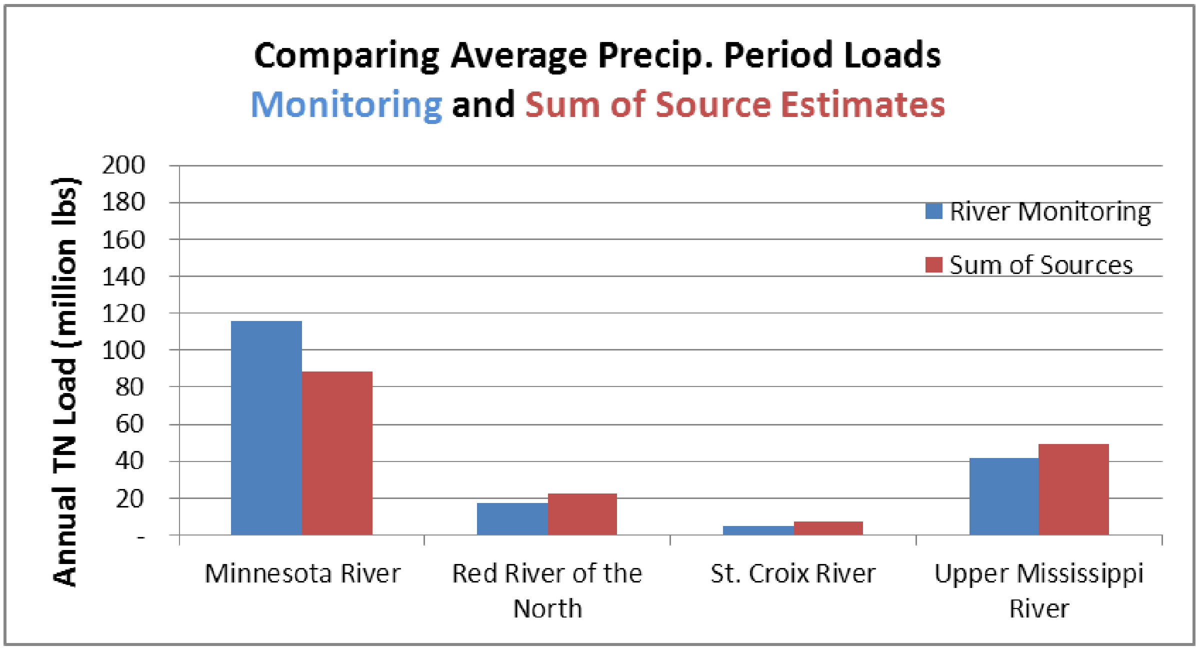

Figure 1. Average TN loads based on monitoring (avg. 1991-2010) of the Minnesota River (Jordan), Red River (Emerson), St. Croix River (Stillwater) and Upper Mississippi River (Anoka), as compared to the sum of estimated N sources to waters for average precipitation conditions.

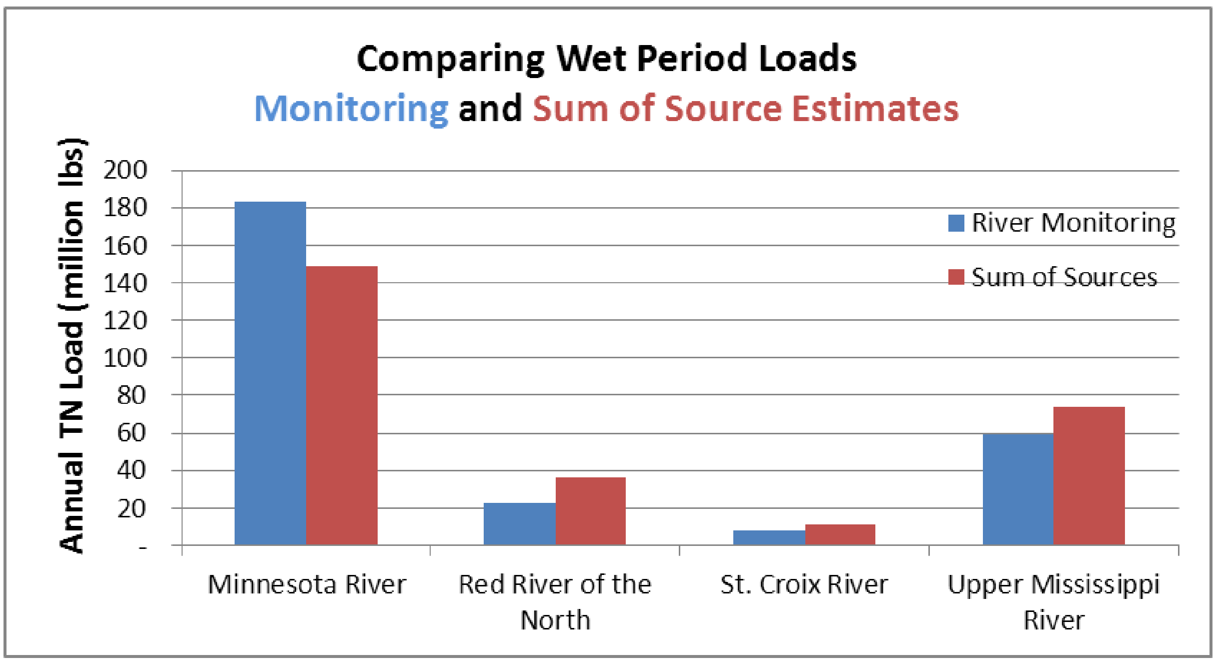

Figure 2. Wet period (90th percentile) TN loads based on monitoring (avg. 1991-2010) of the Minnesota River (Jordan), Red River (Emerson), St. Croix River (Stillwater) and Upper Mississippi River (Anoka), as compared to the sum of estimated N sources to waters for wet period conditions.

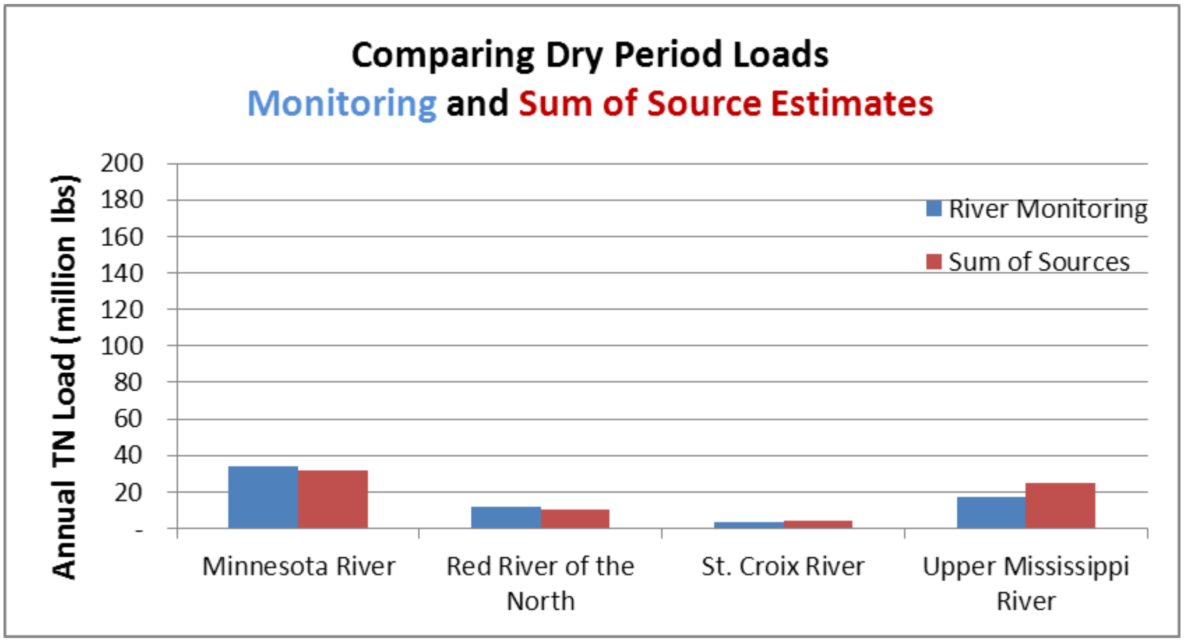

Figure 3. Dry period (10th percentile) TN loads based on monitoring (avg. 1991-2010) of the Minnesota River (Jordan), Red River (Emerson), St. Croix River (Stillwater) and Upper Mississippi River (Anoka), as compared to the sum of estimated N sources to waters for dry period conditions.

Even with the limitations of this type of comparison, the source assessment based loads at the major basin scale were reasonably similar to the monitoring-based results. The relatively close comparison is particularly remarkable when considering that river/stream monitoring results were not used to develop the nonpoint source and point source load assessments, nor were they used to calibrate the source-based load estimates.

In the Minnesota River Basin, the 20-year average monitoring-based results were slightly higher than source-based estimates for the Minnesota River Basin (Jordan). Monitoring-based loads were 31%, 23%, and 8% higher than source-based estimates during average, wet and dry periods, respectfully. As previously noted, we would expect the monitoring results to be less than the sum of sources in areas that are not dominated by groundwater nitrogen inputs to streams. This is because in-stream nitrogen losses are not accounted for in the source assessment, but they are inherently reflected in the monitoring results. Therefore, it is likely that in this basin, which has nitrate levels controlled more by tile drainage than groundwater inputs, the source assessment is under-predicting the sources.

In the other basins, the monitoring-based loads were lower than the source-based estimates. In the Red River Basin (Emerson, Manitoba) monitoring-based loads were 78%, 61%, and 115% of source-based estimates during average, wet, and dry periods, respectfully.

The St. Croix River loads are considerably lower than the other three major rivers during all three precipitation conditions. In the St. Croix River (Stillwater), monitoring-based loads were 69%, 74%, and 89% of source-based estimates during average, wet, and dry periods, respectfully.

In the Upper Mississippi Basin (Anoka), monitoring-based loads were 84%, 80%, and 71% of source-based estimates during average, dry, and wet periods, respectfully.

The relatively close comparison indicates that at the basin scale, the monitoring results alone do not provide a reason to suggest that the source estimates are unreasonable.

HUC8 level comparison with monitoring

Chapter D4 presented a comparison of HUC8 level monitoring results with the nonpoint source (NPS) load estimates in corresponding watersheds. Two analyses were presented: 1) bar graphs showing NPS load estimates with monitoring-based load averages obtained from one to multiple years of monitoring in each watershed; and 2) an X-Y plot showing correlation between NPS load estimates and monitoring-based loads obtained by averaging monitoring results. A discussion of these comparisons is included in Chapter D-4.

In this section of the report, monitoring-based results from average loads during normal flow conditions are compared with the sum of the estimated nonpoint source loads, point source loads, and atmospheric deposition falling directly into rivers and streams.

The 28 watersheds and associated monitoring-based data used for this comparison are described in Chapter B3 under the section “Independent HUC8 Watershed Loads (mid-range flow averages).” The monitoring results are only from those watersheds which are independent HUC8 watersheds (not influenced by upstream main stem rivers) and which had two-year average load results obtained during years with mid-range river flows (between 2005 and 2009). Therefore, the monitoring results are a) recent; b) do not depend on a single year of monitoring; c) do not include extreme dry or wet years; and d) are not influenced by water flowing into the watershed from upstream main stem rivers.

Source load estimates were derived by adding point source contributions from Chapter D2, NPS contributions Chapter D4, and atmospheric contributions directly into rivers and streams from Chapter D3.

The comparison shows that most of the HUC8 watershed monitoring results are reasonably similar with the sum of source loads (Figure 4), especially when considering that the source load estimates were mostly derived from small-plot and field scale research rather than watershed scale monitoring, and that the sum of sources does not include in-stream N losses. Yet there are also some notable differences in certain watersheds.

Monitoring results in the Blue Earth and LeSueur watersheds show substantially higher loads than the sum of the sources. Since the point source contributions in these watersheds are rather small in comparison to nonpoint sources, the lower estimates from the source assessment could be due to an underestimate in the nonpoint source load estimates in these watersheds. Some possible reasons for these differences are discussed by Mulla et al. in Chapter D-3. One watershed that had sum of source estimates considerably higher than the monitoring results was the Chippewa River, indicating that sources may have been overestimated for this watershed or that large in-stream N losses are occurring in this watershed.

The results at the HUC8 level monitoring and basin levels both indicate that source estimates may be reasonable for both scales, but that they are better suited for large scale use, such as the basin level.

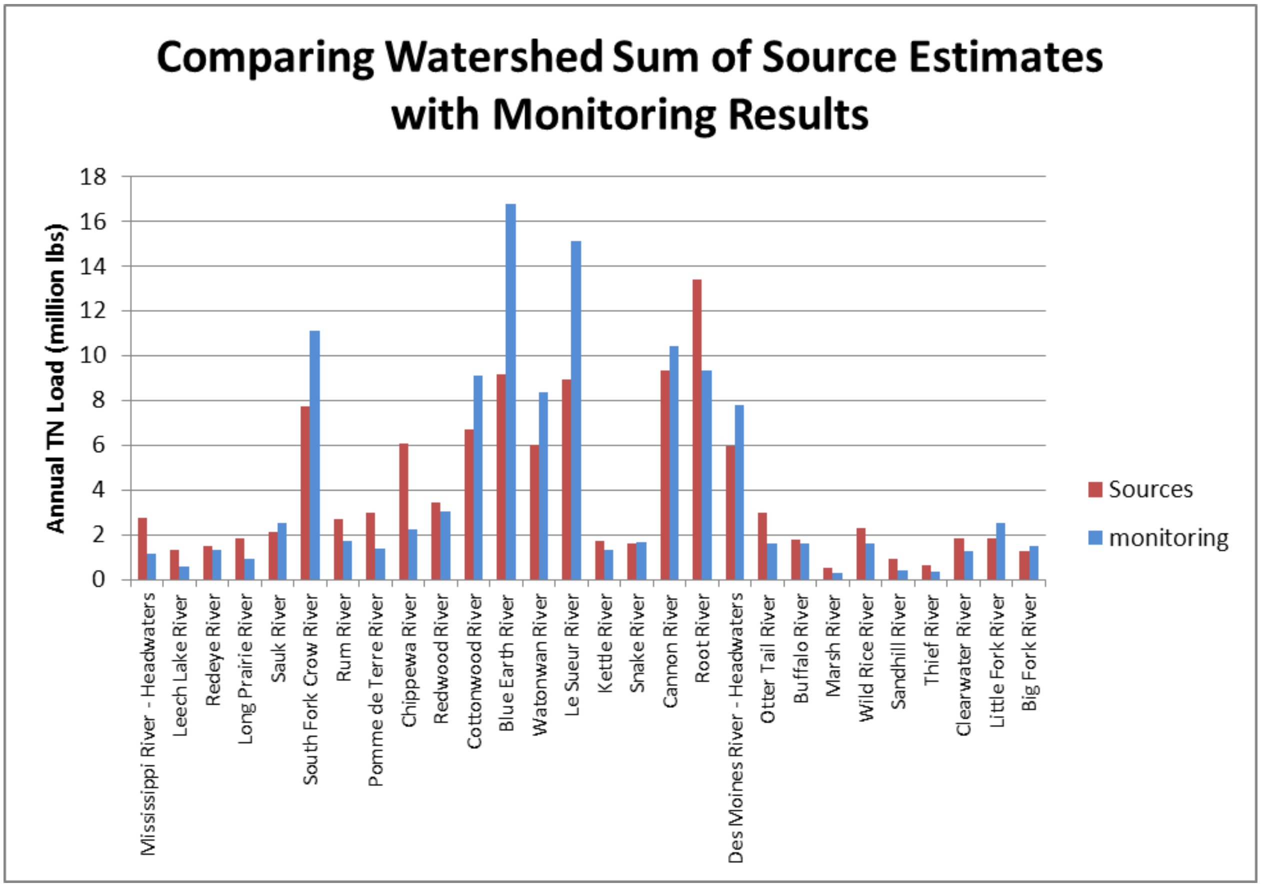

Figure 4. Two-year normal flow average TN loads based on monitoring within the 2005 to 2009 timeframe for independent HUC8 watersheds, as compared to the sum of estimated N sources to waters for average precipitation conditions.

SPARROW nitrogen delivery to receiving waters by source category

The SPARROW model was used to estimate the delivery of nitrogen to receiving waters by major source categories of: agriculture, wastewater point source, and non-agricultural nonpoint sources to waters. The SPARROW modeling effort for this study is described in more detail in Chapter B4. Background information about the SPARROW model is included in Appendix B4-1. The SPARROW model results were compared with the UMN/MPCA source estimates to waters from Chapters D1-D4. While the source categories from the SPARROW modeling in Chapter B4 and the UMN/MPCA source estimates from Chapters D1-D4 were originally categorized differently, we were able to lump the source assessment findings into like categories for comparison purposes, as follows:

> "Agriculture" sources include the cropland tile drainage, cropland groundwater and cropland runoff from the UMN/MPCA source assessment.

> "Non-agricultural Nonpoint Sources" include all other sources which are not included in the agriculture or point source categories. SPARROW outputs label this as atmospheric deposition, and it includes atmospheric deposition and other non-agricultural nonpoint sources which are carried to waters by precipitation.

The SPARROW modeling approach is very different than the approach used by UMN/MPCA to estimate N source loads. The SPARROW model leans heavily on statistics and monitoring-based load calculations.

The UMN/MPCA source estimates were developed mostly from small scale research, multiplied to larger scales through the use of GIS data layers.

The results of the comparison between SPARROW load estimates and the UMN/MPCA load estimates by source are quite similar for the broad source categorizations evaluated (Figures 5 and 6). SPARROW estimates of the percent of load coming from point sources was slightly lower than UMN/MPCA estimates (7% vs. 9%). Estimated agricultural contributions for the state are nearly the same with these two approaches (72% with the UMN/MPCA source assessment approach and 70% with the SPARROW model).

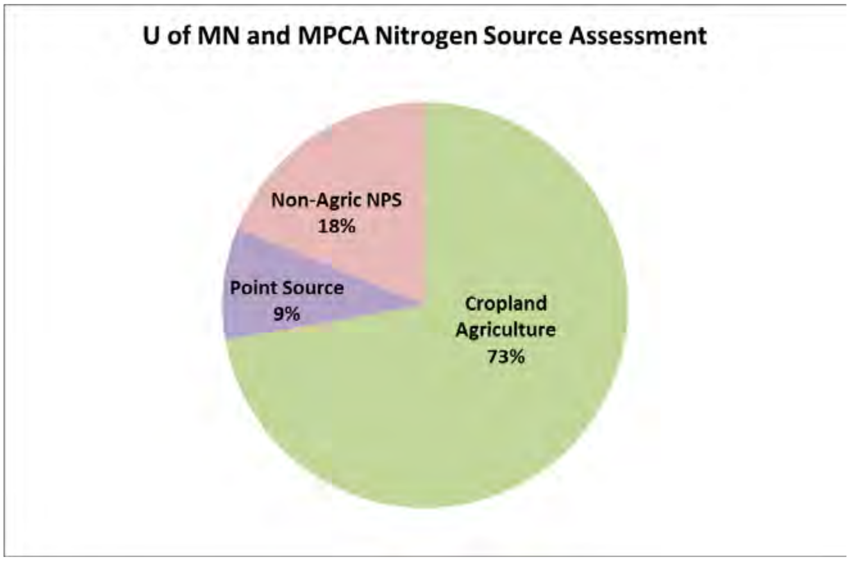

Figure 5. Minnesota statewide nitrogen sources to surface waters developed by the University of Minnesota and MPCA, (from Chapters D1-D4).

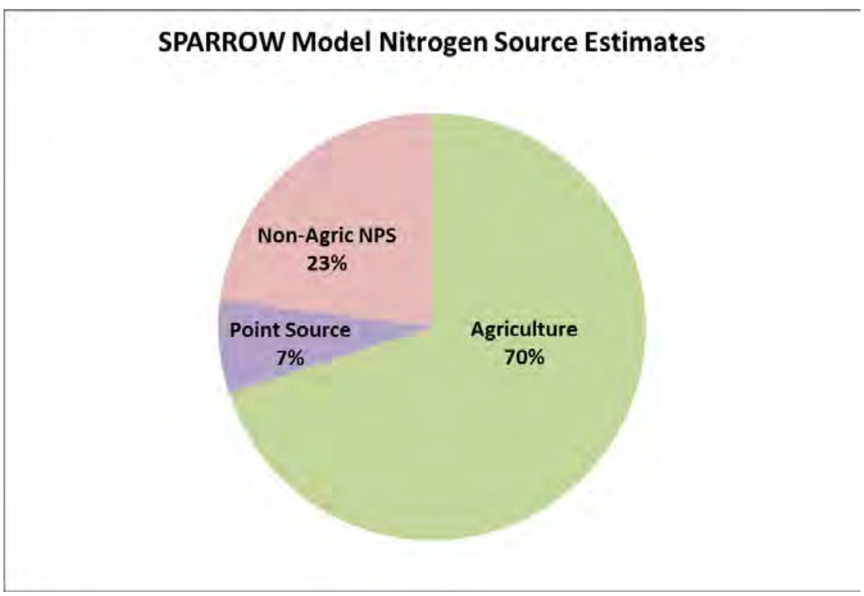

Figure 6. Minnesota statewide nitrogen source estimates for nitrogen delivery to surface waters based on the SPARROW model, as described in Chapter B4.

The close comparison of the SPARROW model source estimates provides another indication that the UMN/MPCA source assessment is reasonably accurate, at least within the broad categories of this comparison.

HSPF modeling – Minnesota River Basin

The Hydrological Simulation Program - FORTRAN (HSPF) model, as applied to the Minnesota River Basin, was used to evaluate NPS inorganic N: a) transport pathways to surface waters; b) sources to streams; and c) effects of wet and dry years on loads. The Minnesota River Basin has the highest N loads in Minnesota, contributing nearly half of all N which leaves the state in the Mississippi River. Since HSPF modeling for other basins was not completed at the time of this study, we were only able to compare Minnesota River Basin HSPF results to the UMN/MPCA source assessment results.

HSPF modeling results for all years between 1993 and 2006 were used to assess source and pathway findings. These results were then compared to the UMN/MPCA estimates presented in Chapters D1 to D4. HSPF uses a very different modeling approach than either the SPARROW model or the UMN/MPCA source assessment methods in sections D1-D4, allowing another rather independent check of source assessment results.

Only inorganic N loading was assessed with the HSPF model for this analysis. Long term monitoring results presented in Chapter B2 showed that inorganic N represents 85% of the TN load in the Minnesota River Basin (at Jordan). Point source discharges, which represent an estimated 4% of the TN long-term average load in the Minnesota River Basin, were not included in this HSPF modeling assessment.

HSPF model background

The HSPF model is a comprehensive model for simulating watershed hydrology and water quality for both conventional pollutants such as nutrients, and toxic organic pollutants. HSPF incorporates the watershed-scale Agricultural Runoff Model (ARM) and NPS models into a basin-scale analysis framework that includes fate and transport in one dimensional stream channels. HSPF allows the integrated simulation of land and soil contaminant runoff processes with in-stream hydraulic and sediment-chemical interactions. The result of this simulation is a time history of the runoff flow rate, sediment load, and nutrient and pesticide concentrations, along with a time history of water quantity and quality at the outlet of any subwatershed.

The quantity of water discharged in surface streams is characterized in the HSPF model by surface runoff, interflow and baseflow. Surface runoff is the water flow that occurs after the soil is infiltrated to full capacity, and excess water from rain, meltwater or other sources flows over the land. Surface runoff is observed in river hydrographs soon after the runoff event. In addition to direct overland runoff, this component of flow can also include runoff which enters waters quickly through open tile intakes and side inlets to ditches. Interflow is water that first infiltrates into the soil surface and then travels fairly quickly in the subsurface to stream channels, reaching streams after surface runoff, but ahead of baseflow. A large component of interflow is tile drainage waters. Yet interflow also can include groundwater that quickly discharges into streams after precipitation events, such as in karst springs or alluvial sands along stream channels. Baseflow results from precipitation that infiltrates into the soil and, over a longer period of time, moves through the soil and groundwater to the stream channel. Baseflow includes most of the groundwater component, but can also include tile drain waters which continue to flow long after storms and melting events.

The HSPF model was calibrated by adjusting model parameters to provide a match to observed conditions. Although these models are formulated from mass balance principles, most of the kinetic descriptions in the models are empirically derived. These empirical derivations contain a number of coefficients which were calibrated to data collected in the Minnesota River Basin. Once calibrated, the model was validated using data independent from that used in calibration. The monitoring data used for both HSPF calibration and validation was different from that used earlier in this chapter to compare monitoring results with the UMN/MPCA source assessment approach in Chapters D1 to D4.

Flow pathways comparison

The HSPF modeling of inorganic N hydrologic pathways to the Minnesota River shows that the subsurface pathways of interflow and baseflow are the dominant pathways. Combined, these pathways account for 89% of the inorganic N transport (Figure 7). Interflow represents the highest contribution (54.7%) and baseflow represents the next highest (34.3%). Tile drainage is a major contributor to the interflow pathway, but also can also represent a fraction of the HSPF model surface runoff and baseflow pathways.

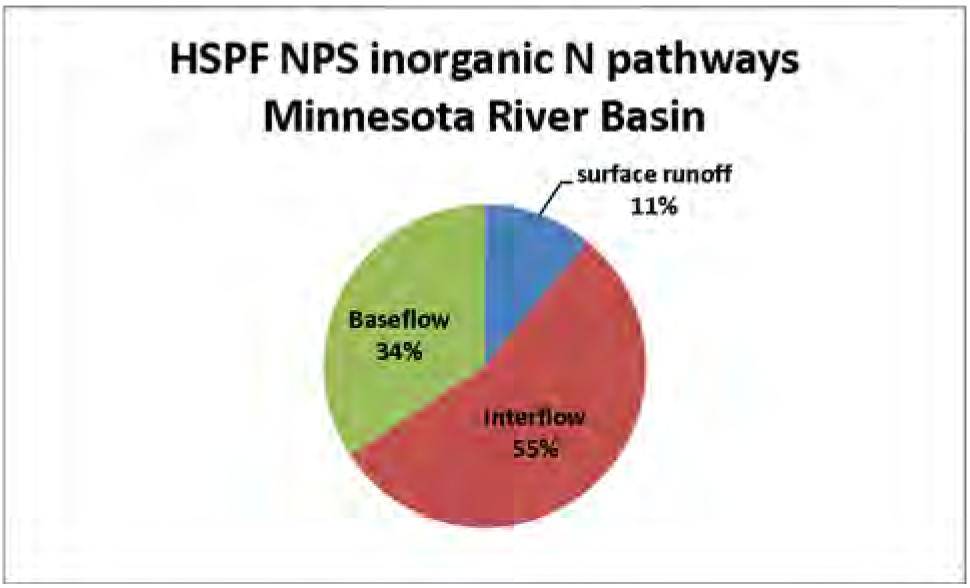

Figure 7. HSPF model estimates of the proportion of nonpoint source inorganic N which enters surface water through the three model flow pathways in the Minnesota River Basin during a typical precipitation year within the timeframe 1993-2006.

The UMN/MPCA estimates of the three major pathways (Figure 8) were determined by assuming the following:

- “Surface Runoff” includes all cropland N runoff, 80% of the N from urban/suburban NPS, 50% of the forested land N, and all feedlot runoff.
- “Groundwater” includes all cropland groundwater, all septic system N, 20% of the urban/suburban NPS component, and 50% of the forested land N.
- “Agricultural Drainage” includes all cropland tile drainage N estimates.

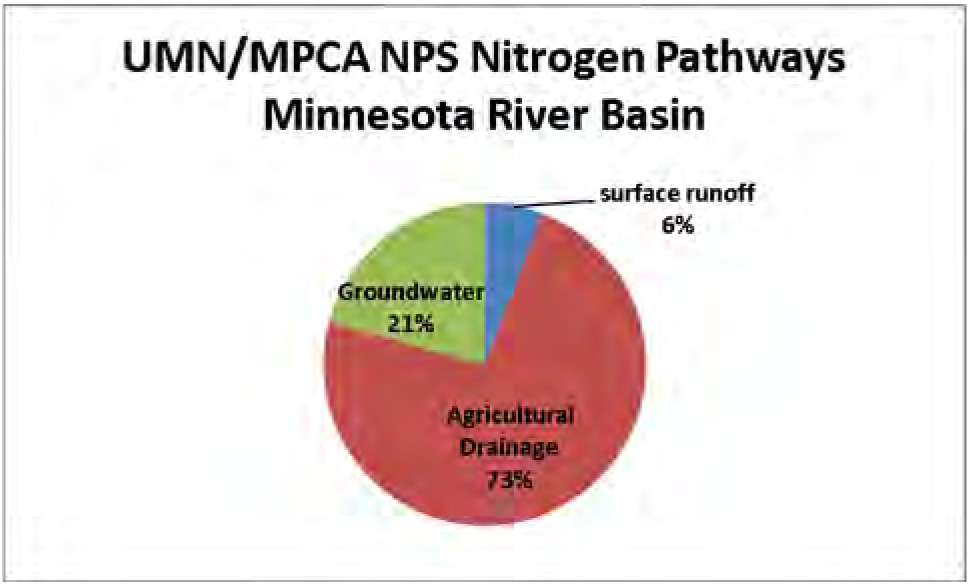

Figure 8. UMN/MPCA N source estimates of the proportion of TN which enters surface water through three major pathways in the Minnesota River Basin during average precipitation conditions(1981 to 2010).

Similar to the HSPF modeling, the UMN/MPCA source estimates show that the dominant pathway of TN in the Minnesota River Basin is subsurface flow, with 94% of N coming from the combined pathways of groundwater and tile drainage. This compares to 89% predicted by the HSPF model for the subsurface pathways. The UMN/MPCA source assessment shows that agricultural drainage is the pathway contributing the most N, representing 73% of the TN into rivers in the Minnesota River Basin. The HSPF model shows interflow to be the largest pathway, accounting for 55% of the inorganic N into the Minnesota River Basin surface waters. In the HSPF model, interflow is mostly affected by tile drainage waters, with a small fraction coming from groundwater adjacent to streams and ditches.

The reason that the HSPF estimated interflow TN fraction is lower than the UMN/MPCA tile drainage estimated TN fraction can be explained by the fact that some of the actual tile drainage waters is represented in HSPF outputs as “baseflow.” When tiles continue to flow into streams long after rain or snowmelt events occur, this tile drainage will be considered as “baseflow” in the HSPF model. This hydrograph “baseflow” component of tile drainage is also supported by Schilling (2008), who found in heavily tiled Iowa watersheds that the “baseflow” component of the hydrograph increased by 40% in the March to July timeframe, the period of time when tiles are flowing. Yet Schilling found no differences in baseflow between drained and undrained lands during the fall to winter months (September to February). This showed that tile drainage waters likely have a substantial effect on the nitrate contributions from the baseflow part of the hydrograph. If 40% of the HSPF modeled baseflow is actually from tile drainage, then the UMN and HSPF estimates of the relative contribution from tile drainage would be nearly the same.

We only compared the HSPF and UMN/MPCA source assessment pathways for the entire basin. Yet, it is noteworthy that the fraction of HSPF estimated nitrate from these three pathways varies among HUC8 watersheds within the Minnesota River Basin (Figure 9). For example, the less-tiled Chippewa River watershed has an estimated 22% of its nitrate coming from interflow and 57% from baseflow, whereas the heavily tiled LeSueur watershed has an estimated 69% of its nitrate from interflow and only 15% from baseflow.

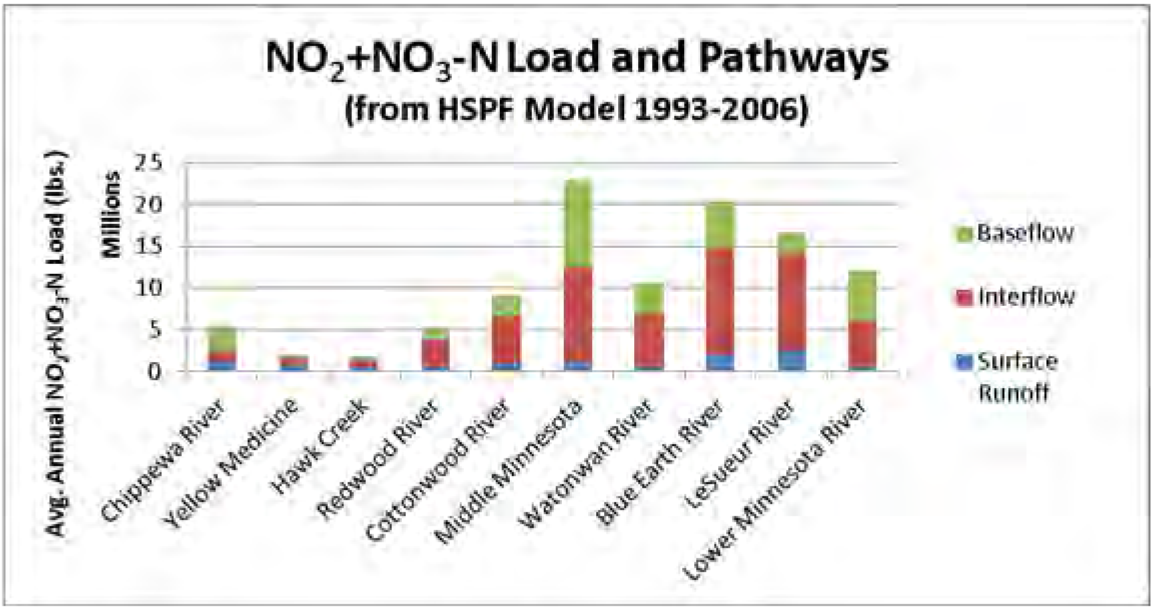

Figure 9. Nitrite+Nitrate-N pathways for HUC8 watersheds in the Minnesota River Basin, as estimated by the HSPF model.

NPS land use contributions in the Minnesota River Basin

The HSPF model results indicate that the dominant contributor of nonpoint source inorganic N to the Minnesota River is cropland, with an estimated contribution of 96.6% (Table 1). The UMN/MPCA estimates for cropland contributions in this same basin are very similar at 97.6%. All other sources are relatively small using both approaches. Note that these results did not include point source contributions, which are approximately 4% of the TN load in the Minnesota River Basin. Also note that the HSPF analysis for this chapter only included inorganic N and the UMN/MPCA assessment was for TN. Given that 85% of the Minnesota River TN is in the inorganic form of nitrate-N, this difference in N forms between the two approaches is not expected to greatly affect the relative source contributions of nonpoint source pollutants.

Table 1. Estimated NPS land use contributions of inorganic N (HSPF) and TN (UMN/MPCA) to surface waters during a typical precipitation year in the Minnesota River Basin.

Land use	HSPF estimated percent of total inorganic nitrogen from nonpoint sources	UMN/MPCA estimated percent of total nitrogen from nonpoint sources
Cropland	96.6%	97.6%
Urban stormwater	2.1%	0.7%
Feedlot facilities (note: manure application is included with “cropland”)	0.19%	0.06%
Forest	0.14%	0.7%
Other	0.97%	0.94
Total	100%	100%

Precipitation effects

The TN load from nonpoint sources was highly influenced by precipitation according to the UMN source assessment results (Chapter D4 – Mulla et al.). Nitrogen loads from the HSPF modeling for wet, normal, and dry years were compared with the loads from the UMN approach for similar climatic situations (Table 2). The increased loads predicted by HSPF for wet years are very similar to those predicted by the UMN source assessment (179% vs. 170% of the median precipitation year loads). Both approaches show substantially lower loads for the dry years (65% and 35% of median year loads). The UMN approach shows a more substantial drop in loads during the dry years. Part of the reason for the larger decrease in dry years from the UMN approach can be explained by the differences in the climatic period of record used for each approach. The HSPF results are based on the three driest years between 1993 and 2006. This period of time was relatively wet compared to the 30-year precipitation record used for developing the UMN/MPCA estimated effects of climate. The dry years between 1993 and 2006 were not as dry as the dry years between 1981 and 2010. The UMN/MPCA approach, using the 1981 to 2010 period of record, included more droughty years, such as the droughts during the late 1980s. Therefore, it is reasonable to expect that the UMN/MPCA approach would show lower loads for the dry years, if all other things are considered equal.

Table 2. Nitrogen loads for the Minnesota River Basin during dry and wet years shown as a percentage of the loads during the median (normal) precipitation. Dry and wet years for the HSPF results analysis considered the average of the 3 driest years (dry) and 3 wettest years (wet) during the period 1993-2006. The UMN/MPCA analysis considered the 10th percentile precipitation (dry) and the 90th percentile precipitation (wet) during the period 1981 to 2010.

Precipitation	**HSPF inorganic N load estimates** (percent of normal year load)	**UMN/MPCA total N load estimates** (percent of normal year load)
Dry years	65%	35%
Average years	100%	100%
Wet years	179%	170%

Summary

The basin and watershed monitoring results overall compared reasonably close to the sum of the sources estimated by the UMN/MPCA source assessment. The monitoring results were not expected to be the same as the sum of sources since the sum of sources do not consider in-stream N losses or lag times in groundwater N transport. Yet the fairly close agreement in the monitoring results, with the source assessment results developed independently from the watershed and basin scale monitoring, provides a greater level of confidence that the source estimates may be realistic. The monitoring results alone do not provide a reason to suggest that the source estimates are unreasonable.

The greatest differences between sum of sources and monitored loads were in the Minnesota River Basin and a few of the high N loading HUC8 watersheds within that basin. In this basin, TN monitoring results were higher than the sum of sources estimates. Monitoring results for the Minnesota River were 131%, 108%, and 123% of the sum of sources estimates for average, wet, and dry periods, respectively. Monitoring results for other basins were lower than the sum of sources.

The SPARROW and HSPF model source estimates both were consistent with the UMN/MPCA source assessment, indicating that cropland sources are the dominant N sources to Minnesota rivers (SPARROW) and surface waters within the Minnesota River Basin (HSPF). The two models use markedly different approaches to arrive at source and pathway estimates, and both models are also very different from the UMN/MPCA source assessment approach. The SPARROW model estimated that cropland sources represent 70% of the statewide TN load (2002), as compared to 73% by the UMN/MPCA source assessment. The HSPF model results estimated that NPS from cropland in the Minnesota River Basin represent 96.6% of the inorganic N to surface waters, as compared to a 97.6% estimated from the UMN/MPCA TN source assessment.

The HSPF model results of N pathways in the Minnesota River Basin were also generally consistent with the UMN/MPCA assessment. The HSPF model estimated that 89% of the Minnesota River Basin inorganic N transport to surface waters is via subsurface pathways of interflow and baseflow. Similarly, the UMN/MPCA N source assessment estimated that 94% of TN reaches waters by subsurface pathways of tile drainage and groundwater.

The effects of high and low precipitation years on N loading to surface waters was also found to be reasonably similar with the HSPF model and UMN/MPCA approach. Wet weather loads were 179% of normal weather loads according to the HSPF modeling, as compared to 170% of normal loads in the UMN/MPCA source assessment. Both approaches estimated substantial load reductions for dry weather periods, but the UMN/MPCA approach showed a much greater reduction, explained in part by the different dry weather climate situations in the timeframes used for the two approaches.

References

Schilling, Kieth E. and Matthew Helmers. 2008. Effects of subsurface drainage tiles on streamflow in Iowa agricultural watersheds: exploratory hydrograph analysis. Hydrol. Processs. Vol. 22 (4497-4506).

E2. Comparing River Nitrogen with Watershed Characteristics

Author: Thomas E. Pearson and Dave Wall, MPCA

Introduction

In-stream nitrogen (N) levels were compared against land use, climate, soils, and other watershed characteristics to determine whether this analysis showed any inconsistencies with the University of Minnesota and the Minnesota Pollution Control Agency (UMN/MPCA) source assessment findings described in Chapters D1 to D4. This analysis was conducted to determine if the relationship between watershed characteristics and stream N levels support or contradict conclusions of the N source assessment, which were derived mostly without the use of statistics or stream monitoring information.

Based on the UMN/MPCA source assessment in chapters D1 through D4, we expected to see the following types of relationships between watershed characteristics and watershed N levels:

- watersheds dominated by forests should have low river N
- watersheds with large percentages of fertilized cropland should have high river N, especially if the land is tiled or is in areas with high groundwater recharge
- river nitrogen loads should be generally independent of human population differences when evaluating rural watersheds

The evaluated watersheds included only those independent 8-digit Hydrologic Unit Code (HUC8) watersheds which: a) were not influenced by upstream main-stem rivers; and b) had two years of N yield and concentration data, obtained during years with mid-range river flows within the 2005-2009 timeframe (see Chapter B3 for more information on the selection of the watersheds meeting minimum criteria).

We analyzed the watershed characteristics and N levels in two different ways: 1) a non-statistical approach to observe the differences in land characteristics between watersheds with low, medium, high, and very high stream N levels; and 2) a statistical multiple regression analysis to identify key watershed characteristics influencing the variability in stream N levels.

This approach follows a central theme in landscape ecology, investigating relationships between spatial patterns in the landscape and ecological processes (Turner et al., 2001), and more specifically, the relationships between land use patterns in watersheds and the conditions of the streams that run through them (Allen 2004). The purpose of the watershed characteristics assessment was to gain a better understanding of similarities and differences among the watersheds with various levels of N pollution. The causes of high and low nitrate levels cannot be isolated as single variables, but are rather due to several confounding factors which involve: the presence or addition of a N source, the amount of water available to drive the N through the soil, an absence of an effective way of removing soil N (such as high density of plant roots), and a transport pathway which circumvents denitrification losses.

This analysis did not include watersheds with large metropolitan areas. This was the case because large metropolitan area watersheds water quality results were influenced by upstream main stem rivers, or we did not have two years of N yield and concentration data for these watersheds, obtained during years with mid-range river flows within the 2005-2009 timeframe.

Watershed characteristics

Methods of extracting land characteristic data

Watershed areas were delineated upstream from 79 water quality monitoring stations across Minnesota. We used ArcHydro in ArcGIS (ESRI 2012) to complete the delineations. Our ArcHydro implementation was developed using a 30-meter hydrologically conditioned digital elevation model (DEM) together with watershed walls enforced using the Minnesota Department of Natural Resources (MDNR) 16-digit catchments, and burned-in streams using the MDNR synthetic flow lines. We selected 28 watersheds that were not influenced by upstream main stem rivers and which also had two years of N yield and concentration data obtained during years with mid-range flows between 2005 and 2009. We used these 28 watersheds to extract data from a series of data layers listed in Table 1. For categorical raster layers such as the National Land Cover Data (NLCD) we calculated the area covered by specific land cover classes. For continuous raster layers such as percent soil organic material, we calculated the average percent of the material for each watershed. For vector layers such as the 2010 Census, we used a spatial overlay apportionment method and summarized the results by watershed to determine density values for each watershed. We used additional spatial overlays and raster analysis tools to determine areas where land cover characteristics overlapped, for example where row crops and shallow depth to bedrock were both present.

Table 1. List of land characteristic data layers and the associated data sources.

Forest and shrub	NLCD 2006 classes 41, 42, 43, 52
Pasture, grass and hay	NLCD 2006 classes 71, 81
Human population density (persons per acre)	U.S. Census 2010 blocks
Livestock and poultry density	MPCA Delta database for feedlots
Shallow depth to bedrock (<= 50 feet)	Preliminary Bedrock Geologic Map of Minnesota, April 2010, Minnesota Geological Survey
Sandy soil areas (>=85%)	USDA NRCS SSURGO soils data
Row crops	USDA Crop Data Layer 2009 including corn, sweet corn, soybeans, dry beans, potatoes, peas, sunflowers, sugarbeets
Small grains	USDA Crop Data Layer 2009
Wetlands	NLCD 2006 classes 90, 95
Precipitation	Minnesota State Climatology Office
Irrigation	Permitted acres from the Minnesota Department of Natural Resources
Soil organic material	USDA NRCS SSURGO soils data
Estimated area tile drained	USDA Crop Data Layer 2009, USDA NRCS SSURGO soils, USGS National Elevation Dataset 30-meter DEM
Derived data layers	
RCD	Row crops over shallow depth to bedrock
RCS	Row crops over sandy soils
RCDS	Row crops over shallow depth to bedrock or sandy soils
RCDST	Row crops over shallow depth to bedrock or sandy soils or tile drain
RCnDST	Row crops not over shallow depth to bedrock, sandy soils, or tile drain

Acronyms	
DEM	Digital elevation model
NLCD	National Land Cover Database
NRCS	Natural Resources Conservation Service
SSURGO	Soil Survey Geographic Database

Our analysis included a data layer to estimate land area with tile drainage. This layer was developed by the authors using information from scientific publications (Sugg 2007, David 2010) and interviews with technical experts working in various rural areas in the state. Our criteria included the presence of row crop agriculture from the 2009 USDA Crop Data Layer, relatively flat slopes of 3% or less from the United States Geological Survey (USGS) National Elevation Dataset 30-meter DEM, and soils that were poorly drained or very poorly drained based on Soil Survey Geographic Database (SSURGO) soils data developed by the U.S. Department of Agriculture, Natural Resources Conservation Service.

We used the data layers listed at the top of Table 1 to create additional spatial data layers to serve as explanatory variables in our analysis. These data layers are listed in Table 1 in the section titled 'Derived Data Layers.' These include row crop over shallow depth to bedrock (RCD), row crop over sandy soils (RCS), row crop over shallow depth to bedrock or sandy soils (RCDS), row crop over shallow depth to bedrock, or sandy soils, or tile drain (RCDST), and finally, row crop with no shallow depth to bedrock, no sandy soils, and no tile drain (RCnDST). The RCD, RCS, and RCDS are considered to be naturally 'leaky' agricultural systems, while the tile drain layer (TD) is considered to be an anthropogenic 'leaky' agricultural system. The RCDST is a combination of these leaky systems, and the RCnDST is a non-leaky system where nutrients are less likely to have rapid pathways to surface waters.

Data coverage for each data layer listed in Table 1 was complete for the full extent of the study area, except for the SSURGO soils layer which was not finished for all areas of Minnesota at the time of this work. However, all 28 watersheds had at least partial SSURGO data coverage, with 17 having 100% coverage; 4 having 80% to 99% coverage; 6 with 50% to 79% coverage; and 1 with less than 50% coverage. For watersheds with incomplete SSURGO data, we assumed that areas with missing data were similar to areas with data present, and we used a proportioning coefficient to reflect that assumption. SSURGO serves as source data for the sandy soil layer and the tile drainage layer, and layers derived from these two. SSURGO was also used to estimate soil organic matter content.

The only watershed with less than 50% SSURGO data coverage was the Little Fork River watershed, which had only 14% coverage. However, we do not believe the minimal SSURGO coverage in the Little Fork River watershed significantly affects the analysis. This watershed has essentially no row crop agriculture, and the only explanatory variables that are based on SSURGO are also based on the presence of row crops (RCS, RCDS, RCDST, RCnDST and TD). So with no row crop agriculture, all these variables have zero values in the Little Fork watershed regardless of the SSURGO soil patterns.

Table 2. List of watersheds with partial SSURGO data coverage

Watersheds with partial SSURGO coverage	Fraction of watershed area covered by SURGO
Otter Tail River	0.99
Crow Wing, Redeye, Long Prairie River	0.96
Wild Rice River	0.87
Snake River	0.81
Rum River	0.73
Big Fork River	0.67
Thief River	0.63
Clearwater River	0.61
Mississippi R Headwaters	0.59
Kettle River	0.54
Little Fork River	0.14

Non-statistical view of watershed characteristics compared to river nitrogen levels

The non-statistical approach we used to compare watershed characteristics with N concentrations was to categorize each watershed as a low, medium, high or very high N watershed, based on the stream N monitoring results. We then assessed the range and mean of numerous watershed characteristics for each of the four N level category watersheds.

Categorizing watersheds into low, medium, high and very high nitrogen levels

Twenty-eight independent watersheds with available normal flow conditions fit into one of four distinct categories based on total nitrogen (TN) and nitrite+nitrate-N (NOx) yields and concentrations. The watersheds fitting the low, medium, high, and very high categories of water N levels are shown in Table 3.

Table 3. Watershed groupings based on stream Nitrite+Nitrate-N and Total N yields and concentrations. Watersheds which did not meet selection criteria are not included in this table.

Category	Low N watersheds	Medium N watersheds	High N watersheds	Very high N watersheds
Major Watersheds	Otter Tail River	Chippewa River	Root River	Blue Earth River
	Rum River	Wild Rice River	Cannon River	Cottonwood River
	Snake River	Clearwater River	Des Moines - Headwaters	South Fork Crow
	Leech Lake River	Buffalo River	Yellow Medicine	LeSueur River
	Kettle River	Pomme de Terre	Redwood River	Watonwan River
	Mississippi R. Headwaters	Sauk River		
	Little Fork River	Sandhill River		
	Big Fork River	Marsh River		
	Thief River			
	Crow Wing + Redeye + Long Prairie Rivers			
Nitrogen ranges				
NOx FWMC (mg/l)	0.05-0.5	0.6-1.9	4.8-7.1	7.9-9.5
TN FWMC (mg/l)	0.7-1.4	1.8-3.4	5.6-8.6	9.8-11.1
NOx Yield (lbs/ac/yr)	0.07-0.53	0.37-2	3.6-8.9	9.3-18.3
TN Yield (lbs/ac/yr)	0.51-2.7	1.4-3.9	7.6-12.1	10.9-21.3

Maps of watershed nitrate and TN concentrations and yields are shown in Figures 1, 3, 5 and 7. The range and average nitrate and TN concentrations and yields for each of the four watershed categorizations in Table 3 are shown in Figures 2, 4, 6 and 8. The same watersheds remain in each of the Table 3 categories throughout all figures in this section. For example, the very high N watersheds are always represented by the Blue Earth, Cottonwood, South Fork Crow, LeSueur, and Watonwan Rivers.

As shown in Figures 1 to 8, the nitrite+nitrate-N (NOx) flow weighted mean concentrations (FWMC) and yields show four distinct ranges and means. For example, the NOx FWMC range in watersheds classified in Table 3 as having high N levels do not overlap at all with the NOx FWMC range of watersheds classified in Table 3 as having medium N levels (Figure 2). The range of TN FWMCs in the four categories of watersheds are also distinct, with no overlapping concentrations among the four categories (Figure 6). NOx yields show the same pattern of a very low range of yields to a very high range of yields in the four categories, although there is a slight overlap in ranges in a couple of the categories (Figure 4). The TN yield ranges are less distinct compared to the NOx yields, since TN includes organic N which is influenced by natural sources as well as human-induced sources (Figure 8).

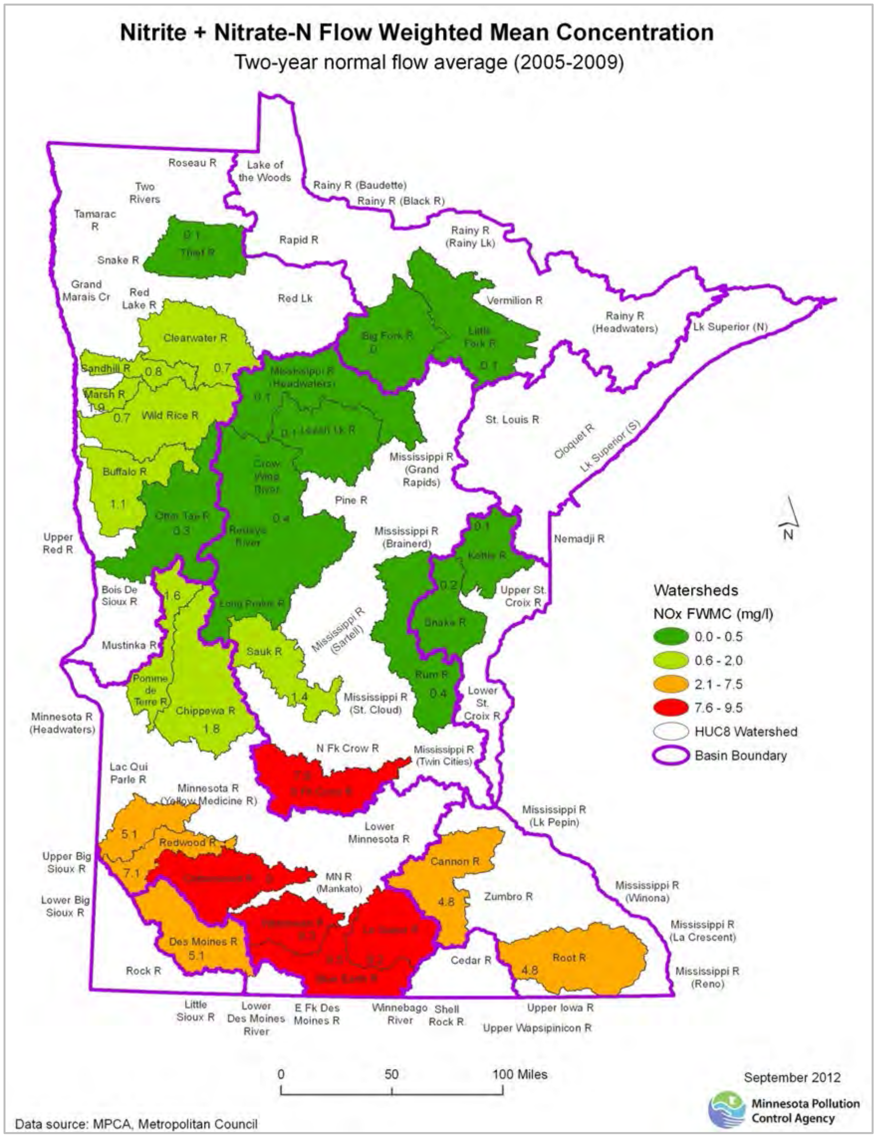

Figure 1. Nitrite+nitrate-N annual flow weighted mean concentration averages from the 28 study watersheds. Monitoring and load calculations were conducted by the MPCA and Metropolitan Council.

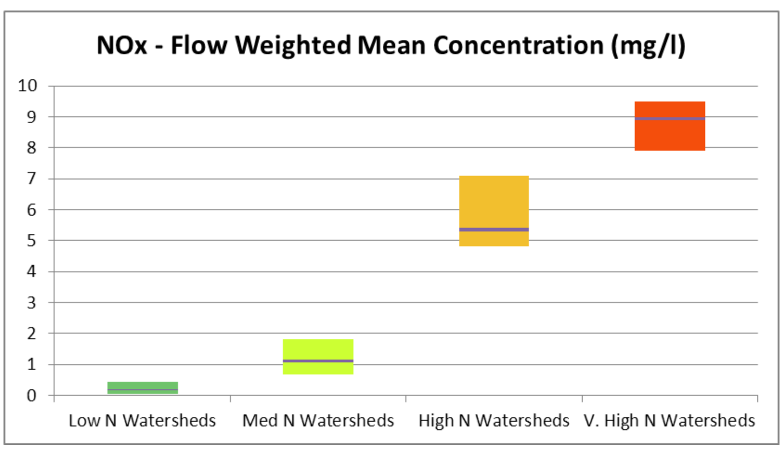

Figure 2. The range (colored bars) and mean (dark line) nitrite+nitrate-N annual flow weighted mean concentration for watersheds in each of the four river N level groupings listed in Table 3.

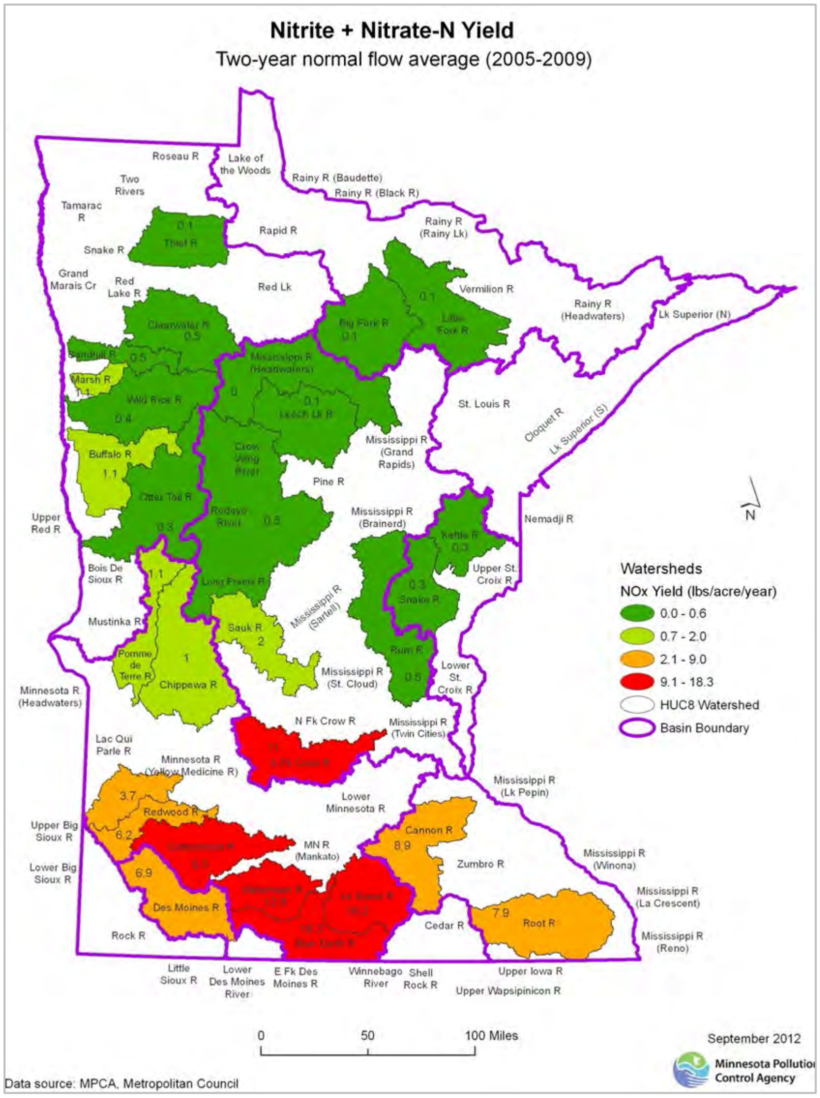

Figure 3. Nitrite+nitrate-N annual yield averages from the 28 study watersheds. Monitoring and yield calculations were conducted by the MPCA and Metropolitan Council.

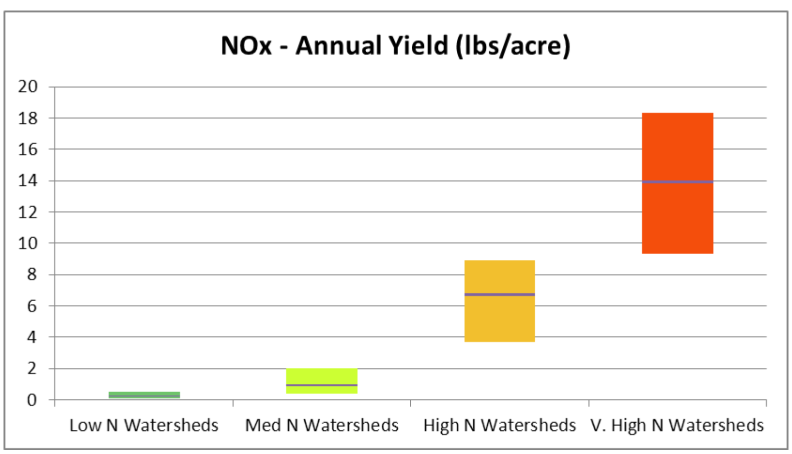

Figure 4. The range (colored bars) and mean (dark line) nitrite+nitrate-N annual yield for watersheds in each of the four river N level groupings listed in Table 3.

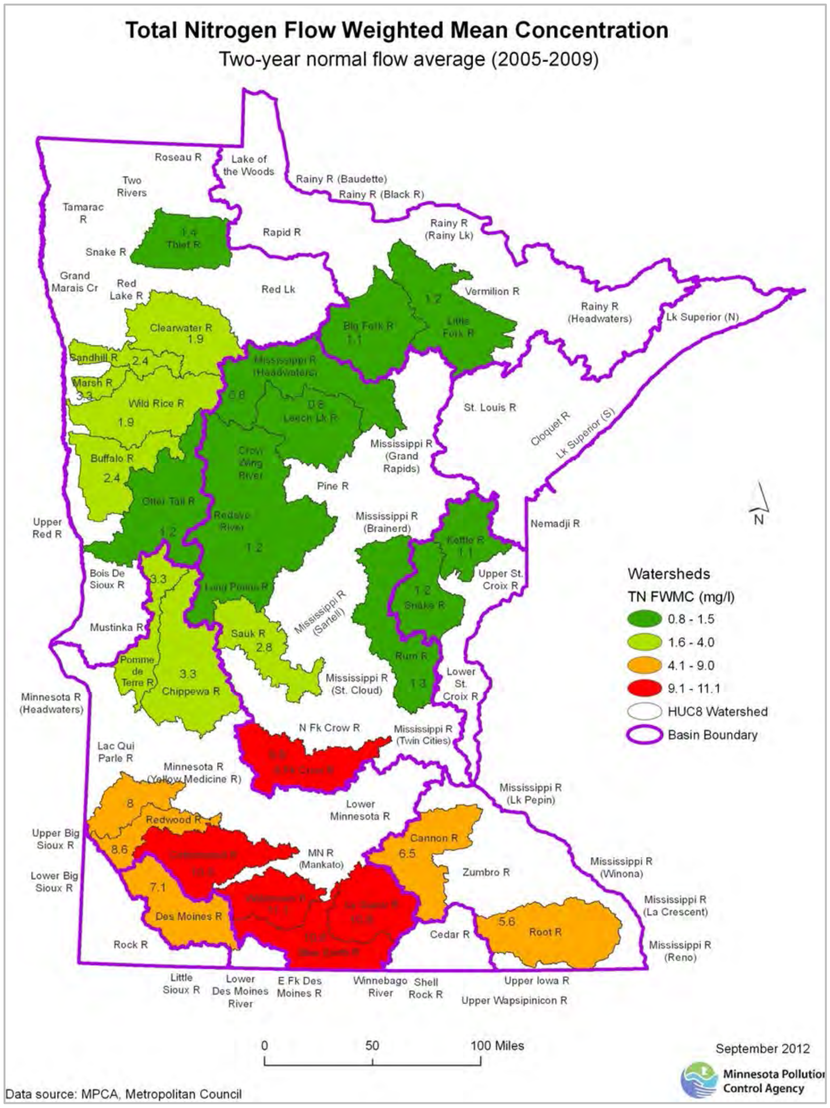

Figure 5. Total nitrogen annual flow weighted mean concentration averages from the 28 study watersheds. Monitoring and load calculations conducted by the MPCA and Metropolitan Council.

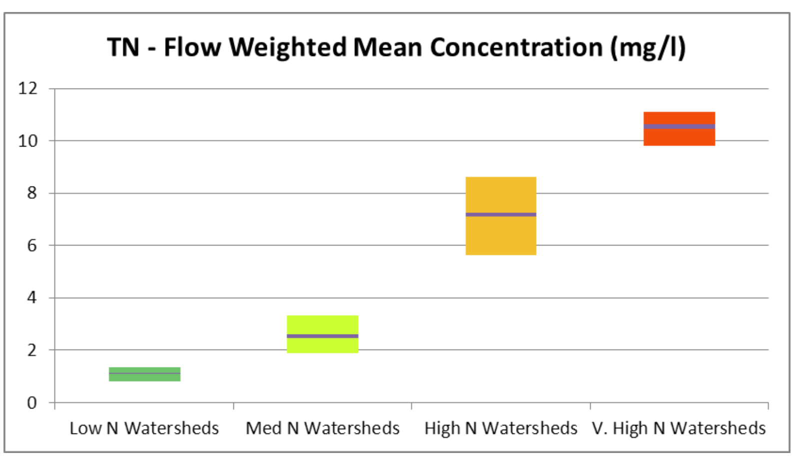

Figure 6. The range (colored bars) and mean (dark line) TN annual flow weighted mean concentration for watersheds in each of the four river N level groupings listed in Table 3.

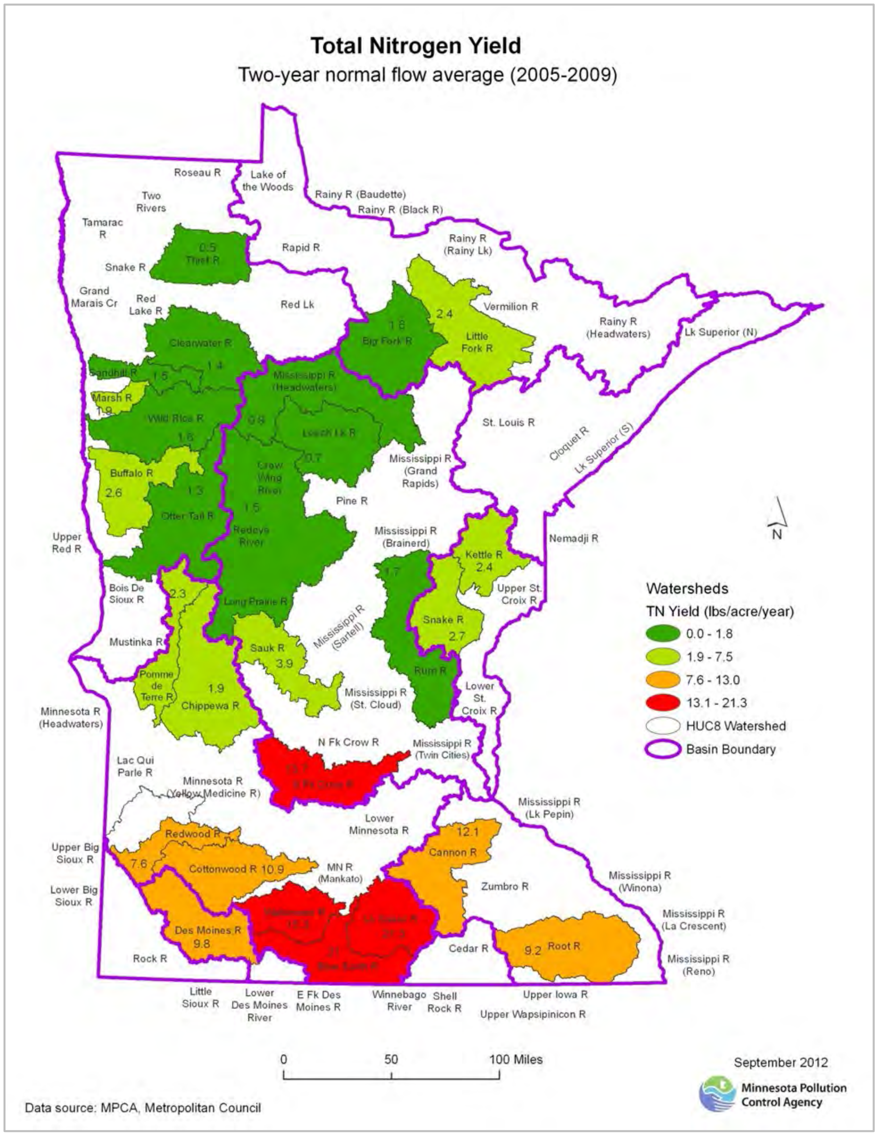

Figure 7. Total nitrogen annual yield from the 28 study watersheds. Monitoring and yield calculations conducted by the MPCA and Metropolitan Council.

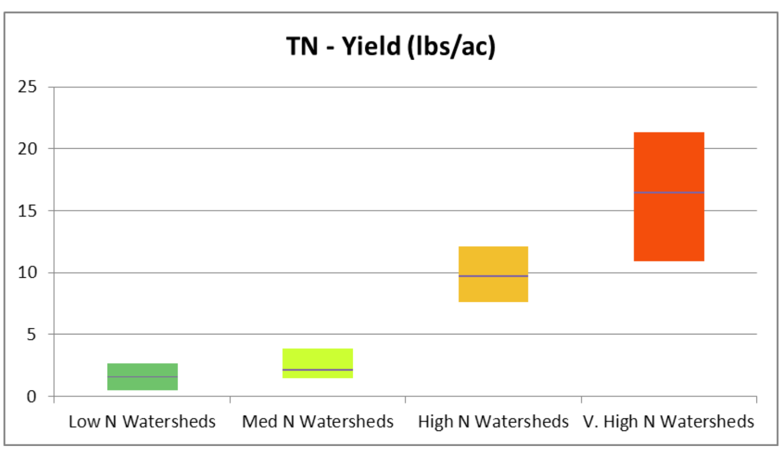

Figure 8. The range (colored bars) and mean (dark line) TN yield for watersheds in each of the four river N level groupings listed in Table 3.

Graphical depictions of watershed land characteristics with nitrogen levels

The range of watershed characteristics for each of the four stream N level categorizations (as listed in Table 3) are shown in Figures 9 to 21. Each bar in these figures represents the range in land use for watersheds assigned to that stream N level category, and the dark line in the middle of the colored bars represents the average of watersheds grouped in each category.

Note: The following results were not used in any way for estimating N source contributions in Section D of this report. The N source assessment uses a completely different approach which does not include statistical relationships between land characteristics and monitoring results.

Forest and grasses

The average percent of watershed land area in forest and grasses is inversely related to the watershed N level, yet there is overlap in the ranges of land percentages in forest and grass among the four categories (Figure 9). The low N watersheds have between 15% and 71% of land in forest and grassland, with a mean of 53%. In contrast, the very high N watersheds have 3% to 15% of their land in forest and grasses, with a mean of 7%.

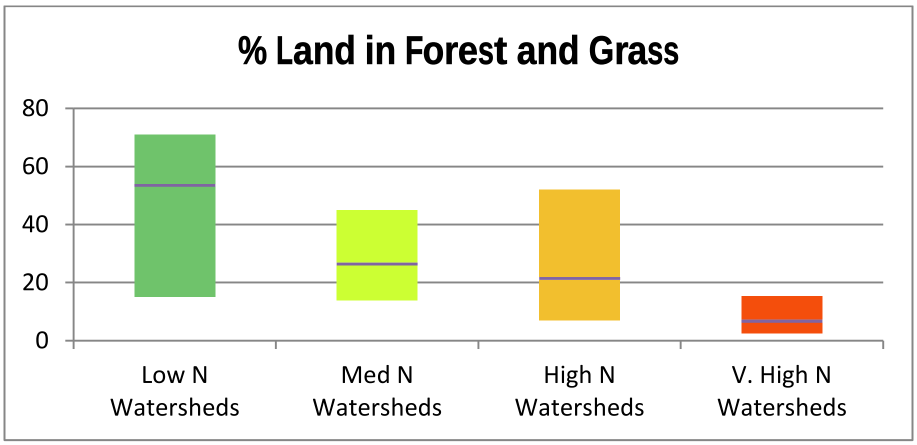

Figure 9. The range (colored bars) and mean (dark line) percent of land in forest and grasses for watersheds classified under each of the four river N level groupings (as listed in Table 3).

Human population

The range in human population densities among the four categories of N level watersheds does not show any definitive patterns (Figure 10), suggesting that differences in human population among the studied watersheds is not a major factor influencing water N ranges in the studied watersheds. Note, however, that the watersheds with major urban centers, such as the Twin Cities, Rochester, or Duluth, did not meet the watershed selection criteria and are not included among the watersheds assessed within this chapter. It is possible that if the evaluated watersheds had included larger urban areas that an effect from high human population centers would be observed.

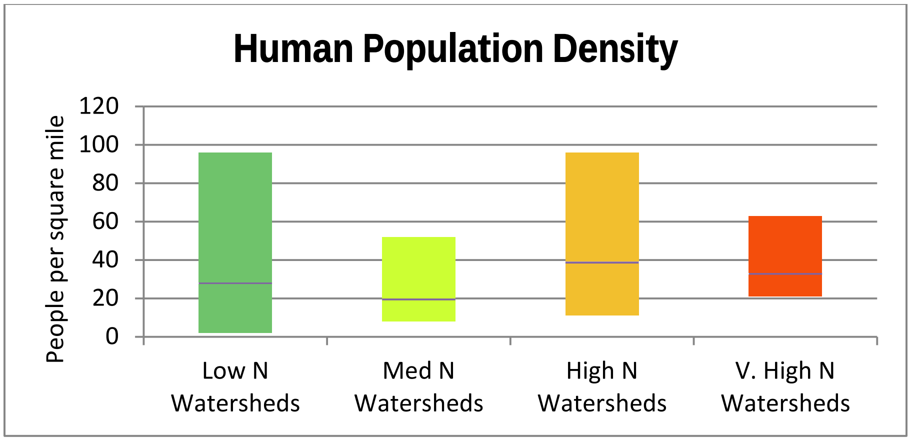

Figure 10. The range (colored bars) and mean (dark line) human population density for watersheds classified in each of the four river N level groupings (as listed in Table 3).

Irrigated agriculture

Differences in stream N levels did not appear to be closely associated with low or high percentages of the watershed under irrigation. The highest average percentage of land under irrigation was in the medium N watershed category (Figure 11). While irrigated fields could contribute N to localized surface waters, the total amount of irrigated acreage was less than 9% in all watersheds and was, therefore, not a dominant land use in any of the studied watersheds. Irrigation does not appear to be an important factor affecting the very high N level watersheds, as these five watersheds each had less than 1% of the land in irrigated agriculture.

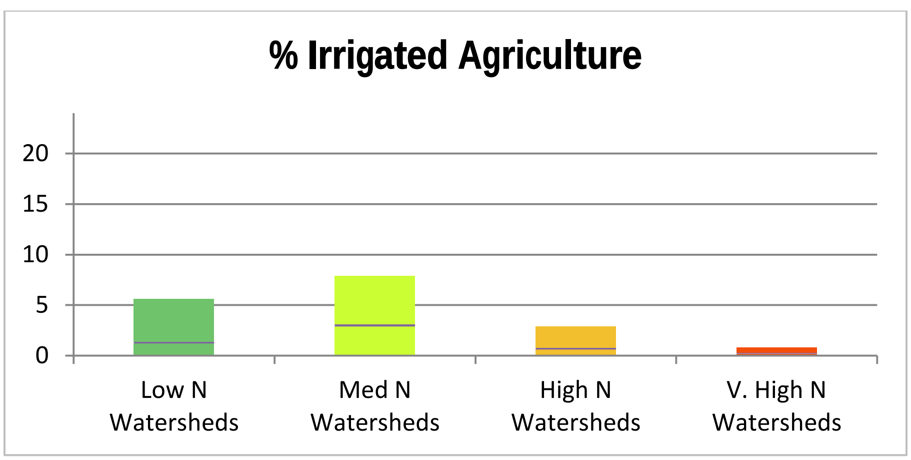

Figure 11. The range (colored bars) and mean (dark line) percent of land under irrigated agricultural production for watersheds in each of the four river N level groupings (as listed in Table 3).

Soil organic matter

Soil organic matter ranges and means were highest in the watersheds with the lowest surface water N levels, followed by the medium N watersheds (Figure 12). The high soil organic matter in the low N watersheds is likely attributable to the abundance of wetland and peat soils common in the northern part of the state where river N levels are low. The high and very high N watersheds had the lowest percent soil organic matter. Soil organic matter is one source of N to waters, but is transported to waters most readily when converted to mobile N forms through a mineralization process affected by temperature, soil moisture, and soil oxygen.

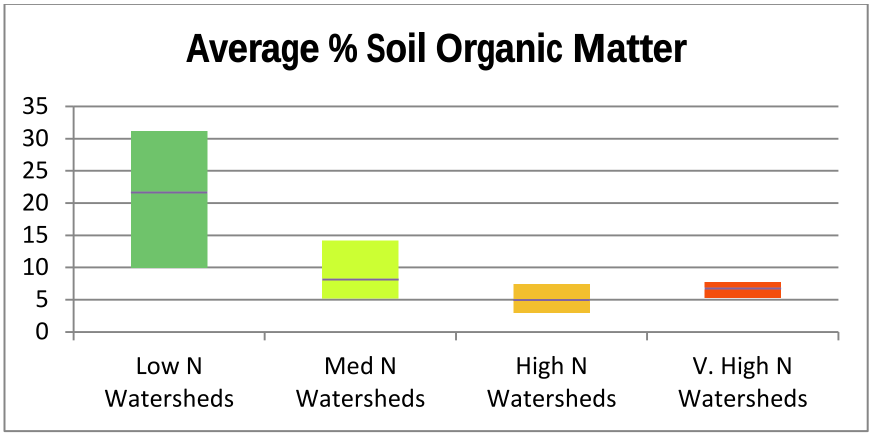

Figure 12. The range (colored bars) and mean (dark line) of the spatial average soil organic matter (%), in watersheds classified under each of four river N level groupings (as listed in Table 3).

Wetlands

The average percent of watershed land in wetlands is inversely related to river N levels (Figure 13). The high and very high river N watersheds have an average of about 3% of the watershed area in wetlands. The mean percent of land with wetlands increases to 8% and 29% in the medium and low N watershed categories, respectively. Wetlands remove considerable amounts of nitrate. However, the low N in watersheds with more wetlands is not necessarily attributable to the wetlands, since these same watersheds also have different land use, soils, and land cover as compared to the higher N loading watersheds.

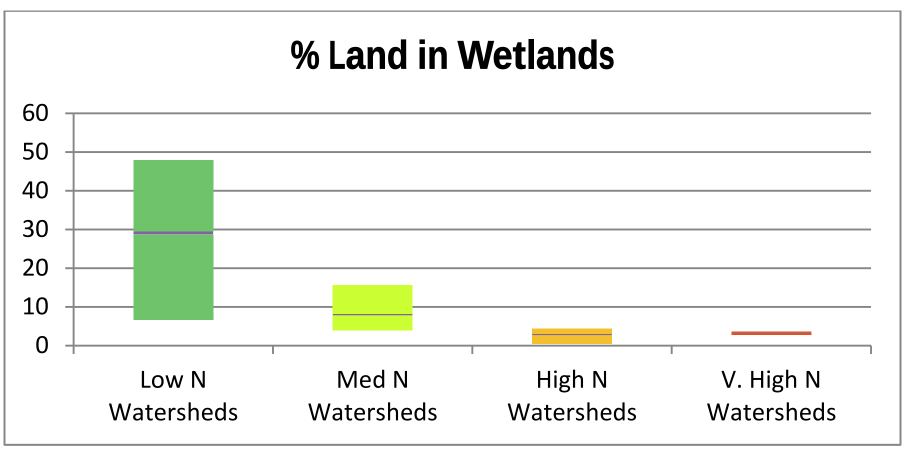

Figure 13. The range (colored bars) and mean (dark line) of the percentage of land with wetlands, in watersheds classified under each of four river N level groupings (as listed in Table 3).

Small grains

The watersheds with the most land in small grain production had low to medium N levels (Figure 14). The small grains are often grown in areas where soils and climate are less suitable for row crop production and, therefore, we cannot directly attribute small grains as a cause of high or low nitrate. Rather, we can only note that our high N watersheds are those with relatively low percentages of land planted to small grains.

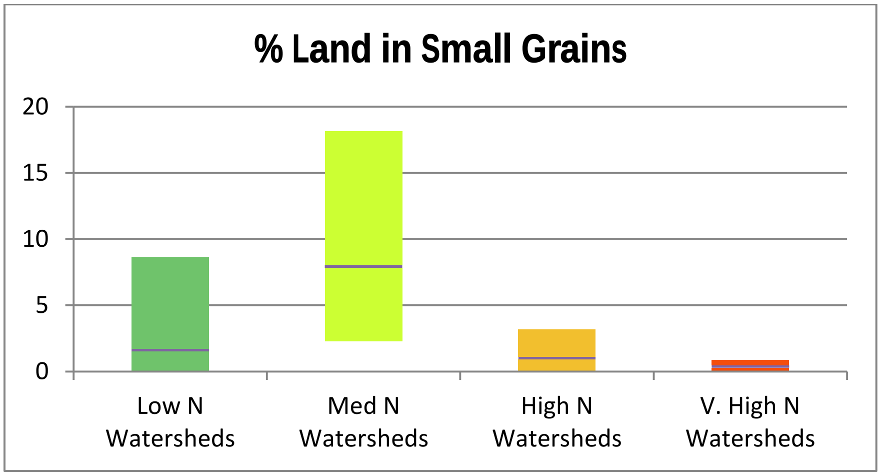

Figure 14. The range (colored bars) and mean (dark line) of the percentage of land in small grain production in watersheds classified under each of four river N level groupings (as listed in Table 3).

Precipitation

Average annual precipitation was slightly lower in the low and medium N category watersheds as compared to the high and very high N watersheds (Figure 15). However, there is considerable overlap in precipitation levels among the four N categories.

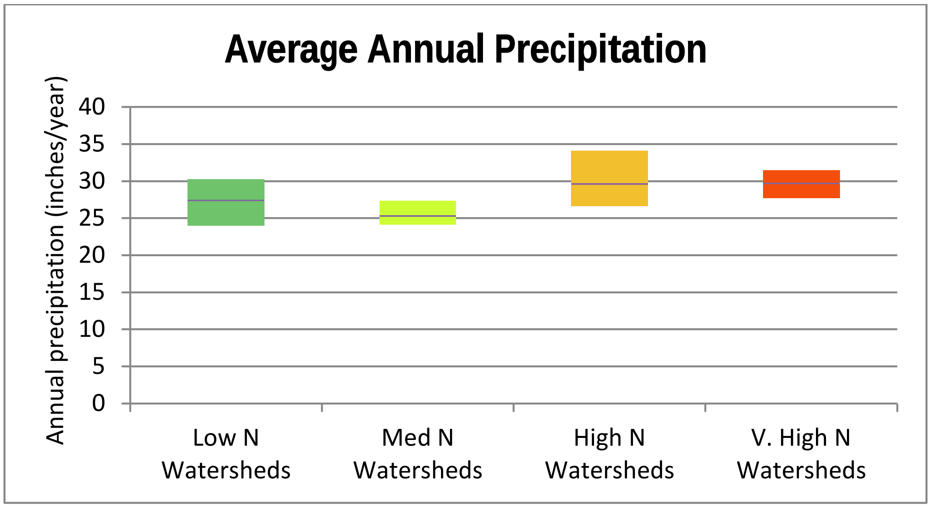

Figure 15. The range (colored bars) and mean (dark line) of the 30 year annual precipitation in watersheds classified under each of four river N level groupings (as listed in Table 3).

Land in row crops over sandy soils

The medium, high, and very high N watersheds each had similar percentages of land in row crop over sandy soils (Figure 16). The "low" river N watersheds had a lower fraction of land in row crop in general, and similarly had a lower percentage of row crops over sands as compared to the other watershed categories.

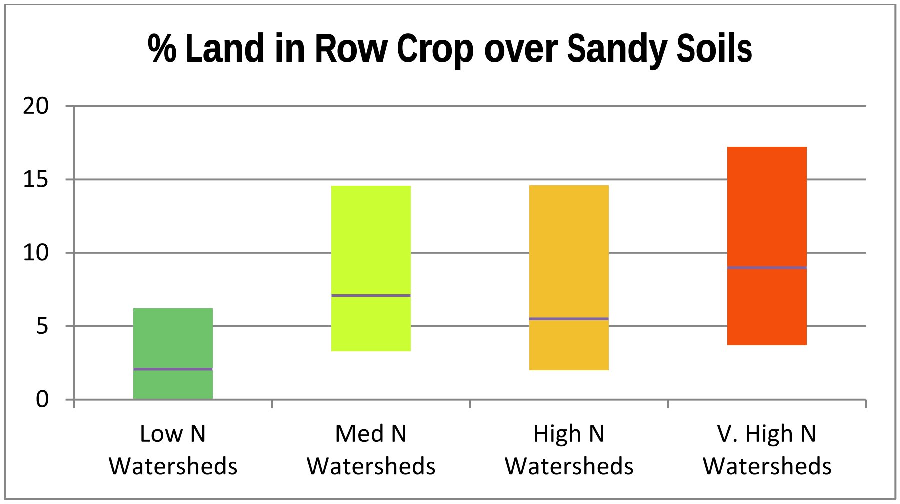

Figure 16. The range (colored bars) and mean (dark line) of the percentage of land in row crops over sandy subsoils, in watersheds classified under each of four river N level groupings (as listed in Table 3).

Land in row crops over shallow bedrock soils

The high and very high river N watersheds each had a couple of watersheds in regions with over 5% of the land having shallow depth to bedrock combined with row crop production. The low and medium N level categories did not have appreciable land with row crop over shallow depth to bedrock (Figure 17).

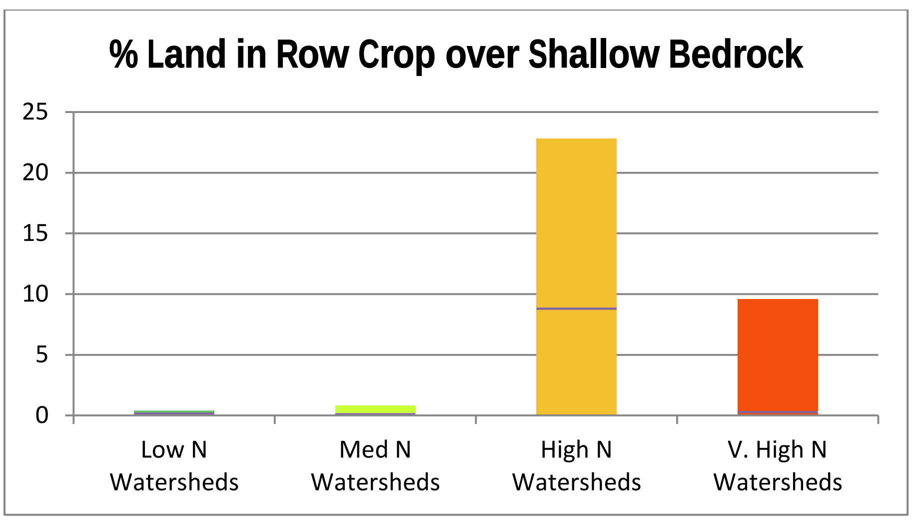

Figure 17. The range (colored bars) and mean (dark line) of the percentage of land in row crops over shallow depth to bedrock soils, in watersheds classified under each of four river N level groupings (as listed in Table 3).

Animal density

The mean watershed livestock density increases from 20 animal units (AU) per square mile in low N watersheds to 225 AUs per square mile in very high N watersheds (Figure 18). An AU is a measure used in feedlot regulations to approximate manure from a 1,000 pound beef cow. One AU represents 56 turkeys, or 0.7 dairy cows, or 3.3 finishing swine. The pattern in Figure 14 does not necessarily mean that livestock is a significant source of N in surface waters since livestock are concentrated in areas where other N sources, such as fertilizer, are also added to soil.

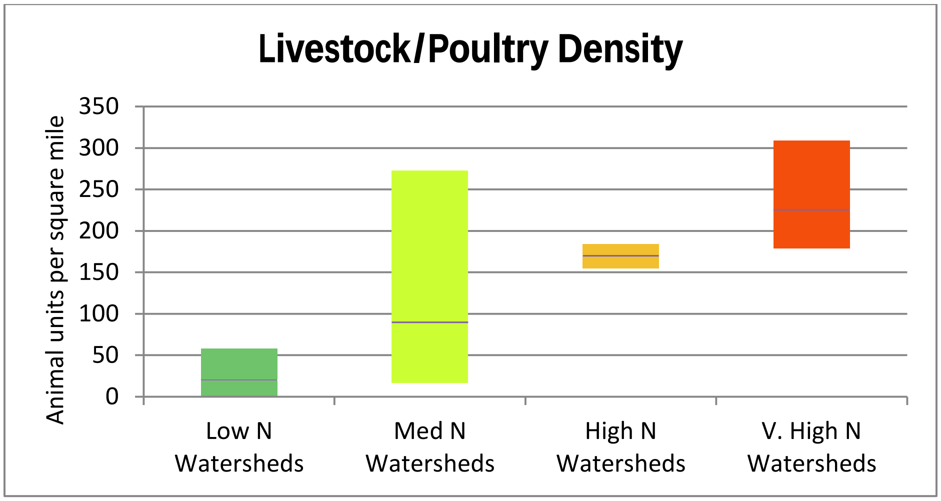

Figure 18. The range (colored bars) and mean (dark line) livestock and poultry AU density in watersheds classified under each of four river N level groupings (as listed in Table 3).

Row crops

The mean percent of watersheds in row crop production increases from about 5% in low N watersheds, to 39% in medium N watersheds, to 60% in high N watersheds, and 76% in very high N watersheds. Row crops are often located in areas that also have tile drainage and animal agriculture production. Therefore, we cannot conclude from this assessment that row crops are the key explanatory variable for stream N levels; rather it appears that row crops directly correlate with N levels in the watersheds used for this analysis.

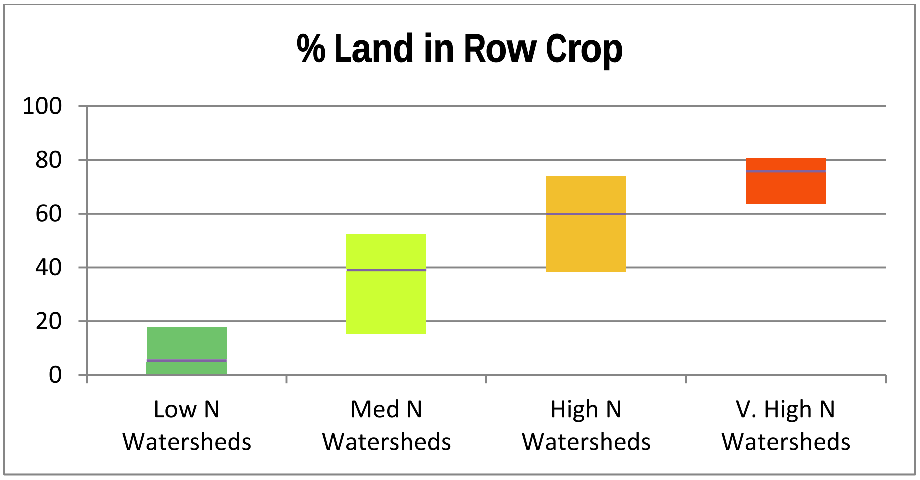

Figure 19. The range (colored bars) and mean (dark line) percent of land in row crop production for watersheds classified under each of the four river N level groupings (as listed in Table 3).

Tile drainage estimates

The relationship between watershed N level categories and percent of estimated tile-drained land (Figure 20) has a similar pattern as percent under row crop production. The mean percent of watershed with estimated tile-drained land is 0.2% in low N watersheds, 5% in medium N watersheds, 22% in high N watersheds, and 42% in very high N watersheds. The similarity between the row crop and tile drain variables is not unexpected because the criteria used to estimate tiled lands includes row crop production together with certain slope and soil conditions; thus, these variables are not independent of each other.

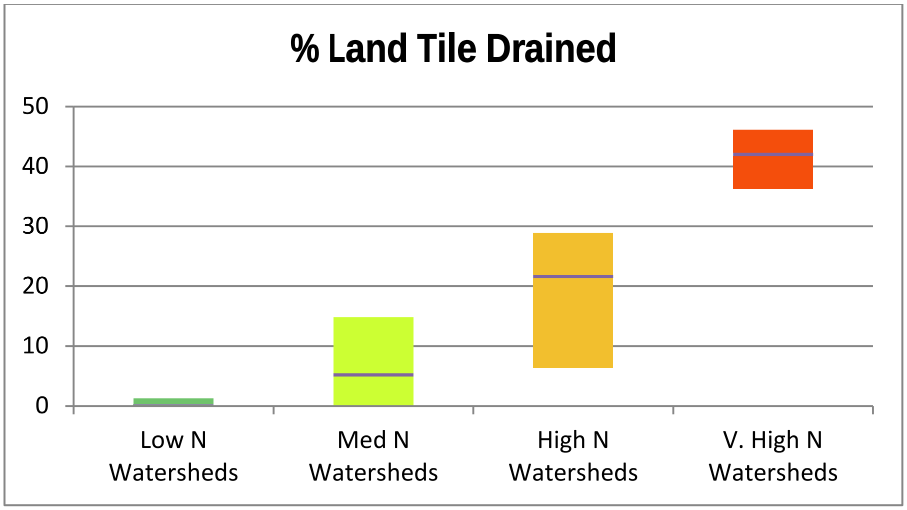

Figure 20. The range (colored bars) and mean (dark line) percent of land estimated to be tile-drained in watersheds classified under each of four river N level groupings (as listed in Table 3).

Row crops over leaky soils

The most distinct pattern observed between watershed N levels and land characteristics was with percent of row crop land in the watershed over leaky soils. “Leaky soils” included estimated tile-drained lands, sandy soils/subsoils, and shallow depth to bedrock (Figure 21). The four watershed N level categories each had a distinct and narrow range of percent row crop over leaky soils.

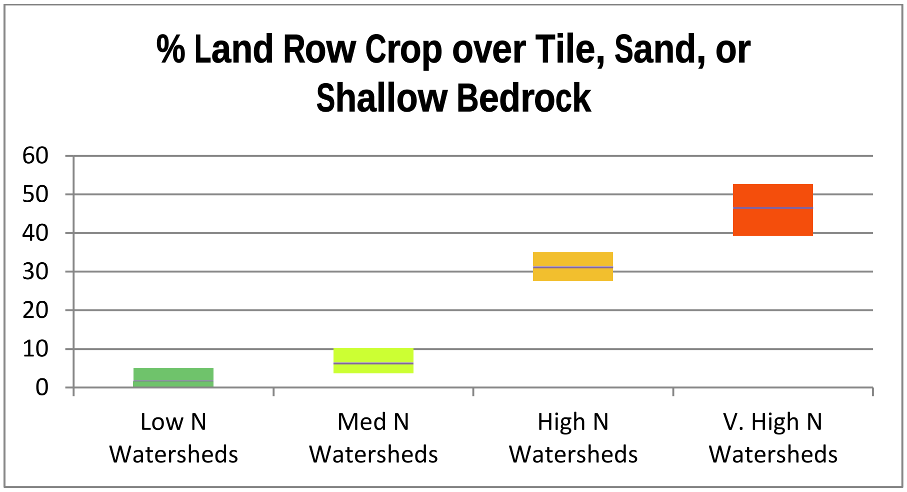

Figure 21. The range (colored bars) and mean (dark line) percent of land in row crops underlain by either tile-lines, shallow bedrock or sandy subsoils, in watersheds classified under each of four river N level groupings as listed in Table 3.

Patterns from graphs

The patterns of watershed characteristics associated with the low to very high river N levels do not show any inconsistencies with the UMN/MPCA source assessment described in chapters D1 to D4, and instead show several relationships which are generally consistent with the findings of the UMN/MPCA source assessment. A statistical analysis using this information is presented in the following section.

The Low N watersheds are characterized by having relatively high wetlands, high soil organic matter, high forest and grass-lands, and low row crop, low tile drainage, and low animal density. The very high N watersheds are characterized by having relatively low wetlands, low forest and grass, low small grain crops, and high row crop, high tile drainage, and high animal density.

Statistical assessment of watershed characteristics and river nitrogen

Methods

We used ordinary least squares (OLS) multiple linear regression analysis to examine relationships between four dependent variables and a set of 18 explanatory variables. Our four dependent variables were nitrite+nitrate (nitrate) flow weighted mean concentration (NOx FWMC), TN FWMC, nitrate yield (NOx Yield) and TN yield (TN Yield). Our 18 explanatory variables and their data sources are listed in Table 1. We considered many combinations of explanatory variables in an attempt to find the strongest regression models for each dependent variable. Scatter plots were examined using all combinations of dependent and explanatory variables. In cases where we found linear relationships (e.g., row crops and NOx FWMC), the explanatory variables were included in preliminary regression models. Where relationships were non-linear, we used logarithmic and exponential transformations with the explanatory variables, and included the transformed variables in the preliminary models (e.g., forest/ shrub and NOx FWMC). Explanatory variables that had strong correlations with dependent variables were considered to be the best candidates for the preliminary regression models. We used tests of statistical significance for explanatory variables, statistical significance of overall models, distribution of model residuals, variable inflation scores (VIF) that measure variable collinearity, Akaike's Information Criterion (AIC) scores that measure overall model fit, and R-squared values to evaluate the strength of each preliminary regression model (Quinn and Keough 2002).

A number of the explanatory variables that we initially considered to be good candidates for inclusion in the final models were not statistically significant in the regression analysis. These included percent of watershed with forest and shrub; pasture, grass and hay; wetlands; human population density; livestock and poultry density; small grain cultivation; irrigated agriculture; and soil organic matter. Other explanatory variables were statistically significant in the analysis but were highly correlated with other explanatory variables, as indicated by high VIF scores. These included row crops, row crops over shallow depth to bedrock (RCD), row crops over sandy soils (RCS), row crops over shallow depth to bedrock or sandy soils (RCDS), row crops over shallow depth to bedrock or sand soils or tile drains (RCDST), row crops not over shallow depth to bedrock, sandy soils or tile drain (RCnDST), and tile drained areas. After completing this exploratory analysis we selected the strongest statistically significant models for each dependent variable.

Results

Equations for the final models are listed in Table 4 and results from the statistical tests are included in Table 5. The final models for each of the four dependent variables were statistically significant at the $p < 0.01$ level. All explanatory variables were statistically significant at the $p < 0.01$ level. All four models had high R-squared values, each over 0.9. And each model had a comparatively low AIC score; a lower AIC score indicates a stronger model fit. VIF for each model were below an acceptable threshold of 7.5 indicating that collinearity among explanatory variables was not significant. Jarque-Bera tests indicated that model residuals were normally distributed for all four models (ESRI 2012). This result suggests that the models are unbiased and that they capture the critical explanatory variables. Koenker tests for each model indicated that the model relationships exhibited stationarity or consistency across geographic space. Global Moran's Index tests confirmed a random spatial distribution of model residual for the NOx and TN FWMC models; however, the Global Moran's Index tests for the NOx and TN yield models showed statistically significant spatial autocorrelation in the residuals. This result is in contrast to the results from the Jarque-Bera and Koenker tests cited above. Spatial autocorrelation in model residuals indicates spatial clustering of high and low values, and suggests that the model is predicting well in some parts of the study area and not as well in others; this is usually caused by important explanatory variables being absent from the model, or non-stationarity in the model (ESRI 2012). We felt that the models did include the important explanatory variables, so we used geographically weighted regression (GWR), a method that specifically addresses non-stationarity, to determine whether non-stationarity was the cause of the spatial autocorrelation.

Geographically weighted regression calculates explanatory variable coefficients for each feature in the model, based on a set of neighboring features within a specified search radius, rather than the full dataset as in OLS, and thus allows model relationships to vary across space. We used a fixed distance search radius calculated by ArcGIS to be the optimal distance for model development based on model AIC scores (ESRI 2012). The calculated search distance was 91.18 miles. We ran GWR with the NOx and TN yield models, and then ran Global Moran's Index tests on the GWR results. The Moran's Index for these models showed random spatial distribution of residuals, results that suggest non-stationarity was the issue with our original OLS models and the issue was resolved by using GWR. These results also indicate that the GWR models predict well across the study area and that the models are well specified and include the important explanatory variables. The GWR also gave lower AIC scores and higher R-squared when compared with the OLS models, suggesting a better fit with GWR for the NOx yield and TN yield models. We also tested the GWR with the NOx FWMC and TN FWMC but in both cases our AIC scores increased and R-squared values decreased compared to our original OLS results, suggesting that for the FWMC models, the GWR does not represent an improvement over the OLS method.

Table 4. Multiple regression equations for nitrite+nitrate-N flow weighted mean concentrations in mg/l (NOx FWMC); nitrite+nitrate-N yield in lbs/acre (NOx Yield); TN flow weighted mean concentration in mg/l (TN FWMC); and TN yield in lbs/acre (TN Yield). Explanatory variables include estimated percent of land with tile drain in the watershed (TD), percent row crop with shallow depth to bedrock or sandy soils (RCDS), and 30-year average precipitation. Explanatory variables were scaled to have a mean of 0 and standard deviation of 1 (method: ((value - mean) / standard deviation) and, therefore, these equations cannot be used for prediction with data not included in the original dataset.

Regression equations	Model
(0.13) (0.14) (0.14)	Standard Errors
NOx FWMC = 2.98 + 2.98 TD + 0.66 RCDS	OLS
(0.29) (0.33) (0.29)	Standard Errors (mean values)
NOx Yield = 2.41 + 3.93 TD + 1.42 Precipitation 30 year average	GWR (mean values)
(0.13) (0.14) (0.14)	Standard Errors
TN FWMC = 4.33 + 3.24 TD + 0.66 RCDS	OLS
(0.39) (0.44) (0.39)	Standard Errors (mean values)
TN Yield = 4.08 + 4.22 TD + 1.76 Precipitation 30 year average	GWR (mean values)
Acronyms	
Tile Drainage	TD
Row crops over shallow depth to bedrock or sandy soils	RCDS
Ordinary Least Squares Regression	OLS
Geographically Weighted Regression	GWR

Table 5. Model parameters and test results

	NOx FWMC	NOx yield	TN FWMC	TN yield
Sample size	28	28	28	27
Adjusted R-squared	0.96	0.98	0.97	0.98
AIC	63.48	73.12	65.15	85.44
Model p-value	< 0.01	< 0.01	< 0.01	< 0.01
VIF	1.22	1.26	1.22	1.29
Model	OLS	GWR	OLS	GWR
Moran's Index score	0.12	0.18	0.06	0.12
Moran's Index z-score	1.15	1.56	0.70	1.20
Moran's Index p-value	0.25	0.12	0.49	0.23
GWR Search Radius	NA	91.18 miles	NA	91.18 miles

Discussion

The N concentration models (NOx FWMC and TN FWMC) suggest that row crop practices using tile drainage and row crop practices on naturally sensitive lands with high groundwater recharge explain much of the nitrate concentration variability in the 28 Minnesota rivers. Sensitive lands in this context are defined as areas that have a depth to bedrock of less than 50 feet, or sand content in the subsoil greater than 85%, or both. The N yield models (NOx Yield and TN Yield) suggest that N yields in the 28 watersheds are influenced largely by row crop practices using tile drainage and by precipitation. That precipitation is a significant explanatory variable in the yield models is not surprising since yield (pounds/acre/year) for any chemical parameter is affected by river flow, which, in turn, is largely influenced by precipitation.

We scaled the explanatory variable data to have a mean of zero and a standard deviation of one, so that a comparison of the relative strength of the variable coefficients in influencing N level variability would be possible. As shown in the concentration equations in Table 4, the influence of the estimated tile drain variable on nitrate has four and half times the magnitude of the influence of the RCDS variable, and for TN tile drainage has almost five times the magnitude of influence as RCDS. In the yield equation for nitrate, the estimated tile drain variable has nearly three times the influence of the precipitation variable, and for TN yield it has more than two times the influence. These coefficient values suggest that the amount of watershed land in tile drainage is the leading predictor of river nitrate and TN concentrations and yields.

In addition, the GWR analysis for the N yield models showed specific spatial trends in the model relationships, as indicated by the variance in the explanatory variable coefficients. Specifically, the model coefficients for estimated percent of watershed with tile drainage, and mean annual precipitation are higher in southern Minnesota than in the northern half of the state (Figures 1-4). This result suggests that with higher amounts of tile drainage and precipitation in the study watersheds, these explanatory variables have increased influence on levels of nitrate and TN yield in corresponding rivers.

Maps showing the spatial pattern of explanatory variables in the regression models are included in Appendix E2-1. Maps showing the GWR coefficients for explanatory variables in the NOx and TN yield models are included in Appendix E2-2. And scatter plots showing relationships between dependent variables and the explanatory variables in the regression models are included in Appendix E2-3.

Summary

The strong correlation between estimated tile drained lands and high nitrate and TN yields and FWMCs is generally consistent with the UMN/MPCA source assessment findings (Chapters D1-D4) showing tile drained cropland as the largest contributor to N loads in the state. The source assessment showed that cropland groundwater was the second highest N source/pathway. This is somewhat consistent with the statistical modeling results showing that cropland over potentially high groundwater recharge lands (shallow bedrock and sandy soils) was another important variable correlated with nitrate and TN FWMCs. The cropland over shallow bedrock and sands variable was not, however, found to be a key explanatory variable affecting nitrate or TN yield in the best statistical models.

The UMN/MPCA N source assessment also showed that loads/yields are highly dependent on precipitation. This is generally consistent with the best statistical models for N yield, which showed that average annual precipitation in the watershed was the second most important variable after tile drainage affecting variability in watershed nitrate and TN yields. Future analyses should assess whether groundwater recharge, integrating precipitation and geologic sensitivity, over cropland is correlated with nitrate and TN yield.

As noted earlier, the statistical analyses do not show causes, but relationships. The multiple regression analyses, along with the single variable graphs and scatter plots, did not show results that are inconsistent with the source assessment findings, and there were several relationships which supported the source assessment findings.

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E3. Other Studies of Nitrogen Sources and Pathways

A review of published literature related to nitrogen (N) sources was conducted to see how other study results compared with the N source assessment findings reported in Chapters D1-D4 (UMN/MPCA Source Assessment). This chapter discusses the findings of the other studies, which is the fifth way we compared the UMN/MPCA source assessment findings with other information (the other four approaches are discussed in Chapters E1 and E2). For this review, we focused mostly on watershed or larger scale studies in Minnesota and the upper Midwest, but also included conclusions from a national study by the U.S. Geological Survey (USGS) to provide broader context.

A national U.S. Geological Survey assessment

In its recently published summary of water quality in 51 hydrologic systems across the nation, the U.S. Geological Survey (USGS) concluded that human impacts are the primary reason for elevated N in United States surface waters (Dubrovsky, et al., 2010). The study also found:

1. Low N levels where land use is dominated by non-urban and non-agricultural land uses
    - Background concentrations were 0.24 mg/l for nitrate-N, 0.025 mg/l for ammonia+ammonium-N and 0.58 mg/l for total nitrogen (TN). These numbers were determined from 110 stream sites across the country which had less than 5% urban and less than 25% agricultural land. The 75th percentile of the flow weighted mean concentrations was determined to represent the background concentration.
    - “Nutrient concentrations in streams and groundwater in basins with significant agricultural or urban development are substantially greater than naturally occurring or “background” levels.”
2. Nitrogen levels are elevated in agricultural and/or urban dominated watersheds
    - Concentrations of nitrate, ammonia, and TN exceeded background levels at more than 90% of 190 streams draining agricultural and urban watersheds.
    - Concentrations of TN were higher in agricultural streams than in streams draining urban, mixed land use, or undeveloped areas. Yet the amounts of N lost from watersheds to streams (expressed as mass per unit area) increased with increasing nutrient inputs regardless of land use.
    - Elevated concentrations of nitrate mostly occurred in streams that drain agricultural watersheds where the use of fertilizers and/or manure is relatively high.
    - Nitrate-N concentrations exceeded the Maximum Contaminant Level (MCL) of 10 mg/l at 7.3% of stream samples draining urban land, 28.1% of streams draining agricultural land uses and 5.3% of streams draining mixed land-use settings; whereas none of the samples from streams draining undeveloped land exceeded the MCL.
    - Most surface-water samples with nitrate concentrations exceeding the MCL were collected from small streams in the corn belt region.

A Minnesota U.S. Geological survey study

Using data collected between 1984 and 1993, the USGS conducted an in-depth study of stream nutrients in large parts of Minnesota, including the southern half of the Mississippi River Basin; the Cannon and Vermillion River watersheds, and the St. Croix River Basin in Minnesota and Wisconsin (Kroening and Andrews, 1997).

The percentages of N added to the land (and water for wastewater additions) in the study area from different sources was estimated to be as follows:

- Fertilizer – 49%
- Manure – 23%
- Nitrogen fixation – 15%
- Atmospheric deposition – 11%
- Municipal wastewater treatment plants – 2%

Nitrate-N concentrations in the tributaries to the Mississippi River were found to be significantly greater in streams draining agricultural lands, as compared to streams draining forested or mixed forest and agriculture areas. Median concentrations in agricultural areas ranged from 2.0 to 5.3 mg/l, and were 0.2 to 0.6 mg/l in mixed forest and agriculture, and 0.05 to 0.1 mg/l in forested areas.

Nearly 11% of the added N was found to be exported to streams. Note that soil mineralization was not included as an added source in the Kroening and Andrews study. If soil mineralization is added to the list of N sources, the percent of inputs lost to waters in this USGS study would be reduced.

Iowa nitrogen budget

While Iowa land uses and characteristics are somewhat different than Minnesota's, there are also many similarities, including population density (66 and 54 people per square mile in Minnesota and Iowa, respectively); cropland acreages (22 and 26 million acres in Minnesota and Iowa, respectively); same average farm size (331 acres); and both states with a large fraction of the corn, soybean, and livestock production in the United States. Therefore, we would expect to see somewhat similar fractions of N inputs and outputs from the various sources and exports in the two states.

Inputs and outputs of N were estimated for Iowa by Libra et al. (2004). Iowa N budget data represent an average year between the period of 1997-2002. Stream load estimates were based on monthly monitoring between 2000-2002 at 68 major watersheds that covered 80% of the state.

Inputs of N to the state total about four million tons per year or about 216 pounds per acre. Estimated annual average N inputs to individual watersheds ranged from 143 to 347 pounds per acre. The inputs in Iowa, expressed as a percent of total inputs, compared similarly to Minnesota estimates (Table 1). Point sources account for about 8% of the stream N loads statewide in Iowa, varying from 1% to 15% for individual watersheds. In Minnesota, point sources were estimated to account for 9% of the N inputs during an average precipitation year. In both states, soil N mineralization and N fertilizer were the two highest N inputs.

The outputs in Iowa were also similar to Minnesota outputs (Table 2). Iowa streams discharged about 200,000 tons of N during the relatively dry 2000-2002 period, an amount equivalent to 11 pounds per acre annually. This represents about 5% to 7% of the inputs. For Minnesota, the amount of N inputs estimated to reach streams was similar to Iowa, with about 6% of N reaching waters during average precipitation conditions. Crop harvest accounted for more than half of the N outputs in both states.

Table 1. Nitrogen inputs to land in Iowa compared to the relative inputs to land in Minnesota. Iowa estimates are from Libra et al. (2004). Minnesota estimates are from Chapters D1 to D4 of this report.

Input source	Inputs (tons of N Iowa)	Iowa Percent of total inputs	Minnesota Percent of total inputs
Fertilizer	984,000	25%	30%
Legumes	762,000	20%	14%
Wet Deposition	363,000	9%	4%
Soil N	1,014,000	26%	38%
Manure	493,000	13%	10%
Human	16,000	<1%	<1%
Dry Deposition	254,000	7%	4%
Industry	2800	<1%	<1%
Total	**3,888,000**		

Table 2. Nitrogen outputs for Iowa compared to the outputs in Minnesota. UMN/MPCA outputs did not include soil N storage, and therefore to allow direct comparisons the relative output percentages for Iowa were recalculated without soil N storage included. Iowa estimates are from Libra et al. (2004). Minnesota estimates are from Chapters D1 to D4 of this report.

Output categories	Outputs (tons of N)	Iowa percent of total outputs	Iowa percent of total if soil N storage not included	Minnesota percent of total outputs
Harvest	1,565,000	40%	53%	63%
Grazing	172,000	4%	6%	
Crop Volatilization	353,000	9%	12%	15%
Soil N (storage)	1,014,000	26%	-	-
Manure Volatilization	249,000	6%	8%	6%
Fertilizer Volatilization	17,000	<1%	1%	
Denitrification	413,000	10%	14%	10%
Waters	198,000	5%	7%	6%
Total	**3,981,000**			

Assessing nitrogen sources in Iowa watersheds

Similar to the Minnesota source estimate conclusions, several studies of large Iowa watersheds concluded that agricultural nonpoint sources accounted for the majority of nitrate reaching streams. Modeling of the Raccoon River in Iowa using the Soil and Water Assessment Tool (SWAT model) indicated that 92% of the nitrate loading was from agricultural nonpoint sources (Jha et al., 2010).

The Des Moines River Basin covers 6,245 square miles and has nitrate concentrations near Des Moines, Iowa, ranging from 0.5 to 14.5 mg/l, exceeding the 10 mg/l maximum contaminant level (MCL) 16.4% of the time between 1995 and 2005. Nitrate yield from the subbasins ranged from 3.2 to nearly 54 pounds/acre, averaging 13.9 pounds/acre. Nearly 40% of the subbasins had nitrate losses greater than 13.3 pounds/acre. Modeling of the Des Moines River Basin in Iowa (and part of southern Minnesota) using the SWAT model indicated that nitrate loading to streams was dominated by agricultural non-point source pollution, affecting 95% of the loading (Schilling and Wolter, 2010). The authors concluded that the greatest influence on nitrate concentrations in this intensively agricultural landscape was fertilizer application. Animal and human waste contributed about 7% and 5% of the nitrate export in streams, respectively. By completely eliminating manure sources, modeled nitrate concentrations in waters were reduced by 7.3%. Elimination of human waste resulted in an estimated 4.8% nitrate reduction.

Row crops – correlation to stream nitrate

Schilling and Libra (2000) found a direct linear correlation ($p<0.0003$) between the percent of row crops in Iowa watersheds and average stream nitrate concentrations. By comparing stream nitrate levels with row crop production acreage in 25 Iowa watersheds, the authors concluded that mean annual stream nitrate-N concentrations in Iowa watersheds can be approximated by multiplying the percentage of land in row crops by a factor of 0.11.

In eastern Iowa (Cedar, Iowa, Skunk, and Wapsipinicon River Basins), Weldon and Hornbuckle (2006) found that in addition to row crop density, feedlot animal unit density was correlated to stream nitrate concentrations.

Watkins et al. (2011) examined stream N concentrations in 100 southeastern Minnesota sampling sites (Figure 1) to see if there was a similar relationship as found in Iowa between percent of land in row crops and stream nitrate levels during periods expected to represent baseflow conditions. Most samples were taken during a minimum of four years at each site, however some sites in the Root River Watershed had less than four years of sampling. In the study area, where relatively few human or urban waste sources exist, the investigators observed a linear relationship between watershed row crops and nitrate levels (Figure 2). The slope of the regression line would suggest that stream baseflow nitrate-N concentrations in non-urban parts of southeastern Minnesota can be approximated by multiplying the percentage of land in row crops by 0.17. The regression analysis indicated that when about 60% or more of the watershed is in row-crop production that the baseflow nitrate-N concentration would be expected to exceed 10 mg/l. The study suggested that nitrate concentrations are essentially zero when there are no row crops in the subwatersheds of this part of Minnesota. Regression analysis studies can show correlation, but not necessarily cause and effect. The investigation showed that other factors besides row crop acreages can affect nitrate concentrations. One stream monitoring point impacted by municipal wastewater discharges showed higher nitrate concentrations (14 mg/l) compared to other sites with similar row crop acreages, and was therefore an outlier in Figure 2.

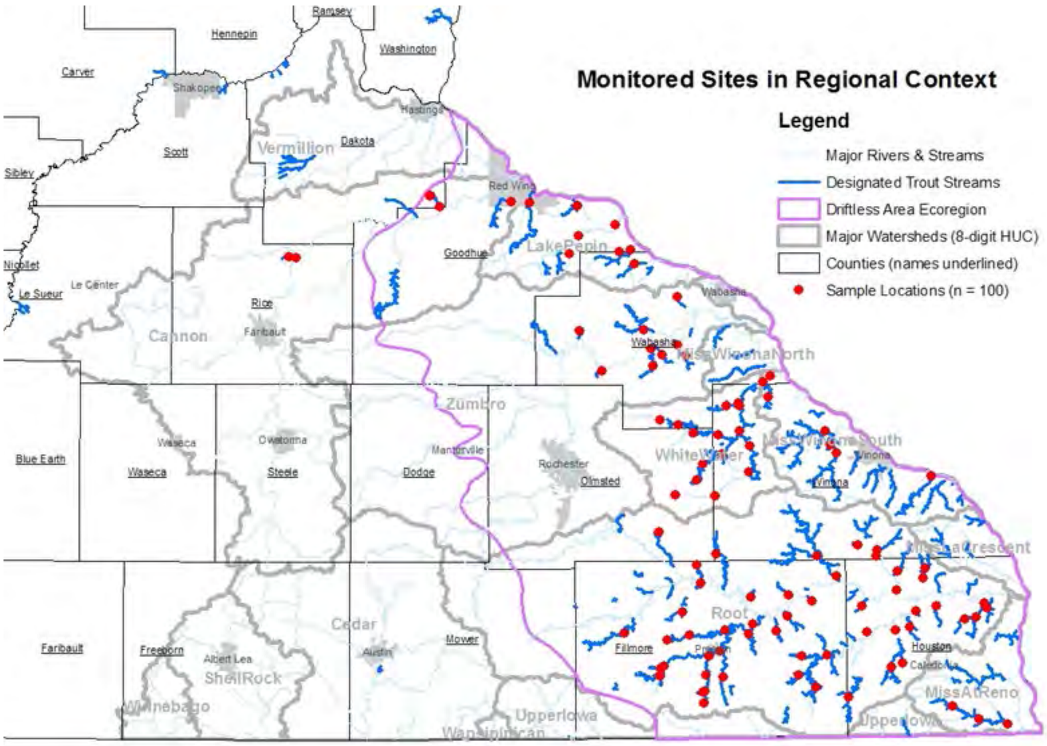

Figure 1. Stream site locations in southeastern Minnesota where samples were taken and analyzed for nitrate-N. From Watkins et al. (2011).

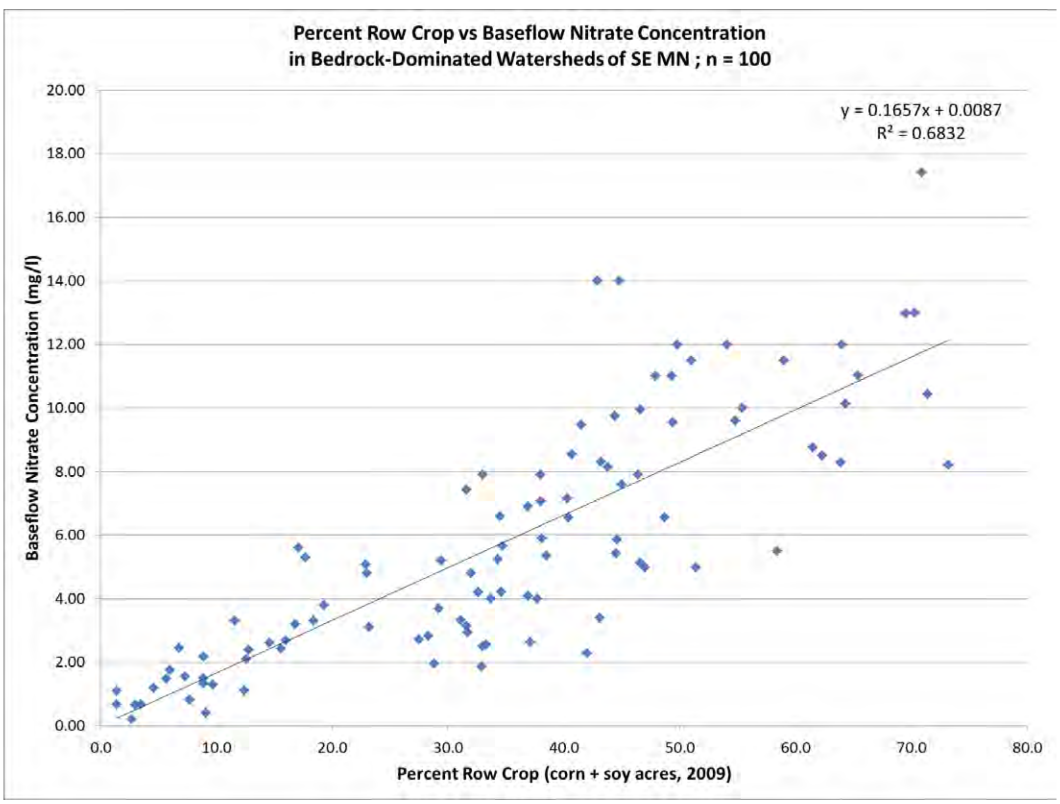

Figure 2. Relationship between the percent of watershed land in row crop production in 2009 and the nitrate-N concentrations of southeastern Minnesota streams during periods of time when stream flow is all or mostly groundwater baseflow (from Watkins et al., 2011).

Tile drainage impacts

David et al (2010) found that N fertilizer and artificial drainage explained most of the variation in stream N loadings, while examining relationships between stream N loads (winter-spring) and land uses in 153 watersheds across the Upper Mississippi River Basin. The greatest N yields to rivers corresponded to the highly productive tile-drained corn belt from southwest Minnesota across Iowa, Illinois, Indiana, and Ohio. Human waste explained 7% of the variability and animal manure was not a significant explanatory variable affecting stream N loads in this large scale study.

Kronholm and Capel (2013) examined nitrate in 16 watersheds located in seven states, including three midwestern states. They found that the highest nitrate yielding watersheds were those which had a dominant flow pathway of subsurface tile drainage. Watersheds dominated by groundwater or surface runoff flow pathways had much lower nitrate levels.

While it is widely acknowledged that artificial tile drainage exerts a large influence on river nitrate loading in the Midwest, Nangia et al. (2010) concluded that the amount of N leaving each field in a given year varies with climate. Substantial year to year nitrate loading variability was found in a heavily drained Minnesota watershed which received varying precipitation amounts.

Groundwater contributions to stream nitrate

Similar to the findings of the UMN/MCPA Minnesota N source assessment, other studies have shown that groundwater baseflow is an important pathway for N entering surface waters, particularly in areas with minimal agricultural tile drainage.

Groundwater baseflow is generally considered to be the portion of stream flow that represents longer term groundwater discharge from underground watershed storages, which typically moves slowly and continuously into streams, even during periods of reduced precipitation. Some use the term “baseflow” to refer to all portions of the streamflow that are not partitioned or separated from surface runoff and quick-flow groundwater in the stream hydrograph (Spahr 2010). Under this second definition, a portion of tile drainage flows can show up in the “baseflow” part of the stream hydrograph, due to the lag time between the storm event and when infiltrating waters reach tile lines and surface waters.

In a study of stream nutrients from around the United States, baseflow was found to contribute a substantial amount of nitrate to many streams (Dubrovsky et al., 2010). In two-thirds of the 148 studied streams, baseflow contributed more than a third of the total annual nitrate load. These findings are based on data from streams that drain watersheds less than 500 square miles. The researchers found less baseflow influence in areas of the Midwest that are heavily tile-drained, similar to the source/pathway assessment findings by the UMN/MPCA in Chapters D1 and D4 of this report.

Tesoriero et al. (2009) examined nitrate flow pathways in five aquifer and stream environments across the United States., including one Minnesota stream (Valley Creek). As the proportion of stream flow derived from baseflow increased, nitrate concentrations also increased. They concluded that the major source of nitrate in baseflow dominated streams was groundwater; and rapid flow pathways (i.e. tile lines) were the major source of N in streams not dominated by baseflow. Another finding of the study was that baseflow does not enter the stream uniformly, but rather through preferential flow paths in high conductivity stream-bed sediments (i.e. sands) or as bankside seeps or springs.

In eastern Washington County, Minnesota, two studied creeks had over 90% of the nitrate load delivered during non-storm event periods (SCWRS, 2003). Groundwater was determined to be the major source of N to the creeks, and the difference in N yields between the two creeks was attributed to differing groundwater nitrate concentrations.

While groundwater baseflow often contributes a substantial part of N loads to streams, not all of the nitrate entering groundwater ends up in streams. Recharge rates of nitrate to groundwater beneath the land are commonly greater than discharge rates of nitrate in nearby streams (Böhlke et al., 2002). Part of the reason is that it can take months to years before the nitrate that leaches to groundwater is transported into streams; and therefore groundwater can continue to contribute nitrate to streams long after all nitrate sources are removed (Goolsby, Battaglin et al. 1999; Tesoriero et al. 2013). Additionally, nitrate can be reduced through denitrification as it flows within groundwater toward streams.

Dubrovsky et al. (2010) concluded that the amount of N in baseflow depends, in part, on how much of the baseflow is coming from deep aquifers and how much is coming from shallow ground waters. Deep aquifers usually contain water with lower concentrations of N than shallow aquifers because of several reasons: (1) it takes a long time—decades or more, in most cases—for water to move from the land surface to deep aquifers (resulting in long residence times for groundwater and any solutes, like nitrate, it may contain); (2) long travel distances increase the likelihood that nutrients will be lost through denitrification; (3) protective low-permeability deposits (which inhibit flow and transport) may be present between the land surface and deep aquifers; and (4) mixing of water from complex flow paths over long distances and time periods tends to result in a mixture of land-use influences on the chemical character of deep groundwater, including contributions of nutrients from areas of undeveloped lands where concentrations are generally lower than those from developed lands.

Groundwater baseflow was found to be an important contributing pathway in several additional studies, especially in areas not dominated by tile line flow. Using data collected between 1984 and 1993, the USGS conducted an in-depth study of stream nutrients in large parts of Minnesota, including the southern half of the Mississippi River Basin; the Canon and Vermillion River watersheds, and the St. Croix River Basin in Minnesota and Wisconsin (Kroening and Andrews, 1997). Nitrate concentrations in the Minnesota River near Jordan, and the Straight and Cannon Rivers in southeastern Minnesota, were found to be greatest in the spring and summer months, when precipitation, runoff, and tile-line flows are typically highest. However, for much of the rest of the study area, nitrate concentrations were greatest in the winter months when stream flow is dominated by groundwater baseflow.

Burkhart (2001) found an association between base flow contributions of nitrate to streams and the permeability of soils and underlying bedrock. The USGS report stated "nitrate loads from base flow were significantly lower (contributing about 27% of total stream nitrate load) in streams draining landscapes with less permeable soils and bedrock than in those draining landscapes with permeable soils and (or) bedrock (contributing 44% to 47% of the total stream nitrate load)."

Other studies have also shown that soil and bedrock permeability affects nitrate levels in water. In a small Wisconsin karst landscape watershed largely under row crop land uses, 80% of nitrate loadings to streams came from groundwater baseflow (Masarik, 2007). Nitrate-N ranged from 4.7 to 23.5 mg/l in the Fever River watershed. In this highly permeable setting of loess soils over fractured carbonate bedrock, baseflow was found to be the dominant pathway of N to surface waters.

The nitrate loading due to baseflow into two south-central Iowa streams in a non-karst watershed with relatively shallow soils were also found to be high, and accounted for 61% to 68% of nitrate loads in Walnut Creek and Squaw Creek watersheds, respectively (Schilling, 2002). Bedrock in the Iowa study is overlain by 20 to 100 feet of soil, in a rolling naturally well-drained landscape.

Schilling et al. (2000) also found that karst watersheds showed higher nitrate than would be expected based on land use influences only. They postulated that this was due to less surface runoff, and alternatively more water going down through the soils into groundwater and coming out as baseflow and springs. Baseflow typically has higher nitrate concentrations than the surface runoff. Sauer (2001) noted that low soil and bedrock permeabilities do not necessarily translate to low nitrate in streams, particularly in areas where tile drainage occurs. In tiled lands, nitrate concentrations in streams are typically elevated, even though the natural permeability of the soil is low.

Conclusions

Other studies of N sources and pathways to surface waters found:

- Agricultural lands, and to a lesser degree urban lands, are the dominant contributors to N in waters, especially where N inputs are high (i.e. fertilizers or manure applied to row crops).
- Tile drainage is the major pathway where agricultural lands have subsurface drainage.
- Groundwater baseflow is a major pathway in non-tiled cropland, and its effects are particularly important in areas with more highly permeable soils such as karst geology and sandy soils.
- Surface runoff is a relatively minor pathway for N in watersheds with high N loads.

These findings are consistent with the conclusions reached in the Minnesota N source assessment (Chapters D1-D4).

Iowa’s N source assessment provides a similar breakdown of N source contributions and outputs, as compared to estimates of N contributions to soils in Minnesota.

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F1. Reducing Cropland Nitrogen Losses to Surface Waters

Author: Dave Wall, MPCA

Technical support from: William Lazarus, David J. Mulla, Geoffrie Kraemer, and Karina Fabrizi (University of Minnesota)

Minnesota is one of a dozen states in the Mississippi River Basin developing a state-level action strategy to achieve and track measureable progress for reducing point and nonpoint nutrient losses. The strategy is driven by a need to reduce Minnesota's contribution of nitrogen (N) and phosphorus pollution to downstream waters such as the Gulf of Mexico and Lake Winnipeg, as well as in-state nutrient reduction needs to protect and improve Minnesota waters from excess nutrients. The strategy, when complete, is expected to identify how far we are progressing with current programs and efforts, and identify ways to reach milestone goals and targets. Scientific assessments are being used to develop priorities, targets, monitoring strategies, and ways to use existing and new programs to continue making long-term progress in reducing nutrient losses.

The strategy development effort is designed to align goals, identify the most promising strategies, and ensure that collective activities around the state are working to achieve our goals. The strategy will be used by agencies and organizations to focus and adjust state-level and regional programs, and will be considered by watershed managers and local water planners to translate ideas and priorities into effective local best management practice (BMP) implementation. In support of the Nutrient Reduction Strategy development, Minnesota is examining recently completed reports and tools estimating N load reductions from BMP adoption. Findings from these efforts are described for cropland sources in this chapter and for wastewater point sources in Chapter F2. The primary purposes of these two chapters are to consider the level of N reduction that can be achieved by individual BMPs and combinations of BMPs adopted on lands suitable for the practices.

This chapter is organized in the following sequence:

- Nitrogen reduction from individual BMPs and conservation practices adopted on treated acreages (i.e. percent reductions on a single field with the applied BMP).
- Statewide adoption scenarios for single practices if adopted everywhere suitable for the practice in the entire state.
- Nitrogen reduction expected from adopting multiple practices on land suitable for each BMP. More specifically, the following are evaluated:
    - BMP adoption levels needed to achieve a 30% and 45% reduction from cropland sources statewide.
    - BMP adoption levels needed to achieve 15% and 25% reductions from cropland sources in representative HUC8 watersheds located in different regions of southern Minnesota.

Where possible, we compared Minnesota results with results developed by Iowa State University, which used a different analytical approach than the Minnesota work.

Best management practices for nitrogen reduction

Best management practices and conservation practices are collectively referred to in this chapter as either "BMPs" or "Practices." Four documents developed in 2012-13 summarize the effects of agricultural BMPs for reducing N to waters: 1) Minnesota BMP Handbook; 2) Nitrogen Fertilizer Management Plan; 3) University of Minnesota literature review; and 4) Iowa State University literature review.

Minnesota best management practice handbook

Miller et al. (2012) completed a Minnesota Agricultural Best Management Practice (BMP) handbook, which describes different BMPs and associated research findings concerning the effect that individual (BMPs) can be expected to have on reducing pollutants to surface waters, including N loads. The BMP Handbook can be found at:
www.eorinc.com/documents/AG-BMPHandbookforMN_09_2012.pdf

Nitrogen fertilizer management plan

The Minnesota Nitrogen Fertilizer Management Plan (NFMP) was written by the Minnesota Department of Agriculture. The NFMP describes and references Minnesota's cropland N BMPs for groundwater protection, as required and defined in Minn. Stat. 103H.151. Fertilizer management BMPs for groundwater protection are also important for protecting surface waters, since a large fraction of surface water N comes from groundwater and saturated soils below cropland (see Chapters D1 and D4). While the NFMP focusses on groundwater protection, widespread adoption of the BMPs in the plan would be expected to result in considerable reductions of N into surface waters. The NFMP, which was still in draft at the time of this writing, can be found at
www.mda.state.mn.us/chemicals/fertilizers/nutrient-mgmt/nitrogenplan.aspx

Literature review by Fabrizzi and Mulla (2012)

Several BMPs can be used either individually or in combination with other BMPs to reduce N entering waters from cropland sources. Two recent efforts were specifically aimed at estimating effects of N BMPs on surface water protection from field studies and literature reviews. Each is described, starting with a Minnesota analysis, which is then followed by an Iowa review.

Fabrizzi and Mulla (2012) conducted a literature review of the primary BMPs which can be used for reducing N from cropland (see Appendix F1-1). These BMPs were classified by the authors into three broad categories of BMPs: 1) Hydrologic, 2) Nutrient Management, and 3) Landscape Diversification (Figure 1).

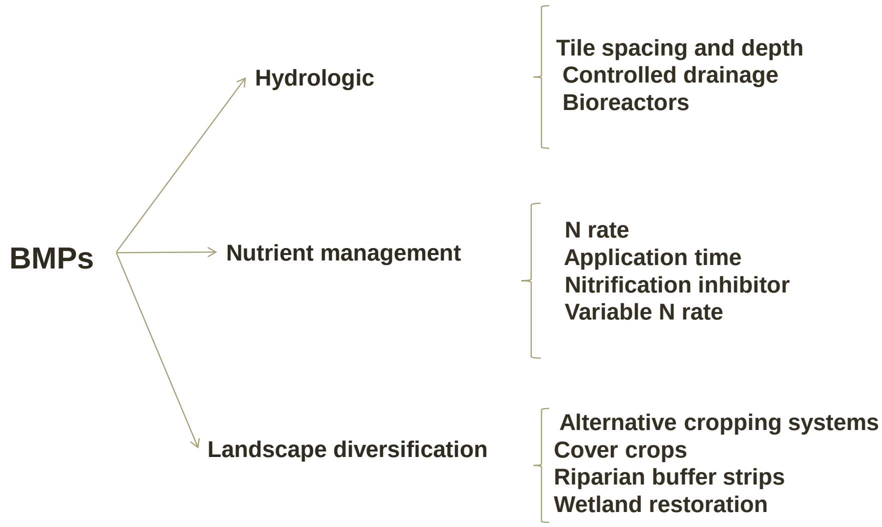

Figure 1. Categories of agricultural BMPs to reduce N loads as defined by Fabrizzi and Mulla (2012).

Table 1 shows the wide range in N reduction effectiveness from different BMPs. The results depend on many variables, such as climate, soils, research design, BMP design, baseline practices and conditions, etc. The wide range in N reductions shown in Table 1 is attributable to the fact that these results include findings from others states and from extreme climatic situations, and are not meant to represent average or typical removals. Lazarus et al. (2012) identified typical N removal percentages for these BMPs when implemented in Minnesota fields suitable for the individual BMP adoption. These results are shown in Table 1 as "N removal default in the NBMP spreadsheet." More information is provided on the NBMP spreadsheet later in this report, including background, assumptions, and how it can be downloaded from the Web.

Table 1. N reductions to waters in the tested/treated area as reported in a literature review by Fabrizzi and Mulla (2012) and compared with typical reduction rates used by Lazarus, Mulla et al., (2012) in the NBMP spreadsheet.

	Range in N reductions from literature review	N removal default in MN NBMP spreadsheet for treated areas	Notes for numbers with *
Tile depth and spacing	15-59%	NA	
Controlled drainage	14-96%	40%	
Bioreactors	10-99%	*13%	*Assumes 44% removal when fully treated, but only 30% of annual flow is treated
Reduced rates of application	11-70%	Varies by watershed and climate	
N application timing and inhibitors	10-58%	Varies by watershed and climate	
Wetlands	19-90%	50%	
Alternative cropping systems	5-98%	*95%	*Perennials replacing marginal land row crops
Riparian buffers	17-99%	*95%	*Perennials replacing row crops near waters
Cover crops	11-60%	*10%	*50% N leaching reduction when successfully established and 10% runoff N reduction. 20% establishment success rate assumed for MN average.

Other BMPs not included in Table 1 are continually being developed and improved. For example, saturated buffers established at field edges to treat tile drainage waters in the subsurface are currently being researched. Additionally, crop genetics research has improved the N use efficiency of crops, allowing farmers to harvest more crops for the same or less N fertilizer use (MDA, 2013). Enhanced fertilizers and other BMP improvements will likely continue to be developed.

Iowa literature review

Iowa recently completed an extensive review of Upper Midwest studies on the effectiveness of N removal when using various individual and collective BMPs. Their report, which was developed by a team of scientists from Iowa Universities led by Iowa State, can be found at www.nutrientstrategy.iastate.edu. Using a slightly different categorization scheme as Fabrizzi and Mulla (2012), Iowa evaluated three types of practices: 1) Nutrient Management, 2) Land Use, and 3) Edge of Field. Anticipated yield reductions or gains and BMP costs were evaluated in the Iowa study and are included in Iowa State University (2012).

The percent of nitrate reduction from each type of practice expected on fields potentially suitable for those practices in Iowa is summarized in Table 2. Similar to the Minnesota review, Iowa also found considerable variability in N reduction efficiency for individual types of practices described in the research literature. Energy crops, perennials, and buffer practices (e.g. changing from corn/soybeans to grasses or other perennials) had reasonably consistent nitrate reductions from study to study and field to field. However, most other practices had high standard deviations and coefficients of variation. All baseline assumptions and findings are reported in Iowa State University (2012).

Table 2. Iowa findings of BMP average nitrate reduction based on a review of research in the Upper Midwest (numbers extracted from Iowa State University, 2012). Reductions represent nitrate concentration reductions, except where noted as "load reduction."

Practice category	Practice	% Nitrate reduction from treated cropland
Change fertilizer timing	From fall to spring pre-plant	6
	From fall to spring pre-plant/sidedress 40-60 split	5
	From pre-plant application to sidedress	7
	From pre-plant to sidedress – soil test based	4
Change source from fertilizer to manure	From spring applied fertilizer to liquid swine manure	4
	From spring applied fertilizer to solid poultry litter	-3
Nitrogen application rate	From existing rates down to rates providing the maximum return to nitrogen value (133 lb/acre corn-soybean and 190 lb/acre on corn-corn)	10
Nitrification inhibitor	From fall applied without inhibitor to fall applied with Nitrapyrin	9
Cover crops	Rye cover crop on corn/soybean or corn/corn acres	31
	Oat cover crop on corn/soybean or corn/corn acres	28
Perennials	From spring applied fertilizer onto corn to perennial energy crops	72
	From spring-applied fertilizer onto corn to land in retirement (CRP)	85
Extended rotations	From continuous row crops to at least 2 years of alfalfa in a 4 or 5 year rotation (stateside estimates assume a doubling of current extended rotations)	42

Practice category	Practice	% Nitrate reduction from treated cropland
Tile drainage waters	Drainage water management – controlled drainage (nitrate load reduction)	33 (load reduction)
	Shallow drainage (nitrate load reduction)	32
	Wetland treatment (statewide estimate assumes 45% of row crops would drain to wetlands)	52
	Bioreactors (statewide estimate assumes bioreactors installed on all tile-drained acres)	43
	Buffers treating water that interacts with active zone below the buffer – load reductions depend on water amounts treated	91

Statewide adoption of individual best management practices

Nitrogen load reduction to waters estimates were made by Minnesota and Iowa for their respective states, while using different methods and assumptions. Iowa is similar enough to southern Minnesota that N reduction estimates from Iowa are included in this discussion for comparison purposes, although it should be noted that differences exist between Iowa and Minnesota climate, land uses, and amount of lands suitable for various BMPs. The climate, soils and landscape in the Red River Valley area are particularly different from Iowa.

Most of the practices can only be used under certain conditions, restricting suitable acreages across the state for each practice. Some examples of limitations include:

- Wetlands are best suited in areas of low slopes and high flow accumulation that were likely historic wetlands on the landscape.
- Controlled drainage is largely limited to tile-drained land with nearly flat slopes (i.e. less than 1% slopes).
- Bioreactors can only effectively treat limited quantities of water at a given time, and during high spring flows are less effective in removing nitrate.
- Climate can be a limiting factor for cover crops in certain areas.
- Changing timing of application from fall to spring is only applicable where fertilizer is currently being applied in the fall.

Because the BMPs for reducing N in waters only work in certain areas and situations, when we assess reductions across large watersheds, the capability of practices to reduce the percent of N loading to waters is not as high as for small areas where the BMP was used on all the land. For example, if a practice achieves a 50% N loss reduction to waters on the area where the BMP is applied, that practice adopted on suitable land throughout a watershed will result in less than a 50% N reduction in that watershed. In this section, we evaluate the adoption of individual BMPs if adopted on land assumed to be suitable for the BMP.

Uncertainties exist in the findings below for several reasons:

1. The literature review points to a wide range of BMP N reduction capabilities. The analyses below use average or representative values for N reduction to waters.

2. The results depend on the assumptions about which land is suitable for the BMPs. These assumptions can greatly affect the number of acres where the BMP can be adopted, and both Iowa and Minnesota use different assumptions about suitable acreages.
3. The N reduction estimates for certain BMPs, such as rate and timing of application, are dependent on the accuracy of the baseline assessments. Uncertainties exist concerning current fertilizer rates, particularly related to N crediting following manure applications.
4. The cost information is not static. Fertilizer costs, application costs, crop prices, and other factors vary from year to year.
5. There is uncertainty regarding the average nutrient reductions to groundwater which take place when adopting fertilizer rate reduction BMPs. Since groundwater can be a significant pathway of transporting nitrate to surface waters, uncertainty regarding leaching to groundwater can also affect the uncertainty of N reductions to surface water estimates.

Fortunately, we have research and survey information in Minnesota which narrows many of these uncertainties so that the final results are believed to provide an approximate estimate of large scale N reduction potential and associated costs. Each finding should be viewed as a rough estimate of the actual achievable reduction and the cost to achieve such reductions.

Iowa statewide adoption of individual best management practices

To support Iowa's Nutrient Reduction Strategy, scientists from Iowa universities estimated the likely nitrate load reductions to state waters which could be achieved through adoption of individual BMPs across the state on all land suitable for the particular BMPs (Table 3). The results show a wide range in estimated effects, from a 28% reduction for cover crops, down to a 0.1% reduction by changing fertilizer timing from fall to spring. The methods and assumptions are described in a report by Iowa State University (2012).

Table 3. Iowa findings of BMP N removal based on a review of research in the upper Midwest (numbers extracted from Iowa State University, 2012) and applied to land suited for those BMPs in Iowa. Negative costs represent a net dollar savings.

		% Nitrate reduction in treated area	Iowa statewide % nitrate reduction*	Cost $ per pound of N reduced
Change fertilizer timing	From fall to spring pre-plant	6	0.1	*
	From pre-plant application to sidedress	7	4	0.00
Nitrogen application rate	From existing rates down to rates providing the maximum return to nitrogen value (133 lb/acre corn-soybean and 190 lb/acre on corn-corn)	10	9	-0.58
Nitrification inhibitor	From fall applied without inhibitor to fall applied with nitrapyrin	9	1	-1.53
Cover crops	Rye cover crop on CS or CC acres	31	28	5.96
	Oat cover crop on CS or CC acres	28		
Perennials	From spring applied fertilizer onto corn to perennial energy crops (statewide estimate assumes 1987 levels of pasture/hay converted to Energy Crops)	72	18	21.46

		% Nitrate reduction in treated area	Iowa statewide % nitrate reduction*	Cost $ per pound of N reduced
Extended rotations	From continuous row crops to at least 2 years of alfalfa in a 4 or 5 year rotation (statewide estimates assume a doubling of current extended rotations)	42	3	2.70
Tile drainage waters	Drainage Water Management – controlled drainage	33	2	1.29
	Wetland treatment (statewide estimate assumes 45% of row crops would drain to wetlands)	52	22	1.38
	Bioreactors (statewide estimate assumes bioreactors installed on all tile-drained acres)	43	18	0.92
Buffers	Buffers treating water that interacts with active zone below the buffer	91	7	1.91

*Statewide percent reductions are lower than reductions at the place of adoption since statewide adoption estimates assume that the BMP cannot be used on all lands, but only on lands suitable for the BMP.

Iowa concluded that no single practice would achieve the hypoxia nutrient reduction goals (unless major land use changes occurred), but that a combination of practices would be needed to meet long term goals.

In Iowa, the N management practices which seem to be the most promising for nitrate reductions to waters are reduced N application rate and planting cover crops. Iowa estimated average N application to a corn following soybeans to be 151 pounds/acre, which compares to 133 pounds BMP rate (maximum return to N assuming$5.00/bushel corn and $0.50/pound N). Average N application rate to corn following corn was 201 pounds/acre, which compares to a 190 pound BMP rate. A 9% nitrate reduction to waters was estimated for the entire state of Iowa if fertilizer rate reductions were to occur on all corn ground. If rye cover crops were planted on all corn and soybean acres, an estimated 28% statewide nitrate reduction is estimated from this practice alone. Other BMPs also showed promise in reducing nitrate, including wetland treatment (22% reduction statewide), bioreactors (18% reduction statewide), and side-dressing N rather than spring pre-plant N (4% reduction statewide).

The researchers at Iowa State University concluded that there is limited potential for nitrate reduction with several other BMPs. Controlled drainage adoption is limited by the land area suitable for this practice (slopes less than 1%). Switching all fall applied fertilizer to spring (without a corresponding decrease in rate) showed little potential for nitrate reduction in the Iowa study.

Changes to perennial vegetation can result in dramatic reductions where adopted, but the level of reduction is dependent on the overall amount of land converted to perennial based systems. The cost per pound of nitrate reduced was found to be particularly high for land converting from row crops to perennial energy crops under the current market and subsidy framework, but was considerably lower for extended rotations.

Minnesota statewide adoption of individual best management practices

To evaluate the expected N reductions to Minnesota waters from individual practices adopted on all land statewide where the practice is suitable for adoption, we used the Nitrogen Best Management Practice watershed planning tool (NBMP or NBMP.xlsm). The NBMP spreadsheet was developed by the University of Minnesota (William Lazarus, David Mulla,et al.) to enable water resource planners developing either state-level or watershed-level N reduction strategies to gauge the potential for reducing N loads to surface waters from cropland, and to assess the potential costs of achieving various reduction goals. The tool merges information on N reduction with landscape adoption limitations and economics. The tool allows water resource managers and planners to approximate the percent reduction of N entering surface waters when either a single BMP or a suite of BMPs is adopted at specified levels across the watershed. The tool also enables the user to identify which BMPs will be most cost-effective for achieving N reductions.

NBMP spreadsheet background

NBMP compares the effectiveness and cost of BMPs that could be implemented to reduce N load entering surface waters from cropland in a watershed. The spreadsheet was not designed for individual land owner decisions, but rather for larger scale watershed or state level assessments. The NBMP.xlsm spreadsheet can be downloaded z.umn.edu/nbmp and more information about the development and use of the spreadsheet is found at faculty.apec.umn.edu/wlazarus/documents/nbmp_overview.pdf.

The spreadsheet contains data for 17 individual watersheds and for Minnesota as a whole. The watersheds that can be assessed individually with the tool at this time include 15 HUC8 watersheds which have high N loading, plus two HUC10 watersheds - Elm Creek and Rush River. The fifteen HUC8 watersheds include the: Lower Minnesota River, Minnesota River – Mankato, Blue Earth River, Le Sueur River, Minnesota River - Yellow Medicine River, Cannon River, Root River, Zumbro River, South Fork Crow River, Cedar River, Cottonwood River, Watonwan River, Des Moines River, Chippewa River, and North Fork Crow River.

The soil, crop, N loading data, and corn fertilizer response functions were provided by David Mulla as developed for work described in Chapter D4 of this report. Assumptions underlying the calculations, including land deemed suitable for each BMP are described in Table 4.

Table 4. Key assumptions in the NBMP spreadsheet for each N reduction practice (based on Lazarus et al. 2012 and personal communication with Lazarus 2013).

Nitrogen fertilizer rates and application timing
Current N rates based on 2010 statewide fertilizer use survey by University of Minnesota (Bierman et al., 2011) as compared to BMP rates based on current U of MN recommendations
U of MN recommendations vary by previous crop.
Corn acres include corn for grain and silage grown during a single year. Because soybeans are typically rotated with corn, the corn acreage during any one year is about half of the total corn/soybean acreage.
N fertilizer product prices vary. Farmer survey information was used to estimate the use of different types of fertilizer.
N fertilizer products change with the timing of application.
Solves for a point estimate of the profit-maximizing N rate based on the corn price and the N price (varies by application timing).
The point estimate of the profit-maximizing rate is increased for fall-application and reduced for spring preplant or sidedressing. Fall application rates were assumed to be 30 pound/acre higher than spring application rates.

The survey of current practices covered only non-manured land.

- Current N rates were adjusted assuming that farm operators are now taking credit for part of the estimated crop available N on manured land as follows:85% for swine, 75% for dairy, and 70% for poultry and beef.
- The manure N is credited in the BMP N rates.

The percent N load reduction to waters varies depending on current N application rate spatial averages for the agroecoregion.

Fall to spring preplant or prepland/sidedress

Switching from fall to spring/sidedressing reduces tile line N loading, but increases the N fertilizer price/pound and adds an extra fertilizer application cost.

This BMP only applies to corn grain and silage acres currently fertilized in the fall (based on farmer surveys as reported by Bierman et al. (2011)). “Sidedressing” here is actually a split application of spring preplant and sidedressing, with a default of 30% preplant and 70% sidedressed.

This BMP Only considers corn acreages for a single year, instead of using all land where corn is grown in the rotation.

The percent tile N load reduction varies between an average year, a wet year, and a dry year because the water volume in the tile line varies. The spreadsheet does not adjust N loading to waters from the surface runoff and groundwater pathways due to this timing BMP.

In a wet year, a percentage of the fertilizer N is lost and not available to the crop. Default is 10% less N available to the crop during the wet year.

Nitrification inhibitors are not a BMP option included with the version of the NBMP spreadsheet used for this analysis.

Riparian buffers

This data layer represents a 100 ft. buffer on either side of every stream on DNR’s 1:24,000 scale maps. It does not account for land that is already in a buffer condition; and therefore represents the maximum available land for buffering, not how much can be added to current buffers.

The annual cost per acre is based on an enterprise budget for a 10-year stand of switchgrass, not harvested.

Acres of buffers are assumed to come out of acres of corn and soybeans.

The N load from the buffer acres is assumed to be 5% of N loads from corn/soybeans.

Wetland restoration

Lands suitable for wetlands were assessed by first using a logistic regression model that utilizes the Compound Topographic Index (CTI) and hydric soil data to isolate areas of low slopes and high flow accumulation that were likely historic wetlands on the landscape. Once these areas are identified, the layer is further refined by intersecting likely historic wetlands with likely tile drained lands. These lands are isolated by finding Crop Data Layer 2009 crops that are likely drained (corn, beans, wheat, sugar beets) and intersecting them with poorly drained SSURGO soils and slopes of 0-3%.

Suitable acres are poorly drained soils with slopes 0-3% and crops that are likely to be drained.

Three types of land are involved: 1) Wetland pool (always flooded); 2) Grassed buffer around the pool that is sometimes flooded so is not available for crop production; and 3) Cropland that is treated by having its water flow into the wetland (assumes approximately 10:1 ratio of cropland to wetland/buffer area (9.87:1))

Costs considered include: 1) Establishment cost, related to the wetland pool and buffer acres annualized over the useful life of the wetland ; 2) Annual maintenance cost related to the pool and buffer acres, and 3) Opportunity cost of the crop returns lost on the pool and buffer acres.

A default 50% reduction in N loading is assumed on treated acres. The N loads on acres shifted to the wetland pool and grassed buffer are assumed to be zero.

Controlled drainage and bioreactors

This layer uses the likely tile drained land layer (poorly drained soils, 0-3% slope, and 2009 CDL corn, soybeans, wheat, or sugar beets). This layer is further refined with slopes using a 30 meter slope grid. The default is slopes less than 1%, on average. Suitable acres for controlled drainage can be adjusted to include an upper slope limit of 0.5% slope, 1% slope, or 2% slope [default is 1%].

Costs considered include an establishment cost, annualized over the useful life, and an annual maintenance cost, per treated acre.

For controlled drainage, a default 40% reduction is assumed in the tile line N load, with no change in leaching to groundwater and runoff N load. The tile line N load reduction can be changed by the user.

For tile line bioreactors, the tile line N load reduction in the treated flow varies based on loading density (treated acres/footprint), with a default of 44%. Only 30% of the drainage system water is assumed to be treated, however, due to factors such as spring overflow, so the default reduction is 13% of the overall tile line N load (44% times 30%).

Cover crops

Suitable acres include total of corn grain, corn silage, and soybean acres in the watershed.

Cover crops of cereal rye are seeded in September into standing corn and soybean crops, by air.

Only a percentage of the seeded acres achieve a successful stand. The default success rate is 20%.

A cost for a contact herbicide and custom application is included for the successfully-seeded acres.

The N loads in tile lines, leaching, and runoff are all reduced, but the runoff reduction is much less than the reductions in tile line and leaching N. On successfully-seeded acres, the tile line and leaching N loads are reduced by a default 50%, with a 10% reduction in the runoff N load. Considering the 20% success rate, the overall reductions/seeded acre are 10% for tile line and leaching N, with a 2% reduction in runoff N.

The corn yield is reduced by default on cover-cropped acres in a wet year, but not in an average year or a dry year.

Perennial energy crops

The default is “marginal land.” This is from a data layer that isolates National Land Cover Database (NLCD) 2006 cultivated land with Crop Productivity Index values of less than 60 to identify marginal cropland that be converted to perennial crops.

The annual net return/acre is based on an enterprise budget for a 10-year stand of switchgrass, with a user-specified crop price/ton. Default switchgrass price is $0.

Revenue losses from the previous crop are based on average crop yields for the agroecoregion – actual revenue loss is expected to be less than on average lands, where perennials are replacing other crops only on marginal cropland.

- If the grass price is high enough to cover the harvest cost, it is harvested and the net returns are based on the crop value minus an annualized establishment cost, annual maintenance cost, and harvesting cost.
- Otherwise, it is not harvested and the only costs are the annualized establishment cost and annual maintenance cost.

The N load from the perennial crop acres is assumed to be zero.

If the adoption rates entered for buffers, wetland treated acres, and perennial crops exceed total corn and soybean acres, the rates are reduced to equal that total, with the difference coming out of wetland or perennial crop acres, whichever is most costly.

The NBMP spreadsheet was designed so that effects of BMPs cannot be double counted. Since some of the BMPs affect the same acreage in a similar way when adoption rates are high, the spreadsheet only includes the most cost-effective practice(s) on the overlapping acreage.

The NBMP tool can be revised and assumptions changed as new information becomes available. We used a March 25, 2013, version of the spreadsheet to obtain most of the estimates described below, using the default assumptions, unless otherwise noted. Best management practice costs and other results are dependent on several variables which can and do change significantly over time (i.e. fertilizer prices, price of corn, price of equipment, etc.). Therefore, the reported cost estimates should not be viewed as a static number, but rather a number which will fluctuate over time. The results represent our best estimates at this point in time.

Additional BMPs exist for N reductions other than what are provided in the NBMP tool (i.e. tile spacing and depth, nitrification inhibitors, saturated buffers, etc.). The developers of the NBMP spreadsheet only included the BMPs which were believed to represent the combination of the most research-proven and effective BMPs for Minnesota waters at this time.

One BMP which can greatly reduce tile line nitrogen loads is installing tile drains at a shallower depth (i.e. 2.5 feet instead of 3.5 to 4.0 feet). This practice is not expected to reduce nitrate concentrations, but it can reduce the flow and thus reduce the load. The focus of this study was reducing nitrogen loads to surface waters from existing conditions. However, installation of shallower drain tiles should be considered for mitigating nitrogen losses to waters where new tile drains are installed.

Minnesota statewide estimates of nitrogen load reduction– from individual BMPs

We used the NBMP tool to estimate statewide N reductions for individual practices, if they were to be adopted on 100% of the suitable acreage in the state during an average precipitation year (Table 5). The most cost-effective BMPs include: optimal N rates, changing from fall to spring/preplant fertilizer timing, controlled drainage and wetland treatment. Since the acreages used for these BMPs would overlap in many cases, the cumulative potential reductions for the state cannot be determined by adding the individual BMPs in Table 5.

Table 5. Nitrogen reduction to waters estimated with the NBMP spreadsheet for individual BMPs, assuming adoption of the individual BMP on all suitable areas for the BMP in Minnesota and average precipitation conditions. A negative cost indicates a net savings.

N reduction BMP	N reduction to waters if adopted statewide (MN) on 100% of suitable acres	Cost - $ per pound of N reduced in water	Percent of land acres suitable for the BMP in a given year
Optimal N rates	9.8%	$-4.03	26.2%
Fall to spring N with lower rates	6.4%	$-0.67	10.5%
Fall to preplant/side-dressing with lower rates	6.7%	$1.41	10.5%
Wetland treatment	5.2%	$6.22	5.3%
Bioreactors	0.8%	$14.09	4.5%
Controlled drainage	2.3%	$2.35	4.5%
Riparian buffers – converting row crop to perennials	7.2%	$42.22	5.7%
Perennials – converting marginal row crops to perennials	11.1%	$38.24	8.3%
Cover crops	7.3%	$49.92	50.1%

The default for the NBMP spreadsheet for cover crops is a 20% successful establishment rate. If we were able to achieve a better average success rate, the potential to remove N would increase substantially. The NBMP tool shows that under a scenario of a 50% cover crop establishment success, the N reduction would increase from 7.3% to 18.3%. And if the cover crop establishment success were to increase to 75%, then the N reduction to waters statewide would increase to 27.4%.

The numbers change when using the BMPs during a wet or dry year (Table 6). For example, if fertilizer and manure N is lost due to a wet spring, the cost per pound of N reduced in waters increases for the wet year. The cost for wetland treatment per pound of N reduced decreases from $6 to $4 during a wet year. The cost for cover crops decreases during a wet year, from $49 to $30 per pound of N reduced.

Table 6. Comparison of wet (90th percentile annual precipitation), average and dry (10th percentile annual precipitation) year estimates of N reduction to waters if adopted on 100% of suitable acres in Minnesota, and the cost ($) per pound of N reduced in waters (rounded to nearest dollar). Wet year calculations assume a 10 percent loss of manure and fertilizer N due to additional denitrification and leaching.

N reduction BMP	Dry year N reduction (million lbs/year)	Average year N reduction (million lbs/year)	Wet year - N reduction (million lbs/year)	Dry year $ per pound of N reduced	Average year $ per pound of N reduced	Wet year - $ per pound of N reduced
Optimal N rates	11	21	27	-7.9	-3.9	-2.7
Fall to spring N with lower rates	8	14	17	-1	-0.5	-0.2
Fall to preplant/side-dressing with lower rates	8	15	18	3	1.6	1.7
Wetland treatment	4	12	21	19	6	4
Bioreactors	0.4	2	3	59	14	8
Controlled drainage	1	5	9	10	2	1
Riparian buffers – converting row crop to perennials	6	17	28	120	42	25
Perennials – converting marginal row crops to perennials	10	26	42	97	38	24
Cover crops	6	17	28	149	49	30

Comparing Iowa and Minnesota best management practice effects

Iowa and Minnesota have several similarities and differences regarding the N reduction and cost from individual BMPs applied to a given treated area or at the statewide scale (Table 7, Figures 2 and 3). Some of the differences are due to:

- Minnesota used GIS-based information to estimate land areas suitable for BMPs, whereas Iowa used a larger scale Major Land Resource Area approach;
- Several assumptions concerning the effectiveness of BMPs throughout the year were different between the states, based on differences in climate and other considerations; and
- Iowa focused on the subsurface pathways of N loss, whereas Minnesota also considered surface runoff pathways. This difference is relatively minor, since most N losses to surface waters occur through the subsurface.

Additionally, Minnesota and Iowa assumptions about the total number of acres that could be used for each individual BMP differed greatly. These differences were due to differences in assumptions and approaches used to determine suitable lands for each BMP, and due to real differences in land, landscape, and climate between the two states. The differences in statewide N reduction estimates in Table 7 can largely be explained by the above stated factors.

Table 7. Minnesota and Iowa estimates of percent N reduction in treated areas and collectively across the state on all lands deemed suitable for the BMPs (average precipitation years).

	N removal range in test area Fabrizi Mulla, 2012	MN NBMP reduction in BMP treated area (average precip yr)	Iowa average removal in BMP treated area	MN reduction statewide w/NBMP (average precip yr)	Iowa reduction statewide ISU, 2012	MN cost per lb N reduced in water (average precip yr)	Iowa cost per lb N reduced in water
	%	%	%	%	%	$/lb N	$/lb N
Tile line water							
Controlled drainage	14-96	44	33	2.3	2	2.30	1.29
Bioreactors	10-99	13*	43	0.8	18	14.09	0.92
Wetlands	19-90	50	52	5.3	22	6.09	1.38
N rates							
Reduced rates of application to MRTN	11-70	16	10	9.8	9	-3.92	-0.58
Timing of application							
Timing of application (general)	10-58						-
Preplant to sidedress			7		4		-
Fall to spring preplant			6		0.1		-
Fall to spring preplant with reduced rate		26		6.4		-0.53	
Fall to preplant / sidedress with reduced rates		29		6.7		1.60	
Fall with nitrification inhibitor	18		9		1		-1.53
Vegetation change							
Extended rotations			42		3		2.70
Alternative cropping systems	5-98						
Riparian buffers	17-99	95	91	7.2	7	42.22	1.91
Cover crops (rye)	11-60	10**	31	7.3	28	49.92	5.96
Perennials		95	72	11.1	18	38.24	21.46

*MN estimates assume that only 30 percent of the drainage into bioreactors is treated on an annual basis, reducing treatment from 44 to 13%.

**MN estimates assume that tile line and leached N is reduced by 50 percent in tile drained systems with cover crops, but that the establishment rate averages 20%, reducing the N removal rates to 10%.

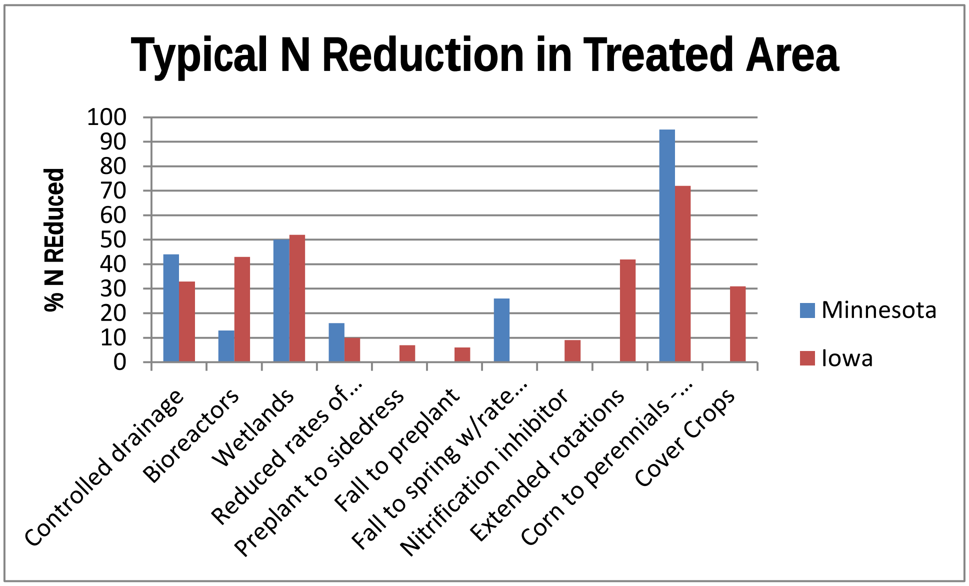

Figure 2. Minnesota and Iowa estimates of the average percent N load reduction in areas treated with the BMPs.

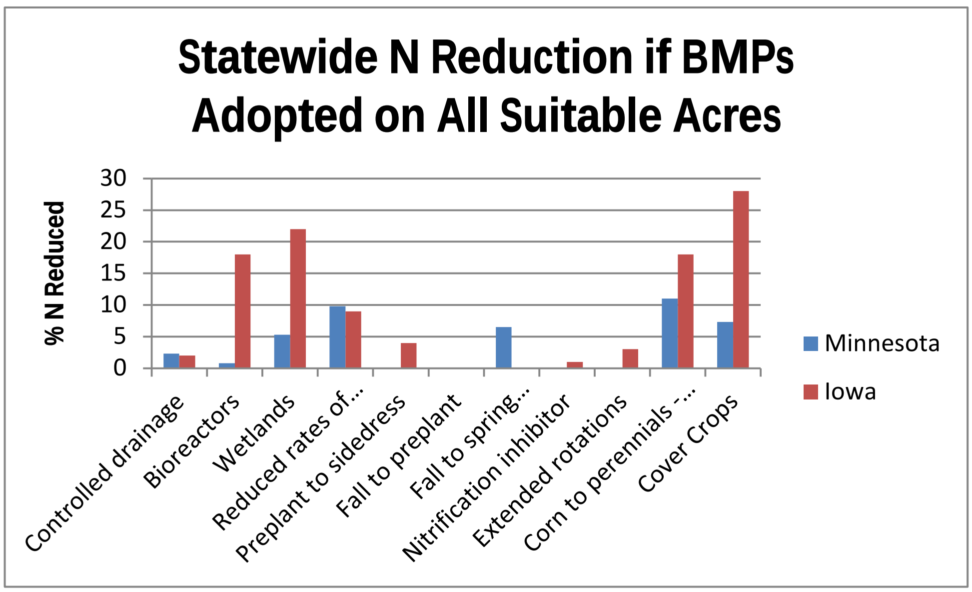

Figure 3. Minnesota and Iowa estimates of the average percent N load reduction statewide if the individual BMPs are adopted on all lands considered suitable for the BMP.

Both states consider that cover crops will reduce large quantities of N when successfully established. Iowa costs are much lower and N removal is much higher for cover crops. The higher Minnesota cost of cover crops compared to the Iowa estimates is largely due to the low assumed success rate (20%) in establishing cover crops in Minnesota. Climate is a factor, and additionally cover crops were assumed to be seeded by air in Minnesota while the Iowa costs assume seeding with a no-till drill after harvest. Aerial seeding requires a greater seeding rate and a higher seeding cost than the Iowa estimates assume. With increasing study of cover crops in Minnesota to develop better ways of more consistently establishing cover crops, the cost per pound of N reduced may potentially decrease. If Minnesota could successfully establish cover crops 75% of the time, the statewide N reduction to waters would be about the same as the Iowa estimates (28%).

Both states estimate a comparable level of treatment expected from controlled drainage BMPs, although Minnesota's estimates with this practice is slightly higher than Iowa. Both states estimate wetland treatment N removals near 50%, but Iowa assumes a higher ratio of cropland to wetland/buffer areas and Iowa determined that this BMP could be adopted in a larger fraction of the state than Minnesota estimates. Therefore the statewide N reduction estimates for wetlands are considerably lower in Minnesota.

Iowa estimates of N reduction from bioreactors is considerably higher than Minnesota estimates. Both states consider a similar average rate of reduction when bioreactors are treating tile waters (40-44% in Minnesota vs. 43% in Iowa), but Minnesota assumes that only 30% of the annual tile waters draining to bioreactors will be treated in a given year due to bioreactor limitations during high-flow seasons.

Both states indicate a similar level of statewide N reductions which can be achieved by reducing fertilizer rates to economically optimal rates. Minnesota estimates of cost savings per pound of N reduced to waters are considerably higher than Iowa estimates. Evaluation of this practice is highly dependent upon assumptions of: baseline conditions, price of corn, price of fertilizer, and climate.

Effects of changing fertilizer timing to closer to when crops need the nutrients are more pronounced in Minnesota estimates, especially in the fall to spring preplant scenario. Minnesota assumes a corresponding 30 pound N rate reduction in association with the change in timing, whereas Iowa did not assume a rate reduction with the change in fertilizer timing.

Iowa included an analysis of nitrification inhibitors, whereas the Minnesota NBMP analysis did not. Iowa assumes an average 9% nitrate reduction to waters on acres treated with inhibitors, but that overall statewide reductions to waters from inhibitors would only be 1%. Nitrification inhibitor use in Minnesota has been increasing during recent years. The Minnesota Department of Agriculture estimates use of inhibitors on over 1.2 million cropland acres in 2012, up from about 0.5 million acres in 2010 (Bruce Montgomery, personal communication).

Both states show reasonably similar N reduction expectations for riparian buffers and perennials. Minnesota's cost estimates are much higher for riparian buffers per pound of N reduced compared to Iowa, largely due to difference in the type of buffers being considered. Iowa focused on buffers which intercept shallow subsurface waters flowing toward the buffers, and therefore the treatment area for Iowa's buffers are larger than Minnesota estimates.

Statewide best management practices combinations needed for a 45% nitrogen reduction

Goals to reduce the Gulf of Mexico Hypoxic zone down to a 5,000 square kilometer area would require an estimated 45% reduction in N and phosphorus loads to the Gulf (see Chapter A2). Iowa and Minnesota used different methods and assumptions to arrive at estimates of BMP adoption levels (and associated costs) required to achieve a 45% N load reduction in surface waters.

Iowa State University (2012) developed several possible scenarios for Iowa to achieve 45% reductions from cropland (Table 8), equating to an overall 41% reduction of N loads from all sources. The scenarios have different up-front and annual costs for the BMPs. The scenarios represent hypothetical combinations of BMPs and do not necessarily represent the most optimal or achievable scenarios.

Table 8. Three Iowa BMP adoption scenarios predicted to achieve an estimated 45% nitrate-N loading reduction to Iowa surface waters from the cropland sources (adapted from Iowa State University, 2012).

	Initial cost (billion $)	Annual cost (billion $)
Scenario 1 · 100% agric. land with optimal N rate (maximum return to nitrogen) · 27% of agric. land draining into wetland treatment · 60% of tile drained land with bioreactor	3.2	0.76
Scenario 2 · 100% agric. land with optimal N rate (maximum return to N) · 95% of row crops with cover crops · 34% of agric. land in best-suited regions with wetlands · 5% of agric. land (additional) retired to perennial vegetation	1.2	1.2
Scenario 3 · 100% agric. land with optimal N rate (Maximum return to N) · 100% of fall N with nitrification inhibitor · 100% of spring N side-dressed · 70% of tiled land treated with bioreactor · 70% of suitable land with controlled drainage · 31.5% of agric. land draining into wetland treatment · 70% of agricultural streams with buffers	4.0	0.08

For Minnesota conditions, we used the NBMP tool previously described to estimate BMP adoption scenarios to achieve 30%, 35%, and 45% reductions for an average precipitation year (Table 9).

Both states show a very high level of BMP adoption needed to achieve a 45% load reduction. Minnesota estimates indicate that the 45% level of reduction is not achievable with current practices included in the NBMP spreadsheet, but could theoretically be achieved with future BMP improvements. Both Iowa and Minnesota show the cost range in billions of dollars to achieve N reductions at or approaching the 45% goal (Tables 8 and 9). The costs in Table 9 incorporate fertilizer savings, where savings are potentially achievable. Costs do not include government and private industry personnel costs to promote BMPs and assist with BMP implementation.

Table 9. Minnesota statewide BMP adoption levels estimated to achieve 30%, 35%, and 45% reductions of N into surface waters. Estimates were developed by using the Minnesota NBMP tool (Lazarus et al., 2012). Percentages of BMP adoption represent percentages of land well-suited for each BMP (i.e. 90% adoption – is 90% of land suitable for the BMP).

	% N reduction	Annual net cost billion $
30% reduction scenario · 90% corn land with optimal N rate (maximum return to N) · 45% fall N switched to spring; 45% fall N switched to preplant/sidedress · 70% of streams with riparian buffers growing perennial grasses 100 ft wide on each side of stream 80% (1.36 million acres) tiled land draining into wetland treatment and 10% into bioreactors · 70% of corn/soybean land with rye cover crop · 90% of suitable land with controlled drainage · 44% of all marginal cropland retired to perennial vegetation (all other marginal land was used for other lower cost BMPs)	30%	1.4
35% reduction scenario · 100% corn land with optimal N rate (maximum return to N) · 50% fall N switched to spring; other 50% fall N switched to preplant/sidedress · 100% of streams with riparian buffers growing 100 ft wide perennial grasses (1.7 mill. acres) · 80% (1.36 million acres) suitable tiled land draining into wetland treatment and 20% into bioreactors · 100% of corn/soybean land with rye cover crop (11.7 mill. acres) · 100% of suitable land with controlled drainage (1.34 mill. acres) · All marginal cropland retired to perennial vegetation (1.35 mill. acres)	35%	1.9
45% reduction scenario More development of BMPs is needed to achieve a 45% reduction. We cannot show a 45% statewide N reduction with the NBMP tool using the current assumptions and default values. We estimate that we can achieve a 45% reduction if we use the above 35% reduction scenario BMP adoption rates and additionally we modify the NBMP tool to assume: a) that we can find ways to improve establishment of cover crops, increasing from a 20% success rate to 60% success rate, and b) application rates to corn are reduced from 100% of optimal to 80% of optimal (80% of maximum return to N rate. With the better success of the cover crop establishment, the overall cost is reduced as compared to the 35% reduction scenario.	45%	*1.6

*this cost assumes that cover crop establishment success increases from 20% (current) to 60% (hypothetical)

To achieve the 35% reduction scenario, the N reduction BMPs would need to be applied to all cropland in the state that is suitable for the BMPs. Similar to Iowa's approach, the scenarios in Table 9 were not evaluated or considered for achievability, and we anticipate that the economic and social constraints would make these scenarios unrealistic at this time.

A 30% statewide N reduction to waters from cropland is theoretically achievable based the NBMP model results, but would require a very high adoption rate of optimal fertilizer management, tile drainage treatment and vegetation change BMPs. According to NBMP tool results, it appears that the first 13% N reduction to waters from cropland sources can potentially be made if optimal fertilizer/manure rate and timing BMPs are adopted on most (over 90%) of the state cropland (Figure 4). NBMP tool estimates indicate that this can be accomplished with a net cost savings (approximately $77 million) to producers during an average precipitation year, and a reduced savings during a wet year. The second tier of BMPs is tile drainage BMPs. An additional 5% N reduction to waters can be accomplished with a $73 million dollar annualized cost to install and maintain wetlands (80% of suitable acres), bioreactors (10% of suitable acres) and controlled drainage (90% of suitable acres). By changing or adding vegetation through another $1.4 billion annual investment, an additional 12% N reduction to waters can be accomplished. The vegetation changes to achieve the added 12% reduction include a rye cover crop on 70% of row crops; change existing crop to grasses on about 100 feet each side of 70% of the streams in the state; and change 44% of the other marginal croplands from corn to grasses. The costs of the vegetation changes are particularly sensitive to changing crop and fertilizer prices.

The N reduction potential and associated costs vary by watershed, and therefore the statewide numbers shown in Table 9 and Figure 4 are not applicable to individual watersheds.

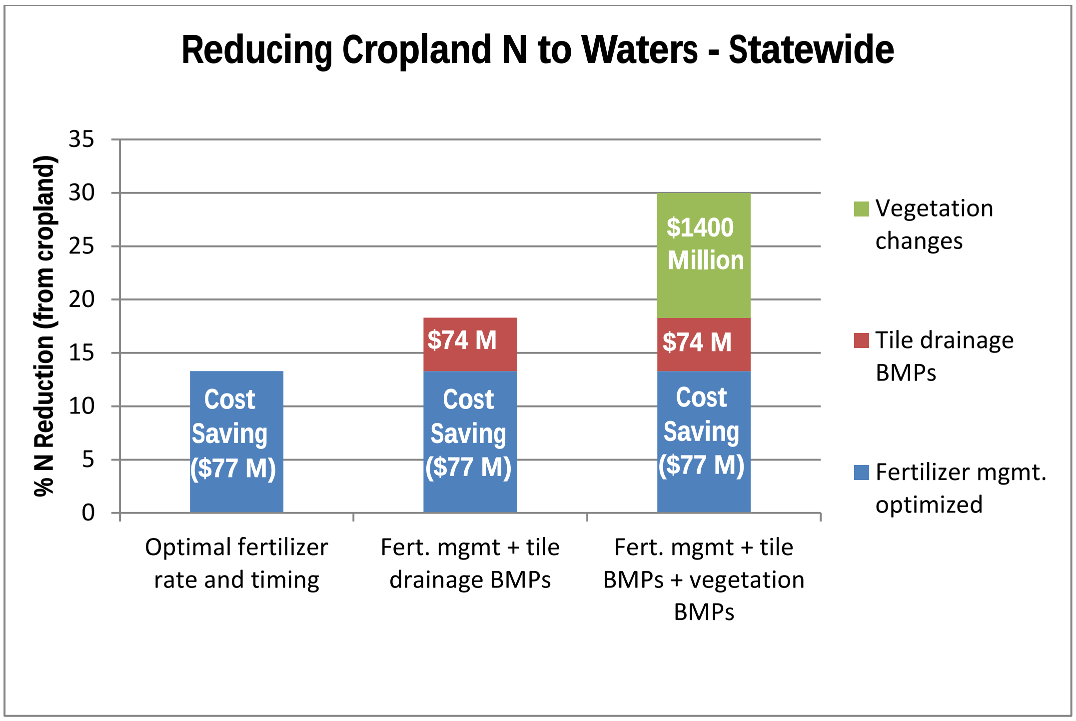

Figure 4. NBMP estimated Minnesota statewide N reductions to surface waters from cropland during an average precipitation year, using fertilizer management BMPs alone (left), fertilizer management with tile drainage BMPs (middle), and fertilizer management with both tile drainage and vegetation change BMPs (right). Cost estimates are incremental in millions of dollars annually calculated for conditions at the time of report writing and will change with fluctuating markets.

Watershed best management practice combinations to achieve 15% and 25% nitrogen load reductions

Since some BMPs are better suited for one region of the state over another, the N reduction potential and associated costs vary considerably across Minnesota. BMP adoption scenarios were developed separately for four watersheds using the NBMP tool, with the goal of showing potential scenarios for reducing watershed N load by approximately a) 15%, b) 25% and c) maximum reduction % under the adoption of BMPs as described in Tables 10-14. Numerous combinations of BMP adoption scenarios can be used to achieve the 15% and 25% reductions. The scenarios chosen below are weighted toward higher adoption of the more cost-effective BMPs at each site, but they are not completely cost-optimized. Each scenario includes a variety of BMPs, recognizing that different farmers will not all choose the same BMPs, and assuming that 100% adoption of any single BMP across a watershed is unrealistic. Nitrogen reduction BMP adoption scenarios for achieving 15% and 22% N load reductions in the Root River Watershed are shown in Table 10. The 25% reduction scenario could not be achieved in the Root River Watershed with 100% adoption of the listed BMPs.

Nitrogen reduction BMP adoption scenarios for achieving 15%, 25% and 38-39% N load reductions in the LeSueur River Watershed in south central Minnesota, Cottonwood Watershed in southwestern Minnesota, and North Fork Crow River Watershed in central Minnesota are shown in Tables 11, 12, and 13. To achieve the higher N load reductions, BMP adoption rates were greatly increased.

Table 10. Nitrogen reduction BMP adoption scenarios for achieving 15% and 22% N reductions in the Root River Watershed during an average precipitation year. All BMPs in the table combined must be adopted at the listed acreage amounts in order to achieve the 15 and 22% reductions.

Root River Watershed		**22% Maximum* N-reduction**	**25%**	**15%**
	Area of watershed suitable for BMP in a single year (% of watershed)	Acres treated with BMP during a given year to get 22% reduction	Acres treated with BMP during a given year to get 25% reduction	Acres treated with BMP during a given year to get a 15% reduction
Corn N rate reduced to optimal (from current avg. down to U of MN rec. avg. for a given year)	38.3	307,400	NA	261,300
Switch fall application to spring application and reduce rate 30 lb/acre (only on corn)	4.8	38,700	NA	31,000
Wetlands installed to treat tile line water (land draining into)	2.4	18,900	NA	5700
Bioreactors (land draining into)	1.4	11,200	NA	1100
Controlled drainage	1.4	11,200	NA	3900
Rye cover crop installed – (assumes 25% success rate for establishing cover crop)	58.6	391,800	NA	233,600
Marginal cropland planted to perennials	5.0	40,000	NA	2000
Avg. N reduced per watershed (million lbs/year)		3.1		2.1
Avg. cost per lb N reduced		7.4		5.0
Avg. annual net cost per watershed (million $/year)		22		10.4
Savings from fertilizer BMPs (million $/year)		+4		
Cost of tile drainage BMPs (million $/year)		0.6		
Cost of perennials and cover crops (million $/year)		26		

*Maximum reduction in NBMP tool with 100% adoption of the BMPs listed in this table.

Table 11. Nitrogen reduction BMP adoption scenarios for achieving 15%, 25% and 39% N reductions to surface waters in the LeSueur Watershed. All BMPs combined in the table must be adopted at the listed acreage amounts in order to achieve the 15%, 25% and 39% reductions.

LeSueur River Watershed		39% *Maximum N-reduction	25%	15%
	Area of watershed suitable for BMP in a single year (% of watershed)	Acres treated with BMP during a given year to achieve a 39% reduction	Acres treated with BMP during a given year to achieve a 25% reduction	Acres treated with BMP during a given year to achieve a 15% reduction
Corn N rate reduced to optimal (from current avg. down to U of MN rec. avg. for a given year)	49.3	274,300	225,000	205,800
Switch fall application to spring application and reduce rate 30 lb/acre (only on corn)	32.2	178,800	143,000	17,900
Wetlands installed to treat tile line water (acres draining into)	17.9	99,400	29,800	19,900
Bioreactors (acres draining into)	18.1	50,500	10,000	
Controlled drainage	18.1	50,500	30,300	
Rye cover crop installed – (assumes 25% success rate for establishing cover crop)	87.7	478,200	193,500	97,100
Marginal cropland planted to perennials	3.3	0 Marginal land used for other BMPs	900	
Avg. N reduced per watershed (million lbs/year)		3.3	2.1	1.3
Avg. cost per lb N reduced		$9.00	4.95	2.83
Avg. annual net cost per watershed (million $/year)		30	10.5	3.6
Savings from fertilizer BMPs (million $/year)		+4		
Cost of Tile drainage BMPs (million $/year)		6		
Cost of perennials and cover crops (million $/year)		27		

*Maximum reduction in NBMP tool with 100% adoption of the BMPs listed in this table.

Table 12. Nitrogen reduction BMP adoption scenarios for achieving 15%, 25% and 38% reductions to surface waters in the Cottonwood River Watershed All BMPs combined in the table must be adopted at the listed acreage amounts in order to achieve the 15%, 25% and 38% reductions.

Cottonwood River Watershed		38% *Maximum N-reduction	25%	15%
	Area of watershed suitable for BMP in a single year (% of watershed)	Acres treated with BMP during a given year to get 38% reduction	Acres treated with BMP during a given year to get 25% reduction	Acres treated with BMP during a given year to get a 15% reduction
Corn N rate reduced to optimal (from current avg. down to U of MN rec. avg. for a given year)	49.8	337,100	286,500	252,800
Switch fall application to spring application and reduce rate 30 lb/acre (only on corn)	27.6	186,700	140,000	26,100
Wetlands installed to treat tile line water (acres draining into)	12.0	78,200	32,600	16,300
Bioreactors (acres draining into)	11.5	38,900	7,800	
Controlled drainage	11.5	38,900	31,100	
Rye cover crop installed – (assumes 25% success rate for establishing cover crop)	92.2	591,400	247,800	124,500
Marginal cropland planted to perennials	3.7	25,300	1,300	
Avg. N reduced per watershed (million lbs/year)		2.6	1.7	1.0
Avg. cost per lb N reduced		$18.5	8.4	5.4
Avg. annual net cost per watershed (million $/year)		47	14.0	5.4
Savings from fertilizer BMPs (million $/year)		+3		
Cost of Tile drainage BMPs (million $/year)		6		
Cost of perennials and cover crops (million $/year)		44		

*Maximum reduction in NBMP tool with 100% adoption of the BMPs listed in this table.

Table 13. Nitrogen reduction BMP adoption scenarios for achieving 15%, 25% and 38% reductions to surface waters in the North Fork Crow River Watershed. All BMPs combined in the table must be adopted at the listed acreage amounts in order to achieve the 15%, 25% and 38% reductions.

North Fork Crow River Watershed		38% *Maximum N-reduction	25%	15%
	Area of watershed suitable for BMP in a single year (% of watershed)	Acres treated with BMP during a given year to get 38% reduction	Acres treated with BMP during a given year to get 25% reduction	Acres treated with BMP during a given year to get a 15% reduction
Corn N rate reduced to optimal (from current avg. down to U of MN rec. avg. for a given year)	33.6	196,900	177,200	161,500
Switch fall application to spring application and reduce rate 30 lb/acre (only on corn)	13.1	76,700	61,400	46,000
Wetlands installed to treat tile line water (acres draining into)	7.8	36,100	29,700	7,300
Bioreactors (acres draining into)	5.1	14,900	3000	
Controlled drainage	5.1	14,900	19,400	4500
Rye cover crop installed – (assumes 25% success rate for establishing cover crop)	58.3	260,000	210,200	50,600
Marginal cropland planted to perennials	13.4	78,400	15,700	3900
Avg. N reduced per watershed (million lbs/year)		25	1.3	0.8
Avg. cost per lb N reduced		23.4	13.7	3.51
Avg. annual net cost per watershed (million $/year)		47	18	2.8
Savings from fertilizer BMPs (million $/year)		+3		
Cost of Tile drainage BMPs (million $/year)		1		
Cost of perennials and cover crops (million $/year)		49		

*Maximum reduction in NBMP tool with 100% adoption of the BMPs listed in this table.

The costs per pound of N reduced increase significantly when achieving higher and higher N reductions (Figure 5). The first 10-20% reductions can largely be achieved with lower cost BMPs and cost-saving optimal fertilizer management BMPs. Further reductions can be achieved by increasing adoption of the more costly tile-drainage management and treatment BMPs. The last 7-20% reductions can be achieved by the most costly BMPs, which involve replacing row crops with perennial vegetation (on marginally productive soils) and establishing cover crops.

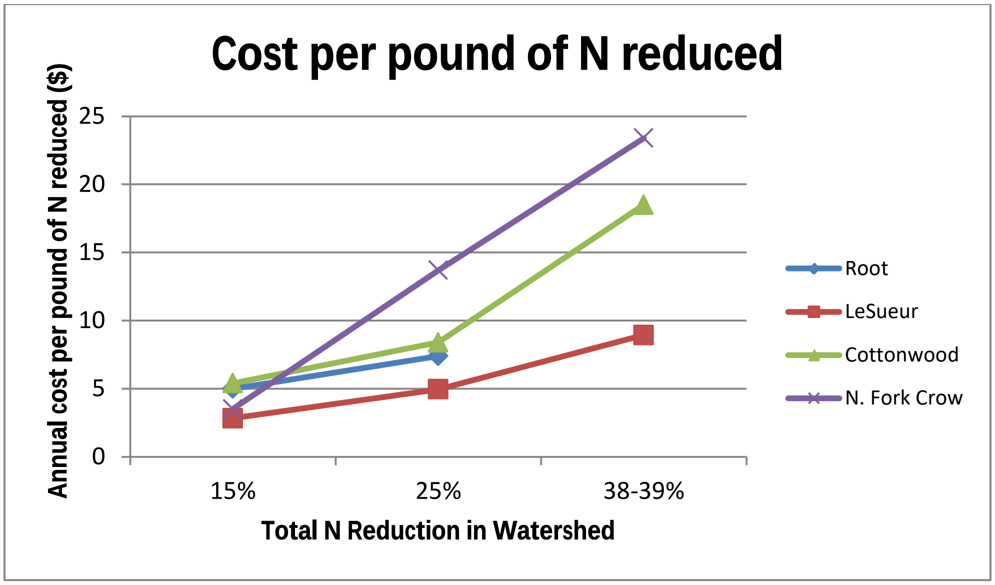

Figure 5. Average estimated net costs per pound of N reduced to waters from four watersheds when achieving N reduction goals of 15%, 25% and 38 to 39% (derived from NBMP tool as presented in Tables 10-13). The 25% reduction scenario for the Root River is actually a 22% reduction, since the 25% reduction could not be achieved with the selected BMPs.

The LeSueur and Cottonwood River Watersheds can achieve a higher estimated N reduction as compared to the Root River Watershed, according to NBMP tool results (Figure 6). This is partly due to a couple of key differences among the watersheds. The Root River Watershed has much less tile-drainage as compared to the other two watersheds, and therefore the BMPs to manage or treat tile-drainage cannot be implemented as much in the Root River Watershed. Additionally, there is little opportunity to switch from fall to spring fertilizer applications in the Root River Watershed, since most farmers in this region are currently applying fertilizer in the spring months. Farmers in the south-central and southwestern watersheds generally have more fall application.

Nitrification inhibitors are being used more frequently with fall applications in these areas to reduce N leaching losses in the fall and early spring months, and sales of these products more than doubled between 2010 and 2012 (personal communication with Bruce Montgomery, MDA). Nitrification inhibitors are not yet included as a BMP in the NBMP tool.

The North Fork of the Crow River can achieve N reduction percentages comparable to the LeSueur and Cottonwood Watersheds (Figure 6). But in order to achieve a 38% reduction in the North Fork of the Crow, a relatively large amount of marginal cropland (13% of the watershed) would need to be converted to perennial vegetation. More marginal cropland is available in this watershed as compared to the LeSueur and Cottonwood Watersheds.

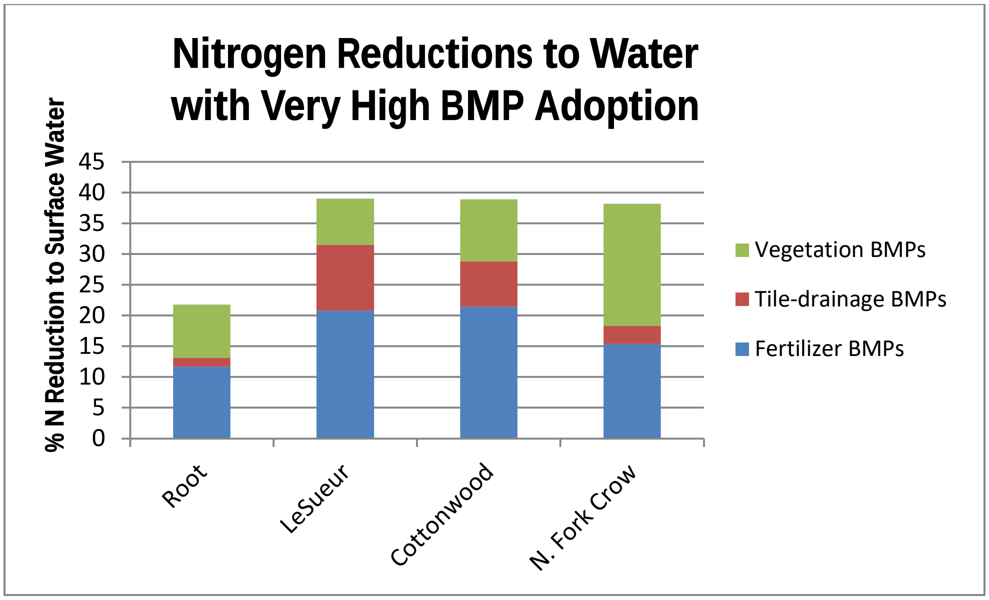

Figure 6. Nitrogen reductions to surface waters (%) in four watersheds which may be achieved by adopting BMPs on 100% of the suitable lands as shown in tables 10-13. The total percentage reduction and reductions from each of the three major BMP categories were estimated with the NBMP tool.

SPARROW model nitrogen reduction scenarios

The SPARROW modeling conducted for this study, as described in Chapter B4, was used to predict expected statewide delivered total nitrogen (TN) load reductions with different source reduction scenarios (Table 13). Based on these results, 30% reductions to both point source and fertilizers applied to land would result in an estimated 11.2% TN load reduction at the state borders. The agricultural fertilizer category does not include manure sources or any other agricultural N sources except for commercial fertilizer. Similar to results obtained from the NBMP spreadsheet, the SPARROW model scenarios suggest that statewide total N reductions in excess of 10 to 15% will be very difficult to achieve by only reducing N additions to soils.

Table 13. Estimated effects of statewide total N load reductions in streams with source reductions in agricultural fertilizer and urban point sources by 10%, 20% and 30% as estimated with the MRB SPARROW model.

	10% source reduction	20% source reduction	30% source reduction
Point source	-0.7% TN	-1.2% TN	-2.0% TN
Agricultural fertilizer	-3.1% TN	-6.1% TN	-9.2% TN
Total	-3.8% TN	-7.3% TN	-11.2% TN

Social constraints to cropland best management practice adoption

Based on farmer interview research conducted by Davenport and Olson (2012) in two highly agricultural and heavily tile-drained watersheds (Rush River and Elm Creek), certain BMPs have a greater acceptance by farmers than other BMPs (see report at Nitrogen Use and Determinants of Best Management Practices: A Study of Rush River and Elm Creek Agricultural Producers). While the Davenport and Olson study of farmer and resource manager viewpoints about N reduction BMPs was limited to two watersheds and a limited numbers of farmers, the results identified social constraints which may also exist in other areas. For example, planting perennial crops for energy or forage shows great promise for reducing nitrate losses, but is not popular due to economic constraints (i.e. current poor market for these crops). Planting riparian buffers along waters is a more accepted practice by farmers, but research shows that it takes large acreages to have a significant effect on reducing N loads. Economic considerations of BMP implementation were the most influential constraints to adoption, including considerations such as cost of the BMP, any associated loss of crop production, land values, and crop prices. Yet, agricultural producer decisions about their farms and BMP adoption are also affected by farm culture, knowledge (education), influence of agricultural professionals, and values such as stewardship, civic responsibility, and human health. Davenport and Olson concluded that the BMPs considered by the interviewed farmers to have the greatest likelihood of adoption at this time are buffer strips along waters, optimal rates as defined by the University of Minnesota, and cover crops.

More information about farmer nutrient management practices and considerations are described in Minnesota Department of Agriculture's Farm Nutrient Management Assessment Program reports found at www.mda.state.mn.us/protecting/soilprotection/fanmap.aspx

Discussion/conclusions

Information on cropland BMPs presented in this chapter can be considered for larger geographic scale planning purposes (i.e. HUC8 watersheds and larger), but is not intended for small scale strategy development. The potential reductions from BMPs and the costs to achieve those reductions are dependent on: a) the accuracy of baseline assumptions about N fertilizer rates/timing; b) accuracy of in-field N leaching and runoff estimates; c) accuracy of assumptions about land suitable for the BMPs; d) annual and regional climate variability; e) ability and willingness of farmers to manage and maintain the BMPs; and f) many other factors. Therefore all N reduction estimates and costs should be viewed as rough approximations for program planning purposes.

Scale of reductions

Based on Chapters B2 to B4, large portions of southern Minnesota contribute high N loads to surface waters (yields exceeding 10 pounds/acre), especially south-central Minnesota, but also portions of southeast and southwest Minnesota. A 45% reduction in the highest single HUC8 watershed in the state will only result in about a 3% loading reduction to state rivers. Little cumulative state-level progress will be made unless multiple watersheds (i.e. the top 10 to 20 N loading watersheds) all work to reduce N levels. Meaningful N reductions to surface waters at regional scales cannot be achieved by solely targeting small "hot spots" based on geologically sensitive areas or by targeting "bad actors."

Priority areas

At the state level, Minnesota will not make meaningful progress in reducing large-scale N loads unless BMPs are adopted on acreages where there is a combination of: high N sources to the land; a seasonally inefficient plant root system which allows considerable vertical movement of the source N; and a way of readily transporting the leached N to surface waters. This pertains mostly to row crops planted on tile-drained lands, but also includes row crops in the karst region and sandy soils.

Magnitude and cost of reductions

Based on the statewide results from the NBMP tool, up to an estimated 13% reduction in river N loads can potentially be achieved through widespread implementation of optimal fertilizer rate and timing practices. These results are similar to Iowa's estimated reductions from optimal fertilizer rates and timing BMPs. To achieve a 25% N load reduction statewide, a suite of more costly BMPs would also be needed (in addition to the optimal fertilizer rate/timing BMPs). The NBMP spreadsheet indicated that a

25% N loading reduction in Minnesota surface waters is theoretically achievable statewide under very high BMP adoption rates of a variety of field and off-field practices. The cost per pound of N reduced in waters varies from one part of the state to the other, and increases significantly in all watersheds when achieving 25% reductions as compared to 15% reductions. A 30 to 35% statewide reduction of cropland N losses to waters was projected to cost between 1 and 2 billion dollars per year with current crop prices and without further improvements in N reduction BMPs.

Reduction strategy considerations

- *Optimal in-field N management* - N reduction strategies should start by optimizing in-field nutrient management, including: fertilizer and manure rates, fertilizer types, timing of application or use of nitrification inhibitors, plant genetic improvements, etc. These types of practices can reduce N transport to waters significantly and typically have the least cost, potentially saving money in reduced fertilizer costs and/or increased crop yields. Many farmers are already using these BMPs, including use of nitrification inhibitors. Yet farmer survey results incorporated into the NBMP tool indicate that further reductions are potentially achievable, on average.
- *Multiple purpose BMPs* – While this study largely isolates N and N removal BMPs, we recognize that many BMPs provide other benefits apart from reducing N. Any evaluation of recommended practices to reduce N should consider the complete costs and benefits of the BMP. For example, BMPs such as constructed wetlands and controlled drainage could potentially help reduce peak river flows through temporary storage of water. Wetlands and riparian buffers have a potential to create wildlife habitat. Cover crops have added benefits of reducing wind and water erosion and potentially improving soil health. Nitrification inhibitors and spring/sidedress fertilizer applications can improve N use efficiency.
- *BMP combinations* – No single type of BMP is expected to achieve large scale measurable reductions in Minnesota River N levels. Instead, we will need to consider a sequential combination of BMPs which includes in-field nutrient management, tile drainage water treatment and management, and vegetation/landscape diversification. We have enough information to make progress in reducing N in waters with existing BMPs. With continued research and development, further N reductions may be more feasible in the future.
- *In-field alternative vegetation* – Several types of in-field vegetation can achieve large N reductions, including extended rotations involving perennials, cover crops, and perennial energy crops or grasses on marginal lands. It is particularly difficult to achieve N reductions of more than 10 to 15% in minimally-tiled watersheds unless in-field alternative vegetation BMPs are used.

    - Cover crops deserve further study in Minnesota due to the potential desirable effects of significantly reducing nitrate leaching, reducing phosphorus and sediment in runoff, reducing pesticides, and improving soil health. Yet the NBMP tool indicated that cover crops are a costly practice per pound of N reduced, and more work is needed to determine the best ways of seeding and managing cover crops in Minnesota's northern climate. If Minnesota can become more successful at establishing and managing cover crops (e.g. 50-75% success rate) this practice, if widely adopted, could reduce N in rivers by as much as 17-27%.

  - Perennial vegetation provides considerable N reductions to underlying groundwater and tile drainage waters. However, the crop revenue losses when converting row crops to perennials, especially during times of high grain prices, makes this practice less likely to be accepted on a widespread scale at this time. If more profitable markets open up for perennial energy crops or forage crops on marginally productive cropland, then this practice will be a more feasible part of N reduction strategies.

  - Converting riparian cropland to perennial buffers will not achieve substantial N reductions by filtering surface runoff, but this can be an effective practice to reduce N leaching on the land where the vegetation change occurs.

- *Tile drainage treatment and management* – Tile line water treatment BMPs are also part of the sequential combination of BMPs needed in many areas to achieve measurable N reductions to waters. Constructed wetlands should be considered in riparian and marginal lands, especially where multiple purpose benefits can be achieved through their use. Bioreactors were found to be more expensive (per pound of N reduced) than wetlands in the Minnesota evaluation, but could be more effective if improvements can be made to treat waters during high-flow times of the year. Bioreactors may be more acceptable in certain areas, such as upland areas where wetland treatment is less feasible. Care must be taken to ensure that BMPs relying on denitrification for N removal do not cause unintended consequences, such as release of metals in waters or greenhouse gasses to the atmosphere.

  One BMP which can greatly reduce tile line nitrogen loads is installing tile drains at a shallower depth. This BMP is not generally considered a BMP for reducing N loads from existing conditions, but it can be a preventative measure to reduce the increase of N loads to surface waters in areas where new tile drainage is installed.

Recommendations for further study

- Develop a cost/benefit planning tool which considers benefits of multiple purpose BMPs, so that planning decisions can be based on a more holistic approach to improving environmental and farm quality, rather than focusing on a single contaminant.
- Research and demonstrate ways to successfully and profitably establish and grow cover crops in Minnesota.
- Research and demonstrate ways to successfully and profitably grow perennial forage and energy crops which have low N losses to waters.
- Further our understanding of how to avoid unintended consequences of adopting BMPs.
- Continue efforts to understanding barriers to adoption of all types of BMPs by discussing with farmers and crop consultants. Refine the existing NBMP tool in the following ways:
  - Verify BMP installation and maintenance cost estimates where developed on limited information.
  - Update with new N fertilizer use surveys and land application of manure data, including how well manure is credited when determining fertilizer rates and current practices related to timing of application.
  - Add nitrification inhibitors as an added BMP option.
  - Continue to add BMP options to the spreadsheet when research demonstrates promising technologies.
  - Annually update default numbers to the latest fertilizer and crop prices.

- Continue researching improved ways of reducing N loads to surface waters. Saturated buffers show some promise but may need further research and demonstration.
- Continue to evaluate BMPs relying on denitrification processes (i.e. bioreactors and wetlands) to ensure prevention of unintended consequences.
- Evaluate the costs of the BMPs compared to the environmental costs without improvements. Consider full cost accounting studies.
- Conduct further analysis using the NBMP tool, testing its use at the watershed scale.

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F2. Reducing Wastewater Point Source Nitrogen Losses to Surface Waters

Author: Bruce Henningsgaard, MPCA

Municipal and industrial wastewater treatment facilities remove nitrogen (N) based on their treatment facilities technology and influent N levels. This chapter focuses on potential wastewater N reductions based on additional treatment technologies that could be installed at some treatment facilities.

As mentioned in Chapter D2 of this report, Minnesota currently has over 900 point sources that actively discharge to surface waters. Of these point sources, approximately 64% are domestic wastewater treatment plants (WWTPs) and approximately 36% are industrial facilities. In total, it is estimated that wastewater point sources discharge an average annual total nitrogen (TN) load of approximately 28,131,772 pounds statewide. Most of this load is from municipal dischargers (24,316,038 pounds/year TN, 86%); the remainder is from industrial facilities (3,815,734 pounds/year TN, 14%).

Nitrogen removal processes

Nitrogen removal from wastewater relies on a number of factors. Two key elements are time and temperature. There must be adequate treatment time for the desired biological activity to occur and the wastewater must be warm enough to insure that the biological activity can occur.

Raw domestic wastewater typically ranges from 20 to 70 mg/L of TN with a typical strength of around 40 mg/L (Water Environment Federation, 2006), consisting of approximately 60% ammonia and 40% organic N. Bacteria take in (assimilate) N from wastewater in a process known as *assimilation*. In the aerobic treatment process, most of the organic N is changed to ammonia in a process known as ammonification. Then all the ammonia is available to the nitrifying organisms. Biological N removal is a two-step process that involves nitrification and denitrification. Nitrification is an oxidizing process that occurs in the presence of oxygen under aerobic conditions using bacteria to oxidize ammonia to nitrite (NO_2), and then using another type of bacteria to oxidize the nitrite to nitrate (NO_3). The treatment process requires both a long solids retention time and hydraulic retention time. Denitrification is a reducing process that occurs in the absence of oxygen under anoxic conditions using bacteria to reduce nitrate to nitric oxide, nitrous oxide and N gas, with the N gas released to the atmosphere from the treatment tank wastewater surface. Nonbiodegradable organic N that is in particulate form is not removed through these processes, but rather through the physical process of solids separation (sedimentation or filtration). For details on estimated TN effluent data from different types of wastewater treatment plants, see the Assumptions and Methods portion of Chapter D2 and Table 2 of that chapter. Table 2 of Chapter D2 shows typical TN effluent values ranging from 6 mg/L at a small pond system up to 19 mg/L at a large class A-type of mechanical plant.

For optimum nitrification, a solids retention time (SRT) long enough to allow a stable population of nitrifiers to be maintained in the process is necessary. The target SRT will vary with temperature, dissolved oxygen, pH, and ammonia concentration. Temperature must be greater than about 45^{o} F to provide a stable population of nitrifiers. A hydraulic retention time (HRT) long enough to allow biomass enough time to react with the ammonia is also necessary. Systems with longer HRTs are less likely to see ammonia break-through due to temperature changes, or variations in flows and loadings.

For optimum denitrification, an anoxic zone that is mixed well and has dissolved oxygen levels less than 0.1 mg/L is necessary. Denitrifying bacteria are facultative and prefer to use oxygen to metabolize Carbonaceous Biochemical Oxygen Demand (CBOD). Any oxygen in the zone will be used before the bacteria start to reduce the nitrate. Sufficient readily degradable CBOD in the anoxic zone is also necessary. Carbon augmentation may be necessary with low CBOD to N ratios and nearly all separate stage denitrification.

Treatment time at a typical mechanical plant, such as an activated sludge plant or trickling filter with contact stabilization, is accomplished through the use of tanks. Tanks can be laid out in a variety of configurations, depending on the type of treatment units.

For aerated wastewater pond systems, N removal may be possible with additional treatment processes. Nitrification can be achieved by either adding an additional treatment unit after the ponds, such as some kind of fixed-film aeration tank/reactor or by modifying the aerated pond system by installing dividing baffling in the pond(s) along with the possible addition of media. A treatment unit for denitrification would also need to be added. This could also include the need for additional clarification. As with mechanical plants, adequate detention time to support the desired biological activity and proper dissolved oxygen concentrations is a key part of the treatment.

Wastewater temperature is the other key element. Raw wastewater temperature varies seasonally and is important because of the significant effect temperature has on the biological process. Heat loss also varies from plant to plant, depending on the treatment units being used. Wastewater temperatures must be greater than about 45° F to provide a stable population of nitrifiers. When wastewater temperatures fall to around 40° F, the nitrification/denitrification process becomes prohibitively slow.

For mechanical plants, wastewater temperatures usually do not fall below this level. Wastewater usually moves through a plant quick enough so that the temperature does not have a chance to drop below 45° F. Also, many mechanical plants have covers on many portions of the plant, especially the head works (grit removal and screening) and the primary clarifiers. For systems with septic tanks, wastewater temperatures in the winter can easily fall below the needed level for N removal. Most septic tanks are buried but they are buried without any insulation and the wastewater can remain in the tank for enough time for the water to cool. This is similar in aerated ponds. Aerated ponds are exposed to the elements and the wastewater easily cools while going from pond to pond prior to discharge. This also applies to stabilization ponds.

The above information regarding temperature was used to estimate N reduction potential at wastewater plants throughout the state. It was estimated that N removal could be implemented at mechanical wastewater treatment plants all year long. While N removal may be possible at aerated ponds during some of the warmer months, it would not be an easy process. Because of this, the analysis below assumes that N removal would not be achieved at aerated ponds. It was also estimated that N removal could not be implemented at stabilization ponds and septic tank-based systems. Of course, this is a general estimation. In reality, each plant would need to be individually evaluated to determine if and/or how N removal could and/or would be implemented. It should also be noted that the operation of a wastewater treatment plant can be a delicate process, easily upset by changes in influent flow and/or loading. This can cause problems in the nitrification process and especially in the denitrification process. In some cases an additional carbon source, such as some type of syrup product, is added to the wastewater.

Nitrogen removal levels from two technologies

The two primary methods of N removal from wastewater evaluated in this study are Biological Nutrient Removal (BNR) and Enhanced Nutrient Removal (ENR). A third tier of nutrient removal, called Limit of Technology (LOT), is sometimes considered (Section 3 of the Iowa Nutrient Reduction Strategy, Iowa Department of Natural Resources [2012].

Biological Nutrient Removal is most commonly associated with sequenced combinations of aerobic, anoxic and anaerobic processes which facilitate biological denitrification via conversion of nitrate to N gas. Effluent limits achievable using BNR at WWTPs that treat primary domestic wastewater are approximately 10 mg/L TN (Iowa Department of Natural Resources, 2012). For a mechanical WWTP the typical type of treatment would be activated sludge, which could be in the form of an oxidation ditch, sequencing batch reactor or “regular” aeration tanks. Another common option is a trickling filter followed by contact stabilization. Contact stabilization is achieved using tanks similar to aeration tanks. Adequate detention time is a key factor in achieving BNR and N removal.

Enhanced Nutrient Removal typically uses BNR along with filtration to achieve lower effluent N levels. This may also involve chemical addition. Effluent limits achievable using ENR at WWTPs are approximately 6 mg/L TN (Iowa Department of Natural Resources, 2012). For a mechanical WWTP the typical type of treatment would be similar to those listed above in the BNR description with the addition of some type of denitrification filter. As mentioned above, adequate detention time is a key factor.

Limit of Technology is generally associated with the lowest effluent concentrations that can be achieved using any treatment technology or combination of technologies. Potential technologies may include tertiary chemical addition with filtration, advanced effluent membrane filtration and ion exchange. It appears that there may not be consensus establishing specific treatment requirements for LOT or what effluent values could be achieved. The effluent values would be something less than the 6 mg/L TN value associated with ENR. Due to the lack of consensus surrounding LOT, there is no reduction estimates made based on this technology. Reduction estimates have been made on BNR and ENR.

Utilizing the above information as a guide, TN reductions were estimated at facilities based on BNR and ENR application. BNR and ENR, it was assumed, could be applied to mechanical facilities. It was assumed that BNR and ENR could not be applied to aerated ponds, stabilization ponds and septic tank-based systems.

Statewide nitrogen reduction from wastewater point sources

Current TN load values are based on actual discharge flow as reported to the MPCA by individual permittees via their discharge monitoring reports. Actual discharge TN concentration data was also used when available, and where not available it was estimated based on the type of treatment facility. Since much of the TN data used to calculate the reductions are estimates and not based on actual discharge TN concentration data, N reduction estimates could change once more actual discharge data become available. For more details on the estimated TN effluent data, see the Assumptions and Methods portion of Chapter D2 and Table 2 of that chapter.

Current estimates of wastewater N loads from Chapter D2, along with N removal efficiencies from BNR and ENR technologies as previously described, were used to estimate statewide N load reductions potentially achievable for wastewater. Reductions due to the implementation of BNR and ENR at all applicable treatment facilities were calculated. Table 1 below, in addition to the estimated current TN load, includes the estimated TN loads if BNR and ENR was implemented. The table also includes the percent reduction compared to the current load.

Implementing BNR technology statewide will reduce N discharges at municipal wastewater discharge points by an estimated 46%, and by 9% at industrial wastewater points of discharge. Implementing ENR technology statewide will reduce N discharges at municipal wastewater discharge points by an estimated 66%, and by 29% at industrial wastewater points of discharge. Combining municipal and industrial wastewater N reductions, BNR and ENR implemented statewide will reduce wastewater point sources by an estimated 41% and 61%, respectively.

Table 1. TN loading rates for the whole state and potential reductions due to BNR and ENR

Discharge source	Current TN load - lbs/year	BNR - lbs/year & (% reduction from current)	ENR - lbs/year & (% reduction from current)
Municipal	24,929,970	13,211,169 (46% reduction)	8,152,457 (66% reduction)
Industrial	3,741,459	3,461,397 (9% reduction)	2,712,060 (29% reduction)
Total	**28,671,429**	**16,672,566 (41% reduction)**	**10,864,517 (61% reduction)**

Nitrogen reductions in select major basins

Table 2 below includes current TN loading rates for three major basins in Minnesota; the Minnesota River, the Upper Mississippi River, and the Red River of the North. Also included is the estimated TN load if BNR and ENR were to be implemented in each basin, comparing the percent reduction to the current load. Reductions have been included for these three basins due to the amount of attention that has been focused on these basins recently. Water quality issues in the Gulf of Mexico and Lake Pepin have focused attention on the Minnesota River basin and the Upper Mississippi River basin over the last 10 to 20 years. Water quality issues in the Red River of the North and Lake Winnipeg, where the Red eventually empties, have come to the surface in more recent years.

Percent reductions in the Minnesota River watershed and the Upper Mississippi River watershed are very similar. BNR percent reductions for the Minnesota and Upper Mississippi are 43% and 44%, respectively. For ENR, the N reduction estimates are 64% and 65% for the Minnesota and Upper Mississippi, respectively. Percent reduction values for the Red River of the North are lower but still substantial at 35% for BNR and 51% for ENR.

Table 2. TN loading rates for three watersheds and potential reductions due to BNR & ENR

Watershed	Discharge source	Current TN load- lbs/year	BNR - lbs/year & (% reduction from current)	ENR - lbs/year & (% reduction from current)
Minnesota River	Total	4,676,235	2,650,818 (43% reduction)	1,695,525 (64% reduction)
Upper Mississippi River	Total	14,249,666	7,941,375 (44% reduction)	5,010,724 (65% reduction)
Red River of the North	Total	659,696	429,850 (35% reduction)	326,314 (51% reduction)

As shown in the tables above, implementation of BNR or ENR could have a substantial impact on the TN discharged in Minnesota. It should be noted that these reductions are only estimates. Actual reductions can be influenced by numerous factors including but not limited to the amount of influent N a plant is receiving and the type of technology chosen. A full scale pilot study may be the only way to really determine the best technology for a given plant and the actual reductions that may occur when that technology is utilized. Currently in Minnesota there are two facilities with a TN limit of 10 mg/L. Both facilities use some form of activated sludge for treatment and both facilities have had problems meeting their TN limit. There are no TN limits lower than 10 mg/L.

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G. Conclusions

Concerns with nitrogen in waters

Nitrogen (N) affects in-state and downstream waters in three primary ways:

1. **Aquatic life toxicity** - Aquatic life have been found to be adversely affected by the toxic effects of elevated nitrate. The nitrate levels that harm aquatic life are currently being studied so that standards can be developed to protect Minnesota fish and other aquatic life.
2. **Gulf hypoxia** - The Gulf of Mexico receives about 6% of its N from Minnesota watersheds. The cumulative effects of multi-state N contributions are largely the cause of the hypoxic (low oxygen) zone in the Gulf of Mexico. While N can increase eutrophication in coastal waters, N has a less prominent role in affecting lake and stream eutrophication within Minnesota, which is mostly controlled by phosphorus.
3. **Nitrate in drinking water** - Fifteen streams, mostly in southeastern Minnesota, exceed a 10 mg/l standard established to protect potential drinking water supplies.

River nitrogen conditions and loads

Stream N concentrations

Maximum nitrite+nitrate-N (nitrate) levels in Minnesota rivers and streams (years 2000-2010) exceeded 5 mg/l at 297 of 728 (41%) monitored sites across Minnesota, and exceeded 10 mg/l in 197 (27%) of these sites. A marked contrast exists between nitrate concentrations in the southern and northern parts of the state. In southern Minnesota, most river and stream sites exceed 5 mg/l at least occasionally. Most northeastern Minnesota streams have nitrate concentrations which remain less than 1 mg/l. Streams in northwestern Minnesota have nitrate that is typically less than 3 mg/l, even during peak times.

Total Nitrogen (TN) concentrations exhibit the same spatial pattern across the state as nitrate, but are typically about 0.5 to 3 mg/l higher than nitrate-N, since TN also includes organic N and ammonia+ammonium-N (ammonium). Ammonium concentrations are less than 1 mg/l even during peak times at 99% of rivers and streams in the state, and median concentrations are mostly less than 0.1 mg/l. River ammonium concentrations decreased substantially in the 1980’s and 1990’s, according to previous studies.

Mainstem river loads

Monitoring-based annual TN loads show that most of the state’s TN load leaves the state in the Mississippi River. Nearly 211 million pounds of TN leaves Minnesota per year in the Mississippi River at the Minnesota-Iowa border, on average, with just over three-fourths originating in Minnesota watersheds, and the rest coming from Wisconsin, Iowa and South Dakota. This compares to about 37 million pounds in the Red River at the Minnesota-Canadian border (17 million pounds from Minnesota and the rest mostly from North Dakota). The highest TN loading tributary to the Mississippi River is the Minnesota River. The Minnesota River adds about twice as much TN as the combined loads from the Upper Mississippi and St. Croix Rivers. This is not because the Minnesota River contributes more flow, but because its TN concentrations are so much higher than the other rivers, four to eight times higher than the Upper Mississippi and St. Croix Rivers, respectively.

South of the Twin Cities, tributaries from Wisconsin and Minnesota contribute additional TN to the Mississippi River. Only small amounts of N are lost in the mainstem rivers, unless the water is backed up in quiescent waters. In the river stretch between the Twin Cities and Iowa, some TN is lost when the river flow slows in Lake Pepin and in river pools behind lock and dams. Monitoring based loads show than an average 9% N loss occurs in Lake Pepin. An additional 3% to 13% of the River N is estimated to be lost in the collective pools along the 168 mile Mississippi River stretch between the Twin Cities and Iowa. The net effect of the TN additions and TN losses in the Lower Mississippi Basin is an average 37 million pound load increase between the Twin Cities and Iowa.

Year-to-year variability in TN loads and river flow can be very high. In the Minnesota River Basin, TN loads during low flow years are sometimes as low as 25% of the loads occurring during high flow years. Total nitrogen loads in the Minnesota, Mississippi, and St. Croix Rivers typically reach monthly maximums in April and May. About two-thirds of the annual TN load in the Mississippi River at the Iowa border occurs during the months of March through July. This is due to both river flow and TN concentration increases during these months.

Priority watersheds

Both monitoring and modeling show that the highest N yields occur in south central Minnesota, where TN flow-weighted mean concentrations (FWMCs) typically exceed 10 mg/l and yields range from about 15 to 25 pounds/acre/year. The second highest TN concentrations and yields are found in southeastern and southwestern Minnesota watersheds, which typically have TN FWMCs in the 5 to 9 mg/l range and yields between 8 and 15 pounds/acre/year.

Watersheds in the northern two-thirds of the state have much lower nitrate and TN concentrations, with TN FWMCs in northeastern Minnesota less than 1.5 mg/l and yields from 0.1 to 3 pounds/acre/year. Total N FWMC and yields are higher in the northwestern part of the state as compared to the northeast.

The highest N-yielding watersheds include the Cedar River, Blue Earth River, Le Sueur River, and Minnesota River (Mankato), each yielding over 20 pounds/acre/year during an average year. The highest 15 N loading HUC8 watersheds to the Mississippi River contribute 74% of the Minnesota TN load which ultimately reaches the Mississippi River. The other 30 watersheds contribute the remaining 26% of the load.

River nitrate trends

Flow adjusted nitrate concentrations in the Mississippi River increased between about 1976 and 2010 at most regularly monitored sites on the river, with overall increases ranging between 87% and 268% everywhere between Camp Ripley and LaCrosse. During recent years, nitrate concentrations have been increasing everywhere downstream of Clearwater at a rate of 1% to 4% per year, except that no significant trend has been detected at Grey Cloud and Hastings in the Metro region. Another study by the National Parks Service and others showed that nitrate and TN loads also increased in the Mississippi River between 1976 and 2005 (see Chapter C2). Because over one-third of the Mississippi River N loads are influenced by groundwater baseflow, ongoing monitoring reflects a mix of waters having recently entered the soil and water, along with waters which entered the soil years to decades ago and are just now starting to reach surface waters.

Increasing nitrate concentration trends were also found in the Cedar River (113% over a 43-year period) and the St. Louis River in Duluth (47% increase from 1994 to 2010). The Red River showed significant increases before 1995, but no significant trends between 1996 and 2010.

Not all locations in the state, however, are showing increasing trends. The two monitored sites on the downstream portion of the Minnesota River (Jordan and Fort Snelling) showed a slight increase from 1979 to 2005, followed by a decreasing trend between 2005-06 and 2010-11. During recent years, all sites on the Minnesota River and most tributaries to the Minnesota have been either trending downward or have shown no trend. Additionally, some tributaries to the Mississippi Rivers have also shown decreasing nitrate trends in recent years, including the Rum, Straight, and Cannon Rivers.

Other rivers in the state have shown no significant trends since the mid-1970s, including the Rainy River, West Fork Des Moines, and Crow Rivers.

Trend studies published elsewhere showed many similarities to the findings in this study; yet the magnitude of percent change was often found to be higher in this study.

Nitrogen sources

Cropland

The amount of TN (hereinafter referred to as “N”) reaching surface waters from cropland varies tremendously, depending on the crops, tile drainage practices, cropland management, soils, climate, geology and other factors. Annual N losses to surface waters are less than 10 pounds/acre/year on some cropland and over 30 pounds/acre/year on other cropland.

According to the N source assessment, during an average precipitation year, cropland sources contribute an estimated 73% of the statewide N load to surface waters and 78% of the N load to the Mississippi River. The statewide estimates are similar to the SPARROW model results, which indicate that 70% of N entering surface waters is from agricultural sources. The relative contribution of N loads to surface waters from cropland sources varies by watershed. Cropland sources account for an estimated 89 to 95% of the N load in the Minnesota portions of the Minnesota River, Missouri River, Cedar River and Lower Mississippi River Basins; whereas cropland N accounts for 49% of the Upper Mississippi River Basin N sources. The statewide fraction of N coming from cropland sources also varies with climate, increasing from 72% of statewide N load during an average precipitation year to 79% during a wet year. During a dry year, cropland sources are still the highest N loading sources, but are reduced to 54% of the estimated statewide source N load.

Inorganic N becomes available to crops from several added sources, including commercial fertilizers (47%), legume fixation (21%), manure (16%), and wet+dry atmospheric deposition (15%). The combination of septic systems, lawn fertilizer, and municipal sludge account for about 1% of all N added to soils statewide. Soil organic matter mineralization also contributes a substantial amount of annual inorganic N to soils, yet the precise amount is more difficult to measure or estimate than other sources. Estimates of net mineralization from this study suggest that statewide mineralization from cropland releases an annual amount of inorganic N that is comparable to N from fertilizer and manure additions combined.

Cropland N reaches surface waters through two dominant pathways: 1) tile-line transport, and 2) leaching to groundwater and subsequent flow to surface waters. Surface runoff from cropland adds relatively little N to waters, contributing 1% to 4% of major basin N loads, except that in the Lower Mississippi River and Red River Basin it cropland runoff contributes 9 and 16% of the N load, respectively.

Tile drainage

Tile drainage over row crops represents the highest cropland source pathway and highest overall source in the state. During an average precipitation year, row crop tile drainage contributes 37% of the N load to waters around the state, and contributes 67% of the N load in the heavily tiled Minnesota River Basin. During a wet year, tile drainage contributes an estimated 43% of statewide N loads to waters, and contributes 72% of the N load to the Minnesota River.

The highest N yielding watersheds in the state are those which are intensively tiled. Statistical analyses of Minnesota watershed characteristics indicated that the amount of tile drainage (estimated) explained nitrate and TN variability more than any of the 17 other factors examined. Other Midwest studies also showed a direct correlation between the amount of estimated tiled land and N levels entering waters.

Cropland groundwater

Nitrogen leaching down into groundwater below cropped fields, and subsequently moving underground until it reaches streams, contributes an estimated 30% of N to statewide surface waters. Groundwater N can take from hours to decades or longer to reach surface waters, depending on the rate of groundwater flow and the flow path distance. Nitrogen leaching into groundwater is the dominant pathway to surface waters in the karst dominated landscape of the Lower Mississippi River Basin, where groundwater contributes an estimated 58% of all N. Yet in the Minnesota River Basin, dominated by clayey and tile-drained soils, cropland groundwater only contributes 16% of the N to surface waters, on average.

If we include both the cropland and non-cropland groundwater N sources, 36% of the statewide N load to surface waters is estimated to be from groundwater. The groundwater source estimates have more uncertainty than other source estimates, due to limited data and high variability in leaching and groundwater denitrification rates. Yet, the importance of the groundwater pathway to surface waters was also supported by results from other studies in the state, region and nation, as referenced in Chapter E3.

Wastewater point sources

Wastewater point sources discharge an estimated average annual TN load of 28.7 million pounds statewide. The loads are dominated by municipal wastewater sources, which were found to contribute 87% of the wastewater point source N load discharges, with the remaining 13% from industrial facilities. Nearly half (49%) of the point source N discharges occur within the Twin Cities Metropolitan Area. The 10 largest point source N loading facilities collectively contribute 67% of the point source TN load.

Wastewater point sources contribute an estimated 9% of the statewide N load according to the source assessment. This is similar to, but slightly more than, the 7% point source contribution estimated from SPARROW model results. River monitoring shows that the sum of the long-term average river N coming into the Twin Cities is 6 million pounds less than the N leaving in the Twin Cities near Prescott/Hastings. The 6 million pound average difference is a statistically insignificant 3.5% of the Mississippi River Load at Prescott.

When we divide the wastewater point source N discharge by the size of contributing sewershed areas in the Twin Cities region, we obtain an average of 14 pounds/acre/year from wastewater point sources. In higher density population areas, the N yield increases to 20 pounds/acre/year. SPARROW simulated TN yield in the urban dominated Mississippi River Twin Cities Watershed was 17.4 pounds/acre/year, similar to the yield range identified through the source assessment study. These N yields are comparable to many cropland yields, but are generally lower than intensively tiled row-crop areas. However, the wastewater N delivery to rivers is different than from cropland, as it enters waters at a few specific points as opposed to being dispersed across the watershed.

Other sources

Two other source categories, atmospheric deposition and forest, each contribute cumulative total statewide N loads that are comparable to wastewater point source N loads. While the N concentrations from these two other sources are much lower than wastewater, the aerial extent of these two sources is vast, thereby accounting for the comparable loads.

Atmospheric deposition is highest in the south and southeast parts of the state and lowest in the north and northeast where fewer urban and cropland sources exist. Atmospheric deposition falling directly into lakes and streams was considered in the source assessment as a direct source of N into waters, contributing about 9% of the statewide annual load to waters. Correspondingly, the areas of the state with the most lakes and streams had the most atmospheric deposition directly into waters. Yet, relatively few other N sources are found in the northern Minnesota lakes regions, and a large fraction of N entering into most lakes will not leave the lake in streams. Some N, typically less than 3 pounds/acre/year, is exported out of forested watersheds. Forest N contributions are nearly negligible in localized areas and N levels in heavily forested watersheds are quite low. Yet since such a large fraction of the state is forested, the total cumulative N to waters from forested lands adds up to about 7% of the statewide N load.

Other sources were very small by comparison, including septic systems (2%), urban/suburban nonpoint source N (1%), feedlot runoff (0.2%) and water fowl (<0.2%).

Sources to the Mississippi River

Just over 81% of the total N load to Minnesota waters is in watersheds which end up flowing into the Mississippi River. If we look only at those Minnesota watersheds which drain into the Mississippi River, N source contributions during an average precipitation year are estimated as follows: cropland sources 78%, wastewater point sources 9%, and non-cropland nonpoint sources 13%. Cropland source contributions increase to 83% for these watersheds during wet (high-flow) years, while wastewater point sources decrease to 6%. During a dry year, cropland sources represent an estimated 62% of N to waters in this region and wastewater point sources contribute 19%.

Reducing nitrogen in surface waters

Because high N levels are pervasive over much of southern Minnesota, little cumulative large-scale progress in reducing N in surface waters will be made unless numerous watersheds (i.e. the top 10 to 20 N loading watersheds) reduce N levels. Appreciable N reductions to surface waters at regional and state-level scales cannot be achieved by solely targeting reductions on relatively small subwatersheds or mismanaged land tracts.

Cropland source reduction

Based on the N source assessment and the supporting literature/monitoring/modeling, meaningful regional N reductions to rivers can only be achieved if Best Management Practices (BMPs) are adopted on acreages where there is a combination of a) high N sources to soils, b) seasonal lack of dense plant root systems, and c) rapid transport avenues to surface waters (bypassing denitrification N losses which are common in some ground waters). These conditions mostly apply to row crops planted on tile-drained lands, but also include crops in the karst region and over many sandy soils.

Further refinements in fertilizer rates and application timing can be expected to reduce river N loads and concentrations, yet more costly practices will also be needed to meet downstream N reduction goals.

BMPs for reducing N losses to waters can be grouped into three categories:

1) *In-field nutrient management* (i.e. optimal fertilizer rates; apply fertilizer closer to timing of crop use; nitrification inhibitors; variable fertilizer rates)
2) *Tile drainage water management and treatment* (i.e. tile spacing and depth; controlled drainage; constructed and restored wetlands for treatment purposes; bioreactors; and saturated buffers)
3) *Vegetation/landscape diversification* (i.e. cover crops; perennials planted in riparian areas or marginal cropland; extended rotations with perennials; energy crops in addition to corn)

Through this study, a tool was developed by the University of Minnesota to evaluate the expected N reductions to Minnesota waters from individual or collective BMPs adopted on lands well-suited for the practices. The tool, Nitrogen Best Management Practice watershed planning tool (NBMP), enables planners to gauge the potential for reducing N loads to surface waters from cropland, and to assess the potential costs of achieving various N reduction goals. The tool also enables the user to identify which BMPs will be most cost-effective for achieving N reductions at a HUC8 watershed or statewide scale.

We used the NBMP tool to assess numerous N reduction scenarios in Minnesota statewide and in specific HUC8 watersheds. Results from the NBMP tool were also compared to results from an Iowa study which used different methods to assess the potential for using agricultural BMPs to achieve N load reductions to Iowa waters. Both the Minnesota and Iowa evaluation concluded that no single type of BMP is expected to achieve large-scale reductions sufficient to protect the Gulf of Mexico. However combinations of in-field nutrient management BMPs, tile drainage water management and treatment practices, and vegetation/landscape diversification practices can measurably reduce N loading to surface waters.

River N loads can potentially be reduced by as much as 13% statewide through widespread implementation of optimal in-field nutrient management BMPs, practices which also have the potential to reduce fertilizer costs. To achieve a 25% N load reduction, high adoption rates of a suite of more costly BMPs will need to be added to the in-field N management BMPs. The achievability and costs of N load reductions vary considerably from one region to another.

A 30% to 35% statewide reduction of cropland N losses to waters was projected to cost between 1 and 2 billion dollars per year with current crop prices and without further improvements in N reduction BMPs. The results also showed that 15% to 25% N load reductions can be made at a substantially lower cost.

Iowa predicted a 28% statewide nitrate reduction if cover crops were planted on row crops throughout the state. Cover crops deserve further study in Minnesota due to a combination of desirable potential benefits to water quality and agriculture. If Minnesota can become more successful at establishing and managing cover crops, and then achieve widespread adoption of this practice, we could potentially reduce N in Minnesota rivers by as much as 17% to 27% from this practice alone.

Tile-drainage water treatment BMPs are also part of the sequential combination of BMPs which can be employed in many areas to achieve additional N reductions to waters. Constructed wetlands and wetland restoration designed for nitrate treatment purposes remove considerable N loads from tile waters (averaging about 50%) and should be considered in riparian and marginal lands. Bioreactors cost more than wetlands to reduce a given amount of N, but show promise if further improvements can be made to treat waters during high-flow times of the year. Bioreactors may be an option in upland areas where wetland treatment is less feasible. If controlled drainage is used in combination with wetlands and bioreactors on lands well-suited for these BMPs, statewide N loads to streams can be reduced by 5% to 6%, and N loads in heavily-tiled watersheds can be reduced by an estimated 12% to 14%.

Perennial vegetation provides large N reductions to underlying groundwater and tile drainage waters. When grasses, hay, and perennial energy crops replace row crops on marginally productive lands and riparian areas, N losses to surface waters are greatly reduced. However, the crop revenue losses when converting row crops to perennials, especially during times of high grain prices, makes this practice less feasible on a widespread scale as compared to other practices.

Wastewater N reduction

Wastewater point source N discharges can be reduced through two primary methods: 1) Biological Nutrient Removal (BNR), and 2) Enhanced Nutrient Removal (ENR) which involves biological treatment with filtration and/or chemical additions.

BNR technologies, if adopted for all wastewater treatment facilities, would result in an estimated 43% to 44% N reduction in wastewater point source discharges to rivers in the Upper Mississippi and Minnesota River Basins, and a 35% reduction in the Red River Basin. These reductions correspond with an estimated overall N reduction to waters from all N sources by 9.3%, 2.2% and 0.8% in the Upper Mississippi, Minnesota, and Red River Basins, respectively.

ENR technologies, if adopted for all wastewater treatment facilities, are estimated to result in a 64% to 65% N reduction in wastewater point source discharges to rivers in the Upper Mississippi and Minnesota River Basins, and a 51% reduction in the Red River Basin. These reductions correspond with an estimated overall N reduction to waters from all N sources by 13.5%, 3.2% and 1.2% in the Upper Mississippi, Minnesota, and Red River Basins, respectively.

Recommendations for future study

Future research can improve the estimates in this study.

Source estimates to surface waters could be improved by conducting the following studies:

- further quantification of N leaching to groundwater for different soils, crops, N management and regions of the state
- evaluate denitrification losses within groundwater under different hydrogeologic settings (as groundwater moves between source area and stream)
- verify amount of cropland tile drainage that exists and determine recent rates of installation
- conduct new and expanded fertilizer and manure use surveys and incorporate the new information
- supplement the Point Source N concentration information with additional effluent monitoring data

Strategies for reducing N losses to waters can be better evaluated with:

- a tool which integrates N, phosphorus, and sediment reduction BMPs and associated costs so that the total costs and benefits are considered when planning for multi-purpose BMP adoption strategies
- additional information about BMPs under development, such as saturated buffers, cover crop use in Minnesota, perennial energy crop economics, and water retention strategies
- improved and updated baseline information on current fertilizer rates and timing practices on both land with, and without, manure additions
- costs for reducing wastewater point sources of N
- see further recommendations for future study at the end of Chapter F1

Appendix B4-1. Overview of the United States Geological Survey SPARROW Watershed Model

Author: Nick Gervino, MPCA

Introduction

The U.S. Geological Survey (USGS) SPAtially Referenced Regressions on Watershed attributes (SPARROW) watershed computer simulation model integrates water monitoring data with landscape information to predict long−term average constituent loads that are delivered to downstream receiving waters. SPARROW models are designed to provide information that describes the spatial distribution of water quality throughout a regional network of stream reaches. SPARROW utilizes a mass-balance approach with a spatially detailed digital network of streams and reservoirs to track the attenuation of nutrients during their downstream transport from each source. Models are developed by statistically relating measured stream nutrient loads with nutrient input sources and geographic characteristics observed in the watershed [Preston et al., 2011a]. A Geographic Information System (GIS) is used to spatially describe constituent sources and overland, stream, and reservoir transport.

The statistical calibration of SPARROW assists in the identification of nutrient sources and delivery factors that are most strongly associated with long-term mean annual stream constituent loads. The mass−balance framework and spatial referencing of the model provides insight to the relative importance of different constituent sources and delivery factors. The networking and instream processing aspects of SPARROW provide the capability of relating downstream loads to the appropriate upstream sources so that constituent contributions from a variety of distant upstream sources can be systematically and accurately evaluated in relation to the delivery point [Preston et al., 2011a]. SPARROW results can be used to rank subbasins within large watersheds and rank the relative difference of constituent sources among subbasins.

The process for developing a SPARROW model enables the ability to identify the factors affecting water quality and their relative importance through the combined use of a mechanistic model structure and statistical estimation of model coefficients. This is accomplished by

(1) imposing process constraints such as mass balance, first-order nonconservative transport, and the use of digital topography and hydrologic networks that provide spatially explicit descriptions of water flow paths; and
(2) using observed data, including long-term measurements of streamflow, water quality, and geospatial data of watershed properties, to inform the complexity of the model so that only statistically significant explanatory variables, which are uncorrelated with one another are selected [Preston et al., 2011a].

The USGS National Water Quality Assessment (NAWQA) program developed 12 SPARROW watershed models for six major river basins in the continental United States (Figure 1). Nutrient estimates for Minnesota were based upon the existing SPARROW Major River Basin 3 (MRB3; Robertson and Saad, 2011) model (Figure 2). The MRB3 model includes 15,000 stream catchments and 848 monitoring stations in North Dakota, Minnesota, Wisconsin, Michigan, Iowa, Illinois, Missouri, Indiana, Ohio, Kentucky, Tennessee, West Virginia, Pennsylvania, and New York.

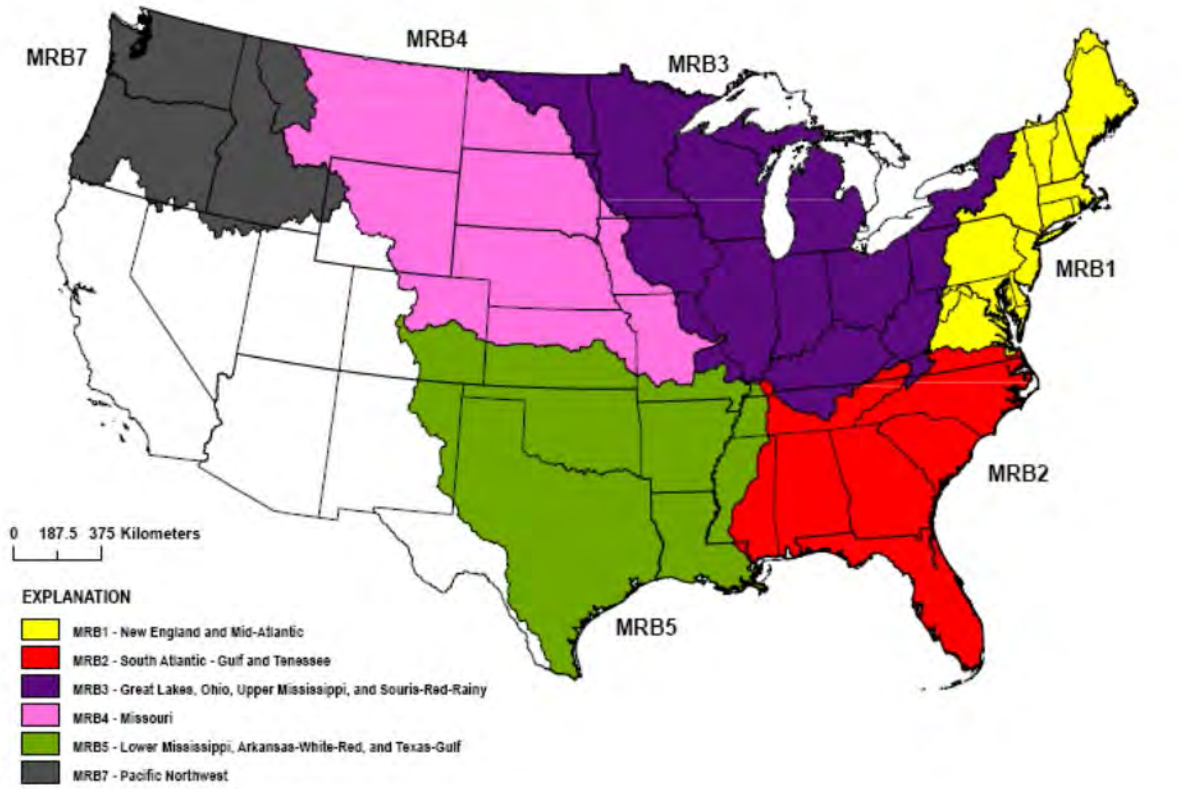

Figure 1. Regions (Major River Basins, or MRBs) selected for the development of SPARROW nutrient models [from Maupin and Ivahnenko, 2011].

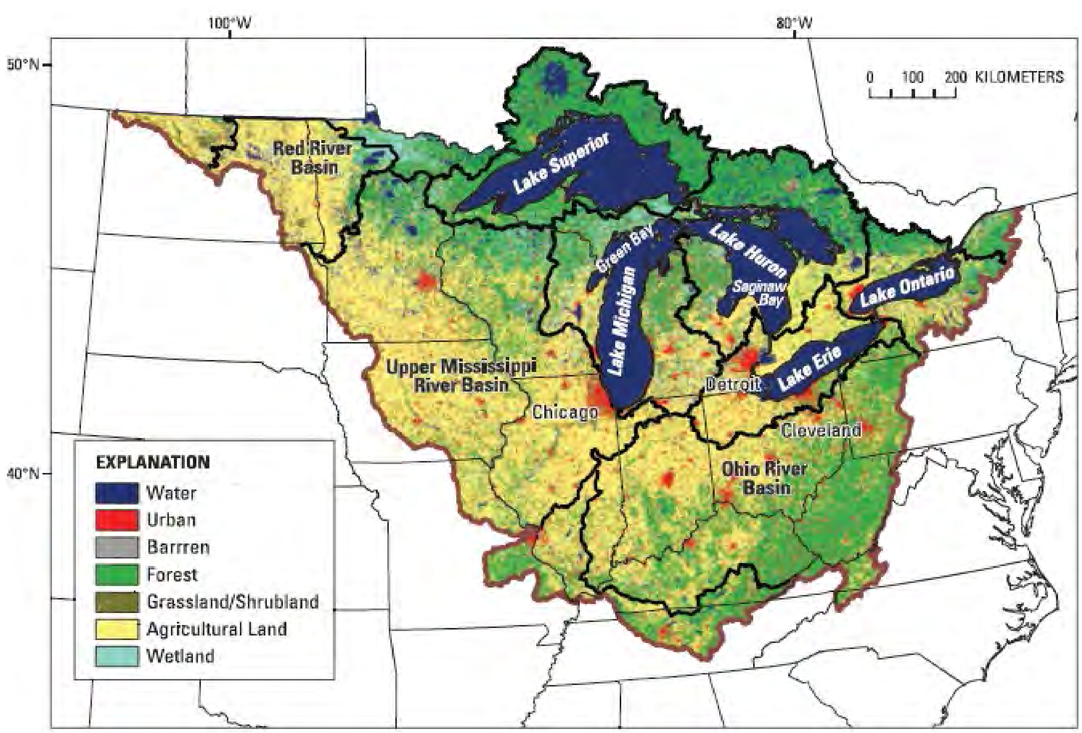

Figure 2. Landuse and land cover of major river basin 3 (U.S. portion) [Robertson and Saad, 2011].

Methodology

Watershed and water quality simulation models utilize various levels of complexity or process detail to represent the hydrologic and biogeochemical processes present in a watershed. The range of model complexity varies from purely statistical models to detailed mass−balance models (Figure 3). Statistical or empirical models use regression techniques to relate stream monitoring data to watershed sources and landscape properties. As described in Chow et al. (1988): "Statistical methods are based on mathematical principles that describe the random variation of a set of observations of a process, and they focus attention on the observations themselves rather than on the physical processes which produced them. Statistics is a science of description, not causality."

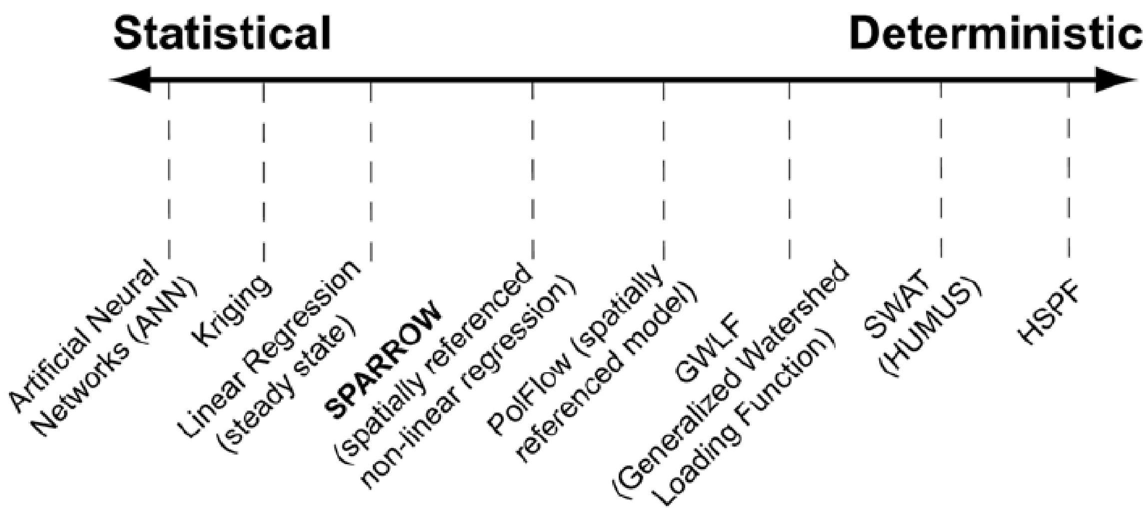

Figure 3. Relationship of SPARROW to the continuum of water quality simulation methods [Schwartz et al., 2006].

At the other end of the scale, deterministic water−quality models have a highly complex mass-balance structure that simulates hydrologic and contaminant transport processes, often according to relatively fine temporal scales. All models reflect some blend of these methods, but most place greater emphasis on one or the other type of model structure and process specification. In comparison to other types of water-quality models, SPARROW may be best characterized as a hybrid process-based and statistical modeling approach. The mechanistic mass transport components of SPARROW include surface-water flow paths (channel time of travel, reservoirs), non-conservative transport processes (first-order in-stream and reservoir decay), and mass-balance constraints on model inputs (sources), losses (terrestrial and aquatic losses/storage), and outputs (riverine nutrient export). The statistical features of SPARROW include the utilization of nonlinear regression techniques to correlate stream monitoring data to pollutant sources, climate, and watershed hydrography and landuse [Schwartz et al., 2006].

The statistical parameters of SPARROW models are estimated with weighted nonlinear regression techniques by spatially relating water−quality flux estimates at monitoring stations with the geography of point−sources, landscape characteristics, and surface-water properties that affect transport. The calibrated models are then used to predict constituent flux for stream reaches throughout a river network. Total constituent flux and flux by contributing source can be estimated. The constituent load from an individual SPARROW subwatershed can be routed to a selected delivery point in the modeled basin.

A load mass−balance is achieved by linking all measured in-stream loads to identified upstream sources, and by requiring that the accumulation of load across sources and reaches be strictly additive. The contaminant load leaving a reach is the sum of two components: the load generated within upstream reaches and transported to the reach via the stream network plus the load originating within the incremental watershed of the reach and delivered to the stream reach.

The dependent variable in SPARROW MRB3 model is long-term mean annual constituent load normalized to a base year. The base year of 2002 was selected to coincide calculated loads with the most recent geospatial datasets of nutrient sources and environmental characteristics [Saad et al., 2011]. Detrended mean annual loads provide an estimate of conditions normalized to a base year. The use of detrended mean annual loads in SPARROW helps compensate for differences in the length and amount of monitoring data available among sites and minimizes the inherent noise introduced by year-to-year variations in rainfall − facilitating the identification of environmental factors that affect loading over long periods. The detrended load estimates estimated with Fluxmaster (Schwarz et al., 2006) are based on two statistical models: a water-quality model and a flow model used to remove trends in streamflow.

Statistical Analysis System

The SPARROW model code is written in the Base Statistical Analysis System (SAS) Macro Language, with statistical procedures written in the SAS IML. SPARROW model execution requires SAS software components Base SAS, the SAS statistical procedures (SAS/STAT) and SAS/IML. The SAS/GIS software component is optional for producing maps of model output. [Schwarz et al., 2006].

Runoff

Runoff is calculated for each streamgage basin by dividing the average daily flow for the water year by the delineated basin area. The runoff for a selected 8-digit hydrologic unit code (HUC8) is determined using an area−weighted method of the streamgage basins. For a HUC8 that is not contained within a streamgage basin, the mean of the HUC8 runoff values within the same HUC4 is used as the runoff value.

SPARROW algorithms

The mechanistic mass transport components of SPARROW include surface-water flow paths (channel time of travel, reservoirs), non-conservative transport processes (first-order in-stream and reservoir decay), and mass-balance constraints on model inputs (sources), losses (terrestrial and aquatic losses/storage), and outputs (riverine nutrient export). Separate land and water components provide estimates of the rates of constituent delivery from point and nonpoint sources to downstream reaches, reservoirs and estuarine waters. The statistical features of the model involve the use of nonlinear parameter-estimation techniques. Parameters are estimated by spatially correlating stream water-quality records with geographic data on pollutant sources (e.g., atmospheric deposition, fertilizers, human and animal wastes) and climatic and hydrogeologic properties (e.g., precipitation, topography, vegetation, soils, water routing).

Flux equation

SPARROW models are developed through a calibration process in which parameter values are estimated to minimize uncertainty in predicting stream constituent loads. Uncertainty is quantified as the residual error in load prediction that cannot be accounted for through parameter adjustment.

The central algorithm of SPARROW is a nonlinear regression equation describing the non-conservative transport of contaminants from point and non-point sources on land to rivers and through the stream and river network. For the MRB3 model, parameter coefficients associated with the sources, land-to-water delivery factors, and in-stream loss and reservoir-loss terms were statistically estimated using weighted nonlinear least squares regression, based on calibrations with long-term mean annual loads normalized to 2002.

SPARROW calculates the load at the downstream end of a stream reach as the sum of monitored and unmonitored contributions to the load at that location from all upstream sources, or

$$L_i = \sum_{n=1}^{N} S_{n,i}$$

where: L_i is contaminant transport in reach *i*;
$S_{n,i}$ is the contaminant load from source *n* delivered to reach *i* from all reaches in the subbasin downstream of the upstream monitoring stations.

The land−to−water delivery and in-stream decay terms in the model dictate the fraction of the contaminant mass that completes the terrestrial and aquatic phases of transport within the watershed draining to each stream reach. The land-to-water terms describe the land-surface characteristics that influence both overland and subsurface transport from sources to stream channels. Similarly, the in-stream decay terms describe the effects of channel characteristics on downstream transport.

Land-to-water delivery

The source terms Sn,i includes the effects of a two-stage watershed constituent delivery process. The first stage of the process is the delivery of constituent mass from the land surface to reach *j* of the receiving channel network. Watershed characteristics that affect land-to-water delivery of nutrients may include soil permeability, wetland area, land-surface slope, and mean annual climatic factors, such as precipitation and temperature. Land-to-water delivery of TP in MRB3 model was found to be significantly influenced by soil permeability and fraction of the stream catchment with tile drains. For total nitrogen (TN), significant variables include stream drainage density (total stream reach length divided by catchment area), precipitation, air temperature, fraction of stream catchment underlain by tile drains, and clay content of the soil (Robertson and Saad, 2011).

Simulation of the transport of land surface constituents to receiving stream reaches is accomplished with a first-order equation:

nonpoint source$_n$: $= \beta_n e^{(-\alpha' Z_j)}$
point source$_n$: $= \beta_n$
upstream monitored load$_n$ $= 1$

where: β_n is a source-specific regression coefficient; and
α' is a vector of regression delivery coefficients associated with a vector of the land-surface characteristics Z_j.

Point sources and other monitored sources enter reach *j* directly and therefore lack the exponential decay term, as there is no land-to-stream decay for point source nutrients. The land-to-water delivery regression coefficients (α') are used to determine the statistical significance of different types of land-surface characteristics (***Z***) for increasing or decreasing the delivery of nutrients from the land surface to the stream reach.

Stream delivery

The second stage of the delivery process is the delivery of constituents from an upstream reach *j* to a downstream reach *i.* The in-stream loss of constituent mass occurs as a function of three variables: travel time, streamflow (serving as a surrogate for channel depth), and the presence or absence of a reservoir.

Time of travel, based on stream velocity, was the factor used to describe nutrient removal in streams. Travel time is computed as the ratio of reach length over stream velocity, and was estimated from the average annual flow for streamgaging stations during the 1975−2007 monitoring period. Stream flow rates were subdivided into three categories to describe in−stream nutrient loss. The flow rates classifying each category were determined in the SPARROW calibration process for total phosphorus (TP) and TN. For TP, the three stream categories are: small, flow <50 ft^3/s; medium, flow 50–80 ft^3/s; and large, flow > 80 ft^3/s. For TN, the three categories of streams were: small, flow <40 ft^3/s; medium, flow ~ 40–70 ft^3/s; and large, >70 ft^3/s.

First order decay of nutrients in streams is simulated as an exponential function of a first-order reaction rate coefficient and the cumulative water travel time as given by:

$$e^{(-\delta' T_{i,j})}$$

where: δ' is a vector of first-order decay coefficients associated with the flow path characteristics $T_{i,j.}$

Denitrification

Analysis of available denitrification rates and mass balance estimates from published studies indicate that N loss rates in streams and lakes generally decline with increases in streamflow, water depth, and hydraulic load (depth/travel time) and decreases in travel time. Stream N loss is simulated using a depth-dependent reaction rate coefficient for each stream size class.

The stream N mass flux at the outlet of a reach *i*, N_i^S, is estimated as a function of the upstream N flux entering reach *i* from reach *j* (N_j^S), the mean water travel time (TR_k^S; units of time) in the modeled reach for stream-size class *k*, and a reaction-rate coefficient dependent upon stream-size (θ_k^S ; units $time^{-1}$) [Boyer et al., 2006]:

$$N_i^S = N_j^S e^{(-\theta_k^S TR_k^S)}$$

Because the SPARROW TN model is based on estimates of the long-term mean-annual flux of TN in rivers, the estimated in-stream loss rates are indicative of permanent or long−term losses of N. Such losses principally include denitrification, but may also include the long-term storage of particulate and organic N in rivers and floodplains.

Reservoirs

First order decay of constituents in reservoirs is simulated as the product of the first-order decay term used for stream nutrient decay and a reservoir settling rate loss term:

$$e^{-\delta' T_{i,j}} \left[\frac{1}{1 + {\theta_i}/{h_{load,i}}} \right]$$

where: q_i is a regression-derived coefficient and $h_{load,i}$ is the areal hydraulic load of the reservoir (average outflow/reservoir surface area), or

$$h_{load,i} = \frac{Q_{ave}}{A_{res}}$$

Hydraulic loading for each reservoir was calculated as average outflow divided by reservoir surface area based on information from the National Inventory of Dams.

Substitution of the transport equations into the original loading equation produces the following SPARROW loading equation for reach *i:*

$$L_i = \left\{ \sum_{n=1}^{N} \sum_{j \varepsilon J(i)} s_{n,j} \beta_n e^{(-\alpha' Z_j)} \, e^{(-\delta' T_{i,j})} \right\} e^{(\varepsilon_i)}$$

Where:

L_i = load in reach *i*

n, N = source index where *N* is the total number of sources

J(i) = the set of all reaches upstream and including reach *i,* except those containing or upstream of monitoring stations upstream of reach *i*

β_n = regression coefficient for source *n*

$s_{n,j}$ = point and nonpoint contaminant mass from source *n* in drainage to reach *j*

α' = vector of land–to–water delivery regression parameters

Z_j = vector of land–surface characteristics association with drainage to reach *j*

δ' = vector of instream–loss regression parameters

$T_{i,j}$ = vector of channel characteristics between upstream reach *j* and the outlet of nested basin *I,* these channel characteristics include time-of-travel and channel size

e_i = error for reach *i*

Data

The estimation of mean annual stream nutrient load, which represents the dependent variable in the SPARROW nutrient models, requires extended periods of coincident nutrient concentration and flow data. However, an extensively long period can invalidate the estimate of the mean if landuse conditions determining water-quality concentrations undergo significant change. For a predominately statistical model such as SPARROW, it is important to have a large number of monitoring sites that represent the most extreme combinations of environmental characteristics in the study area to reduce uncertainty in the estimated model coefficients and improve prediction accuracy.

Any constituent source can be potentially included in a SPARROW model, provided the geospatial data are available to describe it and spatial patterns in the source can be successfully correlated with those in the measurements of stream loading of that constituent. Because SPARROW is based on mass balance, sources must be available for all parts of the region to determine their overall importance. Thus, some data sets that provide detailed information for only a fraction of the model area would not be useful in a SPARROW model because the same information would not be available everywhere. For example, detailed estimates of agricultural inputs of N or estimates of a land-to-water delivery variable collected by one state may not be useful for a model covering the entire country if the data is not collected in the other states.

Water monitoring sites

Daily flow data for each site for the period 1971-2006 were retrieved from the USGS National Water Information System (NWIS) database. Water-quality data for the period 1970-2007 were retrieved primarily from two databases: the U.S. Environmental Protection Agency's STOrage and RETrieval (STORET) database, and USGS's NWIS database. Additional water-quality data was obtained from individual state agencies and local organizations with detailed quality assurance plans. For the 1,371,536 km^2 MRB3 watershed, 1,688 of the 33,118 water quality monitoring sites met the minimum screening criteria, with 708 sites with long-term detrended loads used in the SPARROW model for TN simulation, and 810 sites used for TP. The record of the water quality data was from October 1, 1970, to September 30, 2007. To be included in the data set, a minimum of 25 samples must be collected, and constituent concentrations must be measured for at least two years, with more than one sample collected during each season (winter: Dec.-Feb.; spring: Mar.-May; summer: June-Aug.; fall: Sept-Nov). The principal reasons that monitoring sites were excluded from consideration for use in SPARROW were an inadequate number of samples or too short of a sampling period.

Load computation

The long-term mean annual nutrient loads for each monitored site in the MRB3 watershed were computed with the nonlinear regression methods implemented in the USGS program Fluxmaster. Fluxmaster combines water-quality data at a monitoring station with daily flow values to provide more accurate load estimates than can be obtained by using individual water-quality measurements alone. Total P and TN loads were determined with log-linear water-quality regression models that relate the logarithm of constituent concentration to the logarithm of daily flow, decimal time (to compensate for trends), and season of the year (expressed using trigonometric functions of the fraction of the year). The calculated load and flow rate were detrended (removal of a trend that obscures a relationship of interest, Figure 4) to the 2002 base year. Detrended daily loads were estimated by removing the linear trend in the concentration−discharge relation by using a time value of 2002.5 and using detrended daily flows. Detrended annual loads were then computed by aggregating the daily detrended loads for all years in which a complete record of daily flow was available, and averaged over all such years in the 1971–2006 period to obtain a mean annual detrended load for 2002.

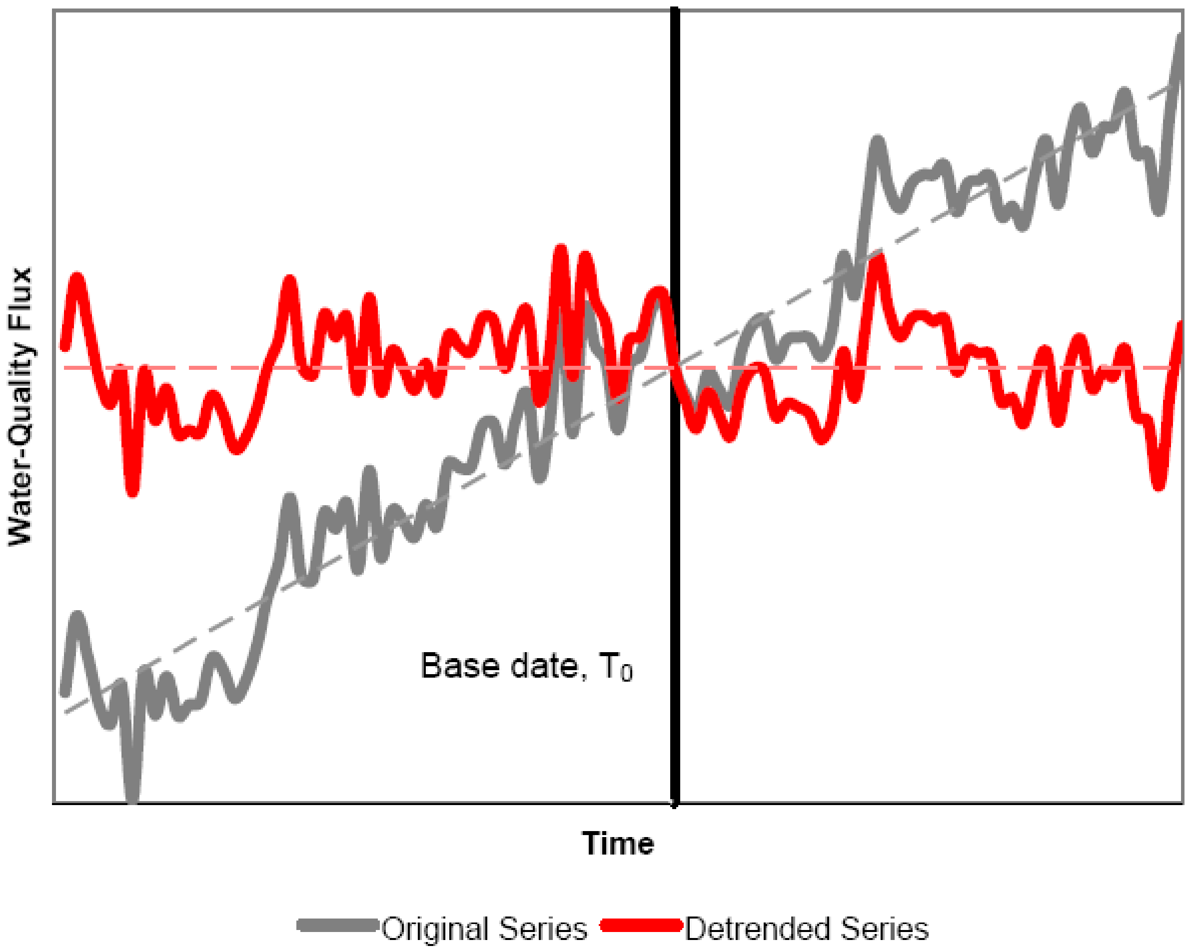

Figure 4. A detrended time series [Schwarz et al., 2006].

The estimates of long-term nutrient loads at monitoring sites used to calibrate the regional model reflect water-quality conditions that should have occurred in 2002, and also incorporate the long-term mean streamflows over the 1971 to 2006 period. The use of the long-term streamflows to estimate the monitoring site loads, rather than the flows during only 2002 ensures that the SPARROW regional model estimates of stream nutrient load, source contribution to streams, and environmental processes that govern the mean rates of nutrient removal and transport in watersheds are representative of long-term hydrologic variability [Preston et al., 2011]. The stream-load values used to calibrate SPARROW models can be interpreted as the mean annual load that would have occurred in a specified base year (2002) if mean annual-flow conditions, based on long-term flow data, had prevailed during that year. Normalizing mean annual nutrient loads to a base year adjusts for differences in monitoring station record lengths and sample sizes, and adjusts for temporal variability related to long-term linear trends (Figure 4), and incorporates the interannual changes in flow.

Hydrography

The MRB3 watershed was developed using the Enhanced River Reach File 2.0 stream network and 100m digital elevation models. The SPARROW subwatersheds are approximately the same size as HUC12 watersheds. In the future, SPARROW models will be developed using the NHDplus stream network.

Atmospheric deposition

Estimates of atmospheric deposition used as input to the SPARROW model are based upon wet inorganic N deposition measurements (nitrate plus ammonia) from National Atmospheric Deposition Program (NADP) sites as a proxy for total (wet plus dry) N deposition [Preston et al., 2011a]

Fertilizer

Commercial fertilizer is allocated to major crops (including soybeans). The allocation is not crop specific. Pasture does not receive commercial fertilizer. Estimates of fertilizer use are derived from county−level fertilizer sales and crop distribution databases, and represent the intensity and areal extent of nutrient inputs to agricultural crops. The county data were allocated to each SPARROW stream catchment by the fraction of the catchment's agricultural land. Fertilizer use may serve as a surrogate for other nutrient inputs and the effects of farm practices (e.g., crop rotation, harvesting, and conservation tillage) on nutrient availability and leaching to soils and streams.

Landuse

Landuse related inputs include additional agricultural inputs from cultivated agricultural areas, urban inputs from urban and open areas, and natural inputs from forested areas. Landuse information was obtained from the USGS 2001 National Land Cover Data set.

Manure

Manure inputs were derived from 2002 county livestock population data from the U.S. Census of Agriculture using species−specific rates. The county−level data was allocated to each SPARROW stream catchment by the fraction of the catchment's agricultural land and grasslands.

Municipal and industrial point sources

Inputs for point−source facilities in the MRB3 watershed (including sewerage treatment, commercial, and industrial effluent) were estimated from data in the Environmental Protection Agency Permit Compliance System (PCS) database, supplemented with data obtained directly from MPCA staff. Municipal and industrial facilities are designated as major or minor. Major facilities typically discharge more than one million gallons per day (mgd) of effluent, and minor facilities typically discharge less than one mgd of effluent. Annual nutrient loads were calculated only for those facilities with measured effluent flow. For facilities which do not monitor nutrients or have missing values, typical pollutant concentrations for similar types and sizes of facilities were used to develop annual loads [Maupin and Ivahnenko, 2011].

Sources

The inclusion of a source in a SPARROW model requires a statistically significant correlation of the source with stream loading measurements. Such correlation is dependent upon whether (a) the source is sufficiently large to make an important contribution to the overall mass balance in the stream network, and (b) the spatial variability in that source as described by the geospatial datasets is sufficiently large.

Constituent sources typically include estimates of N mass in atmospheric deposition, nutrients in commercial fertilizer and manure applied to agricultural land, and nutrients in runoff from urban and other land uses. Regression coefficients estimated for each nutrient source represent the amount of TP or TN delivered to streams, and are expressed as fractions for mass variables (e.g., farm fertilizer input) or absolute quantities (kg⁄km^2⁄year) for land-use variables (e.g., input from urban and open areas). The values of the source coefficients provide an estimate of land−to−water delivery under the assumption that the spatially variable delivery factors are uniformly distributed throughout the land area being considered under average conditions.

Statistical methods were used to identify specific watershed characteristics important in explaining variability in nutrient delivery to streams and losses in streams and reservoirs. Such methods can have statistical limits to building more highly complex models of similar contaminant sources. The individual statistical coefficients of sources with similar or correlated spatial distributions (e.g., confined and unconfined animal wastes; nitrate and ammonia wet deposition) may be difficult to statistically estimate in a SPARROW model. Difficulties can also arise if individual components of a source (e.g., total fertilizer) contribute relatively small quantities of pollutant mass to streams (e.g., urban fertilizer use). In addition, complications can arise if the monitoring stations are located too far downstream to detect the effects of a sub-component of a major source.

Many environmental characteristics thought to be important in nutrient delivery were examined to determine statistically significant land-to-water delivery factors and in-stream-loss and reservoir-loss factors in the SPARROW models. Sources identified as statistically significant in explaining the distribution in TP and TN loads were retained or, if sources were statistically insignificant, they were combined with other sources in a series of model runs until an acceptable regression was obtained.

Some source variables serve as surrogates for other nutrient sources that are spatially correlated with the variables specified in the model. For example, developed urban land may serve as a surrogate measure of various diffuse urban sources in the model, which may include nutrient runoff from impervious surfaces, inflows from groundwater in urbanized catchments related to fertilizers and septic systems, and N deposition associated with vehicle emissions of nitrous oxides.

An objective in developing SPARROW models is to gain insight and to test hypotheses concerning the role of specific constituent sources and hydrologic processes in supplying and transporting constituents in watersheds. Subsequent to the evaluation of a variety of point sources, it was determined that six sources were statistically significant for TP: point sources, confined manure, unconfined manure, farm fertilizers, urban areas, and a combination of forest and wetland (forested areas). Five sources were found to be statistically significant for TN: point sources, atmospheric deposition, confined manure, farm fertilizers, and additional agricultural inputs from cultivated lands (e.g., crop rotation, harvesting, and conservation tillage).

Inputs from forested and urban areas were found to not be statistically significant for TN. Contributions from these sources would be attributed to other sources in the model. The statistical insignificance of unconfined animal manure for TN may be due to the volatilization of most of the N in the manure deposited by unconfined animals prior to runoff from fields and the redeposition elsewhere as part of atmospheric deposition.

In the MRB3 model, receiving stream reaches received 100% of the point source phosphorus, while only 3% of the farm fertilizer, 9% of the confined manure, and 3% of the unconfined manure was received by the stream reach. For TN, 50% of the atmospheric deposition, 80% of the point source, 10% of the farm fertilizer, and 30% of the confined manure was transported to the stream reach. The high percentage of point source TN may be due to an overestimation of point source TN contributions.

Delivery

Results from the calibrated SPARROW MRB3 model indicated that precipitation, stream drainage density, percentage of the drainage area with tile drains, percent clay, and temperature were landscape characteristics that were statistically significant TN delivery variables, with soil permeability and percentage of the drainage area with tile drains significant for TP [Robertson and Saad, 2011].

Stream removal rate

The estimated long-term mean annual rate of nutrient removal in streams is computed in SPARROW as a first−order reaction rate constant. The constant expresses the nutrient removal as the fraction of the nutrient mass that is removed from the water column via denitrification or long-term storage (deposition) per unit of mean travel time in the stream channel. The TN removal rate constants for MRB3 were found to be only statistically significant in streams with depths less than about 1.2 feet, with an exponential decline in magnitude with increasing water depth.

Application of results

Several characteristics of the SPARROW model must be taken into account when applying the model results to management decisions and water-quality assessments. Important among these are that the SPARROW model (1) focuses on spatial rather than temporal detail; (2) integrates long-term discharge and water-quality records to calculate annual stream nutrient loads used for calibration rather than discharges for any specific year; (3) includes only the water-quality factors that are represented in available geospatial data and statistically correlated with stream load; and (4) favors water-quality comparisons across broad regions as opposed to within single catchments.

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Appendix B5-1. Nitrogen Losses in Groundwater – A Review of Published Studies

Author: Dave Wall, MPCA

Introduction

Groundwater can contribute the majority of nitrate to streams in some watersheds, and yet contribute minimal nitrate in other watersheds. In addition to land use influences, the amount of nitrate entering streams is largely influenced by the types of soil, geologic and hydrologic conditions. These factors not only affect the rate at which water travels, but can also affect groundwater chemistry conditions and the likelihood that nitrate will be removed.

Nitrate is the dominant form of nitrogen (N) in groundwater baseflow. Since nitrate moves freely with water, not sorbing to soil particles or aquifer sediments, it will eventually move to surface waters unless it is first lost through "denitification." As long as dissolved oxygen is present in groundwater above 0.5 mg/l (referred to as oxic conditions) and organic carbon content is low, nitrate is stable and persists in groundwater, sometimes for decades (Dubrovsky 2010). If the dissolved oxygen in groundwater is depleted, nitrate becomes unstable and is converted to N gas through this biologically driven process known as "denitrification." Aquifer sediment types and groundwater chemistry have a significant influence on denitrification and correspondingly on nitrate loads delivered to streams (Tesoriero, Duff et al. 2009).

The denitrification process typically begins after bacteria in groundwater break down organic carbon compounds, thereby reducing dissolved oxygen levels. If dissolved oxygen in groundwater becomes depleted (<0.5 mg/l), the bacteria will use nitrate to oxidize the organic carbon. After nitrate is mostly gone, then bacteria can use organic carbon for other redox reactions such as manganese reduction, iron reduction, sulfate reduction, and reduction of carbon dioxide to methane. As a result of these reactions, nitrate may be removed from the groundwater, only to be replaced by manganese, iron, sulfide, or methane. Often these various processes occur in succession as water moves down and through an aquifer.

Denitrification can occur within the unsaturated soil zone, within saturated soils, in the aquifer, and/or in the riparian zone. Where conditions are suitable for denitrification in the aquifer or riparian zone, nitrate contributions from baseflow will be minimal or negligible. Where conditions are not suitable for denitrification, much of the nitrate which moves through the soil into groundwater will eventually emerge in streams via groundwater baseflow.

How much denitrification occurs within groundwater?

In a research review of denitrification within aquifers, Rodvang and Simpkins (2001) noted that studies in till and loess have shown that denitrifying bacteria are present at all depths, and that they become active under the appropriate conditions. They also found studies indicating that the organic carbon content in till and loess in central Iowa was sufficient to facilitate denitrification of large quantities of nitrate. They concluded that denitrification consistently reduces nitrate to non-detectable levels in unweathered Quaternary aquitards.

Data from a St. Cloud area geoprobe study (MPCA, 1998A) suggest the importance of organic carbon in groundwater as a factor affecting denitrification. The median concentration of carbon at the water table of the underlying surficial sand and gravel aquifer was 2.3 mg/L, but increased to 3.1 and 7.8 mg/L at depths of 7.5 and 15 feet, respectively. Over this same depth range, concentrations of dissolved oxygen and redox potential decreased by 0.028 mg/L/feet and 1.7 mv/feet, respectively. Nitrate over this depth range decreased from a median concentration of 5.6 mg/L at the water table to 0.045 mg/L at 15 feet. These observations pointed to the likelihood of denitrification causing nitrate reductions with depth into the water table.

Patch et al. (1994) used groundwater modeling and N isotope data to study the vertical stratification of nitrate at the water table of the Elk Valley Aquifer in Eastern North Dakota. They noted that dispersion alone could not explain the stratification. Furthermore, nitrate present at the lower depths was enriched in the N isotope N15, relative to nitrate nearer the water table. The researchers concluded that denitrification was the major cause of the vertical nitrate stratification.

The Minnesota Pollution Control Agency (MPCA) sampled wells in different aquifers throughout the state to determine nitrate stability (MPCA, 1998B) (Trojan, Campion et al. 2002). Groundwater with dissolved oxygen concentrations exceeding 0.50 mg/L, redox potential greater than 20 mV, and iron concentrations less than 1.0 mg/L, were considered to represent nitrate-stable conditions where nitrate was less apt to convert to N gas through denitrification. Nitrate concentrations under nitrate-unstable conditions were found to be very low, typically less than 0.10 mg/L. They found that nitrate is absent in aquifers with nitrate unstable conditions. Many groundwaters in the state have conditions which are not stable for nitrate to persist. The fraction of samples from each major aquifer in the state with nitrate stable conditions is listed below. With the exception of the Prairie du Chien aquifer, less than half of the samples in each aquifer had nitrate-stable conditions. In several of the aquifers, less than 20% of samples had nitrate-stable conditions.

<u>Percent of well water samples with nitrate-stable chemistry in Minnesota aquifers</u>

Franconia - 33% of 27 samples
Franconia-Ironton-Galesville - 25% of 40 samples
St. Peter - 39% of 23 samples
Prairie du Chien – 53% of 36 samples
Jordan – 42% of 31 samples
St. Peter-Prairie du Chien-Jordan – 46% of 90 samples
Mt. Simon-Hinckley – 19% of 26 samples
Cretaceous – 13% of 39 samples
Galena – 14% of 22 samples
Crystalline Precambrian – 14% of 29 samples
North Shore Volcanics – 35% of 23 samples
Proterozoic Metasedimentary units – 26% of 23 samples
Buried Quaternary artesian aquifers 12% of 386 samples
Unconfined buried Quaternary aquifers – 37% of 104 samples
Buried undifferentiated Quaternary aquifers – 14% of 22 samples
Quaternary water table aquifers – 30% of 119 samples
Cambrian aquifers – 28% of 102 samples
Ordovician aquifers – 38% of 87 samples
Precambrian aquifers – 29% of 80 samples

The same MPCA study reported that waters become more unstable for nitrate as you move further down below the top of the water table and oxygen becomes more depleted. Data from a St. Cloud area geoprobe study (MCPA 1998A) also showed that nitrate concentrations within 7.5 and 15 feet below the top of the underlying sand and gravel aquifer were 0.45 and 0.040 mg/L, respectively, even when concentrations at the water table were well above 1 mg/l. In the St. Cloud area, nitrate concentrations were very low in both deeper wells more than 30 feet below the water table and in buried aquifers (0.030 and < 0.010 mg/L, respectively).

Several researchers have conducted intensive monitoring of groundwater to better define N transformations. Published studies in Minnesota and nearby areas have demonstrated that groundwater denitrification is a common process affecting groundwater and baseflow nitrate levels.

Groundwater was intensively monitored near Princeton, Minnesota as it flowed from under an upland cultivated field to a riparian wetland and stream in a glacial outwash sand aquifer (Böhlke, Wanty et al. 2002). A "plume" of oxic nitrate-rich groundwater present at shallow depths beneath the fields and part of the wetland terminated before reaching the stream or the wetland surface. Groundwater dating and hydraulic measurements indicate travel times in the local flow system of 0 to over 40 years. Zones of active denitrification were found in the aquifer sediments in the recharge area, as well as the discharge area in the more highly organic sediments near the stream. The lower nitrate was therefore due to both older water (recharging decades ago thus predating large nitrate sources) and denitrification. Denitrification was evident in waters moving downward within the surficial sand aquifer, independent of the riparian wetland sediments.

A study in northwestern Minnesota used a mass-balance approach to estimate the amount of N leaching to the Otter Tail outwash aquifer across a 212 km^2 area (Puckett, Cowdery et al. 1999). Due to the very coarse soils within this region, mineralization was assumed to be negligible and was not accounted for in this balance. They found biological fixation to be the largest single source of N to the system (53.1%), followed by fertilizer (40.9%), atmospheric deposition (4.6%), and commercial feed (1.4%). By their estimates, 56% of the excess N in this balance was discharged to groundwater, while 44% was denitrified in the soil and groundwater below the root zone (Puckett, Cowdery et al. 1999). Denitrification was estimated by adjusting its value so the predicted and measured concentrations of nitrate in groundwater agreed. In support of this assumed denitrification, the authors note that they found 43% of wells in settings which supported denitrification. Wells that had nitrate concentrations agreeing closely with predicted nitrate were well oxygenated, and those wells with nitrate much lower than predicted by the N budget had lower dissolved oxygen, suggesting denitrification.

Korom, Schlag et al. (2005) used large stainless steel chambers designed, constructed, and installed to make in situ mesocosms of aquifer sediments representative of Elk Valley Aquifer in Eastern North Dakota. Denitrification rates were measured in the mesocosms and compared to concentration reductions through dilution. Nitrogen isotopes and other water chemistry information indicated that denitrification was occurring in the aquifer sediments. Sulfur from pyrite was found to be a major electron donor, with sulfate oxidation accounting for 58% of the denitrification. The average measured denitrification rate was 0.22 mg/l per day. This estimated rate was in the middle of a wider range (0.033 to 0.59 mg/l/day) of mesocosm denitrification rates found using sediments from several other eastern North Dakota aquifers (Korom, 2010).

While the above studies show potential for substantial nitrate losses through denitrification in the aquifer, there are some situations where denitrification does not readily occur. In a southern Alberta study, leaching nitrate was not denitrified in the shallow upper aquifer unless deeper groundwater mixed with the shallow groundwater. The amount of denitrification was found to be directly correlated with the amount of deeper groundwater mixing with the shallower groundwater (McCallum, Ryan et al. 2008).

Denitrification can also be rather limited in soils under tile-drained fields. Shallow groundwater denitrification represented 1% of inputs in 2001 and 4% of inputs in 2002 in an east central heavily tiled watershed (Gentry, David et al. 2009).

Riparian zone denitrification

Riparian zones often have organic rich sediments conducive for denitrification and substantial biological uptake of N. Both have the potential to reduce nitrate concentrations as shallow groundwater enters the riparian zone.

Many studies have shown nitrate depletion in subsurface flow into riparian zones. Yet other studies have shown that riparian flow paths were ineffective in removing nitrate (Triska 2007) (Duff 2007). Denitrification and plant uptake in riparian zones can remove all nitrate in some environmental settings, but they may be relatively ineffective in others (Puckett 2004). Hydrogeologic and biogeochemical processes can limit denitrification; therefore, not all riparian zones are equally efficient at removing nitrate from groundwater before it reaches stream channels (Hill, 1966; Puckett et al., 2002; Puckett, 2004). Interaction of groundwater N with riparian biota depends on subsurface flow paths that intercept the shallow root zone and soils conducive for denitrification. These flow paths occur where a shallow impermeable sediment layer or aquiclude forces the shallow groundwater into biologically active riparian habitats (Duff 2007) (Duff, Tesoriero et al. 2008) .

The removal of nitrate from groundwater near streams is promoted by a combination of hydrogeologic, biological, and biogeochemical processes. Fine-grained sediments result in slow flow rates that allow more time for denitrification to take place. If the surficial sediments are primarily silt and clay, however, the fine-grained sediments can form a confining layer that forces groundwater to flow below the biologically active zone and may result in less nitrate removal. Coarse-grained sediments may force groundwater to flow through the riparian zone faster than the biological processes can remove nitrate. In addition, if surface runoff occurs or if shallow groundwater is routed through tile drains and ditches, riparian zones can be bypassed and nitrate-rich water is discharged directly to streams.

Riparian zones appear to be most effective in settings with thin surficial aquifers, underlain by a shallow confining layer, and with organic-rich soils that extend down to the confining layer. This combination of factors force groundwater to flow through the biologically reactive portions of the aquifer and promotes nitrate removal.

Spahr (2010) compared mean annual base-flow nitrate concentrations to shallow-groundwater nitrate concentrations for 27 sites across the United States. Nitrate concentrations in groundwater tended to be greater than stream base-flow concentrations for this group of sites. Sites where groundwater concentrations were much greater than baseflow concentrations were found in areas of high infiltration and oxic groundwater conditions. The authors noted that the lack of correspondingly high nitrate concentrations in the base flow of the paired surface-water sites may have multiple causes. In some settings, there has not been sufficient time for enough high-nitrate shallow groundwater to migrate to the nearby stream. In these cases, the stream nitrate concentrations lag behind those in the shallow groundwater, and concentrations may increase in the future as more high-nitrate groundwater reaches the stream. Alternatively, some of these sites may have processes that rapidly remove nitrate as water moves from the aquifer into the stream channel.

Nitrate can be removed from nitrate-rich groundwater as it moves through the riparian zone to the stream, and nitrate can be removed from stream water that flows through sediments in the streambed. Sediments in both of these environments can contain appreciable amounts of organic carbon and other reactants that support bacterial denitrification. In addition, the vegetation in riparian buffer zones can take up nitrate, an important plant nutrient. These processes have been studied in a variety of land-use and hydrologic settings by intensive instrumentation (Puckett (Puckett 2004), (Duff, Tesoriero et al. 2008) (Puckett, Zamora et al. 2008).

Puckett and Cowdery (2002) found that N concentrations in the Ottertail River were very low considering intense agricultural fertilizer inputs. Of the N present in the River, 87% was organic-N (largely dissolved organic N). The riparian buffer zone in this study had only a minor role in preventing nitrate in groundwater from reaching the Ottertail River for two reasons: (1) most nitrate had been removed by denitrification in the upgradient aquifer, and (2) shallow groundwater containing nitrate was able to move along some flow paths below the riparian zone where little nitrate was removed, subsequently moving up into the river along flow paths that did not support denitrification.

Summary

The amount of nitrate entering streams from baseflow will be dependent on the amount entering the top of the water table; the lag time between groundwater recharge and discharge into the stream; the amount of denitrification occurring within the aquifer; and the amount of denitification and biological uptake in the subsurface under and adjacent to the stream.

Studies in loess and till have shown that denitrifying bacteria are present at different depths, and that they become active under the appropriate conditions such as a plentiful organic carbon supply. These bacteria can potentially reduce nitrate to non-detectable levels. Several studies of nitrate losses have found high rates of denitrification where oxygen levels are low. Samples of Minnesota aquifer waters have shown that water chemistry was conducive to denitrification in over half of the wells screened into each aquifer, except for the Prairie du Chien. In several aquifers, over 80% of the wells had water chemistry that would support some level of denitrification. Denitrification is more likely to occur as you move deeper into the aquifer, well below the top of the water table.

While it is difficult to quantify the total amount of nitate lost in groundwater by denitrification, some studies have estimated that over 40% of nitrate may be lost due to denitrification. Other studies have estimated rates of denitrification greater than 0.2 mg/l per day.

Additional nitrate can be lost as groundwater moves into organic-rich zones often found in many river and stream valleys. Fewer losses will occur when groundwater discharge to streams occurs through springs and seeps which bypass subsurface organic sediments in the riparian zone.

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Appendix B5-2. Nitrogen Transport and Transformations in Surface Waters of Minnesota

Author: Dennis Wasley, MPCA

Overview

Generalizing the movement and transformations of total nitrogen (TN) in surface waters of Minnesota is complicated given the wide range of aquatic systems and nitrogen (N) loads delivered to those systems throughout the state. Nitrogen transport in surface waters is spatially and temporally variable which also makes generalizations difficult. The literature of the past two decades has greatly increased our understanding of N transport in surface waters. Some of this work was directly or indirectly related to the transport of N via rivers to estuaries with particular emphasis on N loads from the Mississippi River Basin delivered to the Gulf of Mexico. Research has focused on transport in small streams up to major rivers such as the Mississippi River. Nitrogen data from field-based monitoring have been incorporated into models to estimate downstream transport of N. We will focus on N transport within Minnesota in this chapter. Information for the Mississippi River downstream of the Minnesota state line is summarized in the recent literature (Robertson et al. 2009, Strauss et al. 2011).

Nitrogen is present in detectable amounts in most surface waters in Minnesota. In surface waters with relatively low N inputs, N is typically present in low concentrations of inorganic forms (often near detection limits) with the majority of N present in organic forms bound in various components of living and dead organisms. As N loading increases to a given surface water beyond its ability to assimilate N inputs, detectable amounts of dissolved inorganic nitrogen (DIN) are measured. In well oxygenated waters, DIN is typically present as nitrate (NO_3-N) with lesser amounts of nitrite (NO_2-N) and ammonia/ammonium (combination of both = NH_X-N). The majority of NO_3-N and nitrite NO_2-N (combination of both = NO_X-N) exists as nitrate in streams and rivers and it is common for some to use NO_3-N and NO_X-N interchangeably. This chapter will focus on NO_X-N (NO_3-N + NO_2-N) to be consistent but will specify NO_3-N when NO_2-N was not analyzed in a particular monitoring program. Ammonia and Ammonium (combination of both = NH_X-N) can also make up a portion of DIN in Minnesota waters. It is most common in waters with low dissolved oxygen such as wetlands and the hypolimnion of stratified lakes. NH_X-N is more common and persistent in oxygenated waters during winter immediately downstream of wastewater treatment plants. Nitrification or uptake of NH_X-N by organisms typically processes NH_X-N to other forms of N in oxygenated surface waters during the other seasons.

Many factors influence the transport of N in surface waters of Minnesota. This chapter will discuss factors such as N loading, residence time, temperature, nitrate concentration, discharge, depth, velocity, and land use. Some of these factors are inherently different based on the type of surface water. Wetlands and lakes are common in northeast Minnesota along with relatively low N inputs, all contribute to low N yields. Nitrate concentrations in streams of northeast Minnesota are often near detection limits. Yields of N from watersheds in south-central Minnesota are much higher due to low densities of lakes and wetlands and higher inputs of N (especially NO_X-N) during seasonally higher stream discharge. The concentration of TN in streams can drop during low flow periods in mid-late summer due to a combination of lower input loads and in-stream processing if inputs are not excessive. In terms of downstream loading, the reduction in mid-late summer TN concentration does not result in substantially reduced annual load since the majority of TN is transported from late-March to mid-July when stream discharge is typically highest in Minnesota rivers. Streamflow is highest from spring to early summer in all watersheds in Minnesota resulting in the highest loads during this time frame. Seasonal fluctuations of TN concentrations in rivers draining other watersheds in Minnesota represents a gradual transition from south central to northeast Minnesota. Watersheds in southeast Minnesota are unique to the other watersheds in the state due to the large inputs of high NO_X-N groundwater which maintain elevated TN levels during low flow, and therefore have less seasonal concentration fluctuations of TN than south-central Minnesota.

Residence time is a key factor for N removal across all aquatic ecosystems. Residence time is basically the time it takes to replace the volume of water for a given surface water. Longer residence time allows for more interaction with biota (including bacteria) within a given aquatic resource. Streams typically have much shorter residence times compared to wetlands and lakes. Consequently, streams generally transport more N downstream than lakes and wetlands. The removal efficiency of streams generally decreases with stream size and N loading.

Special consideration was given to the Mississippi River downstream of the Minnesota River due to the unique rapidly flushed impoundments (navigational pools) on this river and availability of models and monitoring data. In this river system and other rivers throughout the state, N loading is typically at its annual peak during spring and early summer when streamflow is seasonally higher. Lake Pepin, a natural riverine lake on the Mississippi River, removed only 6%to 9% of the average annual input load of TN during the past two decades. Lake Pepin has the longest residence time of all the navigational pools on the Minnesota portion of the Mississippi River by a factor of at least 5. Upstream removal and loading reductions of N throughout the tributary watersheds is needed to substantially reduce downstream transport of N by the Mississippi River from Navigational Pools 1 to 8 during spring and early summer. Estimates of the collective impact of all the navigational pools in Minnesota, including Lake Pepin, range from removal of 12% to 22% of average annual input loads.

Outputs from the SPARROW model are useful to illustrate annual downstream delivery of TN loads in Minnesota streams and rivers. The general findings of this review indicate that 80% to 100% of annual TN loads to rivers are delivered to a state border unless a large reservoir with a relatively long residence time is located in the stream/river network downstream of a given headwater stream. Large headwater reservoirs such as Lake Winnibigoshish remove a larger proportion of inputs than riverine lakes such as Lake Pepin which has a much larger contributing watershed. Losses in surface waters upstream of the SPARROW watershed outlets are not included in the SPARROW results presented here, so actual statewide losses in all surface waters exceed those presented here which are more representative of losses in flowing waters and reservoirs included in the SPARROW model. Other approaches described in this chapter based on mass balances estimated from monitored rivers, also showed that the majority of annual TN loads loaded to a given river reach are delivered to downstream reaches.

Basics of nitrogen cycle (emphasis on streams and rivers)

The longitudinal processing of N in a lotic ecosystem (stream or river) is often referred to as N spiraling which is essentially the phenomenon of N cycling in flowing waters. Nitrogen can exist in several forms in surface waters and can change forms depending on various factors (Table 1, Figure 1). Denitrification is the most important process in the N cycle in freshwater for removing N from the water and returning it to nitrogen gas (N_2), which essentially removes it from downstream transport. Nitrogen fixation can return N_2 to a more biologically active form, but this process is generally limited in streams with available DIN. We will discuss most of the components of the N cycle throughout this chapter (Table 2).

Table 1. Most common forms of N in aquatic systems.

Form of nitrogen	Abbreviation	Description
Nitrogen gas	N_2	Biologically inert form of nitrogen that is the most common gas in the atmosphere
Nitrous Oxide	N_2O	Intermediate in denitrification process, greenhouse gas
Nitrate	NO_3^-	Dissolved form of nitrogen common in systems with excess nitrogen loading, most oxidized state of dissolved nitrogen
Nitrite	NO_2^-	Dissolved form of nitrogen, intermediate in N transformations, uncommon when oxygen is present
Organic Nitrogen	NH_2	Generic symbol for various forms of nitrogen in tissue of organisms
Ammonium	NH_4^+	Most common form of ammonia in surface waters
Ammonia	NH_3	Dissolved form of nitrogen that is readily assimilated by algae and bacteria, typically present as NH_4 dependent on pH and temperature

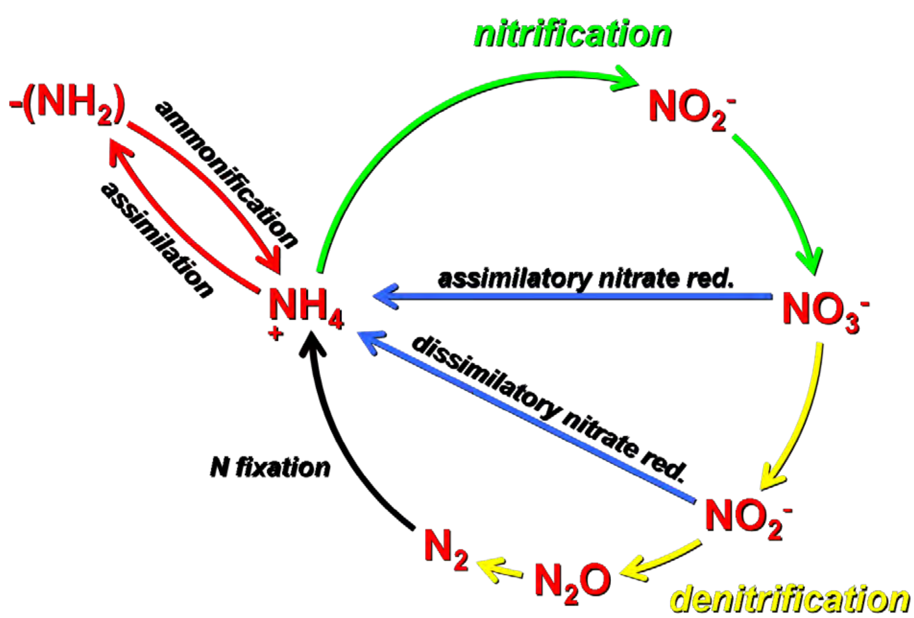


Figure 1. Simplified N cycle for aquatic ecosystems.

Table 2. Generalized transformations and forms of N in aquatic systems.

Process	Inputs	Output	Description
Denitrification	NO_X-N, organic matter	N_2	Bacterial mediated process that occurs in anoxic conditions or sediment interface, carbon source is also needed, inhibited by cold temps
Nitrification	NH_X-N	NO_X-N	Bacterial mediated process that occurs in oxic conditions or sediment interface, inhibited by cold temps
Ammonification	Organic matter	NO_X-N	Bacterial decomposition of organic matter to ammonia
Assimilation	NH_X-N, NO_X-N	Organic-N	Multiple pathways for dissolved inorganic nitrogen to be incorporated into algae, plants and bacteria
Dissimilatory nitrate reduction to NH_X-N	NO_X-N	NH_X-N	Bacterial mediated process that occurs in anoxic conditions or sediment interface, less common than denitrification in streams (Lansdown et al., 2012)
Excretion	Organic matter	Organic-N, NH_X-N	Various forms of Organic-N and urea from organisms may be converted to NH_X-N;
Nitrogen fixation	N_2	NH_X-N	Cyanobacteria are capable of converting nitrogen gas to ammonia for assimilation
Anammox	NH_4^+, NO_2^-	N_2	Anaerobic ammonium oxidation, important in N cycling in oceans

Stream and river transport of nitrogen

Literature/theory

Transport of N in the streams and rivers of Minnesota is influenced by several factors that are temporally and spatially variable throughout the state. Monitoring transport along a stream network is expensive, and existing water-quality monitoring programs are often not designed to specifically estimate fate and transport of N. Thus, available monitoring data is often used to calibrate models to estimate N transport over greater temporal and spatial scales than the original monitoring covered. Even though models are never perfect, they can be useful for estimating the impact of a stream network on the downstream movement of N. The chapter on SPARROW modeling in this report (Chapter B3) summaries the modeled collective impact of streams on downstream transport of N in Minnesota. We will briefly highlight some of the SPARROW results. This chapter will cover some Minnesota examples where adequate data exists and will discuss the key factors that influence downstream transport of TN in streams. Agricultural streams will be discussed in detail since these streams typically receive large N inputs and consequently deliver the largest downstream loads. Forested and urban streams will also be discussed briefly.

A fraction of N transported in streams and rivers is lost to denitrification, some is assimilated and temporarily stored in biota and the rest is transported downstream. The literature has extensive coverage of the loss of NO_X-N via denitrification since this process results in the true loss of DIN within an aquatic system. Burgin and Hamilton (2007) advocate for a more detailed view of all of the alternate pathways for NO_X-N removal beyond just denitrification (Figure 2). They outline multiple pathways for NO_X-N to be assimilated or converted to N_2 beyond the standard denitrification discussed earlier. Recently, Helton et al. (2011) proposed that more complicated models need to be developed over the next decade to address multiple pathways of N transport in river networks (Figure 3). Improved models will include approaches to terrestrial-aquatic linkages including hydrologic exchanges between the channel, floodplain/riparian complex, and subsurface waters, and interactions between coupled biogeochemical cycles.

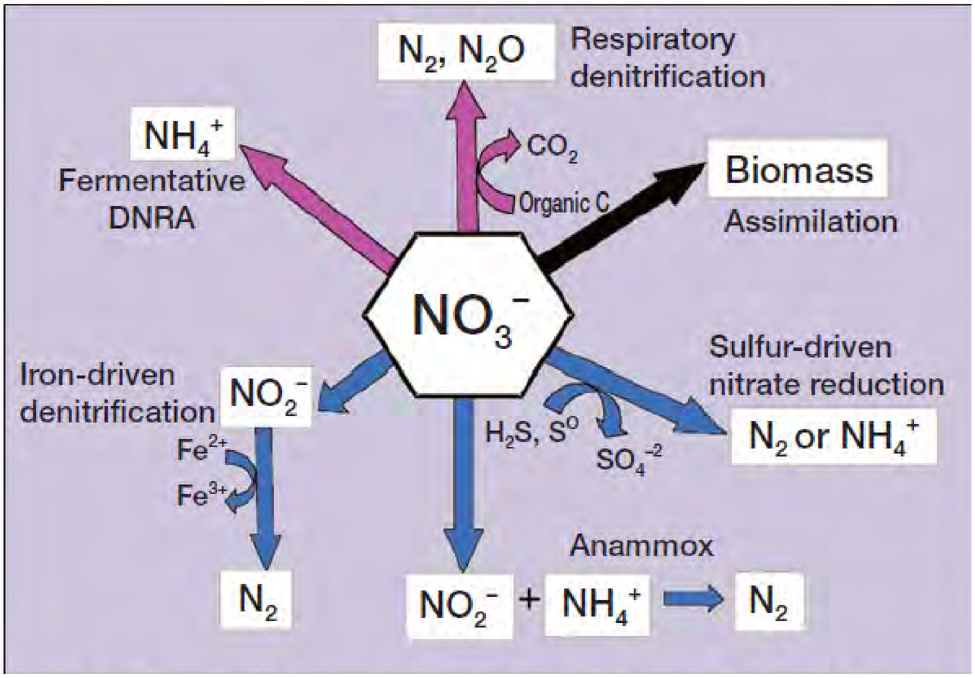


Figure 2. Conceptual diagram of nitrate removal pathways identified by Burgin and Hamilton (2007). Blue arrows denote autotrophic pathways, while purple arrows denote heterotrophic pathways.

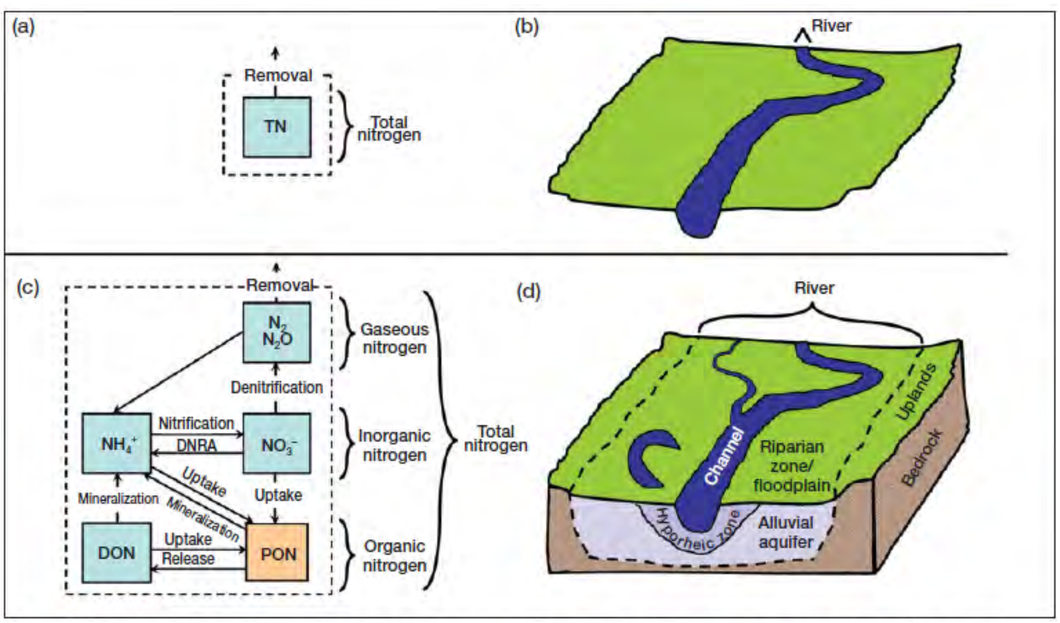


Figure 3. Existing river- network models typically describe one-way TN flux (a) from simple river channels (b). Future models will include more complicated N cycling (c) in both channel and off-channel ecosystem components (d). DON= dissolved organic N, PON = particulate organic N. Reprinted from Helton et al. (2011)

Research studies from Minnesota

Studies in Minnesota have demonstrated the importance of riparian zones and other wetted areas beyond the stream channel itself for impacting downstream N transport. We will briefly discuss their results here to illustrate the complexities of N transport in streams and rivers. Triska et al. (2007) did extensive testing of surface and groundwater of the Shingobee River (second order stream) near the origin of the Mississippi River. The Shingobee watershed is a mix of wetlands, lakes, and intermittently grazed pastures. They found that DIN in the hillslope groundwater (ridge to bank side riparian) and alluvial riparian groundwater was reduced before reaching the river itself especially during summer months. In the hyporheic zone and stream itself, DIN removal was controlled by temperature which resulted in more DIN removal during the summer than winter. Triska et al. (2007) found that watershed retention of DIN during summer was effective given the current land use of the watershed and complex aquatic and riparian features that currently exist. They stated that more intensive land use such as row crops in the watershed would result in decreased NO_3-N retention efficiency and increased loading to surface waters. Most of this chapter will focus on instream transport, but it is important to consider that DIN can be processed before it enters a stream in groundwater and riparian areas. These areas can have a combination of low dissolved oxygen and abundant organic carbon which are ideal for denitrification (See groundwater chapter).

Ditch systems are often relatively simple systems by design and complexity of existing simple models may be adequate to represent these systems. Magner et al. (2004, 2012) found that channels in headwater streams and ditches have been entrenched in the Blue Earth River Basin. They found that highest concentration of NO_X-N occurred in May and June. They also found that the 1.02-2.0 year peak flows have increased 25% to 206% over the past 25 years which certainly contributes to increased loading during high flows. Tile drainage allows nitrate to enter the streams directly without access to the riparian or hyporheic zone which limits N losses. Once the water is in the entrenched stream, it is isolated from the riparian zone which could remove N (Figure 4). The multitude of factors discussed above help illustrate why watersheds with extensive ditching efficiently transport N downstream during wet periods.

Initial findings from altered ditches are promising for removing TN in ditch networks. Large scale networks of altered ditches are not currently available to monitor in Minnesota to determine the total collective impacts of implementing widespread ditch alterations. Two-stage ditches are designed to have floodplain “benches” within the ditch that could potentially increase N removal in ditch systems (Ward et al., 2004; Magner, et al. 2010; Figure 5). Anderson (2008 as cited in Magner 2012) sampled Judicial Ditch #8 in central Minnesota since it had been widened to protect a downstream bridge. The ditch demonstrated the third highest qualitative habitat evaluation index score and some of the lowest values of N (nitrite + nitrate), total phosphorus, and total suspended solids of all the channelized streams surveyed in 2003 in the Minnesota River Basin by the MPCA.

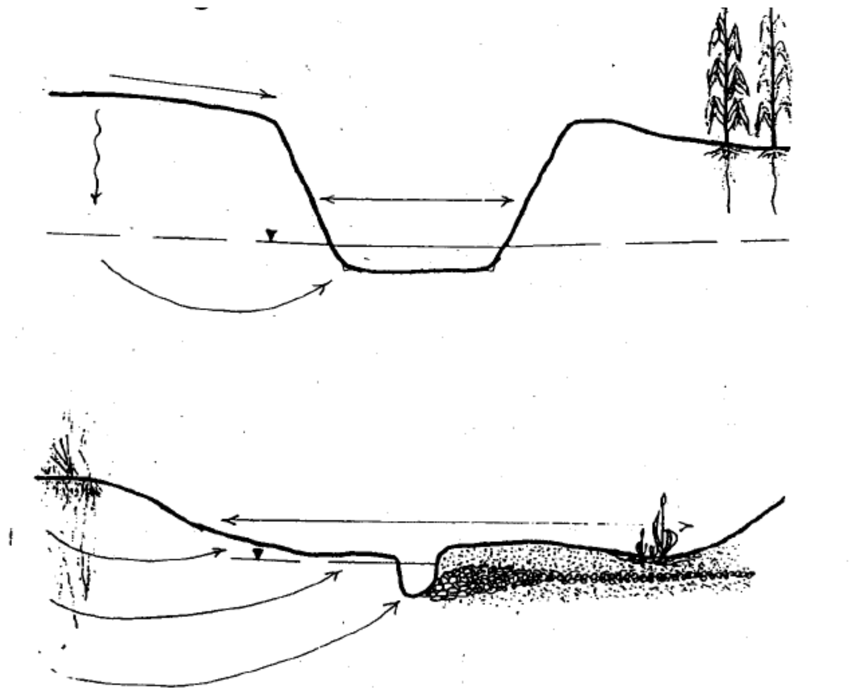


Figure 4. Cross section of trapezoidal ditch (top) and natural stream (bottom). Reprinted from Magner (2001).

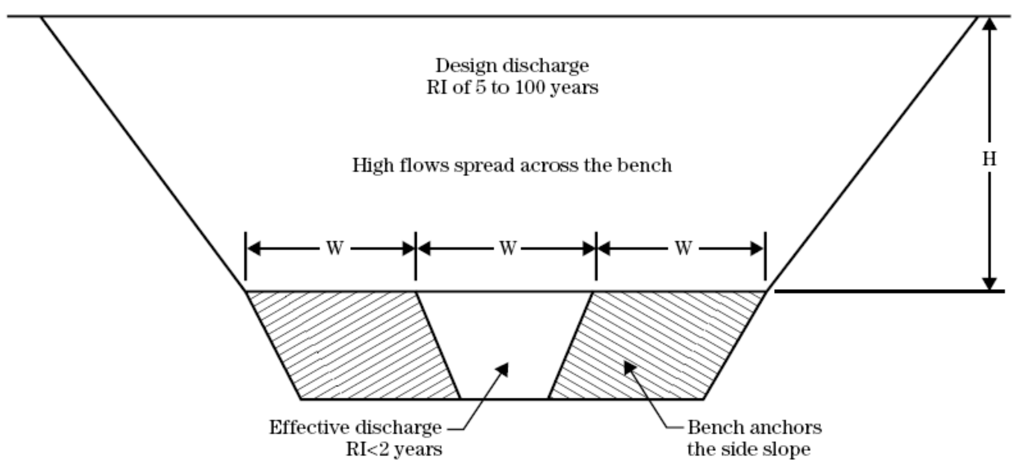


Figure 5. Two-stage ditch geometry illustrating benches not found in typical trapezoidal ditches (Source: USDA NRCS).

Natural headwater streams such as the Shingobee system discussed earlier have greater access to the floodplain and ability to reduce N loading. Magner (2001) found that natural first order streams in the Chippewa River Basin of Minnesota provide both hydrologic and N attenuation compared to trapezoidal ditches. A natural stream maintained a stable bed and bank that was 2-4 times wider than two classic ditch systems that were monitored. NO_X-N concentrations in the ditches were 2.5 mg/L compared to 0.25 mg/L monitored in the natural stream.

Applied modeling of nitrogen transport in streams

The amount of N lost in a given stream reach is influenced by a multitude of factors. Alexander et al. (2009) used a dynamic stream transport model to estimate denitrification based on streamflow, temperature and nitrate concentration. This model was calibrated on monitoring data from 300 measured values from a variety of U.S. streams. The model was then used to develop monthly nitrate budgets for Sugar Creek, an agricultural watershed on the Illinois/Indiana border and the North Nashua River a forested watershed with some urban areas in Massachusetts. Key findings are summarized from a portion of the abstract from the Alexander et al. (2009) paper:

> "Results indicate that the removal efficiency of streams, as measured by the percentage of the stream nitrate flux removed via denitrification per unit length of channel, is appreciably reduced during months with high discharge and nitrate flux and increases during months of low-discharge and flux. Biogeochemical factors, including land use, nitrate inputs, and stream concentrations, are a major control on reach-scale denitrification, evidenced by the disproportionately lower nitrate removal efficiency in streams of the highly nitrate-enriched watershed as compared with that in similarly sized streams in the less nitrate-enriched watershed. Sensitivity analyses reveal that these important biogeochemical factors and physical hydrological factors contribute nearly equally to seasonal and stream-size related variations in the percentage of the stream nitrate flux removed in each watershed."

Factors found to influence nitrate transport by Alexander et al. (2009) will be discussed in terms of the spatial and temporal patterns found in Minnesota (Figure 6). They found that the reaction rate constant "k" (per day) for denitrification is negatively correlated with nitrate concentration, streamflow and depth. When all three of these factors are relatively high such as during wet springs in southern Minnesota, little NO_X-N is lost. Conversely, during late summer when all three of these factors are relatively low, much NO_X-N is lost or converted to organic N.

Mulholland et al. (2008, 2009, as cited in Alexander 2009) predicted the percentage of stream loads to the outlet of two distinct watersheds during May. Modeled percentage of nitrate delivered from the agricultural watershed Sugar Creek is a minimum of 75% from headwaters and increases with proximity to the watershed outlet (Figure 7). Predicted delivery of nitrate loads from the Nashua River, which is primarily a forested watershed with some urban areas, is considerably lower for streams throughout the watershed than that predicted for Sugar Creek. Alexander et al. (2009) also plotted percentage removal by month for the same rivers (Figure 8). Removal rates peaked from August to October. Modeled removal rates in Sugar Creek were approximately 2% from March through June and approximately 5% in July. Even though these watersheds are not located in Minnesota, they serve as an example for watersheds with similar land use and stream networks in this state.

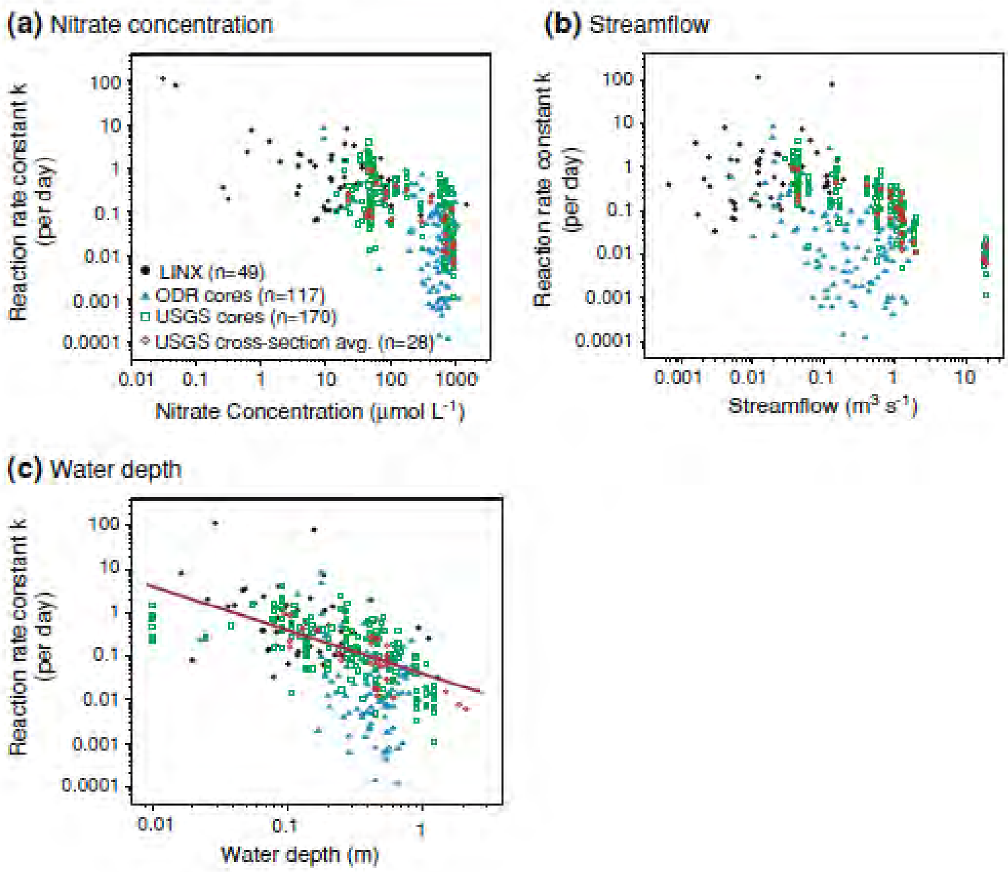


Figure 6. Observed measures of the reaction rate constant k for the separate field data sets, plotted as a function of nitrate concentration(a), streamflow (b), and water depth (c). The field datasets include USGS, LINX, and ODR. The slope of the line in (c) is expected for a constant mass-transfer rate, V_f. Figure reprinted from Alexander et al. (2009).

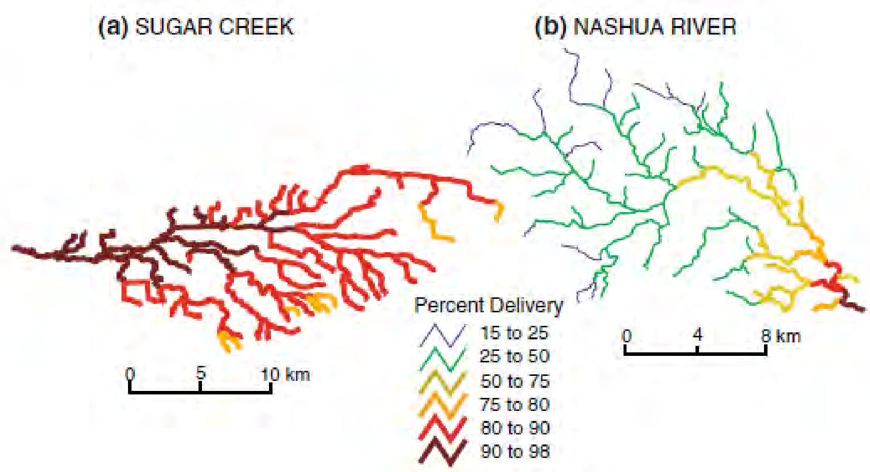


Figure 7. Modeled percentages of nitrate loads delivered to the outlets of Sugar Creek (a) and Nashua River (b) during May. Figure reprinted from Alexander et al. (2009).

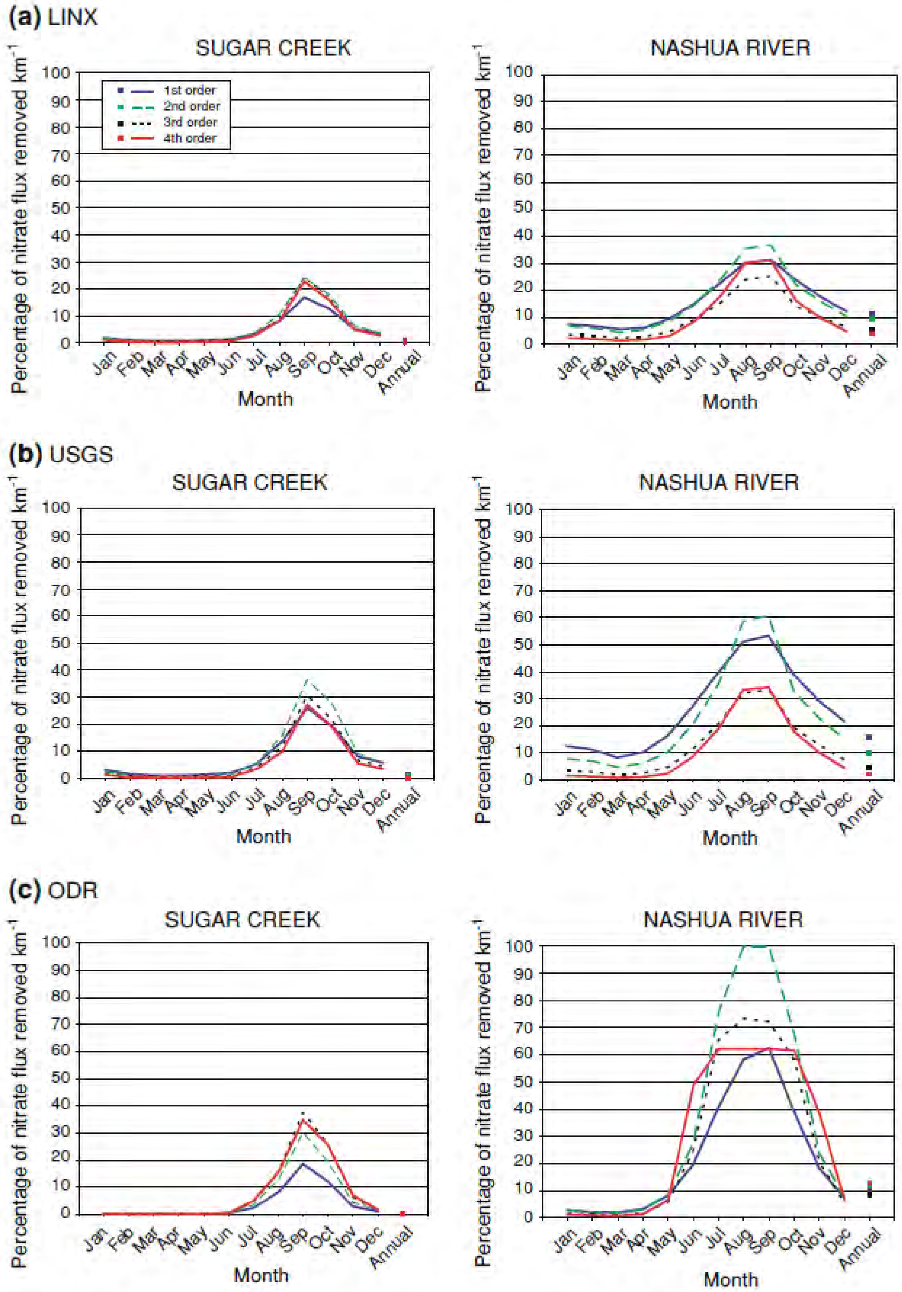


Figure 8. Median percentage of in-stream nitrate flux removed per kilometer of stream channel in streams of the Sugar Creek and Nashua River watersheds by strahler stream order, reported for the reaction rate constant regressions for the field datasets: (a) LINX, (b) USGS, and (c) ODR. Figure reprinted from Alexander et al. (2009).

Further understanding of N transport will be important for targeting approaches that maximize N processing in stream networks to minimize downstream transport of N. Current models may not characterize all N pathways or lateral exchanges but they do help users to determine primary factors that influence downstream movement of N.

SPARROW: transport from SPARROW watersheds to state border

This short section will focus on outputs derived from the Spatially Referenced Regressions on Watershed attributes (SPARROW) Decision Support System (www.cida.usgs.gov/sparrow/). This web based tool provides access to national, regional, and basin-wide SPARROW models. We will focus on the TN model for the Great Lakes, Ohio, Upper Mississippi, and Souris-Red-Rainy Region - 2002 (www.cida.usgs.gov/sparrow/map.jsp?model=41). Users can view maps of modeled water-quality conditions (loads, yields, concentrations, incremental yields) by stream reach and catchment. Percent transport estimates by watershed to a user specified downstream receiving water such as a reservoir or an estuary are useful outputs from this tool. Finally, the tool can be used to evaluate management source-reduction scenarios by reducing inputs from TN sources as specified by the user.

One of the advantages of SPARROW is its ability to estimate downstream delivery fraction of TN from a large contributing area to a user specified downstream reach. The SPARROW outputs presented later in this section represent the fraction of TN loads from the outlet of SPARROW watersheds that are delivered to a specified downstream reach in a river. These losses are a relatively small percentage of TN losses that occur across the land/water continuum of a given watershed (Figure 9). Additional TN is lost in the surface waters upstream of the SPARROW watershed outlets. Quantifying the precise losses of TN in all surface waters within a SPARROW watershed is not possible since the stream reach file that is the base stream network of the SPARROW model does not include all of the surface waters in Minnesota directly.

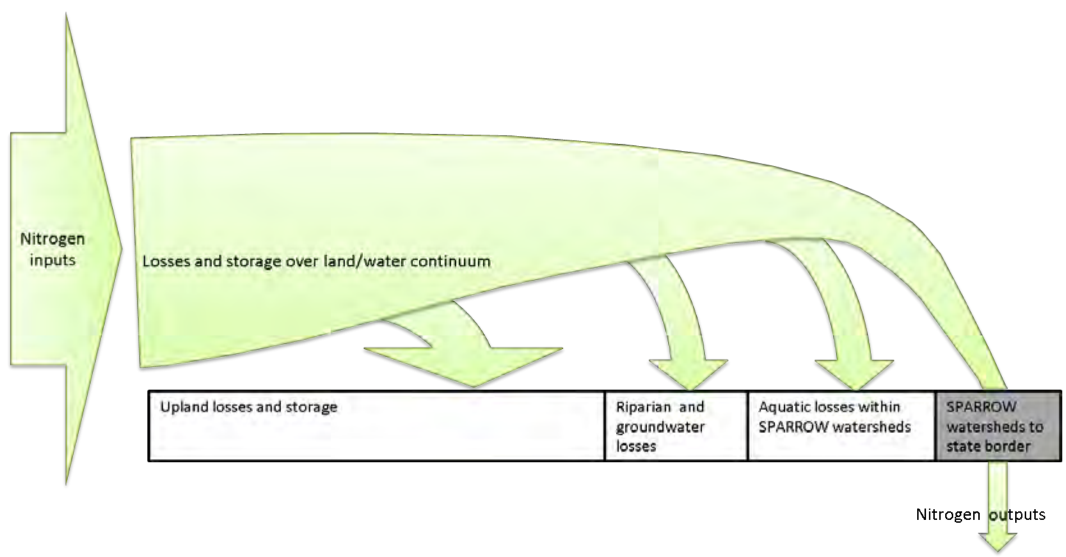


Figure 9. Generalized losses of TN inputs across the land/water continuum of a river basin. Note that the distribution of losses is highly variable depending on a given watershed in Minnesota and the magnitude of individual losses are not drawn to a specified scale here.

The Mississippi River at Minnesota/Iowa (MN/IA) border is the largest river in terms of contributing watershed area, annual TN load and average flow in the state of Minnesota. Based on estimated delivery fractions from SPARROW, the majority of TN loads at the outlets of the SPARROW watersheds in the Mississippi River Basin are delivered to the MN/IA border (Figure 10). The contributing watersheds with the highest delivery fractions are direct tributaries to the Mississippi River downstream of the Twin Cities Metro Area. In most of the remainder of the contributing watershed, greater than 80% of TN loads from the SPARROW watersheds are delivered to the state border. A few SPARROW watersheds have lower delivery fractions due to in-stream lakes/reservoirs [i.e. Cannon River headwaters, Mississippi River headwaters, Minnesota River headwaters, and Chippewa River (Wisconsin) headwaters]. Since the majority of loads loaded to reaches in the Mississippi River Basin are delivered to the MN/IA border, local TN loads to reaches within the SPARROW watersheds in the basin are the most important driver to the total load of the Mississippi River.

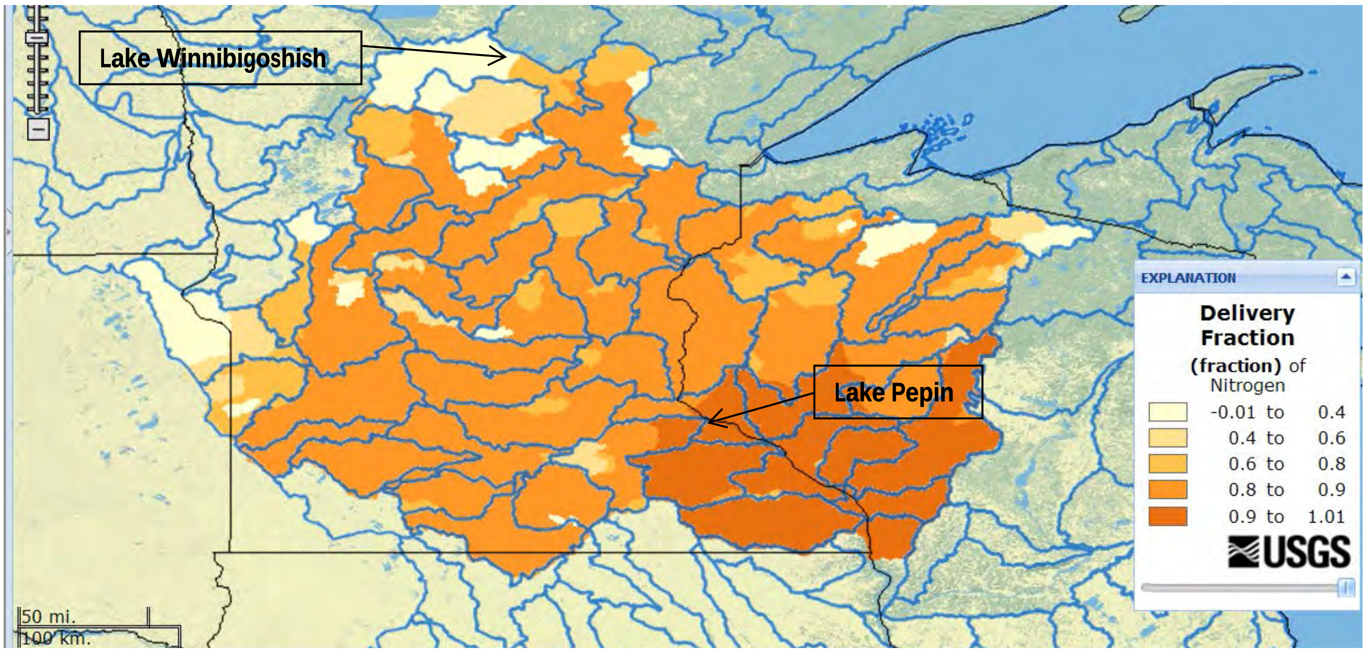


Figure 10. Annual estimated downstream delivery fraction of TN from outlets of SPARROW watersheds to the Mississippi River at the Minnesota/Iowa border.

Estimated delivery of TN from SPARROW watershed outlets in the Red River of the North Basin is quite variable. Model results indicate that 54% of the modeled SPARROW watersheds in the Red River Basin (including North Dakota watersheds) deliver more than 90% of their outlet loads to the Red River of the North at Pembina at the U.S./Canada border (Figure 11). Many of these reaches are direct tributaries or tributaries to direct tributaries to the Red River of the North. There are few to no lakes or reservoirs on these stream reaches. Certain areas of the Red River Basin have lakes or reservoirs downstream of SPARROW watershed outlets. The combination of distance from Pembina and lakes and reservoirs on some reaches results in 25% of the contributing watersheds delivering less than 20% of their TN load to the international border. Reaches near upper and lower Red Lake and the city of Detroit Lakes are examples of reaches that deliver a small fraction of their TN loads to the Red River at Pembina, North Dakota.

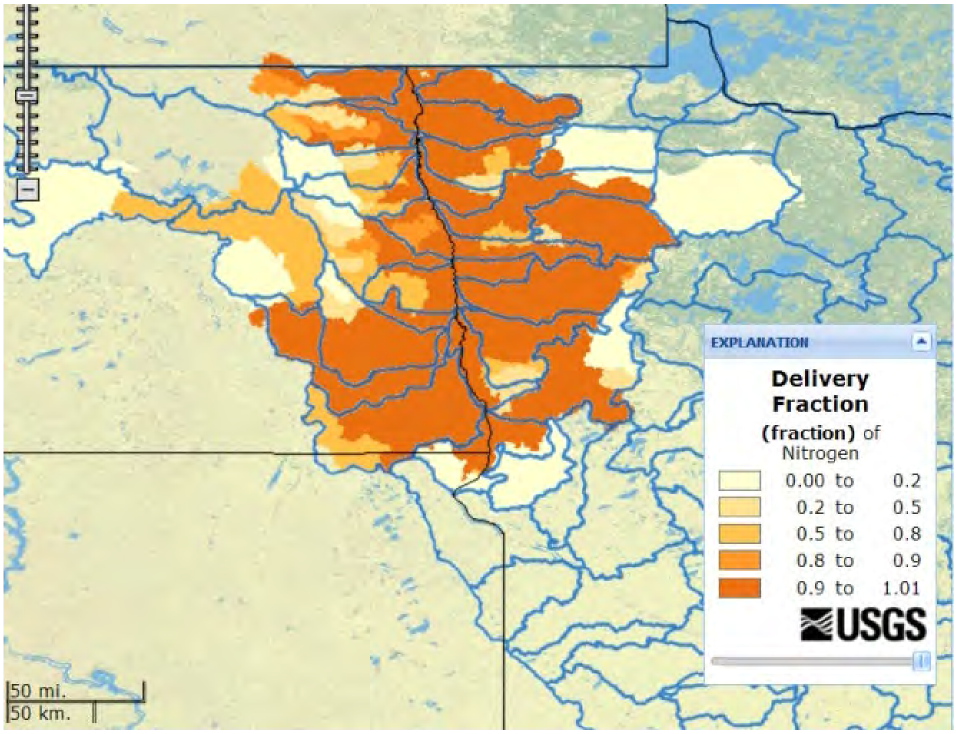


Figure 11. Annual estimated downstream delivery fraction of TN from outlets of SPARROW watersheds to the River of the North at the US/Canada border.

Monitoring results from Minnesota rivers and streams

Seasonality of N delivery has already been discussed elsewhere in this report and this chapter. The Rush River of central Minnesota is a predominately agricultural watershed with extensive drain tiles to improve production of row crops. Stream samples were collected at road crossings throughout the watershed on June 4, 2003, by Sibley Soil and Water Conservation District (Matteson, S., personal communication). Flow at the outlet of watershed was 161 cfs which was a 79th percentile flow (based on monitoring from April through September). Streamflow was at 1,150 cfs two weeks prior to the sampling event. Drain tiles were flowing at low to moderate levels on this date according to field observations, and most stream samples that were greater than 20 mg/L NO_X-N. The relatively consistent downstream concentration of NO_X-N implies conservative transport of nitrate during early June of 2003 (Figure 12). The only stations below 10 mg/L were downstream of the lakes in the watershed. Clearly the ability of Rush River watershed to remove high inputs of nitrates was overwhelmed on this date. Without streamflow data at all of the sampling stations and a comprehensive sampling network of sources such as tile outlets and groundwater, a mass balance calculation cannot be completed to estimate percentage of N lost in streams for this watershed for one day or season. The relatively high transport rate of nitrate in the Rush River during late spring is similar to the modeling results for the Sugar River discussed earlier in this chapter [Mulholland et al. (2008, 2009) as cited in Alexander et al. (2009)].

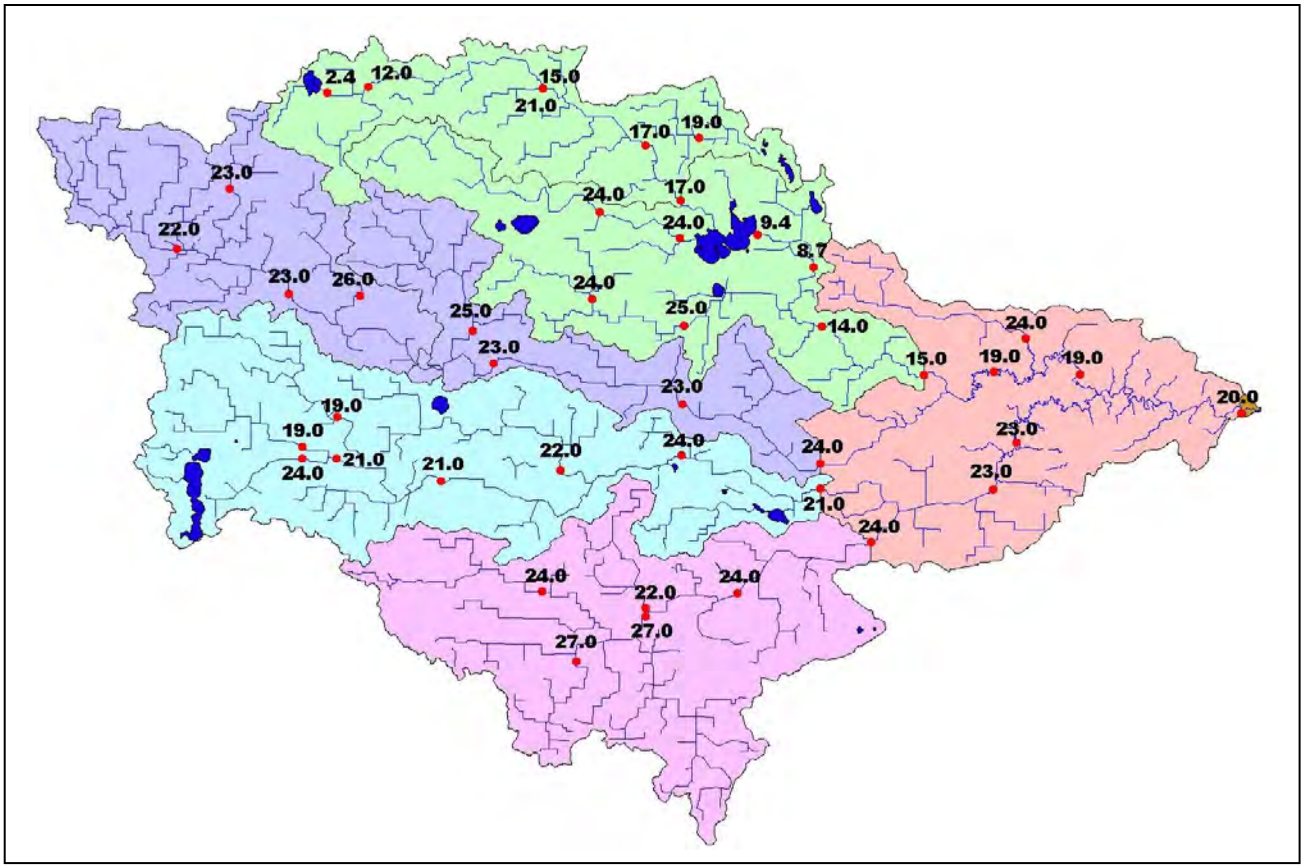


Figure 12. Nitrate (NO_X-N) concentration in mg N /L of streams throughout the Rush River watershed monitored at bridge crossing on June 4th 2003.

Transport of NO_X-N and TN in the Minnesota River from La Qui Parle (River Mile 284) to St. Peter (river mile 89.7) is relatively conservative based on annual loads calculated from monitoring collected in 2009 (Table 3). This is consistent with previous results from a nitrate budget on a shorter reach of the Minnesota River from 2000-2008 (Matteson, S., Unpublished data, Table 4, Figure 13). Given that the Minnesota River is a relatively large river with seasonally high N loads, it should be expected that losses in the Minnesota River itself are relatively small on an annual basis. To further explain the factors that minimize transport losses, the average annual hydrograph of the Minnesota River needs to be examined. The five months from March to July account for 75% of the average water budget of the Minnesota River at Mankato based U.S. Geological Survey (USGS) monitoring from 1903-2011. NO_x-N and consequently TN concentrations are also elevated during this time of year so the load is even greater than 75% of the annual budget from March to July. Recent data suggest that May-July flows are increasing in the Minnesota River (Figure 14) which could translate into higher annual loads if concentrations remain stable or increase in these months.

Table 3. Annual TN mass balances for two reaches (A and B) of the Minnesota River for 2009 based on calculated loads for tributary watershed and mainstem stations. Water volume and catchment area are included for water balance and total area of upstream stations respectively.

A) Upstream station and tribs	Mass (kg)	Mass (lbs)	Vol (acre ft)	Catchment (acres)
Minnesota River nr Lac Qui Parle, MN	4,707,520	10,378,305	1,210,000	2,592,000
Yellow Medicine R. Granite Falls, MN	366,483	807,957	68,029	424,960
Chippewa River nr Milan, MN40	1,670,465	3,682,745	416,151	1,203,200
Hawk Creek nr Granite Falls, CR52	1,081,695	2,384,728	89,444	323,082
Redwood R. nr Redwood Falls, MN	630,325	1,389,629	75,237	402,560
Total upstream: Minn. R. at Lac Qui Parle plus tributaries	8,456,488	**18,643,364**	1,858,861	4,945,802
Downstream, Minnesota River at Morton, MN	8,652,176	**19,074,782**	1,750,660	5,740,800
B) Upstream station and tribs	**Mass (kg)**	**Mass (lbs)**	**Vol (acre ft)**	**Catchment (acres)**
Minnesota River at Judson, CSAH42	9,660,620	21,298,021	2,165,170	7,216,237
Le Sueur River nr Rapidan, MN66	2,152,120	4,744,613	203,655	710,400
Blue Earth River nr Rapidan, CSAH34	3,432,217	7,566,743	398,540	987,029
Watonwan R. nr Garden City, CSAH13	930,254	2,050,859	110,565	544,640
Mankato WWTP*	139,434	307,400	6,209	NA
Total upstream: Minn. R. at Judson plus tributaries	16,175,211	**35,967,636**	2,884,139	9,458,306
Downstream: Minnesota River at St. Peter, MN22	17,027,940	**37,540,182**	2,799,830	9,661,384

***** Estimate based on limited monitoring data

Table 4. Average annual nitrate and water balance for Minnesota River from Judson (river mile 120) to St. Peter (river mile 89.7). The Blue Earth River (river mile 12.0) and LeSueur River (river mile 0.3) are the only monitoring inputs or tributaries included in this mass balance. (S. Matteson, unpublished)

2000-2008 Flow (cf) and Constituent Loads (tons)

Parameter	BLU 12.0 + LES 1.3	MIN 120.0	Total	MIN 89.7	% Difference
Acres	2,265,670	7,186,921	9,452,591	9,634,760	98.11%
Flow	415,747,996,215	562,552,030,275	978,300,026,489	1,000,813,294,620	97.75%
TSS	4,155,740	2,390,131	6,545,871	6,889,747	95.01%
NO3-N	136,572	95,125	231,697	232,139	99.81%
TP	5,537	4,901	10,438	10,606	98.41%
PO4	1,563	1,890	3,453	3,275	105.44%

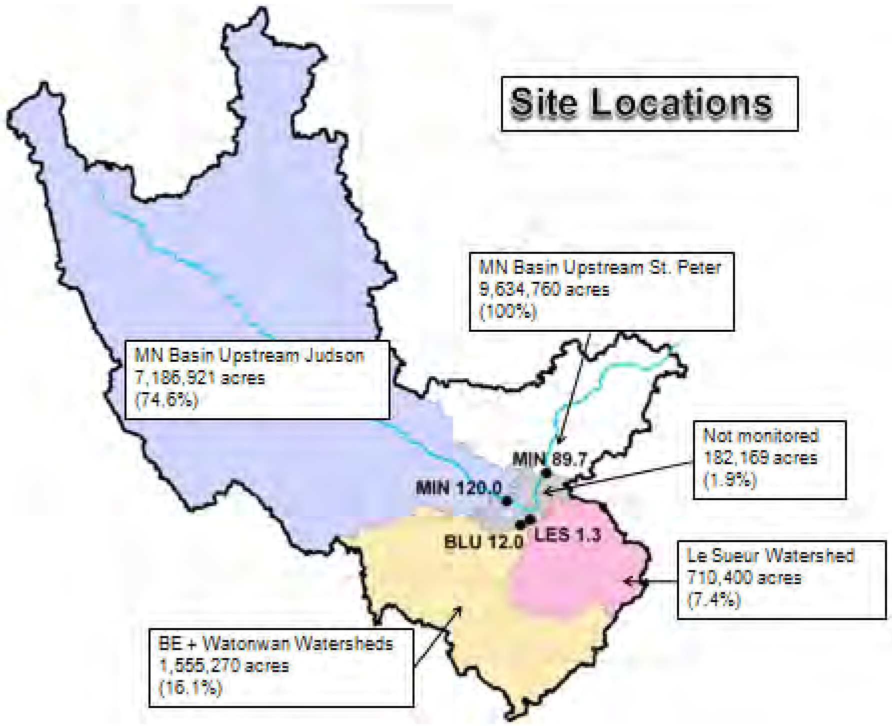


Figure 13. Monitoring locations on Minnesota River and tributaries used to calculate a nitrate mass balance from 2000-2008.

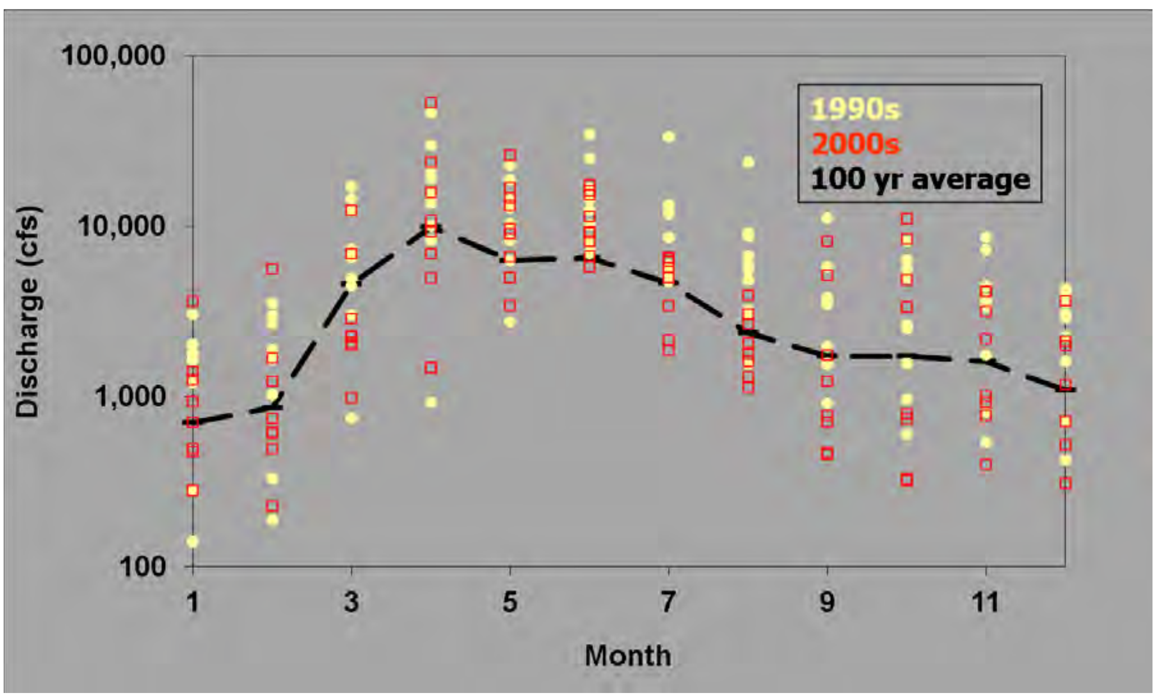


Figure 14. Average monthly discharge of the Minnesota River at Mankato for 1903-2008. Individual symbols represent monthly average for a given year in the past two decades.

The Mississippi River Basin upstream of Anoka has an extensive monitoring network similar to the Minnesota River Basin. Mass balances for TN during 2009 were examined for the Mississippi River to determine transport losses. Approximately 90% of the estimated TN loaded from the Mississippi River at Aitkin and other tributaries was found at the downstream monitoring site near Royalton. Eight percent of the watershed upstream of Royalton was not accounted for in this approach so losses of TN may be greater than 10%. These results are based on calculated loads for tributaries and Mississippi River stations designed for estimating loads. Transport in this reach of the Mississippi River may not be completely conservative, but more monitoring is needed to confirm the transport losses observed in 2009. The flow-weighted mean concentration of NOx-N for the Mississippi River and tributaries ranged from 0.09 to 0.76 mg/L. These concentrations are certainly lower than the Minnesota River where high NO_x-N concentrations/loads overwhelm removal via denitrification during higher flows when a large portion of the load is transported downstream. Mass balance results from the Mississippi River from Sauk Rapids to Anoka indicate conservative transport (near 100% transport), but missing tributaries such as the Elk River make this evaluation difficult. The flow weighted mean of NO_x-N increases from 0.31 mg/L at Sauk Rapids to 1.2 mg/L at Anoka primarily due to tributaries like the south fork of the Crow River. This reach of the Mississippi River is simply receiving a large load of TN from tributaries near the end of the reach where there is limited travel time to remove any meaningful amount of TN.

Mississippi River from the Twin Cities to Minnesota/Iowa border

Nitrogen transport in the Mississippi River downstream of the Minnesota River confluence to the MN/IA border (Lower Miss) has been monitored and studied for N transport in rivers as much as anywhere in the state. Metropolitan Council Environmental Services (MCES) and the Long Term Resources Monitoring Program (LTRMP) of the USGS have maintained monitoring programs for at least 20 years to collect water quality samples on the Lower Miss. Wasley (2000) assembled much of the available N data up to 1997 for the Lower Miss and its tributaries and found that TN was generally conservative, meaning that a relatively small percentage of N was lost during transport down the river. Houser and Richardson (2010) summarized transport, processing and impact of phosphorus, and N on the Lower Miss. This paper adds much detail to what was previously known about the processing of N within the river compared to the original mass balance budgets that were completed prior to their summary work. Questions regarding assimilation, storage and loss of N in the Lower Miss still remain after many years of study, but the original findings that the majority of N is transported downstream have been confirmed. The complex and dynamic biology and hydrology of the Lower Miss greatly influence the transport of N in this system. Bruesewitz et al. 2006 found that zebra mussels may increase denitrification near sediments via coupled nitrification and denitrification of high NH_X-N mussel wastes. Dynamic levels of phytoplankton and submersed aquatic plants certainly influence N spiraling in the river, but their overall impact on movement of TN downstream has not been fully quantified. Detailed pathways have been monitored on backwater lakes that will be discussed later in this section.

A recent paper from Strauss et al. (2011) utilizes the extensive research on the Mississippi River to estimate N losses from a 2,400 km reach of the Mississippi River from Minneapolis, Minnesota to the Atchafalaya diversion in Louisiana (Figures 15 - 18). The entire length of the Mississippi River downstream of Minneapolis has been classified for habitat type. Denitrification rates monitored in Navigational Pool 8 by habitat were used to estimate TN removal rates throughout the Mississippi River. They estimated that 9.5% of TN load is lost through denitrification from Minneapolis to the Atchafalaya Diversion. Losses and assimilation are higher in upper portions of the river such as Minnesota’s reach where impoundments and backwaters elevate TN losses. The percentage of backwaters and impounded areas drop dramatically after Pool 13 resulting is less processing of TN inputs (Figure 14). Unfortunately, the TN loads to the Mississippi River increase downstream of Pool 13 due to large tributaries: Des Moines River, Illinois River, Missouri River, and Ohio Rivers (Figure 16).

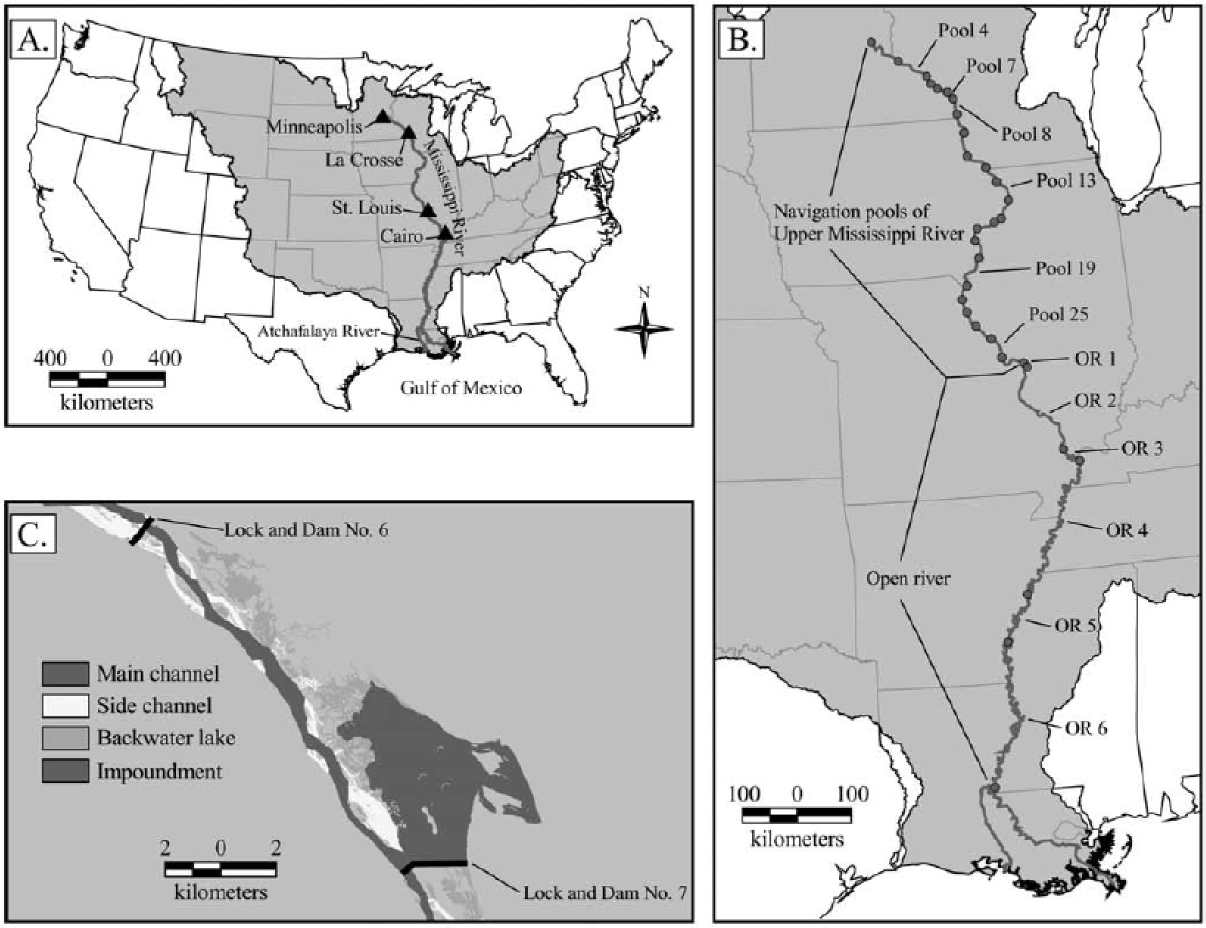


Figure 15. The Mississippi River watershed (A) covers 41% of the conterminous United States (shaded area on map). The two main reaches analyzed in this study (B) were the reach containing the navigation pools (Minneapolis, Minnesota to St. Louis, Missouri) and the open river reach (St. Louis, Missouri to the Atchafalaya River diversion in Louisiana). The circles located on the river are the nodes of the 30 sub-reaches used. Select sub-reaches of the northern reach and all the open river (OR) reaches are labelled. Navigation Pool 7 (C) is a representative example of the aquatic habitat spatial data used to extrapolate N loss in the river. Reprinted from Strauss et al. (2011).

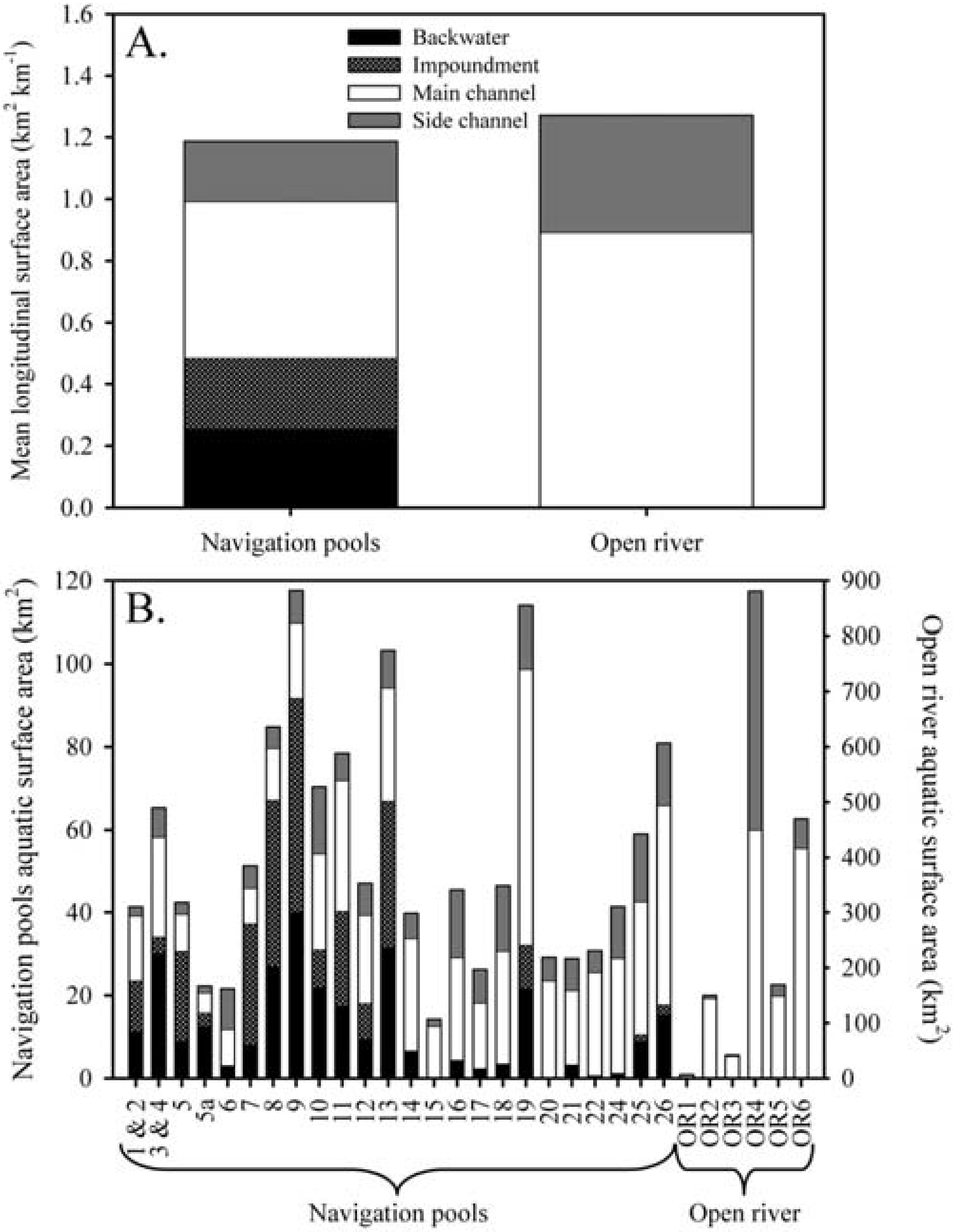


Figure 16. Mean longitudinal surface area (A) of the four aquatic habitats in the two main reaches of the Mississippi River. Total surface area (B) of the aquatic habitats in all of the navigation pool reaches of the Mississippi River north of St. Louis and the open river south of St. Louis to the Atchafalaya River diversion in Louisiana. Reprinted from Strauss et al. (2011).

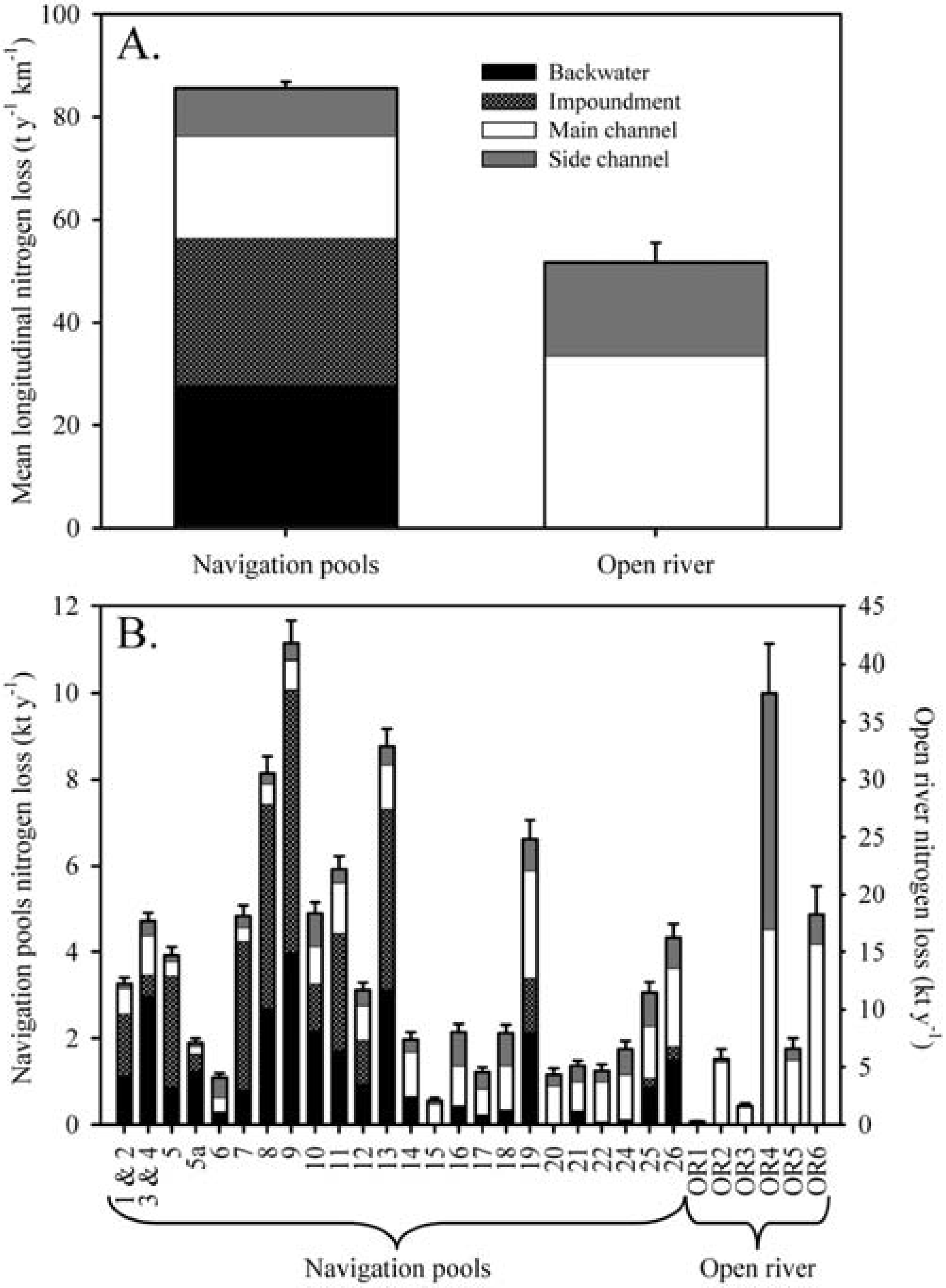


Figure 17. Mean longitudinal N (N) loss (A) within each of the four aquatic habitats in the two main reaches of the Mississippi River. Total N loss (B) in the aquatic habitats of the navigation pool reaches and the open river. Error bars = +1 standard error of total N loss. Reprinted from Strauss et al. (2011).

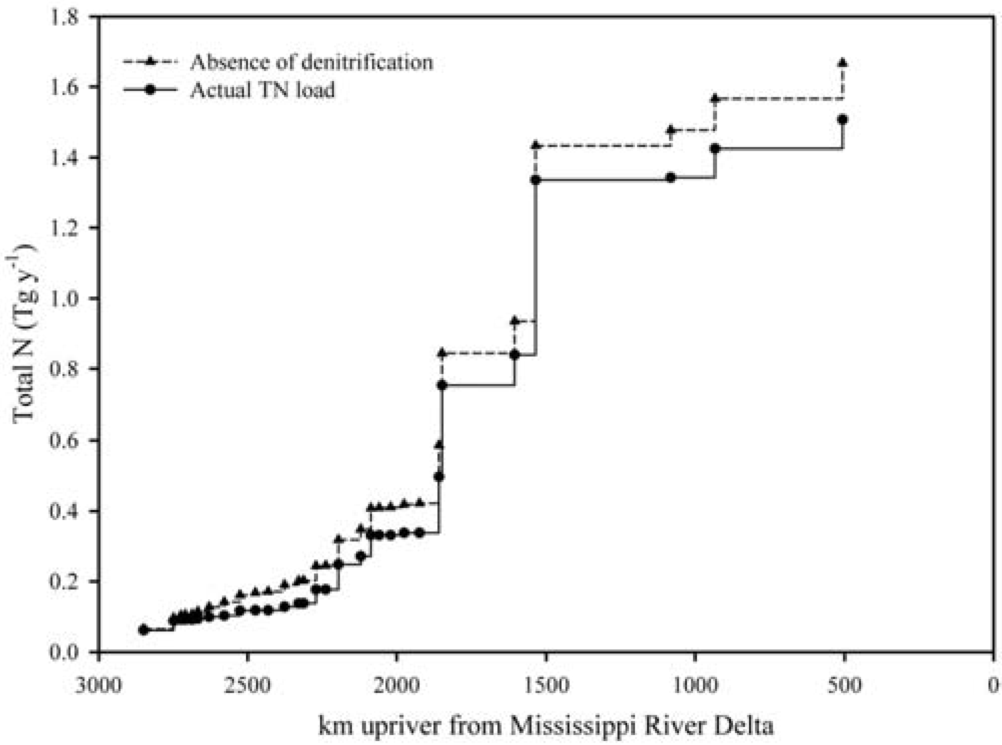


Figure 18. Total nitrogen (N) flux in the Mississippi River in the presence and absence of denitrification. The vertical distance between the two lines depicts the cumulative loss of N from denitrification. The symbols on the lines show the location of the 30 sub-reach nodes used for analysis. Reprinted from Strauss et al. (2011).

Mississippi River Pools 2-4

Mass balance results and model outputs for shorter segments of the Lower Miss are useful to compare to other approaches such as SPARROW or the extrapolation approach by Strauss et al. (2011). Recent models results and load calculations confirm that the majority of annual TN loads to the Lower Miss are transported downstream. The MPCA and their consultant LimnoTech Inc. (LTI) combined data from MCES, LTRMP and other sources to develop a 3-dimentional model of the Mississippi River from Pool 2 through Pool 4 including Lake Pepin (LTI 2009, Figure 19). Model results from Pools 2 to 4 and a recent mass balance budget of Lake Pepin by the author estimate that over 90% of input N loads to a given pool are transported to subsequent pools or reaches (Table 5, Table 6). Some of the same data was used for these two estimates but they are not the same method. The cumulative impacts of minor losses of N in a given reach of river will be discussed in more detail in the SPAAROW chapter of this report.

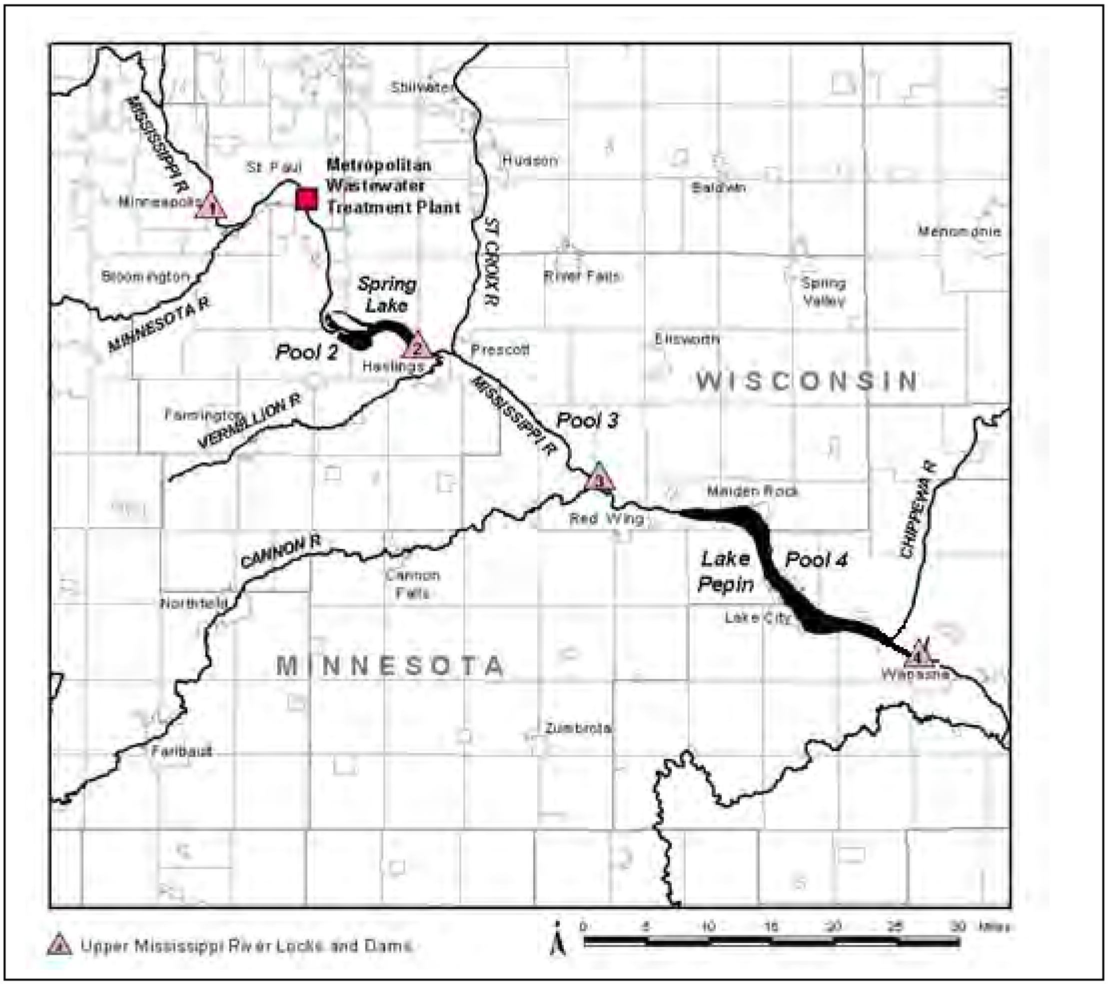


Figure 19. Navigational Pools 2 through 4 of the Mississippi River. Pools are located upstream of Lock and Dams (e.g. Pool 2 is located between Lock and Dams 1 and 2).

Table 5. Average annual TN budgets in metric tons for Pools 2-4 based on the UMRLP model from 1985-2006. Note that Lake Pepin is contained within Pool 4.

Reach	Input	Tributaries	WWTP	Total inputs	Output	Transport coefficient
Pool 4	193,004	46,213	-		223,095	0.93
Lake Pepin	210,449	572	-		198,131	0.94
Pool 3	176,417	19,842	126		193,291	0.98
Pool 2	43,207	123,721	12,668		176,437	0.98

Table 6. Average estimated monthly percentage transport of the TN and NO_X-N through Lake Pepin based on loads calculated from 1993-2009. " percent transport" = output load / input loads

	% transport	
Month	**TN**	**NO_x-N**
1	1.07	1.13
2	1.07	1.13
3	0.89	0.97
4	0.83	0.93
5	0.85	0.92
6	0.86	0.92
7	0.96	1.02
8	1.04	0.78
9	0.96	0.72
10	1.04	0.78
11	1.01	1.10
12	1.05	1.12
Average*	0.91	0.94

*Annual average is based on transport of annual loads. It is not an average of monthly averages.

Closer examination of the N load transported through Lake Pepin is useful for several aspects of river transport since Lake Pepin is fed by three large river basins (i.e. Mississippi, St. Croix, and Minnesota). Annual patterns in streamflow and N loads to Lake Pepin serve as an example for general patterns observed in the streams throughout the state. Average annual discharge (22,000 cfs = long-term average) of the Mississippi River upstream of Lake Pepin peaks in April and gradually falls until August when average flows stabilize until late March (Figure 20). Elevated flows can occur from March to October. From November to February, flows seldom exceed 40,000 cfs.

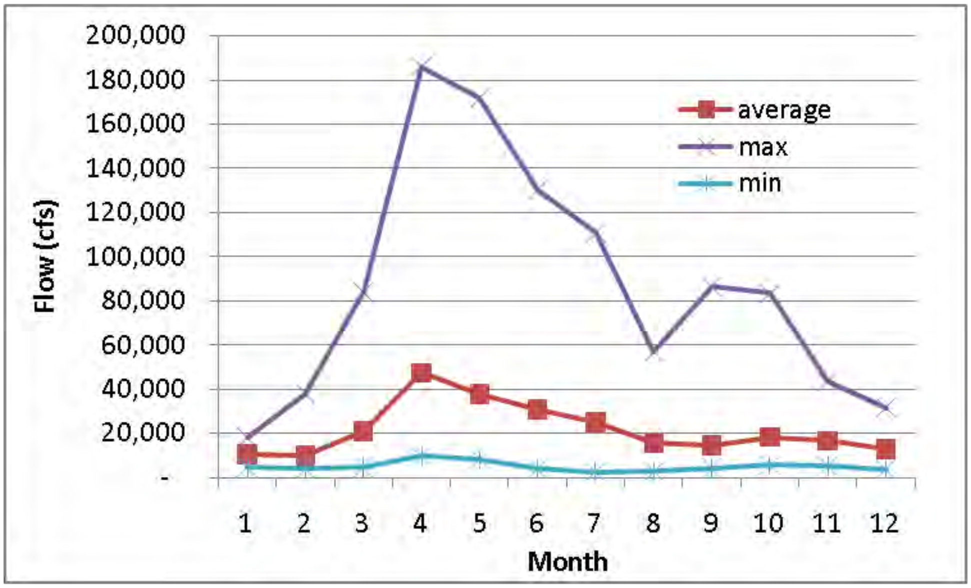


Figure 20. Average, maximum and minimum daily discharge of the Mississippi River at Prescott, Wisconsin by month from 1980-2009.

The different fractions of TN are processed differently by Lake Pepin. Residence time for Lake Pepin during summer is rather short (range 5-50 days) and less than 7 days on average during spring (Figure 21). The majority of TN entering and present in Lake Pepin is DIN which is generally conservative during most months (Table 6, Figure 22). NO_X-N transport is greater than 92% for all months except August and September when nitrate is likely transformed into organic N during late summer/early fall algal blooms when residence time is greater and NO_X-N loads are reduced from tributaries compared to spring and early summer. Riverine production of algae is significant upstream of Lake Pepin, and there is generally a peak in algal levels in upper Lake Pepin before levels decline at the deeper downstream portion of the lake. Deposition of organic N is prevalent from April to June when suspended solids loads are greatest. Lake Pepin is a trap for total suspended sediment with only 41% of average inputs exiting the lake on an annual basis (LTI 2009). Algal settling and processing in bottom sediments also complicate the spiraling of N through Lake Pepin. Algal processing is certainly important to the biology of Lake Pepin but it does not have a major impact of N transport in Lake Pepin during average conditions. On average during August, only 5% of the TN pool loaded to Lake Pepin is contained in viable algae and only 3% of the TN pool at the outlet is contained in viable algae (LTI 2009).

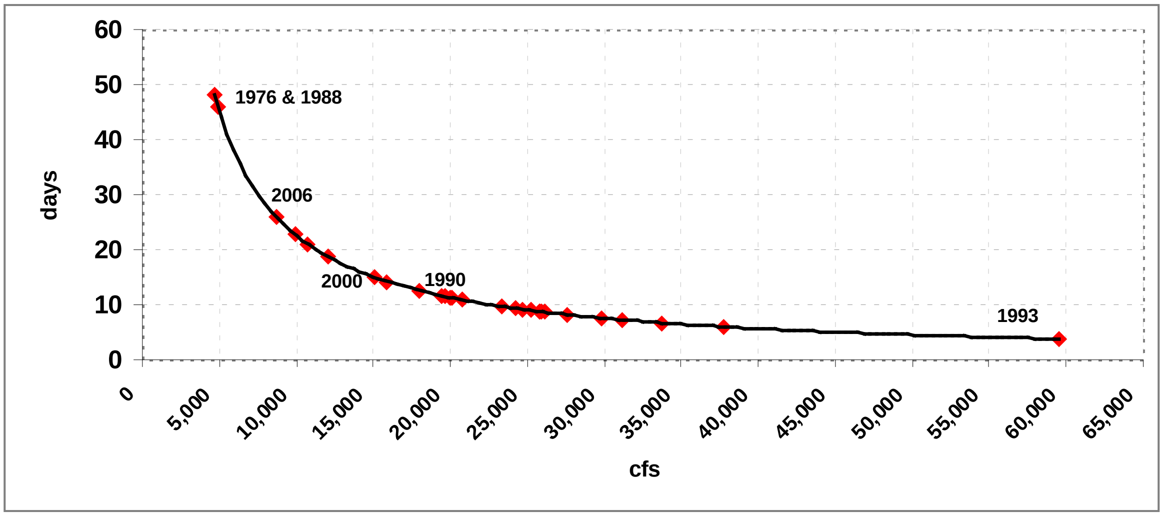


Figure 21. Estimated residence time of Lake Pepin verses mean summer (June- September) discharge of the Mississippi River at Prescott. Individual summers are identified for reference (1976=drought, 1993 = flood).

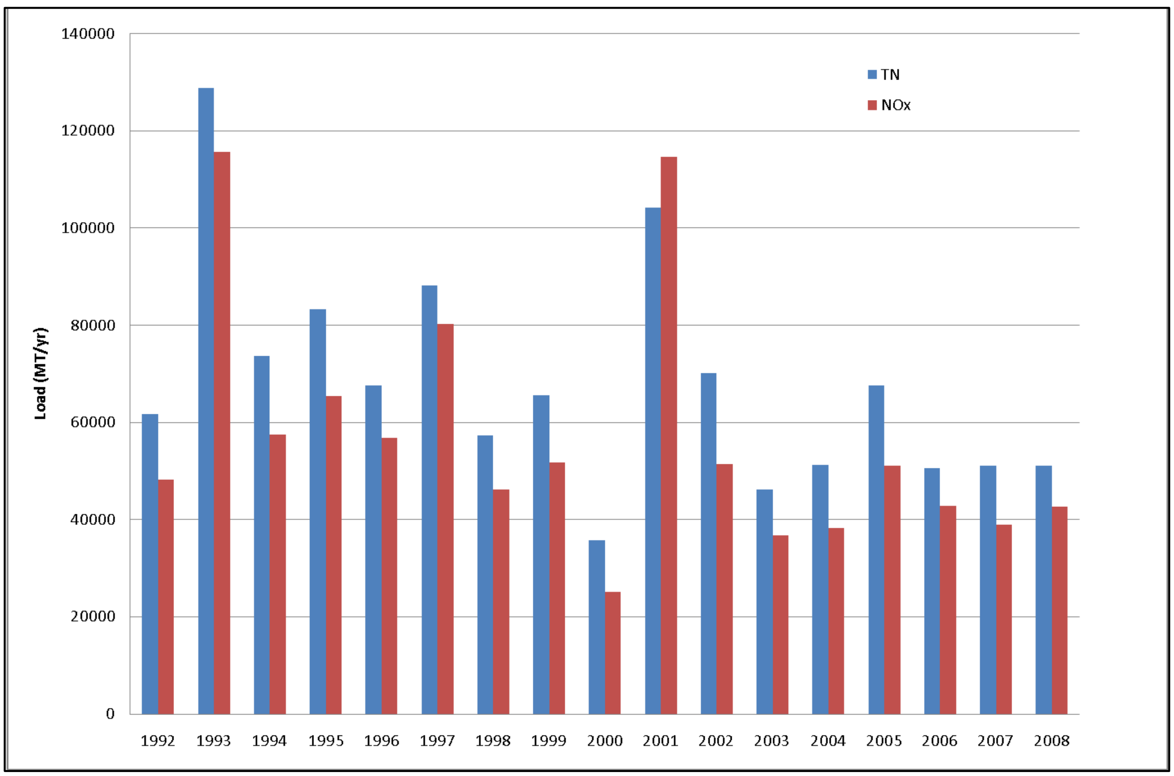


Figure 22. Average monthly load of TN and NO_X-N of the Mississippi River at the outlet of Lake Pepin from 1993-2009.

A comprehensive set of loads of the Mississippi River and its tributaries from the outlet of Lake Pepin to lower Pool 8 have not been compiled at this time to update results from Wasley (2000) or validate results from Strauss et al. (2011) and SPARROW modeling results. Loads at lower Pool 8 are greater than the outlet of Lake Pepin due to tributary loads and relatively conservative transport in this reach (Figure 23). Large tributaries to this reach include the Black and Chippewa Rivers from Wisconsin and the Zumbro and Root Rivers from Minnesota. Submersed aquatic vegetation is common in impounded areas and backwaters of the Mississippi downstream of the outlet of Lake Pepin. Average residence time of Navigational Pools 5-8 is less than two days on average (Wasley, 2000).

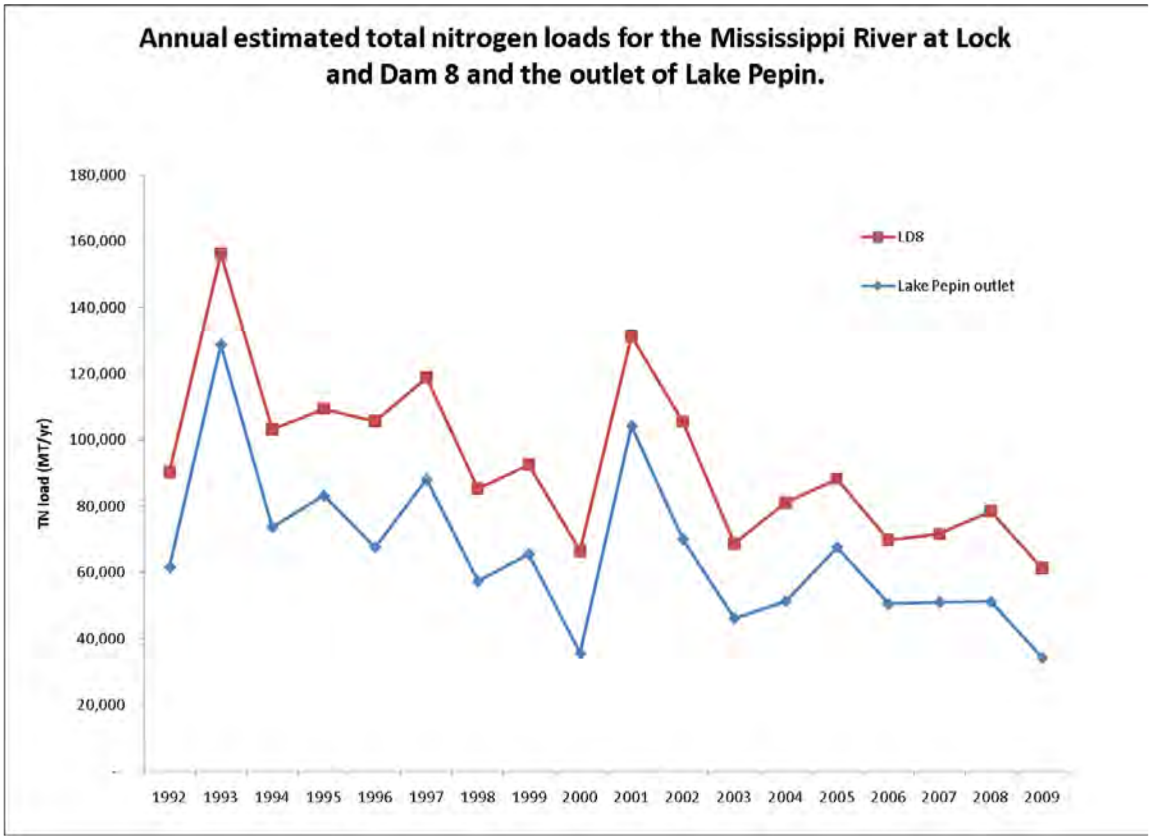


Figure 23. Annual estimated TN loads for the Mississippi River at the outlet of Lake Pepin and Lock and Dam 8.

Backwaters of the Mississippi River

Nitrogen processing in backwaters of the Mississippi River can alter the N levels, but the overall impact of reductions in backwaters is generally overwhelmed by the large load transported in the main channel of the river. Research on backwaters can be applied to other shallow lakes and deep wetlands where study of N processing in Minnesota has been less thorough. Houser and Richardson (2010) have documented that NOX-N is often lower in backwater areas than the main channel, but quantifying the volume of water exchanged with backwaters is often lacking which prevents an accurate estimate of N lost in any individual or group of backwaters. Forshay and Stanley (2005) found that the floodplain including backwaters of the lower Wisconsin River were responsible for rapid depletion (within days) of nitrate delivered to the floodplain. During April of 2011 as discharge levels fell and connectivity between the river and floodplain was disrupted, nitrate levels in water trapped on the floodplain were reduced from 1.09 mg/L to <0.002 in 8 days. They concluded that enhancing the connection of large rivers to their floodplains may enhance overall retention of TN loads from large rivers.

James (2010) completed extensive N processing analysis of Second Lake from mid-May to October of 2006. Second Lake is a backwater lake in upper Pool 5 with a metered culvert at its inlet so a detailed mass balance could be completed for this backwater (Figure 24, 25). This shallow backwater lake has a surface area of 7.5 ha with mean depth of 0.4m (max depth = 2.4 m). Thirty-one percent and 54% of TN and NO_X-N inputs to Second Lake were removed respectively during the monitoring period in 2006. Estimated removal via denitrification in Second Lake accounted for 57% of retained NO_X-N, suggesting assimilation of NO_X-N by biota for the remainder of NO_X-N losses. Second Lake had extensive *Lemna sp*. (duckweed) during June and July when 86% of macrophyte transects were occupied with floating *Lemna sp.* Submersed macrophytes dominated by *Ceratophyllum demersum* (Eurasian water milfoil) and *Potamogeton crispus (*curly leaf pondweed) occupied 46% to 65% of transect stations. *C. demersum* biomass peaked in August. *P. crispus* dies back in early June after peaking earlier in the season than most natives. *Nymphaea odorata* (white water lily) was also present. A large pulse of DON or DIN was not observed as various plants went through senescence in late summer and early fall. James (2010) suggests that N could be trapped in plant tissue which may be lost to sedimentation, processed later via aerobic or anaerobic mineralization of N, or exported as larger fragments of plant tissue that are not sampled via typical water-quality sampling techniques. It is common for backwaters to export *Lemna sp*. during water level fluctuations on the Mississippi River. The overall significance of N in large particulate matter to the overall N budget of a given pool has not been quantified. Flow through Second Lake was fixed at 4.24 ft^3/s via the metered culvert, resulting in a theoretical residence time of 3.3 days for the entire study. Flow in the Mississippi River at Winona from mid-May to October 2006 (best gaging station near Pool 5) ranged from 8,430 to 70,600 ft^3/s with a median and mean of 14,000 and 21,015 ft^3/s respectively. Even during the lowest flow in the Mississippi River of the study period, the flow through Third Lake only represents 0.05% of the downstream flow of the Mississippi River. Needless to say, the impact of this individual backwater lake on downstream transport of N is very small. Extrapolation of removal rates in backwaters and other habitat types is required to determine the collective impact of all habitat types on the downstream movement of TN (Strauss et al. 2011).

Radio-isotopes have been used with in situ mesocosm experiments to measure nitrate assimilation rates of macrophytes, epiphyton and microbial fauna (Kreiling et al. 2010). This study was completed during June and July of 2005 on Third Lake which is a backwater lake directly west of Second Lake discussed in the previous paragraph. Tracking of ^{15}N– NO_3-N revealed that denitrification accounted for 82% of NO_3-N losses with the remainder being assimilated by macrophytes and epiphytes (Figure 26). This study also found that denitrification potential and assimilation rates increased with increasing nitrate concentration. Denitrification potential (represents maximum removal rate of sediments) was measured in the laboratory with sediments from Third Lake. Denitrification potential rates plateaued at 5 mg/L suggesting that backwaters can remove up to 3,000 mg $N \cdot m^{-2} \cdot d^{-1}$ (Figure 27). NO_X-N loading beyond this rate to a given flow-through backwater will be transported downstream. Backwaters with excessive loading at concentration greater than 5 mg/L are essentially NO_X-N saturated.

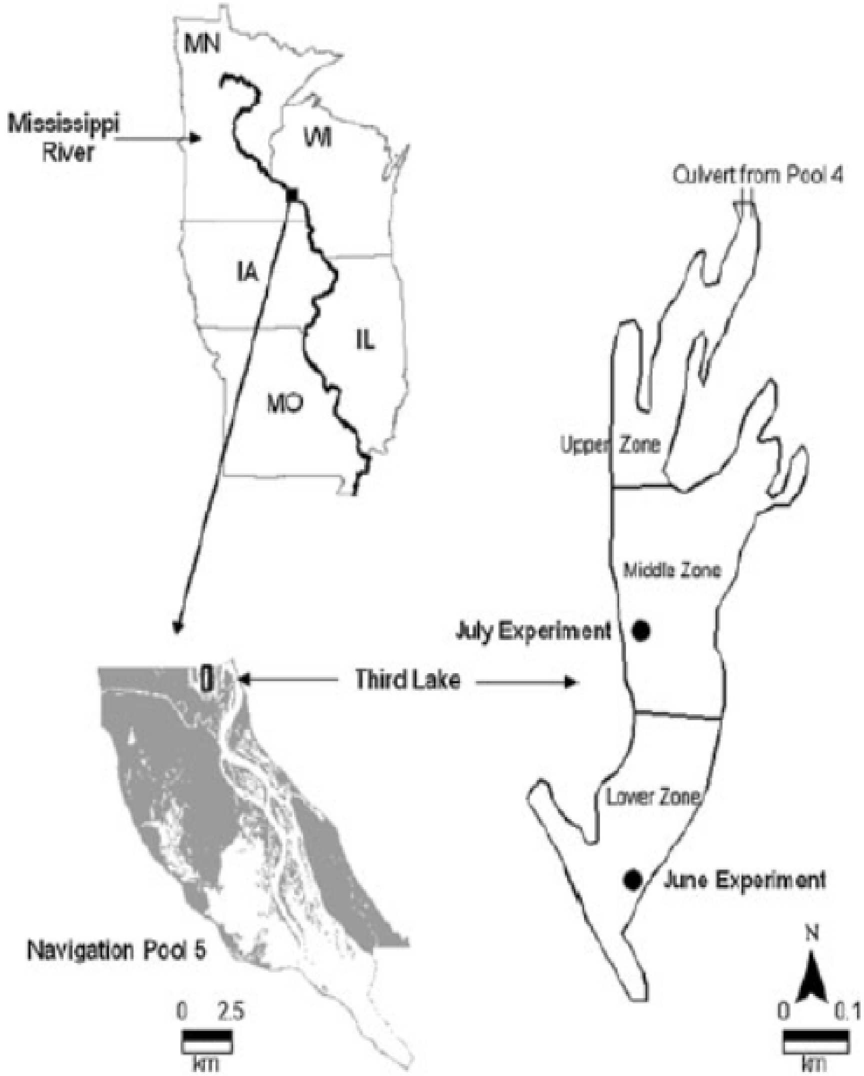


Figure 24. Third Lake is three miles east of Kellogg, Minnesota in the upper portion of Navigational Pool 5 of the Mississippi River. Reprinted from Kreiling et al. (2010).

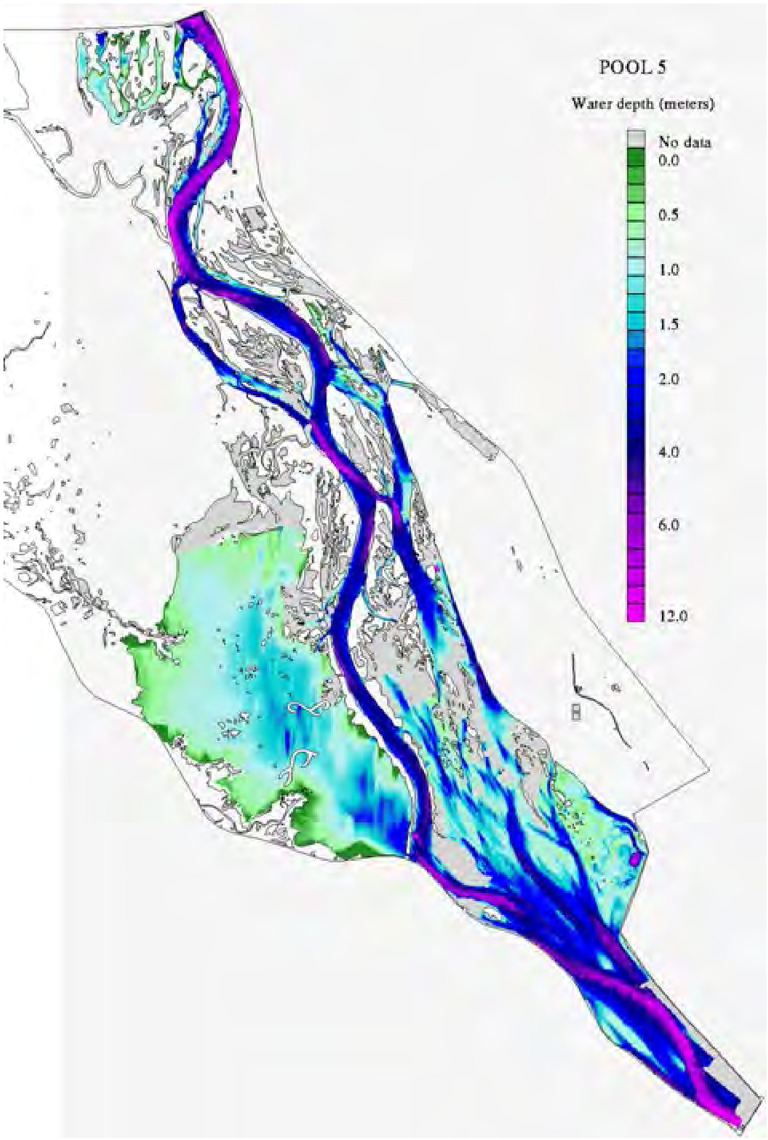


Figure 25. Bathymetric map of Navigational Pool 5 of the Mississippi River. (Solid oval = Third Lake, dashed oval = Second Lake). Source: USGS.

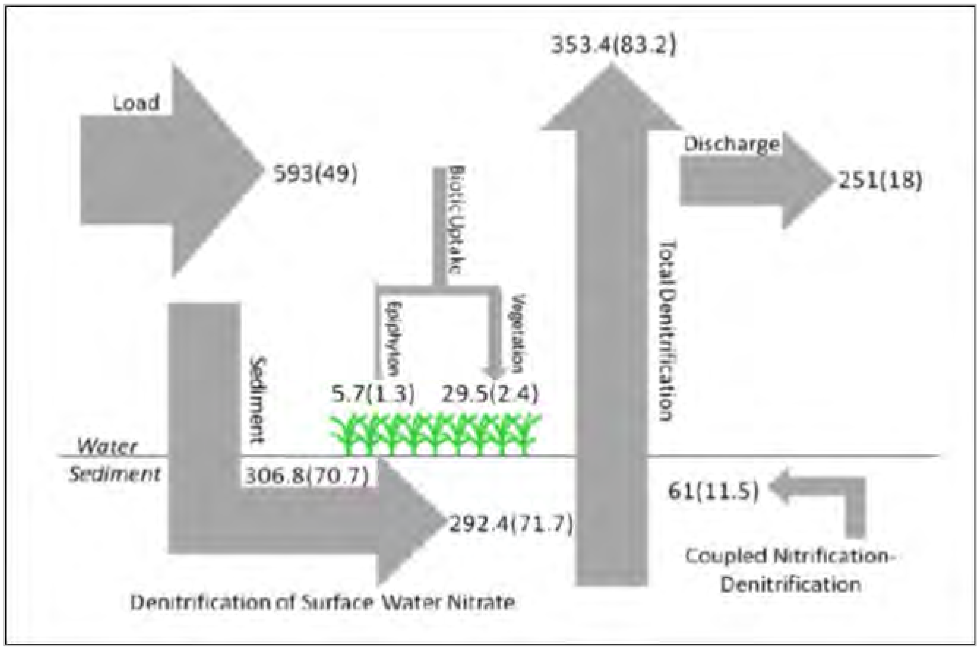


Figure 26. Net NO_3-N budget (mean (1 SE), (mg m-2 h-1) for Third Lake, Navigation Pool 5 during June and July 2005. n = 3 for discharge and load, n = 8 for coupled nitrification–denitrification and total denitrification, n = 16 for biotic uptake and denitrification of surface water nitrate. Reprinted from Kreiling et al. (2010).

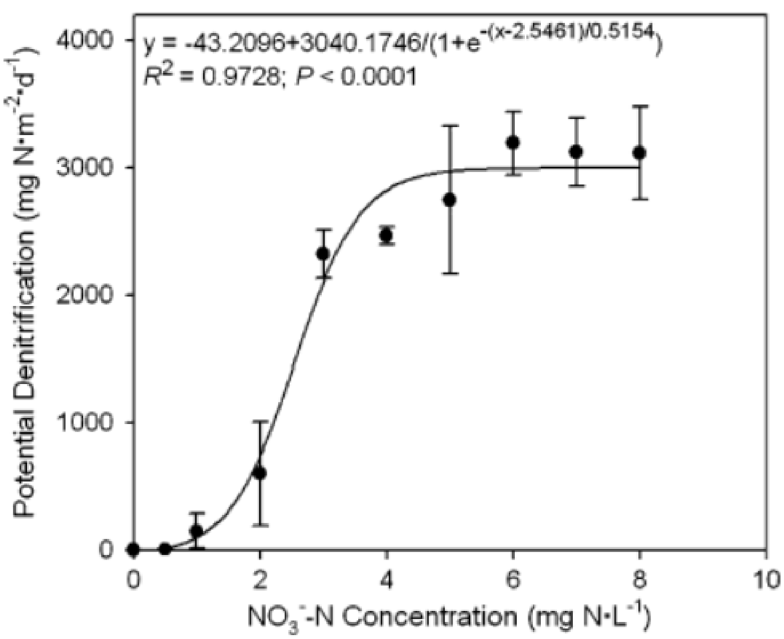


Figure 27. Relationship between NO_3^-–N concentration and potential denitrification rates (mean ± 1 SE, n = 8) for Third Lake, Navigation Pool 5. Sediment was taken from the middle and lower portions of the lake in June and July 2005. Reprinted from Kreiling et al. (2010).

The two backwater studies by James (2010) and Kreiling et al. (2010) examined similar backwaters and found different rates of denitrification by a factor of three (94 mg m^{-2} day^{-1}, 292 mg m^{-2} day^{-1} respectively). The difference in denitrification rates may be expected given the differences in the two studies including spatial, temporal and design differences. The more important finding is that denitrification was the dominant path for NO_X-N removal in both studies. This suggests that removal of NO_X-N from the system is more prevalent than assimilation. Thus, the dominant pathway is removal verses assimilation which may result in a delayed transport of N in the system. The applicability of these results to other surface waters may be best suited for shallow vegetated lakes and wetlands.

Fate of wastewater treatment plant nitrogen loads

The fate of N discharged by wastewater treatment plants (WWTPs) is dynamic and generally similar to the processing of N inputs from other sources. The actual rate of contribution from point sources to aquatic resources is much more constant than that of sources such as atmospheric deposition, overland runoff or tile line flow. Based on the discussion in the previous sections of this chapter, it is assumed that during high flows much of the N from all sources is transported downstream. Transport of DIN from WWTPs during low flows in summer is variable with some assimilation into biota and losses to denitrification depending on the receiving stream. Many WWTPs promote nitrification to comply with NH_X-N limits. Thus, NO_X-N is the dominant form of N discharged by many WWTPs. More information regarding the forms of N in wastewater is covered in the WWTP chapter of this report.

Literature

Isotopic signatures of NO_3-N sampled longitudinally throughout the Illinois River indicated the presence of NO_3-N discharged from the Chicago area WWTPs throughout the river system (Panno et al. 2008). During high flow periods, NO_3-N in the upper Illinois River, which is dominated by point source loading, was slightly diluted by NO_3-N derived from tributaries with extensive drainage tiles as it flows to the Mississippi River. Even though concentration decreases in the river during high flows, the load goes up dramatically due to the substantial contributions of the tributaries. NO_3-N transport during high flows was generally conservative regardless of the source of N. During low flows in August of 2005, NO_3-N in the Illinois River was predominately from point sources. Dilution from deep groundwater, which showed the highest degree of denitrification in the study, was the primary source of water besides point sources to the river during low flows. Approximately 50% of NO_3-N (concentration drop of 1.69 to 0.83 mg/L) in the Illinois River was removed in Peoria Lake (impoundment on Illinois River) during low flow. Further investigation would be needed to definitively determine whether NO_3-N was lost to denitrification or assimilated into algae in Peoria Lake. Assimilated N may still be transported downstream as algae or transported when higher river flows return.

Available N data for WWTPs and receiving waters in Minnesota are not adequate to estimate annual transport losses of WWTP N loads in rivers. Low-flow sampling was completed from the late 1970s through early 1990s to assess the conversion rate of NH_X-N downstream of WWTPs in headwater streams. Concentration of NH_X-N typically returns to upstream levels with 2-3 miles downstream of point sources during low flow conditions in summer. Sampling results are inconclusive to discern if the NH_X-N is converted to NO_X-N via nitrification, assimilated by biota or lost to N_2 gas via coupled nitrification denitrification. During winter low flows, NH_X-N from WWTPs is more conservative due to low temperatures which reduce rates of nitrification and assimilation. Downstream sampling beyond the first five miles was not available to determine when or if NH_X-N is lost downstream of WWTPs in winter. NO_X-N and TKN were generally conservative downstream WWTPs for the first five miles during summer and winter. Many factors such as ungaged tributaries, groundwater contributions, and low sample numbers at any given site make it difficult to characterize transport of NO_X-N and TN downstream of WWTPs. We will discuss transport beyond five miles in the following paragraph.

The following example is based on available data at the time of this report. The city of Marshall, Archer-Daniels-Midland Company, and other smaller point sources, discharge approximately 441 pounds/day (75% DIN) to the Redwood River. During August of 2009, the load of NO_X-N and TKN of the Redwood River upstream of the Minnesota River confluence was 22 pounds/day and 110 pounds/day respectively indicating that at least 70% of TN was lost in the Redwood River. Continued monitoring of the MPCA's load monitoring sites located at the outlets of HUC 8 watersheds will be useful for quantifying what level of flow would be considered low flow for all the watersheds in the state in the future. Additional point source monitoring will greatly improve our estimates of N losses during low flow periods. The loss of N described here during a low flow in summer is a stark contrast to what happens during spring when a much higher portion of NO_X-N loaded to rivers is transported downstream.

Nitrogen transport in lakes and reservoirs

Definitions: 1) Residence time: Time in days or years to replace water in a given lake (Volume of lake / volume of water inputs per unit time= residence time). 2) Areal hydraulic load (m yr-1) = (annual water inputs in m^3 / surface area of lake in m^2)

Lakes and reservoirs (lentic systems) are important sinks for N throughout the world. Harrison et al. (2009) modeled the amount of N removed by lentic systems on regional and global scales to estimate the cumulative impacts of these resources. They estimated that small lakes (<12,355 acres) were responsible for removal of 47% of N removed by lentic systems. Certainly the majority of Minnesota lakes are smaller than 12,355 acres (50 km^2). They also found that although reservoirs only occupy 6% of the total surface area of lentic systems, reservoirs remove 33% of all N removed by lentic systems. Given the relatively short residence of reservoirs compared to lakes this may not seem probable. One major difference in lakes and reservoirs is the load of N delivered to these systems. Reservoirs may or may not be as efficient as lakes for removing N, but the large watersheds of reservoirs' typically deliver much larger loads of N to reservoirs.

Nitrogen removal efficiency of lakes is influenced by external loading and size of the lake relative to that loading. Alexander et al. (2008) calculated areal hydraulic load (see definitions) and compared it to percentage of N and phosphorus removed. They found that percentage of N removal is negatively correlated with areal hydraulic load (Figure 28). They compared modeled results with results from the literature to verify their model. Their findings are consistent with the basic concept that N can be removed from aquatic systems if loading rates are low and residence time is high. The larger the areal hydraulic loading to a given lake the shorter the residence time assuming that depth is the same for all lakes being compared. Greater depth also increases residence time; so large lakes with small watersheds remove most of the input N while small (relative to watershed) lakes tend to remove very little input N.

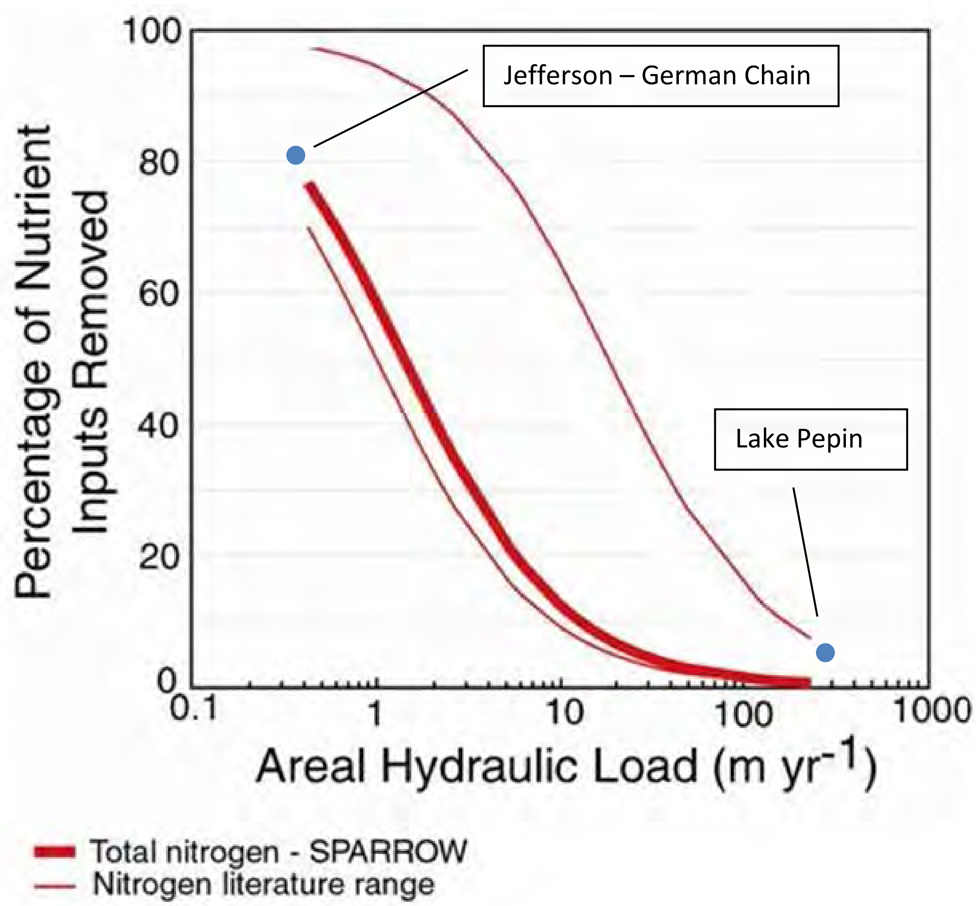


Figure 28. SPARROW predicted removal rates of N for lakes and reservoirs based on areal hydraulic load. Modified and reprinted from Alexander et al. (2008). Lake Pepin and Jefferson-German estimates were added to original figure.

David et al. (2006) found that Lake Shelbyville in central Illinois removed 58% of input NO_3-N on average from 1981-2003. Average residence time during this time period was 0.36 year with a range of 0.21 – 0.84 yr. The watershed for Lake Shelbyville is > 80% row crops (corn and soybeans) with extensive tile drainage to enhance crop yields. David et al. (2006) found that incorporation of NO_3-N to organic N (measured as TKN) accounted for approximately 10% of NO_3-N losses observed in Lake Shelbyville from 2002-2003. They also commented that even though reservoirs can be effective N traps the expense of constructing reservoirs are excessively high. Problems with sedimentation of reservoirs in the Midwest often limit the effective lifespan of reservoirs. Several reservoirs in Minnesota in key locations for N removal that have lost (and/or continue to lose) much of their original volume include: Lake Redwood on Redwood River, Lake Zumbro on Zumbro River, Lake Byllesby on Cannon River, Rapidan Dam on Blue Earth River, and Lake Pepin on Mississippi River.

A recent study found that monitoring nitrogenous gases (N_2O and N_2) is another technique to directly measure N lost to denitrification. Deemer et al. (2011) found that N_2O and N_2 accumulated in the hypolimnion of Lacamas Lake (small eutrophic reservoir) in Washington State. Their results were comparable to other techniques for estimating denitrification rates. Early in the stratification period NO_X-N was present and N_2 was the primary gas produced close to the sediment-water interface. Later in the season as NO_X-N was depleted, N_2O production increased and was produced throughout the water-column. This suggested that nitrification was a source of N_2O. Overall production of N_2 was seven times that of N_2O produced on average. N_2O is a potent greenhouse gas so quantifying its production is important.

Minnesota lakes and reservoirs

Existing monitoring programs are typically designed to monitor the surface water-quality of lakes at their center or deepest portion. Natural lake outlets often drain water from the epilimnion (upper portion of thermally stratified lake) of the upstream lake. This section will focus on N data collected at the top two meters of lakes since this where the majority of the samples have been collected in Minnesota and is most representative of what is expected to be exported via lake outlets. Most N in Minnesota lakes is present as organic N during summer (June-September) when most lake samples are collected. Summer average TN for lakes ranges from 0.2 to 4.0 mg/L (Figure 29). NO_X-N is typically near detection limit and is most common in early spring when watershed loads are greatest and possibly due to conversion of NH_X-N (accumulated during winter) to NO_X-N. Sampling data is limited during early spring to confirm NO_X-N concentration when lakes are most likely to discharge water to downstream resources. NH_X-N is also scarce in lakes except in anoxic hypolimnions of stratified lakes where NH_X-N at concentrations greater than 1 mg/L are common. This is important at turnover when mixing exposes NH_X-N to aerobic conditions where it is likely converted to NO_X-N or assimilated by algae.

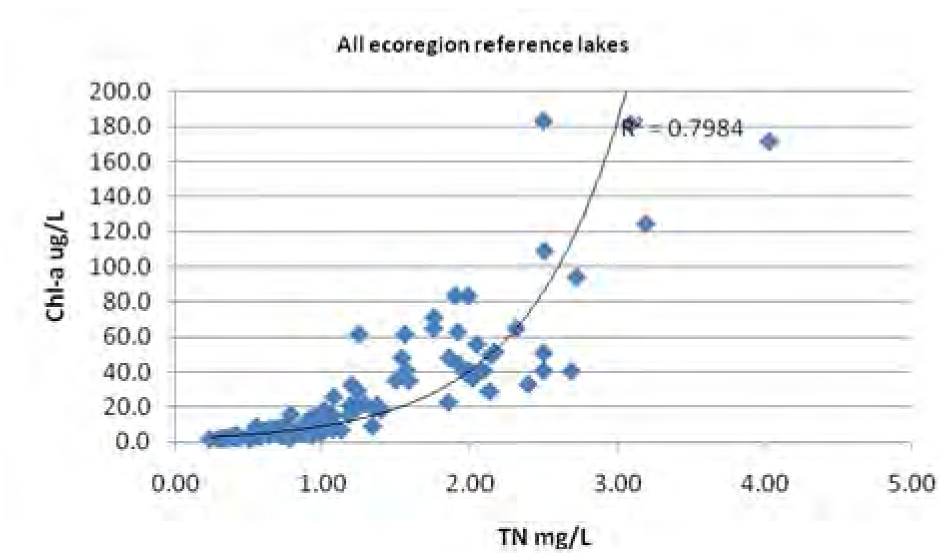


Figure 29. Summer average TN verses chlorophyll-a for reference lakes in Minnesota monitored from 1985-1988.

Minnesota has relatively few reservoirs on rivers with adequate residence time to process high nitrate loads in the southern portion of the state. We will examine actual data from some Minnesota lakes and reservoirs to determine if these systems mimic what has been documented in the literature. We have already discussed Lake Pepin in a previous section. This is one of our best examples of system where relatively little N is removed due to short residence time and high external loading. Nitrogen budgets for other lakes in Minnesota are not nearly as comprehensive as what we have available for Lake Pepin. True N removal is difficult to determine given the relatively scarce amount of TN data for the outlets of lakes throughout a given sampling year. We know that N is loaded to lakes to some degree throughout the state and we know that NO_X-N is typically below detection limit in most lakes unless nitrate loading is high and residence time is short. NO_X-N loaded to lakes is assimilated into biota of the lake which would be measured as TN if it was assimilated by suspended algae. Nitrogen assimilated by plants, epiphyton and other organisms would not be measured in typical surface monitoring techniques. Based on research from reservoirs and backwaters discussed earlier, we know that much of the NO_X-N is lost via denitrification (David et al. 2006, Kreiling et al. 2010). The practical matter is that the TN exports from lakes and reservoirs are low given adequate residence time. Whether the TN is stored in lake sediments via plant and algae settling and ultimately denitrified or denitrified directly is likely variable depending on a given lake and its watershed.

Many of the lakes in northern Minnesota can be characterized as aquatic systems with long residence times and low to modest N loading. The concentrations of these systems are less than detection level for NO_X-N and approximately 1 mg/L TN. The combination of low TN loading and TN removal/assimilation in these systems result in low loading to downstream lakes and rivers. Lake "chains" or networks exist in certain areas of the state where a series of lakes are directly connected or connected by streams or rivers. Nitrogen removal rates from these lakes are quite high for several reasons. First, residence time of chain of lakes is typically much longer than that for a single lake. Second, these systems tend to slow the rate of runoff since the outlets to lakes often restrict flow which results in more time to process N during wet periods. Third, streams that connect lake chains can be shallow and slow moving with wetland fringes. All of these factors result in low N exports. Jones (2010) discussed the ecological impact of lakes on lake/stream networks and found that the location and density of lakes in a watershed influences the ultimate impact of lakes on a stream network. The impact of stream order upstream of a lake network can be used to estimate N removal (Figure 30). Smaller streams have lower water and N loads which allows for greater residence time to remove a relatively smaller N load. Extremely large lakes such as Lake of Woods and Lake Superior would be exceptions to the general pattern discussed here, but the use of stream order upstream of a given lake or lake network is a useful predictor for N removal potential.

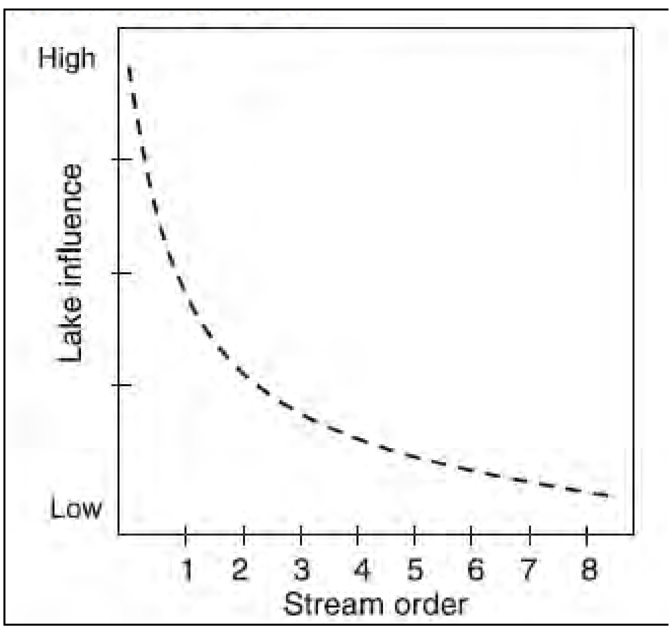


Figure 30. The influence of a lake is likely to decrease as increase in size down a stream network (reprinted from Jones 2010).

The Cannon River watershed has several headwater lakes that remove approximately 83% of inflowing N loads (Pallardy et al, in review). The Jefferson-German Lake chain (J/G chain) has a relatively small watershed with a watershed area to lake area ratio of approximately 3.5 (Figure 31). Hydraulic loading (0.47m yr^{-1}) to this system is low and residence time is a minimum of five years for the major basins in the chain. The landuse for the J/G chain's watershed is a mix of corn, soybeans, pasture/hay, forest and other minor categories. In 2010, the monitored NO_X-N flow weighted mean for the tributaries was 11.2 mg/L from March 17 to November 1. It is likely that NO_X-N loads of tributaries monitored in 2010 were not radically different than that of the past decade. Total nitrogen was not monitored, but it was likely 12-13 mg/L based on organic N levels in other streams in the state. The NO_X-N concentration of the J/G chain outlet flowing from German Lake was 0.2 mg/L for this same time period. Based on the chlorophyll-a concentration of German Lake in 2010 the TN at the outlet was likely 2.0 mg/L. Based on all the available data and assumptions based on statewide datasets, only 2% of the NO_X-N and 20% of TN that was loaded to J/G chain was exported in 2010 respectively (Table 7). Due to the residence times of the individual lakes of the J/G chain that exceed multiple years, multiple years of monitoring would be needed to confirm that a pulse of nitrate loaded during high flow years is not subsequently released in future years. Based on relatively stable landuse in the watershed, it is likely that NO_X-N loading to J/G chain has been elevated for many years prior to the 2010 monitoring season.

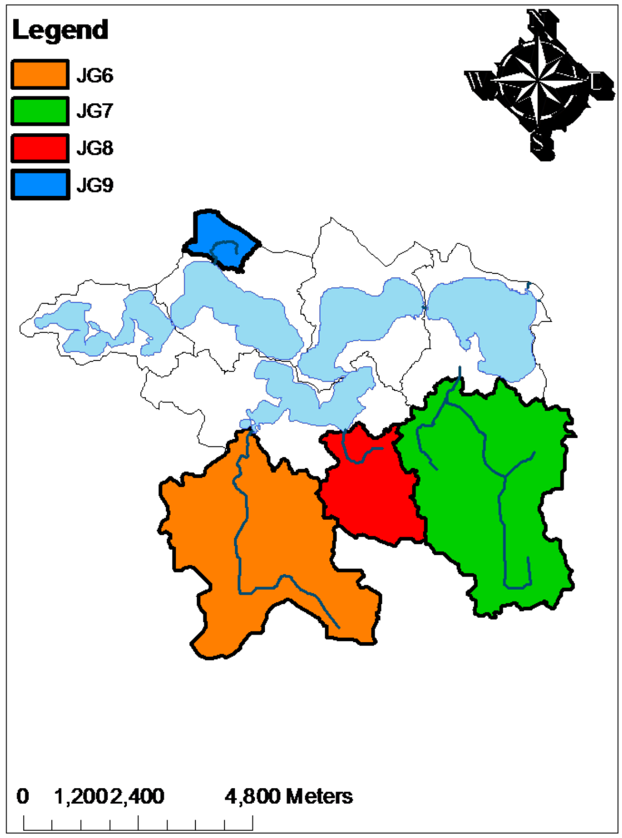


Figure 31. Watershed for Jefferson-German Lakes including highlighted inlets that were monitored in 2010 to estimate nutrient loading. Reprinted and modified from Pallardy et al. (in review).

Table 7. Monitored flow and nitrate loads for the inlets and outlet to Jefferson-German chain for March through November 2010.

Station	Flow rate (hm^3/yr)	Nitrate load (kg/yr)	Flow weighted mean (mg/L)
JG6	2.71	46,727	17.2
JG7	2.49	16,406	6.6
JG8	0.78	1,157	1.5
JG9	0.39	6,848	17.9
Sum	6.37	71,138	11.2
Outlet	4.51	801	0.18

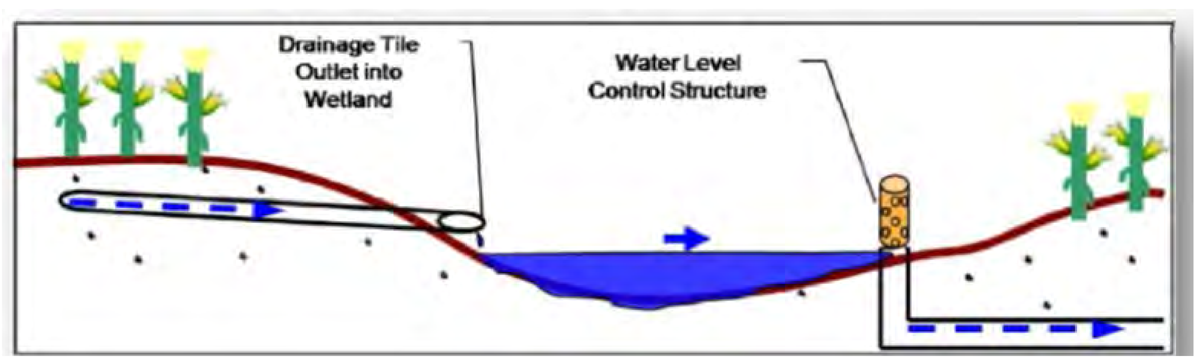
Nitrogen transport in wetlands

Wetlands are generally considered as aquatic systems with a high capacity to assimilate and ultimately denitrify N inputs. Wetlands have several characteristics that allow for TN removal including abundant labile organic carbon, anoxic sediments, generally long residence times and small watersheds. Mitsch and Day (2006) proposed the creation and restoration of wetlands throughout Mississippi-Ohio-Missouri Basin to intercept field drainage along with diversion wetlands fed by flooding river waters as a means to mitigate eutrophication in the Gulf of Mexico. They based this recommendation on an extensive review of field studies that demonstrated 33% to 95% NO_X-N retention in wetlands. Flow-through and riparian wetlands must be strategically positioned within a watershed to have the most impact on N transport. Many of the principles discussed in the lake and riverine backwater sections of this chapter also apply to wetlands. For instance, a large wetland receiving a modest load of TN from a small watershed would generally remove more N than a small wetland receiving a large load of TN from a large watershed.

The landscape of much of northern Minnesota has extensive wetlands. Limited monitoring from MPCA's wetland sampling program indicates that NO_X-N in these wetlands is at or below detection limit and total kjeldahl (organic N + NH_X-N) is approximately 1.2 mg/L. Certainly N transport in relatively pristine wetlands is both complicated and interesting, but the downstream export of N from these systems is rather small compared to wetlands with excessive N inputs. Concentration of NO_X-N in the temperate prairies region of Minnesota averages 1.0 mg/L while the median concentration is below detection limit. Given the limited temporal coverage (one sampling visit per wetland) of these wetlands datasets (n=60 wetlands per region) and the general ability of wetlands to remove/assimilate NO_X-N documented in the literature, we can only conclude that some wetlands in the temperature prairies are receiving more NO_X-N inputs than can be assimilated.

Completely isolated wetlands which are very valuable for many reasons may indirectly impact transport of N out of watersheds. The impact of isolated wetlands on the hydrology and N transport of watersheds is beyond the scope of this chapter. Certainly if water from an isolated wetland is lost to evapotranspiration or deep groundwater recharge there is a benefit of less water delivered to streams verses an isolated wetland that has been drained or altered to convey water to a nearby stream. The most practical aspect of N transport regarding wetlands for this chapter is the loss of N in flow-through and riparian wetlands. This is most important where N inputs are excessive and wetlands can potentially remove some N which otherwise would likely to be transported downstream in the absence of wetlands.

Wetlands have been constructed in Minnesota to remove excess nitrate from tile lines (Figure 32). Dr. Bill Crumpton of Iowa State University was brought in to help design and site constructed wetlands. Research indicates that 1 acre of wetland is needed to treat drainage from 100 acres of tile drained field. Constructed wetlands to treat tile outfalls in south-central Minnesota are rare for various reasons, but they are an example of the potential of engineered waterbodies to enhance N removal upstream of stream networks. A constructed wetland (i.e. County Ditch 58 wetland) in the Seven Mile Creek watershed removed about 40% to 70% of NO_X-N inputs from tile lines from 2005 to 2007 (Figure 33) (Kuehner 2009). Removal rates were lowest during high flow events with relatively cool temperatures. Limited results from a constructed wetland in the Little Cottonwood River watershed achieved 92% removal of NO_X-N from May 17th to October 3rd, 2007 (Kuehner 2008). Total nitrogen data was not available for either of the wetlands discussed here. The portion of NO_X-N lost to denitrification versus the portion that was assimilated by biota is not known. Input N as NO_X-N assimilated to organic N can still be lost via additional cycling in wetlands especially during extended dry periods when wetlands have no outlet flow.



drain water. Reprinted from Kuehner (2009).

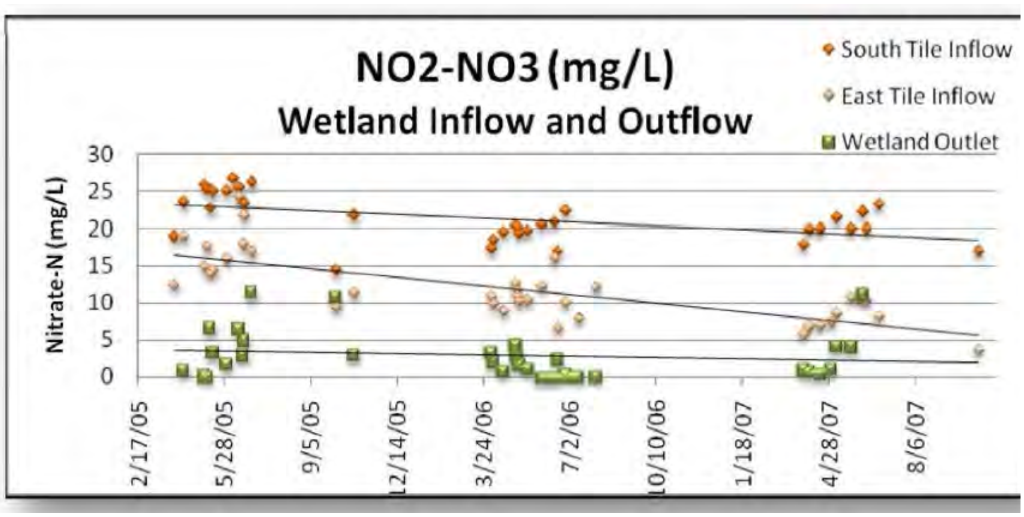


Figure 33. Inlet and outlet NO_X-N concentration for County Ditch 58 constructed wetland, located in Seven Mile Creek watershed in Minnesota, from 2005 to 2007. East tile inflow was treated by another upstream constructed wetland prior to the County Ditch wetland. Reprinted from Kuehner (2009).

Riparian interception wetlands can mitigate excess water and N from tile lines contributing to streams. Magner and Alexander (2008) found that tile water that was intercepted by a wetland adjacent to Hawk Creek was effective at removing incoming NO_X-N. Evapotranspiration was the major export pathway for water entering the wetland. The wetland was relatively isolated from Hawk Creek due to the relatively impermeable soils of the Des Moines Lobe till. Low hydraulic conductivity of Des Moines Lobe till which is found throughout southern Minnesota was documented by Komor and Magner (1996). Site selection to maximize N removal and prevent crop damage is an important consideration of interception wetlands (Magner and Alexander 2008).

Summary

As described in the overview, it is very difficult to generalize transport of N in surface waters for a state such as Minnesota with a myriad of surface waters and watersheds. What is relatively clear is that larger rivers with high TN loads like the Minnesota River deliver most of the annual N load that is delivered to the mainstem of the river from contributing watersheds to downstream surface waters. Cool temperatures and relatively short retention times in the Minnesota River during spring to early summer during the peak of the TN load limit N removal. Even the complex mosaic of habitat types in the Mississippi River downstream of the Twin Cities only facilitates removal of up to 2% of annual TN loads per navigational pool based on estimates for Pools 2 and 3 (LTI 2009). Pool 4, which includes Lake Pepin, is a unique pool on the Minnesota portion of the Mississippi River from LD 1 to the MN/IA border. Total nitrogen removal rates for Pool 4 range from 7% to 10% (LTI 2009, and Lake Pepin mass balance respectively). Collectively, the section of the Mississippi River from LD 1 to the MN/IA border (168 miles) removes 12% to 22% of annual TN inputs based on the approaches outlined in this chapter. Impressive cycling has been documented in this system, but the input load simply overwhelms the capacity of the river to remove the majority TN inputs during most years.

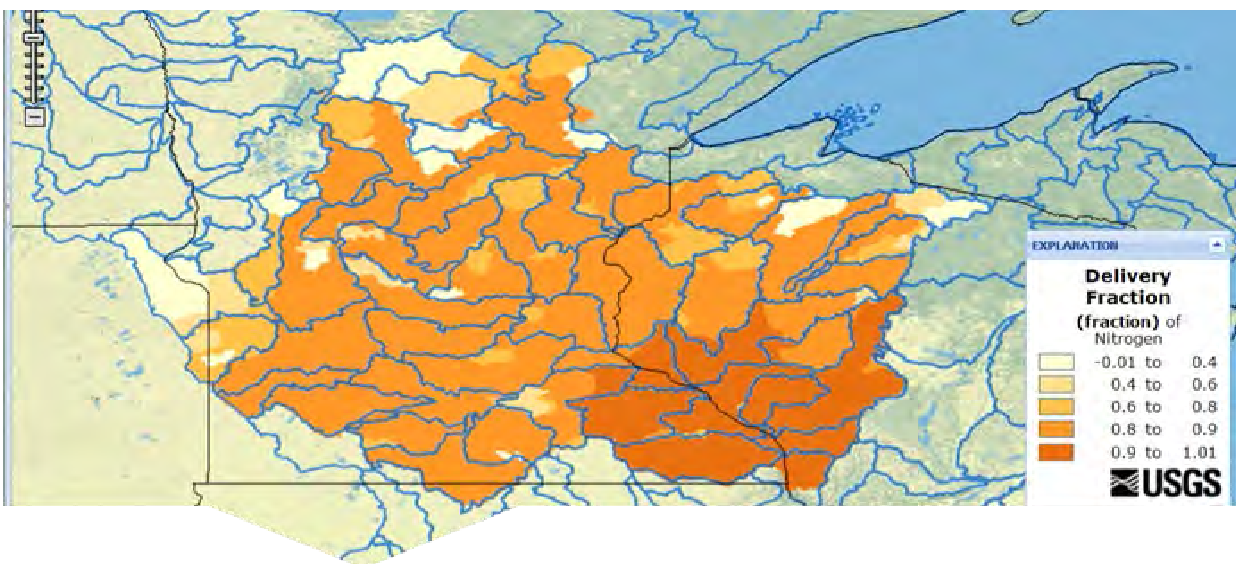


Figure 34. Percent delivery of annual TN loads from SPARROW watersheds to the Mississippi River at the MN/IA border.

The collective removal rate of N loading in Minnesota's lakes, wetlands, ephemeral streams, and headwaters streams is less certain. National models developed for the Gulf of Mexico such as SPARROW can estimate the collective losses of TN for modeled rivers and streams of a given watershed. Figure 34 illustrates the delivery fractions for the SPARROW watersheds upstream of Mississippi River at the

MN/IA border. As noted elsewhere in this report, the SPARROW load estimates do match monitored loads reasonably well. The model was not specifically designed to estimate losses across all aquatic systems in a given SPARROW watershed. Less than 200 lakes and reservoirs are included in the model's stream reaches while the vast majority of natural lakes in Minnesota are not included. Losses in wetlands, headwater streams, and lakes not in the model reaches are accounted for in overland losses. Again, the SPARROW results presented here do not represent the total losses of TN in all aquatic resources, but they are useful to estimate the movement of TN in stream and river networks.

Many factors influence the losses in smaller lotic systems (Table 8). Watersheds with extensive lakes and wetlands and modest N loading certainly remove or transform DIN inputs. Watersheds with extensive tile drainage and limited lakes and wetlands often transport large loads of DIN to watershed outlets with some removal in headwaters. Percentage of delivered DIN load typically increases with proximity to large rivers in all watersheds. Weather and precipitation of any given year certainly influences transport dynamics in any given watershed. Higher precipitation translates into greater loading and increased stream velocity which both contribute to increased downstream transport of DIN. Drought conditions lead to reduced loading and lower stream velocities which contribute to increased losses and transformations of DIN.

Table 8. Positive and negative factors that influence downstream movement of NO_X-N in Minnesota.

Factor	Conditions that enhance N removal	Example	Conditions that generally reduce N removal	
Streamflow	Low flow	Drought	High flow	Wet periods/spring
Annual precipitation	Low	Western MN	Moderate/high	Eastern MN
Depth	Shallow (inches)	Headwater streams	Deep (9 ft)	Impounded portion of Mississippi River
Carbon content of sediment	High organic content	Backwaters, impoundments, wetlands	"Clean" sand with low organic content	Main channel of large rivers
Input loads/concentration	Low	Northern MN watersheds	High	Southern MN watersheds
Season	Late summer	Low flows and high temperature	Early Spring	High flow and cool temperatures
Riparian area	Natural	Forested stream	Rock or concrete	Urban areas
Riparian wetlands	Common	Northern MN	Few	Ditches in southern MN
Temperature	Warm	Summer	Cold/cool	Winter

Lakes including backwaters of rivers and wetlands can remove and/or assimilate and DIN inputs as long as inputs are not excessive. Long hydraulic residence times in these surface waters along with carbon rich sediments are key to removing DIN inputs. The overall impact of these surface waters on downstream transport of TN from Minnesota is difficult to quantify, but it is certain that existing surface waters of these types currently reduce TN loads to downstream waters.

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Appendix D2-1.

Basin summaries of wastewater facilities

Estimated average annual point source nitrogen load per basin from 2005-2009

						Annual Load (pounds/year)			
Basin	Area (acres)	Facilities	Domestic	Industrial	Flow (MG)	NHx	TKN	NOx	TN
Upper Mississippi River	12,864,220	260	142	118	105,910	1,245,703	3,399,879	11,300,233	14,742,576
Minnesota River	9,583,767	236	155	81	39,806	279,232	1,102,104	3,629,542	4,717,144
Lake Superior	3,931,107	60	24	36	83,554	421,652	614,397	2,255,984	2,870,381
Lower Mississippi River	4,030,136	121	78	43	27,543	230,725	650,071	2,005,170	2,643,750
Rainy River	7,231,608	28	18	10	25,807	335,418	509,163	1,180,357	1,689,520
Cedar River	665,643	29	21	8	4,497	68,235	144,645	490,599	635,348
Red River of the North	11,315,451	95	78	17	5,749	173,946	168,265	449,607	617,872
St. Croix River	2,249,920	25	21	4	4,164	53,848	121,357	250,692	372,049
Des Moines River	983,753	21	16	5	2,163	10,707	78,498	205,855	284,353
Missouri River	1,141,169	27	22	5	1,051	10,654	27,543	70,893	98,436
Total	**53,996,774**	**902**	**575**	**327**	**300,243**	**2,830,119**	**6,815,922**	**21,838,932**	**28,671,429**

Estimated annual point source nitrogen yield per basin from 2005-2009

		Yield (lbs/acre)			
Basin	Area (acres)	NHx	TKN	NOx	TN
Upper Mississippi River	12,864,220	0.0968	0.2643	0.8784	1.1460
Minnesota River	9,583,767	0.0291	0.1150	0.3787	0.4922
Lake Superior	3,931,107	0.1073	0.1563	0.5739	0.7302
Lower Mississippi River	4,030,136	0.0572	0.1613	0.4975	0.6560
Rainy River	7,231,608	0.0464	0.0704	0.1632	0.2336
Cedar River	665,643	0.1025	0.2173	0.7370	0.9545
Red River of the North	11,315,451	0.0154	0.0149	0.0397	0.0546
St. Croix River	2,249,920	0.0239	0.0539	0.1114	0.1654
Des Moines River	983,753	0.0109	0.0798	0.2093	0.2890
Missouri River	1,141,169	0.0093	0.0241	0.0621	0.0863
Total	**53,996,774**				

Appendix D2-2.

Major watershed summaries of wastewater facilities

Major Watershed Name	Hydrologic Unit Code	Basin	Facilities	Domestic	Industrial
Mississippi River - Twin Cities	07010206	Upper Mississippi River	85	8	77
Lower Minnesota River	07020012	Minnesota River	53	22	31
St. Louis River	04010201	Lake Superior	39	16	23
Rainy River - Black River	09030004	Rainy River	3	2	1
Zumbro River	07040004	Lower Mississippi River	30	20	10
Mississippi River - St. Cloud	07010203	Upper Mississippi River	18	12	6
Mississippi River - Lake Pepin	07040001	Lower Mississippi River	12	7	5
Mississippi River - Grand Rapids	07010103	Upper Mississippi River	20	14	6
Cannon River	07040002	Lower Mississippi River	26	17	9
Mississippi River - Brainerd	07010104	Upper Mississippi River	15	10	5
South Fork Crow River	07010205	Upper Mississippi River	24	19	5
Minnesota River - Mankato	07020007	Minnesota River	31	16	15
Cedar River	07080201	Cedar River	16	12	4
North Fork Crow River	07010204	Upper Mississippi River	25	21	4
Vermilion River	09030002	Rainy River	8	3	5
Mississippi River - Sartell	07010201	Upper Mississippi River	13	10	3
Upper Red River of the North	09020104	Red River of the North	10	5	5
Lower St. Croix River	07030005	St. Croix River	12	9	3
Des Moines River - Headwaters	07100001	Des Moines River	16	12	4
Root River	07040008	Lower Mississippi River	27	20	7
Shell Rock River	07080202	Cedar River	11	7	4
Redwood River	07020006	Minnesota River	9	8	1
Blue Earth River	07020009	Minnesota River	25	14	11
Long Prairie River	07010108	Upper Mississippi River	10	8	2
Sauk River	07010202	Upper Mississippi River	15	10	5
Otter Tail River	09020103	Red River of the North	15	7	8
Cottonwood River	07020008	Minnesota River	21	16	5
Le Sueur River	07020011	Minnesota River	17	14	3
Mississippi River - Winona	07040003	Lower Mississippi River	18	8	10
Watonwan River	07020010	Minnesota River	14	9	5

Major Watershed Name	Hydrologic Unit Code	Basin	Facilities	Domestic	Industrial
Kettle River	07030003	St. Croix River	8	7	1
Lake Superior - South	04010102	Lake Superior	15	3	12
Chippewa River	07020005	Minnesota River	15	14	1
Minnesota River - Yellow Medicine River	07020004	Minnesota River	26	23	3
Rum River	07010207	Upper Mississippi River	14	11	3
Rock River	10170204	Missouri River	19	16	3
Mississippi River - Headwaters	07010101	Upper Mississippi River	4	2	2
Rainy River - Headwaters	09030001	Rainy River	5	2	3
Lac Qui Parle River	07020003	Minnesota River	8	5	3
Red Lake River	09020303	Red River of the North	8	5	3
Lake Superior - North	04010101	Lake Superior	6	5	1
Crow Wing River	07010106	Upper Mississippi River	6	6	
Pomme de Terre River	07020002	Minnesota River	10	8	2
Snake River	07030004	St. Croix River	4	4	
Redeye River	07010107	Upper Mississippi River	5	5	
Lower Big Sioux River	10170203	Missouri River	6	5	1
Clearwater River	09020305	Red River of the North	7	7	
Buffalo River	09020106	Red River of the North	7	7	
Red River of the North - Grand Marais Creek	09020306	Red River of the North	3	3	
Roseau River	09020314	Red River of the North	2	2	
Wild Rice River	09020108	Red River of the North	10	10	
Mississippi River - La Crescent	07040006	Lower Mississippi River	1	1	
Lower Des Moines River	07100002	Des Moines River	1	1	
East Fork Des Moines River	07100003	Des Moines River	4	3	1
Pine River	07010105	Upper Mississippi River	3	3	
Mississippi River - Reno	07060001	Lower Mississippi River	2	2	
Snake River	09020309	Red River of the North	7	6	1
Red River of the North - Marsh River	09020107	Red River of the North	5	5	
Upper Iowa River	07060002	Lower Mississippi River	5	3	2
Minnesota River - Headwaters	07020001	Minnesota River	7	6	1
Mustinka River	09020102	Red River of the North	6	6	
Rainy River - Baudette	09030008	Rainy River	2	2	
Bois de Sioux River	09020101	Red River of the North	2	2	
Two Rivers	09020312	Red River of the North	4	4	

Major Watershed Name	Hydrologic Unit Code	Basin	Facilities	Domestic	Industrial
Little Fork River	09030005	Rainy River	2	2	
Lake of the Woods	09030009	Rainy River	3	2	1
Red River of the North - Sandhill River	09020301	Red River of the North	4	4	
Big Fork River	09030006	Rainy River	5	5	
Little Sioux River	10230003	Missouri River	2	1	1
Red River of the North - Tamarac River	09020311	Red River of the North	2	2	
Winnebago River	07080203	Cedar River	2	2	
Leech Lake River	07010102	Upper Mississippi River	3	3	
Upper St. Croix River	07030001	St. Croix River	1	1	
Thief River	09020304	Red River of the North	2	2	
Upper/Lower Red Lake	09020302	Red River of the North	1	1	

Estimated annual average point source load per major watershed from 2005-2009

		Annual Load (pounds/year)			
Major Watershed Name	**Flow (MG)**	**NHx**	**TKN**	**NOx**	**TN**
Mississippi River - Twin Cities	76,149	356,428	2,386,411	8,547,016	10,972,760
Lower Minnesota River	24,564	121,985	719,124	2,451,801	3,170,968
St. Louis River	34,211	406,583	590,327	2,130,904	2,721,231
Rainy River - Black River	14,872	255,072	386,058	879,002	1,265,059
Zumbro River	9,436	33,308	227,843	733,298	961,146
Mississippi River - St. Cloud	6,636	171,375	233,049	631,181	864,231
Mississippi River - Lake Pepin	6,725	110,029	207,295	538,990	746,284
Mississippi River - Grand Rapids	6,398	97,561	163,936	509,513	672,501
Cannon River	3,947	47,060	126,113	415,406	541,519
Mississippi River - Brainerd	2,349	238,443	131,865	351,669	487,618
South Fork Crow River	2,950	43,287	96,178	339,064	435,234
Minnesota River - Mankato	4,893	41,892	86,137	358,050	422,285
Cedar River	2,838	63,720	92,124	299,303	391,530
North Fork Crow River	2,856	41,566	131,476	250,990	382,466
Vermilion River	6,176	37,631	109,835	255,684	365,518
Mississippi River - Sartell	3,924	62,856	101,369	227,557	328,926
Upper Red River of the North	2,068	57,085	67,470	240,684	308,155
Lower St. Croix River	3,232	39,701	93,568	202,019	295,587
Des Moines River - Headwaters	1,904	7,146	70,154	196,108	266,263
Root River	5,021	17,889	46,505	198,372	244,877
Shell Rock River	1,641	4,344	52,072	190,320	242,392

Major Watershed Name	Flow (MG)	Annual Load (pounds/year)			
		NHx	TKN	NOx	TN
Redwood River	1,481	6,113	48,802	177,842	226,644
Blue Earth River	1,611	33,363	50,121	141,855	199,210
Long Prairie River	1,412	135,488	49,579	146,950	196,529
Sauk River	1,439	60,590	40,869	145,011	185,880
Otter Tail River	1,358	74,814	42,639	137,078	179,716
Cottonwood River	1,342	7,660	41,474	125,781	167,255
Le Sueur River	1,114	9,340	36,405	94,964	131,369
Mississippi River - Winona	2,143	14,598	32,372	96,820	129,193
Watonwan River	908	12,234	29,325	93,863	123,289
Lake Superior - South	48,571	218	556	108,457	109,013
Chippewa River	807	7,398	26,876	81,953	108,829
Minnesota River - Yellow Medicine River	1,312	27,947	35,689	57,363	93,052
Rum River	754	11,213	23,302	61,381	84,686
Rock River	646	5,093	18,750	52,832	71,582
Mississippi River - Headwaters	430	15,334	13,906	48,239	62,145
Kettle River	692	8,800	17,320	32,134	49,454
Rainy River - Headwaters	4,590	40,906	8,495	40,495	48,989
Lac Qui Parle River	872	7,836	17,094	24,490	41,584
Red Lake River	671	28,330	16,806	24,416	41,222
Lake Superior - North	772	14,851	23,513	16,623	40,136
Crow Wing River	319	6,645	13,295	21,443	34,739
Snake River	345	6,223	13,099	19,217	32,315
Pomme de Terre River	804	2,650	8,613	19,137	27,770
Redeye River	217	2,852	10,834	14,887	25,721
Lower Big Sioux River	373	5,295	7,997	17,264	25,261
Clearwater River	255	2,059	6,376	11,379	17,756
Buffalo River	282	2,356	7,067	7,067	14,133
Red River of the North - Grand Marais Creek	231	1,927	5,782	5,782	11,563
Roseau River	214	1,787	5,362	5,362	10,724
Wild Rice River	196	1,638	4,913	4,913	9,826
Mississippi River - La Crescent	85	5,060	4,959	7,084	12,043
Lower Des Moines River	187	1,564	4,693	4,693	9,387
East Fork Des Moines River	71	1,996	3,651	5,053	8,704
Pine River	57	1,911	3,344	4,777	8,120
Mississippi River - Reno	115	2,704	3,755	13,699	5,959
Red River of the North - Marsh River	84	705	2,114	3,142	5,257
Upper Iowa River	87	1,090	2,221	2,917	5,138

Major Watershed Name	Flow (MG)	Annual Load (pounds/year)			
		NHx	TKN	NOx	TN
Minnesota River - Headwaters	98	815	2,444	2,444	4,888
Mustinka River	76	635	1,905	1,905	3,811
Rainy River - Baudette	63	529	1,588	1,588	3,175
Bois de Sioux River	62	513	1,540	1,540	3,080
Two Rivers	61	512	1,537	1,537	3,073
Little Fork River	56	468	1,404	1,404	2,808
Lake of the Woods	16	521	912	1,303	2,215
Red River of the North - Sandhill River	38	318	954	954	1,909
Big Fork River	35	291	873	882	1,755
Little Sioux River	32	265	796	796	1,593
Red River of the North - Tamarac River	31	259	778	778	1,556
Winnebago River	18	171	450	976	1,426
Leech Lake River	19	155	466	555	1,021
Upper St. Croix River	7	62	186	186	372
Thief River	6	54	162	162	324
Upper/Lower Red Lake	2	18	55	55	111

Estimated annual average point source yield per major watershed from 2005-2009

			Yield (pounds/acre/year)			
Major Watershed Name	**Hydrologic Unit Code**	**Area (acres)**	**NHx**	**TKN**	**NOx**	**TN**
Mississippi River - Twin Cities	07010206	644,320	0.55	3.70	13.27	17.03
Lower Minnesota River	07020012	1,174,348	0.10	0.61	2.09	2.70
St. Louis River	04010201	1,831,462	0.22	0.32	1.16	1.49
Rainy River - Black River	09030004	329,206	0.77	1.17	2.67	3.84
Zumbro River	07040004	909,363	0.04	0.25	0.81	1.06
Mississippi River - St. Cloud	07010203	717,374	0.24	0.32	0.88	1.20
Mississippi River - Lake Pepin	07040001	382,780	0.29	0.54	1.41	1.95
Mississippi River - Grand Rapids	07010103	1,332,793	0.07	0.12	0.38	0.50
Cannon River	07040002	940,540	0.05	0.13	0.44	0.58
Mississippi River - Brainerd	07010104	1,076,295	0.22	0.12	0.33	0.45
South Fork Crow River	07010205	818,100	0.05	0.12	0.41	0.53
Minnesota River - Mankato	07020007	861,882	0.05	0.10	0.42	0.49
Cedar River	07080201	454,029	0.14	0.20	0.66	0.86
North Fork Crow River	07010204	944,854	0.04	0.14	0.27	0.40
Vermilion River	09030002	661,296	0.06	0.17	0.39	0.55
Mississippi River - Sartell	07010201	656,113	0.10	0.15	0.35	0.50
Upper Red River of the North	09020104	319,533	0.18	0.21	0.75	0.96
Lower St. Croix River	07030005	585,735	0.07	0.16	0.34	0.50
Des Moines River - Headwaters	07100001	798,595	0.01	0.09	0.25	0.33
Root River	07040008	1,061,506	0.02	0.04	0.19	0.23
Shell Rock River	07080202	157,701	0.03	0.33	1.21	1.54
Redwood River	07020006	447,531	0.01	0.11	0.40	0.51
Blue Earth River	07020009	777,240	0.04	0.06	0.18	0.26
Long Prairie River	07010108	565,076	0.24	0.09	0.26	0.35
Sauk River	07010202	666,747	0.09	0.06	0.22	0.28
Otter Tail River	09020103	1,222,024	0.06	0.03	0.11	0.15
Cottonwood River	07020008	840,782	0.01	0.05	0.15	0.20
Le Sueur River	07020011	711,113	0.01	0.05	0.13	0.18
Mississippi River - Winona	07040003	419,200	0.03	0.08	0.23	0.31
Watonwan River	07020010	558,963	0.02	0.05	0.17	0.22
Lake Superior - South	04010102	399,371	0.02	0.07	0.21	0.27
Chippewa River	07020005	1,330,147	0.02	0.03	0.04	0.07
Minnesota River - Yellow Medicine River	07020004	1,332,769	0.01	0.02	0.05	0.06
Rum River	07010207	1,013,790	0.01	0.02	0.05	0.07
Rock River	10170204	582,106	0.03	0.02	0.08	0.11
Mississippi River - Headwaters	07010101	1,228,884	0.01	0.01	0.03	0.04

Major Watershed Name	Hydrologic Unit Code	Area (acres)	Yield (pounds/acre/year)			
			NHx	TKN	NOx	TN
Kettle River	07030003	672,924	0.00	0.00	0.16	0.16
Rainy River - Headwaters	09030001	1,607,846	0.03	0.01	0.03	0.03
Lac Qui Parle River	07020003	487,022	0.02	0.04	0.05	0.09
Red Lake River	09020303	857,496	0.03	0.02	0.03	0.05
Lake Superior - North	04010101	1,015,865	0.01	0.02	0.02	0.04
Crow Wing River	07010106	1,268,954	0.01	0.01	0.02	0.03
Snake River	07030004	643,542	0.01	0.02	0.03	0.05
Pomme de Terre River	07020002	560,231	0.00	0.02	0.03	0.05
Redeye River	07010107	572,067	0.00	0.02	0.03	0.04
Lower Big Sioux River	10170203	326,851	0.02	0.02	0.05	0.08
Clearwater River	09020305	869,460	0.00	0.01	0.01	0.02
Buffalo River	09020106	724,094	0.00	0.01	0.01	0.02
Red River of the North - Grand Marais Creek	09020306	378,808	0.01	0.02	0.02	0.03
Roseau River	09020314	679,895	0.00	0.01	0.01	0.02
Wild Rice River	09020108	1,047,065	0.00	0.00	0.00	0.01
Mississippi River - La Crescent	07040006	60,544	0.08	0.08	0.12	0.20
Lower Des Moines River	07100002	55,733	0.03	0.08	0.08	0.17
East Fork Des Moines River	07100003	129,425	0.02	0.03	0.04	0.07
Pine River	07010105	500,885	0.00	0.01	0.01	0.02
Mississippi River - Reno	07060001	117,447	0.02	0.03	0.12	0.05
Red River of the North - Marsh River	09020107	231,541	0.00	0.01	0.01	0.02
Upper Iowa River	07060002	138,756	0.01	0.02	0.02	0.04
Minnesota River - Headwaters	07020001	501,739	0.00	0.00	0.00	0.01
Mustinka River	09020102	550,852	0.00	0.00	0.00	0.01
Rainy River - Baudette	09030008	196,591	0.00	0.01	0.01	0.02
Bois de Sioux River	09020101	355,934	0.00	0.00	0.00	0.01

Major Watershed Name	Hydrologic Unit Code	Area (acres)	Yield (pounds/acre/year)			
			NHx	TKN	NOx	TN
Two Rivers	09020312	704,816	0.00	0.00	0.00	0.00
Little Fork River	09030005	1,198,291	0.00	0.00	0.00	0.00
Lake of the Woods	09030009	736,643	0.00	0.00	0.00	0.00
Red River of the North - Sandhill River	09020301	395,583	0.00	0.00	0.00	0.00
Big Fork River	09030006	1,315,131	0.00	0.00	0.00	0.00
Little Sioux River	10230003	205,753	0.00	0.00	0.00	0.01
Red River of the North - Tamarac River	09020311	567,036	0.00	0.00	0.00	0.00
Winnebago River	07080203	45,649	0.00	0.01	0.02	0.03
Leech Lake River	07010102	857,968	0.00	0.00	0.00	0.00
Upper St. Croix River	07030001	347,719	0.00	0.00	0.00	0.00
Thief River	09020304	671,021	0.00	0.00	0.00	0.00
Upper/Lower Red Lake	09020302	1,241,686	0.00	0.00	0.00	0.00

Appendix D3-1.

Table 1. Modeled inorganic nitrogen deposition amounts in pounds/acre falling in different watersheds during average, low, and high precipitation years.

ID	HUC8 Watershed Name	Oxidized Wet	Unoxidized Wet	Oxidized Dry	Unoxidized Dry	Avg. precip. Total N Wet + dry	Low precip. Total N Wet + dry	High precip. Total N Wet + dry
1	Lake Superior - North	1.20	1.68	1.47	0.31	4.67	4.21	5.24
2	Lake Superior - South	1.48	2.17	2.10	0.46	6.20	5.62	6.93
3	St. Louis River	1.27	1.99	1.86	0.54	5.66	5.14	6.31
4	Cloquet River	1.37	2.08	1.98	0.52	5.95	5.40	6.64
5	Nemadji River	1.63	2.57	1.95	0.86	7.02	6.34	7.86
7	Mississippi River - Headwaters	1.05	1.78	1.39	0.91	5.14	4.69	5.71
8	Leech Lake River	1.07	1.80	1.36	0.91	5.14	4.68	5.72
9	Mississippi River - Grand Rapids	1.25	2.03	1.60	0.67	5.55	5.03	6.21
10	Mississippi River - Brainerd	1.59	2.82	1.60	1.88	7.89	7.19	8.77
11	Pine River	1.25	2.14	1.45	1.04	5.88	5.34	6.56
12	Crow Wing River	1.18	2.19	1.41	1.77	6.56	6.02	7.23
13	Redeye River	1.17	2.31	1.36	2.40	7.24	6.68	7.94
14	Long Prairie River	1.41	2.79	1.42	2.94	8.57	7.89	9.41
15	Mississippi River - Sartell	2.10	3.73	1.71	3.47	11.01	10.07	12.17
16	Sauk River	1.88	3.50	1.51	4.32	11.20	10.34	12.27
17	Mississippi River - St. Cloud	2.59	4.33	2.08	3.18	12.20	11.09	13.58
18	North Fork Crow River	2.35	4.10	1.76	4.14	12.36	11.33	13.65
19	South Fork Crow River	2.47	4.25	1.81	4.24	12.77	11.70	14.11
20	Mississippi River - Twin Cities	2.88	4.62	3.54	3.07	14.11	12.91	15.61
21	Rum River	2.28	3.68	2.14	1.81	9.91	8.95	11.10
22	Minnesota River - Headwaters	1.36	2.41	1.29	2.91	7.97	7.37	8.72
23	Pomme de Terre River	1.23	2.40	1.32	3.24	8.20	7.62	8.92
24	Lac Qui Parle River	1.62	2.77	1.35	3.33	9.07	8.36	9.94
25	Minnesota River - Yellow Medicine River	1.80	3.22	1.42	4.38	10.83	10.02	11.83
26	Chippewa River	1.44	2.77	1.37	3.67	9.25	8.57	10.09
27	Redwood River	1.81	3.16	1.45	4.41	10.82	10.02	11.81
28	Minnesota River - Mankato	1.95	3.53	1.61	5.06	12.15	11.27	13.24
29	Cottonwood River	1.84	3.26	1.50	4.92	11.52	10.70	12.54
30	Blue Earth River	2.10	3.70	1.68	5.44	12.93	12.00	14.09
31	Watonwan River	2.02	3.65	1.60	5.48	12.74	11.84	13.88
32	Le Sueur River	2.34	4.03	1.81	4.92	13.11	12.09	14.38
33	Lower Minnesota River	2.44	4.18	2.32	4.30	13.23	12.18	14.56

ID	HUC8 Watershed Name	Oxidized Wet	Unoxidized Wet	Oxidized Dry	Unoxidized Dry	Avg. precip. Total N Wet + dry	Low precip. Total N Wet + dry	High precip. Total N Wet + dry
34	Upper St. Croix River	2.01	3.33	1.83	1.04	8.21	7.36	9.28
35	Kettle River	1.76	2.85	1.77	0.93	7.33	6.59	8.25
36	Snake River	2.09	3.39	1.94	1.40	8.83	7.95	9.93
37	Lower St. Croix River	2.75	4.26	2.52	2.04	11.57	10.45	12.98
38	Mississippi River - Lake Pepin	2.76	4.61	2.53	4.15	14.05	12.87	15.52
39	Cannon River	2.63	4.37	2.12	4.71	13.83	12.71	15.23
40	Mississippi River - Winona	2.91	4.27	2.09	3.76	13.03	11.88	14.46
41	Zumbro River	2.88	4.50	2.13	4.35	13.85	12.67	15.33
42	Mississippi River - La Crescent	2.63	3.48	2.21	3.08	11.41	10.43	12.63
43	Root River	2.54	3.60	2.08	4.16	12.38	11.40	13.61
44	Mississippi River - Reno	2.40	3.23	2.19	3.24	11.06	10.16	12.19
46	Upper Iowa River	2.21	3.18	2.03	4.38	11.80	10.94	12.88
47	Upper Wapsipinicon River	2.10	3.21	1.95	5.71	12.98	12.13	14.04
48	Cedar River	2.26	3.52	2.03	4.75	12.57	11.64	13.72
49	Shell Rock River	2.15	3.46	2.03	4.37	12.01	11.11	13.13
50	Winnebago River	2.20	3.59	1.92	4.80	12.51	11.58	13.66
51	Des Moines River - Headwaters	1.78	3.17	1.57	4.63	11.15	10.36	12.14
52	Lower Des Moines River	1.65	3.01	1.63	5.51	11.80	11.06	12.73
53	East Fork Des Moines River	1.78	3.22	1.59	5.62	12.21	11.41	13.21
54	Bois de Sioux River	1.22	2.35	1.32	3.01	7.91	7.33	8.62
55	Mustinka River	1.22	2.36	1.32	3.14	8.04	7.47	8.76
56	Otter Tail River	1.09	2.16	1.34	2.37	6.96	6.44	7.61
57	Upper Red River of the North	1.07	2.14	1.43	3.08	7.72	7.21	8.36
58	Buffalo River	1.04	2.03	1.39	2.58	7.04	6.54	7.65
59	Red River of the North - Marsh River	0.98	1.92	1.24	2.98	7.12	6.66	7.70
60	Wild Rice River	1.05	2.02	1.30	2.25	6.62	6.13	7.23
61	Red River of the North - Sandhill River	1.07	2.07	1.21	2.38	6.74	6.23	7.36
62	Upper/Lower Red Lake	1.14	2.00	1.24	0.90	5.28	4.78	5.91
63	Red Lake River	1.17	2.20	1.15	2.03	6.54	6.00	7.21
65	Thief River	1.12	2.11	1.09	1.44	5.76	5.24	6.40
66	Clearwater River	1.16	2.20	1.19	1.73	6.28	5.74	6.95
67	Red River of the North - Grand Marais Creek	1.11	2.16	1.07	2.31	6.65	6.13	7.30
68	Snake River	1.10	2.15	1.01	1.97	6.24	5.72	6.89
69	Red River of the North - Tamarac River	0.99	1.97	0.94	2.18	6.08	5.60	6.67
70	Two Rivers	0.95	1.90	0.94	1.98	5.77	5.31	6.34

ID	HUC8 Watershed Name	Oxidized Wet	Unoxidized Wet	Oxidized Dry	Unoxidized Dry	Avg. precip. Total N Wet + dry	Low precip. Total N Wet + dry	High precip. Total N Wet + dry
71	Roseau River	1.04	2.05	0.97	1.44	5.50	5.01	6.12
72	Rainy River - Headwaters	1.03	1.60	1.57	0.40	4.59	4.17	5.12
73	Vermilion River	0.99	1.50	1.75	0.45	4.69	4.29	5.19
74	Rainy River - Rainy Lake	0.98	1.57	1.30	0.46	4.31	3.90	4.82
75	Rainy River - Black River	1.05	1.83	1.23	0.65	4.75	4.29	5.33
76	Little Fork River	1.00	1.53	1.66	0.52	4.71	4.31	5.22
77	Big Fork River	1.07	1.73	1.45	0.65	4.91	4.46	5.47
78	Rapid River	1.10	1.93	1.24	0.80	5.07	4.58	5.67
79	Rainy River - Baudette	1.12	2.07	1.09	0.84	5.12	4.61	5.75
80	Lake of the Woods	1.13	2.12	0.83	0.79	4.87	4.35	5.52
81	Upper Big Sioux River	1.56	2.73	1.48	3.68	9.45	8.77	10.31
82	Lower Big Sioux River	1.63	3.03	1.51	5.02	11.19	10.44	12.12
83	Rock River	1.62	3.04	1.56	5.47	11.70	10.95	12.63
84	Little Sioux River	1.64	3.06	1.62	5.18	11.50	10.75	12.44

Table 2. Atmospheric deposition estimates of wet+dry inorganic nitrogen falling directly into rivers and streams, marshes/wetlands, lakes, dry-land, and the total onto all land and waters. Results are shown for each HUC8 watershed in Minnesota.

ID	HUC8 Name	Rivers	Marsh	Lakes	Land	Total
1	Lake Superior - North	19,182	182,854	301,631	4,238,004	4,741,671
2	Lake Superior - South	17,175	102,086	12,067	2,344,485	2,475,813
3	St. Louis River	43,837	3,859,744	267,072	6,190,143	10,360,796
4	Cloquet River	9,893	556,977	181,826	2,269,595	3,018,290
5	Nemadji River	8,865	179,056	12,780	1,039,890	1,240,591
7	Mississippi River - Headwaters	13,958	1,088,600	902,133	4,309,974	6,314,665
8	Leech Lake River	7,513	714,060	867,737	2,824,423	4,413,733
9	Mississippi River - Grand Rapids	23,279	2,427,883	450,565	4,497,790	7,399,518
10	Mississippi River - Brainerd	30,972	1,527,410	452,334	6,484,335	8,495,050
11	Pine River	6,069	389,348	366,184	2,185,009	2,946,610
12	Crow Wing River	25,498	736,502	562,014	6,998,316	8,322,330
13	Redeye River	19,706	391,968	62,058	3,667,956	4,141,688
14	Long Prairie River	18,912	288,606	356,160	4,177,958	4,841,636
15	Mississippi River - Sartell	38,612	468,203	145,067	6,569,361	7,221,243
16	Sauk River	44,222	110,769	329,734	6,983,058	7,467,784
17	Mississippi River - St. Cloud	38,896	258,305	270,001	8,181,505	8,748,707
18	North Fork Crow River	46,165	211,573	747,855	10,671,358	11,676,951
19	South Fork Crow River	46,678	116,063	372,917	9,911,898	10,447,555
20	Mississippi River - Twin Cities	33,634	289,587	688,082	8,078,161	9,089,463
21	Rum River	36,446	1,045,295	1,471,647	7,489,333	10,042,722
22	Minnesota River - Headwaters	16,184	59,426	186,887	3,736,698	3,999,196

ID	HUC8 Name	Rivers	Marsh	Lakes	Land	Total
23	Pomme de Terre River	17,119	27,507	337,227	4,210,348	4,592,200
24	Lac Qui Parle River	37,005	19,980	21,193	4,336,731	4,414,910
25	Minnesota River - Yellow Medicine River	86,788	28,730	157,479	14,155,457	14,428,454
26	Chippewa River	55,684	136,429	594,267	11,513,663	12,300,043
27	Redwood River	27,502	12,579	63,744	4,737,474	4,841,299
28	Minnesota River - Mankato	49,418	109,315	197,359	10,114,728	10,470,820
29	Cottonwood River	60,193	21,971	63,151	9,539,145	9,684,459
30	Blue Earth River	39,189	23,234	136,608	9,849,406	10,048,437
31	Watonwan River	38,335	16,861	93,284	6,973,672	7,122,152
32	Le Sueur River	44,329	90,334	191,544	8,993,149	9,319,355
33	Lower Minnesota River	82,417	205,237	412,026	14,840,895	15,540,575
34	Upper St. Croix River	11,490	557,861	11,352	2,274,915	2,855,617
35	Kettle River	20,011	949,579	83,438	3,877,104	4,930,131
36	Snake River	21,358	780,092	71,907	4,808,473	5,681,831
37	Lower St. Croix River	28,195	437,977	368,374	5,944,629	6,779,174
38	Mississippi River - Lake Pepin	33,609	13,152	148,979	5,181,829	5,377,569
39	Cannon River	79,146	249,839	354,177	12,325,826	13,008,988
40	Mississippi River - Winona	49,509	25,234	29,653	5,357,299	5,461,696
41	Zumbro River	113,547	1,076	26,159	12,456,009	12,596,790
42	Mississippi River - La Crescent	6,323	25,359	13,254	645,590	690,527
43	Root River	120,512	5,696	5,307	13,012,481	13,143,995
44	Mississippi River - Reno	12,140	27,314	17,954	1,241,556	1,298,964
46	Upper Iowa River	17,389	0	489	1,619,870	1,637,748
47	Upper Wapsipinicon River	823	0	0	106,409	107,233
48	Cedar River	33,954	10,365	24,239	5,636,964	5,705,521
49	Shell Rock River	7,199	19,297	57,097	1,810,624	1,894,217
50	Winnebago River	2,732	16,874	11,381	539,913	570,900
51	Des Moines River - Headwaters	47,519	35,983	224,525	8,594,514	8,902,541
52	Lower Des Moines River	3,822	0	972	652,952	657,745
53	East Fork Des Moines River	5,661	0	50,265	1,524,158	1,580,084
54	Bois de Sioux River	14,437	12,582	68,413	2,718,656	2,814,089
55	Mustinka River	25,413	23,774	89,305	4,291,972	4,430,465
56	Otter Tail River	15,828	270,089	1,204,913	7,013,636	8,504,466
57	Upper Red River of the North	12,734	18,630	3,280	2,431,884	2,466,529
58	Buffalo River	23,133	63,359	148,452	4,859,337	5,094,281
59	Red River of the North - Marsh River	9,502	654	1,638	1,637,022	1,648,815
60	Wild Rice River	35,058	253,869	212,659	6,426,256	6,927,843
61	Red River of the North - Sandhill River	16,357	15,060	44,200	2,588,817	2,664,434
62	Upper/Lower Red Lake	18,918	2,446,425	1,584,141	2,511,245	6,560,728
63	Red Lake River	23,811	797,620	18,181	4,768,358	5,607,970
65	Thief River	23,214	1,109,961	154,758	2,575,845	3,863,778

ID	HUC8 Name	Rivers	Marsh	Lakes	Land	Total
66	Clearwater River	29,382	378,888	128,234	4,920,107	5,456,611
67	Red River of the North - Grand Marais Creek	9,525	4,733	3,425	2,501,323	2,519,006
68	Snake River	17,346	54,924	922	3,035,964	3,109,157
69	Red River of the North - Tamarac River	15,809	21,041	11,713	3,397,154	3,445,716
70	Two Rivers	18,079	265,211	4,465	3,777,001	4,064,757
71	Roseau River	21,314	1,130,514	55,991	2,533,911	3,741,730
72	Rainy River - Headwaters	21,313	658,690	976,630	5,730,218	7,386,851
73	Vermilion River	9,209	430,375	387,308	2,272,770	3,099,662
74	Rainy River - Rainy Lake	7,852	446,191	448,652	1,608,381	2,511,076
75	Rainy River - Black River	4,552	1,054,945	297	504,557	1,564,351
76	Little Fork River	20,730	1,706,296	125,729	3,792,184	5,644,939
77	Big Fork River	16,737	2,907,141	270,896	3,263,846	6,458,619
78	Rapid River	14,532	2,379,493	583	664,976	3,059,583
79	Rainy River - Baudette	5,718	550,915	1,705	447,547	1,005,885
80	Lake of the Woods	8,528	929,398	1,473,364	1,174,219	3,585,510
81	Upper Big Sioux River	2,327	0	0	247,819	250,146
82	Lower Big Sioux River	36,539	1,856	1,465	3,617,679	3,657,540
83	Rock River	62,910	0	4,462	6,742,999	6,810,371
84	Little Sioux River	10,621	5,528	77,184	2,272,828	2,366,161

Appendix E2-1.

Maps showing the spatial pattern of explanatory variables in the best regression models:

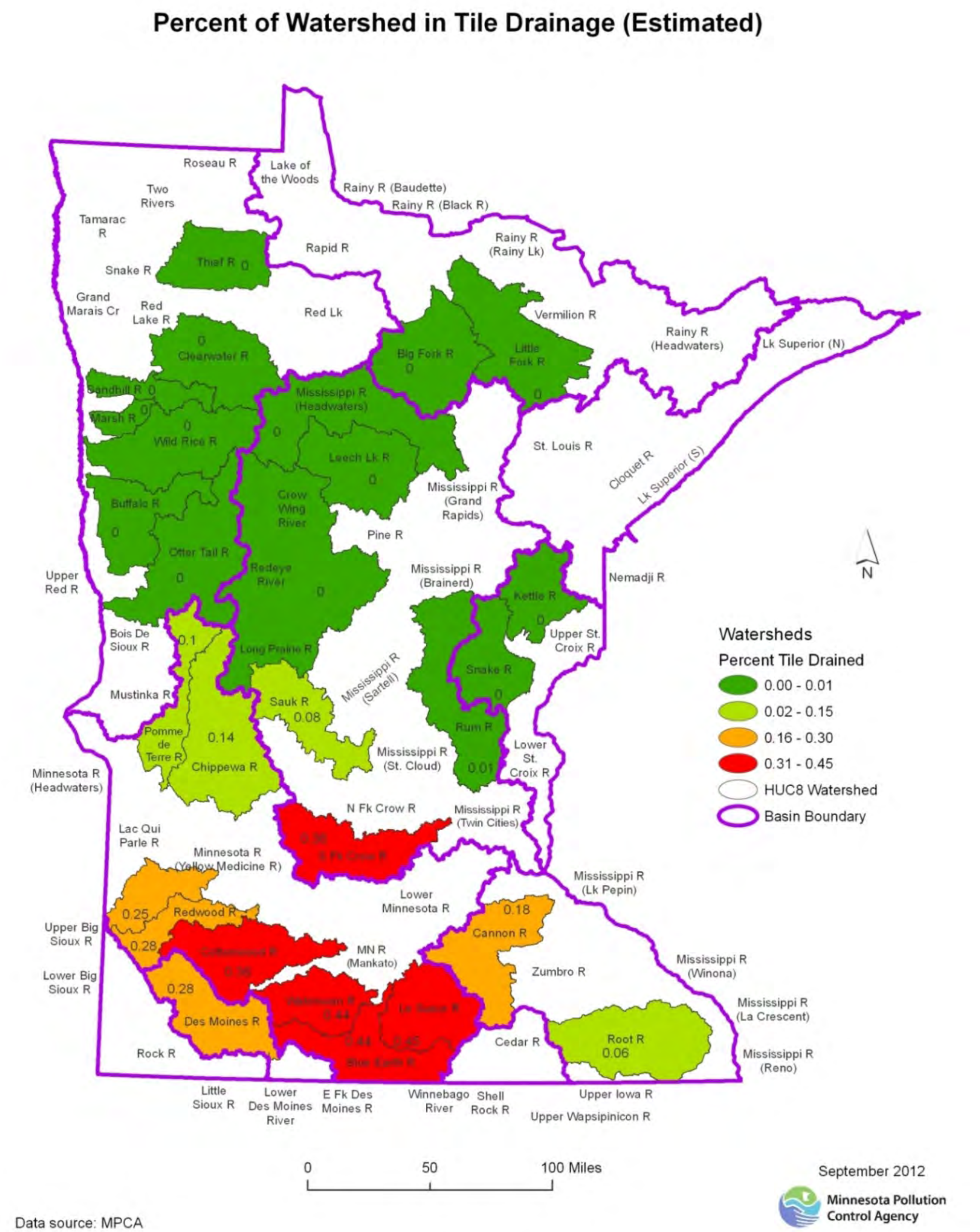


Figure E2-1-1. Fraction of watershed estimated to be tile drained for each of the 28 assessed watersheds analyzed in chapter E2.

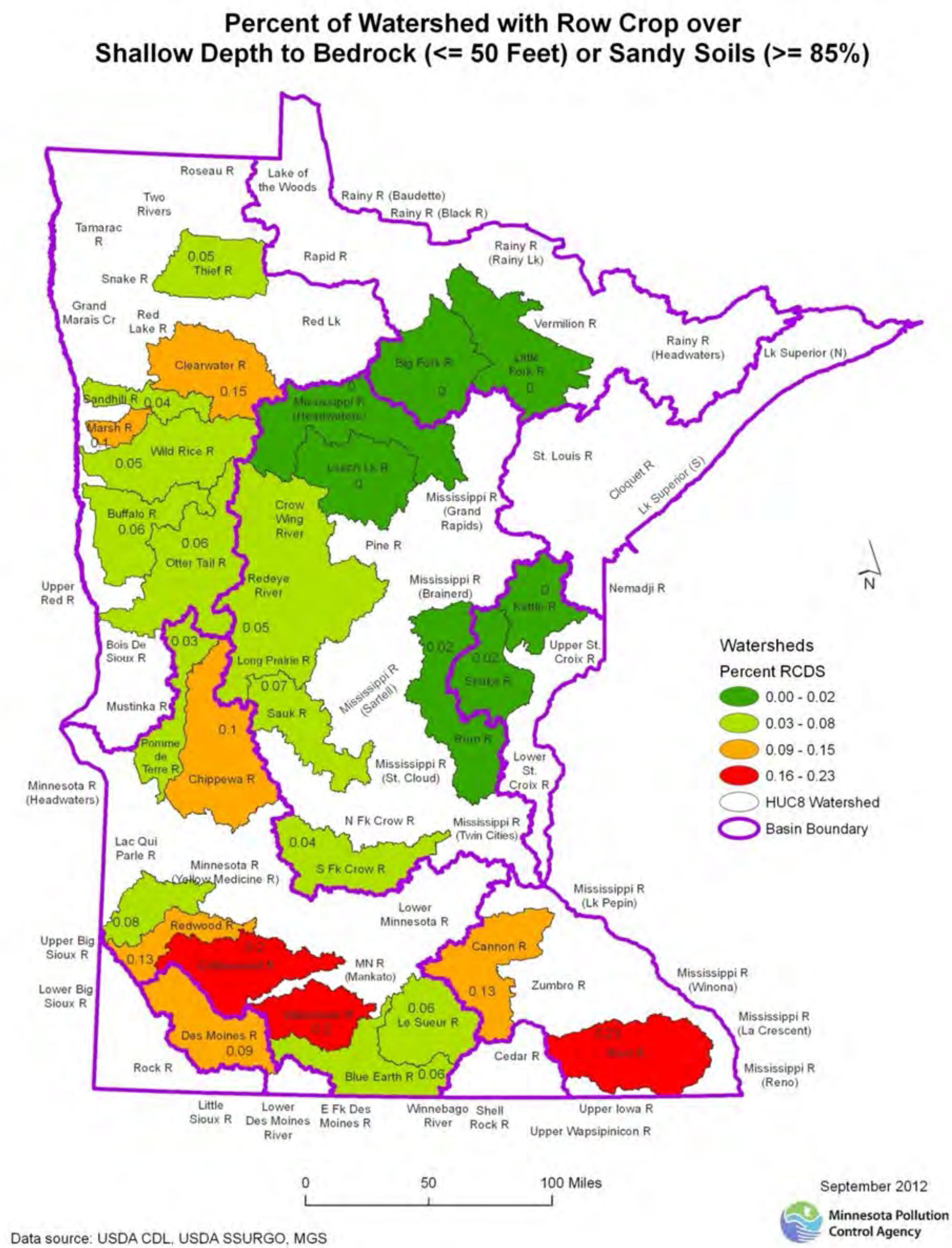


Figure E2-1-2. Fraction of watershed with a depth to bedrock estimated to be less than 50 feet plus fraction with sandy soils (>85% sand in subsoils) for each of the 28 assessed watersheds analyzed in chapter E2.

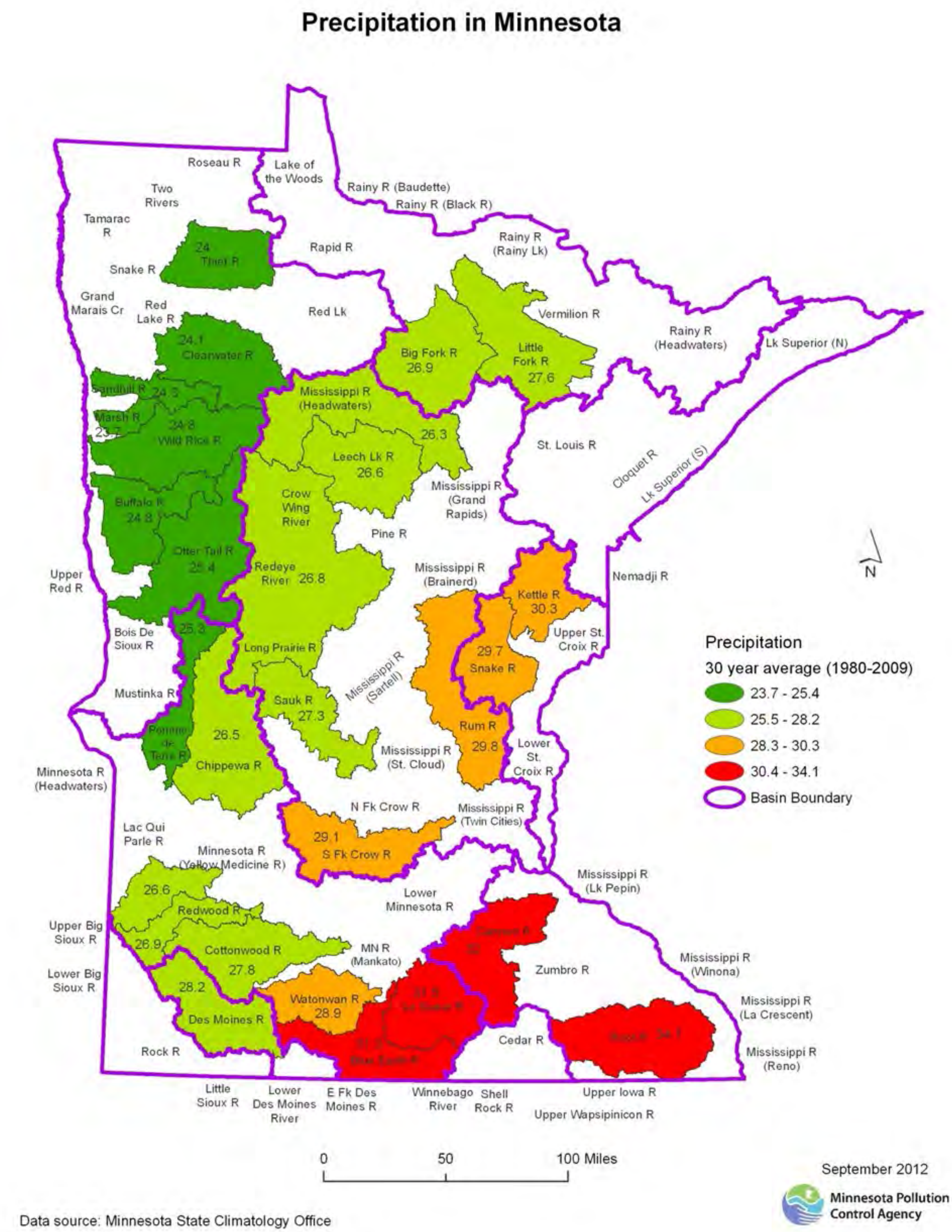


Figure E2-1-3. Average annual precipitation in each HUC8 Watershed (1980-2009).

Appendix E2-2.

Geographically weighted regression coefficients for the explanatory variables included in the multiple regression analysis in Chapter E2.

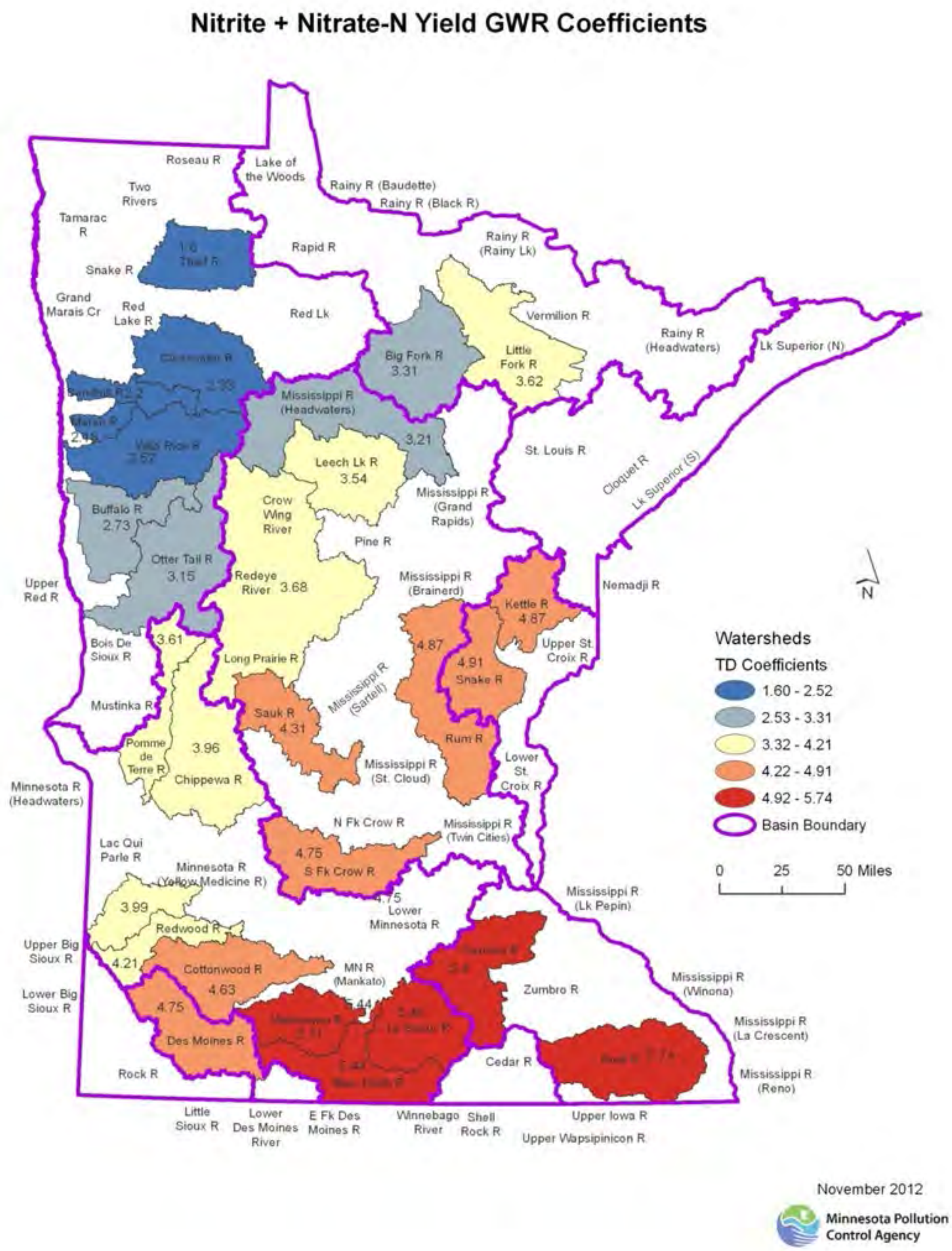


Figure E2-2-1. Geographically weighted regression coefficients for the tile drain explanatory variable for nitrite+nitrate-N yield included in the multiple regression analysis in Chapter E2.

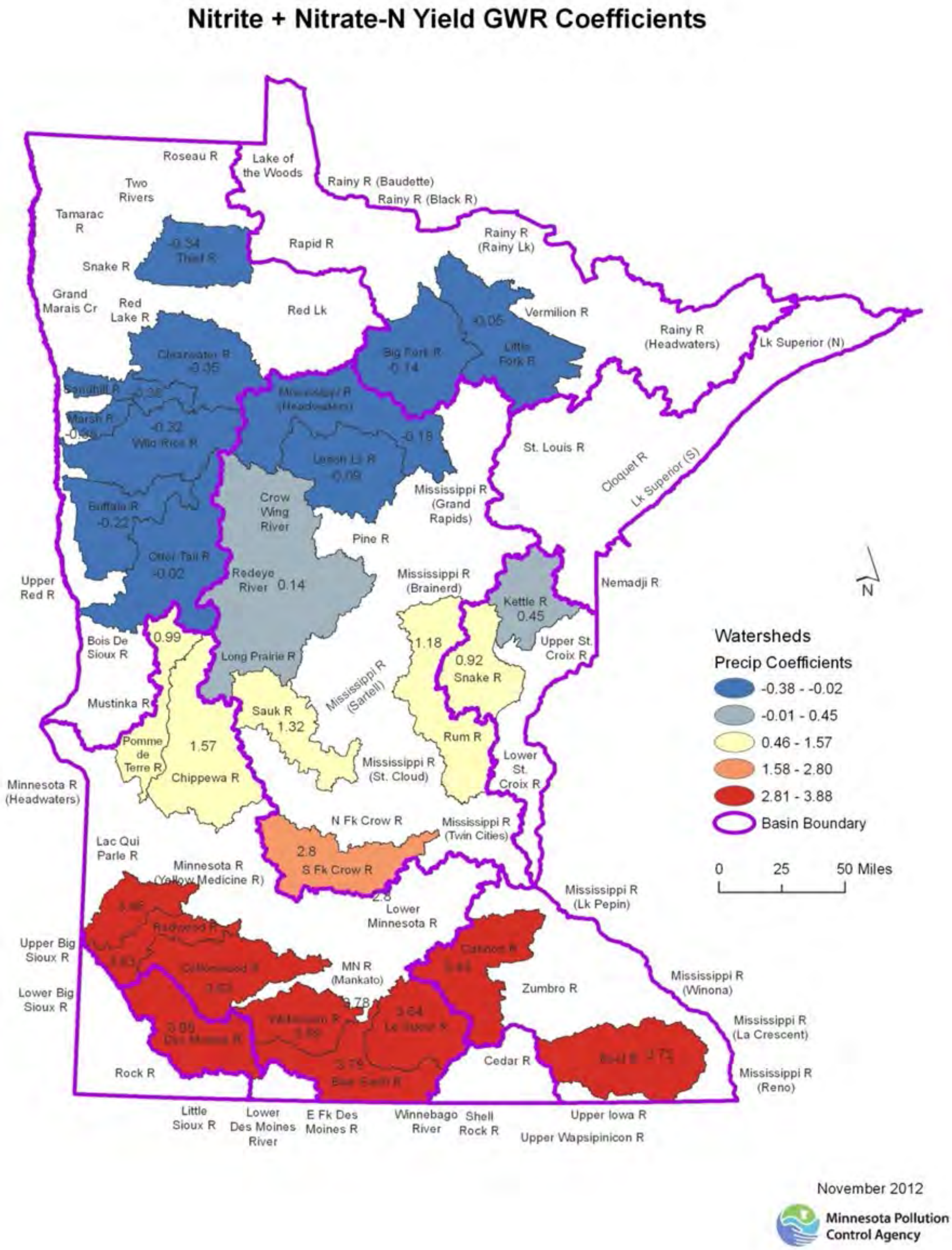


Figure E2-2-2. Geographically weighted regression coefficients for the precipitation explanatory variable for nitrite+nitrate-N yield included in the multiple regression analysis in Chapter E2.

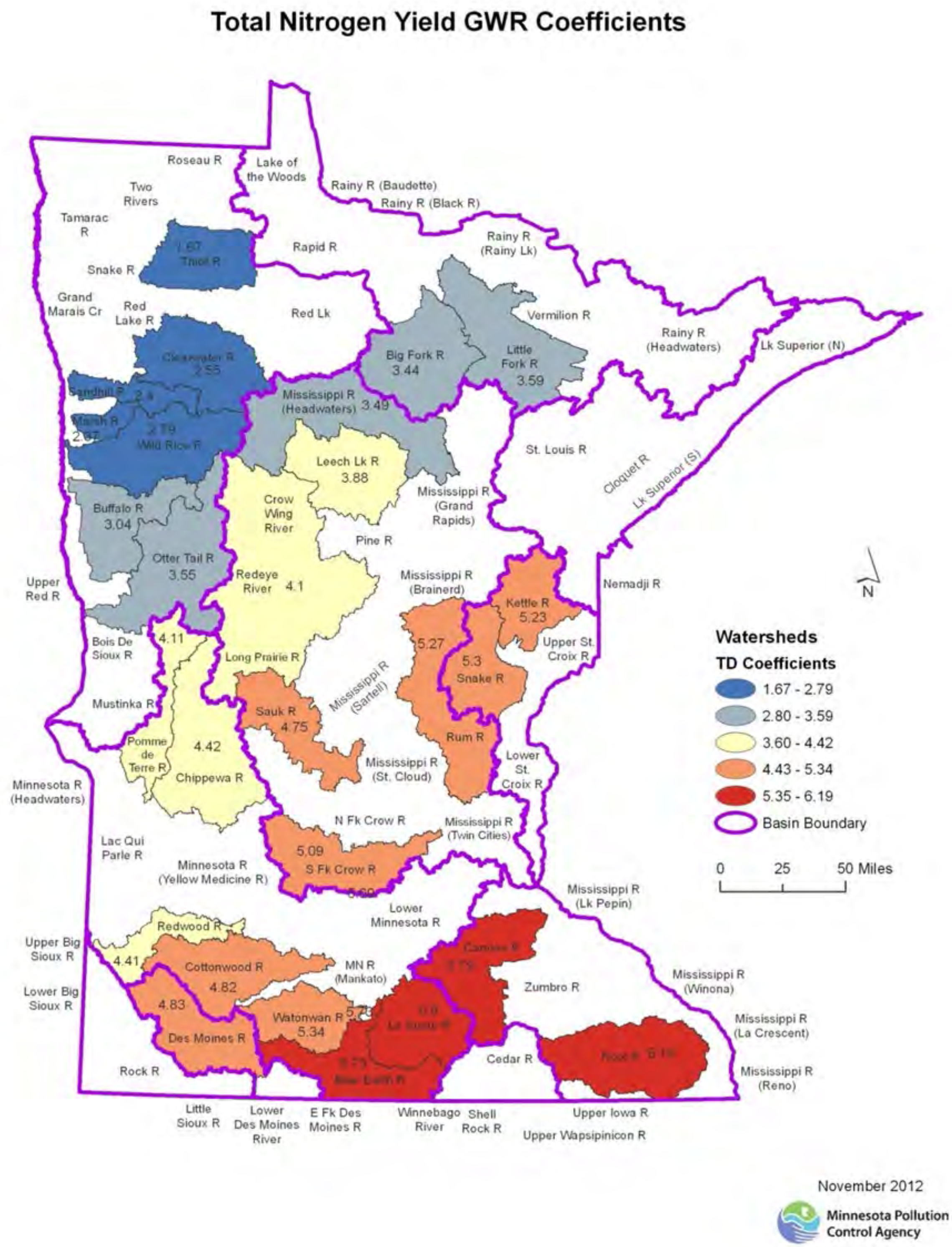


Figure E2-2-3. Geographically weighted regression coefficients for the tile drainage explanatory variable for TN yield included in the multiple regression analysis in Chapter E2.

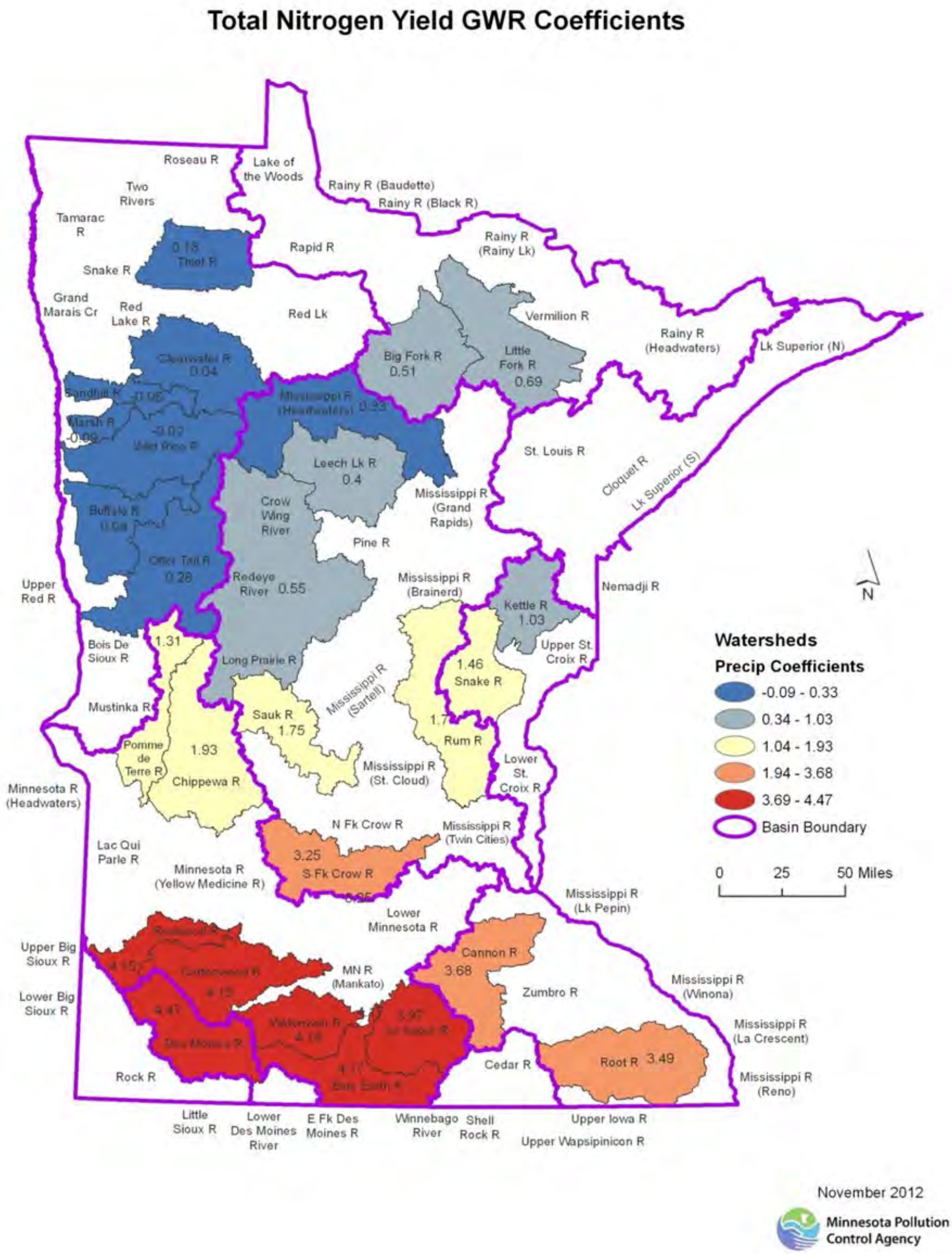
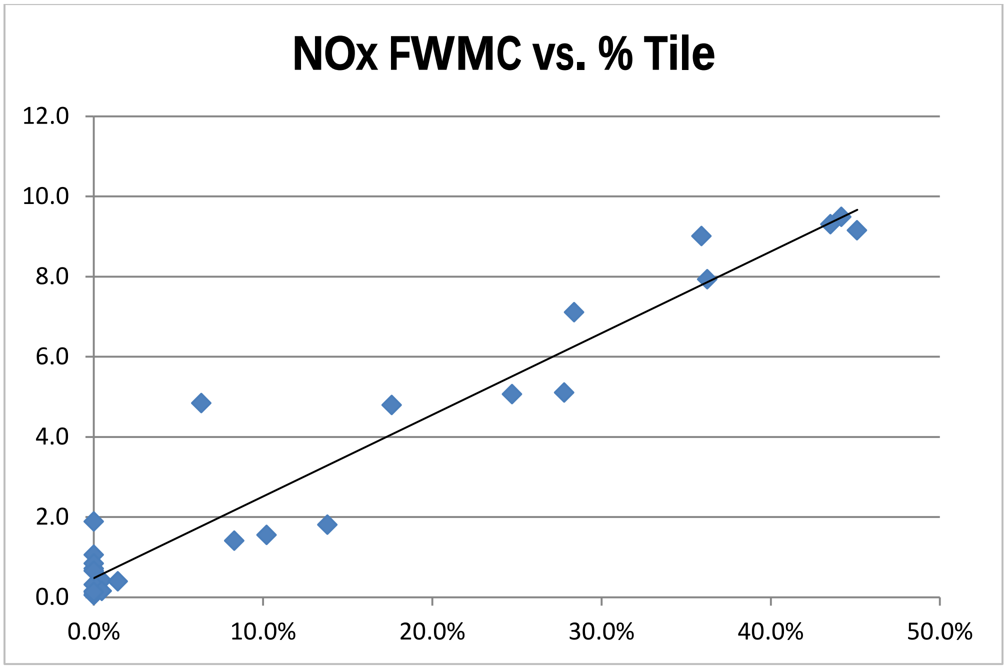
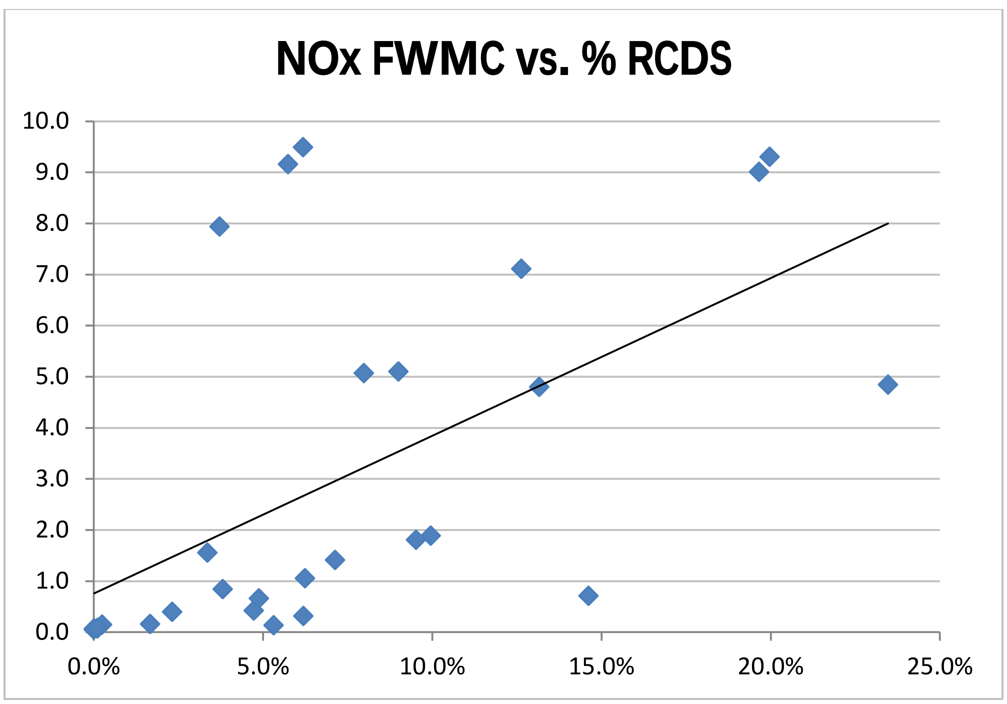


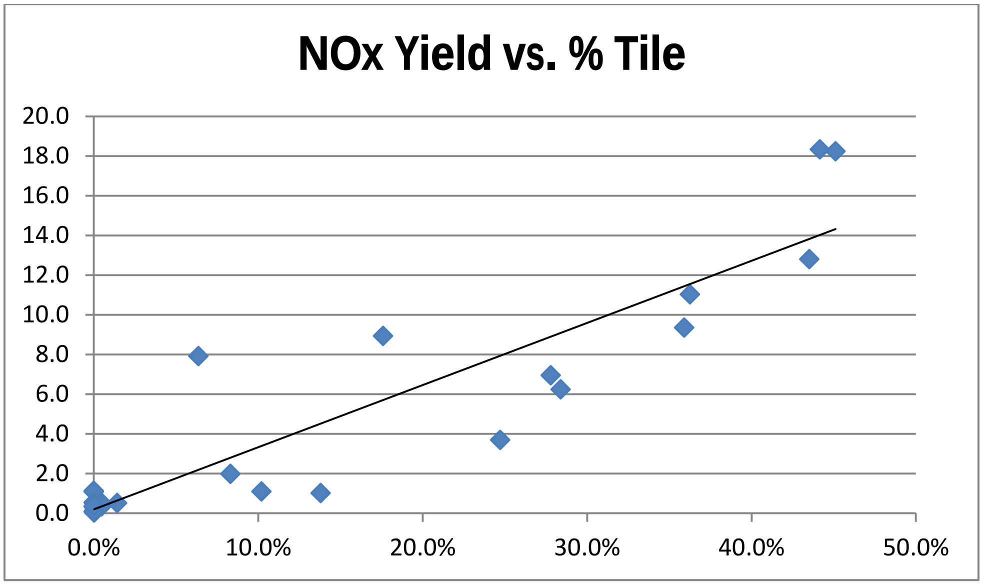
Figure E2-2-4. Geographically weighted regression coefficients for the precipitation explanatory variable for TN yield included in the multiple regression analysis in Chapter E2.

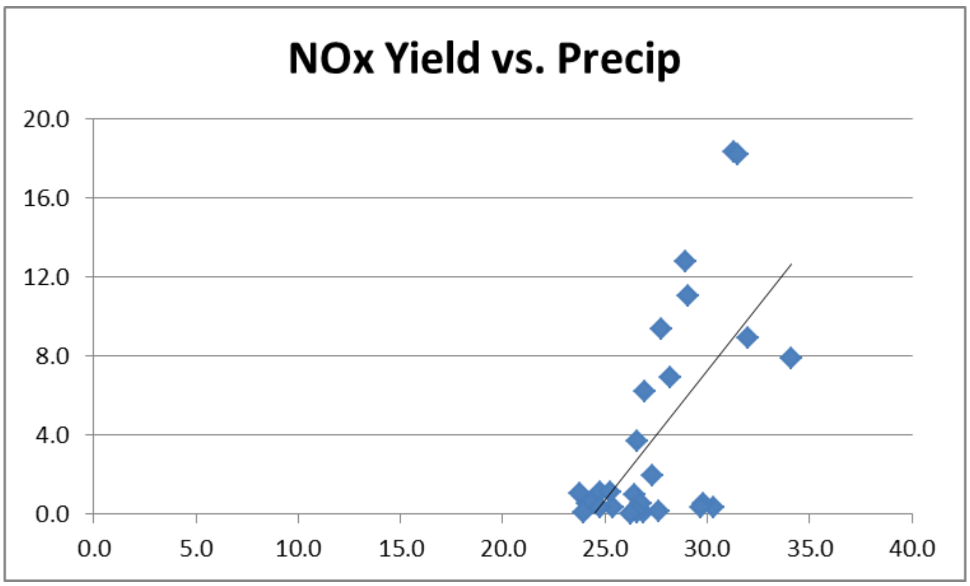
Appendix E2-3.

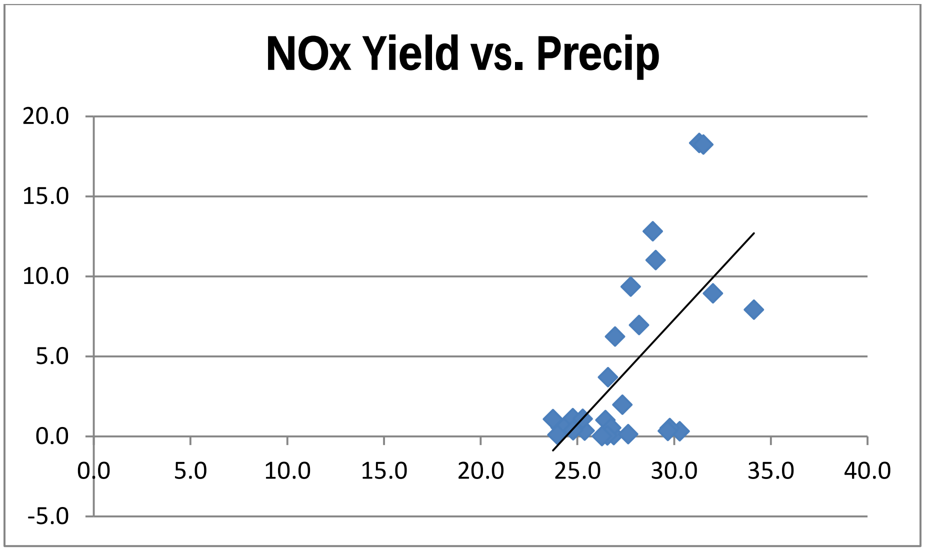
Scatter plots showing how individual explanatory variable results used in the best statistical models in Chapter E2 compare with stream nitrite+nitrate-N (NOx) and TN FWMCs and yields in Chapter E2. FWMCs are in mg/l. Yield is average pounds/acre across the lands contributing N to the monitoring station near the outlet of the watershed.

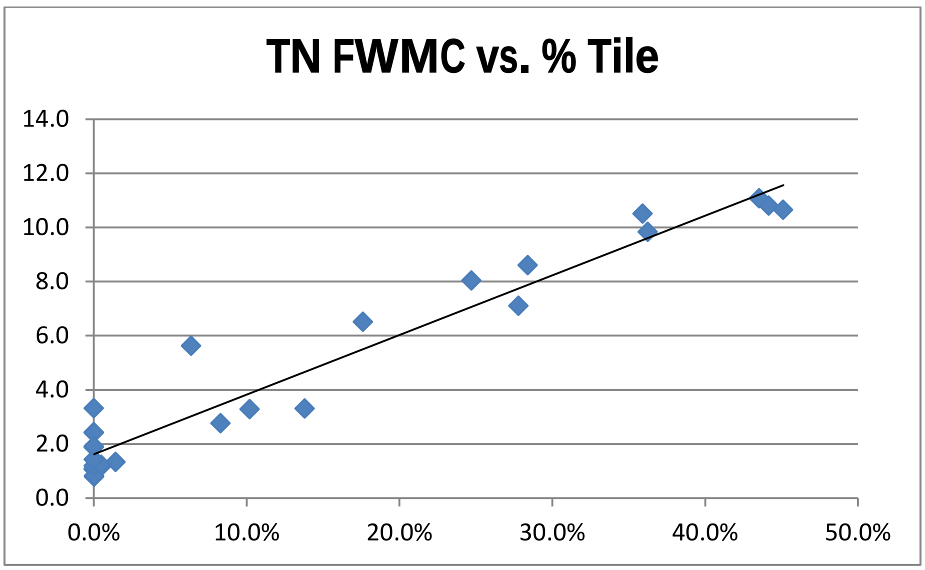


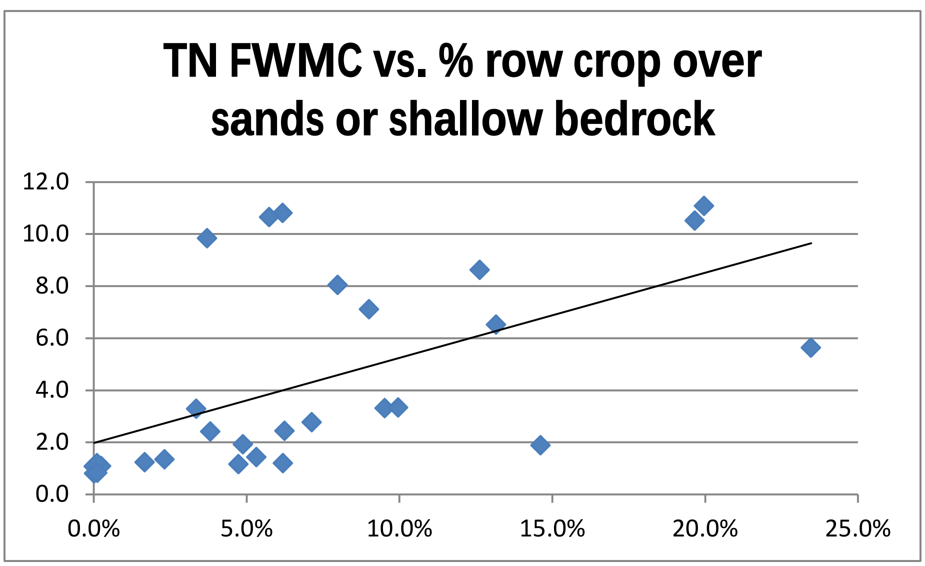


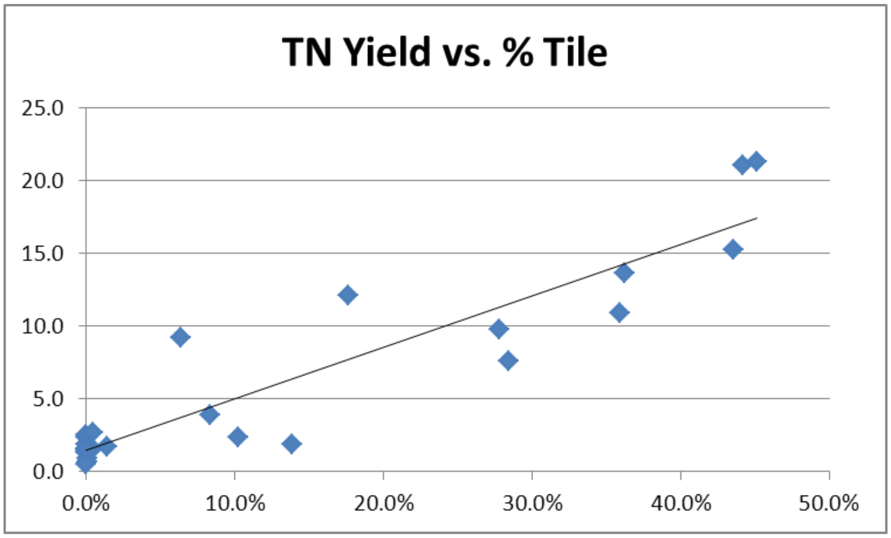

NOx Yield vs. % Tile
20.0
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
0.0%
10.0%
20.0%
30.0%
40.0%
50.0%

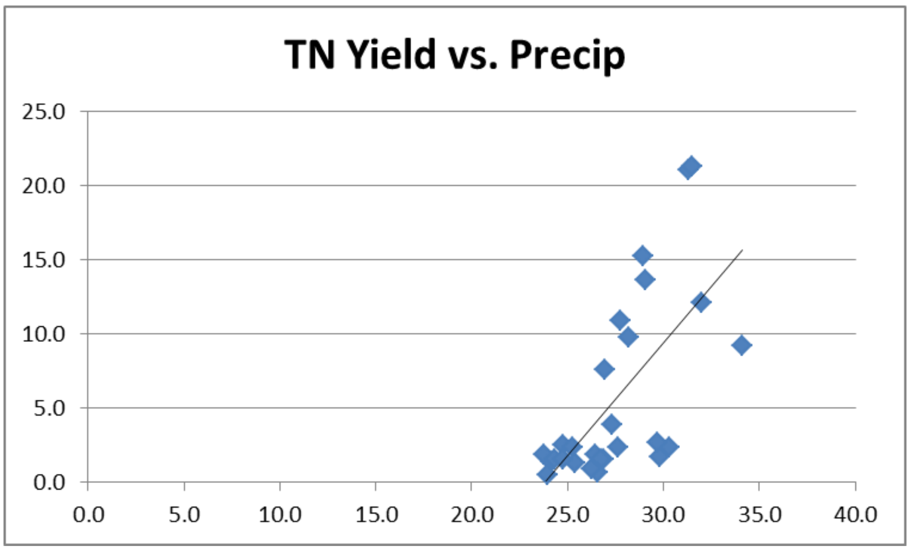

NOx Yield vs. Precip
20.0
16.0
12.0
8.0
4.0
0.0
0.0
5.0
10.0
15.0
20.0
25.0
30.0
35.0
40.0


NOx Yield vs. Precip
20.0
15.0
10.0
5.0
0.0
-5.0
0.0
5.0
10.0
15.0
20.0
25.0
30.0
35.0
40.0


TN FWMC vs. % Tile
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
0.0%
10.0%
20.0%
30.0%
40.0%
50.0%


TN FWMC vs. % row crop over sands or shallow bedrock
12.0
10.0
8.0
6.0
4.0
2.0
0.0
0.0%
5.0%
10.0%
15.0%
20.0%
25.0%


TN Yield vs. % Tile
25.0
20.0
15.0
10.0
5.0
0.0
0.0%
10.0%
20.0%
30.0%
40.0%
50.0%


TN Yield vs. Precip
25.0
20.0
15.0
10.0
5.0
0.0
0.0
5.0
10.0
15.0
20.0
25.0
30.0
35.0
40.0

Appendix F1-1. Effectiveness of Best Management Practices for Reductions in Nitrate Losses to Surface Waters in Midwestern U.S. Agriculture

Authors: Karina Fabrizzi and David Mulla, University of Minnesota

Abstract

Several best management practices (BMPs) are available to reduce NO_3-N loading from agricultural lands to surface water. These management practices are classified into three main categories: hydrologic, nutrient management, and landscape diversification BMPs. A literature review was conducted to identify the range of effectiveness of these BMPs in the Midwestern U.S. region in general, and Minnesota in particular. Hydrologic BMPs include practices to reduce discharge from subsurface tile drainage systems, such as changes in spacing or depth of tile drain systems, or installation of controlled drainage (CD) and bioreactors. Nutrient management BMPs consist of practices to reduce the impact of nitrogen (N) fertilizer, including reductions in rate of N applied, use of nitrification inhibitors, changes in timing of application, and split applications. Landscape diversification BMPs include alternative cropping systems that include perennial crops, use of cover crops or riparian buffer strips, and restoration of wetlands. Hydrologic BMPs can reduce nitrate loadings at the edge of field by an average of from 43-63%. Reductions at the watershed scale will be less than this; because not all land is suitable for these BMPs. Nutrient management BMPs can reduce nitrate loadings at the edge of field by an average of from 19-27%. Landscape diversification can reduce nitrate loadings at the edge of field by an average of from 42-73%.

Best management practices for nitrogen

Nitrogen from agriculture sources is a key contributor to the hypoxia in the Gulf of Mexico (Burkart and James, 1999). Nitrate (NO_3-N) entering the Gulf of Mexico through the Mississippi-Atchafalaya Rivers has led to nutrient over-enrichment, causing detrimental effects such as growth of phytoplankton, reduction in oxygen concentrations, fish migration, and mortality of some species (Mulla, 2008).

Several agricultural BMPs have been proposed to reduce NO_3-N losses into the surfaces water. The Gulf of Mexico Hypoxia Task Force set a goal to reduce the area of the hypoxic zone by 30% by 2015 (Mitsch et al. 2001). A BMP can be defined as a practice or combination of practices which are economically and technologically effective to reduce pollutant loads by nonpoint sources and reach water quality goals (EPA, 1980). Best management practices fall into three main categories: hydrologic, nutrient management, and landscape diversification practices (Figure 1).

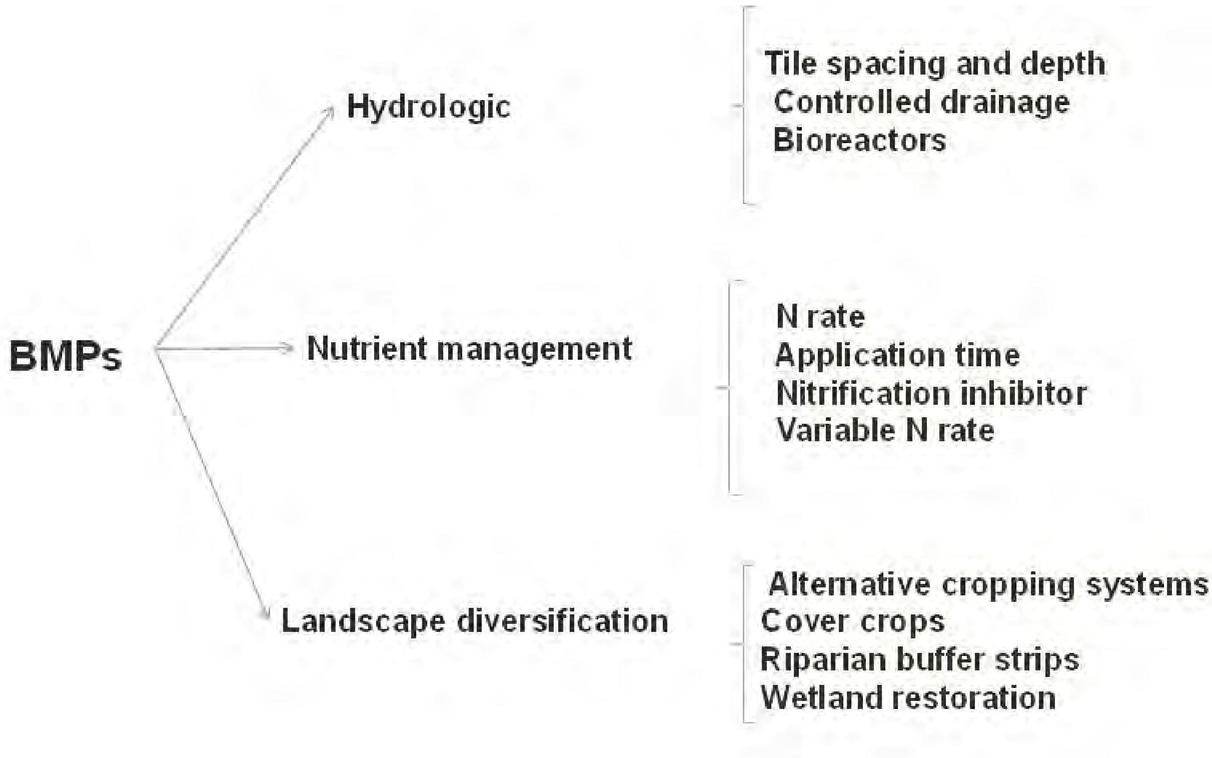


Figure 1. Best management practices to reduce N loading to surface water. Adapted from Mulla (2008).

1. Hydrologic best management practices

Agricultural drainage is an important practice in Minnesota implemented by farmers to facilitate trafficability of the fields and cropping systems operation such as crop planting and harvesting, reducing standing water on the fields during the growing season (Strock et al. 2010). Subsurface drainage is typically practiced on flat poorly drained soils with limited internal drainage due to an impermeable clay layer deep in the soil profile. In these cases, subsurface drainage may boost crop yields by as much as 30%.

Subsurface drains are typically installed at spacings of 20 to 30 meters (m) and depths of from 1 to 2 m in Minnesota. These systems were first installed using clay pipes during the 1920s after the advent of widespread construction of ditches throughout southern Minnesota. As these systems age, they are being replaced by more modern corrugated plastic pipes which became popular during the 1980s. New subsurface drain tile installations can be designed with environmental as well as production goals, the idea being that shallower tile installations could be used along with narrower spacings to maintain crop productivity while enhancing denitrification and reducing losses of nitrate to the environment.

In Minnesota, Sands et al. (2006) conducted a field experiment with a corn-soybean rotation designed to evaluate flow and nitrate-N losses from subsurface tile drains installed at depths of 0.9 or 1.2 m, and at spacings of roughly 10 or 20 m. They found an 18% reduction in annual flow and a 15% reduction in nitrate-N losses for the 0.9 m depth in comparison with the 1.2 m depth, without significant differences in nitrate-N concentrations. These results show that reductions in nitrate-N losses were largely attributed to reduced drainage flows at shallower tile depths.

Nangia et al. (2005a) used the Agricultural Drainage and Pesticide Transport (ADAPT) model to investigate the influence of subsurface tile drain depth and spacing on discharges of water and nitrate-N from tile drains under a corn-soybean rotation using a 50 year record of climatic conditions in southern Minnesota. The ADAPT model was calibrated and validated using a 10 year dataset for flow and nitrate-N losses from a 21 ha corn-soybean field in southern Minnesota. Baseline conditions for simulations included a tile spacing of 27 m, a tile depth of 1.2 m, and a fall application of 123 kg/ha N fertilizer. For a subsurface tile depth of 1.2 m, increasing the tile spacing from 27 to 100 m reduced nitrate-N losses from 43.1 to 9.5 kg/ha, a reduction of 78%. Reductions in nitrate-N losses are also possible by decreasing depth of tile drains, at a spacing of 27 m, reducing tile depth from 1.5 m to 0.9 m reduced nitrate-N losses from 43.1 to 17.5 kg/ha, a reduction of 59%.

1.1 Controlled drainage

Controlled drainage is one of the BMPs proposed to reduce nutrient loading to surface water. Controlled drainage consists in placing a water control structure near the outlet of the drainage systems such as stop logs or float mechanisms that can regulate the level of the water table. Controlled drainage has been used as a BMP in North Carolina for reducing N and P loadings to surface waters, and recently research has indicated that CD is an effective BMP to reduce N losses under different soils and climatic conditions (Skaggs and Youssef, 2008). In Ontario, Canada Drury et al. (1996) reported a 43% decrease in the total annual NO_3-N loading on a clay loam soil when comparing CD, sub irrigation and drainage treatments. In Quebec under a silt loam soil, Lalonde et al. (1996) found a reduction in NO_3 losses of 76% and 69% in 1992, and 62% and 96% in 1993, under water table control levels of 0.25 and 0.50 m above the drain, respectively, in the CD compared to subsurface drainage system. Thorp et al. (2008) using the RZWQM-DSSAT hybrid model simulated the effect of conventional drainage and CD over 25 years across 48 locations in the Midwestern of U.S. on drain flow and N losses. They reported a long-term average simulated reduction in drain flow of 53% and a 51% reduction in N losses. Drain flow reductions were offset by increases in surface runoff and evapotranspiration, and N loss reductions by increases in soil N storage, denitrification and plant uptake, so a more conservative percentage of NO_3 reduction would be 31% to consider these other effects. Fausey (2005) reported reductions of 41% in drain flow and 46% in N losses for a study conducted in Ohio. Tan et al. (1998) found greater reduction in NO_3 losses under CD treatments than in free drainage (FD) systems. NO_3 losses were reduced by 14% under conventional tillage and 25.5% under no-tillage systems, when comparing CD and FD systems. In Iowa, Kalita and Kanwar (1993) reported a reduction in NO_3 losses of 39% using a drainage water management system. In Ontario, Canada, under a sandy loam soil in a study conducted on corn, Ng et al. (2002) found that the cumulative drainage water volume from CD and sub irrigation treatments were 8% greater than for free tile drainage, but the flow weighted mean of nitrate concentration was reduced by 41% with the CD treatments, so the total nitrate loss was reduced by 36% compared with free tile drainage treatments. In Ontario Canada, Drury et al (2009) compared CD systems and controlled drainage systems with subsurface irrigation (CDS) with unrestricted tile drainage under a corn-soybean rotation. Reductions in NO_3-N of 44% and 66% were reported for CD and CDS when 150 kg N ha^{-1} was applied to corn, and no N was applied to soybean. They found that nitrate losses were reduced by 31% and 62% for CD and CDS when 200 kg N ha^{-1} was applied to corn, and 50 kg N ha^{-1} was applied to soybean.

Woli et al. (2010) conducted a field study in Illinois comparing CD and FD systems. Controlled drainage had greatly reduced NO_3-N removal (17 kg N ha^{-1} yr^{-1}) compared to FD systems (57.2 kg N ha^{-1} yr^{-1}) averaged over three years, representing an overall reduction of 70% with CD systems. Recently, Feser (2012) reported a 25% reduction in NO_3-N yields in a field study in Southwest Minnesota comparing conventional FD and CD in a loam texture soil.

Most of the cited studies indicated a positive response to the implementation of the CD systems in improving water quality. However some limitations are still in need for more research on this system. One of the limitations is that CD is only economically feasible on flat landscapes with less than 1% of surface slope. Also, this system requires maintenance by farmers after installation, including removal or adjustments to the weir boards according to the time of the year (Feser, 2012).

1.2 Bioreactors

In the Midwest, the use of bioreactors has potential to reduce N loads from agricultural drainage. Denitrification is the main mechanism to remove N through bioreactors. Bioreactors and denitrification walls are designed to intercept drainage water before leaving the field, and increase denitrification using a C source (Greenan et al. 2009). Nitrate in the drainage water is converted to N gas (dinitrogen, N_2) by denitrifying bacteria present in the soil and bioreactor. These bacteria use the carbon source added to the bioreactor (woodchip, sawdust, compost, paper fibers, etc.). There are two main characteristics that need to be considered when a bioreactor is designed; one is the volume of discharge that will circulate through the bioreactor, the second is having a long enough retention time to allow bacteria to convert the nitrate to N_2 (Christianson et al., 2009). Efficiency of bioreactor removal decreases during high flow periods such as spring runoff.

Some of the advantages of using bioreactors are: 1) no modification of current practices is needed, 2) No land has to be taken out of production, 3) there is no decrease in drainage effectiveness, 4) bioreactors require little or no maintenance, 5) carbon sources in bioreactors can last for up to 20 years (Cooke et al., 2008). As a new technology, still there are some concerns with its implementation related to 1) export of methyl mercury when water is retained in bioreactors for long periods of time, 2) discoloration of the outflow water, and 3) the production of nitrous oxide, a greenhouse gas, if the denitrification process is not complete (Christianson and Helmers, 2011).

Early research showed a reduction in NO_3-N concentration using bioreactors containing a C source to enhance denitrification (Blowes et al. 1994; Robertson and Cherry, 1995; Schipper and Vojvodić-Vuković, 1998, 2001).

More recent research also shows that bioreactors are effective at reducing the amount of NO_3-N reaching surface waters. In a laboratory study, Greenan et al. (2009) found a 100, 64, 52, and 30% efficiency of NO_3-N removal for flow rates of 2.9, 6.6, 8.7 and 13.6 cm d^{-1}, respectively, using column bioreactors that contained woodchips as a C source. The authors also state that denitrification was the main mechanisms for NO_3-N removal, and the denitrification process (NO_3 to N_2) was complete since the production of nitrous oxide was insignificant (0.003 to 0.028% of N denitrified). Chun et al. (2009) using a laboratory scale bioreactors reported a range of NO_3-N removal depending on the retention time. High retention time results in 100% NO_3-N removal, while low retention time produced a 10-40% removal of NO_3-N. Greenan et al. (2006) compared different C sources in a laboratory study, and found greater NO_3-N removal with cornstalks followed by cardboard fibers, wood chips with oil, and wood chips alone. For all C sources, denitrification was the main pathway of NO_3-N removal.

Chun et al. (2010) observed a 47% removal of NO_3-N in a field-scale bioreactor using woodchips as C source and a retention time of 4.4 h in Decatur, Illinois. This is a greater amount removed than those reported in laboratory scale bioreactors with similar retention time (Chun et al. 2009). A pilot-scale evaluation of a bioreactor was performed in Iowa by Christianson et al. (2011). The authors observed that from 30 to 70% of NO_3-N was removed with a retention time ranging from 4 to 8 h. In Illinois under a corn soybean-rotation, Woli et al. (2010) showed that NO_3-N loading could be reduced by 33% for a bioreactor associated with CD.

Verma et al. (2010) evaluated the performance of bioreactors to remove NO_3-N from tile drainage in three experimental sites located in Illinois. Percentages of load NO_3-N reduction were 42, 54 and 81% for a loading density (acres/100 sq. feet of bioreactor area) of 1.25, 4, and 8.5 in 2007-08, respectively, and 48 and 98 % for loading densities of 8.5 and 1.25, respectively, in 2008-09. The authors presented a relationship between load reduction and loading density (bioreactor efficacy curve) which showed that NO_3-N reductions decreased as loading density increased. The relationship between these two parameters could help to improve the design of bioreactors.

In Ontario, van Driel et al. (2006) tested two bioreactor designs using alternating layers of fine and coarse wood particles as a labile carbon source in a corn field (lateral flow design) and golf course (upflow design). NO_3-N removal averaged 33% and 53% for the corn field and golf course sites, respectively. Authors also estimated that carbon consumption from denitrification was less than 2%, which indicates that these reactors can be used for several years without replenishment of the C source. Thus, it appears that bioreactors have a great potential for use as a BMP to control N loading, are relatively cheap, and have low maintenance.

Jaynes et al. (2008) compared NO_3 losses from a conventional drainage system and two alternative systems: deep tile (DT) and a denitrification wall (DW) in a corn-soybean rotation in Iowa, reporting an annual NO_3-N reduction of 55% with the denitrification wall over a 5 year period; however DT treatments did not lower NO_3-N concentrations or mass loss in drainage.

Ranaivoson et al (2012) evaluated the performance of two woodchip bioreactors in Minnesota. At Dodge County site, nitrate loading reduction was of 26 and 10% during snowmelt period in 2010 and 2011, respectively. During rainfall season reductions were 48 and 21% in 2009 and 2010, respectively, and the differences between years could be related to the greater rainfall in 2010. In Rice County site, the bioreactor presented an overall nitrate loading reduction of 47%.

Table 1. Effectiveness of hydrological management practices to reduce nitrate (NO_3-N) concentrations under tile drainage management.

Type of study	Reference	Site	% Reduction in NO_3-N loss
Drainage	Sands et al. (2006)	Minnesota	15%
	Nangia et al. (2010)	Minnesota	59 to 78%
	Kalita and Kanwar (1993)	Iowa	39%
	Lalonde et al. (1996)	Quebec, Canada	62 to 96%
	Drury et al. (1996)	Ontario, Canada	49%
	Drury et al. (2009)	Ontario, Canada	31 to 44%
	Thorp et al. (2009)	Midwestern U.S.	31%
	Tan et al. (1998)	Ontario, Canada	14 to 26%
	Fausey (2005)	Ohio	46%
	Feser 2012	Minnesota	25%
	Ng et al. (2002)	Ontario, Canada	36%
	Woli et al. (2010)	Illinois	70%
	Range of % reduction		**14 to 96%**
Bioreactors	Blowes et al. (1994)	Ontario (field)	99%
	Roberson and Cherry (1995)	Canada (septic systems)	58 to 96%
	Schipper and Vojvodić-Vuković (1998)	New Zealand (field)	60 to 88%
	Schipper and Vojvodić-Vuković (2001)	New Zealand (field)	>95%
	Greenan et al. (2009)	Laboratory experiment	30 to 100%
	Greenan et al. (2006)	Laboratory experiment	80 to 96%
	Chun et al. (2009)	Laboratory experiment	10-40 to 100%
	Chun et al. (2010)	Illinois (field)	47%
	Christianson et al. (2011)	Iowa (field)	30-70%
	Verma et al. (2010)	Illinois (field)	42 to 98%
	Woli et al. (2010)	Illinois (field)	33%
	van Driel et al. (2006)	Ontario (field)	33 to 53%
	Jaynes et al. (2008)	Iowa (field)	55%
	Robertson et al. (2000)	Ontario (field)	58%
	Ranaivoson et al. (2012)	Minnesota (snowmelt+ rainfall-field)	31 to 74%
	Ranaivoson et al. (2012)	Minnesota (field)	47%
	Range of % reduction		**10 to 99%**

2. Nutrient management best management practices

2.1. Nitrogen rate

Reducing N rates from fertilizer or manure, shift in time of application and use of nitrification inhibitors are some of the BMPs available to reduce N loading to surface water. Several studies in the Midwest on tile drained lands have shown that reducing N fertilizer rates for corn resulted in decreased NO_3-N concentrations in tile discharge (Kladviko et al., 2004; Buzicky et al., 1993; Nangia et al., 2005; Gowda et al., 2006a, Jaynes et al., 2004a).

In Minnesota, Buzicky et al. (1983) reported a 28% reduction in NO_3-N losses from tile drainage by reducing spring-applied N rates from 202 to 134 kg ha^{-1}. Using the ADAPT model, Nangia et al. (2005a) estimated a reduction of 12% to 15% in nitrate-N losses at the field scale when reducing N rates from 180 to 135 kg N ha^{-1} under a corn soybean rotation. Nangia et al. (2010), using the ADAPT model in Seven Mile Creek, Minnesota, estimated that decreasing N rates from 179.3 to 112 kg N ha^{-1} could reduce nitrate losses by 23% (28.2 to 21.8 kg NO_3-N ha^{-1}).

Besides N rate reductions, cropping systems also had an influence on the amount of NO_3 losses on tile drainage. Losses were greater under continuous corn than under corn-soybean rotations, which could be explained by the frequency of annual fertilization. Under continuous corn, N is applied to corn every year, however, in corn-soybean rotations N is applied every other year, reducing the total amount of N entering the system. Several researchers showed decreases in NO_3-N losses when cropping systems were shifted from continuous corn to corn-soybean (Wee and Kanwar, 1996; Kanwar et al. 1997; Bakhsh et al. 2005; Randall et al. 1997). Kladivko et al. (2004) reported a reduction of 70% in the concentration of NO_3-N (28 to 8 mg NO_3-N L^{-1}) in tile drainage during a 14 year period with such a shift in cropping system. This reduction could also be attributed to decreases in N rate over time and the inclusion of a winter cover crop in the SC rotation.

In summary, there is a potential to reduce NO_3 losses through tile drainage by reducing N application rate if producers are currently applying N at rates greater than the maximum net economic return, however at the optimum N rate producers will face an economic reduction to achieve lower NO_3-N concentrations in tile drainage (Sawyer and Randall, 2008).

Table 2. Effectiveness of N management practices to reduce nitrate (NO_3-N) concentrations under tile drainage management.

Type of study	Reference	Site	% of Reduction in NO_3-N loss
N rates	Buzicky et al. (1983)	Minnesota	28%
	Nangia et al. (2005a)	Minnesota (model)	12 to 15%
	Gowda et al. (2006)	Minnesota (model)	11 to 14%
	Jaynes et al. (2004a)‡	Iowa	30%
	Baksh et al. (2004)	Iowa	17%
	Nangia et al. (2010)	Minnesota (model)	23%
	Kladivko et al. (2004)†	Indiana	70%
	Range of % reduction		**11 to 70%**
N application time and Inhibitors			
	Smiciklas and Moore (1999)	Illinois	58%
	Randall and Mulla (2001)	Minnesota	36%
	Gowda et al (2006)	Minnesota	34%
	Nangia et al. (2005b)	Minnesota	6%
	Randall et al (2003)	Minnesota	17 to 18%
	Randall and Vetsch (2005)	Minnesota	10 to 14%
	Range of % reduction		**10 to 58%**
	Randall et al. (2003)	Minnesota	13%
Split applications	Jaynes et al. (2004)	Iowa	30%
	Range of % reduction		**13 to 30%**

† This reduction also includes the effect of changing crop rotation and adding cover crops plus changing N rate over time.
‡ This reduction is also related to changing time of application.

2.2. Nitrogen application time, split applications and use of inhibitors

Shifting from fall to spring N fertilizer application is a BMP to reduce NO_3 losses to surface water. This practice is, however, challenging for farmers because it implies a greater risk due to a narrow time window for applying spring fertilizer. In spring, soils are typically wet, and rainfall is frequent. Thus some producers want to avoid the risk of failing to have enough time to apply N fertilizer in spring, and do not want to risk a loss of crop

Randall and Mulla (2001) reported a 36% reduction in nitrate losses when comparing fall to spring application in Minnesota. For two Minnesota watersheds, Gowda et al (2006) estimated a 34% reduction in nitrate losses by switching from fall to spring application. Randall et al. (2003) evaluated the influence of time of N application and use of nitrapyrin on nitrate losses in a corn-soybean rotation at Waseca, Minnesota from 1986-1994. They showed that NO_3-N losses in drainage were reduced by

18% with fall N + NP and by 17% in spring, and by 13% for split-applications relative to fall N application without NP. Randall and Vetsch (2005) reported that for the period from 1993 to 2000, NO_3-N losses were reduced by 14% with spring N applications, and by 10% with late fall + NP application.

Split applications of N are another alternative to reduce NO_3-N losses through tile drainage. With split applications, N use efficiency by crops should increase due to better synchronization in the amount of N available and crop uptake (Randall and Sawyer, 2008). Jaynes et al. (2004) evaluated the effect of using the late spring nitrate test (LSNT) in corn and reported that in two of the four years, LSNT significantly reduced N applications, and annual NO_3-N concentrations for the last two years were 11.3 mg N L^{-1} for LSNT and 16 mg N L^{-1} for the control subbasins. The authors concluded that a reduction of 30% in NO_3-N losses in tile drainage could be attained if LSNT programs are adopted. The LSNT method is not, however, widely used in Minnesota. As mentioned before, Randall et al. (2003) also reported a 13% reduction for split-applications relative to the fall N without NP treatments. However, some studies reported higher losses of NO_3-N with split applications under continuous corn (Baker and Melvin, 1994).

3. Landscape diversification best management practices

3.1 Buffers

Conservation buffers are defined as areas of permanent vegetation that intercept and slow runoff, improve infiltration and overall water quality. Conservation practices such as field strips, riparian forest buffers, and riparian herbaceous cover, conservation cover, contour buffer strips, alley cropping, grassed waterways, and vegetative barriers are considered buffers (Helmers et al. 2008). Riparian buffers help to regulate the stream environment, controlling sediments and contaminants carried in surface runoff, including nitrate in shallow groundwater moving to the streams (Lowrance et al. 2000). The effectiveness of riparian buffers to remove nitrate will depend on the proportion of the groundwater moving in or near the biologically active root zone, the residence time, the site and weather conditions as well buffer design (Helmers et al. 2008). Nitrate in shallow groundwater can be removed by several mechanisms: including dilution (Hubbard and Lowrance, 1997; Spruill, 2000), plant N assimilation (Lowrance, 1992; Hubbard and Lowrance, 1997; Mayer et al. 2007); or denitrification (Jacobs and Gilliam, 1985; Addy et al. 1999, Gold et al. 1998). In the Midwestern region, the use of these buffers has not been effective in removing NO_3-N in tile drained soils, since tile discharge bypasses the buffers and goes directly into surface water; however alternative strategies to treat tile discharge with buffers are under current study (Isenhart and Jaynes, 2012). Riparian buffers generally have lower flow rates, less buildup of organic C in soils, and higher redox potential than wetlands (Mitsch et al. 2001).

In North Central Minnesota, Duff et al. (2007) evaluated three well transects from a natural, wooded riparian zone adjacent to the Shingobee River. The authors reported a reduction in groundwater NO_3-N concentrations from 3 mg N L^{-1} beneath the ridge to 0.01 to 1 mg N L^{-1} at wells 1 to 3 m from the channel, which represents a 67 to 99% efficiency. However, an increase in NO_3-N due to cultivation could result in an increased in NO_3-N movement to the channel.

Petersen and Vondracek (2006) evaluated the effect of buffer width on sediment, N, phosphorus, and runoff in the Karst region of Minnesota using a spreadsheet model. The authors reported that buffers around sinkholes could contribute to the reduction of sediment and nutrients in Minnesota, with buffers 15 m wide being more cost effective in relation to the cost of the Conservation Reserve Program management practice.

Table 3. Effectiveness of landscape diversification management practices to reduce nitrate (NO_3-N) concentrations.

Type of study	Reference	Site	% Reduction NO_3-N
Riparian Buffers*	Barfield et al. (1998)	Kentucky	95 to 98%
	Blanco-Canqui et al (2004a)	Missouri	94%
	Blanco-Canqui et al (2004b)	Missouri	47 to 69%
	Dillaha et al (1989)	Virginia	54 to 77%
	Magette et al. (1989)	Maryland	17 to 72%
	Schmitt et al. (1999)	Nebraska	57 to 91%
	Lowrance and Sheridan (2005)	Georgia	59 to 78 %
	Duff et al (2007)	Minnesota	67 to 99%
	Range of % reduction		**17 to 99%**
Wetlands	Appelboom and Fouss (2006)		37 to 83%
	Kovacic et al. (2000)	Illinois	33 to 55%
	Crumpton et al. (2006)	Iowa	25 to 78%
	Hunt et al. (1999)	North Carolina	70%
	Xue et al. (1999)	Illinois	19 to 59%
	Iovanna et al. (2008)	Iowa	40 to 90%
	Range of % reduction		**19 to 90%**

***Note:** none of the riparian buffer studies referenced here were at sites with subsurface tile drainage.

3.2 Wetlands

Wetlands are saturated or inundated areas in landscape depressions. In the Midwest, wetlands are an alternative management practice to reduce nitrate concentrations in tile drained areas before nitrates are transported to surface waters. Some of the mechanisms that cause wetlands to act as a “sink” of N are:1) NH_4 is the predominant form of N in most flooded wetlands soils and can be taken up by the vegetation through roots, or can be immobilized and transformed in organic matter (Mitsch et al. 2001), and 2) NO_3 can be used as the terminal electron acceptor for oxidation of C sources under anaerobic conditions and denitrification and 3) dissimilatory reduction of NO_3 to NH_4 can occur, with NH_4 being absorbed by plants (Bowden, 1987). Several factors influence the effectiveness of wetlands to remove nitrate: scale, landscape position, geographic location, ratio of runoff volume to storage volume of the wetland, the extent of subsurface tile drainage, resident time of the water, water temperature, vegetation type, N loading rates and forms of N (NO_3 vs. NH_4 or organic N), and soil characteristics (texture, permeability) (Mulla, 2008, Crumpton et al. 2008).

Kovacic et al. (2000) evaluated the effect of constructed wetlands to reduce N in Illinois. They reported that in a three year period 37% of the incoming N (most of as NO_3) was removed and if a buffer strip was between the wetland and the river, an overall efficiency removal rate of 46% was achieved. Crumpton et al. (2006) reported annual NO_3-N removal rates of 25, 68, and 78% in three wetlands in Iowa. Xue et al. (1999) evaluated the capacity of constructed wetlands to remove NO_3-N on tile drained soils in Illinois. The authors found that the ratio of denitrification capacity and mean NO_3-N loads ranged from 19 to 59 % with an average of 33%.

Constructed wetlands on tile drained lands are being considered as a potential BMP to improve water quality in the Corn Belt. In 2001, Iowa initiated a conservation program (Conservation Reserve Enhancement Program) to promote the adoption of practices that could reduce the effects of tile-drained lands on water quality; wetlands are one option being implemented. To date, 27 wetland pools have been constructed, and monitoring data suggest that 40 to 90% of the NO_3-N can be removed (Iovanna et al. 2008).

Although more research is needed to determine the effectiveness of the wetlands to reduce N loadings in tile drained lands (design, maintenance, size, amount of N load into the wetland), the main constraint for adoption is related to the cost associated with the restoration and construction of the wetlands and land taken out of production (Crumpton et al. 2008).

3.3 Alternative cropping systems

The use of alternative cropping systems has shown advantages to reduce nitrate losses. Randall et al. (1997) reported a reduction of 7% in NO_3-N flux over a 4-year period involving a shift from continuous corn to a corn-soybean rotation. In the same study, greater reductions were achieved when alfalfa was included in the rotation (97%) and with the implementation of the Conservation Reserve Program (98%). Including perennials in the rotation implies that crops are actively growing for a longer time and had greater evapotranspiration than annual crops, which would contribute to greater N uptake and less drainage. Also perennial crops receive less N input through fertilization than annual cropping systems, thereby reducing NO_3-N leaching potential.

3.4 Cover crops

Cover crops are planted before or after crop harvest. Cover crops such as rye, small grains, and clover can accumulate N during the fallow period, thus preventing leaching of the residual soil N. Other advantages of using cover crops are related to improved soil quality, increasing soil organic matter and protecting soil from erosion (Lal et al., 1991, Kaspar et al., 2001). Kladivko et al. (2004) found over a 15 year period annual NO_3-N losses from tile drained soil were reduced by 60% (38 to 15 kg ha^{-1}) when continuous corn was replaced by a corn-soybean rotation with a fall cover crop of winter wheat. Strock et al. (2004) evaluated the effect of autumn winter rye to reduce NO_3-N losses in subsurface tile drainage under a corn- soybean rotation at Lamberton, Minnesota. The authors reported a 13% reduction in NO_3-N losses with corn- soybean and a rye cover crop. Also, for southwestern Minnesota, Feyereisen et al. (2006) showed that NO_3-N losses could be reduced by 30% or 11% depending on the planting day of the cover crop (September 15 or October 15, respectively). Kaspar et al. (2007) reported a decrease in NO_3-N loads (4 year average) of 61% in subsurface drainage water using a rye winter cover crop, but no differences were observed with the inclusion of gammagrass (Tripsacum dactyloides L.) in the corn-soybean rotation.

Winter cover crops have the potential to reduce N loadings because they decrease water flow, nitrate concentrations and N loading to surface waters (Kaspar et al. 2008), thereby improving soil and water quality. However, their general adoption is affected by some limitations that affect the development of cover crops as a function of climate (lack of rainfall), poor soil conditions and delays in planting time of the cover crop.

Table 4. Effectiveness of landscape diversification management practices to reduce nitrate (NO_3-N) concentrations under tile drainage management.

Type of study	Reference	Site	% Reduction in NO_3-N loss
Alternative cropping systems	Randall et al. (1997)	Minnesota	7 to 98%
	Boody et al. (2005)	Minnesota	51 to 74%
	Simpkins et al. (2002)	Iowa	5 to 15%
	Range of % reduction		**5 to 98%**
Cover crops			
	Kladivko et al. (2004)	Indiana	<60%
	Feyereisen et al. (2006)	Minnesota	11 to 30%
	Strock et al. (2004)	Minnesota	13%
	Jaynes et al. (2004b)	Iowa	60%
	Kaspar et al. (2007)	Iowa	61%
	Range of % reduction		**11 to 60%**

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Minnesota Department of Agriculture

Pesticide and Fertilizer Management Division

STATEMENT OF NEED AND REASONABLENESS

In the Matter of Proposed Permanent Rules relating to Groundwater Protection

April 30, 2018

The *State Register* notice, this Statement of Need and Reasonableness (SONAR) and the proposed Rule will be available during the public comment period on the MDA's website:
www.mda.state.mn.us/nfr

Alternative Format:

In accordance with the Americans with Disabilities Act, this information is available in alternative forms of communication upon request by calling 651-201-6000. TTY users can call the Minnesota Relay Service at 711. The MDA is an equal opportunity employer and provider.

Contents

List of Tables

List of Figures

Acronyms or Abbreviations

Acronym or Abbreviation	Full Text
AMT	Alternative Management Tool
BMP	Best Management Practice
CFR	Code of Federal Regulations
Commissioner	Commissioner of the MDA (unless otherwise noted)
DAP	Diammonium Phosphate
DWSMA	Drinking Water Supply Management Area
USEPA	United States Environmental Protection Agency
HRL	Health Risk Limit
LAT	Local Advisory Team
MAP	Monoammonium Phosphate
MAWQCP	Minnesota Agricultural Water Quality Certification Program
mg/L	Milligrams per liter
MDA	Minnesota Department of Agriculture
MDH	Minnesota Department of Health
MDNR	Department of Natural Resources
MPCA	Minnesota Pollution Control Agency
N	Nitrogen
N2	Gaseous molecular nitrogen
N2O	Nitrous oxide
NFMP	Nitrogen Fertilizer Management Plan
NH3	Ammonia
NH4	Ammonium
NO	Nitric oxide
NO2	Nitrite
NO3	Nitrate
NRCS	Natural Resources Conservation Service
NRS	Nutrient Reduction Strategy
P	Phosphorus
SSURGO	Soil Survey Geographic Database
SONAR	Statement of Need and Reasonableness
SWCD	Soil and Water Conservation District
TTP	Township testing program
U of M	University of Minnesota
USDA	United States Department of Agriculture
USGS	United States Geologic Service
UAN	Urea and Ammonium Nitrate (solution)
WHPA	Wellhead Protection Area

I. Introduction

The Groundwater Protection Act states, *"it is the goal of the state that groundwater be maintained in its natural condition, free from any degradation caused by human activities. It is recognized that for some human activities this degradation prevention goal cannot be practicably achieved. However, where prevention is practicable, it is intended that it be achieved. Where it is not currently practicable, the development of methods and technology that will make prevention practicable is encouraged."* Minn. Stat. § Section 103H.001.

Nitrate is a compound that naturally occurs in our environment at very low levels, generally less than 3 mg/L, and has many human-made sources. Nitrate is in some lakes, rivers, and groundwater in Minnesota. The Minnesota Department of Health (MDH) Health Risk Limit (HRL) for nitrate (expressed as nitrate-nitrogen) is 10 mg/L; consuming too much nitrate can be harmful — specifically for infants under the age of six months. The majority of Minnesota households have access to safe drinking water supplies. However, in areas vulnerable to groundwater contamination, some public wells have nitrate-nitrogen concentrations that exceed the MDH HRL. While elevated concentrations of nitrate-nitrogen in groundwater can result from several factors, a major contributor in rural Minnesota is nitrogen fertilizer that leaches past the crop root zone (MDA. n.d. (d)). When groundwater resources become contaminated with nitrate, efforts to remove or mitigate the contamination are challenging and expensive. These results show that action is needed in order to ensure that Minnesotans have safe drinking water for years to come.

State agencies, under Minn. Stat. §103H.101, subd. 7, must identify and develop best management practices (BMPs) for programs under their authority that have activities that may cause or contribute to groundwater pollution. For those activities which may cause or contribute to pollution of groundwater, but are not directly regulated by the state, BMPs shall be promoted through education, support programs, incentives, and other mechanisms.

Specifically, Minn. Stat. § 103H.151, subd. 2, requires the Minnesota Department of Agriculture (MDA), in consultation with local water planning authorities, to develop BMPs for agricultural chemicals and practices. The MDA must give public notice and solicit comments from affected persons interested in developing BMPs. Once developed, Minn. Stat. § 103H.151, subd. 3 requires the MDA to promote the BMPs and provide education on how the use of BMPs will prevent, minimize, reduce, and eliminate the source of groundwater contamination. The MDA is also required to monitor the use and effectiveness of BMPs. BMPs are defined in Minn. Stat. § 103H.005, subd. 4 as, *"practicable voluntary practices that are capable of preventing and minimizing degradation of groundwater, considering economic factors, availability, technical feasibility, implementability, effectiveness, and environmental effects. BMPs apply to schedules of management plans; practices to prevent site releases, spillage, or leaks; application and use* *of chemicals; drainage from raw material storage; operating procedures; treatment requirements; and other activities causing groundwater degradation."*

Additionally, the MDA is also required under Minn. Stat. § 103H.251 to evaluate the detection of pollutants in groundwater of the state as it pertains to agricultural chemicals and practices. If conditions indicate a likelihood of the detection of the pollutant or pollutant breakdown to be a common detection, the MDA must begin developing BMPs and continue to monitor for the pollutant or pollutant breakdown products. Once detected, the MDA must develop and implement groundwater monitoring and hydrogeologic evaluations to evaluate pollution frequency and concentration trend.

Minn. Stat. § 103H.275 states that if groundwater pollution is detected, the MDA must also promote the implementation of BMPs to prevent or minimize the source of pollution to the extent practicable. Further, the MDA may also develop adopt water resource protection requirements by rule that are consistent with the goal of Minn. Stat. § 103H.001 and are commensurate with the groundwater pollution if the implementation of BMPs has proved to be ineffective. The water resource protection requirements are defined in Minn. State. § 103H.005, subd. 15 as, *"requirements adopted by rule for one or more pollutants intended to prevent and minimize pollution of groundwater. Water resource protection requirements include design criteria, standards, operation and maintenance procedures, practices to prevent releases, spills, leaks, and incidents, restrictions on use and practices, and treatment requirements."* They must be based on the use and effectiveness of BMPs, the product use and practices contributing to the pollution detected, economic factors, availability, technical feasibility, implementability, and effectiveness. The water resource protection requirements may be adopted for one or more pollutants or a similar class of pollutants. (Minn. Stat. § 103H.275, subd. 2).

The MDA has complied with all requirements under Minn. Stat. chap.103H to develop, educate and promote BMPs. The MDA has also conducted monitoring and testing as required under Minn. Stat. chap.103H, and, based on the extensive information gathered by the MDA, believes that the implementation of the nitrogen fertilizer BMPs have proven to be ineffective. Based on this determination, the MDA has proposed the Groundwater Protection Rule (the proposed Rule) under the authority of Minn. Stat. § 103H.275, subds.1 and 2.

This Statement of Need and Reasonableness (SONAR) is laid out in the following format:

- Background of the Nitrogen Pollution Issue
- Outline of the MDA's requirements under Minn. Stat. chap. 103H and how the MDA has complied with those requirements
- Justification of the MDA's authority to issue the proposed Rule (implementation of BMPs ineffective)
- Why the proposed Rule is needed and reasonable

II. Background regarding Nitrogen Fertilizer and its effects on Groundwater

A. What is Nitrogen Fertilizer?

Nitrogen fertilizers as addressed by the proposed rule are substances containing nitrogen that are designed for use or claimed to have value in promoting plant growth.

The behavior of nitrogen (N) in the environment is governed by a complex set of interrelated chemical and biological transformations. These reactions are summarized in the "nitrogen cycle" (Figure II-1). The nitrogen cycle describes the inputs, pools, pathways, transformations, and losses of nitrogen in the environment.

Current agricultural crop production systems require the input of nitrogen fertilizer to increase food and feed production for consumption by humans and livestock as well as fiber and fuel. However, nitrate that is not utilized by the crop may leach into the groundwater. Many of Minnesota's groundwater aquifers are susceptible to contamination due to diverse geology and soils, climate, and land use. Concentration of nitrates in the groundwater can be harmful, especially to infants under 6 months.

The complex interrelationships between nitrogen use, benefits, and long term environmental consequences are termed by Nobel Peace Prize recipient Dr. Otto Doering as a "*wicked problem*" (Frear, 2014; Charles, 2013). Some experts believe that 50% of the world's current population would not exist without the additional food supplies produced through the use of commercial nitrogen fertilizers. The problem of nitrogen fertilizer use is termed "wicked" because, despite the benefits of the additional food production, there is no clear consensus on how to solve the environmental issues due to the complexities and interrelationships between crop production and the environment. This has led to an enormous research effort to develop the nitrogen fertilizer Best Management Practices (nitrogen fertilizer BMPs). These nitrogen fertilizer BMPs are designed to improve use efficiencies, quantify movement into the atmosphere and water resources, as well as ensure economic benefits for increased food production.

One of the most in-depth examinations of nitrogen usage and subsequent losses to water and air was released by the USEPA Science Advisory Board (2011). This Board concluded that agriculture uses more nitrogen and accounts for more nitrogen losses to the environment than any other economic sector. The Board concluded that synthetic nitrogen fertilizers are the largest sources of nitrogen inputs to agricultural systems. The Board further characterized the nitrogen in the environment issue through the following statement:

> *"In the past 60 years N fertilizers have had a beneficial effect on agriculture both nationally and globally by increasing crop yields. However, the high loading of N from*

agricultural nutrient sources has led to deleterious effects on the environment, such as decreased visibility from increased aerosol production and elevated N concentrations in the atmosphere, ground, and surface waters." (USEPA Science Advisory Board, 2011)

The Nitrogen Cycle

The nitrogen cycle is the biogeochemical cycle by which nitrogen is converted to multiple chemical forms as it circles through the air, ground, and water. The nitrogen cycle reactions are influenced by the interaction of numerous chemical, biological, environmental, and management factors (Figure II-1; Lamb et al. 2008). The interaction of these factors complicates predictions of the behavior of nitrogen introduced into the environment. Understanding the nitrogen cycle is important to help understand how multiple factors will interact to influence nitrogen behavior at a given site. Sound nitrogen management decisions can then be made based upon knowledge of the nitrogen cycle.

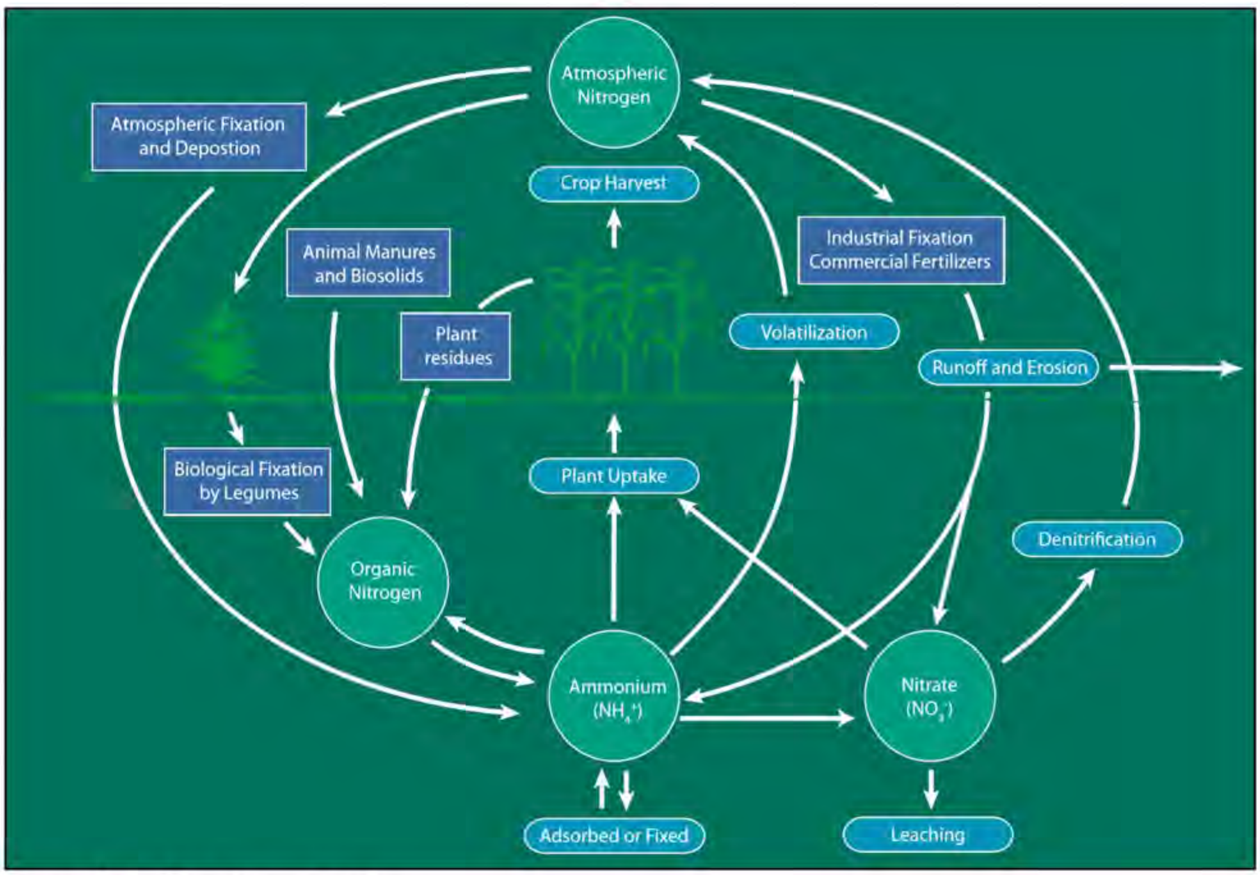


Figure II-1. The nitrogen cycle.

<u>There are multiple terms used in this rule when referring to nitrogen.</u> Nitrogen is used when referring to the nutrient for plant growth, fertilizer containing nitrogen or nitrogen fertilizer Best Management Practices (BMPs). Nitrate is a general term used in reference to leaching or

groundwater. Nitrate-nitrogen describes the concentration in groundwater and the health risk limit in milligrams per liter (mg/L).

Components of the nitrogen cycle

Although several nitrogen compounds are involved in the cycle, the primary compounds in the soil are nitrate-nitrogen (NO_3^-), ammonium nitrogen (NH_4^+), and organic nitrogen. Nitrogen in the nitrate form is highly water soluble and extremely mobile, which poses economic and environmental concerns. The characteristics of these compounds and related processes are summarized below:

- **Organic nitrogen:** Organic nitrogen is the predominant nitrogen compound in the soil profile. Organic nitrogen first must be transformed into inorganic forms by microbial action (mineralization) in order to dissolved into water. Organic nitrogen may be the primary source of nitrogen in surface runoff but rarely contributes to groundwater contamination.

- **Nitrate (NO_3^-):** Nitrate is extremely soluble in water. Due to its chemistry, nitrate does not tend to stay attached to the soil, but instead moves through soil. These characteristics mean it is highly susceptible to leaching and therefore groundwater contamination.

- **Nitrite (NO_2^-):** Nitrite is an intermediate product in the conversion of ammonium to nitrate in the soil and is the compound of toxicological concern in the human system. Although nitrite is highly soluble, it is also very unstable and is rarely detected in groundwater except at very low levels.

- **Ammonia (NH_3)/ammonium (NH_4^+):** Ammonia (gas) is the primary form of nitrogen feedstock applied in fertilizers. It reacts to form ammonium immediately upon contact with water. Ammonium will be temporally immobile until soil bacteria convert it to the much more soluble nitrate form.

The primary chemical and biological processes of the nitrogen cycle include:

- **Leaching:** Leaching is the process where nitrates move through soil via water. Nitrate is the principal nitrogen compound transported in subsurface water due to its solubility and exclusion from adsorption onto soil colloid surfaces. Nitrate leaching is one of the primary avenues of nitrogen loss, particularly during years with above-normal precipitation.

- **Mineralization:** The microbial degradation of organic nitrogen to produce the inorganic forms of nitrogen (nitrate, nitrite, and ammonia).

- **Immobilization:** The assimilation of inorganic forms of nitrogen by plants and microbes, producing various organic nitrogen compound.

- **Net Mineralization:** The cumulative balance at the end of the growing season between mineralization and immobilization.

- **Nitrification:** The transformation through microbes of ammonium to nitrite and then to nitrate. This is the primary nitrate-producing reaction in the cycle.

- **Denitrification:** The biochemical reduction of nitrate and nitrite to gaseous molecular nitrogen (N_2) or a nitrogen oxide form nitrous oxide (N_2O), nitric oxide (NO), or nitrogen dioxide (NO_2). This is a primary volatile loss pathway to the atmosphere. Over 78% of the atmosphere is comprised of N_2.

There are multiple potential sources of nitrogen in the soil system. In an agronomic context, all nitrogen sources applied to a field should be taken into account in determining the appropriate nitrogen fertilizer rate. All nitrogen sources perform the same function in the context of the nitrogen cycle, although they may enter the cycle at different points. This means that all nitrogen sources are potential nitrate sources and could contribute to groundwater contamination. It is important to recognize that nitrate occurs naturally in the soil system. Nitrate losses can occur under natural vegetative conditions, (such as grassland and forestland), although these losses are typically minor. Losses can be much higher after major events such as prairie fires, land clearing and/or disturbances, and the initiation of major tillage operations. Significant losses can also occur after extended drought conditions followed by prolonged wet cycles.

Nitrogen sources include agronomic inputs and external sources:

Agronomic Inputs:
- Soil organic matter and crop residue
- Commercial fertilizers
- Atmospheric deposition
- Atmospheric fixation (legumes fixing nitrogen in the soil)
- Land-applied manure and other organic residues

External Sources:
- Municipal Wastes and Landfills
- Septic systems
- Feedlots (concentrated animal wastes)
- Turf grass (golf course, parks, private and public lawns)
- Wildlife excretions.

B. Understanding Nitrogen Fertilizer Usage and Impacts to Water Resources

Nitrogen fertilizer is a major input to agricultural land, and fertilizer sales have increased along with nitrogen demanding crops. Unfortunately, nitrate can also leach into groundwater (MDA. n.d. (d)). Given the importance of this topic, there have been many studies on different soils and rates, and research to develop the nitrogen fertilizer BMPs. Studies in Minnesota and other Midwestern states have identified nitrogen fertilizer as a major source of nitrate in some aquifer systems.

1. Although there are multiple sources of nitrogen, the majority of nitrogen inputs are applied to agricultural land.

One significant challenge in dealing with nitrogen related environmental issues is the fact that there are multiple sources from either natural or human-induced sources (Figure II-2). Nitrogen inputs statewide have been evaluated by the Minnesota Department of Agriculture (MDA). The majority (over 82%) of the nitrogen inputs occur on agricultural lands. The sources include cropland mineralization (net); commercial nitrogen fertilizers; contributions from nitrogen fixing legume crops such as alfalfa, clover and soybeans; manure applications, and atmospheric deposition. There are also other minor sources such as septic tanks and feedlot contributions.

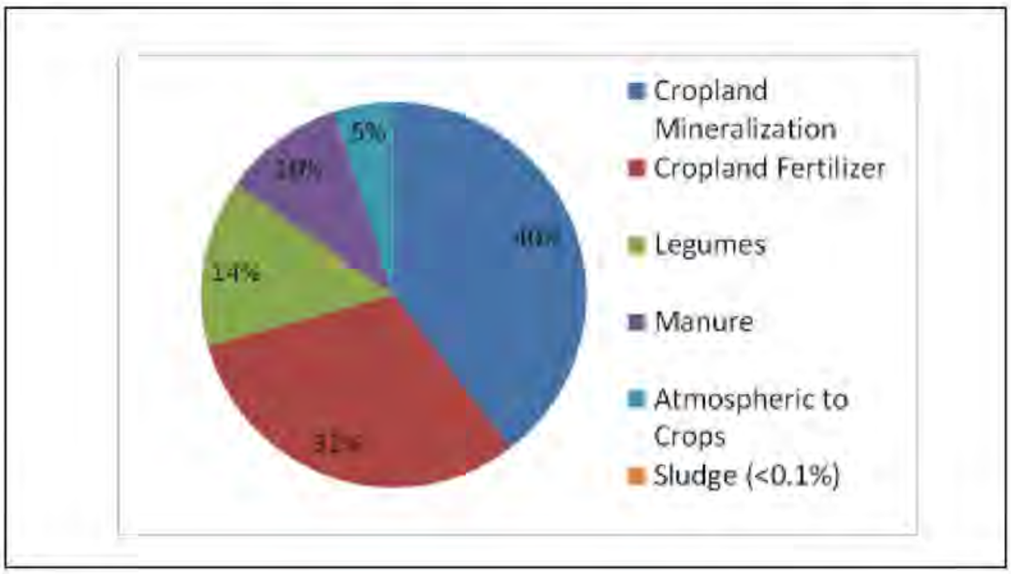


Figure II-2. Comparison of Minnesota's major agricultural nitrogen sources. (MDA, 2015)

Other inputs that are applied to non-agricultural landscapes include fertilizers applied to turf grass (lawns, parks and golf courses), non-cropland mineralization, septic system waste, and atmospheric deposition.

To put these inputs in perspective in terms of a representative acre of Minnesota farmland growing corn (in a corn-soybeans rotation which encompasses about 75% of the state's cropland), the nitrogen inputs would be in the following general ranges: 1) Commercial nitrogen fertilizer 120-150 lb/acre; 2) Legume credits of 30-40 lb/acre based on U of M soybean crediting; 3) Mineralization 50-100 lb/acre; and 4) Manure. Manure inputs are highly variable---about 15-20% of the intended corn acres in livestock regions get manure applied. Typically, manure inputs are under-represented, resulting in over-applications of commercial fertilizer.

It is generally accepted that anhydrous ammonia is one of the best commercial nitrogen sources available. Anhydrous ammonia is a gas and is applied by injecting it into the soil. For a number of reasons, this product generally produces the best yields and less likely to leach or be lost to various gaseous pathways. Despite being an excellent nitrogen source, anhydrous ammonia sales have dropped significantly over the past 25 years (Figure II-3; MDA, 2015). The primary reasons for the downward trends are likely safety and complex requirements regarding its storage, transportation, and use. Anhydrous ammonia must be stored and handled under high pressure and is highly dangerous. Misuse of this fertilizer can cause serious burns and death in severe cases (Shutske, 2013). Additionally, it is a difficult product to work with within precision type applications.

Urea has overtaken anhydrous ammonia as the most sold nitrogen fertilizer product. Urea is a solid. Urea sales have steadily increased and have taken up much of the marketplace sales reductions in anhydrous ammonia. This product (containing 46% nitrogen) is a solid and when properly used, can produce yields similar to anhydrous ammonia if leaching and gaseous losses can be managed. Because Urea is soluble, it should not be used in a fall application in areas with leaching concerns.

Nitrogen solutions (28%, 30%, and 32%) account for 10% of the statewide sales. These products are frequently applied as an application in the spring with a herbicide after the crop has already begun to grow. Many of the products listed as "Misc. Sources" in Figure II-3 are frequently custom dry blends for specialty crops.

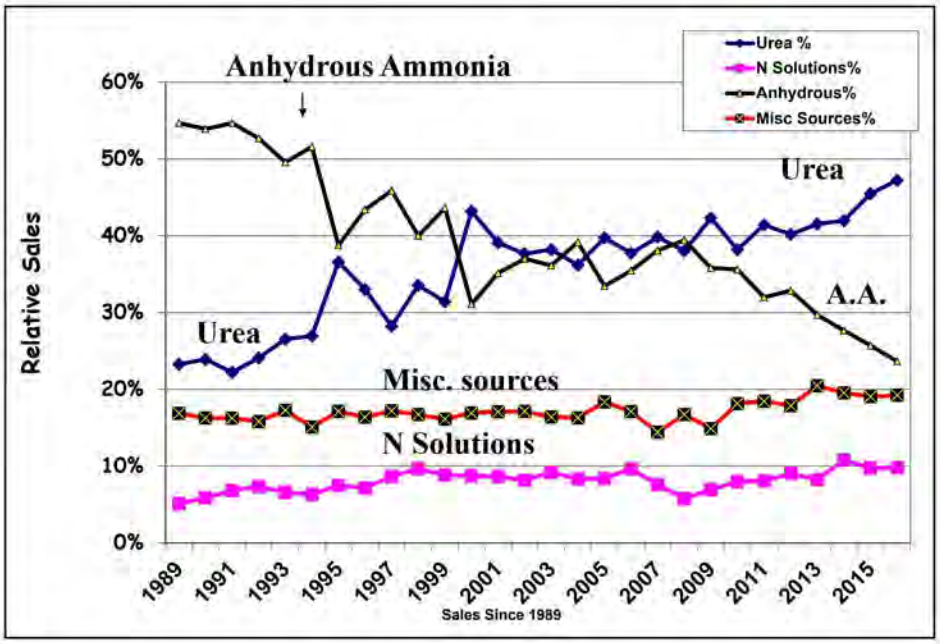


Figure II-3. Trends in three major nitrogen fertilizer sources used in Minnesota: 1989-2016. (MDA, 2015)

Nitrogen fertilizer is a valuable tool for producers. Unfortunately, it can also leach into groundwater and cause significant health concerns. The most prevalent use of nitrogen is application to agricultural land.

2. Studies show an increase in sales of nitrogen fertilizer and an increase in planting of nitrogen-demanding crops, resulting in an increase potential of leeching of nitrogen into groundwater.

Reliance on nitrogen fertilizers and subsequent consequences to water and air quality align with the post-war era. From a historical perceptive, the industrial process for creating ammonia was first developed in the early part of the 20th century. However, it was not until World War II ended that synthetic ammonia was readily available for agricultural use. Adoption of commercial fertilizer proceeded slowly but then catapulted in the United States during the 1960s and 1970s as a result of educational efforts, lower costs, and introduction of improved plant genetics that needed increased inputs.

Minnesota sales are very similar to the national trends (Figure II-4, data sourced from MDA, Tennessee Valley Authority, and the American Association of Plant Food Control Officials). Sales rapidly increased in the 1960-1970 era, stabilized during the 1980s, and then remained fairly consistent during the 1990s (averaging 653,000 tons/year) and the early 2000s (averaging 648,000 tons).

Figure II-4. Commercial nitrogen fertilizer sales trends, Minnesota and U.S.

More recently, nitrogen fertilizer sales have been trending upward with a notable jump when grain prices were high in 2010-2014. Nitrogen consumption over the past five years is averaging 760,000 tons/year, which is a 14-15% increase compared to the twenty-five-year average. Overall, Minnesota's nitrogen fertilizer sales have increased over six-fold since 1965 while at the same time corn production has increased four-fold and corn acres have substantially increased (MDA, 2015). This increase in corn production has had a significant impact on the use of nitrogen.

Crop selection, as reported by the National Agriculture Statistics Service (USDA NASS, n.d. (a)) over the past ninety years, has changed dramatically. Before the mid-1950s, Minnesota annually planted over 8 million acres of small grains, including wheat, oats, rye, barley and other minor crops (Figure II-5). Small grain acres dropped significantly in the late1950s and again during the 1980s and 1990s. Over the past decade, approximately 2 million acres of small grains have been grown. Small grains are generally considered to have a low-to-moderate impact on groundwater quality for the following reasons: solid seeding resulting in a uniform root distribution; they are typically grown in areas of low groundwater vulnerability; and they require moderate nitrogen inputs due to lodging concerns.

The following are some of the major crops currently grown in Minnesota:

- **Corn:** Corn acres have been steadily increasing for the last ninety years. Corn has high nitrogen requirements and has a narrow uptake period. Those implementing Minnesota's nitrogen fertilizer BMPs can select from options to ensure that corn crops have the nutrients needed during this critical uptake period.

- **Legumes:** Looking back at the trends in several legume crops since the 1920s, there has been a very steady decline of alfalfa and clover acres. These declines are linked to the significant changes in the dairy industry and due to lower production costs in neighboring states. These crops have strong, positive implications on groundwater quality and have been demonstrated to be extremely effective at removing nitrate from the soil profile resulting in high quality recharge into groundwater.

- **Soybeans:** Despite being one of the oldest crops known to human civilization, soybeans did not become an important crop in the U.S. until the turn of the 20th century. Soybean production started in Minnesota in the early 1940s and has steadily increased to about 7-8 million acres. Provided with the proper nitrogen-fixing bacteria (via inoculum), soybeans are highly capable of supplying their own nitrogen needs as well as utilizing residual soil nitrate from previous crops.

- **Other crops:** There are other nitrogen-demanding crops grown on a small scale in the state of Minnesota, but they can have significant impacts (both economic and environmental) on a local level.

Table II-1. Typical nitrogen requirements and potential impacts on nitrate leaching losses for crops/cover in Minnesota (MDA, 2015; p 117)

Commonly grown Agricultural Crops or Alternative Cover	Typical Nitrogen Requirements (Pounds per Acre)	Characteristics	Relative Nitrogen Leaching Loss Rating System*
Corn (Grain or Silage)	70-180	Deep rooted; Inputs highly dependent on anticipated yields	M-H Spring Applied; H-VH Fall Applied; M-H Irrigated; M-VH Manured
Wheat, Barley, Oats	60-100	Solid seeded	L-M
Soybeans	Legume; No additional nitrogen needed	Poor scavenger of residual soil nitrate	M
Potatoes – Irrigated	200-250	High management, shallow root system	H-VH
Sugar Beets	100-120	Sugar quality decreases if too much nitrogen available	M
Alfalfa	Legume; No additional nitrogen needed	Very deep rooted, excellent scavenger; Crediting to subsequent crops critical upon termination	L; Potential losses after crop is terminated
Grass-Legume Mixtures	60; Lower nitrogen rates allow for legume growth	NA	VL-L
Pasture/Grazing	Plant nutrition provided by manure or supplemental fertilizer	NA	L (typically); Dependent upon grazing pressure
Conservation Reserve Program Mixtures	Application at establishment	Mixtures vary but diverse systems tend need less nitrogen	VL
Lawns and Golf Fairways	40-160	Fall nitrogen applications; Split applications	L; L
Golf Greens, High Input Areas	120-220	Split applications needed	M-H

* VH= Very High, H=High, M=Medium, L=Low, VL=Very Low, NA=Not Applicable

Between the 1920s and 1960s, amounts of nitrate-nitrogen leaching below the root zone were relatively minor compared to recent years. The major changes over the past ninety years are: 1) the additional influx of commercial fertilizers (Figure II-4); 2) substantially more acres of nitrogen demanding crops (Figure II-5); and 3) replacement of nitrogen conserving crops, such as alfalfa, clovers, pasture, and hay grasses with soybeans. These changes combined contribute to an increased risk of nitrate entering groundwater. The continuance of these trends will lead to an ongoing increased risk of nitrate loading to groundwater.

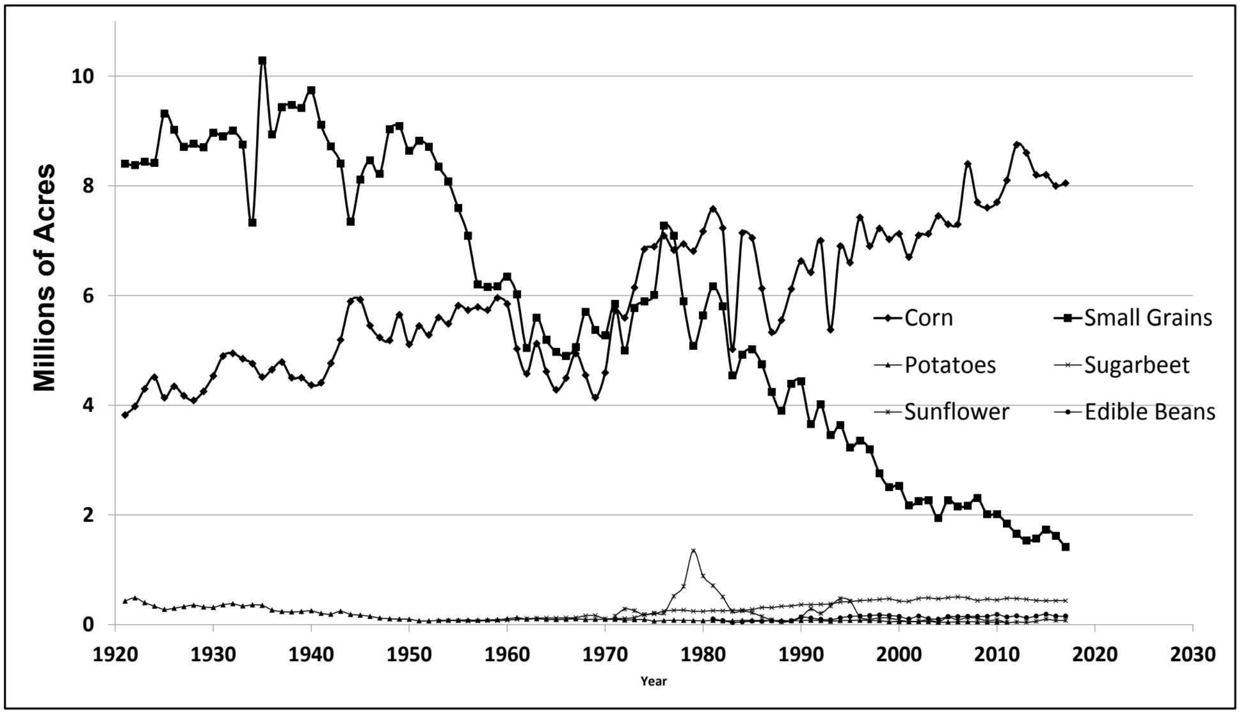


Figure II-5. Acreage trends for Minnesota's nitrogen demanding crops. (USDA NASS n.d. (a); MDA, 2015)

Therefore, studies showing an increase in nitrogen fertilizer sales, along with the change from planting nitrogen-friendly crops to more nitrogen-demanding crops, have created a greater probability of nitrogen leeching into groundwater.

3. Understanding Groundwater's susceptibility to nitrate pollution.

Groundwater is the most abundant source of freshwater in the world.

Groundwater is water found beneath the soil surface that resides in the soil pore spaces or within cracks of fractured rock. Most of groundwater is stored in underground layers known as aquifers. These saturated layers allow water to flow into and through them relatively easily. Even though water can move through these layers, the water typically moves slowly. In certain environments, where there are larger fractures or conduits in the rocks, groundwater can move more rapidly through these spaces. The susceptibility of groundwater to contamination is referred to as "vulnerability". Several environmental factors determine the vulnerability of an area, including 1) physical and chemical properties of the soil and geologic materials, 2) climatic effects, and 3) land use. These factors vary widely throughout Minnesota, making vulnerability very site-specific.

Nitrate can occur naturally in groundwater at levels typically in the range of 0 to 3 parts per million (ppm) (MDH, n.d.). Human activities such as sewage disposal, livestock production, and crop fertilization can elevate the level of nitrate in groundwater. The Minnesota Department of Health (MDH) has set a Health Risk Limit (HRL) of 10 milligrams per liter (10 mg/L, or 10 ppm) for nitrate-nitrogen (MDH, n.d.). Nitrate-nitrogen contamination above the MDH HRL is most commonly found in aquifers that are vulnerable to contamination from the land surface, such as sand and gravel aquifers and fractured bedrock aquifers. Areas with heavy row crop agriculture and vulnerable groundwater are especially at risk.

A simple search via Google Scholar using the key words "nitrogen fertilizer water quality Minnesota" will yield hundreds of studies conducted over the last three to four decades. There have been many small plot research efforts conducted that studied nitrogen movement below the crop root zone or via a tile drainage system. Much of the Minnesota research evolved from the finer textured, tile-drained soils found at the U of M Research and Outreach Centers (Waseca and Lamberton). Frequently variables include different rates, timings, sources, and other potential techniques to improve fertilizer use efficiency and reduce environmental impacts (Carlson et al., 2017; Davis et al., 2000; Feyereisen et al, 2006; Huggins et al, 2001; Jokela and Randall, 1989; Miao et al., 2007; Mulla and Strock, 2008; Nangia et al., 2008; Oquist et al., 2007; Randall, 1984; Randall and Mulla, 2001; Randall and Vetsch, 2005(a); Randall and Vetsch, 2005(b); Randall et al. 2003 (a); Randall et al., 2003(b); Randall and Goss, 2001; Schmidt et al. 2000; Schmitt et al., 1996; Vetsch and Randall, 2004; Yost et al., 2014). Studying nitrate leaching losses in the irrigated outwash soils is extremely difficult and consequently the knowledge base is smaller (Bierman et al., 2015; Hopkins et al, 2008; Venterea et al., 2011; Wilson et al., 2009; Zvomuya et at., 2003; Walters and Malzer, 1990, MDA. n.d. (d)).

These types of studies are extremely valuable for the development of nitrogen fertilizer BMPs and are frequently used to model nitrogen movement on a larger scale. These studies provide information on nitrogen fertilizer rate and management practices, and how these impact in crop yields and nitrate movement in the soil profile.

A small percentage of these Minnesota studies included the use of ^{15}N isotope technology. This approach allows researchers to effectively track the fate of nitrogen fertilizer as it is taken up by the crop, the atmosphere, the organic fraction or lost in the leachate (Zvomuya et at., 2003; Walters and Malzer, 1990). This is one of the most reliable methods for isolating fertilizer contributions from other inputs such as through mineralization of organic matter. Due to the high costs and complexities of analysis, these types of studies are very limited.

4. Studies demonstrate significant nitrogen contamination of groundwater in certain areas of the state where there is a demonstrated increase of nitrogen use.

Due to the post-World War II increase of nitrogen fertilizer use and the subsequent rise in nitrate-related water quality issues, there are few nitrate monitoring studies conducted prior to the 1960s and 1970s. It was uncommon to have the research opportunity to observe water quality conditions prior to the nitrogen fertilizer use era. Most monitoring reports for either groundwater or surface waters began in the 1980s or later.

For purposes of the statement of need and reasonableness (SONAR), groundwater conditions in Hastings, Minnesota and surface water conditions of the Minnesota River will serve as examples of monitoring studies illustrating the relationship between the increase in nitrogen fertilizer use and increased nitrate-related water quality concerns.

The Hastings public water supply, along with Perham and St. Peter, were some of the first to start showing rapidly increasing nitrate-nitrogen concentrations (Figure II-6).

In the case of Hastings, numerous studies were conducted with producers within the wellhead protection area (WHPA). Most of the soils there are vulnerable to leaching due to being coarse-textured, as well as areas of karst, and frequently under center pivot irrigation. Nitrogen from fertilizer, manure, and legumes were the dominant sources that could be managed or controlled by producers.

Over a number of years, nitrate-nitrogen concentrations continued to climb nearing the MDH HRL, forcing the city of Hastings to install a nitrate removal system in 2007 at a cost of $3.5 million. The city of Perham was experiencing similar trends and how they reversed these trends is discussed below. (Section II.b).

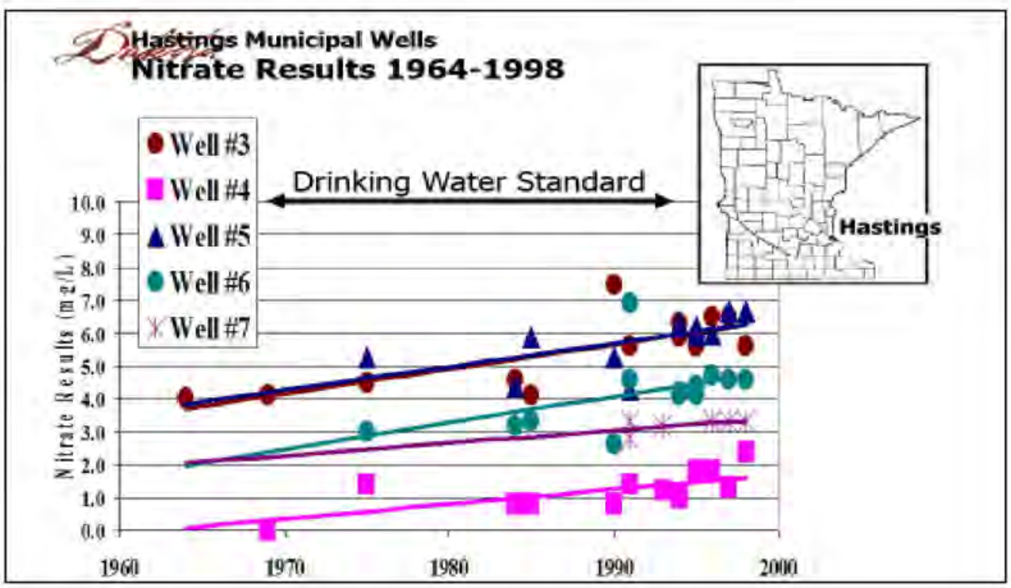


Figure II-6. Forty years of nitrate-nitrogen concentration trends in municipal wells, Hastings, Minnesota.

Another example is Mankato, which withdraws water from both the Minnesota and the Blue Earth Rivers for its public water supply. Nitrate-nitrogen concentrations and annual loads are slowly trending upward in the Minnesota River near Mankato (Figure II-7, S. Matteson, MDA. Personal Communication. 2017) and are highly influenced by rainfall and runoff amounts. Nitrate-nitrogen concentrations have doubled since the early 1970s. More importantly, the extremes are getting much larger.

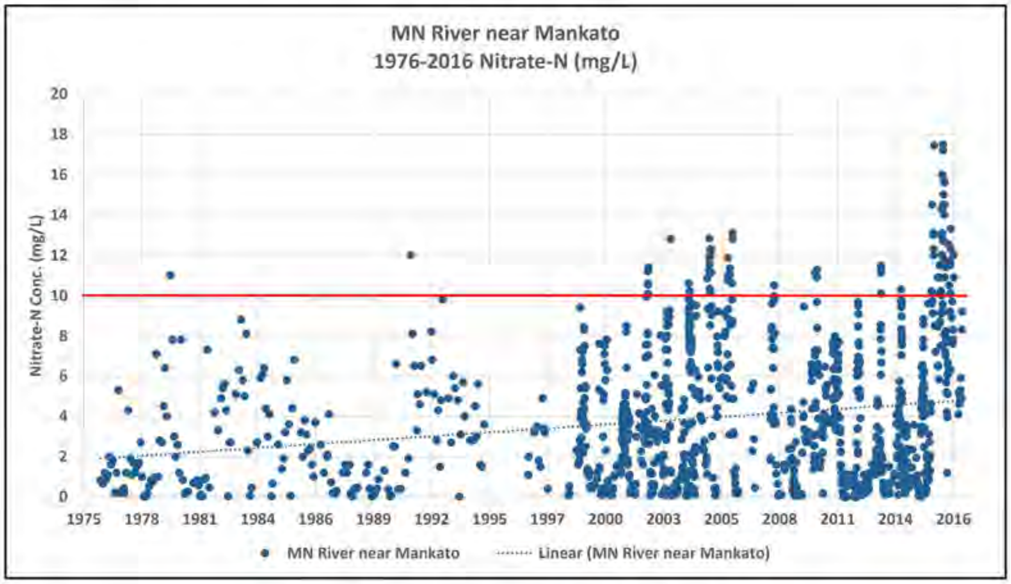


Figure II-7. Forty years of nitrate-nitrogen concentration trends in the Minnesota River.

a) Nitrogen fertilizer use and impacts to groundwater

In answering the question "what role does nitrogen fertilizer play in understanding elevated nitrates in groundwater systems," researchers from United States Geological Survey (USGS) conducted some significant studies in the Midwest, including Minnesota, which started in the 1970s (Figure II-7, S. Matteson, MDA. Personal Communication. 2017; Figure II-8, Puckett et. al, 2011; Puckett and Cowdery, 2002; Böhlke et al., 2002 and Puckett et al., 1999). These USGS reports are pertinent to the SONAR because they are highly focused on vulnerable groundwater systems typically found in Minnesota and the researchers have investigated potential sources. When nitrate-nitrogen concentrations were readjusted for denitrification losses, USGS concluded that nitrate-nitrogen concentrations in groundwater increased from about 2 mg/L in the early 1940s to about 15 mg/L in 2003 (Figure II-8 & Figure II-9, Puckett et al., 2011). Two of the eight sites were in Minnesota (Princeton and Perham) and represented vulnerable conditions found in the Midwest. This analysis also estimated that 14-18% of the nitrogen reaching the land surface as fertilizer, manure, and atmospheric deposition eventually would leach into groundwater.

Figure II-8. U.S. nitrogen sales and nitrate-nitrogen concentration in groundwater from 20 long-term sites (including Perham and Princeton, Minnesota).

USGS scientists also reported that within these 20 vulnerable areas, the probability of finding nitrate-nitrogen concentrations above the MDH HRL of 10 mg/L increased from <1% in the 1940s to over 50% by 2000 (Figure II-9, Puckett et al., 2011). Nitrogen fertilizer was clearly identified as the major source of nitrate in selected Minnesota aquifer systems (Puckett and Cowdery, 2002; Puckett et. al, 1999).

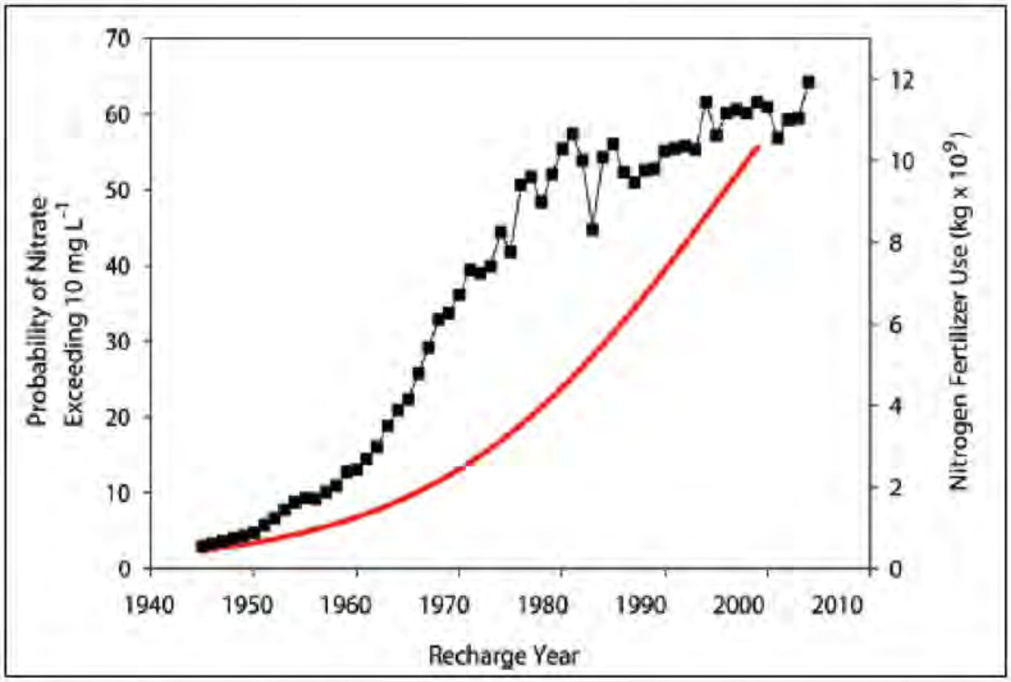


Figure II-9. Probability of nitrate-nitrogen concentrations in recharging groundwater exceeding 10 mg/L in areas of nitrogen fertilizer use (including Perham and Princeton, Minnesota).

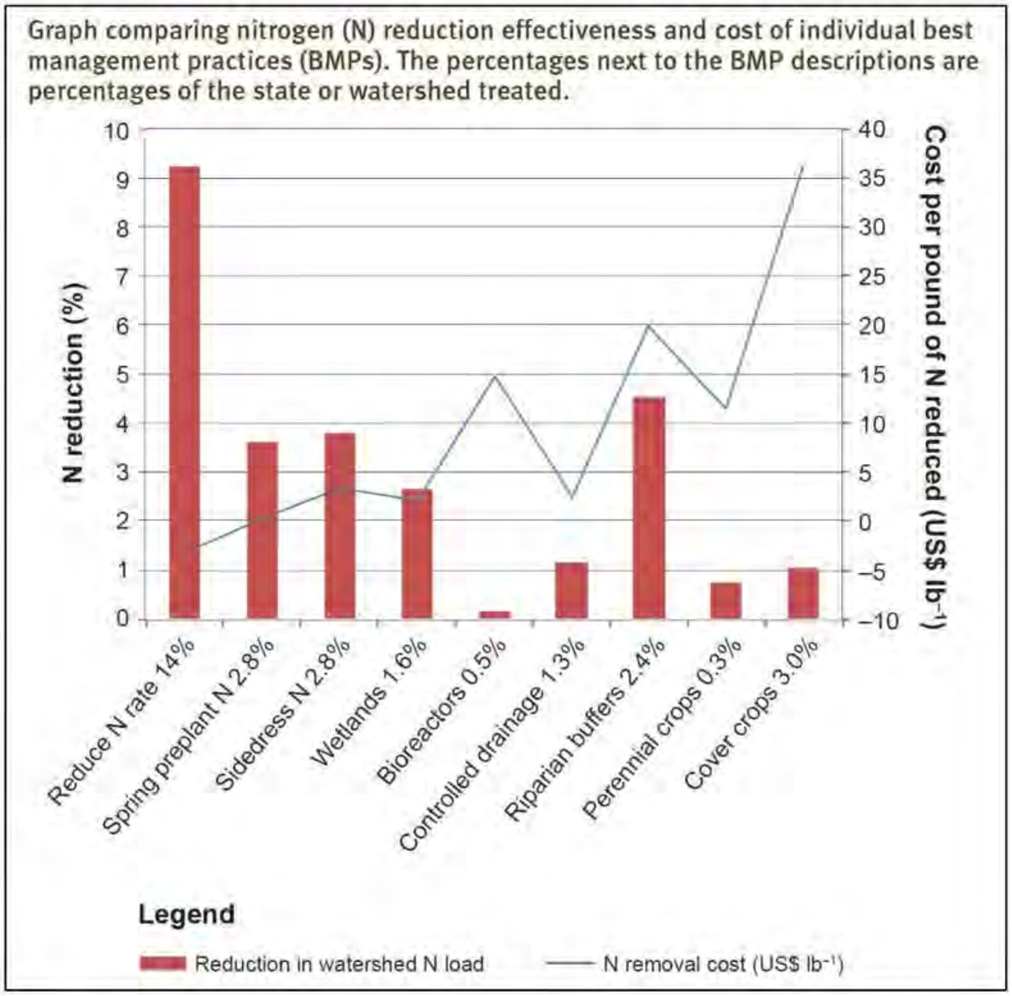


Figure II-10. BMP treatment opportunity (percent) in Minnesota's watersheds and corresponding nitrogen reduction effectiveness and cost estimated in the Nutrient Reduction Strategy. (Lazarus et al., 2014)

b) Perham drinking water protection

In the early 1990s, the city of Perham began to recognize that nitrate-nitrogen concentrations in their drinking water were rapidly increasing. By the late 90s, some of the city's wells sporadically exceeded the MDH HRL of 10 mg/L nitrate-nitrogen, requiring city staff to blend water from multiple wells to provide safe drinking water. Coarse textured soils, shallow groundwater, and an agricultural crop rotation demanding a high amount of nitrogen fertilizer created a challenging situation for groundwater protection in this area.

During this time, Perham leaders partnered with the MDA through state wellhead protection programs to engage local agricultural partners in reducing nitrate-nitrogen groundwater concentrations. Through combined efforts of the city and the agricultural community over 20 years, average annual nitrate-nitrogen concentrations in community wells have declined (Figure

II-11). Educational events, on-farm nitrogen trials, crop variety trials, fertilizer management changes, the use of new fertilizer technology, and perennial crops in select fields have led to higher nitrogen use efficiency across agricultural fields in the area. In addition, the city worked with area farmers in the early 2000s to purchase and trade land immediately up-gradient of public supply wells to further protect the city's drinking water. These elements are incorporated into the proposed Rule.

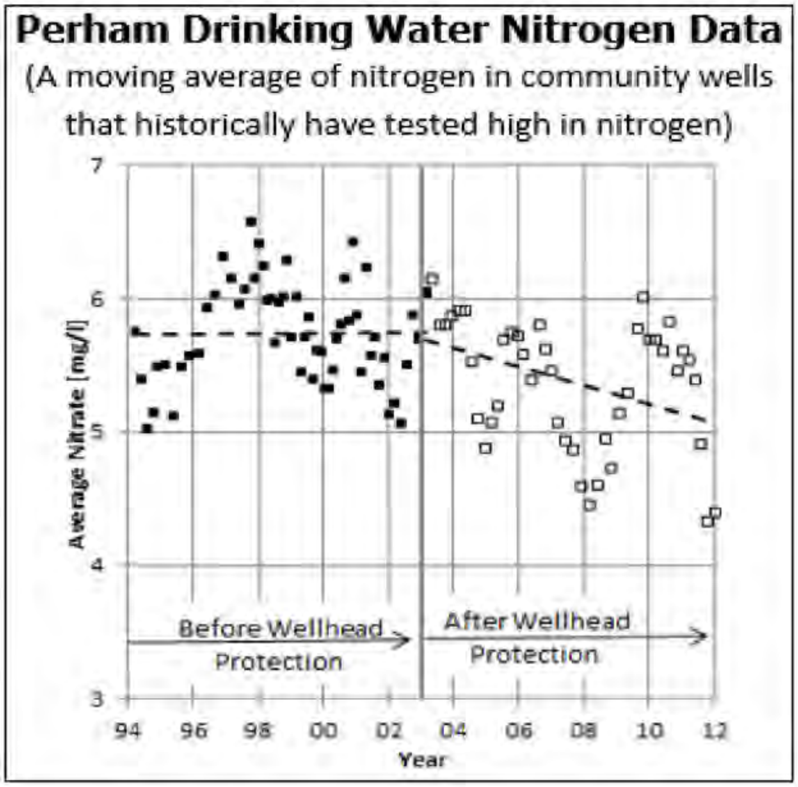


Figure II-11. Perham community well nitrate-nitrogen concentrations before and after wellhead protection efforts (Luke Stuewe, MDA Personal Communication)

c) Other Midwestern States have also linked nitrogen fertilizer use to water quality issues.

Commercial nitrogen fertilizer has been identified as the major source of groundwater nitrogen-contamination nationwide (Rupert, 2008; Burow et al., 2010, MDA. n.d. (d)) and has long been recognized as the major source of contamination in Nebraska's aquifers (Exner and Spalding, 1979; Gormly and Spalding, 1979).

Nebraska has extensive experience dealing with elevated nitrates in groundwater. Numerous Natural Resource Districts, in partnership with the University of Nebraska, have been pioneers in developing innovative methodologies for identifying nitrate sources, developing monitoring approaches, and implementation strategies, including the nation's first nitrogen fertilizer regulations. Scientists successfully developed a technique enabling them to distinguish nitrogen sources based on the inherent ratios of natural abundance ^{15}N (a naturally occurring nitrogen isotope) to ^{14}N (the normal atomic number). Scientists were also able to “age” groundwater to better understand the timeframe when most of the contamination occurred. A significant amount of loading occurred in the 1970s-1980s when the management of N and water inputs (via flood irrigation) was much less efficient compared to current practices. An excellent historical summary on various Nebraska nitrate research can be found in Exner et al., 2014.

Wisconsin is reporting a large increase in the number of municipal water supply systems exceeding the state’s 10 mg/L level of concern (WI GCC, 2017). A 2012 survey found that 47 systems had raw water samples in excess of 10 mg/L compared to 14 systems in 1999. Collectively over $32.5 Million was spent in 2012 for mitigating nitrate contamination. Similar to Minnesota’s private well results, about 10% of the private wells tested in Wisconsin exceed the MCL and 20-30% in highly cultivated regions.

Wisconsin researchers report that 20% of nitrogen fertilizer ends up in groundwater and estimated in 2007 that over 100,000 tons of nitrogen fertilizer was applied to agricultural lands in excess of UW recommendations (WIDATCP, 2015).

d) Drinking Water Supply Management Areas in Minnesota

Some Minnesota communities using groundwater supplies have exceeded the nitrate-nitrogen HRL 0f 10 mg/L in recent years, and others are approaching unsafe levels. Installing nitrate removal systems is one approach taken by public water suppliers within impacted communities. The number of community water systems with removal systems has increased from six systems serving 15,000 people in 2008 to eight systems serving 50,000 people in 2014.

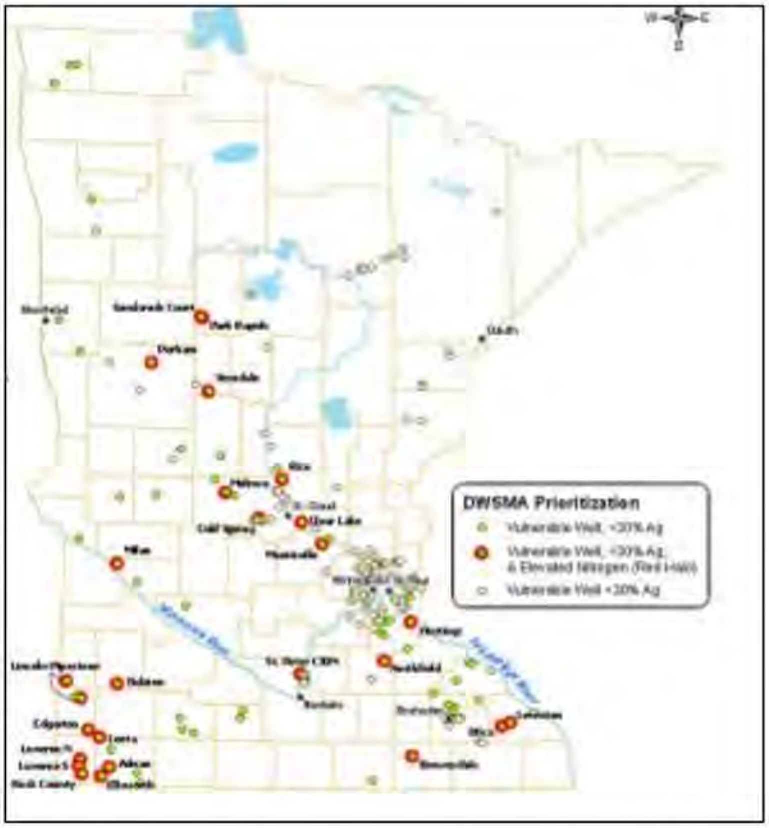


Figure II-12. Nitrate levels in public water supplies in agricultural areas.

There are roughly 30 to 40 public water suppliers in predominantly agricultural areas that are currently dealing with elevated nitrate-nitrogen concentrations. Associated costs for new wells, blending facilities, or installing nitrate removal systems can be significant, particularly to the smaller communities. Large systems serving many customers often can provide treatment at a lower cost per gallon than small communities. The cost of safe drinking water is not the same across the state and often the sources of contamination are outside water suppliers' control.

MDA has estimated that water costs to the consumer are several times higher in communities that are dealing with elevated nitrate levels compared to communities were nitrates are not an issue (UM, 2007).

III. Outline of the MDA's Requirements under Minn. Stat. chap. 103H

A. MDA must develop, educate and promote the use of BMPs for agricultural chemicals and practices.

Minn. Stat. § 103H.101, subd. 7 instructs state agencies to identify and develop best management practices (BMPs) for programs under their authority that have activities that may cause or contribute to groundwater pollution. For those activities which may cause or contribute to pollution of groundwater, but are not directly regulated by the state, BMPs shall be promoted through education, support programs, incentives, and other mechanisms.

Minn. Stat. § 103H.151, subd. 2-4 instructs the MDA specifically to develop and promote nitrogen fertilizer BMPs and provide education about how the use of BMPs will prevent, minimize, reduce and eliminate the source of groundwater degradation. The commissioner shall give public notice and contact and solicit comments from affected persons and businesses interested in developing the best management practices. The MDA also must monitor the use and effectiveness of the nitrogen fertilizer BMPs that the MDA has developed and promoted.

1. Nitrogen fertilizer BMP development

The nitrogen fertilizer BMPs are tools to manage nitrogen efficiently, profitably, and with minimized environmental loss. Nitrogen fertilizer BMPs were first developed for Minnesota in the late 1980s and early 1990s by the U of M and are based upon many decades of crop response research. The nitrogen fertilizer BMPs are tools to manage nitrogen efficiently, profitably, and with minimized environmental loss. Nitrogen fertilizer BMPs are a reflection of our understanding of the nitrogen cycle and are predicated on hundreds of site years of agronomics and environmental research. While acknowledging that no generalized recommendations are relevant all of the time, the nitrogen fertilizer BMPs represent a combination of practices that will reduce risk of excessive nitrogen loss in a normal year.

The nitrogen fertilizer BMPs are built on a four-part foundation that takes into account the nitrogen rate, application timing, source, and placement of the application, known as the "4Rs." If one of the "Rs" is not followed, the effectiveness of the system will be compromised, and there will be agronomic and or environmental consequences.

Minnesota has officially recognized statewide and regional nitrogen fertilizer BMPs. The MDA adopted the nitrogen fertilizer BMPs developed by the U of M according to the process laid out in Minn. Stat. § 103H.151, subd. 2. The MDA published public notice in the State Register, as well as contacted and solicited comment from affected persons and businesses that were interested in developing or who would be affected by the nitrogen fertilizer BMPs. The nitrogen fertilizer BMPs were published in the state register and adopted by the MDA in 1991, and irrigated potatoes were developed and adopted in 1996. The nitrogen fertilizer BMPs were updated in 2008 and the MDA again published in the State Register and solicited comment from affected persons and businesses as required by statute.

Due to major differences in geology, soils, and climate across the state, nitrogen fertilizer BMPs are not only needed statewide, but also on regional scale (Figure III-1; Table III-1). These regional recommendations give specific instructions on how to utilize the most appropriate nitrogen rate, source, timing, and placement. For example, practices that may work well in southwestern Minnesota may not be appropriate for southeastern Minnesota. Regional and specialized nitrogen fertilizer BMPs can be found on the MDA's website at http://www.mda.state.mn.us/protecting/bmps/nitrogenbmps.aspx.

- Best Management Practices for Nitrogen Use in Minnesota
- Best Management Practices for Nitrogen Use in Northwestern Minnesota
- Best Management Practices for Nitrogen Use in South-Central Minnesota
- Best Management Practices for Nitrogen Use in Southeastern Minnesota
- Best Management Practices for Nitrogen Use in Southwestern and West-Central Minnesota
- Best Management Practices for Nitrogen Use on Coarse-textured Soils
- Best Management Practices for Nitrogen Use: Irrigated Potatoes

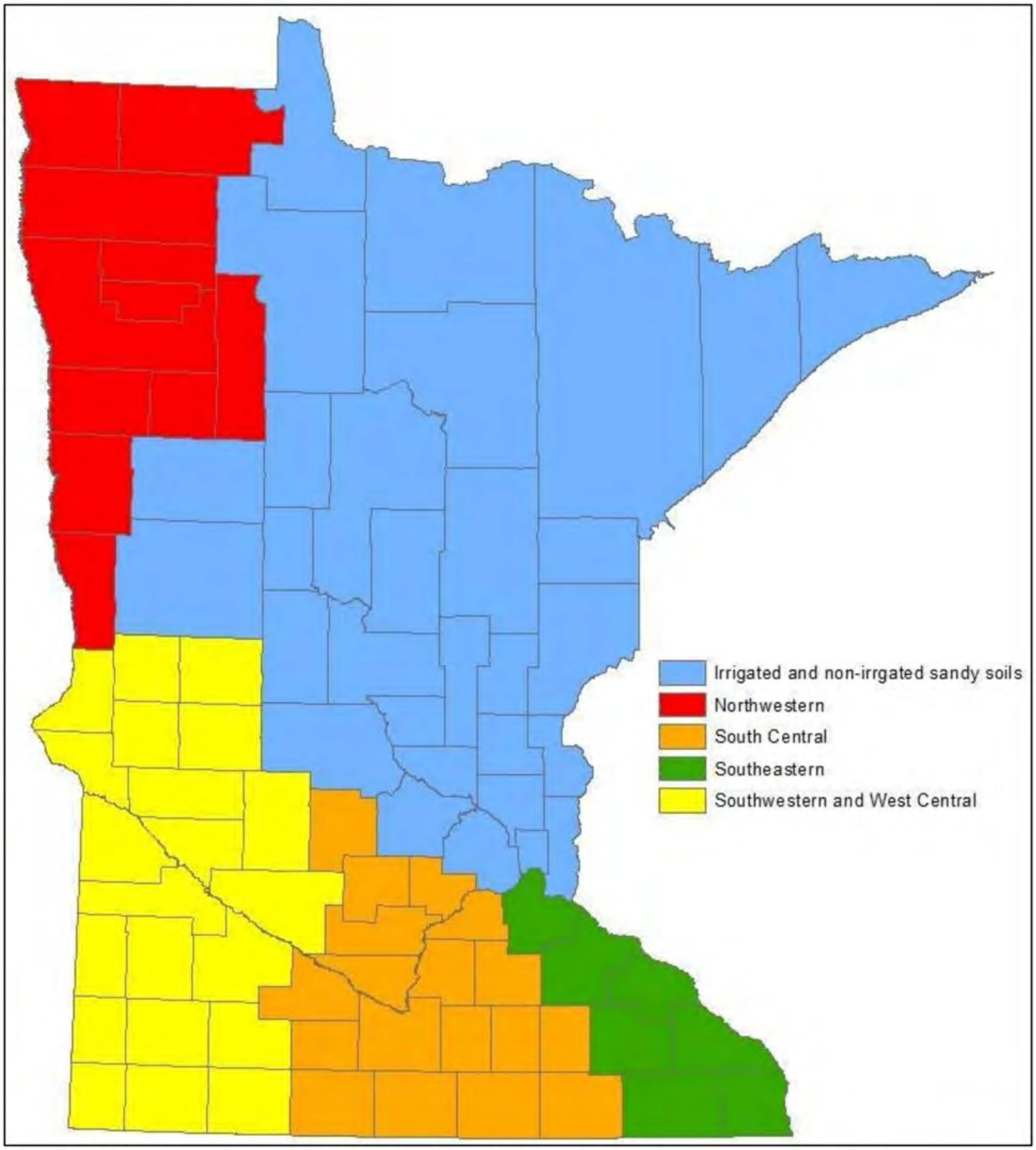


Figure III-1. Nitrogen fertilizer BMP regions. (Lamb et al., 2008).

Table III-1. Summary of the major nitrogen application timing and source BMP recommendations for corn by region (MDA, 2015).

	Minnesota Recommended Application Timing for Corn		
Nitrogen BMP Region	Fall*	Spring Preplant	Split or Sidedress
Southeast	Not Recommended	Highly Recommended: AA or Urea Acceptable with Risks: Preplant with UAN or ESN	Highly Recommended: AA, Urea, or UAN
South-Central	Acceptable with Risks: AA or Urea with N-Serve Not Recommended: Fall Application of Urea or UAN	Highly Recommended: AA or Urea Acceptable with Risks: Preplant with UAN or ESN	Highly Recommended: Split Applications of AA, Urea, or UAN
Coarse-Textured Soils	Not Recommended	Acceptable with Risk: AA or Urea with N-Serve, Single Sidedress w/o N-Serve, or Single Preplant with ESN	Highly Recommended: Use Split Applications, N-Serve with Early Sidedress
Southwest/West-Central	Recommended: Fall Application of AA or Urea Acceptable with Risk: Late Fall ESN or use of N-Serve or Agrotain Not Recommended: Fall UAN or Any Fertilizer Containing Nitrate	Recommended: Urea, AA, or UAN	Recommended: Sidedress Prior to V7 Growth Stage
Northwest	Recommended: Fall Application of AA or Urea Acceptable with Risk: Late Fall ESN or Use of N-Serve or Agrotain Not Recommended: Fall UAN or Any Fertilizer Containing Nitrate	Recommended: Urea, AA, or UAN	Recommended: Sidedress Prior to V7 Growth Stage

*Only after six inch soil temperatures fall below 50 °F

Note: AA=Anhydrous Ammonia, ESN=Environmentally Smart Nitrogen, UAN=Urea Ammonium Nitrate Solution

Recognizing that nitrogen fertilizer use efficiency is profoundly impacted by management (rate, timing, source, and placement) and significant nitrogen losses can occur under agricultural production, the U of M developed (and subsequently updated) a very complete set of nitrogen fertilizer BMPs in conjunction with the passage of the 1989 Groundwater Protection Act (Lamb et al., 2008; Randall et al., 2008 (a)(b); Rehm et al., 2008(a)(b); Rosen and Bierman, 2008; Sims et al., 2008). Minnesota has a great deal of variability in terms of soils, climate, geology, and crop selection. All these factors influence nitrogen management, so the state was divided into five BMP regions. Each region has specific recommendations in terms of nitrogen timing, placement and sources as well as the use of nitrification inhibitors and other helpful guidance for increasing fertilizer efficiencies. Nitrogen rate recommendations are imbedded within the BMP publications for corn, sugar beets, coarse textured soils, and selected other crops (Kaiser et al., 2016; Kaiser et al., 2011; Lamb et al., 2015). The U of M is continually studying the nitrogen requirements to account for changes in varieties, climate variability and similar, and are updating their rate recommendations annually. The updated rates are available at http://cnrc.agron.iastate.edu/

Figure III-2. Minnesota's nitrogen fertilizer BMPs. (Lamb et al., 2008; Randall et al., 2008 (a)(b); Rehm et al., 2008(a)(b); Rosen and Bierman, 2008; Sims et al., 2008).

The U of M also provides critical fertilizer rate guidance for the minor crops and special situations such as under irrigated conditions (Kaiser et al., 2011; Lamb et al., 2015).

The selection of the correct nitrogen rate is one of the most important decisions that farmers make in terms of potential impacts to water resources. A relationship exists between nitrogen rates, yields, and environmental outcomes. The cornerstone of the nitrogen fertilizer BMPs is identifying the optimum rate and then a series of other related practices (timing, split applications, inhibitors, etc.) to ensure that the nitrogen will be there when the crop needs it.

There are a number of key points worth noting:

1. First, nitrogen losses are never zero under row crop production. Even with corn/soybean production where no commercial nitrogen is applied, many Minnesota fields on fine-textured soils are losing approximately 10 lb/acre/year (Carlson et al., 2017). Background losses on coarse textured outwash (irrigated) ranged from 20-50 lb/acre (Struffert et al, 2016);

2. Losses under U of M recommendations tend to be linear up to the optimum rates. Nitrogen losses at optimum rates are frequently found to be between 15-40 lb/acre (weather dependent) on fine-textured soils. Losses on the soils using U of M recommended rates will range from 50% to 300% higher than non-fertilized conditions and are highly dependent on rainfall patterns (Carlson et al., 2017). Losses can be also significant on the irrigated outwash (Struffert et al, 2016);

3. Once rates exceed U of M recommendations, losses tend to increase in a quadratic response. When nitrogen rates were increased from 120 to 150 lb/acre in southern Minnesota, yields were increased by four bushels but the amount of residual nitrate left over in the soil profile increased by 40% (Carlson et al., 2017); and

4. Year to year climatic variability can strongly impact losses and general relationships.

A significant percentage of Minnesota's corn acres are receiving nitrogen rates above the MRTN (Maximum Return to Nitrogen) as recommended by the U of M.

2. Education and promotion of the nitrogen fertilizer BMPs

Field demonstration projects

As part of its statutory mandate to demonstrate and promote the effectiveness of the nitrogen fertilizer BMPs, the MDA has several on-going education and field demonstration programs. Educational outreach from these demonstrations are primarily with the participating farmers and their crop advisor(s), which in turn reaches other farmers and crop advisors they associate with. Educational outreach also occurs through presentations at field days and winter meetings, in media articles, and annual summary reports. Below are some examples of MDA's education and promotion work:

- *Rosholt Farm*
  In the coarse-textured irrigated sands of Minnesota, suction cup lysimeters have been utilized at the Rosholt Farm (MDA, n.d. (m)) in Pope County to quantify the loss of

nitrate from the root zone under nitrogen rate plots that are currently being managed by U of M Extension. These nitrogen rate plots are part of the ongoing effort to revise and refine nitrogen fertilizer BMP application rates for irrigated coarse-textured soils (Struffert et al., 2016). MDA staff have developed additional demonstration sites in the coarse-textured soils of Dakota, Lyon, Otter Tail, Stearns, and Wadena Counties.

- *Nutrient Management Initiative*
  The Minnesota Nutrient Management Initiative (NMI) assists farmers and crop advisers in evaluating nitrogen fertilizer BMPs (MDA, n.d. (h)). Farmers can compare nitrogen rates, timing, placement, or the use of a stabilizer product on their own fields. Many famers choose a rate trial, comparing their normal nitrogen rate to a 30 lb reduction. At the end of the season, farmers are provided with a yield comparison and a simple economic analysis based on their actual nitrogen costs and corn yields. The Nutrient Management Initiative is designed to help farmers and crop consultants evaluate management decisions using the farmer's actual field conditions. On-farm trials allow farmers to compare different practices and evaluate their outcome. Some of the data from this program is used to inform the U of M Corn Nitrogen Rate Calculator and help evaluate nitrogen fertilizer BMP effectiveness. From 2015 through 2017 there have been more than 380 NMI field trial sites. On average, 100 farmers and 30 crop advisers participate annually in approximately 100-125 field trials per year.

- *Minnesota Discovery Farms*
  Minnesota Discovery Farms (MDF, n.d.), a farmer-led program that is directed by the Minnesota Agricultural Water Resource Center (MAWRC) and supported by the MDA, is also contributing to the promotion of the nitrogen fertilizer BMPs and our understanding their field scale impact along with other conservation practices. Minnesota Discovery Farms encompass numerous farm enterprises across Minnesota and will inform our understanding the water quality impacts of common agricultural practices. Staff from MAWRC meets annually with the participating farmers to review the monitoring data. The monitoring data is available on the Discovery Farm program’s website. Monitoring data is additionally shared at field days and farmer meetings.

- *Root River Partnership*
  The Root River Partnership is designed to help southeastern Minnesota farmers and policy-makers better understand the relationship between agricultural practices and water quality (MDA, n.d. (j)). The purpose of this study is to conduct intensive surface and groundwater monitoring at multiple scales in order to provide an assessment of the amount and sources of nutrients and sediment delivered to the watershed outlet and also to determine the effectiveness of the nitrogen fertilizer BMPs and other conservation practices. This project includes an edge-of-field evaluation of the nitrogen fertilizer BMPs at one on-farm location. The study also includes a side-by-side field trial

comparing the U of M recommended rates and the farmer's normal nitrogen rates. Data is collected to compare crop yield as well as nitrate loss through tile drainage. This project has used monitoring data to provide information on the nitrogen fertilizer BMPs and other conservation practices needed to address water quality. This project is now transitioning from water monitoring to implementing conservation practices in the field. Project staff meet with the participating farmers annually to review the monitoring data, and the information is shared at field days, farmer meetings, professional meetings, as well as one-on-one meeting with area agronomists.

- *On-farm nitrogen fertilizer BMP studies with the U of M*
  MDA staff partner with U of M staff and staff of other partner organizations to conduct detailed nitrogen fertilizer BMP studies for the purposes of confirming or revising U of M guidelines on which the nitrogen fertilizer BMPs are based. Monitoring depends on the study being done and can include soil water nitrate-nitrogen concentration, as well as nitrogen concentrations in soil and tissue samples. Including in these studies is historic work done in Dakota County and current work at the Rosholt Farm in Pope County (MDA, n.d. (m)) and studies done as part of the Southeast Minnesota Nitrogen BMP Outreach Program. Education and outreach occurs through presentations at field days and winter meetings, media articles, and annual summary reports.

- *Soil temperature network*
  The MDA maintains a network of soil thermometers to assist farmers and applicators to follow the nitrogen fertilizer BMP of avoiding application in the fall until soil temperatures cool to 50^0 F (MDA, n.d. (l)). Every fall the MDA communicates through the media to remind farmers and applicators of this BMP and to remind them there are areas of the state where fall application of nitrogen fertilizer is not recommended, namely on coarse-textured soils and southeast Minnesota's region of karst geology.

a) Nitrogen fertilizer BMP education and outreach

There are many other outreach activities throughout the state that provide education about and promote the use of the nitrogen fertilizer BMPs. Some of these education and outreach programs are put on by other private or public groups outside of the MDA, with MDA either supporting or participating in the programs. All of these education and outreach opportunities "provide education about how the use of the best management practices will prevent, minimize, reduce, and eliminate the source of groundwater degradation."

- *Nitrogen Smart*
  Nitrogen Smart (UME, n.d.) is a training program for producers that presents fundamentals for maximizing economic return on nitrogen investments while minimizing nitrogen losses. The workshops deliver high-quality, research-based education so producers can learn:

- Sources of nitrogen for crops
- How nitrogen is lost from soil and how you can reduce losses
- How to manage nitrogen in drainage systems
- What the new NRS and NFMP mean for Minnesota producers
- Practices to refine nitrogen management, including split applications, alternative nitrogen fertilizers, soil and tissue testing, and nitrogen models

The Nitrogen Smart trainings are presented by U of M Extension, funded by Minnesota Corn Growers, and hosted by the Minnesota Agriculture Water Resource Center (MAWRC) at 8-10 locations throughout Minnesota during the winter months. There were 11 Nitrogen Smart trainings between February and March 2018.

- *Annual Nitrogen Conference*
  The U of M Minnesota Extension organizes an annual state-wide Nitrogen Conference that brings experts together to focus entirely on this valuable crop input (MAWRC, n.d.). The MDA is a lead sponsor of the conference. MDA staff regularly presents at the conference. Current topics in crop production and environmental stewardship are explored that are relevant and informative for farmers and their advisors. The conference attracts 125-175 attendees each year.

- *Annual Nutrient Management Conference*
  The MAWRC hosts an annual state-wide Nutrient Management Conference. The MDA is a lead sponsor of the conference. MDA staff members regularly presents at the conference. Although the conference covers all crop nutrient management issues, a substantial portion of its content is on nitrogen management. The conference is attended by farmers, their advisors, and water resource specialists and attracts up to 400 attendees each year.

- *U of M Extension winter meetings and summer field days*
  U of M Extension holds two winter meetings: the Research Updates held at the university's Research and Outreach Centers across the state and the Crop and Soil Days held at eight to ten state-wide locations. In addition to winter meetings, summer field days are held at the Waseca and Lamberton research and outreach centers, and the Institute for Agricultural Professionals Field School is held on the Saint Paul campus. Nitrogen fertilizer management is almost always on the agenda for meetings and field days because of its importance to agriculture agronomically and environmentally.

- *Minnesota Crop Production Retailers Association Short Course & Trade Show*
  Held jointly by the Minnesota Crop Production Retailers Association and the U of M Extension, this annual state-wide event for pesticide and fertilizer suppliers and

applicators is a reliable forum for sharing nitrogen management issues and technologies with licensed pesticide applicators, farmers, and crop advisors.

- *Source water protection plans*
  Public water suppliers are required to develop source water protection plans and update them on a ten-year schedule. When elevated nitrates in drinking water is an issue, these plans include educational activities to promote nitrogen fertilizer BMPs and AMTs in their WHPAs. Local soil and water conservation districts (SWCDs) are usually utilized to carry out the nitrogen fertilizer BMP and AMT education.

- *Ag supplier education and support*
  The primary source of nitrogen fertilizer management information for most farmers is their fertilizer dealer agronomist. It is with this advisor that most farmers decide on an annual NFMP. Fertilizer dealer agronomists provide education to their client farmers on crop nitrogen need, management, and water quality protection concerns. They also provide support services such as monitoring fall soil temperature to let farmers know soil temperatures have reached 50° F so they can apply fall nitrogen.

- *Ag supplier winter meetings*
  A regular feature of Minnesota's agricultural industry is the agricultural suppler winter meeting. Suppliers of seed, fertilizer, and pesticides invite their farmer clients to meetings where they will provide a free meal and information on upcoming product and program developments. Nitrogen fertilizer management is almost always on the agenda for these meetings because of its importance to agriculture agronomically and environmentally.

b) MDA's external partnerships providing education and promotion of the nitrogen fertilizer BMPs

In addition to the Fertilizer Field Unit within the Pesticide and Fertilizer Management Division of the MDA, there are several staff throughout the state whose positions are dedicated to providing education about and promote the use of nitrogen fertilizer BMPs.

- *Agricultural Water Quality Protection Educators, U of M Extension*
  The U of M supports two extension educator positions in the area of crop nitrogen fertilizer management, one in Saint Cloud and one in Rochester. The focus of their positions is assisting crop producers in implementing nitrogen fertilizer BMPs and AMTs as outlined in the state's NFMP. The positions are funded by state Clean Water Fund dollars administered by the MDA.

- *Irrigation Management Specialist, U of M Extension*
  The U of M supports an irrigation management specialist extension educator position that focuses on crop irrigation management as it relates to nitrogen management and water

quality protection. The position's objective is to increase the capacity of farmers and their advisors to more effectively manage cropland irrigation state-wide, especially in areas vulnerable to groundwater contamination (MDA, n.d. (e)). The position is funded by state Clean Water Fund dollars administered by the MDA.

- *Nitrogen management specialist, U of M Extension*
  The U of M supports a nitrogen management specialist position within its Department of Soil, Water, and Climate. Funded by the Minnesota Corn Growers Association, the position concentrates through research and outreach education on environmental issues related to nitrogen management of corn cropping systems, seeking to identify and implement nitrogen management practices that are sustainable both in terms of water quality protection and improving crop yields. This position is critical to developing and updating the nitrogen fertilizer BMPs, conducts MDA-sponsored research projects, consults regularly with MDA staff, and serves on several MDA advisory boards including the nitrogen fertilizer BMP Education and Promotion.

- *Source Water Protection Specialists, Minnesota Rural Water Association*
  The Minnesota Rural Water Association has two staff positions, one in Park Rapids and one in Rochester, which focus on addressing elevated nitrate-nitrogen concentration of rural public water suppliers. Since the source of this nitrate is often agriculture, they are actively involved in promoting nitrogen fertilizer BMPs and AMTs in WHPAs. These staff are frequently partners on a variety of demonstration sites, including the promotion of Kernza and other perennials with the wellhead protection areas (WHPAs) and will be directly or indirectly active with future Local Advisory Team activities.

- *Southwest Minnesota Regional Water Resources Specialist*
  MDH and local funds supports a Regional Water Resources Specialist who works with six counties in southwest Minnesota with a focus on nitrogen management. The position promotes nitrogen fertilizer BMP and AMT use in WHPAs that are vulnerable to nitrate groundwater contamination. MDA staff partner with the person in this position on various demonstration and outreach activities. The person in this position also will be directly or indirectly active with future LAT activities.

c) Minnesota Agricultural Water Quality Certification Program

The Minnesota Agricultural Water Quality Certification Program (MAWQCP) is a voluntary opportunity for farmers and agricultural landowners to take the lead in implementing conservation practices that protect our water (MDA, n.d. (f)). Those who implement and maintain approved farm management practices will be certified and in turn obtain regulatory certainty for a period of ten years. Part of the farm operation review process associated with certification is a discussion and evaluation of nitrogen management, including the nitrogen fertilizer BMPs and AMTs. As of March 2018, 544 farmers are certified, comprising 341,800 acres of agricultural land.

d) Historic nitrogen fertilizer BMP Promotion: 1990-2011

- *Source Water Protection Areas*
  Focused education and demonstration projects related to nitrogen management within key agricultural SWPAs (Perham, St. Peter, Verndale, Lincoln-Pipestone, and Cold Spring);

- *Nitrate Testing Clinics*
  Successfully created awareness of nitrates in private drinking wells through the testing of over 50,000 wells from 1996 to 2006. The clinic format provided many excellent opportunities to discuss nitrogen fertilizer BMPs with farmers and home owners;

- *Field Scale Demonstrations*
  Created water quality demonstration sites at Red Top Farm (Nicollet Co), Highway 90 (Blue Earth Co), Perham SWPA (Otter Tail Co), Verndale SWPA (Wadena Co), and others. Sites were instrumented to measure nitrate losses as a function of various nitrogen fertilizer BMPs and crop selection. Numerous field day events and winter educational events provided outlets for the results;

- *Soil and Manure Testing Certification Programs*
  In support of nitrogen fertilizer BMPs related to soil and manure testing, the MDA developed certification programs for laboratories providing these services to farmers. The programs require approved testing procedures and the presentation of results that are in an understandable and standardized format. The vast majority of soil and manure analysis now come from certified labs;

- *MDA Leadership in nitrogen fertilizer BMP Research Projects*
  The MDA partnered and managed numerous grants from the Legislative Commission on Minnesota Resources/Legislative-Citizen Commission on Minnesota Resources (LCMR/LCCMR) and USEPA 319 grants to assist the U of M in the development and validation of nitrogen fertilizer BMPs;

- *Nitrogen Fertilizer BMP Insurance Concept*
  This was a pilot project funded by USDA-Federal Crop Insurance Corporation, led by the MDA in partnership with Iowa Department of Natural Resource and Wisconsin Department of Natural Resources. The project provided insurance protection for growers experimenting with nitrogen rates recommended by the land grant universities. Although the program eventually was discontinued, several key features led to the development of the MDA's Nutrient Management Initiative.

B. Nitrogen Fertilizer Management Plan (NFMP)

Laws of Minnesota 1989, Chapter 326, Article 6, Section 33, subd 2 required MDA to establish the following:

(1) establish best management practices and water resources protection requirements involving fertilizer use, distribution, storage, handling, and disposal;

(2) cooperate with other state agencies and local governments to protect public health and the environment from harmful exposure to fertilizer; and

(3) appoint a task force to study the effects and impact on water resources from nitrogen fertilizer use so that best management practices, a fertilizer management plan, and nitrogen fertilizer use regulations can be developed.

The law further required that this Task Force be made up of a diverse group of representatives from agriculture, environmental groups, and local and state governments. The Task Force was responsible for reviewing current information regarding the impact of nitrogen fertilizer on water resources and for making recommendations on ways to minimize these effects. The nitrogen fertilizer management plan must include components promoting prevention and developing appropriate responses to the detection of inorganic nitrogen from fertilizer sources in ground or surface water.The MDA uses the state's NFMP as the blueprint for prevention and minimization of the impacts of nitrogen fertilizer on groundwater. The NFMP, revised in 2015, was developed using a multi-stakeholder advisory committee and a public review process. It emphasizes involving local farmers and agronomists in problem-solving for local groundwater concerns when nitrate from fertilizer is a key contributor. Nitrogen fertilizer BMPs are the cornerstone of the NFMP and the proposed Rule. Authority for the proposed Rule comes from the Groundwater Protection Act, Minn. Stat. § 103H.275. The plan lays out education and promotion activities, how the MDA monitors groundwater and provides the framework for the proposed Rule.

In 2010, the MDA began the process of revising the 1990 NFMP to reflect current agricultural practices and activities, apply lessons learned from implementation activities and other work, and to better align it with current water resource conditions and program resources. The MDA assembled an Advisory Committee with 18 members, including three members from the original Task Force. The MDA hosted eighteen Advisory Committee meetings between 2011 and 2012 to review information related to the nitrogen cycle, nitrate contamination of ground and surface water, hydrogeologic conditions, crop production, nitrogen management, research, and implementation. Before the final version of the plan was released the MDA had a final public comment period. During this comment period, the MDA received 32comments from various stakeholders. These comments were addressed before releasing the final version of the NFMP (MDA, 2015). The NFMP is attached as appendix 9 and is available online at http://www.mda.state.mn.us/nfmp. The general approach used by the NFMP to address nitrate in groundwater consists of the following activities: prevention, monitoring and assessment, and mitigation.

The proposed Rule follows the process outlined in the NFMP and works with local farmers to make sure they are following the nitrogen fertilizer BMPs before moving to regulation.

Thus, MDA has satisfied its statutory obligation of education, promotion, and development of BMPs through their development in cooperation with the University of Minnesota, the numerous field demonstration projects, training programs and conferences, funding of positions dedicated to education of BMPs, and the Agricultural Water Quality Program. Through the NFMP, MDA has continued its development and education of BMPs, and is using the NFMP as a blueprint for the development of the rule.

C. MDA monitoring of nitrates in groundwater

MDA has been part of monitoring of groundwater for nitrates since 1987. Monitoring is done on both private and public wells.

A well is a hole drilled into the ground used to access water. A pipe and a pump move the water from an aquifer to a sink, shower, or other location for drinking, washing, etc. Wells can be either private or public. A private well is usually owned by a person and is intended to supply water to a home or for another nonpublic use. Public wells supply water to city residents, hotels, lodging facilities, schools, and other entities. If a public well is contaminated with nitrate, the water supplier bears the cost of treating the water or providing a safe source of water. Those costs are usually passed on to the ratepayers. Additional information on alternatives and costs is available in, the Regulatory Analysis section under, Alternative methods of achieving the proposed Rule that were considered and rejected, of the SONAR.

1. Private Wells – Township Testing

Water samples from large areas show that relatively small percentages of private wells exceed the health risk limit. The MDH estimates that around 1% of new Minnesota wells exceed 10 mg/L nitrate-nitrogen. A USGS report on nitrate concentrations in private wells in glacial aquifer systems of the United States estimates that less than 5% of wells had nitrate-nitrogen concentrations exceeding the health risk limit (Warner and Arnold, 2010).

However, wells in areas with vulnerable soils and geology are at much greater risk and exceed the health risk limit in larger numbers. The MDA is in the midst of offering nitrate testing to private well owners in areas vulnerable to groundwater contamination and with significant row crop production. The wells are sampled in townships and it is called the Township Testing Program (TTP).

From 2013 to 2017, 242 vulnerable townships from 24 counties participated in the TTP. Overall, 10.1% (2,583) of the 25,652 wells exceeded the health risk limit for nitrate in the townships that have been sampled. Some townships with initial results have yet to be analyzed for possible nitrogen sources, so the final percentage of wells over the health risk limit from a non-point source may change based on follow-up sampling (MDA, 2018 (b)). More than 70,000 private well owners will be offered nitrate testing in over 300 townships by 2019.

Table III-2. Township Testing Program nitrate-nitrogen summary: 2103-2017

Total Wells	Nitrate-Nitrogen mg/L (ppm)			
	<3	3<10	≥10	≥10
	Number of Wells			Percent
25,652	19,277	3,792	2,583	10.1

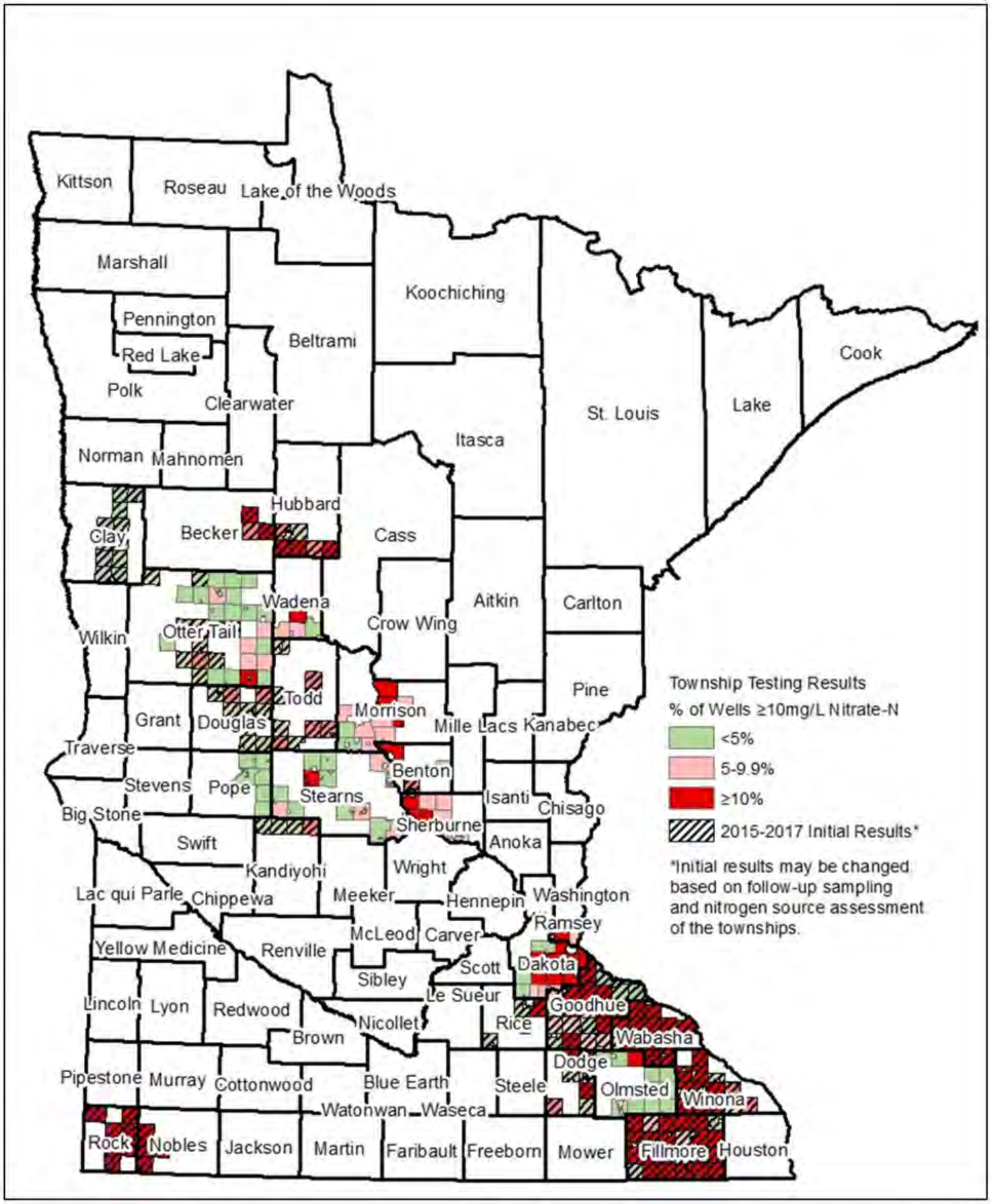


Figure III-3. Percentage wells in each Minnesota Township exceeding 10 mg/L nitrate-nitrogen MDH HRL at initial sampling.

2. Public wells

Various communities that use groundwater as their water source have exceeded the health risk limit for nitrate in recent years. According to the MDH, 15 community public water supplies had nitrate levels in groundwater above the health risk limit as of 2014. (MDH, 2015). The number of community water suppliers that treat for nitrate has increased from 6 systems serving 15,000 people in 2008 to 8 systems serving 50,000 people in 2014. Six non-community systems exceeded the 10 mg/L nitrate-nitrogen health risk limit in 2016, requiring corrective action (MDH, 2017). Non-community systems provide water to people in schools, lodging facilities, and businesses that are not connected to community water systems.

3. Monitoring wells

To monitor in areas with shallow groundwater, nested groundwater wells are installed by the MDA in or near areas with row crop agriculture. Monitoring these areas aids in early detection if chemicals are present, and is considered a preventive and proactive approach to protecting Minnesota's waters. Although the MDA's current groundwater monitoring program was originally designed for pesticides, the MDA collects and analyzes samples for nitrate to provide information about the potential environmental impact to groundwater associated with agricultural activities in the state. A description of the networks is available in the Nitrogen Fertilizer Management Plan (MDA, 2015)

In 2004, the MDA groundwater monitoring program, with assistance from the University of Minnesota, established a regional monitoring network that divided the state into ten regions. These regions were developed to facilitate water quality monitoring efforts, pesticide management, and BMP development, promotion, and evaluation. These regions were termed Pesticide Monitoring Regions (PMRs).

A 2012 report provided a summary of the MDA's nitrate groundwater monitoring activities (MDA, 2012). The nitrate data were compiled and analyzed on an annual basis for each region. The Central Sands area (PMR 4) and the Southeast karst area (PMR 9) were determined to be the most vulnerable to and the most impacted by nitrate contamination. Nitrate was detected in 94% to 100% of the samples from 2000 to 2010 in PMRs 4 and 9. According to the most recent data available, nitrate was detected in all samples from the two regions. Seventy-six percent of the samples collected in the Central Sands area (PMR 4) exceeded the HRL along with 26 percent in the southeast karst area (MDA, 2017).

The monitoring wells described here are properly constructed for monitoring and are not located near nitrogen point sources. They are located at the edges of fields. Therefore, it is reasonable to conclude nitrate is coming from agricultural practices.

Figure III-4. Minnesota Pesticide Monitoring Regions (NFMP, 2015).

4. Southeast and Central Sands Private Well Volunteer Monitoring Networks

The MDA and partners have worked with private well owners to sample their wells for nitrate, and have found there can be variability in monitoring data in individual wells from year to year. The Southeast Volunteer Monitoring network has been in place since 2008 in 9 counties. Between 2008 and 2015, ten sampling events occurred representing approximately 4,300 samples. During this period, the percentage of wells exceeding the health risk limit for each sampling event ranged between 8 and 15 percent. Each year, between 373 and 519 wells were sampled. The MDA launched a similar project in the Central Sands area of Minnesota, which includes 14 counties. From 2011 to 2015, 3 to 4 percent of the wells exceeded the health risk limit. The number of wells sampled annually during this period ranged from 402 to 534.

The MDA in cooperation with other state agencies have done extensive monitoring of groundwater. Based on the above, MDA has complied with all its requirements under 103H, and has determined that the implementation of the BMPs has proven ineffective as it relates to Nitrogen fertilizer.

D. Nitrogen Fertilizer Management Plan (NFMP)

1. Development Process

The MDA uses the state's NFMP (MDA, 2015) as the blueprint for prevention and minimization of the impacts of nitrogen fertilizer on groundwater. The NFMP, revised in 2015, was developed using a multi-stakeholder advisory committee and a public review process. It emphasizes involving local farmers and agronomists in problem-solving for local groundwater concerns when nitrate from fertilizer is a key contributor. Nitrogen fertilizer BMPs are the cornerstone of the NFMP and the proposed Rule. Authority for the proposed Rule comes from the Groundwater Protection Act, Minn. Stat. § 103H.275. The plan lays out education and promotion activities, how the MDA monitors groundwater and provides the framework for the proposed Rule.

The first NFMP was adopted in 1990. The original 1990 NFMP was created with the guidance of the Nitrogen Fertilizer Task Force. This Task Force was made up of a diverse group of representatives from agriculture, environmental groups, and local and state governments. The Task Force was responsible for reviewing current information regarding the impact of nitrogen fertilizer on water resources and for making recommendations on ways to minimize these effects (MDA, 2015). In 2010, the MDA began the process of revising the 1990 NFMP to reflect current agricultural practices and activities, apply lessons learned from implementation activities and other work, and to better align it with current water resource conditions and program resources. The MDA assembled an Advisory Committee with 18 members, including three members from the original Task Force. The MDA hosted eighteen Advisory Committee meetings between 2011 and 2012 to review information related to the nitrogen cycle, nitrate contamination of ground and surface water, hydrogeologic conditions, crop production, nitrogen management, research, and implementation. Before the final version of the plan was released the MDA had a final public comment period. During this comment period, the MDA received 32 comments from various stakeholders. These comments were addressed before releasing the final version of the NFMP (MDA, 2015). The NFMP is attached as appendix 9 and is available online at http://www.mda.state.mn.us/nfmp. The general approach used by the NFMP to address nitrate in groundwater consists of the following activities: prevention, monitoring and assessment, and mitigation.

With the updated NFMP in place the MDA has decided to adopt water resource protection requirements to support the state's plan to reduce nitrate in groundwater. The proposed Rule follows the process outlined in the NFMP and works with local farmers to make sure they are following the nitrogen fertilizer BMPs before moving to regulation.

IV. The MDA has determined that the Implementation of BMPs Related to Nitrogen Fertilizer is not Effective.

Minn. Stat. § 103H.275, subd. 1, states that the MDA may adopt water resource protection requirements by rule that are consistent with of Minn. Stat. § 103H.001 and are commensurate with the groundwater pollution if the implementation of BMPs has proved to be ineffective. This section will address the implementation of nitrogen fertilizer BMPs throughout the state.

The MDA is the designated lead state agency through Minn. Stat. chap.18C for the regulation of commercial fertilizers. Additional responsibilities, as stated in Minn. Stat. chap. 103H, require the MDA to protect groundwater from the use of nitrogen fertilizer. As part of these requirements, the MDA is required to assess the status of nitrogen fertilizer BMP implementation. Accurate nitrogen fertilizer BMP assessments are a critical component of the NFMP. Since 1993, the MDA has developed innovative assessment tools and techniques to determine the implementation of the nitrogen fertilizer BMPs at the statewide, regional, and local scales. Over the past 25 years, the MDA has interviewed thousands of Minnesota producers who represented different geologic settings, climatic regimes, crop rotations, and livestock operations. These various assessment tools help MDA and the agricultural community understand how farmers manage their nitrogen inputs including fertilizers, manures, and legume credits, as well as the rate, timing, placement, and sources of nitrogen fertilizers. The MDA also has developed several different groundwater monitoring systems to monitor the presence of pesticides and fertilizers in groundwater around the state. One of these systems uses edge of field monitoring wells, with no nearby point sources, indicating there is a high presence of nitrate in groundwater.

It has been established that Nitrogen fertilizer sales have increased over the years as the amount of nitrogen-demanding plants has replaced more nitrogen friendly plants. It has also been proven that Minnesota has seen an increase in nitrogen in the groundwater in some areas vulnerable to groundwater contamination, including DWSMAs. The surveys described in this section have been important for educating to farmers. The education process is an important tool, but by itself, is not effective in securing nitrogen fertilizer BMP adoption or stopping the increase in nitrates in groundwater, especially in areas where nitrate levels are the highest. The MDA concludes that excessive rates are used in some locations, credit for existing nitrogen is not always taken, and the excess of nitrate in groundwater in some agricultural areas needs to be decreased by requiring the adoption of water resource protection requirements. This data proves that the implementation of the BMPS is ineffective.

A. Data shows that producers are over-applying nitrogen fertilizer, including miscalculating how much nitrogen is applied when manure is used.

The MDA has authored and published numerous reports using the localized and highly detailed Farm Nutrient Management Assessment Program (FANMAP) (MDA, n.d. (b)) approach as well as a broader phone-based approach in partnership with the National Ag Statistics Service (NASS) (MDA, n.d. (i)). Through these assessment tools and routine monitoring of fertilizer tonnage sales, the MDA has developed extensive knowledge on nitrogen fertilizer trends and associated management practices in Minnesota. These various assessment tools help understand how farmers manage their nitrogen inputs including fertilizers, manures, and legume credits as well as the rate, timing, placement and sources of nitrogen fertilizers.

The MDA has authored and published numerous reports through the FANMAP which provides highly detailed information about agricultural inputs such as fertilizer, manure, and pesticides. This tool is extremely useful when working with farmers in different regions across Minnesota.

In order to conduct a FANMAP survey, it is critical to develop a representative sampling population. In all FANMAP activities, County Educators (Minnesota Extension Service) and SWCD staff from the appropriate counties are contacted and individually interviewed. The purpose of the interviews is to inform them of the specifics of the particular project and overall goals; obtain pertinent county information (i.e. locations and demographics); and identify potential candidates (farmers) and their agronomic management skills as perceived by the County Educator. Information about on-farm management and inputs is collected by a personal visit to each farm and typically requires one to two hours of contact. Since its inception, thousands of Minnesota farmers have shared valuable information about their farming practices. For more information, please visit the MDA's FANMAP website (MDA, n.d. (b)).

More recently, the MDA has partnered with the USDA National Agricultural Statistic Service (NASS) and U of M researchers to collect information about fertilizer use and farm management on a broader scale than FANMAP (MDA, n.d. (i)). Partners have pioneered a survey tool for characterizing fertilizer use and associated management on a regional and statewide scale. Surveys are conducted over the phone. Enumerators from NASS are highly skilled at obtaining critical information over the phone with minimal time and burden on the producer. Over the past 25 years, the MDA has interviewed thousands of Minnesota producers who represented different geologic settings, climatic regimes, crop rotations, and livestock operations. The first attempt using this technique was in 2010 and has been conducted on a yearly basis since then. NASS enumerators surveyed approximately 1,500 corn farmers from across the state to gather information about commercial fertilizer use. The statewide fertilizer use survey alternates every other year. Much of the focus is on corn production, where 70% of the commercial inputs are used. During alternate years, the survey focuses on regional issues in areas of the state where there is a high risk of groundwater contamination. Reports are compiled and available on the MDA's website. While the MDA has conducted numerous fertilizer use surveys, for purposes of this SONAR, much of the supporting documentation is derived from three extensive NASS surveys conducted in 2010, 2012 and 2014, which included thousands of Minnesota's corn producers.

In summary, the following general practices which directly threated groundwater quality are routinely observed on both a statewide level and on a localized (DWMSAs) scale. While there are many areas where Minnesota farmers have made great improvements in nitrogen management, a very significant number of cropland acres are using practices that threaten groundwater resources.

- *Lack of Nitrogen Crediting from Legumes:* The MDA found that 18 – 38 pounds in excess of U of M guidelines are commonly applied after growing soybeans. Soybeans are a legume and can put nitrogen back into the soil, so less nitrogen is needed for the next crop.

- *Lack of Nitrogen Crediting from Other Fertilizers:* The total amount of nitrogen fertilizer from all sources needs to be taken into account, or credited, when calculating the total amount of nitrogen applied to a crop. Phosphorus fertilizer sources that also contain nitrogen, such as monoammonium phosphate (MAP) or diammonium phosphate (DAP), and more recently ammonium sulfate, are seldom credited when they should be.

- *Lack of Manure Crediting:* Similar to not taking crediting for other fertilizers or legumes, manure sources are not being properly credited when producers are calculating the total amount of nitrogen applied to a crop. Over-application rates are frequently compounded when in tandem with legume crops.

- *Fall Applications:* Surveys indicate that 30-40% of all nitrogen is applied in the fall. Different areas of the state have different nitrogen fertilizer BMPs when it comes to fall application. The nitrogen fertilizer BMPs specify where and when fall application is appropriate. The surveys show concerns about improper nitrogen source selection, lack of using a nitrification inhibitor when recommended, applications made prior to proper soil temperatures, and application onto inappropriate soil types.

- ***Collectively, Excessive Nitrogen Fertilizer Use:*** Across the various rotations and different scenarios, it is conservatively estimated that Minnesota producers use 10-15% more nitrogen fertilizer then necessary to maintain optimum yields. Nitrogen sales should be reduced by approximately 100,000 tons/year to not only improve water quality but also reduce the financial burden on producers.

There is a very strong body of knowledge indicating that BMPs are not being adopted to an acceptable level and an equally strong body of knowledge on the related impacts to groundwater quality. Therefore is it needed and reasonable for MDA to move forward with Part One and Part Two of the proposed Nitrogen Rule.

The amount of nitrogen fertilizer that is used can have a great impact on the amount available to leach into groundwater (MDA. n.d. (d)). Rates are generally viewed as the most important single factor impacting both economic and environmental perspectives in comparison to the other remaining practices of right source, right placement and right timing. The choice of the appropriate rate is not easy to determine because of the transient nature of nitrogen in soil (Kaiser et al, 2016).The amount of nitrogen fertilizer that is used can have a great impact on the amount available to leach into groundwater.

The U of M has based their recommendations for nitrogen fertilizer rate on the maximum return to nitrogen (MRTN). This is determined using the ratio between the price per pound of nitrogen divided by the price per bushel of corn in order to determine the rate of nitrogen fertilizer that should be used in order for a farmer to get the greatest return from their crop (Kaiser et al., 2016). Numerous factors influence the price per pound of nitrogen and the price per bushel of corn which will vary over time and across individual farm operations. It is generally accepted that over the long haul, the prices of grain and fertilizers are closely linked within the marketplace and for most situations, the 0.10 ratio is highly appropriate for corn production when manure resources are not used.

By further examining the application rates for various crop rotations and comparing these rates with the U of M fertilizer recommendations, it is possible to make estimates on the amount of excess nitrogen that is applied during selected rotations. Appendix 1 shows the calculations used to determine over-application of nitrogen fertilizer in various rotations.

There are appreciable over-application rates found in the corn-soybean rotation. Over-application rates within this rotation range from 18 to 38 lb/A, depending up which top rate U of M recommendation is used. Statewide across all associated acres in this rotation, this translates into excessive nitrogen inputs between 32,000 and 67,000 tons of N per year. This was between 4 to 9% of the statewide N sales for 2014.

In rotations where manure is applied, an additional 3-4% of nitrogen fertilizer, conservatively, is over-applied. It is important to note that the acres of this over application are relatively small but the rate of over-application occurring on this land is high. In the continuous corn rotation, the excessive nitrogen inputs are minimal (1,765 to 3,437 tons per year) which is less than 0.4% of the statewide N sales for 2014.

When these two rotations are considered collectively, 55,000 to 100,000 tons of nitrogen fertilizer is used in excess of the U of M nitrogen fertilizer recommendations. This is 7 to 12% of the annual nitrogen fertilizer sales in the state of Minnesota. Based on the studies cited above, we know that this over-application threatens the quality of Minnesota’s groundwater.

Below are summaries from the 2010, 2012 and 2014 NASS survey’s documenting how the nitrogen fertilizer rate BMPs are ineffective based on crop rotation.

NASS Survey: Corn following Corn

Statewide, nitrogen fertilizer application rates for corn following corn averaged 158 lbs of nitrogen per acre (MDA and NASS, 2014, 2016, and 2017). The current U of M MRTN rate is 155 lbs with a range of 145-170 lbs of nitrogen per acre (Figure IV-1).

The average percentage of fields in a corn following corn rotation that exceed the guidelines in the past 3 surveys is 37%. Nitrogen rates in excess of the University of Minnesota guidelines frequently result in excessive residual soil nitrates at the end of the growing season. There is an increased probability that this extra nitrogen will be leached below the root zone by the following spring.

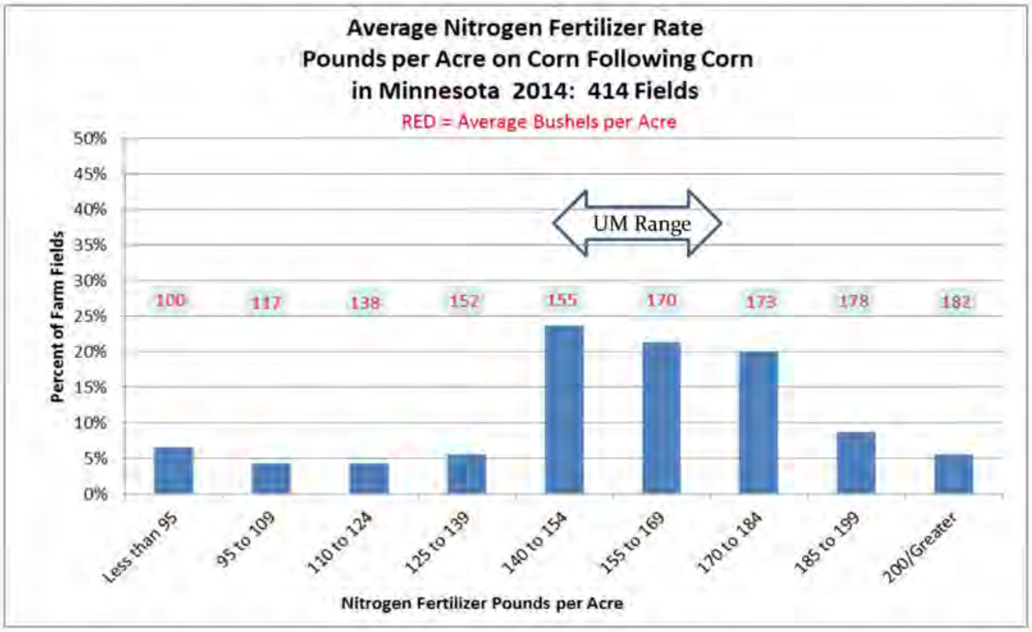


Figure IV-1. Percent fields within U of M recommended nitrogen rate ranges for corn following corn.

NASS Survey: Corn following Soybeans

Statewide, nitrogen fertilizer application rates for corn following soybeans averaged 145 lbs nitrogen per acre (MDA and NASS, 2014, 2016 and 2017). The current U of M MRTN rate is 120 lb with a range of 105 to 130 lb nitrogen per acre (Figure IV-2).

The percentage of fields in a corn following soybeans rotation exceeding the guidelines averages 65%. Surveys found that farmers were applying 20-40 lb in excess of the U of M guidelines in a corn following soybean rotation, which means there is extra nitrate present on the fields available that is leaching into groundwater.

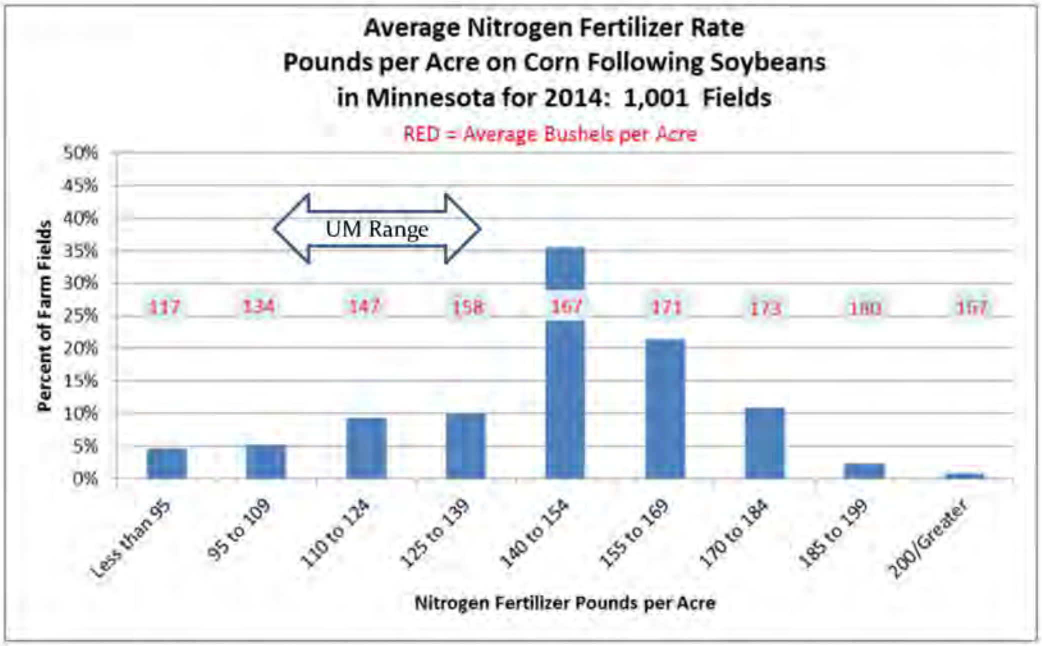


Figure IV-2. Percent fields within U of M recommended nitrogen rate ranges for corn following soybeans.

NASS Survey: Corn following Manure

Generally, 15-20% of the corn acres in the state will get a manure application either the fall before or just prior to spring planting. These percentages will vary significantly based on local livestock densities. Manure crediting is much more difficult to predict than other nitrogen sources. The nitrogen content of the manure is highly dependent on the type of manure, climatic conditions, how the manure was stored, and many other variables. Because of the high number of uncertainties associated with manure nitrogen credits, livestock producers and agricultural professionals tend to be conservative in their estimates of need and frequently over-apply manure in combination with nitrogen fertilizer.

Additionally, the manure applications are frequently made by either the producer or a commercial manure applicator. Proper nitrogen crediting requires that manure records are shared with the fertilizer dealer, so they can accurately reduce commercial inputs. However, even though the sharing of this information is required, the surveys show that it is not commonly communicated, and over-applications frequently occur.

A 2012 survey (MDA and NASS, 2016) documented the frequency and magnitude of nitrogen inputs on manured acres on corn (Figure IV-3). For purposes of the survey, manured acres are defined as those acres that had manure applied in the previous fall (after harvest) through applications made in the spring before planting. The survey documented average nitrogen inputs from manure at 120 lb/acre and from commercial nitrogen fertilizer at 76 lb/acre, totaling 196 lbs per acre. The current U of M MRTN rate is 155 lb per acre with a range of 145 to 170 lbs nitrogen per acre (Figure IV-3).

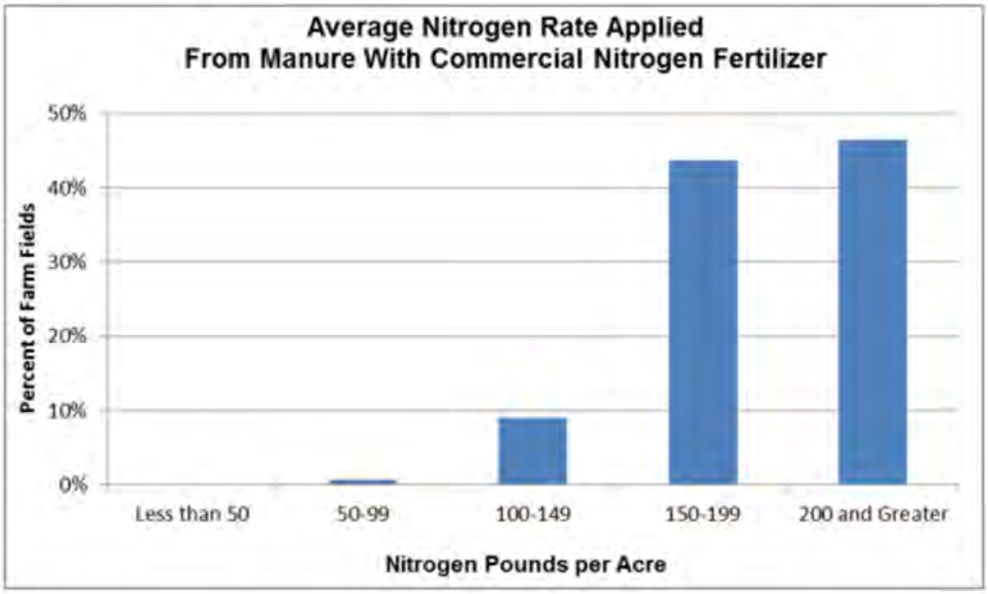


Figure IV-3. Average nitrogen inputs (fertilizer and all forms of manure) statewide.

Corn following Alfalfa, with Manure

Despite the large nitrogen credit typically provided by the killing of alfalfa (75-150 lb/acre), producers frequently apply manure before planting corn on fields with killed alfalfa. In a recent joint study, the U of M and USDA-ARS found fields where manure was applied to killed alfalfa prior to the first year of growing corn, the over-application rates were frequently found to be 100-200 lb nitrogen per acre over U of M guidelines (Figure IV-4, Yost et al., 2015).

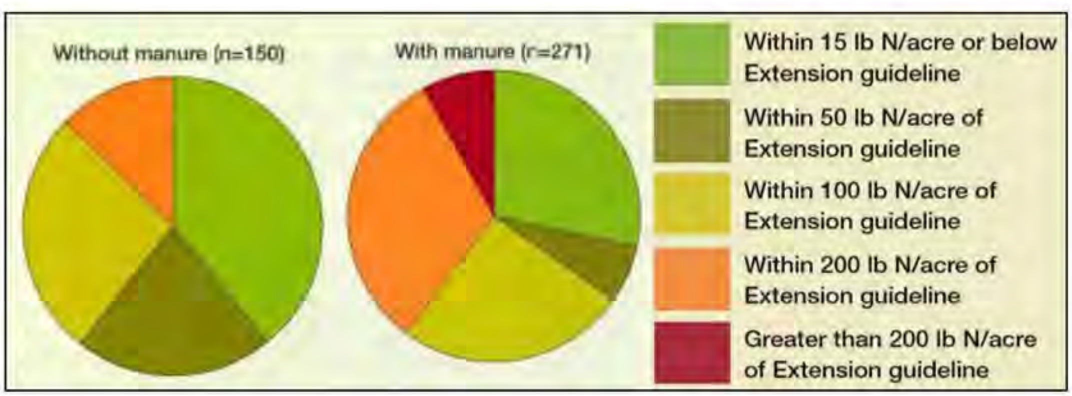


Figure IV-4. Applications of nitrogen fertilizer with or without manure on first-year corn following alfalfa.

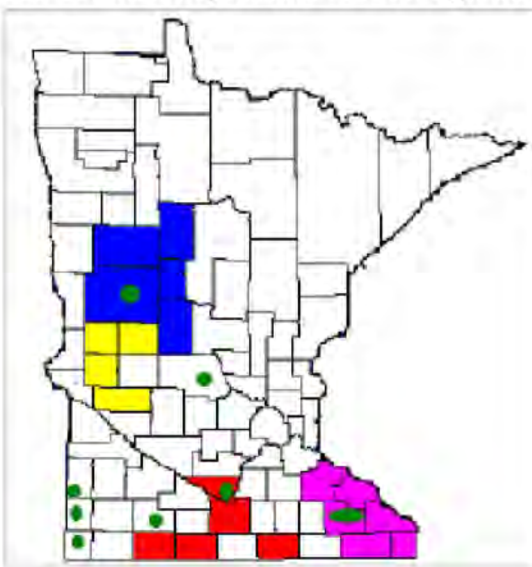
Based on the NASS survey results presented above, there is ample evidence that nitrogen fertilizer is being over applied and that the BMP implementation is ineffective.

BMP Adoption Assessments within DWMSAs

Results from FANMAP surveys have been used to design focused water quality educational programs for localized areas such as DWMSAs. Data collected in the program's infancy were used as a baseline to assist in determining if voluntary BMPs are being adopted. Over the years, hundreds of farmers have volunteered two to four hours of their time to share information about their farming operations.

Since Part 2 of the proposed nitrogen Rule is very specific to DWMSAs, it is highly relevant to present DWMSA information on BMP adoption in a similar fashion to the statewide assessments previously provided. Most of MDA's experience and knowledge on BMP adoption evolved from working closely with farmers within DWMSAs. A listing of individual FANMAP reports can be found by going the following web link: http://www.mda.state.mn.us/protecting/soilprotection/fanmap.aspx).

Locations of the FANMAP Analysis
(Green Circles Represent Focused DWMSAs Studies
Shaded Counties Represent Broader Region Studies)



Data Source: Montgomery et al., 2001

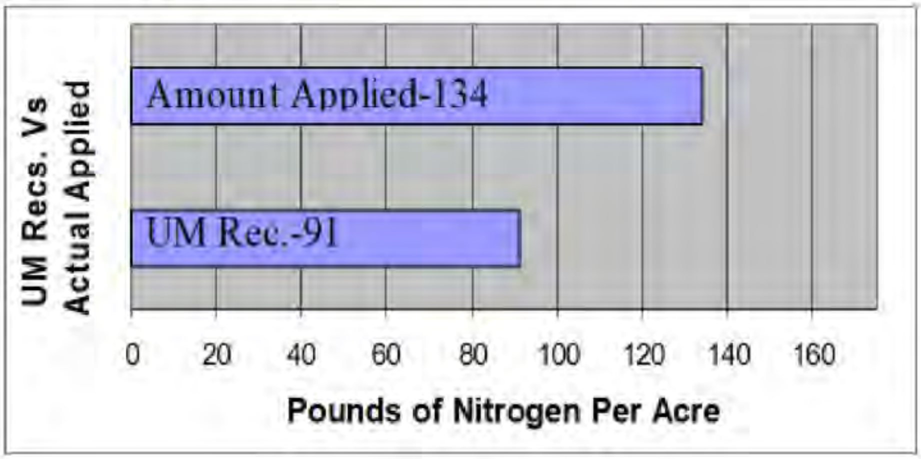
Figure IV-5. Locations of FANMAP Analysis

A general FANMAP overview is provided in Minnesota's Nonpoint Source Management Plan 2001 (Montgomery et al., 2001). While the results represent a composite of studies across the state, many of the farmers were located within DWMSAs. The communities of Perham, St.

Peter, Cold Spring, and the Lincoln-Pipestone Rural Water System are strongly represented in the 2001 report. The shaded counties shown were broader regional studies with various commodity groups.

1. FANMAP Assessment within DWMSAs

Corn following Soybeans

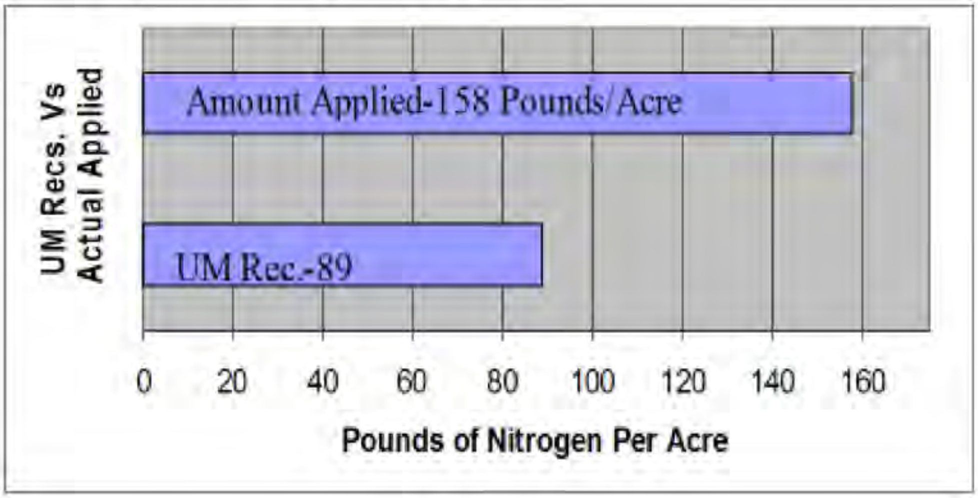


Data Source: Montgomery et al., 2001

Figure IV-6. FANMAP results across multiple DWSMAs. Actual applied nitrogen rates vs U of M recommended nitrogen rates for corn following legumes.

It is common to find corn in rotation with soybeans. In the 2001 report (Montgomery, 2001), 61% of the corn acres were in rotation with soybeans. Very similar to the previously reported statewide assessment (Figure VII-2) for this rotation, a significant amount of over-application was observed due to lack of proper crediting. In these early FANMAP assessments, over-application rates were commonly between 20-40 lb. N/A. This is very similar to the over-applications reported in the statewide MDA/NASS reports (MDA and NASS, 2014, 2016, and 2017).

Corn following Manured Legume Crops



Data Source: Montgomery et al., 2001

Figure IV-7. FANMAP results across multiple DWSMAs. Actual applied nitrogen rates vs U of M recommended nitrogen rates for corn following a manured legume crop.

Within the DWMSAs and other locations (Montgomery, 2001), over-application rates of nitrogen fertilizer averaged 70 lb. /A.

B. Studies have found that fall application of fertilizer in certain soil conditions can lead to groundwater leaching

The specific nitrogen fertilizer BMPs for the five nitrogen fertilizer BMP Regions contain detailed information on the timing recommendations which are highly linked to nitrogen source and soil type. Appropriate timing of nitrogen applications is variable due to soil texture, annual precipitation, and geologic considerations.

It is important to time the application of nitrogen fertilizer to when it can best be used by the plants. The more nitrogen that is used by the plants on the field, the less there will be available to leaching into groundwater. On some soil types, nitrogen fertilizer can be placed in the fall and still be available for plant uptake in the spring. With other soil types, such as coarse textured soils, nitrogen fertilizer must be applied in the spring. In some cases, it can be best to divide the nitrogen fertilizer application into several applications. Nitrogen fertilizer can even be applied between the rows of a growing crop. This type of application is called sidedressing.

The greater the time from application to actual crop uptake, the more opportunities for nitrogen loss. For this reason, farmers who rely on fall application frequently use higher nitrogen rates (additional 10-30 lb/A) compared to spring applications in the same region. Under Minnesota climatic conditions, nitrates left at the end of the growing season are frequently prone to leaching loss which result in potential groundwater contamination. Nitrates left in the soil have been shown to be 40% higher when a nitrogen fertilizer rate of 150 lbs of nitrogen per acre is used, compared to the U of M recommendation of 120 lb of nitrogen per acre (Carlson et al., 2013).

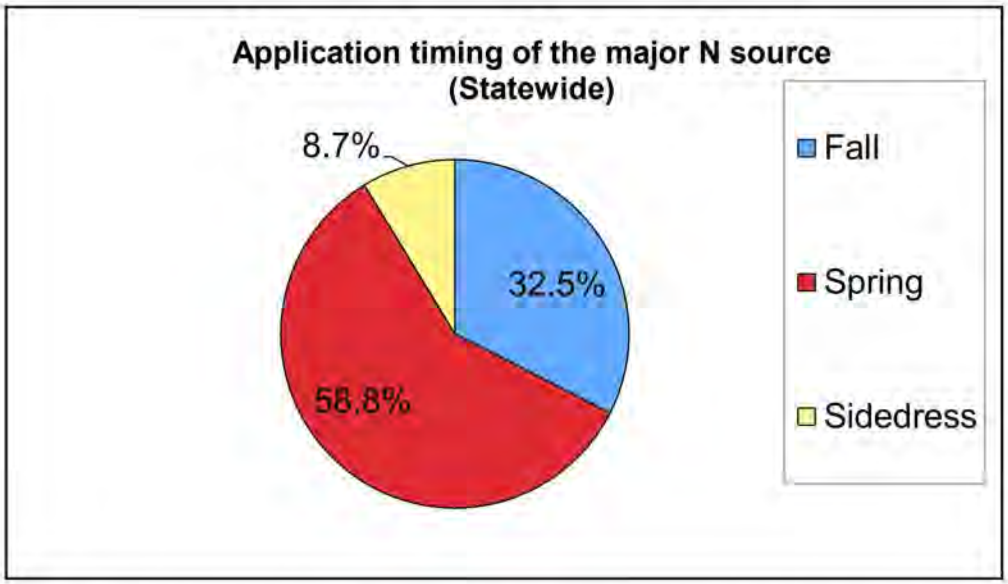


Figure IV-8. Nitrogen fertilizer application (non-manure) timing on corn statewide.

Secondary sources of nitrogen fertilizer: Timing and Crediting

The crediting and timing of secondary nitrogen sources are frequently overlooked in the nutrient planning process. Secondary nitrogen sources are fertilizers that primarily contain large amounts of other nutrients important for plant growth, such as phosphorus and potassium. In many cases these fertilizers also contain nitrogen, and this nitrogen should be subtracted from the total amount of nitrogen applied to the crop. Examples of secondary nitrogen sources include phosphorus fertilizers such as MAP (containing 11% nitrogen in addition to its phosphorus) and DAP (containing 18% nitrogen in addition to its phosphorus). In the past five years, there have been large increases in the use of sulfur products. Some of these products, such as ammonium sulfate (containing 21% nitrogen in addition to its sulfur) need to be managed appropriately for their nitrogen.

C. Conclusion

Based on the evidence provided above, the MDA has determined that the implementation of the BMPs has proven ineffective. Farmers are not taking proper credit for existing nitrogen in the ground and, in addition, are applying nitrogen fertilizer at rates over the recommended levels. This has resulted in leaching of nitrates into the groundwater. Strong evidence has shown that the groundwater in certain areas of the State are over the MDH recommendations. The evidence gathered demonstrates that the implementation of the BMPs as it relates to nitrogen has proven ineffective, and therefore, MDA can proceed with the proposed rule.

V. Statutory Requirements

A. Statutory Authority

Authority for the proposed Rule comes from Minn. Stat. § 103H.275, which was adopted in 1989. All sources of statutory authority for the proposed Rule were adopted and effective before January 1, 1996 and have not been revised by the Legislature, so Minn. Stat. § 14.124 does not apply per Minnesota Laws 1995, chap. 233, article 2, section 58.

Under these statutes, the MDA has the necessary statutory authority to adopt the proposed Rule.

Minn. Stat. § 103H.275, subd. 1(b).
"…the commissioner of agriculture may adopt water resource protection requirements under subdivision 2 that are consistent with the goal of section 103H.001 and are commensurate with the groundwater pollution if the implementation of best management practices has proven to be ineffective."

Minn. Stat. § 103H.275 lists requirements that the MDA must follow when adopting rules for water resource protection requirements.

Minn. Stat. § 103H.275, subd. 2.
"Adoption of water resource protection requirements. (a) …for agricultural chemicals and practices, the commissioner of agriculture shall adopt by rule water resource protection requirements that are consistent with the goal of section 103H.001 to prevent and minimize the pollution to the extent practicable…The water resource protection requirements must be based on the use and effectiveness of best management practices, the product use and practices contributing to the pollution detected, economic factors, availability, technical feasibility, implementability, and effectiveness. The water resource protection requirements may be adopted for one or more pollutants or a similar class of pollutants.

"(b) Before the water resource protection requirements are adopted…the commissioner of agriculture…must notify affected persons and businesses for comments and input in developing the water resource protection requirements.

"(c) Unless the water resource protection requirements are to cover the entire state, the water resource protection requirements are only effective in areas designated by the commissioner of the Pollution Control Agency by order or for agricultural chemicals and practices in areas designated by the commissioner of agriculture by order. The procedures for issuing the order and the effective date of the order must be included in the water resource protection requirements rule.

"(d) The water resource protection requirements rule must contain procedures for notice to be given to persons affected by the rule and order of the commissioner. The procedures may include notice by publication, personal service, and other appropriate methods to inform affected persons of the rule and commissioner's order.

"(e) A person who is subject to a water resource protection requirement may apply…for agricultural chemicals and practices [to] the commissioner of agriculture, and suggest an alternative protection requirement. Within 60 days after receipt, the agency or commissioner of agriculture must approve or deny the request. If the Pollution Control Agency or commissioner of agriculture approves the request, an order must be issued approving the alternative protection requirement.

"(f) A person who violates a water resource protection requirement relating to pollutants, other than agricultural chemicals, is subject to the penalties for violating a rule adopted under chapter 116. A person who violates a water resource protection requirement relating to agricultural chemicals and practices is subject to the penalties for violating a rule adopted under chapter 18D."

B. Regulatory Analysis

In some places, Statewide Water Resource Protection Requirements will be referred to as Part 1 of the proposed Rule; and Drinking Water Supply Management Area: Mitigation Level Designations will be referred to as Part 2 of the proposed Rule.

1. Persons affected

A description of the classes of persons who likely will be affected by the proposed Rule, including classes that will bear the costs of the proposed Rule and classes that will benefit from the proposed Rule.

Classes of persons affected by the proposed Rule
The regulatory portions of the proposed Rule apply to "Responsible Parties," defined as an owner, operator, or agent in charge of cropland.

Bear the costs of the proposed Rule
There are two parts to the proposed Rule: Part 1 restricts fall application in areas vulnerable to groundwater contamination; and Part 2 requires the adoption of nitrogen fertilizer BMPs if they are not adopted voluntarily, and can require AMTs if they are funded, as well as other practices within scope of Minn. Stat. § 103H.275, subd. 2 if the nitrogen fertilizer BMPs are not adopted or if nitrate concentrations in soil below the root zone or in groundwater continue to increase. For purposes of Part 2, the nitrogen fertilizer BMPs are designed specifically to be economically viable and their adoption in most cases will not result in any increased costs and should result in

increased profitability to farmers. The adoption of AMTs if they are funded also will not result in increased costs, as they would be funded. The requirements under Minn. Stat. § 103H.275, subd. 2 directs the MDA to consider economic factors and implementability, among other considerations before requiring a practice, and therefore are also unlikely to impose significant costs on Responsible Parties.

Under Part 1 of the proposed Rule, land owners, operators, and suppliers of nitrogen fertilizer could bear some cost. Restrictions on fall application in vulnerable groundwater areas have been a U of M recommended nitrogen fertilizer BMP for many years. The MDA believes that a large majority of farmers in southeast and central Minnesota, where most vulnerable groundwater areas occur, do not currently fall apply nitrogen fertilizer. In these areas there should be very little or no increased cost. It could even result in some savings by not losing nitrogen fertilizer to leaching.

Shifting from fall to spring application could possibly result in some additional costs for some farmers if fertilizer prices increase due to increased demand and a shorter time period for application. This is likely to be more of an issue in the western part of the state. Comments received during the listening sessions indicated that farmers fall apply in these areas, although there are far fewer vulnerable groundwater areas in these parts of the state, so this would not affect the majority of farmers (Bierman et al., 2011). It is possible that farmers or applicators could incur labor costs if they need to hire additional labor to apply in the spring; however, this was an issue primarily in the northwest part of the state, which is excluded from Part 2 of the proposed Rule. The MDA also heard comments about inadequate bulk dry fertilizer storage capacity and an extremely short spring planting season in some parts of the state. The climate exclusion should help alleviate the majority of these concerns.

The logistics of switching from fall to spring application in vulnerable groundwater areas might be more difficult and more expensive for some facilities in western Minnesota than in other parts of the state. The effective date of January1, 2020 is intended to provide additional time to adjust to these changes.

As for the Drinking Water Supply Management Area: Mitigation Level Designations, land owners, operators, and suppliers of nitrogen fertilizer could bear some cost if the DWSMA in which they raise crops are designated as regulatory mitigation levels and are required to follow the nitrogen fertilizer BMPs or water resource protection requirements. Since the nitrogen fertilizer BMPs are generally economically viable, those costs generally should not be substantial. If water resource protection requirements are imposed at mitigation level 4, then owners and operators could be affected, depending on what is contained in a mitigation level 4 commissioner’s order. The proposed Rule requires the commissioner to consult with local advisory teams, with the goal of creating water resource protection requirements that are specifically tailored to the region and minimize the burdens or costs to the responsible parties.

Benefit from the proposed Rule

High nitrate-nitrogen concentration in drinking water can pose a health risk for infants. When an infant consumes water with nitrate, it is converted into another compound called nitrite. Nitrite causes the hemoglobin in the blood to change into a substance called methemoglobin. This reduces the ability of the blood to carry oxygen, causing a condition known as methemoglobinemia, or "blue baby syndrome." In severe cases, nitrate poisoning can be fatal (MDH, n.d.). The MDH HRL of 10 mg/L nitrate-nitrogen in drinking water was developed based on epidemiological studies published in the 1950s and 1960s. Methemoglobinemia is not a reportable disease so is not tracked by the Center for Disease Control or the MDH. The proposed Rule will provide the greatest direct health benefit to infants under 6 months of age and to community water suppliers and private well owners who need, or are required by law, to provide water that is safe for infants or a general population which includes infants.

Various epidemiological and animal studies have reported a wide range of negative health effects attributable to consumption of water with elevated nitrate-nitrogen including birth defects, miscarriages, hypertension, stomach and gastro-intestinal cancer, and non-Hodgkin's lymphoma (MDH, 2014).

The proposed Rule will benefit citizens served by public water suppliers as well as private well owners in DWSMAs. This will occur by reducing nitrate in groundwater where nitrate levels are elevated and preventing it from occurring in areas where it is not. Preventing and reducing nitrate in groundwater decreases the costs public water suppliers spend to provide drinking water to the public.

There is a large social benefit to the general public from having groundwater with nitrate-nitrogen concentrations below the MDH HRL. This benefit is difficult to quantify but is important for Minnesota with the high value that citizens put on the quality of the waters in the state. One way the value is demonstrated resulted in an amendment to Minnesota's Constitution. In 2008, Minnesota's voters passed the Clean Water, Land and Legacy Amendment increasing the state sales tax. Two of the goals include the protection of drinking water sources and the restoration of groundwater, among others (LCC, n.d.).

Another way this value is demonstrated is through the passage of the Groundwater Protection Act in 1989. The Groundwater Protection Act states. "*It is the goal of the state that groundwater be maintained in its natural condition, free from any degradation caused by human activities. It is recognized that for some human activities the degradation prevention goal cannot be practicably achieved. However, where prevention is practicable, it is intended that it be achieved. Where it is not currently practicable, the development of methods and technology that will make prevention practicable is encouraged.*" The Groundwater Protection Act gives the MDA the authority to adopt the proposed rule.

2. Probable costs to state agencies

The probable costs to the MDA and to any other agencies of the implementation and enforcement of the proposed Rule and any anticipated effect on state revenues.

What is the cost to implement Statewide Water Resource Protection Requirements?
The primary cost for implementing Part 1 of the proposed Rule is the cost of education and enforcement. Education is needed to inform people about the locations of vulnerable groundwater areas and requirements of the proposed Rule. Enforcing the fall application and frozen soil restrictions will take place in 1) quarter-sections where 50% or more of the acres are designated as vulnerable groundwater areas; and 2) DWSMAs that exceed 5.4 mg/L nitrate-nitrogen. The MDA expects to enforce this part of the proposed Rule on a complaint-driven basis.

What is the cost to implement Drinking Water Supply Management Area: Mitigation Level Designation?
Total costs for the MDA to implement and enforce the Drinking Water Supply Management Area: Mitigation Level Designation section of the proposed Rule will vary depending on the number of DWSMAs that are found to have high nitrate. The MDA will bear the costs of evaluating the nitrogen fertilizer BMPs adopted in the DWSMA, establishing any groundwater monitoring networks, as well as providing education within the DWSMAs about the nitrogen fertilizer BMPs and providing financial and technical assistance to facilitate the local advisory team and associated activities. Enforcing the proposed Rule will also be a cost.

Additionally, if DWSMAs move to regulatory status, there will be costs for public notice and hearings.

There are minor or no increased costs to other agencies since where other agencies have roles related to the proposed Rule, the additional work should be limited in scope or should fit into current MDA responsibilities. Other Minnesota state agencies such as the MPCA and MDH will be invited to provide staff to advise regarding technical aspects of the projects. This will occur when topics involve their authority such as manure management or public water suppliers, respectively. The MDA will use nitrate-nitrogen concentration well data that is collected by MDH, but this information is already required to be collected by the federal Safe Water Drinking Act. No additional monitoring or sampling will be required by the MDH. SWCDs are also invited to participate in local advisory teams on a voluntary basis. Their participation is important but not mandatory, and the additional staff costs would be modest. The MDA has already convened several local advisory teams under the NFMP and has provided funding for SWCD participation.

There are no anticipated effects on state revenue associated with the proposed Rule.

3. Less costly or intrusive methods

Determination of whether there are less costly methods or less intrusive methods for achieving the purpose of the proposed Rule.

The MDA considered the cost and potential burden of the proposed Rule. The purpose of the proposed Rule is to reduce nitrate in groundwater and maintain the quality of groundwater to the extent practicable in its natural condition. There are many possible approaches that could be taken to meet this goal. When drafting the NFMP, the MDA convened an advisory committee to provide extensive review and input on the draft plan, which provided the conceptual framework for the proposed Rule.

Statutory requirements also influence the approach for the proposed Rule. Minn. Stat. § 103H.275 specifies that nitrogen fertilizer BMPs be promoted in areas where groundwater pollution is detected. Water resource protection requirements need to be consistent with the goal of Minn. Stat. § 103H.001 and be commensurate with the groundwater pollution if implementation of nitrogen fertilizer BMPs has proven to be ineffective before adopting the proposed Rule. Additionally, the water resource protection requirements must be designed to prevent and minimize pollution to the extent practicable and prevent pollution from exceeding the MDH HRL for nitrate-nitrogen, which is why these requirements are included in the proposed Rule and the reason for not taking a "less costly" approach or using "less intrusive methods."

<u>Less Costly</u>
Not adopting the proposed Rule would be less costly for the MDA. However, there would be costs for others as described in this SONAR (Section 2) and the goals of the Groundwater Protection Act would not be met. There might be less costly methods to accomplishing parts of the purpose of the proposed Rule, but these processes would not address either the presence and/or increase of nitrate in groundwater and would result in higher costs to society in the long run. For example, it might be less costly to install nitrate removal systems in all private and public drinking water systems to address the issue of public health. While this would provide safe drinking water for those individuals, the approach would not meet the goals of Minn. Stat. chap. 103H, which requires *"...groundwater be maintained in its natural condition, free from any degradation caused by human activities,"* and the water quality problems due to nitrates in groundwater would continue to increase.

The MDA has provided promotion and education on the nitrogen fertilizer BMPs since they were adopted in 1991. Nitrate in groundwater continues to be an issue and in some places has increased significantly over the past 25 years. During a comment period on the proposed Rule, a number of commenters stated that the Groundwater Protection Act's purpose could be achieved through continued and additional research and education. While the MDA strongly supports ongoing and increasing research and education efforts, the MDA also believes that such efforts, as noted above, are not enough to ensure that groundwater be maintained in its natural condition or to ensure that nitrate-nitrogen concentrations will not exceed the MDH HRL.

Less Intrusive

Water quality varies significantly throughout the state. Current adoption of the nitrogen fertilizer BMPs is mixed based on region; they are adopted at higher rates in some parts of the state than others. In some places, implementing the nitrogen fertilizer BMPs will be more effective than in other places.

The proposed Rule is targeted in vulnerable groundwater areas and DWSMAs where nitrate-nitrogen concentrations meet certain criteria. Areas that do not meet the vulnerability criteria or that do not meet the nitrate-nitrogen criteria do not fall under regulation. The proposed Rule is designed to be tailored to local conditions and practices. The MDA could have developed a statewide rule requiring the implementation of the nitrogen fertilizer BMPs. Although this approach may have been less work for the MDA, the MDA believes that not actively engaging local farmers and their agronomists in problem-solving to address the local water quality concerns would be far less effective while also being more intrusive for farmers and the agricultural industry throughout the state.

4. Alternative methods of achieving the proposed Rule that were considered and rejected

Description of any alternative methods for achieving the purpose of the proposed Rule that were seriously considered by the MDA and the reasons why they were rejected in favor of the proposed Rule.

Alternatives considered regarding Statewide Water Resource Protection Requirements

Alternative of exclusively relying on water resource protection requirements in proposed Rule – The MDA considered a rule solely based on nitrate-nitrogen concentrations in groundwater and not restricting the application of nitrogen fertilizer in fall and on frozen soils. The second part of the proposed Rule defines a process in which time is allowed for input from local advisory teams and the adoption of nitrogen fertilizer BMPs. It also requires adoption of the nitrogen fertilizer BMPs if 80% of the cropland is not implementing the nitrogen fertilizer BMPs or if certain nitrate-nitrogen water quality criteria are met. The MDA rejected this alternative because restricting the application of nitrogen fertilizer in the fall and to frozen soils in vulnerable groundwater areas serves as a preventive measure in some areas and a mitigation measure in others, allowing MDA to meet its obligation to achieve the goals of 103H.001.

Alternatives considered to Drinking Water Supply Management Area: Mitigation Level Designation

Alternative of regulating townships –The MDA considered a rule that included regulatory levels and water resource protection requirements for private wells in vulnerable townships with high nitrate-nitrogen concentrations that were similar to those in the proposed Rule for DWSMAs. The MDA rejected this alternative because the DWMSAs are the highest priority in the NFMP and the need to make DWSMAs a high priority was a recurring theme in many comments on a draft rule. DWMAs represent the greatest concentration of population at risk from high nitrate. Public water suppliers face substantial costs for addressing nitrate in groundwater as discussed in this SONAR (Section 2). Additionally, the large land area represented by the townships would have required an entirely new program requiring significant resources that the MDA currently does not have. The MDA's current proposed framework allows it to focus its resources on the highest priority areas affecting the greatest number of people, thus having the greatest impact on public health. The MDA will continue to implement the work set out in the NFMP for townships, including private well testing, development and promotion of nitrogen fertilizer BMPs, establishing monitoring networks where feasible, and helping to form local advisory teams to involve local farmers and their advisors in water quality issues in their area.

5. Probable costs of compliance

Probable costs of complying with the proposed Rule, including the portion of the total costs that will be borne by identifiable categories of affected parties, such as separate classes of governmental units, businesses, or applicants.

Statewide Water Resource Protection Requirements

Fall application prohibition – For most farmers, complying with Part 1 of the proposed Rule should not result in additional costs. The MDA believes that most farmers in southeast and central Minnesota, where most vulnerable groundwater areas are located, already follow the nitrogen fertilizer BMP restricting fall application on vulnerable soils or in karst that applies to these areas. It is possible that some farmers may have some additional costs if certain events occur – such as fertilizer prices going up in the spring due to higher demand at that time. Some farmers might incur additional costs if they need to pay for additional help to get their fertilizer applied in the spring. However, these costs are speculative and difficult to quantify.

Suppliers of nitrogen fertilizer, as well as agricultural chemical facilities, could face additional shipping and storage costs since applications will occur in spring and summer. We heard this comment primarily from those entities in the northwest part of the state, but that area is excluded from Part 1 under the current proposed Rule.

Drinking Water Supply Management Area: Mitigation Level Designation

Farmers could face additional costs if nitrogen fertilizer BMPs are required in mitigation level 3 and mitigation level 4 of the proposed Rule. Examples include additional education, soil and manure testing, using soil amendments, and splitting nitrogen fertilizer applications to apply smaller amounts at one time. However, most nitrogen fertilizer BMPs are developed to be economically viable and farmers may increase their profitability by following them.

Requiring the adoption of AMTs in DWSMAs for mitigation level 3 will increase overall costs, but the practices may only be required if funding is available, so it would not result in increased costs to Responsible Parties.

Water resource protection requirements in mitigation level 4 are based Minn. Stat. § 103H.275 and could increase costs. The criteria for evaluating water resource protection requirements cited in the statute include the use and effectiveness of best management practices, the product use and practices contributing to the pollution detected, economic factors, availability, technical feasibility, implementability, and effectiveness. Thus, economic factors and implementability are major considerations that are likely to prevent excessive increased costs to farmers. Further, the proposed Rule requires that these practices be selected in consultation with the Local Advisory Team (LAT), which should provide important input on which practices are practicable and implementable.

There will be no or limited additional costs to other units of government. The primary costs of implementing the proposed Rule will be borne by the MDA. The MDA will be using nitrate-nitrogen concentration data from public wells that the MDH is already required to collect through the Safe Drinking Water Act.

6. Probable costs of not adopting the proposed Rule

Probable costs or consequences of not adopting the proposed Rule, including those costs or consequences borne by identifiable categories of affected parties, such as separate classes of governmental units, businesses, or individuals.

If the proposed Rule is not adopted, public water suppliers dealing with high concentrations of nitrate-nitrogen will be required to continue to perform drinking water treatment while incurring increased costs, which can be very substantial. Public water suppliers who face high concentrations of nitrate-nitrogen in the future will need to take action. This could involve drilling a new well, blending from additional wells, or building a facility to treat water prior to consumption. Often current water pricing cannot cover the additional costs of new wells or treatment (MEQB, 2015), so public water suppliers have to raise water rates.

Public water suppliers are required to monitor quarterly if nitrate-nitrogen concentrations exceed 5.4 mg/L. If concentrations exceed 10 mg/L, public water suppliers must issue a drinking water advisory to the community and are required to take immediate steps to return to compliance, while monitoring, as directed by the MDH. Monitoring occurs until concentrations fall below the 10 mg/L nitrate-nitrogen limit. Residents, businesses and industries bear the economic cost of water use restrictions during the drinking water advisory (paying for bottled water, and possibly business-related costs).

The section provides cost estimates for alternatives that public water supplies may consider providing safe drinking water to the public. The estimates come from the MDH, from a report developed by the MDA based on interviews with seven water suppliers, and from a report titled Addressing Nitrate in California's Drinking Water.

Installing a new well - In some cases, a new public water supply well may need to be installed in a deeper or uncontaminated aquifer. Communities face considerable costs for locating and drilling wells and associated needs such as land purchase and constructing pump houses and transmission mains. Interviews from public water suppliers in 2007 estimated drilling, pump installation and well housing costs of $162,000 in Park Rapids and $246,300 in Clear Lake (UM, 2016). A California report estimates small community costs range from $40,000 to $290,000 to drill new wells and $80,000 to $100,000 to drill deeper wells (UC Davis, 2012). Although deep aquifers tend to be lower in nitrate, the water pumped from them may require treatment to remove iron, manganese, sulfate, arsenic, or radium. Installing a new well is not an option if a deeper aquifer is not available or if other aquifers contain nitrate.

Source water blending – Some public water suppliers blend water from a high nitrate source with water from a low- or no-nitrate source. Costs for blending include labor, pumping, monitoring, and reduced capacity. This alternative blend depends on having a connection to a source of water that is low in nitrate with adequate capacity. Annual costs ranged from $900 to $3,000, and capital costs may include the need to replace pumps and add transmission mains ($500,000 or more) (MDH, Personal Communication. 2018).

Purchase water from another entity – This can be an option if a nearby water supplier is able to provide low nitrate water. Costs can be substantial including costs for building the infrastructure to distribute the water and to ensure the chemistry or treatment is adequate for the distribution system.

Treatment – Nitrate removal (treatment) may be the only feasible option in situations where an adequate quantity or quality of water is not available. Nitrate removal systems used by public water suppliers include:

- *Reverse Osmosis Process* – Pressure forces water through a semi-permeable membrane leaving most contaminants behind along with a portion of the rejected solution. For one municipal reverse osmosis system, the initial construction cost was more than $7 million. Estimated annual operating and maintenance costs for these types of treatment plants can range from tens of thousands of dollars to more than $100,000. Disadvantages with this type of treatment is that the system uses up to 4 gallons of water for every gallon produced, has a large energy footprint, creates a salty waste product that is discharged to the environment, and it enhances corrosion potential for lead and copper exceedances in finished drinking water.

- *Anion Exchange Process* – Contaminated water is passed through a resin filled bead tank. The resin is saturated with chloride, which chemically trades places with the similarly charged nitrate ion. Eventually the resin needs to be recharged by back washing it with a sodium chloride solution. Construction costs range from $300,000 for a nonmunicipal system to more than $4 million for a municipal system, with annual maintenance costs at $7,000 to $22,000, or more. Disadvantages with this type of treatment is that it creates a salty waste product that is discharged to the environment, and it enhances corrosivity potential for lead and copper in finished drinking water.

According to the report based on interviews with public water suppliers, the installation and maintenance of municipal nitrate removal systems increased the cost of water delivered by fourfold or more. Additional costs range from $0.82 to $7.23 to produce 1,000 gallons. Communities with treatment also need to hire staff with higher class licenses and provide an adequate payscale to operate the treatment plant. These additional costs are passed on to rate payers.

The MDH estimates that the number of community water systems that treat for nitrate has increased from six systems serving 15,000 people in 2008 to eight systems serving 50,000 people in 2014. For communities with nitrate-nitrogen above 10 mg/L, annual costs over the five-year period of 2011 to 2016 ranged from $46 to $7,900 per household. Six noncommunity systems exceeded the 10 mg/L nitrate-nitrogen MDH HRL in 2016, requiring system owners to take corrective action (MDH, 2017). If community water systems that either sealed a well or removed a well from use are included, the number of affected communities increased to 56 between 1994 and 2016 (MDH, Personal Communication., 2018).

7. Assessment of differences between proposed Rule and federal regulations

The proposed Rule covers areas that are not addressed by federal law; therefore, this consideration is not applicable for those portions of the proposed Rule.

8. Assessment of cumulative effect of Rule with federal and state regulations

Minn. Stat. § 14.131 defines *"cumulative effect" as "the impact that results from incremental impact of the proposed rule in addition to other rules, regardless of what state or federal agency* *has adopted the other rules. Cumulative effects can result from individually minor but collectively significant rules adopted over time."*

There are no existing rules that regulate the use of nitrogen fertilizer. The proposed Rule is complementary to and works efficiently with existing regulations. Minn. R. chap. 7020 regulates animal feedlots and land application of manure. The proposed Rule does not regulate the application of manure, but manure application will need to be considered in order to determine the total amount of nitrogen fertilizer applied. The MDA has included a provision in the proposed Rule to allow the use of manure management plans and related approvals and inspections to document that appropriate nitrogen fertilizer BMPs are being followed as an efficiency option.

The MDH has the authority to administer the Safe Drinking Water Act in Minnesota. Public water suppliers monitor drinking water. Residents are informed, and corrective action is action if nitrate-nitrogen exceeds the 10 mg/L MDH HRL. The actions public water suppliers pursue involve providing alternative sources of safe water (MDH, 2015). The proposed Rule will complement these existing requirements by addressing nitrogen fertilizer, which is one of the main sources of nitrate in groundwater, prior to public water supplies reaching the 10 mg/L HRL.

E. Cost of Complying for Small Business or City

Minn. Stat. § 14.127, subd. 1. states, *"An agency must determine if the cost of complying with a proposed rule in the first year after the rule takes effect will exceed $25,000 for: (1) any one business that has less than 50 full-time employees; or (2) any one statutory or home rule charter city that has less than ten full-time employees. For purposes of this section, "business" means a business entity organized for profit or as a nonprofit, and includes an individual, partnership, corporation, joint venture, association, or cooperative."*

The rule does not apply to cities; therefore, there will be no cost to them.

The MDA does not believe that compliance with Part 1 of the rule will exceed $25,000 for any Responsible Party subject to the fall restriction. As noted above, most farmers in vulnerable groundwater areas already are not fall applying, or they should not be fall applying according to University of Minnesota BMPs. Potential scenarios where a Responsible Party would incur a cost of more than $25,000 would either be based on voluntary choices made by the Responsible Party, or are very speculative.

The MDA does not believe that compliance with Part 2 of the rule will exceed $25,000 for any responsible party subject to the rule within the first year after the rule takes effect. As noted in 1573.0060, Drinking Water Supply Management Areas will be initially designated level 1 or level 2 – both of which involve solely voluntary measures. Under part 2 of the rule, a Responsible Party cannot move to a level with mandatory regulations until after at least three growing seasons. DWSMAs can only move up one level at a time, so the first year of regulation that any Responsible Party would face would be level 3, which would entail a commissioner's order requiring implementation of nitrogen fertilizer BMPs. The nitrogen fertilizer BMPs are designed to be economically viable and their adoption in most cases will not result in any increased costs and should result in profitable to farmers. In level 3, the commissioner could order the implementation of AMTs but only if they are funded, so that will not result in increased costs.

F. Determination About Rules Requiring Local Implementation

The proposed Rule will not apply to local government (LGUs) because there is no requirement that a LGU must adopt any or all of this proposed Rule. The MDA has sole authority for the proposed Rule and the regulations therein. The MDA notes that there is no state pre-emption of local regulation of the use of nitrogen fertilizer (Minn. Stat. chap. 18C). A LGU may choose to regulate the use of nitrogen fertilizer with or without the MDA's proposed Rule.

G. Performance-Based Regulatory Systems

The SONAR must describe how the MDA, in developing the proposed Rule, considered and implemented the legislative policy supporting performance-based regulatory systems set forth in section 14.002 which states, *"whenever feasible, state agencies must develop rules and regulatory programs that emphasize superior achievement in meeting the agency's regulatory objectives and maximum flexibility for the regulated party and the agency in meeting those goals."*

Part 1 of the proposed Rule restricts the application of nitrogen in the fall and on frozen soils in vulnerable groundwater areas. This rule contains performance-based standards in that the proposed Rule focuses on areas that are most vulnerable to nitrates leaching into groundwater. The area covered in this proposed Rule includes quarter-sections that are equal to or greater than 50% vulnerable and does not include quarter-sections less than 50% vulnerable. Rather than regulate on invisible lines, the use of known boundaries is clearer for regulated parties. The proposed Rule is also performance-based in that, in Part 2, all of the regulations will be based on objective measures, such as documented increase in nitrates or the failure to implement BMPs, which are aimed at achieving the goal of the Groundwater Protection Act.

The proposed Rule also incorporates maximum flexibility for regulated parties and the MDA in achieving the MDA's regulatory goals. Some areas of the state are excluded based on climate or where counties are less than 3% agriculture. Exceptions are made in cases where fall fertilization is necessary and for fertilizers where phosphorus or micronutrients are included, among others.

In Part 2 of the proposed Rule, the primary purpose is to work with farmers to come up with local solutions to address nitrate levels in groundwater. The approach is designed to allow flexibility and for local input to influence the practices that are adopted or required in a DWSMA. Under the site specific water resource requirements, DWSMAs meeting the criteria will start in voluntary mitigation levels 1 or 2. This provides time for discussion and the formation of a local advisory team. The Local advisory teams will advise the MDA commissioner on the nitrogen fertilizer BMPs that should be adopted in that area, based on soils, crops grown, equipment available and other factors. Farmers will have at least 3 growing seasons to adopt the practices and to address nitrate levels. Farmers also have the option of implementing Alternative Management Tools, which are designed to go beyond the nitrogen fertilizer BMPs and to be local solutions. All of these factors make for a proposed Rule that meets the MDA's regulatory objectives and provides maximum flexibility for the regulated party.

H. Consultation with MMB

The MDA will consult with Minnesota Management and Budget (MMB) as required by Minn. Stat. § 14.131. The MDA will do this by sending MMB copies of the proposed Rule, SONAR and proposed Rule and SONAR form that will be sent to the Governor's office for review and approval prior to publication. The MDA will send these to MMB on, or near, the same day they are submitted to the Governor's office, well in advance of publishing the proposed Rule in the State Register. A copy of the correspondence and any response received from MMB will be included in the record the MDA submits to the Office of Administrative Hearings (OAH) for the required Administrative Law Judge's review.

I. List of Witnesses

If the proposed Rule goes to a public hearing, it is anticipated that the MDA will be represented by the following personnel involved at the administrative hearing on the need for and reasonableness of the proposed Rule.

1. Susan Stokes – Assistant Commissioner, Minnesota Department of Agriculture
2. Doug Spanier – Department Counsel, Minnesota Department of Agriculture
3. Dan Stoddard – Assistant Director, Pesticide and Fertilizer Management Division
4. Bruce Montgomery – Manager, Fertilizer Non-Point Section

J. Public Participation and Stakeholder Involvement

The proposed Rule has been in development for several years and the MDA has made extensive efforts to inform and engage specific stakeholders and the general public. The MDA used a number of mechanisms to encourage public participation and provide access to information.

Minn. Stat. §103H.275, subd. 2(b) requires the Commissioner of Agriculture to notify affected persons and businesses for comments and input in developing the water resource protection requirements. The MDA believes that it has met this requirement by conducting the activities outlined below. These activities are also part of the MDA's efforts to provide additional notification under Minn. Stat. § 14.14, subd. 1(a), to persons or classes of persons who may be affected by the proposed Rule.

1. Pre-proposal outreach and notice

The MDA began outreach activities with the updating of the NFMP in 2010 and these activities will continue beyond the adoption of the proposed Rule. The draft rules were part of the activities to address nitrate in groundwater included in the NFMP. This section describes the MDA's public outreach efforts.

Nitrogen Fertilizer Management Plan Advisory Committee

In revising the 1990 NFMP, the MDA used an advisory committee that consisted of representatives from the agricultural community, the environmental community, state and local government, and representatives from the U of M. The input from this advisory committee as well as the NFMP (which was revised and adopted in 2015) was used as guidance for the proposed Rule. (MDA, 2015).

Website – The Nitrogen Fertilizer Rule website (www.mda.state.mn.us/nfr) was created to provide information on the draft rule and the rulemaking process to interested parties. The availability of this website was included in correspondence with interested parties and linked to by other related websites. The website included information on the rulemaking process, details regarding components of the draft rule, and information about listening sessions held throughout the state and frequently asked questions (FAQs) about the rule. Also included was a comment page where persons were able to submit comments directly to the MDA. Drafts of the rule were also posted to the website. The website also provides MDA staff contact information if someone wished to contact the department directly.

A website was also created for the revision of the NFMP. This website contained factsheets, drafts of the revised NFMP, and links to other sites with information about projects related to the NFMP revision.

GovDelivery – GovDelivery is a self-subscription service that MDA uses to electronically notify interested or affected persons of various updates and public notices issued on a wide range of topics. Individuals can register their email address and choose the notifications they want to receive from the MDA at the following webpage:
https://public.govdelivery.com/accounts/MNMDA/subscriber/new

The Nitrogen Fertilizer Rule was added to the list of topics for subscribers when the service became available to the MDA in 2015. Prior to GovDelivery being available, the MDA used a different service for notifying large groups via email. The listserv from the previous service was copied to GovDelivery when MDA transferred services. A notice was sent via GovDelivery when the Request for Comments became available for comment. Notice was also sent to this list when the draft Nitrogen Fertilizer Rule was made available for comment. Reminders were also sent regarding the listening sessions. The MDA will continue to use GovDelivery to inform stakeholders about the proposed Rule and the implementation of the NFMP.

Request for Comments – A Request for Comments on the Nitrogen Fertilizer Rule was published in the State Register on Monday, October 26, 2015. The MDA received 23 original written comments and over 100 copies of a form letter. These letters were made available on the MDA's website at http://www.mda.state.mn.us/chemicals/fertilizers/nutrient-mgmt/nitrogenplan/mitigation/wrpr/wrprcomments.aspx. These comments were considered by the MDA when drafting the language for the proposed Rule. The MDA asked for comments on specific areas proposed in the Rule, but also requested any additional information stakeholders thought might be relevant any comments interested parties wished to provide.

Public Presentations – Several public presentations were made to various groups throughout the state of Minnesota to gather input from various groups prior to, and during the writing the rules.

- Groundwater Conference, October 2016
- Nitrogen Conference, February 2017
- Nutrient Conference, February 2017

Draft Nitrogen Fertilizer Rule Comment Period – The MDA made a draft of the rule available for public comment. This draft was published on the MDA's website, distributed via the GovDelivery email list, and the MDA had a comment period open from June 7, 2017 until August 25, 2017. The comment period was originally scheduled to end on August 11, but after requests for an extension by many interested parties, especially agriculture associations and industry, the MDA extended it until August 25th. During this time the MDA received over 820 comments, held 11 listening sessions throughout the state and gave presentations at 6 invited meetings.

Listening Sessions on the Draft Rule – After the draft of the rule was published on June 7, 2017 the MDA held eleven public listening sessions at locations throughout the state in order inform stakeholders and interested parties about the Nitrogen Fertilizer Rule. Each of these listening sessions included a formal presentation by MDA regarding details of the draft rule, followed by participant questions and answers. Listening Sessions were held at the following locations:

Table V-1. Draft Nitrogen Fertilizer Rule listening session locations, dates and times: June 2017.

Location		Date	Time
Marshall:	**Marshall Public Library 201 C Street Marshall, MN 56258**	Thurs. June 22	5:00 pm
Chatfield:	**Chatfield Center for the Arts 405 Main Street Chatfield, MN 55932**	Wed. June 28	6:00 pm
Farmington:	**University of MN Extension Office 4100 220th St W. Farmington, MN 55024**	Thurs. June 29	2:00 pm
St. Cloud:	**Great River Regional Library 1300 W. St. Germain Street St. Cloud, MN 56301**	Thurs. July 6	3:00 pm
Wadena:	**Robertson Theatre Wadena-Deer Creek High School 600 Colfax Ave. SW, Wadena, MN 56482**	Tues. July 11	6:00 pm
McIntosh:	**McIntosh Community Center 115 Broadway NW, McIntosh, MN 56556**	Wed. July 12	4:00pm
St. Paul:	**Orville Freeman Building 625 Robert Street North, St. Paul, MN 55155**	Mon. July 17	2:00pm
Fairmont:	**Holiday Inn 1201 Torgerson Dr. Fairmont, MN 56031**	Tues. July 25	2:00pm
Roseau:	**Roseau Civic Center 121 Center Street East Roseau, MN 56751**	Wed. July 26	6:30 pm
Warren:	**Warren Community Center 110 West Johnson Avenue Warren, MN 56762**	Thurs. July 27	8:30 am
Hawley:	**Hawley High School 714 Joseph Street Hawley, MN 56549**	Thurs. July 27	7:00 pm

After the publication of the draft rule the MDA also gave presentations and received feedback from groups requesting that the MDA provide more information on the proposed Rule. These additional meetings included:

Table V-2. Draft Nitrogen Fertilizer Rule presentation locations and dates: July 2017-December 2017.

Additional Meetings	Location	Date
Greater Blue Earth River Basin Alliance	Mankato, MN	Friday, July 14, 2017
Soybean Growers Meeting	Mankato, MN	Thursday, July 20, 2017
Corn Growers Meeting	Shakopee, MN	Thursday, July 27, 2017
MCPR Member Meeting	Morgan, MN	Monday, July 31, 2017
MPCA/MDA meeting on Nitrogen Fertilizer Rule	MPCA office, St. Paul, MN	Friday, August 11, 2017
MCPR Member Meeting	Cold Spring	Wednesday, August 16, 2017
Cooperative Network Farm Supply, Grain and Fuel Committee	Brainerd, MN	Wednesday, September 6, 2017
BWSR Board Presentation	St. Paul, MN	Wednesday, October 25, 2017
Minnesota Association of Townships Annual Meeting	Rochester, MN	Friday, November 17, 2017
Minnesota Association of Soil and Water Conservation Districts Annual Meeting	St. Paul, MN	Tuesday, December 5, 2017

In addition, the MDA held six stakeholder listening sessions in conjunction with Governor Dayton's 25 by 25 listening sessions. The rule was a primary topic addressed in those listening sessions. Those meetings were held at the following locations and dates:

Table V-3. MDA listening sessions held in conjunction with the 25 by 25 listening sessions.

Location	Date
Rochester	Monday, July 31, 2017
Mankato	Wednesday, August 16, 2017
Marshall	Thursday, August 17, 2017
Crookston	Tuesday, September 5, 2017
St. Cloud	Wednesday, September 6, 2017
Bemidji	Wednesday, September 13, 2017

2. Additional notice plan

Minn. Stat. §§ 14.131 and 14.22 require that the SONAR contain a description of MDA's efforts to provide additional notice to persons who may be affected by the proposed Rule.

Because of the degree of public interest in the proposed Rule, the MDA intends to conduct more outreach and public notice than the minimum required by the state Administrative Procedures Act. When the MDA publishes the Notice of Hearing, the MDA intends to conduct the following additional activities to ensure that all interested people and affected communities will be notified and have a chance to meaningfully engage in the comment process.

This additional notice plan was sent to the Office of Administrative Hearings for review and approval by Administrative Law Judge_____________ on _________________.

The additional notice plan consists of the following steps:

1. Mail the Notice of Hearing, proposed Rule and SONAR to all registered parties on the MDA's rulemaking list, per Minn. Stat. §14.14, subd. 1(a).
2. Email the Notice of Intent, proposed Rule and SONAR to the Minnesota Legislature per Minn. Stat. § 14.116.
3. Email the Notice of Intent, proposed Rule and SONAR to the House and Senate committees with jurisdiction over the environment, natural resources and agriculture as required in Minn. Stat. § 103H.275, subds. 2(a) and 1(c)(3).
4. Publish the Notice of Intent to Adopt Rules, a copy of the proposed Rule, and the SONAR on the MDA's Nitrogen Fertilizer Rule website for public viewing and comment.
5. Issue a press release announcing the publication of the Notice of Intent to Adopt Rules and directions on how to comment.
6. Email the Notice of Intent, proposed Rule and SONAR to all parties that were sent the Request for Comments in October 2015.
7. Email all parties who have expressed interest in the proposed Nitrogen Fertilizer Rule by signing up for a GovDelivery email mailing list.
8. Email the Notice of Hearing, proposed Rule language and SONAR to other governmental agencies – MDNR, MPCA, MDH, BWSR, and SWCDs.

The Additional Notice Plan does not include notifying the state Council on Affairs of Chicano/Latino People because the proposed Rule does not have a primary effect on Chicano/Latino persons.

K. Effect on Local Government Ordinances

The proposed Rule will not apply to local government because there is no requirement that a local government must adopt any or all of this proposed Rule. The MDA has sole authority for the proposed Rule and the regulations therein. The MDA notes that there is no state pre-emption of local regulation of the use of nitrogen fertilizer. A local government may choose to regulate the use of nitrogen fertilizer with or without the MDA's proposed Rule.

VI. Rule by Rule Analysis of Need and Reasonableness

A. 1573.0010 Definitions

The proposed Rule 1573.0010 defines the terms used throughout the proposed Rule parts 1573.0010 – 1573.0090. The definitions are necessary to ensure that the proposed Rule is clearly understood. The inclusion of definitions is reasonable so that the MDA may consistently apply the proposed Rule, and so that regulated and other affected parties do not become confused as to how to interpret the language contained in the proposed Rule.

Twenty-two terms used in the proposed Rule were identified as needing definitions. Seven of these terms and their associated definitions were derived from existing terms and definitions in other state statutes or rules including: *commissioner, drinking water supply management area, groundwater, municipal public water supply well, public well, responsible party, section*.

Fifteen terms are unique to this proposed Rule and are further described below.

Subp. 2. Definitions. – Alternative management tools (AMTs)

This definition is needed and reasonable in order to clarify that these are practices and solutions that are different from the nitrogen fertilizer BMPs as defined in this SONAR. AMTs are designed to go beyond the nitrogen fertilizer BMPs and be local solutions for addressing groundwater nitrate problems that are implemented on a site-specific basis. Local advisory teams will be able to identify and promote these beneficial practices (AMTs) that go beyond the nitrogen fertilizer BMPs. Examples include alternative cropping systems, low nitrogen input crops, continuous cover such as CRP, or putting perennials in key charge areas, and land swapping to shift high nitrogen using crops to non-vulnerable land. Precision agriculture is included in the definition to provide clarity to stakeholders that various precision agricultural techniques such as variable rate planting and fertilization, soil and plant tissue sampling, nitrogen enhancement products, and others are recognized and encouraged. This term comes from the NFMP, which serves as the basis for the proposed Rule. Further discussion about how these tools will be defined and where they will be available is discussed in this SONAR, under 1573.0090 Alternative Management Tools; Alternative Protection Requirements (MDA, 2015).

Subp. 3. Definitions. – Coarse textured soils

This definition is needed because coarse texture is an important criterion within the vulnerable area definition and needs to be defined in order to provide clarity to the regulated party. While ‘coarse textured soils’ is a commonly used term, its definition varies depending on the context within which it is used. A definition of coarse textured soils is needed because coarse texture is a physical characteristic of soil that makes underlying groundwater at a higher risk for contamination by agricultural chemicals (IPNI, 2018). The U of M nitrogen fertilizer BMPs specify nitrogen fertilizer management practices for coarse textured soils, including not recommending fall nitrogen fertilizer application, regardless of form. However, a clear definition of ‘coarse texture’ is not provided in the nitrogen fertilizer BMPs (the term ‘sandy soil’ is used interchangeably with ‘coarse textured soil’), therefore it is reasonable that the proposed Rule provide a definition in order to clearly define the soils where this criterion applies. The United States Department of Agriculture Natural Resources Conservation Service (USDA-NRCS) is the national source for soils information (Soil Survey Staff, n.d.). The USDA-NRCS definition is used in federal practice standards and technical assistance programs, and this soils data has been used by farmers, agriculture and natural resource professions for many years, therefore it is reasonable that the definition comes from the USDA-NRCS.

This definition of coarse textured soils also aligns with the definition used by the Minnesota Pollution Control Agency (MPCA) for applying manure in areas sensitive to leaching of nutrients through the bottom of the root zone (MPCA, 2005) and the USDA-NRCS Minnesota conservation practice standard for nutrient management (USDA NRCS, 2007).

Subp. 5. Definitions. – Cropland

This definition is needed to clarify for the regulated party what is included as ‘cropland.’ This term is based on the USDA National Agricultural Statistics Service (NASS) definition of cropland and includes the major and minor row crops, hay and silage crops, a variety of pasturing scenarios, idle cropland such as Conservation Reserve Program and other set aside programs, and numerous miscellaneous crops. NASS conducts hundreds of national agriculture-related surveys on cropland and other features each year, therefore it is reasonable to use the NASS definition of cropland. It is broadly understood and anticipated that these lands would receive commercial nitrogen fertilizer applications somewhere in the rotation, and the vast majority of these acres would receive annual or biannual applications of nitrogen fertilizer.

Commercial sod production acres fall under this definition as sod is harvested from the land surface as an annual crop. Turfgrass is not included in this definition as it is not removed for use as a food, forage, fiber or energy crop and is not used as pasture. Forestland is not included in the definition of cropland as the land remains covered by trees for multiple growing seasons, is minimally fertilized not typically in an agricultural rotation and the risk of nitrate movement to the groundwater under forestland is normally small.

Subp. 7. Definitions. – Fall application

The definition is needed so the MDA and regulated parties have clarity and a mutual understanding of when fall fertilizer restrictions apply. This term defines the time of year where application of nitrogen fertilizer has the greatest potential for runoff or leaching through the soil. Fall applications on coarse texture soils and in karst regions are not recommended by the nitrogen fertilizer BMPs, therefore a definition of fall application is needed to define when nitrogen fertilizer application should not occur. This is a reasonable approach because a specific date provides the greatest clarity when this restriction goes into effect.

Subd. 8. Definitions. – Frozen soil

The term frozen soil is needed to define under what conditions nitrogen fertilizer should not be applied. When nitrogen fertilizer is applied to frozen soils, it is not able to be properly incorporated into the soil, resulting in a greater chance of fertilizer to runoff the soil surface or convert to a gaseous form. The MDA considered a definition of frozen soil using a temperature of 32 °F. However, this was ruled out, since there could be variability in soil temperature at different soil depths as well as variability by locations. In addition, it would take greater effort by the regulated parties to take temperature measurements and for the MDA to verify these. The MDA chose to use a more practical definition of frozen based on the physical ability to apply and incorporate fertilizer. Frozen soil is a commonly used term in the proposed Rule and defining it is reasonable to clarify the intent of the proposed Rule.

Subd. 10. Definitions. – Groundwater monitoring network

This definition is needed to define how the MDA may monitor shallow groundwater in a DWSMA. A groundwater monitoring network consists of multiple wells. The network will allow the MDA to determine the current nitrate levels in groundwater instead of waiting up to ten years to detect how nitrate levels in a public well respond to changes in agricultural practices in the DWSMA. It provides an approach to monitor nitrate in groundwater as required in Minn. Stat. § 103H.251, subd. 2.

Subd. 11. Definitions. – Growing season

This term is needed as it defines the timeframe and time of year in Minnesota where normal conditions for crop growth occur. The length of the growing season varies by crop and impacts the applicable nitrogen fertilizer BMPs. Growing season is a commonly used term in the proposed Rule and defining it is reasonable to clarify the intent of the proposed Rule.

Subd. 12. Definitions. – Lag time

The definition of this term is necessary to ensure the proposed Rule addresses, in a scientifically correct manner, how long it will take before changes in practices on the land surface will result in changes in water quality that can be observed in groundwater wells. Since regulatory requirements may be based on changes in water quality it is reasonable and necessary that the proposed Rule describe what lag time means. Since lag time is a method used by hydrogeologists in determining the potential impacts of surface land use on groundwater, it is reasonable that the MDA uses lag time criteria in the proposed Rule (Sousa et al., 2013).

Subd. 13. Definitions. – Leaching index

This term is needed to explain the risk of nitrate from nitrogen fertilizer moving through the root zone towards the groundwater in different parts of the state. The leaching index is calculated as the daily precipitation minus evapotranspiration (evaporation of water from the soil and from the vegetation) summed to annual values. The leaching index can be a positive or a negative number. A more negative leaching index indicates less water available for moving through the soil resulting in lower risk of nitrate leaching losses. The input data from the gridMET dataset is developed based on gridded climate data from the national PRISM dataset and reanalysis data from NASA's NLDAS-2 dataset (Abatzoglou, 2013). Evapotranspiration is estimated using the standardized, grass-based Penman-Monteith equation. (ASCE-EWRI, 2005)

Subd. 14. Definitions. – Local advisory team

The term local advisory team (LAT) comes from the NFMP. One of the goals of the proposed Rule is to involve the agricultural community in problem solving at the local level. This definition is needed in order to help meet that goal, and advise the MDA regarding appropriate response activities for the area and to support implementation of these activities. The team will help develop, communicate, and implement locally viable solutions to address elevated nitrate in the local project area. The intent is to develop a team which will consist of 15-20 people who are from the area, including farmers, crop advisors/consultants, representatives of local groups/organizations, representatives of public water supply systems (in Drinking Water Supply Management Areas, or DWSMAs), and government staff and/or professionals who can provide technical or financial support. The majority of the members will be local farmers and their crop advisors/consultants. It is reasonable that LATs be formed because they are best able to identify local conditions and nitrogen management practices to address nitrate in groundwater. In addition to LATs providing recommendations to the MDA on nitrogen fertilizer BMPs and other practices, successful LATs will provide credibility and support for the nitrogen management activities to be implemented.

Subp. 16. Definitions. – Nitrogen fertilizer best management practices

This term is needed to define the nitrogen fertilizer BMPs adopted under Minn. Stat. § 103H.151, subd. 2, the MDA developed best management practices (BMPs) for agricultural chemicals and practices specific to nitrogen fertilizer with the help of the U of M. The MDA gave public notice and solicited comments from affected persons and business interested in developing the nitrogen fertilizer BMPs and has updated these BMPs using the process outlined in Minn. Stat. § 103H.151, subd. 2, so as to reflect U of M updates to fertilizer recommendations. It is needed to provide farmers a set of practices to use to address nitrate in groundwater and is reasonable because the practices are based on U of M research.

Subp. 17. Definitions. – Nitrogen fertilizer

There are many different products that contain nitrogen and are used for agricultural purposes. This definition is needed to clarify what agricultural products are covered under the rule. This definition is reasonable because it is based on the definition of fertilizer in Minn. Stat. 18C.215 and modified based on public comment. Public comments were received stating that biosolids, industrial by-products, industrial wastewater, and irrigation water should not be included in this definition and they were removed.

Subp.19. Definitions. – Residual soil nitrate tests

For purposes of the proposed Rule, this term is needed to define the process of analyzing the results from soil samples between the root zone and the water table on an established time frame to evaluate changes in nitrate levels in soil. This definition is reasonable as this technique may be needed in areas where lag times are very long (typically in terms of decades) and where it may be cost prohibitive to install monitoring wells due to excess drilling depths.

Subp. 22. Definitions. – Spring frost-free date

The term was needed to specify the date where the probability of the last day of frost occurring in the spring is 10% or less. The spring frost-free date depends on the climate and varies across Minnesota. A later spring frost-free date indicates a shorter period in the spring to complete farm field operations and a greater risk of crops being damaged by frost. This is important for nitrogen fertilizer management because it is indication of when crops will be actively growing and using nutrients. The input data is from National Oceanic & Atmospheric Administration's (NOAA) National Climatic Data Center (NCDC) and is available through the Minnesota Department of Natural Resources (MDNR) State Climatology Office (MDNR, 2018).

Subp. 23. Definitions. – Vulnerable groundwater area

The term vulnerable groundwater area is needed to define the areas of the state where nitrate can move easily through the soil and/or bedrock to the groundwater. The criteria for this definition was developed using soil information from the USDA-NRCS (Soil Survey Staff, n.d.) and geology information from the MDNR to identify areas with the greatest risk of nitrate traveling into groundwater. In addition, the MDNR 'ultra-low' sensitivity layer (Adams, 2016) was used as a criterion to identify areas that are not vulnerable. A further discussion about the general need and reasonableness for this term can be found in this SONAR, 1573.0030 Statewide Water Resource Protection Requirements.

B. 1573.0020 Incorporation by Reference

Rather than repeating the content of these guidance documents in the proposed Rule, they are incorporated by reference. While not subject to frequent change, these guidance documents are updated more frequently than rules. These documents are all readily available on the MDA's website www.mda.state.mn.us/nfr/references.

C. 1573.0030 Statewide Water Resource Protection Requirements

Background on vulnerable groundwater areas
The proposed Rule restricts the application of nitrogen fertilizer in the fall and to frozen soils in vulnerable groundwater areas. Vulnerable groundwater areas are defined as:

- Coarse textured soils, as identified in the USDA-NRCS, Soil Survey Geographic Database (SSURGO) soil database (Soil Survey Staff, n.d.);
- Soils with shallow depth to bedrock as identified in the USDA-NRCS, SSURGO soil database, Web Soil Survey (Soil Survey Staff, n.d.); and
- Karst geology as identified in the Department of Natural Resources Pollution Sensitivity of Near-Surface Materials (Adams, 2016).

The MDA used the criteria above to define vulnerable groundwater areas, and it is needed, because of the increased risk of nitrogen fertilizer leaching into groundwater.

It is well established in research literature that nitrogen fertilizer is a source of nitrate, and nitrate, due to its high solubility in water can leach easily through soil to reach groundwater (IPNI, 2018). For this reason, U of M nitrogen fertilizer BMPs do not recommend fall nitrogen fertilization in vulnerable groundwater areas due to environmental and financial risk (Lamb, 2008). The financial risk is that a farmer applies nitrogen fertilizer in the fall and loses the investment if the nutrient has moved away from the root zone and is no longer available for next year's crop.

Factors influencing nitrate leaching
Nitrate is highly water soluble in water and due to its negative charge, it easily moves through the soil profile. The degree of leaching is affected by many factors, including soil characteristics (such as soil texture and moisture holding capacity), climate (such as timing and amounts of precipitation), and plant water use. These factors must be considered when designing appropriate nitrogen fertilizer BMPs and are discussed later in this document.

Minnesota has over 21 million acres of cropland. The MDA has recently estimated that 2.6 million acres are "vulnerable," meaning that nitrogen inputs must be very carefully managed to protect groundwater quality. This is a mixture of coarse-textured soils, karst landscapes, and situations where there is shallow depth to bedrock. The following section presents criteria used for identifying the vulnerable groundwater areas and other options considered in the process. Soils that are shallow to bedrock are those soils where the bedrock is within 5 feet of the surface.

Coarse textured soils and soils that are shallow to bedrock criteria
The MDA identified coarse textured soils and soils that are shallow to bedrock using the USDA-NRCS Soil Survey Geographic (SSURGO) soil database Web Soil Survey, an online tool USDA-NRCS developed to display the SSURGO data. The SSURGO database and Web Soil Survey are produced and distributed by USDA-NRCS.

Web Soil Survey, Nutrient Management for Sensitive Soils (MN) query. This data will be used as soil criteria to identify vulnerable groundwater areas. This definition of 'coarse textured soils' is also used in the USDA-NRCS Minnesota conservation practice standard for nutrient management (590) (USDA NRCS, 2007).

It is reasonable to use the SSURGO database for the following reasons:

- Soil maps have been used by farmers and their agriculture advisors for decades. This includes such things as soil testing for nutrients, variable rate fertilizer application, crop productivity index, as well as many other soil interpretations.

- Use of USDA-NRCS soils information is well established. Farmers, local government, and others have been using soils information for many years. Farmers participating in federal farm programs have been subject to soil evaluations on their fields and therefore will be familiar with an evaluation based on soil characteristics.

- It is readily available and contains the best available statewide data. Soils data provides continuous coverage across the state, including agricultural areas. (Note that portions of Pine, and 'Arrowhead' counties have not yet been soil mapped; it is anticipated these will be completed in 2022). There is a very low occurrence of agriculture in these areas of the state.

- Soil survey information is used, since it is the statewide (and nationally) recognized 'standard' for soils information. Rigorous investigation, mapping, evaluation, and scientific interpretation of soil information has been and continues to be done by USDA-NRCS Soil Scientists and others. Each soil mapping unit has been examined and soil interpretations are standardized throughout the state.

- This soils data used are based on published soil surveys which are of consistent scale and quality statewide. Soils data are reviewed and updated annually (if applicable) in Web Soil Survey. The scale of soils map range from 1:12,000 to 1:63,360, with most being 1:20,000 or less. The soils were mapped in each county, and data correction was done to ensure soil information matches across county lines.

- Criteria for "Sensitive Soils for Nutrient Management" data set is used in the USDA-NRCS Minnesota Nutrient Management specification. This is already being used (and has been for many years) by resource professionals for on farm nutrient management plans. This 'sensitive soils' data set includes nitrogen management and leaching into groundwater criteria, and specifically notes coarse textured and shallow to bedrock soils as soil features that must be considered.

- The SSURGO soil database is available in a user-friendly format online and can be searched by the public through Web Soil Survey portal (Soil Survey Staff, n.d.).

Using this 'coarse textured' soils definition is consistent with the U of M Extension nitrogen fertilizer BMPs (Table III-1). Consistency with the terminology between the proposed Rule and the nitrogen fertilizer BMPs will add clarity for the regulated party. U of M Extension has developed fertilizer application rate guidance and other nitrogen fertilizer BMPs specifically for coarse textured soils. It is beneficial to use the same soil criteria and consistent soils maps and criteria for fall restrictions in the first part of the Rule (see 1573.0030 Statewide Water Resource Protection Requirements,) and follow nitrogen fertilizer BMPs for coarse textured soils in the second part of the proposed Rule (see 1573.0040 Drinking Water Supply Management Areas; Mitigation Level Designations).

The USDA-NRCS definition of coarse textured and shallow to bedrock soils also aligns with the definition used by MPCA for applying manure in areas sensitive to leaching of nutrients through the bottom of the root zone (MPCA, 2015).

Other soil options considered
MDA staff evaluated alternative soil criteria that could be used to characterize the vulnerability of groundwater contamination from nitrogen fertilizer application. This included soils information from federal and state agencies as well as academic institutions, including the U of M. The MDA specifically worked with the USDA-NRCS Minnesota State Soil Scientist staff to discuss alternatives and they provided the statewide soil query results based on criteria identified by the MDA. The following are various options that the MDA considered. Note that some of these soils criteria were considered in combination but are generally discussed individually as follows:

- The texture of the uppermost soil layer, or soil horizon, was considered, because soil units within the USDA-NRCS Soil Survey system are named based on the surface texture. Users of soils information are normally familiar with the names. The MDA considered using soils with surface textures defined by the USDA-NRCS as sand, loamy sand, and sandy loam as a criterion. However, the surface horizon does not necessarily represent the texture of the soil layers below the surface and is not a good indicator of water movement through the soil profile. Based on this, the MDA decided against basing vulnerable groundwater areas on surface texture alone.

- A 0-5 foot soil profile depth was considered, since this is the standard depth of a typical soil profile. Soil profile data is available statewide (except in some or all of Pine, Cook, St. Louis and Lake Counties) at these depths. The USDA-NRCS is transitioning to a 0-2 meter profile depth and this depth was also considered in the evaluation process. This would provide additional depth information; however, the 2-meter depth was ruled out since it is not available yet statewide.

- Soil physical characteristics based on the USDA textural triangle were considered (Figure VI-1). The MDA, in the Request for Comments, specified that sand, loamy sand, and sandy loam would be considered. These textures represent the coarsest of the soil textures, and can be itemized by percentage of sand, silt, and clay thresholds. However, regulated parties may not be aware of these distinctions. Also, closer examination showed that sandy loams are diverse in characteristics that make them difficult to characterize as vulnerable based on texture alone. Some responses to the Request for Comments and subsequent comments during the summer 2017 comment period suggested that sandy loam should not be included as coarse texture criteria.

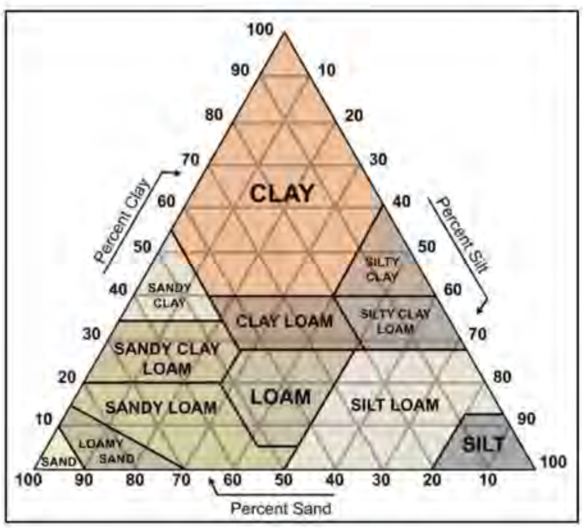


Figure VI-1. USDA soil textural triangle.

- Saturated Hydraulic Conductivity (Ksat), was considered as vulnerable soil criteria. Ksat is an objective measure of the ability of water to move through a saturated soil. Ksat values are available for each soil horizon of the soil mapping units; therefore a weighted average of the combined horizons was considered. The NRCS delineates values for high versus low Ksats that provide differentiation criteria for water movement through a saturated soil. Based on this, a Ksat >10 micrometers per second (µm/s; equivalent to approximately 1.4 inches per hour) criteria was considered 'high' for water movement through the soil profile; and therefore was considered by the MDA as the threshold for vulnerable soil. Combined criteria with other soil features was also considered to further refine vulnerable soil criteria. This included using Ksat in combination with coarse texture soils, using a Ksat<1 um/s value for any soil layer (horizon) within the soil profile as a disqualifying criterion to represent a confining layer for water movement within the soil profile, and slope >12% to represent slopes where water is more likely to runoff than infiltrate into the soil profile.

During the draft rule summer 2017 listening sessions, the MDA presented to stakeholders information on Ksat and vulnerable soil criteria. The MDA determined Ksat was not known or well understood by many stakeholders or policymakers, therefore it may be difficult for regulated parties to follow. In addition, stakeholders tended to know soils based on texture, including in many cases, the nitrogen fertilizer BMPs for coarse textured soils. Significantly, Ksat does not necessarily align with the nitrogen fertilizer BMPs for coarse textured soils. For these reasons, the MDA determined that Ksat should not be used.

- Bulk density, a measure of the weight of soil per volume, was considered because it could be a relative comparison of water movement through the soil profile by measuring 'compactness' a volume of soil occupied by soil and air (hence density). While this would provide a good indication of water movement through soil, there are other soil characteristics that better represent soil vulnerability. In addition, bulk density also does not necessarily align with soil texture. For these reasons, the MDA determined bulk density should not be used.

- The depth from the soil surface to the water table from NRCS was considered as vulnerable soil criteria. However, the NRCS definition provided in the soil survey data may not represent permanent water table conditions of an aquifer that is useable or extractable. A permanent water table is the level where saturated soil occurs. The water table definition for the NRCS data set may not represent the permanent groundwater level and may be present due to a soil confining layer, which keeps the water closer to the land surface and not connected to the aquifer. The water table level can change by season and the amount of precipitation in a given year, or could be altered due to drainage activities (ditching or tiling). For these reasons, the MDA determined depth from the soil surface to the water table should not be used.
- Hydrologic Group: The USDA-NRCS places soils into hydrologic group classes based on runoff potential. The classification in the four groups or three dual groups are based either on historic measurements or interpolation to similar soils based on factors including depth to restrictive layer or water table, texture, structure, and Ksat. Because: 1) the hydrologic

groups are designed for use with surface runoff, not water movement through the soil, 2) the groups are qualitative and there is substantial uncertainty associated with assigning quantitative flow rates to each category, and 3) many soils with a seasonally high water table are assigned a dual classification that may change based on drainage status (such as presence of artificial drainage), the MDA decided not to use hydrologic group as a criterion.

- Permeability: The term permeability has often been used synonymously with hydraulic conductivity. Confusion has arisen since the term permeability has been used to describe a soil's readiness to transmit water or other fluids, or as a parameter estimated based on hydraulic conductivity, fluid density and viscosity, and the gravitational pull. Because the meaning of permeability is not specifically discernable, the USDA-NRCS emphasizes Ksat rather than the term "permeability" and Ksat classes rather than Permeability Classes to prevent confusion and avoid scientific inaccuracies (Schoeneberger et al., 2012). (See previous discussion of Ksat.) For these reasons, the MDA determined permeability should not be used.

- Organic Matter: Percent organic matter was considered. Generally, soils with higher organic matter have greater water holding capacity, which would allow more water storage in the soil profile versus migration to groundwater. However, for the most part (i.e. for organic peat soils called histosols), organic matter is dominant in the surface profile and diminishes at soil depth. Due to this limitation, the MDA ruled out organic matter as criteria to determine vulnerable soils.

- Restricting fertilizer application based on soil temperature: The MDA considered using the U of M nitrogen fertilizer BMP language, "no fall N fertilization until soil temperatures have stabilized to less than 50 degrees [50ºF]." Soil temperature affects the activity of bacteria that converts nitrogen fertilizer to nitrate (Fernandez, 2017).

  It is difficult to ensure consistent depth at which soil temperature is measured (for example, it varies from 4 to 6 inches (MDA (n.d. (l)). Erosion, tillage, or animal disturbance may further change the depth of the soil temperature sensors over time. In addition, it may be difficult to determine when soil temperatures have 'stabilized' due to annual differences, temperature unpredictability and day versus nighttime temperatures. In addition, requiring soil temperature readings could be burdensome for the regulated party and regulator, since this could involve many and multiple readings per farmer and per field. It would be inefficient for MDA as well due to the volume of soil temperature readings that may need to be reviewed. There may be inconsistency in time and location between soil temperature supplied by the famer and those done by MDA is a compliance check. Therefore, soil temperature was not chosen to define fall application.

- The MDA considered using its soil temperature network to define fall nitrogen fertilizer application restrictions (MDA, n.d. (l)). This would rely on actual soil temperature readings at established sites. An advantage is that it uses known locations with accessible data to all. However, the issue of 'stabilized below 50 ^{o}F' would still be a concern, as described above. Additionally, it may be unclear to regulated parties which soil temperature station(s) to use for regulatory purposes, and the network only has a limited number of monitoring sites. Due to these difficulties, the MDA did not choose this option.

- There is climate variability throughout the state, so the MDA considered choosing various fall dates based on climate and location within the state. This would be difficult, however, since temperature patterns do not fall naturally on county or other cultural feature boundary. This would also create a substantial regulatory burden to the MDA, and to fertilizer suppliers and farmers that cover multiple counties. In addition, historic soil temperature data may be inadequate, and yearly variability would not be accounted for.

- August 31st was chosen because it represents the end of the quarter for meterological season as described by the State Climatology Office: The MDA consulted the MDNR State Climatologist when making and drafting this definition.

  The MDA provided this draft date during the request for comments and draft rule summer 2017 listening sessions. Though stakeholders provided some comments on this, most did not find an August 31st date unreasonable.

The MDA also considered some combinations of these criteria. These combinations were ruled out, primarily because the resulting criteria would be too complicated for regulated parties and difficult to administer by the MDA.

Geology criteria
The MDA used karst geology as identified by the DNR's Pollution Sensitivity of Near-Surface Materials Minnesota Hydrogeology Atlas (Adams, 2016) and Minnesota Regions Prone to Surface Karst Feature Development report (Adams et al, 2016) as one of the criteria for the proposed Rule's Part 1 restrictions.

Karst features are the most significant geologic feature that needs to be considered for determining groundwater vulnerability (Runkel et al, 2014, Steenberg et al, 2014, Gordon, 2016, Groten and Alexander, 2013, Katz, 2012). Karst geology is fractured bedrock, generally limestone, overlaid by shallow soils. This combination allows for nitrate dissolved in soil water to readily move downward into groundwater once below the plant rooting depth. Therefore, it is necessary and reasonable for the rule to include areas with karst geology when considering areas vulnerable to groundwater contamination.

The rule uses groundwater vulnerability data from the sources that provide the most accurate data with the highest level of resolution for the characteristic that is being evaluated and mapped. It is necessary to provide clear maps of areas subject to regulatory requirements in order for individuals to understand what is expected of them under the rule. It is reasonable to use the most accurate information available so that the purpose of the rule, to reduce nitrate contamination in groundwater, will be implemented in a practicable and effective manner as directed in the Groundwater Protection Act.

The rule uses DNR pollution sensitivity reports and maps (The Pollution Sensitivity of Near-Surface Materials Atlas) for defining areas with karst geology because it is the most accurate information available on areas with karst geology.

The rule also considers areas with ultra-low vulnerability to groundwater contamination. These are areas primarily in northwestern Minnesota where thick clay deposits provide an exceptionally high level of protection for groundwater. In these areas there may be shallow sandy soils near the ground surface but because of the thick clay layer the groundwater is not vulnerable to contamination. Considering this land characteristic is necessary to ensure that the vulnerability of groundwater is assessed accurately in all areas of the state. The rule uses DNR pollution sensitivity reports and maps (The Pollution Sensitivity of Near-Surface Materials Atlas) for mapping these areas. This is reasonable because they are the most detailed and accurate maps available on this characteristic and to use less accurate maps would be unreasonable.

Other geology options considered

The MDNR has completed geologic evaluations in some areas of the state through the County Geologic Atlas Program (MDNR, n.d.). However, these atlases are not available statewide; they are available only for some regions and counties. In addition, the criteria used for developing the atlases have changed over time, resulting in maps being inconsistent across the state. Hence, applying the Geologic Atlases would result in applying inconsistent vulnerable geology criteria depending on map availability and when the geologic investigation was done. For these reasons, the MDA determined the Geologic Atlases are inadequate to use for the purpose of developing geologic criteria.

The MDA considered using the ‘Bedrock at or Near the Surface’ criteria within the Pollution Sensitivity of Near-Surface Materials Report (Adams, 2016). This data source provides a statewide illustration where rock underlays the soil and unconsolidated surficial materials. This was ruled out because, as noted above under geologic criteria section, other sources of data provide a much higher level of resolution of this characteristic which is important for accurately defining those areas subject to regulatory requirements.

During the summer 2017 comment period, several comments recommended not including the shallow to bedrock geology criteria. This was because they were unclear on the criteria, and/or they felt it did not accurately represent actual ground features, and represent a sensitivity to groundwater contamination.

The MDA considered using other geology criteria as well, such as those shown on pages 13-20 of the NFMP (MDA, 2015). These were ruled out because they have the same scale limitations as other geology maps as previously described (all are approximately 1:500,000). Also, the Pollution Sensitivity of Near-Surface Materials Report was published more recently and contains the same or similar geology as those shown in the geology maps in the NFMP.

Based on the previous discussion, the agency determined that 'vulnerable area' must include both soils data for coarse texture and shallow to bedrock conditions, and geology data for karst, and an 'ultra-low' geologic sensitivity rating of the near surface as defined by vertical travel time to represents glacial lake geology (Breckenridge, 2015).

Subp. 1. Prohibitions. A. (1) – Fall application of nitrogen fertilizer in DWSMAs

The agency considers DWSMAs as high priority under the proposed Rule. Public wells supply drinking water to many people including homes, businesses, and public facilities. Communities rely on public wells to provide safe drinking water, therefore proper land and water management within the DWSMA must take place.

MDH delineates WHPAs based on a ten-year time of travel. DWSMAs are defined by MDH based on readily identifiable physical or political features as specified in Minn. R. 4720.5100, subp. 13.

On average there are 136 people served by a public well for every person served by a private well (MDH, 2017).

The proposed Rule restricts the application of nitrogen fertilizer in the fall and to frozen soils in DWSMAs with any municipal public water supply wells with concentrations greater than or equal to 5.4 mg/L nitrate-nitrogen. This is needed and reasonable because, public water supplies exceeding 5.4 mg/L nitrate-nitrogen value are required to monitor water as specified in Code of Federal Regulations (CFR) 141.23: National Primary Drinking Water Regulations (USEPA, 1998). *"(2) For community and non-transient, non-community water systems, the repeat monitoring frequency for groundwater systems shall be quarterly for at least one year following any one sample in which the concentration is ≥50 percent of the MCL. The State may allow a groundwater system to reduce the sampling frequency to annually after four consecutive quarterly samples are reliably and consistently less than the MCL."*

Accordingly, the MDH Drinking Water Protection Section Community Public Water Supply Unit uses a value of 5.4 mg/L as nitrogen-nitrogen when comparing analytical results with regulatory monitoring triggers (D. Rindal, MDH. Personal communication. March 5, 2018). Public wells that exceed this threshold need to monitor nitrate-nitrogen concentrations quarterly.

The public water supplier must be a municipal public water supplier. This is reasonable because the agency will use its resources to regulate larger DWSMAs and not those that are extremely small under this part of the proposed Rule.

There also must be a DWSMA established by the MDH so it is clear where the proposed Rule applies.

Currently, there are 30 DWSMAs that have nitrate-nitrogen in groundwater greater than or equal to 5.4 mg/l.

Subp. 1. Prohibitions. A. (2) – Fall application of nitrogen fertilizer where vulnerable groundwater makes up 50% of quarter-section

When more than 50 percent of a quarter-section has vulnerable groundwater areas (see SONAR, 1573.0010, Definitions), there is a progressively greater risk that nitrate from nitrogen fertilizer could make it into the groundwater. Therefore, the agency sees a need to restrict the application of nitrogen fertilizer to non-vulnerable groundwater areas in these quarter-sections, including on areas within the quarter section that are otherwise not considered vulnerable.

The agency considered many different options when deciding the scale on which vulnerable groundwater areas should apply. Vulnerable groundwater areas are based on soils and geology, and since these are natural features, their boundaries do not align with features such as county boundaries, roads, townships or sections. Defining an area is needed and reasonable in order to be clear to both the regulated party and regulator where fall nitrogen fertilization will be prohibited.

The approach of using a portion (percentage) of an area to designate an entire area is already used by USDA-NRCS under the federal farm bill. Use of percentage of an area criterion is used by the USDA-NRCS to determine highly erodible cropland (HEL). This criterion uses 33% or more of a field that contains highly erodible soils, then the entire field is considered highly erodible. The agency considered using 33% like the HEL criteria. However, this is used as criteria for soil erosion potential which is dissimilar to groundwater vulnerability which includes different soils characteristics as well as geology.

The agency considered using the section (1 square mile) scale. This scale was considered because a section of land is at an identifiable scale, nitrogen management is practicable at this scale, and in most cases in agricultural areas, and this involves few landowners. The agency presented this option to the public during the summer 2017 listening sessions. Many commenters believed that a section scale is too large of an area, and thus was an unnecessary and overly broad application.

Use of natural soil and geologic boundaries were considered, since this is their defined boundary and no vulnerable area extrapolation is needed because no additional conditions are included. However, even though this would identify vulnerable groundwater areas based on their mapped boundaries, soils and geology boundaries can be difficult to identify. This is not only because they are often irregular in shape and size, but they may not be visible at the surface. Therefore, it would be difficult for a regulated party to identify the exact boundaries on the ground. Though some comments noted soil boundaries should be used to define vulnerable groundwater area boundaries, and farmers are capable of doing this, it would be difficult to manage and regulate in a field where only some of the field is vulnerable. Individual vulnerable area mapping features are often variable and irregular in size and shape. This makes it more difficult to manage and understand for the agency and regulated parties. For example, in a field with various separate vulnerable soils and where fertilizer is custom applied, the farmer would need to provide vulnerable area information to the dealer. The dealer would need to ensure that applicator staff is aware of and able to avoid nitrogen fertilizer application in vulnerable groundwater areas of the field when fertilizing others. This is logistically more difficult both from a communication standpoint as well as actual application. For these reasons, the agency ruled out using the boundaries of soil and geology features in determining vulnerable groundwater areas.

As a subset of defining vulnerable groundwater areas based on soil and geology boundaries, the agency considered *de minimis* criteria. This would address 'small' vulnerable groundwater areas that were deemed to be too small to be a concern to impact groundwater contamination. *De minimis* criteria considered included area (acreage) and percentage. The agency considered an area too small based on whether it would likely cause practical difficulties for farming (i.e. too small to manage differently) or an administrative burden to the agency. The agency considered various *de minimis* acre ranges; from approximately 1-10 acres. The agency also considered *de minimis* based on a small percentage of an area. In the end, the agency concluded that any number or percentage used would create practical and administrative difficulties. There was no clear consensus on *de minimis* number or percentage that was reasonable, therefore *de minimis* criteria was ruled out.

The agency considered vulnerable area designation at a township scale. This would make sense because townships are a defined area, and the agency is actively monitoring townships for nitrate and is establishing Local Advisory Teams, as outlined in the NFMP. However, this is a large area (36 square miles) so a township with variable vulnerable area could have significant area (literally several square miles) that would be included or excluded from fall application, vulnerable or not. Therefore, due to this scale issue, this was ruled out.

The agency considered vulnerable designation based on BMP region. This was considered because U of M nitrogen management recommendations (as part of the nitrogen fertilizer BMPs) are variable by BMP region. However, this would include many counties, so is much too large of a scale to implement vulnerable area criteria. Therefore, this option was ruled out.

Using cropland boundaries to identify vulnerable area was considered. This could be ideal because farmers manage based on field boundaries; this is where the nitrogen fertilizer management activities take place. However, farmers and contractors who apply fertilizer on fields may not be able to apply nitrogen fertilizer based on variable vulnerable area in a field. In these cases, it is reasonable to determine whether the entire field is vulnerable. The 'scale' would be variable since fields vary significantly in size throughout the state (ranging for less than 1 acre through approximately 640 acres in size). Additionally, the boundaries of cropland are not public information, therefore is not available for the agency. USDA- Farm Service Agency (FSA) holds this information as non-public data, available only to FSA staff and the cropland owner and/or operator. Cropland information could be provided by the landowner or land occupier, however there may not be an incentive for them to provide this, and this could create an extra step and unreasonable burden to the landowner/land occupier and the agency. The agency considered determining crop field area through using USDA NASS (n.d. (b)) CropScape since this source provides statewide coverage on an annual basis. Claire et al. (2011) reported the mapping accuracies were 85%-95% correct for the major crop categories. Reitsma et al (2016) found crops were mapped correctly between 43% and 95%, with the largest errors occurring in landscapes with many different crop types present, making field boundaries indistinguishable. Reitema (2016) further stated that errors at this magnitude introduce uncertainty in land use calculations. Based on these findings, the MDA determined that the errors in the CropScape estimates are too high for this purpose.

Subp. 1. Prohibitions. A. (3) – Fall application of nitrogen fertilizer to frozen soils in vulnerable groundwater area or DWSMA

Applications of nitrogen fertilizer to frozen soils are not recommended by U of M nitrogen fertilizer BMPs. Nitrogen fertilizer products not properly incorporated on frozen soils are more likely to run off or be lost to the atmosphere thus lowering fertilizer use efficiency and possibly increasing groundwater contamination.

Rationale for vulnerable groundwater areas and DWSMAs is provided in this SONAR in 1573.0010 Definitions.

In vulnerable groundwater areas, nitrogen applications should be made much closer to the time period when the crop needs the nitrogen. This is why it is needed and reasonable for the agency to prohibit nitrogen fertilizer application in fall and on frozen soils in these vulnerable groundwater areas.

In many areas across the state, 75% of deep percolation and subsequent nitrate losses occurs between the spring thaw and early June (Struffert et al, 2016). Excessive nitrate leaching will occur most years with fall applications in these areas.

Subp. 1. Prohibitions. B. and C. – Vulnerable groundwater areas map

The map will be reviewed periodically to allow for adjustments to be made to account for new information in the rare instances where soils and karst geology information is updated. Additionally, the list of public water suppliers restricted from applying nitrogen fertilizer in the fall and to frozen soils will change as nitrate concentrations fluctuate above and below 5.4 mg/L nitrate-nitrogen. This indicates that the parties in charge of cropland in the areas shown on the map are responsible for meeting the requirements in this part of the proposed Rule.

Subp. 2. Exclusions. A. – Fall application restriction

During the comment period on the draft rule (summer of 2017), the agency heard many concerns from farmers in the western and northern parts of the state about the importance of fall nitrogen applications because of the short application window in the spring. Additionally, there were concerns that climate factors were not factored into the draft rule. The agency responded by evaluating statewide climate information to determine various factors that potentially impact fall nitrogen fertilizer management decisions. This statewide evaluation also reviewed climate factors that influenced leaching potential and nitrification rates. This evaluation confirmed that there is significant climatic variation across the state that must be considered when drafting the fall restriction rules. For example, in southeast Minnesota there is more precipitation, resulting in more water available to movie through the soil profile, and warmer spring soil temperatures resulting in a greater potential for fall-applied nitrogen to be converted to nitrate and potentially lost. In contrast, the cooler spring soil temperatures in tandem with less precipitation found in northern and northwest Minnesota create conditions of reduced risk of nitrogen loss to the groundwater.

After evaluating a variety of climate variables, the agency determined the following criteria when used in tandem provided meaningful metrics for guiding fall nitrogen fertilizer management restrictions:

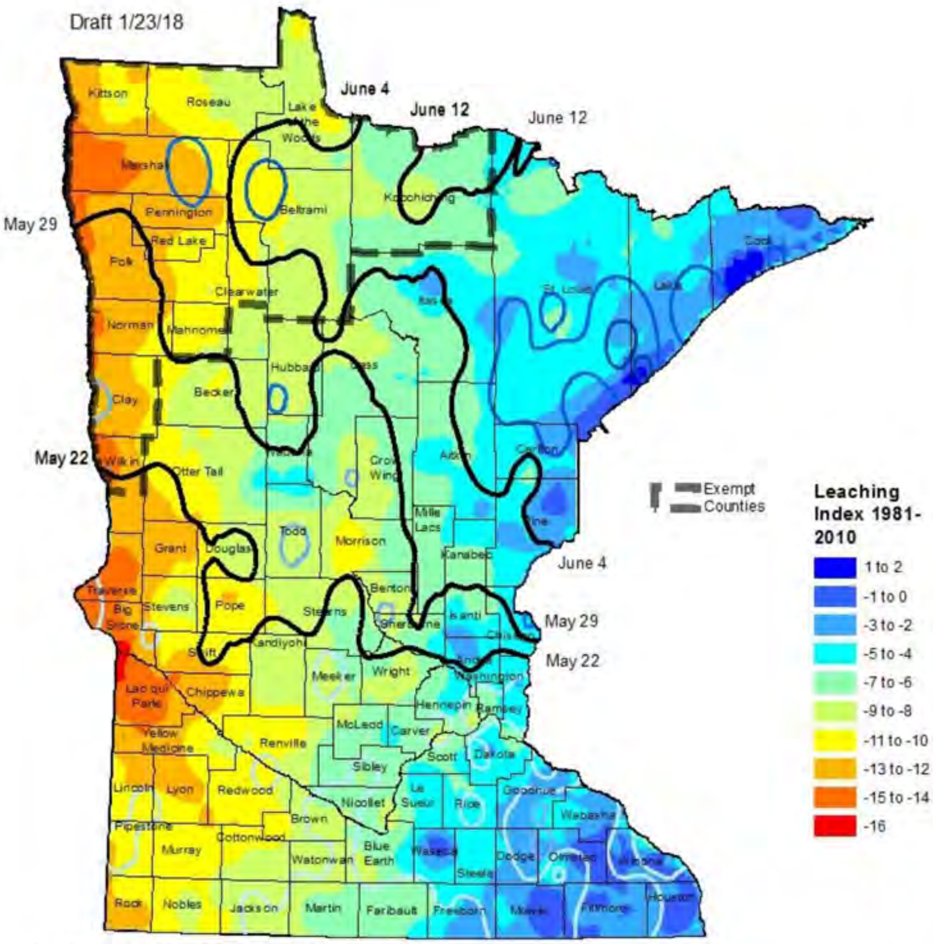
- leaching index
- spring frost-free date

Leaching Index: The leaching index is defined as the daily rainfall minus daily evapotranspiration summed to annual values. This index provides a very broad approximation of annual water movement through the soil profile. Nitrate will not move through the soil without water, so it is relevant to evaluate the nitrate leaching risk based on the amount of water available to move through the soil (Lamb et al., 2008). Therefore it is reasonable to exclude areas of the state from the fall application restriction where water movement is minimal under typical climatic conditions.

The leaching index was a core concept factored into the early recommendations for fall nitrogen applications. For years, the general U of M guidelines were that the use of the soil nitrate test worked west of Highway 71 (except for coarse-textured soils) because the leaching index was low. Corresponding, similar logic for fall nitrogen applications was used.

Spring Frost-free Date: Using the spring frost-free date provides some general guidance on spring soil temperatures. The later the date, it is more likely that spring soil temperatures will be cooler. This date also provides general guidance on the amount of time available for getting spring field work completed. The later the date, the narrower the timeframe for applying spring fertilizer, tillage and planting. There is a northwest to southeast gradient when the last frost-free date in the spring occurs (Figure VI-2). The spring frost free date intervals were derived by the MDNR State Climatology Office (MDNR, 2018).

Isolines indicating late to very late spring conditions with spring frost-free dates after May 22 are illustrated on the provided map. It is very difficult to grow long season crops like corn in these cooler regions and any unnecessary delays must be avoided. There are logistical problems such as with an insufficient numbers tender trucks and spreaders to complete all fertilizer applications in this compressed spring period.



Leaching Index (LI) and Spring Frost Free Date (SFFD) criteria:

- The delineation is based on county boundaries (unless otherwise stated) meeting ≥ 50% of the leaching index area, and spring frost free dates contiguous isolines (i.e. 'bullseyes' not included) based on the criteria below.
- If the SFFD is on or after May 22 and the LI is ≤ -12, and
- If the SFFD is on or after May 29 and the LI is ≤ -10, and
- If the SFFD is on or after June 5 and the LI is ≤ -6, and
- For Clearwater County, the area north of Highway 2 will be excluded from areas considered vulnerable.
- For Wilkin County, the area north of Highway 210 will be excluded from areas considered vulnerable.

Figure VI-2. Spring frost-free dates and leaching index.

Using Leaching Index and Spring Frost-free Date in Tandem: It is necessary and logical to create this dual criteria approach due to major climate variability across the state. Both leaching index and spring frost free date factors are significant contributors to affecting nitrogen fertilizer management. A graduated combined approach that corresponds the different risk frost free date and leaching index is needed to address this.

Taken together, the leaching index and the spring frost free dates show the risk of nitrate-nitrogen leaching loss and movement to the groundwater is greatly reduced in counties in the northern and western parts of the state. The criteria listed in the proposed Rule are based on the combined risk of nitrate-nitrogen leaching loss explained by the leaching index and the spring frost free dates.

The years 1981-2010 were used for the leaching index and spring frost free dates because this was the most recent decadal period of record that was available. A 30-year time period was used to be consistent with common practice within climatological contexts where 30-year periods are used to define 'normal' conditions (MDNR, 2018).

Since both of these are significant factors and in combination have greater influence on water movement, these were combined into one map (Figure VI-2) which was used to exclude the indicated counties from the fall application restrictions.

Subp. 2. Exclusions. B and C. – County lines or other geographical boundaries

While the criteria identified to exclude areas from the fall application restriction do not necessarily follow identifiable boundaries, boundaries are needed for the proposed Rule so that the regulated parties and the agency have clarity in understanding where the regulations apply. The criteria used as a basis for the exclusions to Part 1 of the proposed Rule are reflected on a map as isolines, meaning they are not based on a constant value. Isolines shown on the map of the exclusions are not easily identifiable or known on the ground or may be in the middle of a field. Therefore, the agency believes the leaching index and spring frost free date exclusion criteria largely should follow county boundaries. Using county boundaries and (Highway 2 in Wilkin County) will provide complete clarity for the regulated parties as to where the exclusions are in place. It is reasonable to use these geographic features versus the leaching index and spring frost free date isolines, which will in most cases be unidentifiable 'on the ground.'

Subp. 2. Exclusions. D. – DWSMAs

The exclusion listed under Subp. 2, A does not apply to DWSMAs. As described under 1573.0030, Subpart 1. A. (1), communities of more than 25 people rely on the public wells in DWSMAs for safe drinking water. The agency will have water quality monitoring results showing that there are water quality problems in the DWSMAs public well and therefore it is needed and reasonable that fall application should be restricted in DWSMAs with nitrate-nitrogen concentrations greater than or equal to 5.4 mg/L.

Subp. 2. Exclusions. E. – Counties with less than 3% agriculture

USDA NASS (n.d. (a)) provides statistics for agricultural cropland in every county. The agency has used this data to exclude counties with very low agricultural intensity from the fall application restriction. This proposed exclusion is reasonable because in these identified counties, there is a low concentration of crops grown and therefore low nitrogen fertilizer use. Since nitrate in groundwater is associated with cropland acres, it is reasonable to exclude areas where minimal cropland acres exist. The agency used 3% because this value represents very few acres compared to the total county acres. It is reasonable that the agency allocates limited resources to counties with higher areas of land in cropland, where the public health and environmental risks are greater.

Subp. 2. Exclusions. F. – Point sources of pollution

In some cases, elevated nitrate levels within DWSMAs are due to point sources of nitrogen. Examples of point sources could include but are not limited to an improperly sealed well, animal feedlot or an agricultural chemical incident. This exclusion is needed and reasonable to exempt land owners within DWSMAs from the fall application restriction if the agency determines that elevated conditions where induced by a point source.

Subp. 2. Exclusions. G. – Partial DWSMA Exclusion Based on Low Risk

The commissioner may exclude part of a drinking water supply management area from the fall application restrictions if the commissioner determines that the area is not contributing significantly to the contamination of the public well in the drinking water supply management area. This provision in the rule is necessary to allow the commissioner to exempt parts of a DWSMA which are not contributing significantly to the groundwater contamination in the public well from fall application restrictions.

Fall application restrictions statewide are based on areas where 50% of more of a quarter section is vulnerable to groundwater contamination. This criteria was developed, in part, based on feedback from the public comment period that the previously proposed size, which was based on a full section, was unreasonable because sufficiently detailed information exists to better refine the areas subject to the restriction and not impose those restrictions on areas where it they will provide limited environmental benefit. This concern regarding an appropriate scale for the restrictions applies similarly to DWSMAs. MDA will be focusing more closely on DWSMAs and should be able to more precisely define areas that should be exempt from fall restrictions due to lower risk to groundwater based on a more precise analysis of the characteristics of the DWSMA.

DWSMAs vary in size from very small, less than a hundred acres, to relatively large, on the scale of tens of thousands of acres. For most DWSMA the soils types and vulnerability to groundwater contamination are likely to be fairly uniform across the DWSMA and this exclusion will not be needed. But for large DWSMAs it is reasonable to expect that there will be areas with significantly different soils types and groundwater vulnerability such that some parts of the

DWSMA may not be contributing significantly to high nitrate-nitrogen concentrations in the public well. For large DWSMAs there may be differences in soils types, land features or groundwater vulnerability such that the implementation of fall application restrictions may provide little environmental benefit to the public well with some cost for implementation to the farmer.

This provision is necessary to ensure that the commissioner does not impose requirements and related costs in areas where they will not significantly help reduce nitrate-nitrogen concentrations in the public well. It is reasonable because the Groundwater Protection Act directs that Water Resource Protection Requirements should be practicable and consider factors such as economics, implementability and effectiveness, and implementing fall application restrictions uniformly across a DWSMA including in areas where they may provide limited environmental benefits would not meet this requirement.

Supb. 3. Exceptions. A. - Fall application

In many cases, nitrogen applied in the fall increases the risk of groundwater contamination. The agency recognizes that in some cases, the practice of fall nitrogen application is a necessary agricultural practice despite being located in a vulnerable area. There are a few agricultural crops and practices that require an exception to the proposed Rule. The agency met with U of M staff as well as with internal experts to determine all possible exceptions. This list was then narrowed down based on applicability, feasibility, and relevance to applying nitrogen to crops in the fall. The list of possible exceptions was included when the agency released the request for comments in winter of 2015-2016. Many comments were received on this topic during the comments on the proposed Rule (summer 2017). The agency reviewed these comments and determined it was reasonable to include the following exceptions.

None of these exceptions apply to the application of nitrogen fertilizer to frozen soils. No benefit were identified from the application of nitrogen fertilizer to frozen soils.

Subp. 3. Exceptions. A. (1). Winter grains planted in the fall.

Phosphorus fertilization serves an important role in the winter hardiness of small grains. Since the common forms of phosphate fertilizers contain some ammonium, it is also considered a nitrogen fertilizer and it is needed and reasonable to have an exception to ensure that the proper phosphorus amounts are available. (Kaiser, 2011). Therefore it is reasonable to create this exception.

Subp. 3. Exceptions. A. (2). – Pasture fertilization

Under most production systems using cool season grasses (bromegrass, orchardgrass and reed canarygrass), an early spring nitrogen application is the recommended timing. However, in a high yield system, split applications are recommended with ¾ applied in early spring and the remaining ¼ in late summer/early fall. (Kaiser, 2011). Therefore it is reasonable to create this exception.

Subp. 3. Exceptions. A. (3). – Perennial crops

Research has shown that the most effective time to fertilize perennial crops is during the late summer and early fall (Kaiser, 2011 U of M Extension Service). Prior to freeze up, much of the fertilizer nitrogen will be absorbed by the root system and not subject to leaching. The net result is a healthier, more productive crop the following spring. Therefore it is reasonable to create this exception.

Subp. 3. Exceptions. A. (4). – Grass seed production.

Regarding grass seed production, the U of M Extension recommendations (Kaiser, 2011) provide criteria for rate selection but are silent on the timing. South Dakota State University (Gelderman et al., 1987) provides guidance for the cool season grasses. Adequate nutrition during the initiation of the tiller buds is important. For this reason, either a fall application or very early spring application is recommended and it is reasonable to create this exception.

Subp. 3. Exceptions. A. (5). – Cultivated wild rice.

Fall is also the most effective time to apply nitrogen to cultivated wild rice, but for very different reasons than perennial grasses or winter grains. Minnesota grows about 20-30,000 acres of cultivated wild rice with the majority grown in the north-central portion of the state. Cultivated wild rice is grown as an annual. Frequently the rice is seeded in the fall, nitrogen is then applied in the ammonium form, and then the field is flooded. The ammonium does not convert to the mobile nitrate form because it lacks oxygen needed for the bacteria to live. That bacteria is are necessary for the nitrification process. Because the nitrogen fertilizer does not convert to nitrates, there is no leaching risk when the rice fields are flooded in the fall. Additionally, the rice is protected in the flood conditions and will germinate the following spring. In the spring, water levels are lowered and the nitrification and germination process begins. (Kaiser, 2011). Therefore it is reasonable to create this exception.

Subp. 3. Exceptions. A. (6). – Cover crops to reduce the use of soil fumigants.

Cover crops are typically not fertilized, since the general concept of cover crops revolves around the concept of tying up any residual soil nitrates left after the growing season. However, one special situation was identified within a potato rotation. Soil fumigants are typically applied in the fall to fields scheduled for potatoes the following spring. The residual chemical compounds from cover crops such as brown mustard and other brassica plants have been found to reduce the need for the fumigants. However, to create enough biomass, it is recommended to fertilizer the cover crops with 25-50 lb N/acre. Therefore it is reasonable to create this exception.

Subp. 3. Exceptions. B. – Nitrogen fertilizer rates

When applying fall nitrogen to the exempted crops in a vulnerable groundwater area, nitrogen fertilizer application rates must follow the rates in the nitrogen fertilizer BMPs under Minn. Stat. § 103H.151, subd. 2. This information has taken in consideration both economic and environmental factors and the agency can be confident that nitrate leaching losses are minimized. Therefore it is reasonable to create this exception.

Subp. 3. Exceptions. C. (1). – Exception for ammoniated phosphates, micronutrient formulations

Growers frequently need to apply phosphorus fertilizer to maintain optimal yields with most traditional crops. In some areas of the state, phosphorus is commonly applied in the fall in tandem with the tillage operation. With Minnesota's short growing seasons, it is important to get as much soil fertility work completed in the fall as possible so that there are minimal delays with the spring planting operation.

In a corn-soybean rotation, growers typically will apply 100-120 pounds of phosphate (P205) to satisfy crop needs for the two-year rotation (i.e. it is applied in one year to meet the crop needs for 2 years). Phosphorus is very immobile in soil so applying it in the fall does not pose environmental issues as long as it is incorporated to reduce runoff risks and soil erosion is minimized. However, both MAP and DAP, the two dominate forms of phosphorus fertilizer, contain ammonium in the formulation. When applying 100 pounds of phosphate (a common application rate for a two-year corn-soybean rotation), 21 pounds of nitrogen will be applied with MAP and 39 pounds of nitrogen will be applied with DAP, per acre. Like all nitrogen fertilizer products, eventually the ammonium will be converted to the more soluble nitrate form and subject to leaching losses.

The purpose of the 40-pound nitrogen limitation is to guide producers to use practices that minimize unnecessary nitrogen losses without putting complete restrictions on fall applied phosphate in vulnerable groundwater areas. .

The forty-pound nitrogen limit was selected because:

- It satisfies phosphorus needs across all yield goal ranges when using the U of M Fertilizer Recommendations under medium soil testing levels (or higher) for either broadcast or banded (the two most common) application methods;

- It satisfies phosphorus needs across the majority of yield goal ranges when using either MAP or a private label product (e.g., 12-40-0-10, containing 12% nitrogen);

- For growers who can only purchase DAP in their region, they can still achieve the forty-pound ceiling limit by using the common standard of 100 pounds of phosphate within a corn-soybean rotation, recognizing that they may have to add supplemental phosphate prior to the soybean year if they have high crop removal values;

- Cropping scenarios have been analyzed to estimate yield goal of corn in a corn-soybean rotation while accounting for nitrogen input contributions from ammoniated phosphate and micronutrient formulation (Table IX-1). The example scenario illustrates an estimated yield goal of 200-219 bushels soils with a phosphorus (P) test in the medium range. Method One is the U of M recommendation for a broadcast application, Method Two is the U of M recommendation for a banded application, and Method Three uses phosphorus crop removal values across the rotation. Table IX-1 illustrates nitrogen inputs from MAP (11% nitrogen), DAP (18% nitrogen), AMS (ammonium sulfate ;) and Micro Essentials. The yellow cells represent combinations that result in summations that are below the 40-pound rate restriction. Conversely the red cells represent combinations exceeding the proposed restriction;

- The vast majority of Minnesota fields test “medium” or higher in (S. Murrell, IPNI. Personal Communication, 2015). Fields testing “Low” or “Very Low” need to address P deficiencies in order to use nitrogen and other inputs more efficiently. These fields are temporarily exempt from the nitrogen restriction. Once the soil P test moves into the medium range or higher, the restriction becomes active.

Table VI-1. Expected corn yield goal in a corn-soybean rotation on medium-P soils as affected by use of ammoniated phosphate and micronutrient formulations

Scenario #2: Average Yield Goals (200-219 Bushels) and Medium P Testing Soils

Data from Table 9 in AG-FO-3790-D (Revised 2016) FERTILIZING CORN IN MINNESOTA : Important--Yield Goal in still used for non-Nitrogen nutrients. In this table, the Expected Yield Goal is 200-219 Bu/Acre AND a MEDIUM Soil P (Bray 11-15 PPM or Olsen 8-11 PPM)

	Phosphorus and Sulfur Source		Method 1	Method 2	Method 3
	Yield Goal: 200-219	Phosphorus Approach	UM Recommendation for Broadcast Application	UM Recommendation for Banded Application	Based on P Crop Removal for Two Year Rotation (Slight Grow in Yield Goals)
Primary Phosphorus Sources	DAP (18-46-0)	N Input (lb/N/A) from DAP	21.5	11.7	47.7
		Total DAP Rate (lb/A)	120	65	265
		P205 Application Rate (lb/A)	55	30	121.8
	MAP (11-52-0)	N Input (lb/N/A) from MAP	11.4	6.2	25.3
		Total MAP Rate (Lb/A)	104	57	230
		P205 Application Rate	55	30	121.8
Phosphorus and Sulfur Sources	DAP (18-46-0) and AMS	N Input (lb/N/A) from DAP	21.5	11.7	47.7
		N Input (lb/N/A) form AMS	17.4	17.4	17.4
		Total N Input from DAP and AMS	38.9	29.1	65.1
	MAP (11-52-0) and AMS	N Input (lb/N/A) from MAP	11.4	6.2	25.3
		N Input (lb/N/A) form AMS	17.4	17.4	17.4
		Total N Input from DAP and AMS	28.8	23.6	42.7
	MicroEssentials SZ (12-40-0-10)	N Input (lb/N/A) from MESZ	16.5	9	36.5
		N Input (lb/N/A) form AMS	0	0	0
		Total MESZ Rate (Lb/A)	137.5	75	304.5
		P205 Application Rate	55	30	121.8
		Total N Input from MESZ	16.5	9	36.5

Subp. 3. Exceptions. C. (2). – Application of agricultural chemical contaminated soil and other media

Land application of contaminated soil and other media may be approved by the commissioner in accordance with Minn. Stat. § 18D.1052 if the commissioner determines that the land application will not cause unreasonable adverse effects on the environment. Land application of contaminated media is a critical component of the agency point source cleanup programs in the Incident and Emergency Response programs. Fertilizer-contaminated media is removed from agricultural chemical spill sites and samples of the contaminated media are analyzed and the number of pounds of nitrogen is determined. The contaminated media is typically applied at a rate less than or equal to 100 lb N/ acre and the most common crops utilized for land application are corn and soybeans. In order to prevent leaching to groundwater or runoff of contaminants, contaminated media cannot be applied within 200 feet of a well, abandoned well, or sinkhole; within 200 feet of intermittent or perennial surface water, on soil types prohibited by the label of a limiting pesticide, or on areas with slopes greater than 6%. The contaminated media is immediately tilled into the receiving soil. As part of the application approval process, the grower is asked to use the nitrogen in the contaminated media as an application credit for fertilizer applications for the following crop year.

Land application of contaminated media must occur in the spring before planting or in the fall after harvest. Most of the land application of contaminated media occurs in the fall because the longer timeframe between harvest and soil freeze up allows time to apply the media rather than in the very short window in the spring between soil thaw and planting. It is also difficult to store contaminated media over the winter for spring applications. The cost for land application of contaminated media is lower than disposal in landfills or other treatment or disposal methods and is a very effective way to use the agricultural chemicals that are present in the contaminated media for their intended purpose. Because disposal of contaminated media is a critical component of the agency's duties, it is needed and reasonable to include this exception.

Subp. 3. Exceptions. C. (3). – Research

In review of past U of M research projects involving phosphorus research, the vast majority use "small plot" research trials with a large number of replications. Since most Minnesota soils are medium or higher in phosphorous, researchers are generally seeking plots or entire fields that are in the medium or lower phosphorous range, then superimpose a range of phosphate levels with small, replicated plots. It is conceivable that future Discovery Farms or other field scale activities may want to monitor a portion of the field with higher than normal phosphate inputs. The 20-acre ceiling provides ample opportunity for this scale of demonstration/research.

D. 1573.0040 Drinking Water Supply Management Areas; Mitigation Level Designations

This part of the proposed Rule is intended to reduce or mitigate the nitrate concentration in groundwater in areas where nitrate has been identified as a concern in DWSMAs. The approach to mitigation in the proposed Rule is comprehensive, consistent with the goals and direction outlined in the Groundwater Protection Act (Minn. Stat. chap. 103H) and follows the conceptual approach to mitigation which is outlined in the NFMP (MDA, 2015).

The proposed Rule is the end product of an effort that began in 2010 to revise and implement the state's approach to address nitrate from fertilizer in groundwater. This development process included significant stakeholder engagement with an advisory committee and three comment periods before reaching the point of this draft proposed Rule. The process began with the revision of the NFMP using an advisory committee with stakeholder participation from a wide range of stakeholder groups. This included strong participation from the agricultural sector in addition to other groups referenced in the Groundwater Protection Act. This advisory committee met 18 times over approximately two years and brought in multiple experts including a representative from Nebraska, where a similar approach is in use. The goal of this process was to ensure that the committee understood the opportunities and limitations of agricultural practices and policies related to the management of nitrogen fertilizer to reduce nitrate leaching to groundwater, and that the approach used in Minnesota would be effective and practicable as directed in the Groundwater Protection Act. Every member of the advisory committee was welcome to suggest policies and criteria for consideration in developing the plan and conversations of options were extensive and thorough. As an outcome from the advisory committee process the MDA developed a draft NFMP, which was submitted for a public comment period, and held a series of public meetings around the state.

The MDA finalized the NFMP in March 2015 and immediately began implementation of the voluntary parts of the plan and developing the proposed Rule. The proposed rule is designed to implement the regulatory components of the plan. The development of this proposed Rule included two public comment periods to ensure that comments from stakeholders were fully considered before finalizing the proposed Rule. Although the NFMP outlined a conceptual approach to addressing nitrate in groundwater, significant changes have been made during the drafting of the proposed Rule based on careful consideration of stakeholder comments. While the proposed Rule is intended to provide the regulatory components for the plan, the proposed Rule has been developed using a significant public development process separate from any specific requirements in the plan. The plan outlines the regulatory components in a very general sense whereas the proposed Rule has gone through an extensive review process and, in consideration of that input, provides detailed requirements for decision making and regulation.

The draft proposed Rule released for the public comment during the summer of 2017 included draft regulatory approaches based on a township scale for private wells and by DWSMAs for public water supply wells. For reasons stated in more detail under Subp 1 below, the MDA decided to focus regulatory efforts and limited resources on the highest priority areas, which are DWSMAs.

Subp. 1. DWSMA mitigation levels. – Application

Approximately 75% of Minnesotans (4 million) rely on groundwater either from public or private wells for their drinking water supplies (MDA, 2015). Over half of the state's population is served by public water suppliers that use groundwater as the source of drinking water (Figure VI-3).

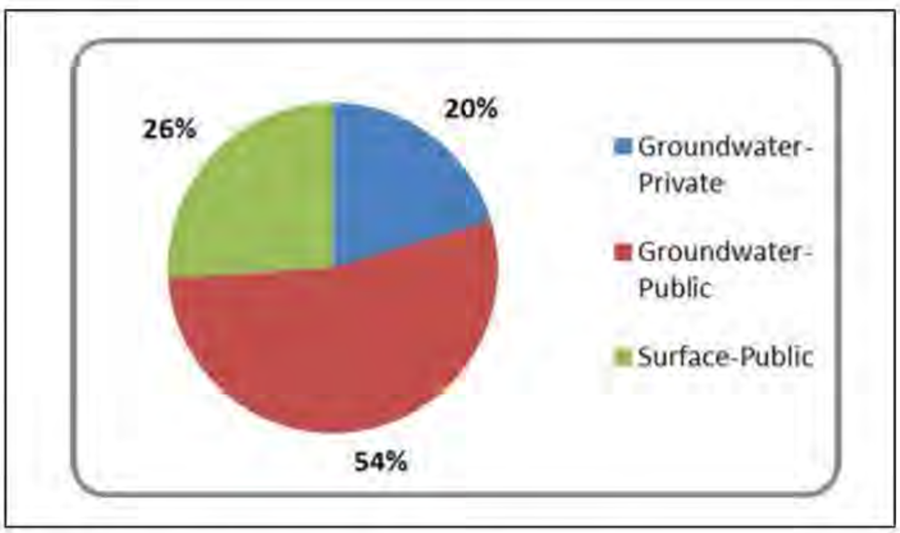


Figure VI-3. Drinking water sources in Minnesota.

Community and non-community public water supplies

Part 1573.0030, also referred to as Part 2 of the Proposed Rule, focuses on areas that provide groundwater to public water supplies or public wells. These areas surrounding public water supplies are called drinking water supply management areas (DWSMAs) The MDH is the lead agency dealing with public water suppliers (PWS). There are approximately 7,091 PWSs in Minnesota. These include those classified as "community" water suppliers, which include small to large communities. A community public water supplier by definition must serve at least 15 service connections used by year-round residents or regularly serve at least 25 year-round residents. There are currently 963 community water suppliers in Minnesota. The remaining systems are classified as non-community water suppliers. By definition, a non-community system must serve an average of at least 25 people at least 60 days a year at a place other than their home. Examples include restaurants, churches, schools, and businesses. Because of the large population in the state that public water supplies serve, it is needed and reasonable for the MDA to use the DWSMA scale for regulatory purposes in the proposed rule.

Wellhead Protection Areas and Drinking Water Supply Management Areas

The terms "Wellhead Protection Areas" (WHPAs) and "Drinking Water Supply Management Areas" (DWSMAs) are important to the proposed rule. WHPAs and DWSMAs are defined in Minn. R. 4720.5100, subp.43 and Minn. R. 4720.5100, subp.13, respectively, and the process for how WHPAs and DWSMAs are delineated is outlined in Minn. R. 4720.5205. The WHPA boundaries are established using a ten year time of travel (Minn. R. 4720.5510, subp. 2), which is based upon multiple scientific criteria, including hydrologic boundaries, which may or may not be identifiable on the land surface. Since WHPA boundaries may not be easily identifiable, DWSMAs are established. DWSMAs help define the WHPA by providing readily identifiable physical or political features as specified in Minn. R. 4720.5100, subp. 13.

The MDA determined that the rule should focus mitigation efforts on DWSMAs. Under the Groundwater Protection Act the MDA is directed to take action to prevent and minimize pollution to the extent practicable and to prevent the pollution from exceeding the health risk limit (see 103H.275 subd. 1 (c)). Therefore it is necessary for the rule to support actions that will reduce contamination in groundwater to meet these goals. Under the federal Safe Drinking Water Act a public well cannot exceed the drinking water standard and as the source water starts to approach 10 mg/L the municipality or party responsible for the well will have to take steps to ensure they don't exceed that concentration. These steps may include blending water from multiple sources, drilling a new well if a suitable alternative aquifer is available, or installing a water treatment system. These steps can be very expensive, difficult to implement and burdensome, especially for smaller communities. They create an urgent need to take action in areas where the nitrate-nitrate concentration is approaching the drinking water standard. In addition public water supply wells have the largest population that will be directly impacted by high nitrate levels in drinking water. Further, DWSMAs were identified in the NFMP as the highest priority areas for action. For these reasons it is reasonable for the rule to prioritize mitigation efforts in DWSMAs.

The DWSMAs also provide a useful regulatory boundary for protecting public water supply wells in the proposed Rule. It is necessary to define some geographic boundary for evaluation, implementation and regulatory purposes. It is reasonable to use the DWSMAs since they are already well-understood, and they are precisely defined by MDH hydrologists using computer modeling and other assessment tools to define the area where actions are needed to protect the source water for the well, and then applying it to a clear geographic boundary. If the MDA did not use the existing DWSMAs then the MDA would need to duplicate that effort in some manner in order to provide a technically defensible and easily explainable boundary for the area subject to this proposed Rule.

Alternatives considered: A significant effort was dedicated by the NFMP Advisory Committee to addressing private wells within the framework of the original 1990 NFMP. The 2015 NFMP focused on private well implementation on a township scale. In accordance to the revised NFMP (MDA, 2015), the MDA considered including regulation of private wells in townships in the MDA's Township Testing Program in the proposed Rule. That provision was included during the request for comment period during the summer 2017 listening sessions. After considering the comments from the request for comments and summer 2017 listening sessions, the MDA determined that the regulatory steps (mitigation levels 3 and 4) on a township scale would not be included. The MDA will continue to implement the NFMP with regard to townships designated as mitigation levels 1 and 2. Those activities are discussed briefly in a subsequent paragraph.

Some of the key factors influencing this decision were:

- The geographical area is involved if townships were included could be potentially extremely large. The MDA, through its preliminary results from the Township Testing Program, determined that at least twenty townships would more than likely be classified as a mitigation level 2 (NFMP, 2015) and a strong possibility that 10 to 20 additional townships would be added to the list. This would require a tremendous number of staff to focus on over 1 million cropland acres involving thousands of Minnesota producers;
- Installing the appropriate groundwater monitoring network across this number of townships that would be rigorous enough for regulatory purposes would be extremely expensive and the MDA currently does not have funding for establishing these networks;
- Comments from producers in the informal comment period during the summer of 2017 indicated that they are implementing a variety of practices beyond BMPs to address leaching, and they expressed strong support for a voluntary approach, rather than a regulatory approach, particularly in the townships.
- This will be the first rule promulgated by the MDA since the Groundwater Protection Act was passed in 1989. The proposed Rule creates a new regulatory structure, which will take