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DEPARTMENT OF AGRICULTURE

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**

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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.

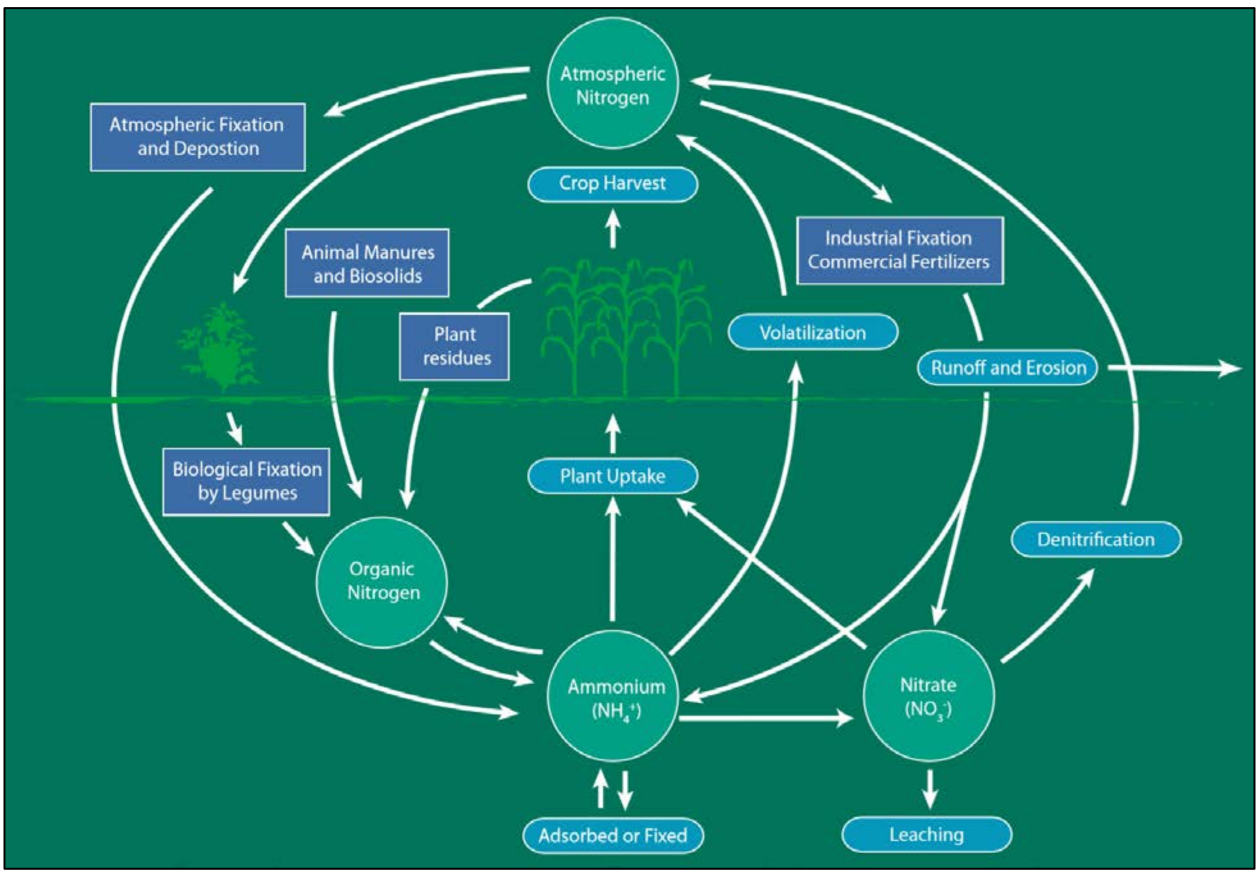


Figure II-1. The nitrogen cycle.

<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.

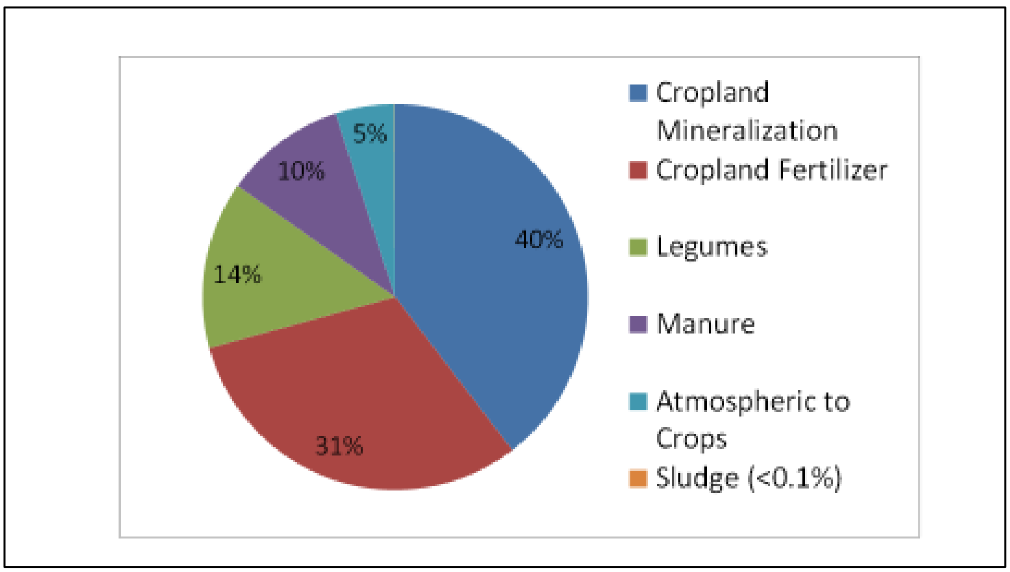


Figure II-2. Comparison of Minnesota's major agricultural nitrogen sources. (MDA, 2015)

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.

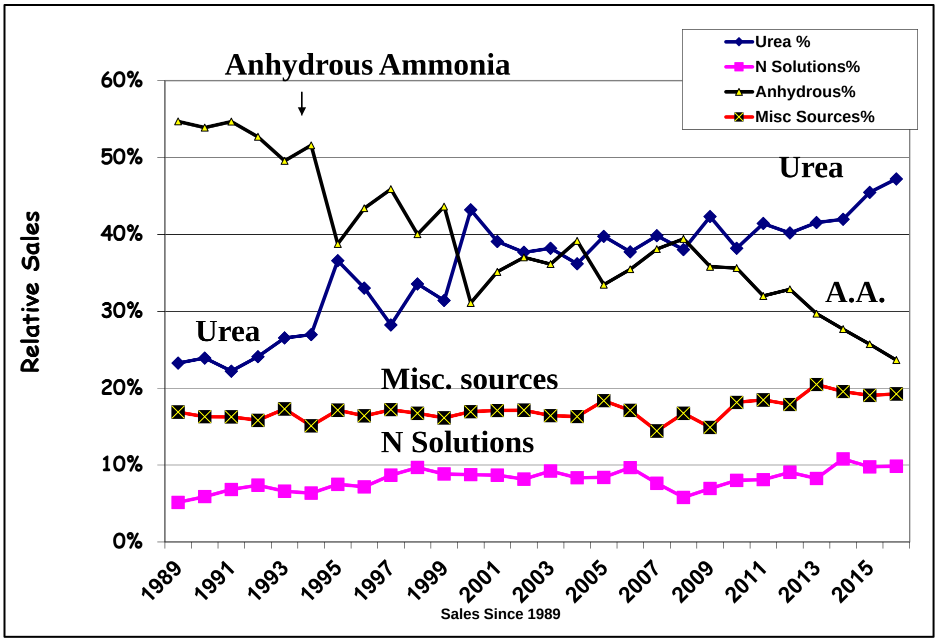


Figure II-3. Trends in three major nitrogen fertilizer sources used in Minnesota: 1989-2016. (MDA, 2015)

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.

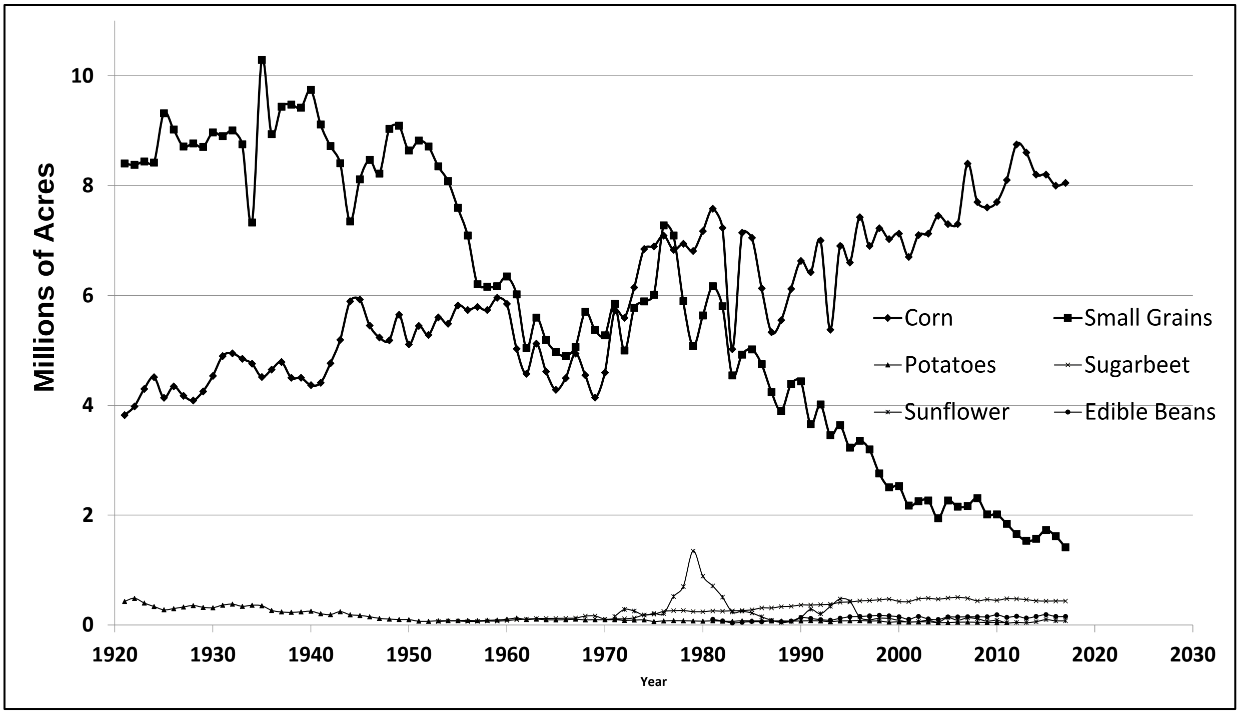


Figure II-5. Acreage trends for Minnesota's nitrogen demanding crops. (USDA NASS n.d. (a); MDA, 2015)

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).

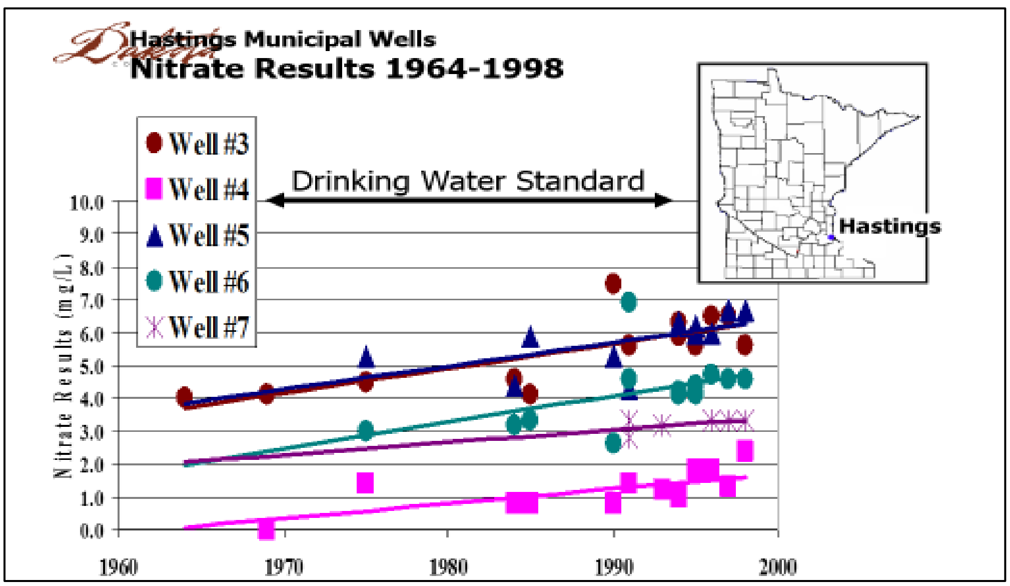


Figure II-6. Forty years of nitrate-nitrogen concentration trends in municipal wells, Hastings, Minnesota.

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.

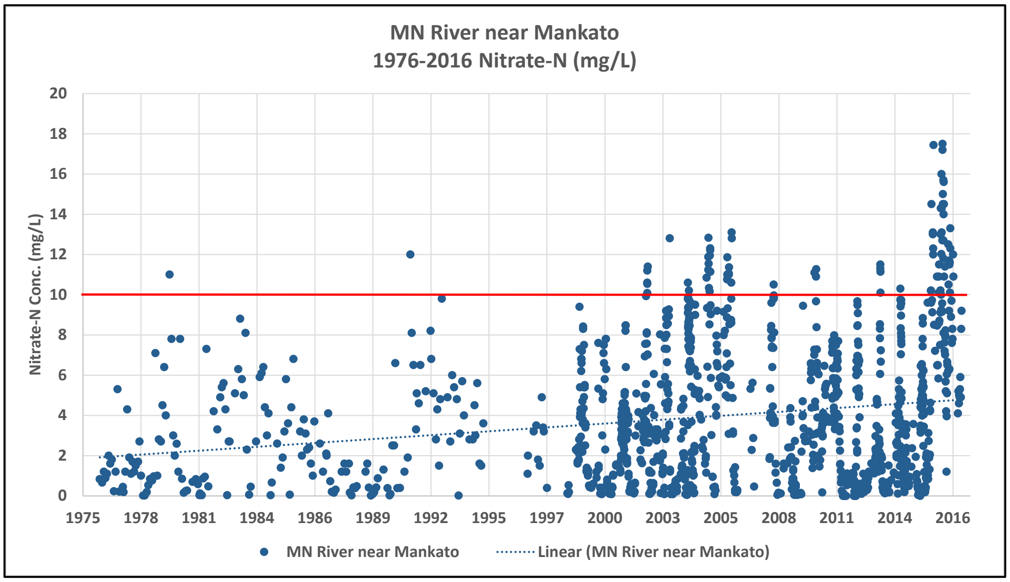


Figure II-7. Forty years of nitrate-nitrogen concentration trends in the Minnesota River.

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.

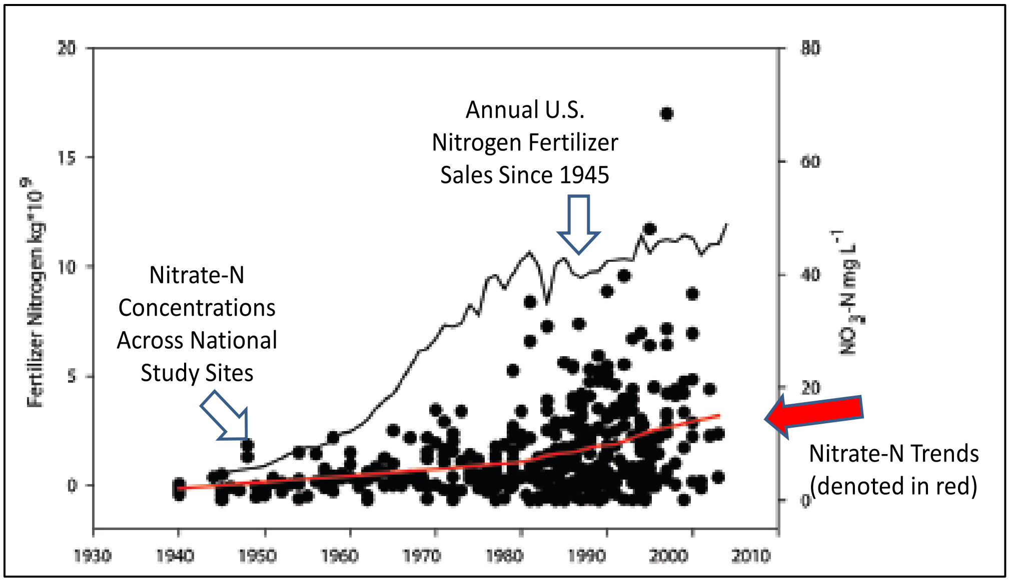


Figure II-8. U.S. nitrogen sales and nitrate-nitrogen concentration in groundwater from 20 long-term sites (including Perham and Princeton, Minnesota).

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).

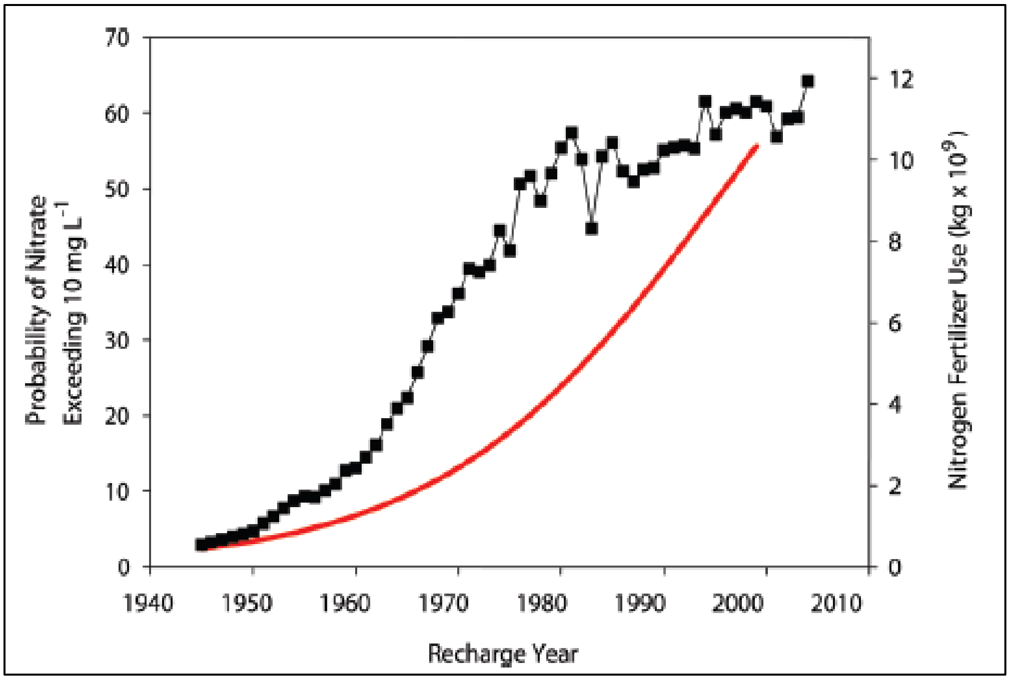


Figure II-9. Probability of nitrate-nitrogen concentrations in recharging groundwater exceeding 10 mg/L in areas of nitrogen fertilizer use (including Perham and Princeton, Minnesota).

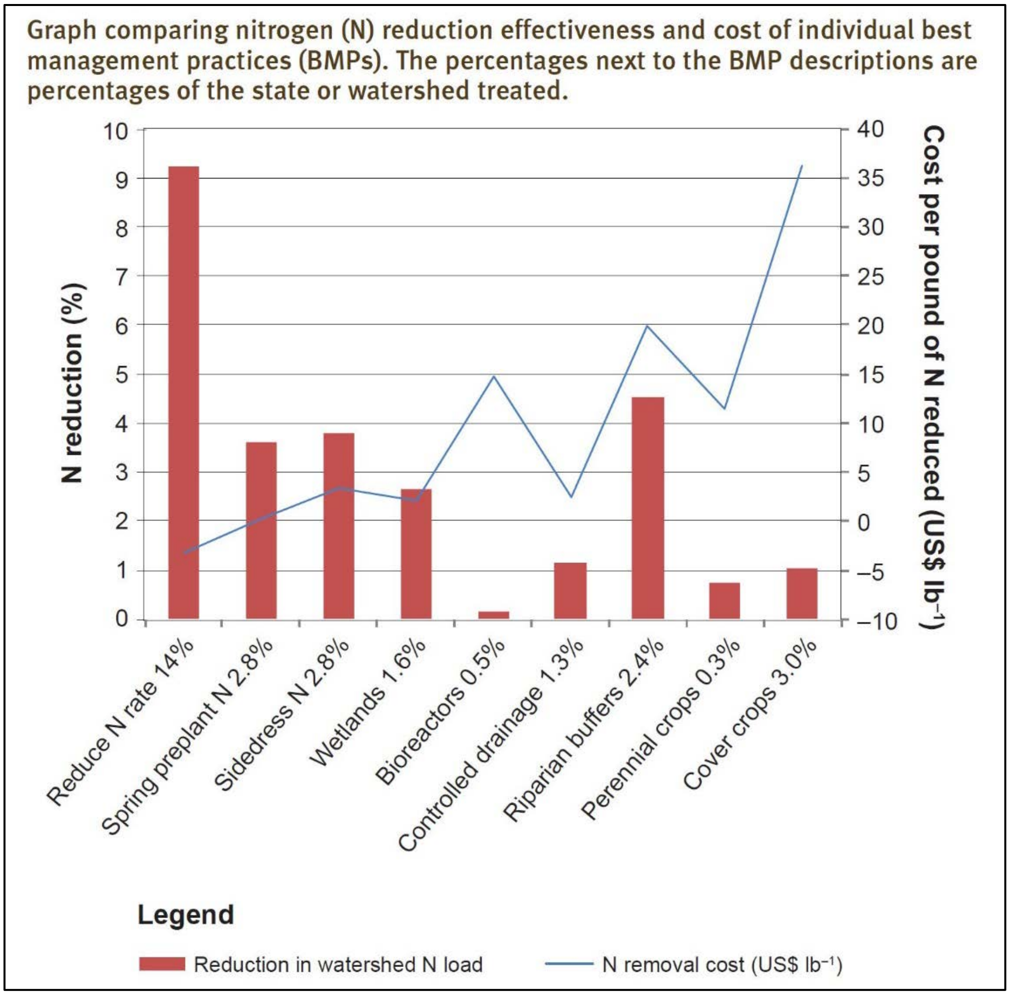


Figure II-10. BMP treatment opportunity (percent) in Minnesota's watersheds and corresponding nitrogen reduction effectiveness and cost estimated in the Nutrient Reduction Strategy. (Lazarus et al., 2014)

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.

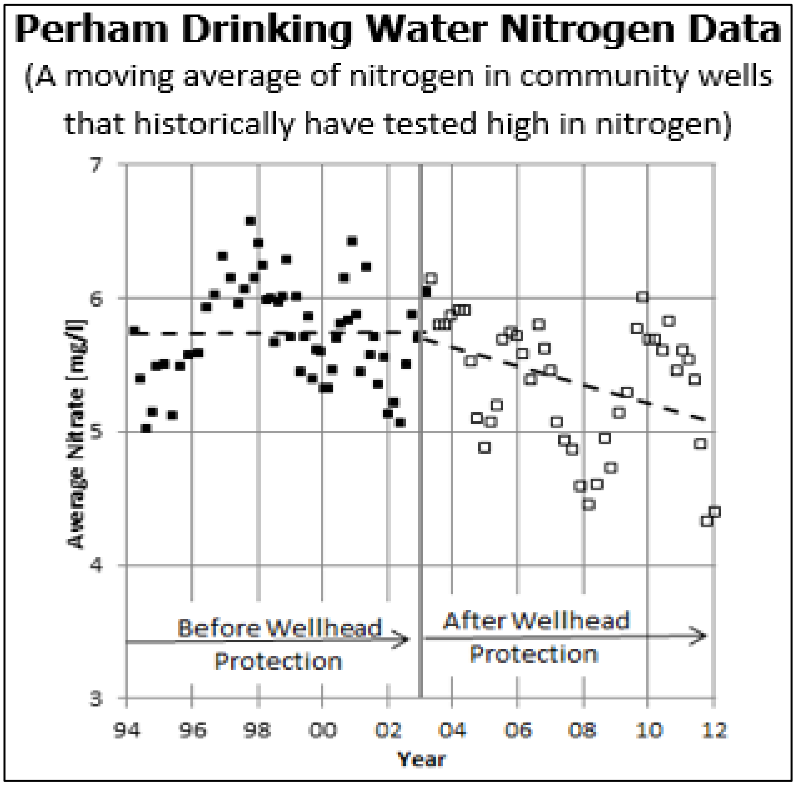


Figure II-11. Perham community well nitrate-nitrogen concentrations before and after wellhead protection efforts (Luke Stuewe, MDA Personal Communication)

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.

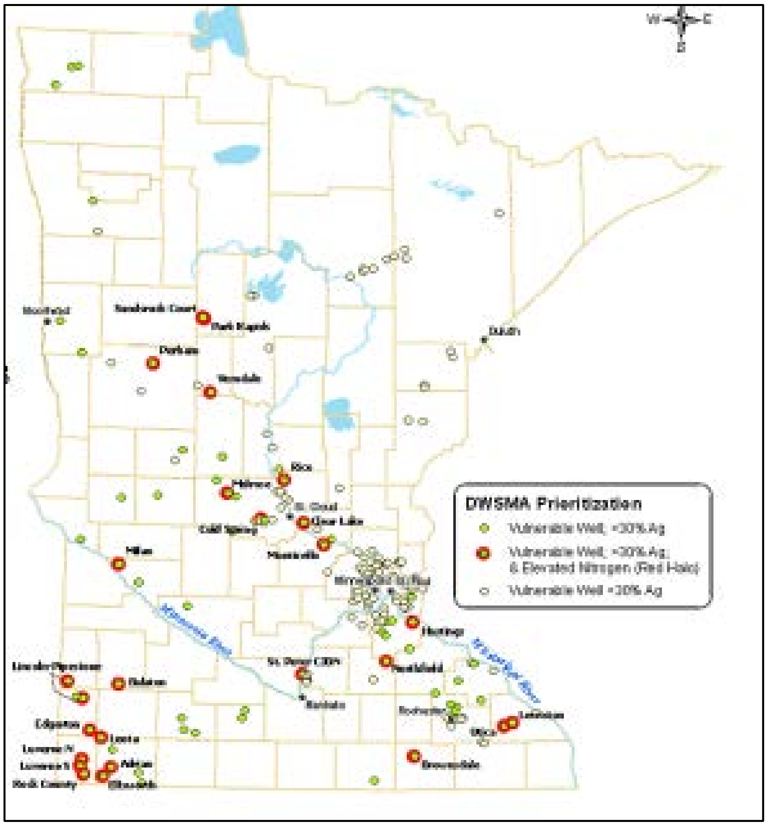


Figure II-12. Nitrate levels in public water supplies in agricultural areas.

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

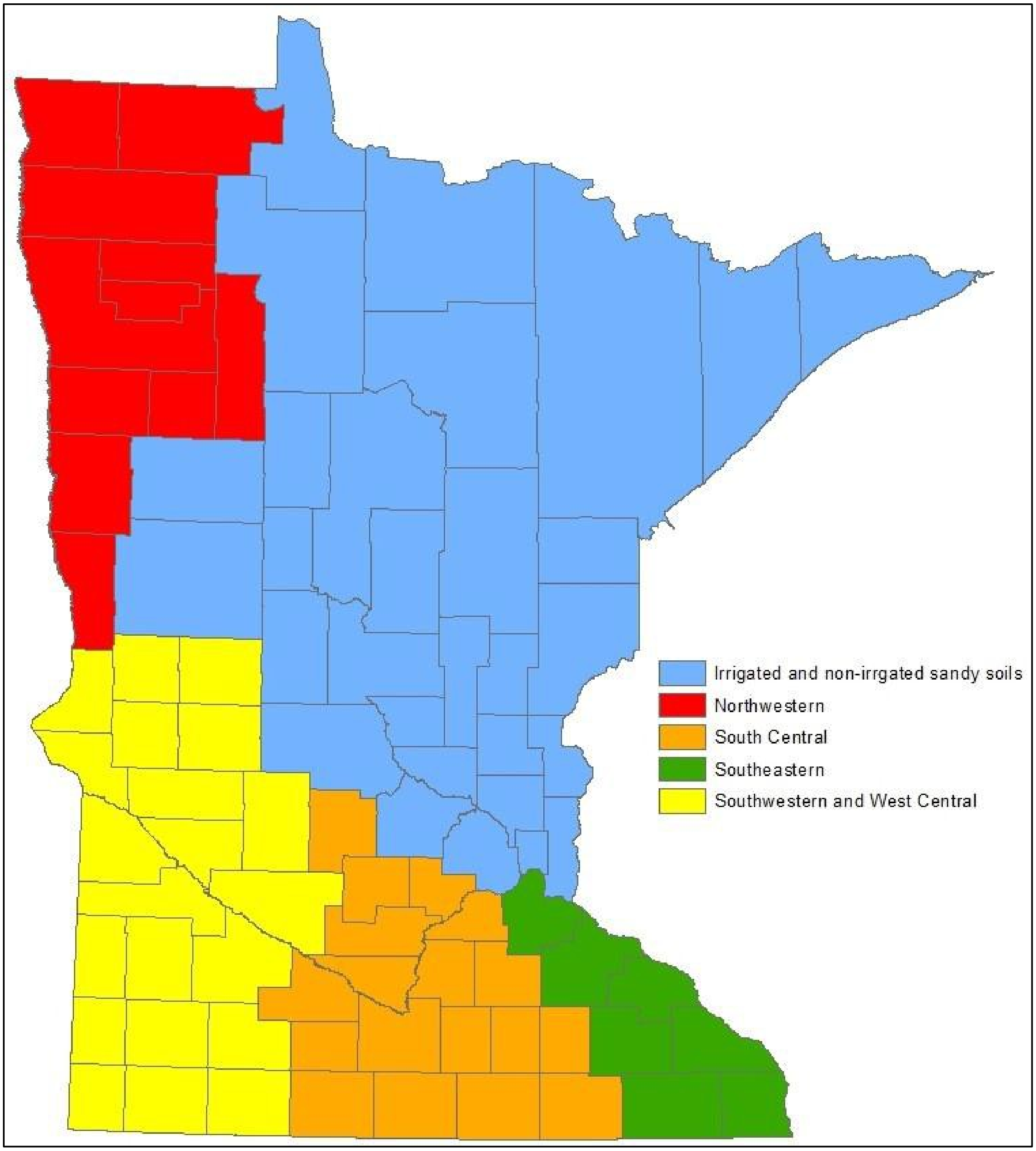


Figure III-1. Nitrogen fertilizer BMP regions. (Lamb et al., 2008).

Table III-1. Summary of the major nitrogen application timing and source BMP recommendations for corn by region (MDA, 2015).

<table>
<tr><th></th><th colspan="3">Minnesota Recommended Application Timing for Corn</th></tr>
<tr><th>Nitrogen BMP Region</th><th>Fall*</th><th>Spring Preplant</th><th>Split or Sidedress</th></tr>
<tr><td rowspan="2">Southeast</td><td rowspan="2">Not Recommended</td><td>Highly Recommended: AA or Urea</td><td rowspan="2">Highly Recommended: AA, Urea, or UAN</td></tr>
<tr><td>Acceptable with Risks: Preplant with UAN or ESN</td></tr>
<tr><td rowspan="2">South-Central</td><td>Acceptable with Risks: AA or Urea with N-Serve</td><td>Highly Recommended: AA or Urea</td><td rowspan="2">Highly Recommended: Split Applications of AA, Urea, or UAN</td></tr>
<tr><td>Not Recommended: Fall Application of Urea or UAN</td><td>Acceptable with Risks: Preplant with UAN or ESN</td></tr>
<tr><td>Coarse-Textured Soils</td><td>Not Recommended</td><td>Acceptable with Risk: AA or Urea with N-Serve, Single Sidedress w/o N-Serve, or Single Preplant with ESN</td><td>Highly Recommended: Use Split Applications, N-Serve with Early Sidedress</td></tr>
<tr><td rowspan="3">Southwest/West-Central</td><td>Recommended: Fall Application of AA or Urea</td><td rowspan="3">Recommended: Urea, AA, or UAN</td><td rowspan="3">Recommended: Sidedress Prior to V7 Growth Stage</td></tr>
<tr><td>Acceptable with Risk: Late Fall ESN or use of N-Serve or Agrotain</td></tr>
<tr><td>Not Recommended: Fall UAN or Any Fertilizer Containing Nitrate</td></tr>
<tr><td rowspan="3">Northwest</td><td>Recommended: Fall Application of AA or Urea</td><td rowspan="3">Recommended: Urea, AA, or UAN</td><td rowspan="3">Recommended: Sidedress Prior to V7 Growth Stage</td></tr>
<tr><td>Acceptable with Risk: Late Fall ESN or Use of N-Serve or Agrotain</td></tr>
<tr><td>Not Recommended: Fall UAN or Any Fertilizer Containing Nitrate</td></tr>
</table>

*Only after six inch soil temperatures fall below 50 ºF

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°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^{o} 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

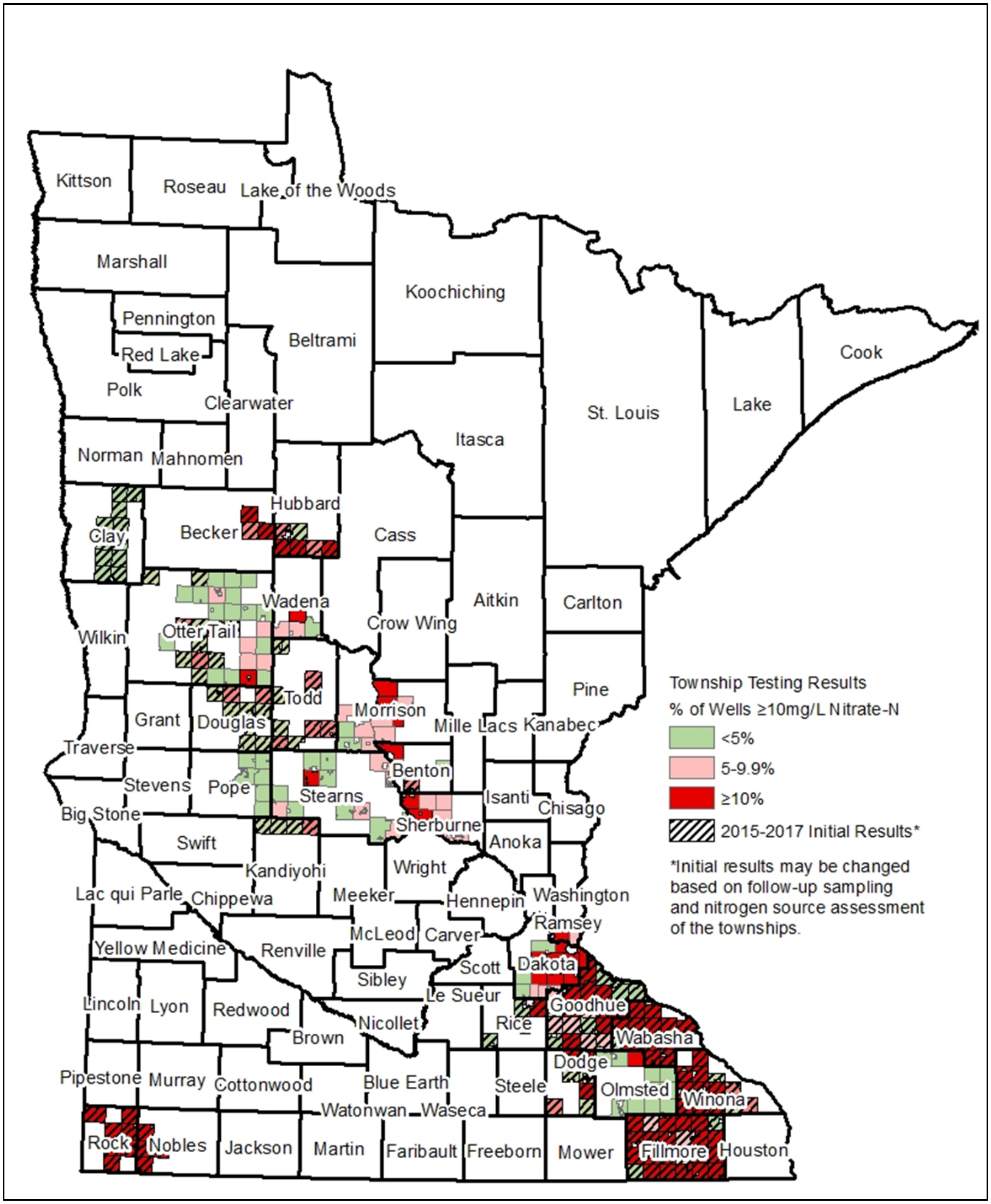


Figure III-3. Percentage wells in each Minnesota Township exceeding 10 mg/L nitrate-nitrogen MDH HRL at initial sampling.

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.

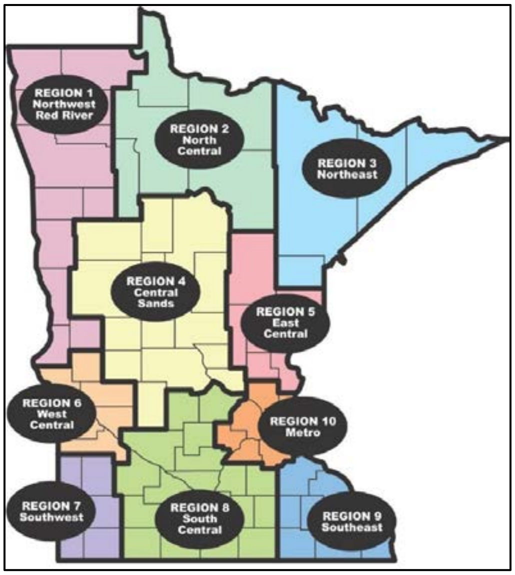


Figure III-4. Minnesota Pesticide Monitoring Regions (NFMP, 2015).

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.

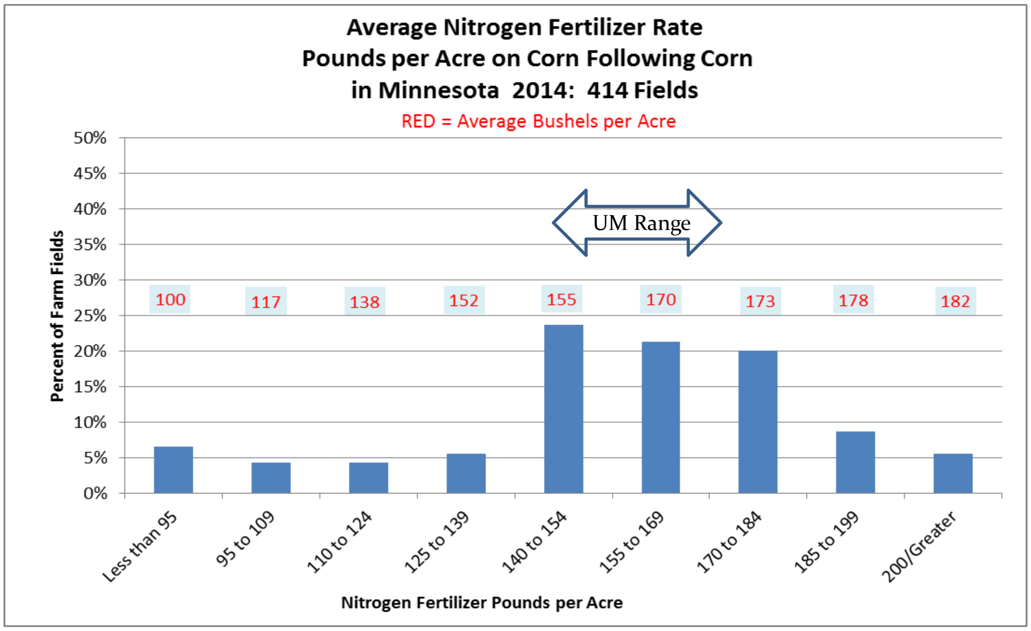


Figure IV-1. Percent fields within U of M recommended nitrogen rate ranges for corn following corn.

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.

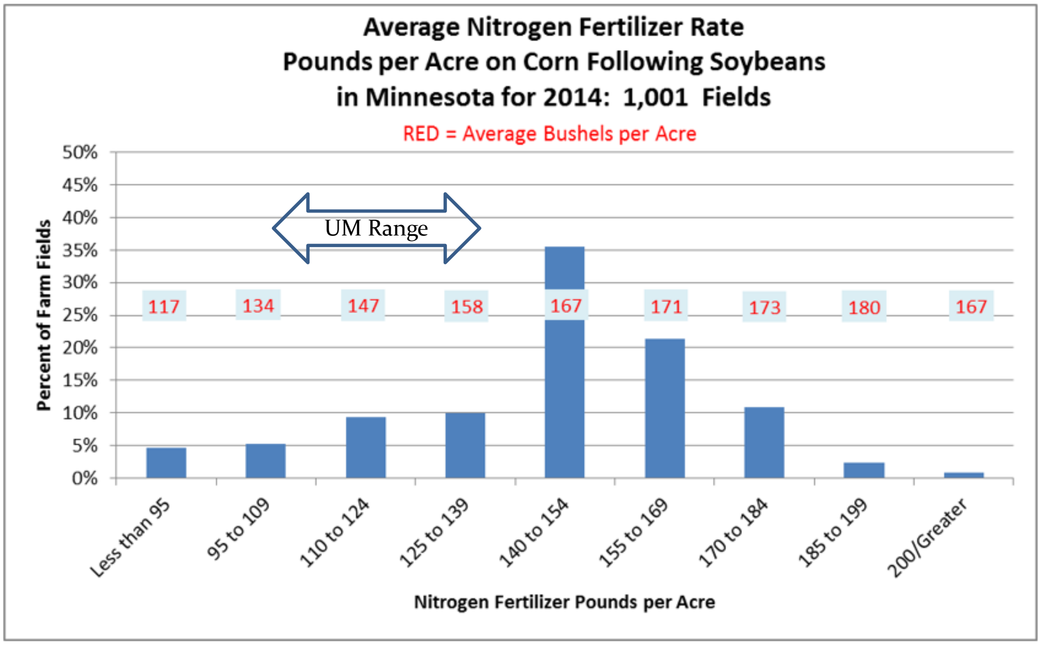


Figure IV-2. Percent fields within U of M recommended nitrogen rate ranges for corn following soybeans.

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).

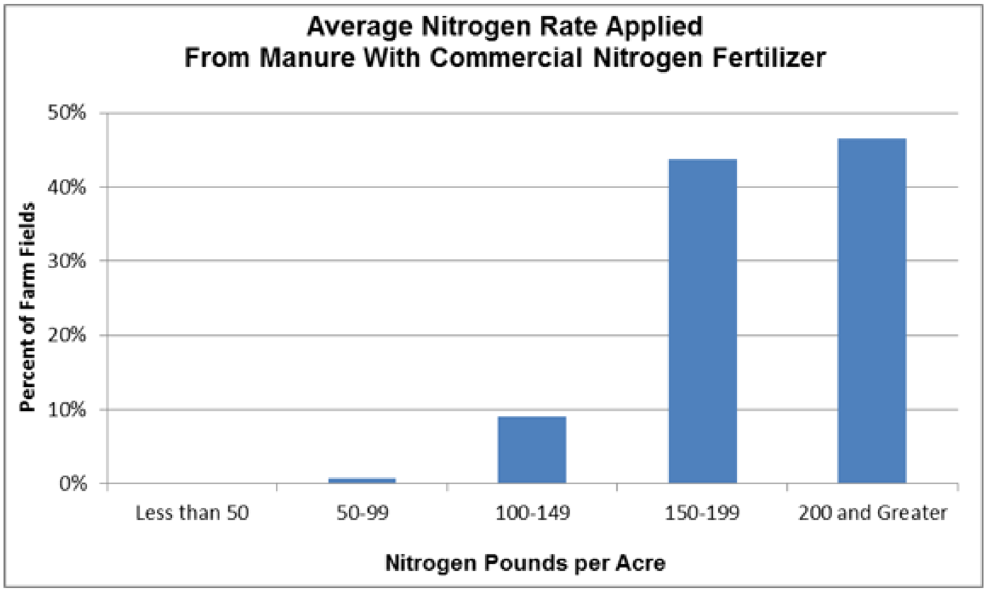


Figure IV-3. Average nitrogen inputs (fertilizer and all forms of manure) statewide.

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).

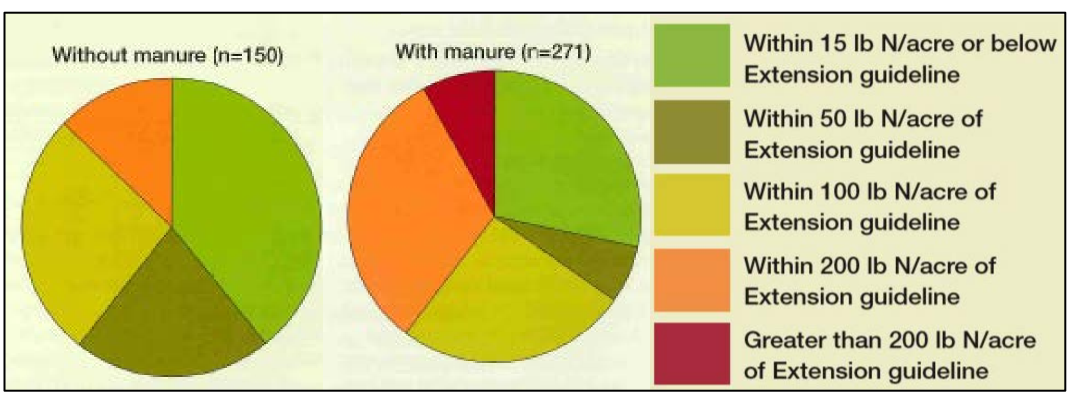


Figure IV-4. Applications of nitrogen fertilizer with or without manure on first-year corn following alfalfa.

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).

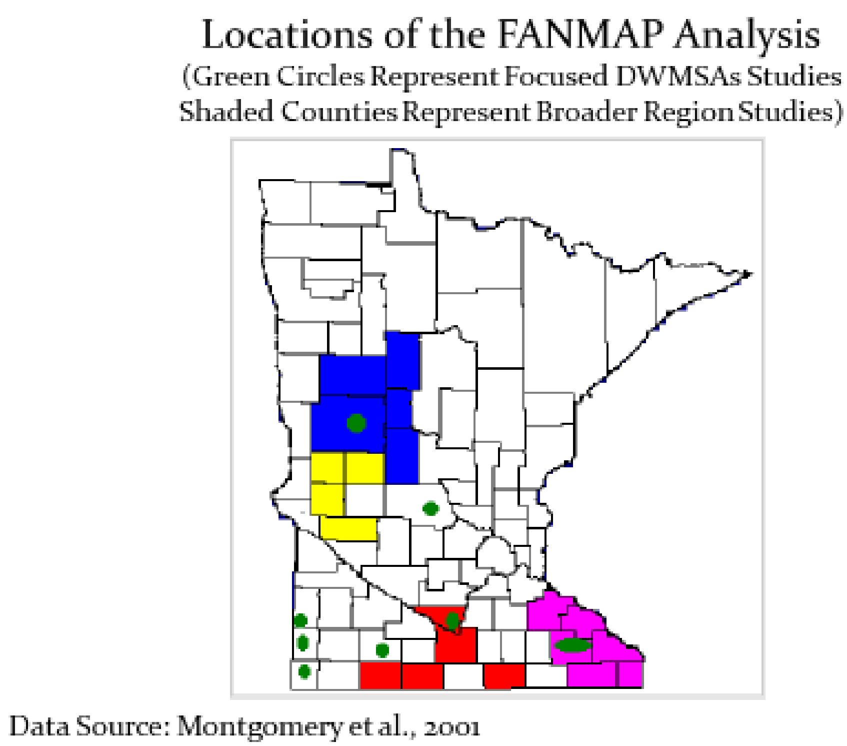


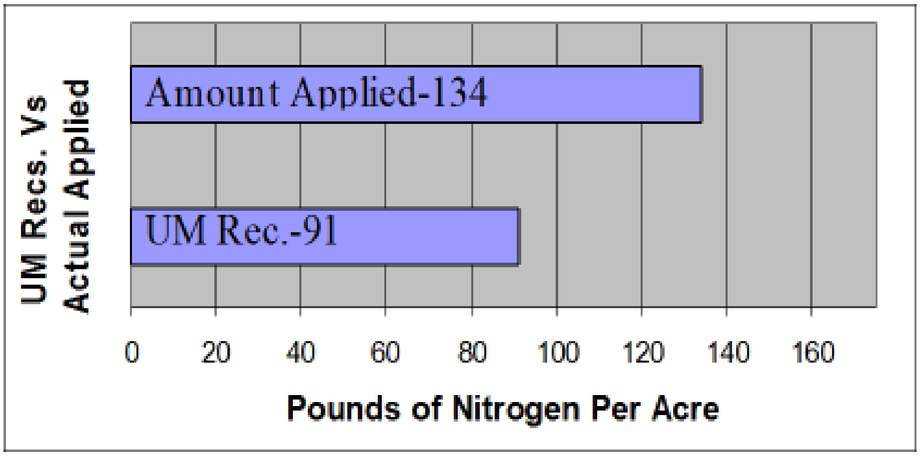
Figure IV-5. Locations of FANMAP Analysis

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

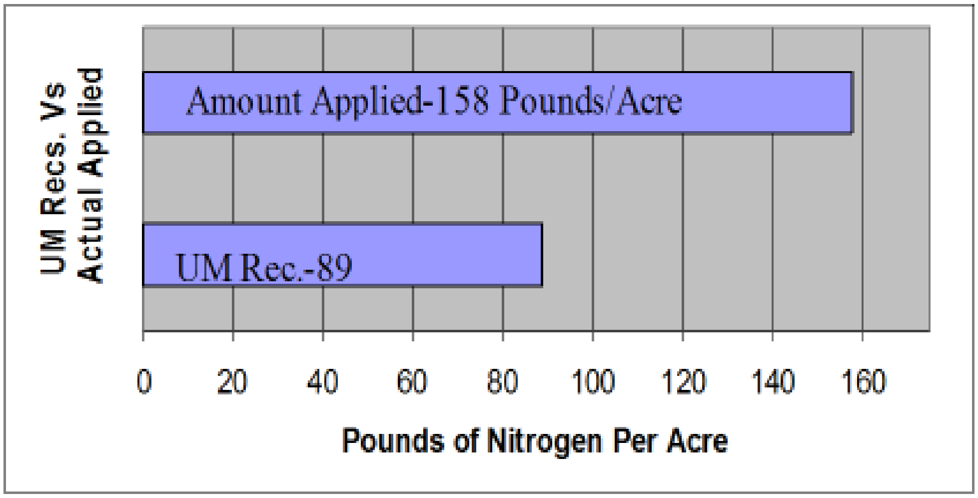


Data Source: Montgomery et al., 2001

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).

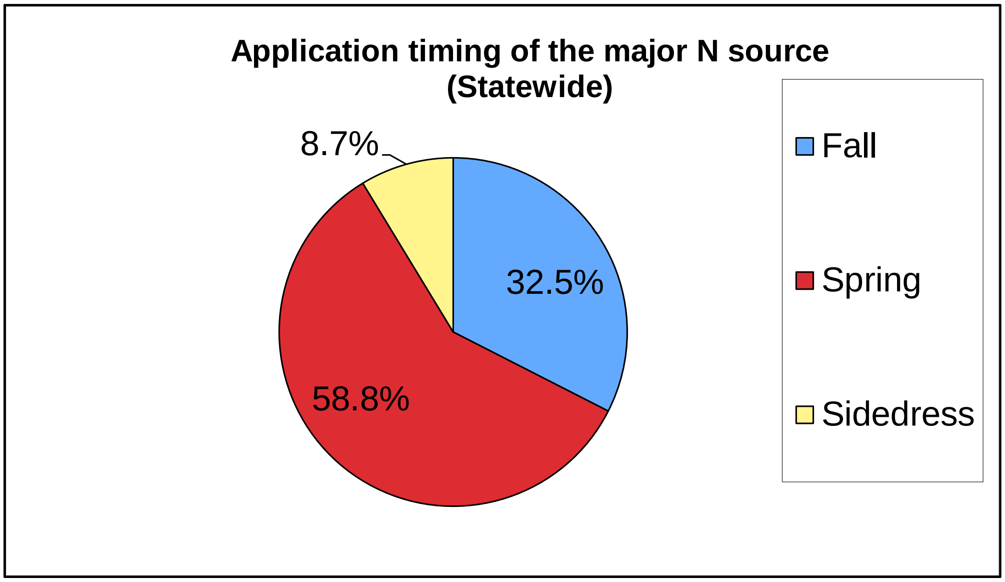


Figure IV-8. Nitrogen fertilizer application (non-manure) timing on corn statewide.

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."

Less Costly

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 Palmer-Denig on Friday, April 20, 2018.

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.

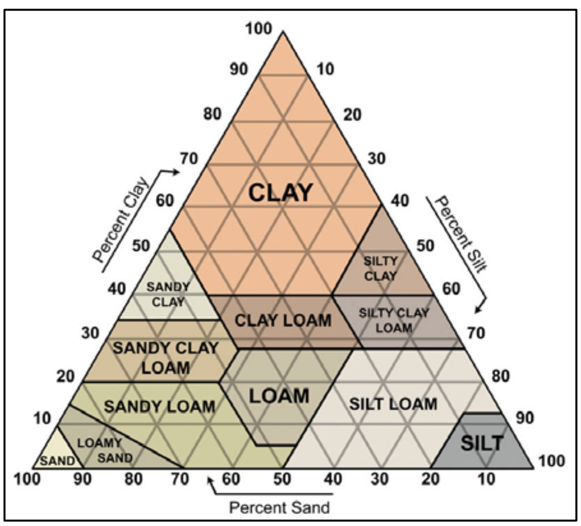


Figure VI-1. USDA soil textural triangle.

- 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 [50^{o}F]." 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:

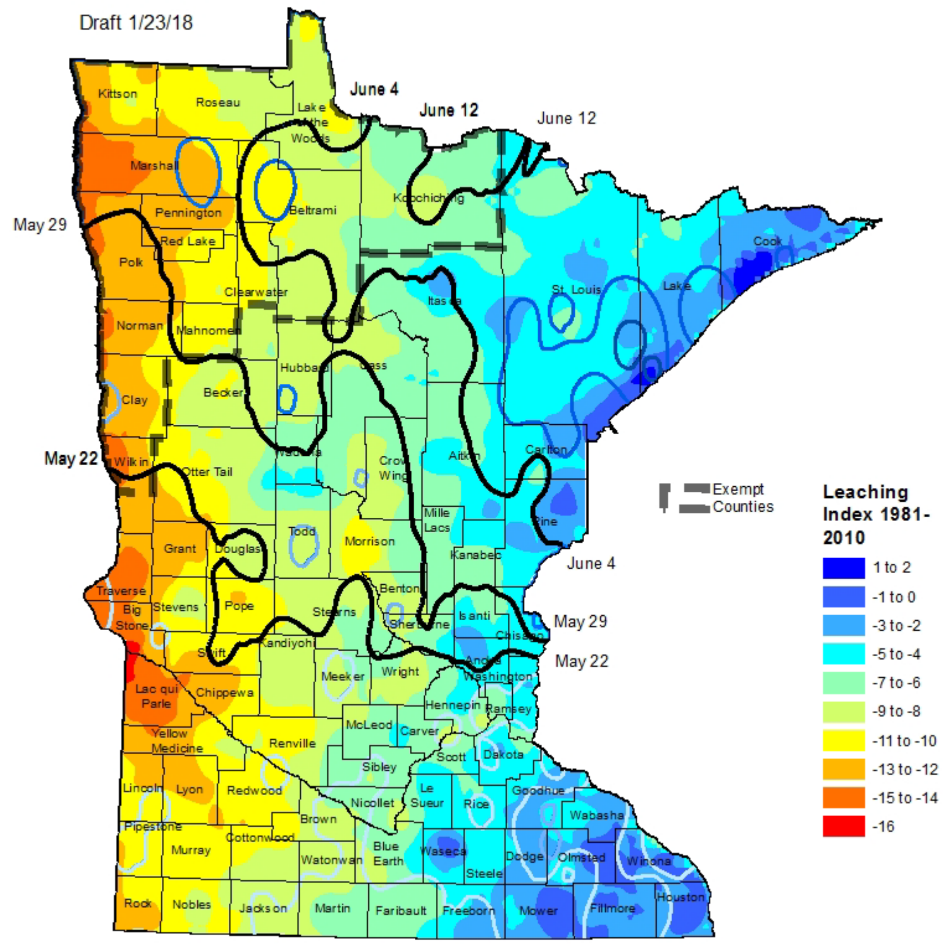
- leaching index
- spring frost-free date

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

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)

Scenario #2: Average Yield Goals (200-219 Bushels) and Medium P Testing Soils

	Phosphorus and Sulfur Source	Phosphorus Approach	Method 1	Method 2	Method 3
	Yield Goal: 200-219		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).

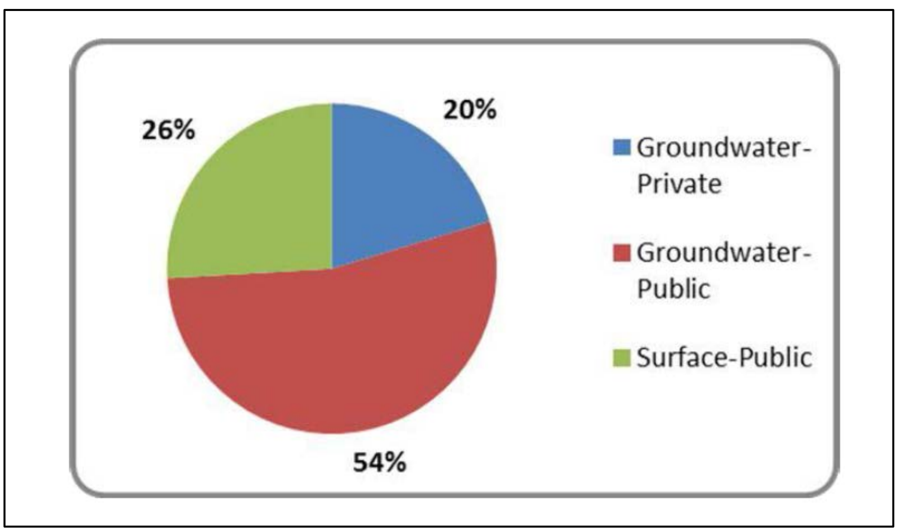


Figure VI-3. Drinking water sources in Minnesota.

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

significant staff time and resources to implement. It is necessary and reasonable to focus the limited staff time and resources on the highest priority DWSMA areas. Through implementation of the proposed Rule in the DWSMAs, the MDA will build the Rule infrastructure and will learn important lessons, such as what land use practices worked, what elements contribute to a successful Local Advisory Team, and if there are parts of the Rule that are more or less difficult to enforce. These learnings can then be applied to a broader geographic area in the future, if circumstances warrant.

The MDA will implement the voluntary parts of the 2015 NFMP in townships up to level 2, including forming LATs and conducting groundwater monitoring. Based on the above, it is reasonable for the MDA to focus its regulatory efforts on DWSMAs and continue with the voluntary approach for townships that was outlined in the NFMP, based on available resources.

MDH's authority governing public water suppliers?

The state's Safe Drinking Water Act (SDWA) was adopted by the legislature in 1977 (Minn. Stat. §§ 144.381-144.387). It authorizes the MDH commissioner to promulgate rules which are no less stringent than federal regulations governing public water supplies (Minn. Stat. § 144.383(e)). This authority was granted by the legislature to allow the state, under the federal Safe Drinking Water Act of 1974 (Public Law 93-523 and amendments thereto), to assume primacy for enforcement of the USEPA safe drinking water regulations.

MDH collects data on public water supply wells which includes nitrate-nitrogen analysis. At a minimum, PWSs are required to submit annual samples. If the wells have exceeded 5.4 mg/L nitrate-nitrogen in the past, then quarterly testing is required in order to more closely monitor, evaluate and identify ways to reduce nitrate-nitrogen concentrations in their water supply.

For purposes of the proposed Rule, the MDA will use the nitrate-nitrogen data collected by the MDH in order to evaluate public water supply wells and their surrounding DWMSAs for mitigation levels. These monitoring results are an 'official record' of groundwater conditions that supply the public well. PWS monitoring has been conducted for many years and hence a relationship between communities and MDH is well established. Using this data for purposes of determining mitigation levels is reasonable because the public water supply monitoring program is firmly established and the additional testing requirement at 5.4 mg/L nitrate-nitrogen is an already established 'action level.' In addition, the value of 5.4 mg/L is used in Part 1 for DWSMAs, therefore it is reasonable to be consistent between both parts of the proposed Rule.

Subp. 2. DWSMA mitigation levels. – Evaluation of nitrate-nitrogen concentrations in groundwater

Nitrate-nitrogen concentration data from public wells

Minn. Stat. § 103H.251, subd. 1(a) directs the commissioner to evaluate the detection of pollutants from agricultural chemicals and practices in groundwater of the state. The statute does not provide details on how this is done, therefore giving the MDA the discretion on how to conduct the evaluation of pollutants. For purposes of public water protection, it is needed for the proposed Rule to use public water supply wells to initially determine the nitrate-nitrogen concentrations in groundwater. This is reasonable because the MDH has conducted annual monitoring in these PWSs over the history of the wells; therefore, in many cases, there is reliable past data available on nitrate-nitrogen concentrations. Subsequent monitoring may continue to use the public well(s) monitoring data or a groundwater monitoring network may be established within the DWSMA for mitigation levels 2, 3 and 4. This approach will yield reliable, accurate results while allowing the MDA flexibility to monitor based on local conditions and allocate its resources appropriately.

Where did the mitigation level criteria come from?
The mitigation part of the NFMP and the proposed Rule is based broadly on a multi-level approach currently in use in the State of Nebraska (Central Platte NRD, 2016). The approach was modified in consideration of the requirements in the Groundwater Protection Act, conditions and data that are Minnesota-specific, and the existing MDH program. The NFMP advisory committee was presented with Nebraska's nitrate groundwater protection activities (including an in-person presentation from University of Nebraska staff) at advisory team meetings in 2011 and 2012. The advisory committee recommended that the MDA develop a phased approach which includes both groundwater monitoring and nitrogen fertilizer BMP adoption criteria, and voluntary and regulatory phases (now called levels). See also MDA, 2014.

There are four levels, two are voluntary and two are regulatory. Each mitigation level in the proposed Rule is designed to initiate actions commensurate with the level of contamination in the source water, or threatening the source water, in the public water supply well. DWSMAs that fall under Part 2 of the proposed Rule will be monitored and will move up or down according to changes in water quality or increases in residual soil nitrate below the root zone which can leach into the groundwater. Factors used for moving within levels include: past nitrate concentrations, the length of time of past public well monitoring, projecting future nitrate concentrations, residual soil nitrate below the root zone, and the adoption of nitrogen fertilizer BMPs. (These are discussed in greater detail below). A DWSMA will always start in a voluntary level and will only progress to a regulatory level if the voluntary approach is unsuccessful either because the nitrogen fertilizer BMPs are not being adopted or groundwater monitoring or soil sampling data indicates that nitrate levels are increasing. DWSMAs may only move up one mitigation level at a time. For example, a DWSMA will never go from mitigation level 1 to mitigation level 3 in a single cycle. (see also Subp. 10)

Initial designation of mitigation levels 1 and 2
The initial designation of mitigation levels 1 and 2 is necessary and reasonable for several reasons. The NFMP, published draft rule and proposed Rule follow the overall intent of and are necessary under the Groundwater Protection Act (Minn. Stat. chap. 103H). Prevention and

implementation must be conducted within a voluntary framework until there is adequate information to provide feedback that the voluntary efforts are not effective in addressing nitrate concerns. The evaluation of monitoring results of the public water supply wells will be used by the MDA to initially designate an area as mitigation level 1 or 2. Mitigation levels 1 and 2 are voluntary levels with no immediate regulatory components. These voluntary levels are meant to encourage farmers to adopt nitrogen fertilizer BMPs and other nitrogen management practices and make changes on their own, without regulation. The MDA will always start the process at either a mitigation level 1 or 2 based on monitoring results. This approach was supported by the NFMP advisory committee, comments received during the NFMP public comment period, request for comments on the proposed rule and the summer 2017 comment period for the draft rule as well. Farmers are always given the chance to voluntarily comply with the nitrogen fertilizer BMPs and other practices (as recommended by the LAT). If they choose not to voluntarily adopt nitrogen fertilizer BMPs for level 2 sites, the MDA will proceed to a regulatory level. For these reasons, the initial designation is reasonable.

The approach is designed to prevent and minimize nitrate-nitrogen concentrations in groundwater to the extent practicable and to prevent pollution from exceeding the health risk limits as directed in Minn. Stat. § 103H.275, subd. 1(c) by working with local farmers and their agronomists to evaluate, promote, and adopt practices that are able to reduce nitrate-nitrogen concentrations in groundwater. The approach starts in a voluntary step because, based on the NFMP advisory committee discussions, the approach likely will be more effective if it is voluntary. This will be done through the formation of a local advisory team (LAT). It was noted that if local farmers and their agronomists are actively consulted and become committed partners in trying to address local nitrate concerns, they will have a much greater potential for solving the problem than any other group. Most farmers live in or near the communities that are experiencing nitrate problems and are concerned about protecting water quality. They control the land and have the ability to manage and change the use of the land in a manner that will be far more effective and efficient in reducing nitrate leaching than is the likely outcome of a purely regulatory approach. The goal of the plan and proposed Rule is, in part, to create a formal approach and structure to facilitate that engagement process. However, the proposed Rule and the specific actions outlined in the proposed Rule are necessary in the event that the voluntary approach is not successful and to outline a clear set of expectations regarding what performance-based outcomes are required before a regulatory action is justified and necessary.

The mitigation process in the proposed Rule has been designed to increase the level of response activity as the water quality gets worse in a manner commensurate with the nitrate pollution as directed in Minn. Stat. § 103H.275, subd. 1(b). It is also designed to be integrated in a practical manner with existing MDH source water protection strategies and regulations. The use of monitoring data, regulatory boundaries, and action level criteria all are based to a large extent on the existing MDH source water protection program. It is necessary for the MDA to determine regulatory boundaries and action levels in order to create an effective proposed Rule. It is reasonable for the MDA to align our regulatory process and guidance with the existing program requirements in order to prevent the inefficient duplication of efforts and in order to take advantage of the extensive amount of effort which has already been dedicated to protecting public water supplies.

Subp. 3. Criteria for initial mitigation level designation

The initial level designation will be based on the nitrate-nitrogen concentration from public water supply wells. The initial level designations are designed to prioritize DWSMAs based on the risk to human health from elevated nitrate. The MDA will continue to work on education and implementation activities in mitigation level 1 DWSMAs and will continue to evaluate nitrate-nitrogen concentrations from the public water supply wells but will not establish monitoring networks in mitigation level 1 DWSMAs. Mitigation level 2 DWSMAs are areas where nitrate-nitrogen concentrations are at or exceed 8.0 mg/L or have been at or exceeded that concentration at any point during the previous 10 years, or are projected to exceed the 10 mg/L MDH HRL within the next ten years. Farmers and their agricultural advisors are provided the opportunity to engage in local work groups to decide and implement local solutions before regulations are necessary. This is a reasonable approach, using objective data and making progressive decisions based on that data.

Subp. 3. Criteria for initial mitigation level designation. A. (1) – Mitigation Level 1

For a mitigation level 1 designation, a threshold concentration of 5.4 mg/L nitrate-nitrogen was selected because it is the concentration under which the MDH, as the lead state agency implementing the federal Safe Water Drinking Act, (Minn. Stat. § 144.381-144.387) requires more frequent monitoring of a well because of the potential for increased health risk due to elevated nitrate-nitrogen concentrations.

Mitigation level 1 is voluntary. However, a mitigation level 1 designation provides notice to the local agricultural community and others within a DWSMA that the source water to the well and groundwater within the DWSMA have significantly elevated concentrations of nitrate-nitrogen and require immediate increased attention and care to nitrogen management practices. This is reasonable because it uses an existing and established guideline for action. For mitigation level 1 DWSMAs the MDA will seek to work with the local agricultural community to increase protective actions, including nitrogen fertilizer BMP adoption, and promotion and funding for implementation of AMTs, within the DWSMA.

Mitigation level 1 DWSMAs will continue to be monitored through the MDH’s programs. If nitrate-nitrogen concentrations increase and meet the requirements for a mitigation level 2, the MDA will reevaluate and re-designate the mitigation level of the DWSMA.

Subp. 3. Criteria for initial mitigation level designation. A. (2). – Mitigation Level 2

A DWSMA will initially be placed in mitigation level 2 if the source water has met or exceeded a concentration of 8.0 mg/L nitrate-nitrogen at any time during the previous 10 years or if the projected trend of the source water nitrate-nitrogen concentrations will exceed 10 mg/L within 10 years. These criteria are necessary because some clear benchmarks are needed to determine when the nitrate concentrations are increasing such that increased actions are required commensurate with the nitrate contamination and to prevent the water quality from exceeding the MDH HRL as directed in the Groundwater Protection Act. They are reasonable because they are appropriate indicators that there is an increasing risk that the source water for the public water supply well may exceed the MDH HRL. They were selected specifically to provide for increased response actions before the source water for a well exceeds the MDH HRL.

The concentration of nitrate in groundwater can vary significantly in a well based on a number of factors. For shallow wells or wells constructed in areas with karst geology, the nitrate concentrations in groundwater can vary rapidly over short periods of time due to rapid travel times through the aquifer (Runkel et al, 2014, Steenberg et al, 2014). For deeper wells or wells in slightly less vulnerable aquifers concentrations tend to change at slower rates. Nitrate concentrations in groundwater can also change in response to changes in land use, for example, a significant increase or decrease in the number of acres planted to a high nitrogen using crop like corn, or because of adverse weather which can affect the rate of nitrate leaching. Because of the range of possible situations considering well construction, hydrogeology, land use and weather, the MDA selected indicators for a level 2 determination which are applied over a long period of time. A single detection of nitrate-nitrogen over 8 mg/L at any time over the last 10 years or a projected increase in nitrate-nitrogen concentration to over 10 mg/L over the next 10 years should provide sufficient notice that the source water is at risk and additional actions are needed to prevent the source water from exceeding the MDH HRL of 10 mg/L.

The criteria in the proposed Rule changed from the previous draft and the NFMP by reducing the benchmark from 9 mg/L nitrate-nitrogen over the previous 10 years to 8 mg/L nitrate-nitrogen over the previous 10 years. MDA concluded that this change was needed and reasonable to provide an increased margin-of-safety to take action before source water might exceed the MDH HRL. This change represents moving from an action level that was 10% below the MDH HRL to one that is 20% below the MDH HRL, for a single sampling event.

The proposed Rule requires that the projected increase in nitrate-nitrogen concentrations to greater than 10 mg/L over 10 years be based on a statistical analysis. The statistical trend analysis is reasonable because this is a standard practice already used to evaluate trends in data (generally and specifically water quality trends). Statistical analysis is a rigorous evaluation, using scientific methodology to arrive at results that are highly reliable. The analysis of monitoring data is described in this SONAR, 1573.0040, Supb. 5. Monitoring.

Moving to mitigation level 2 will initiate several actions to address the nitrate-nitrogen concentration concern. These include, most importantly, the formation of a LAT including local farmers and their agronomists to advise on appropriate nitrogen fertilizer BMPs and AMTs to reduce nitrate levels in groundwater. These actions are described in other places in this SONAR.

Subp. 3. Criteria for initial mitigation level designation. B. – Exceptions

The proposed Rule allows the Commissioner to make exceptions for increasing the mitigation level designations for non-municipal public water supply wells. These exceptions might be for one or more of the following reasons:

1. whether there has been a significant change in the amount of land used for agricultural production within a drinking water supply management area;
2. the severity of the nitrate-nitrogen concentration found in other wells in a drinking water supply management area;
3. the population affected by the groundwater contamination of nitrate-nitrogen; and
4. other factors expected to influence nitrate-nitrogen concentration.

Non-municipal community wells serve at least 25 year-round residents or 15 service connections used by year-round residents and are privately owned. They might include nursing homes, mobile home parks, or housing developments. There are about 260 such wells in Minnesota. They typically have much lower capacity (lower pumping rate) wells compared to municipal systems. Because of the low capacity wells, the DWSMA might be very small – on the order of a few hundred acres or less. Many of these systems do not currently have DWSMAs delineated by the MDH, but MDH staff have indicated they plan to develop DWSMAs for the systems that are located in areas with vulnerable groundwater (Steve Robertson, MDH Supervisor, personal communication).

Although these systems are small in scale, they may involve a significant amount of MDA staff work to implement the proposed Rule within them. These exceptions were included in the proposed Rule to allow the MDA to prioritize work with the larger systems which are the most contaminated and serve the largest population being addressed as a higher priority than smaller systems with a smaller served population and less nitrate-nitrogen contamination. In addition, the exceptions allow the commissioner to consider changes in land use that can be especially significant for small DWSMAs. An example would be a nursing home on the edge of a town where the land in the DWSMA is being developed and converted from cropland to residential housing. The exceptions also allow the MDA to consider other factors because of the potential for unusual situations that can occur but are difficult to fully predict.

This provision in the proposed Rule is necessary because it allows the MDA to prioritize work in a practical manner if there are insufficient staff resources to address all of the community water systems with elevated concentrations of nitrate-nitrogen at one time, or if actions in the DWSMA are unlikely to improve water quality because of changes in land use or for other reasons. It is reasonable because it is anticipating situations that might realistically occur, it will ensure that staff resources are used efficiently by working on those areas that pose the greatest risk first, and because the MDA has professional staff able to exercise good judgement when allowing exceptions to the mitigation level criteria for smaller non-municipal water systems.

Subp. 3. Criteria for initial mitigation level designation. C. – Point Sources of Pollution

As stated in the SONAR for 1573.0030, Subp. 2. F., in some cases, elevated nitrate levels within DWSMAs are due to point sources of nitrogen. Examples of point sources may include but are not limited to an improperly sealed well, animal feedlot or an agricultural chemical incident. This exclusion is needed and reasonable since it is clearly inappropriate to consider any mitigation actions, especially regulations, for nitrogen fertilizer if the source of the contamination in the public well is not related to the use of nitrogen fertilizer.

Subp. 3. Criteria for initial mitigation level designations. D. - Partial Exclusions Due to Low Risk

The commissioner may exclude part of a drinking water supply management area from a level designation 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 the level determination and subsequent requirements in the rule.

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 DWSMAs 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, land features, and groundwater vulnerability such that some parts of the DWSMA may not be contributing significantly to high nitrate-nitrogen concentrations in the public well.

This provision is necessary to ensure that the commissioner does not implement surveys, install monitoring wells, promote practices, and potentially impose regulatory requirements and related costs in areas where these activities 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 certain practices uniformly across a DWSMA including in areas where they may provide limited environmental benefits would not meet this requirement.

Subp. 4. Determination of nitrogen fertilizer best management practices and mitigation levels. A. – Determination of BMPs and LATs.

Determination of nitrogen fertilizer BMPs for each DWSMA?

The U of M nitrogen fertilizer BMPs are developed and promoted as general guidance for the majority of the soils, climate conditions and crops found in the each of the five BMP Regions. Frequently localized conditions can be considerably different requiring site specific recommendations. In many DWMSAs, the unique conditions are frequently much more conducive for nitrogen leaching. Many of the DWMSAs already identified having elevated nitrates are frequently those with significant acres comprised of coarse texture soils or thin mantles of loamy soils underlain by sands and gravels. For these reasons, the local advisory teams (LATs), in partnership with experts from the U of M and the MDA will be helpful in recommending the most appropriate practices.

A primary goal of the NFMP and the proposed rule is to create a process which encourages local farmers and their agronomists to learn about and adopt the most current and effective practices and technologies that will help reduce nitrate contamination in highly vulnerable groundwater areas. The use of LATs is intended specifically to accomplish that goal.

Local advisory team

When a DWSMA is designated as a mitigation level 2, it indicates that additional monitoring and education/promotion activities need to begin. After a DWMSA is designated in mitigation level 2 status, a very important step is the establishment of a local advisory team (LAT). The purpose of LATs will be to make recommendations to the commissioner about the appropriate nitrogen fertilizer BMPs and AMTs that should be used in the DWSMA While the formation of the LAT in a mitigation level 2 is not mandatory, it is desirable because the LAT can help develop and implement locally viable solutions to address elevated nitrate-nitrogen concentrations. The LAT will be critical to advising the MDA on designing educational aspects including field demonstrations, the Nitrogen Smart training program (U of M Extension/Minnesota Corn Growers) and other outreach approaches.

The LAT will consist of people who are from the area, including farmers, representatives of local groups/organizations, public water supply systems, and government staff and/or professionals who can provide technical or financial support. The majority of members will be local farmers and their crop advisors/consultants. The size and composition of the team will vary depending upon the size of the area, the nature of the problem and availability of local stakeholders; however, it will likely be no more than 15 -20 people. The MDA will develop guidance that outlines the roles and responsibilities of the LAT.

Local farmers and their crop advisors/consultants are critical in helping develop and implement appropriate activities to address elevated nitrate in their groundwater because they control the land use. The mitigation strategy is constructed specifically to involve the local agricultural community in problem solving with the opportunity to avoid regulations if voluntary actions are taken.

LAT decisions will not be determined by majority vote, but rather the team will seek consensus and common ground. The team will advise the MDA in an open process. All members' comments and recommendations will be considered. The MDA will be responsible for final determinations of potential regulatory actions and will seek to provide consistency in decision making for similar situations/areas.

In addition, the MDA believes LAT members know their local area the best, and therefore are best able to determine what will work locally. The MDA acknowledges that a 'one size fits all' approach is not ideal. Instead, the LAT is a reasonable and better alternative to find local solutions to address nitrate in groundwater. During the summer 2017 comment period, there were significant comments supporting the formation and use of LAT to address local nitrate in groundwater issues.

Subp. 4. Determination of nitrogen fertilizer best management practices and mitigation levels. B. – Notice.

Legal notice of proposed and established commissioner's orders is required in Minn. Stat. § 103H.275, subd. 2. Providing legal notice is a balance between providing adequate and appropriate notice to affected parties, but not creating an undue burden (time and expense) to the regulator in providing this notice. Use of a local legal newspaper is a reasonable alternative for the larger DWMSAs. Due to the limited number of producers in many of the smaller DWMSAs, the MDA will contact the landowners, operators, and dealerships directly if they are known. If not, the MDA will publish the water resource protection requirements in two consecutive issues of the legal newspaper.

In addition, it is reasonable to provide other options to provide notices of proposed Rule actions. The agency website is a reasonable option because this is a likely location where individuals impacted by the proposed Rule will go to find more information.

Supb. 5. Monitoring. A and B – Public wells and groundwater monitoring networks

The primary monitoring point for water quality in a water supply well is the raw (untreated) water pumped from the well. This is the source of nitrate-nitrogen concentration data that will be used to evaluate if the source water has exceeded the water quality thresholds used for mitigation level determinations and for assessing if nitrate concentrations are projected to exceed 10 mg /L within a 10-year period. It is reasonable to use this data for decision making since it is the actual water being provided for use by the public water supply system and it is the point where monitoring is conducted under the direction of the MDH.

Public wells

Historical nitrate data provided by the MDH from the water supply well(s) will be evaluated to estimate future nitrate concentration in the well(s). This analysis will use the most recent 10 years of nitrate-nitrogen concentration data provided by the MDH to project future nitrate-nitrogen concentrations. Using regression techniques, the future nitrate-nitrogen concentration in the well(s) will be projected to determine if the concentration is likely to exceed the MDH HRL within ten years.

When a groundwater monitoring network is established within a DWSMA, the groundwater nitrate-nitrogen concentration data will be evaluated after a minimum of three growing seasons or the estimated lag time, whichever is longer. A statistical analysis will be performed to assess change in the nitrate-nitrogen concentration by comparing pre-and post-implementation periods for nitrogen fertilizer BMPs. Changes will be assessed using the 90th percentile concentration from nitrate samples collected from the groundwater monitoring network. It is anticipated that the 90th percentile concentration will generally indicate changes in the nitrate-nitrogen concentration distribution sooner. The statistical significance of change in the 90th percentile concentration will be determined utilizing a 90% confidence level ($p < 0.10$).

It is necessary and reasonable to use statistical methods to evaluate changes in water quality data which sometimes includes considerable variability in the data. Statistical analysis will provide robust analysis of the groundwater nitrate-nitrogen concentration data (from public wells and the groundwater monitoring network – if applicable) to ensure confidence in the results. It is reasonable to consider and use statistical methods that have been developed for this purpose.

The MDA hired a national expert in statistical analysis of groundwater monitoring data to provide guidance on the groundwater monitoring network design and the interpretation of groundwater monitoring data. (Comments on statistics of the conceptual design, the five assumptions of network design, and the seven statistical questions in the Township Nitrate Monitoring Scope of Work, July 2017). Statistical analyses such as those suggested by Dr. Helsel provide a basis for evaluating change in nitrate-nitrogen concentration within the DWSMAs. Dr. Helsel outlines a variety of statistical analyses that can be used to evaluate changes in concentrations over time. These methods will be evaluated to determine which would be the most appropriate for the data being assessed.

Groundwater monitoring network

The MDA may also conduct monitoring to evaluate the effectiveness of nitrate reduction practices in two other ways, through the installation of a groundwater monitoring network within the DWSMA or through monitoring of residual soil nitrate below the root zone. Both of these approaches to monitoring can be used to determine if nitrate levels are increasing or decreasing in the DWSMA.

The MDA may install a groundwater monitoring network to evaluate if the nitrate-nitrogen concentrations are increasing or decreasing across the DWSMA. This is reasonable because a DWSMA is defined as the area that contributes water to a pumping well over a period of 10 years. That means it will take 10 years for groundwater to travel from the boundary of the DWSMA to the pumping well. As such, it would take a minimum of 10 years for changes in practices across the entire DWSMA to be reflected in the water quality in the pumping well. A groundwater monitoring network can be designed and installed to evaluate changes in water quality in the upper portion of the aquifer, at multiple locations within the DWSMA. This will reduce the amount of time required to measure changes in water quality associated with practices that have been implemented at the land surface. This approach is reasonable since the network will be specifically designed to provide an accurate assessment of changes in water quality across the agricultural areas of the DWSMA and will reduce the time required to evaluate those changes. The groundwater monitoring network data will not be used to determine if source water in the DWSMA meets water quality thresholds in the public water supply well, because it is not directly representative of the water supply well. The pumping well may be screened at different depths in an aquifer or in different aquifers and nitrate-nitrogen concentrations can change with increasing depth in an aquifer. Therefore the monitoring data in the public well is not directly comparable to the water quality measured in the shallowest portion of the aquifer.

The wells in the groundwater monitoring network will be constructed to evaluate the water quality in the upper portion of the shallowest aquifer. The groundwater monitoring network will specifically target row crop agricultural areas to assess changes in water quality as a result of changes in agricultural and land management practices within the DWSMA. The groundwater monitoring network will meet the minimum requirements for statistical analysis and may include a variety of well types (monitoring wells, temporary monitoring wells, domestic wells), provided each of the wells meet the specifications and requirements for the monitoring network. The requirements could include but are not limited to: well depth, construction, age, screen length, and well access.

If a groundwater monitoring network cannot be installed, changes in water quality can still be evaluated for regulatory decision making using water samples collected at the pumping well following a period of time equal to the lag time plus the groundwater travel time within the DWSMA.

Subp. 5 Monitoring C. – Residual soil nitrate tests

Residual Soil Nitrate Tests

Researchers routinely examine residual soil nitrate levels while developing and evaluating new nitrogen fertilizer management practices. If application rates exceed crop consumption or if other management changes (such as timing or source) result in reduced fertilizer recovery, the efficiency of the imposed practices can be evaluated through examining the nitrate levels remaining in the soil profile upon crop termination. Quantifying residual soil nitrate levels is an important metric because it is this fraction of the overall nitrogen inputs that has a high probability of escaping through the soil and eventually reaching groundwater supplies. Generally, soil scientists monitor the root zone or directly below the root zone using this technique.

Besides using standard groundwater monitoring approaches, the MDA also considered employing two soil sampling procedures used in Nebraska to evaluate changes in shallow "residual" soil nitrates levels: shallow residual soil nitrate monitoring and deep residual soil nitrate monitoring. In both Nebraska techniques, the idea is to determine if the potential for nitrogen loading is changing without having to wait for the groundwater to respond. Inorganic nitrogen is analyzed by depth increments providing valuable quantitative values on the nitrogen amounts in transport to the water table. Subsequent resampling provides critical information on the rate which the nitrogen is moving and if improvements over time are being achieved. The two different Nebraska approaches are described below.

Shallow Residual Soil Nitrate Monitoring

In a number of nitrate-impacted areas of Nebraska, farmers are required to provide three-foot soil samples annually from each field which grew either corn, potatoes or sorghum. Ferguson (2015) examined forty years of soil testing (0 to 3') results from the Central Platte Natural Resource District and determined that a strong correlation existed between the residual soil nitrate levels and nitrate-nitrogen concentrations of the underlying shallow groundwater in areas of coarse-textured soils. This is important because it provides strong evidence that Nebraska's approach for addressing elevated nitrate-nitrogen concentrations in groundwater is working and the timeframe for seeing measurable improvements is better understood.

Canadian researchers have also used nationwide residual soil nitrate information from shallow sampling over time to make policy decisions related to fertilizer use efficiencies and groundwater implications (Yang et al., 2007; Drury et al., 2007).

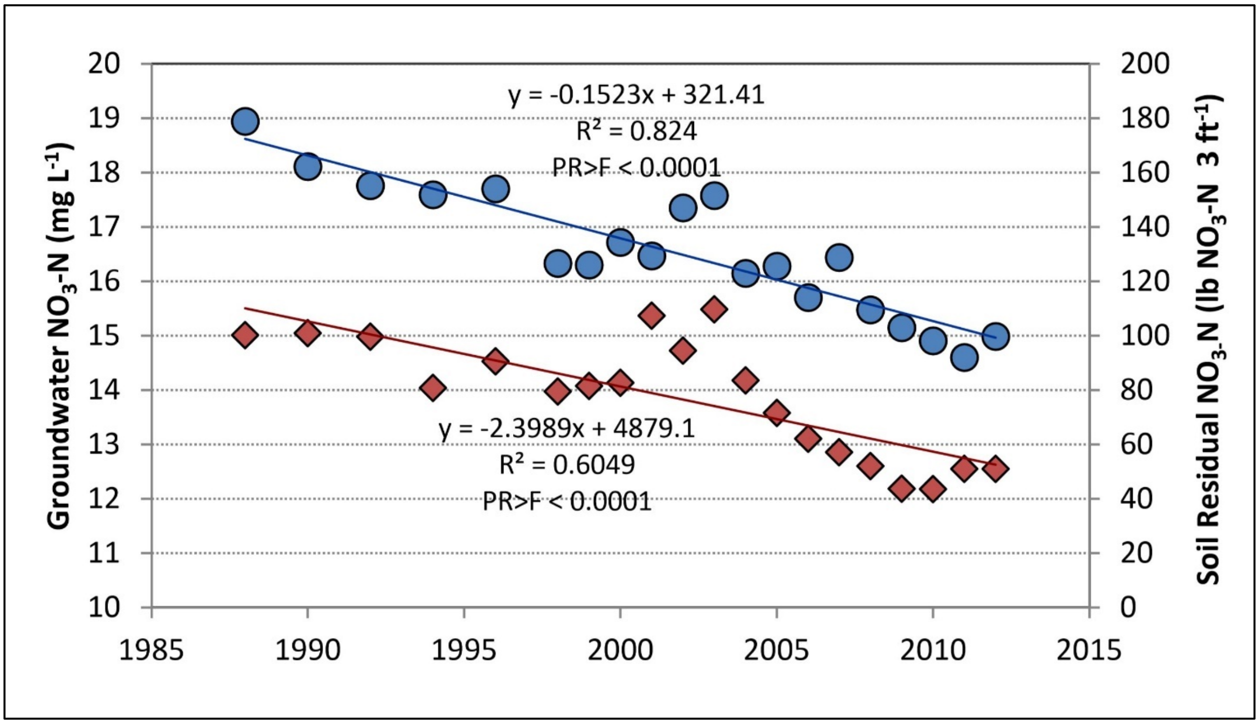


Figure VI-4. Relationship between nitrate-nitrogen in soil and shallow groundwater.

Deep Residual Soil Nitrate Monitoring

Some regions of Nebraska have very deep soils ranging from loams to clay loams. The estimated lag time (the travel time for nitrogen applied to the soil surface to the time it enters the groundwater) is frequently measured in decades. University of Nebraska scientists have experimented with the concept of using deep soil coring information (60 to 100 feet) in order to better understand the nitrogen inventory and the travel speed to groundwater. Routine groundwater monitoring in these types of environments can be greatly enhanced with the associated time lags.

Shields et al. (2017) summarized a number of previous related research projects which established a small number of study sites in the 1990s. The original researchers found that there were very high amounts of inorganic nitrogen (frequently over 1,000 lb. /acre) between the crop zone and the water table. Much of this excess nitrogen is believed to be from poor fertilizer and water management practices used in the 1970s. In the recent re-sampling, Shields determined that nitrogen was traveling at a rate of approximately 29 inches/year. **Error! Reference source**

not found. (Shields and Snow, 2017). Figure IX-5 illustrates a soil coring down to 80 feet at two different time intervals. After twenty years of nitrogen and water management outreach and regulations, this data suggests some drastic reductions in nitrate leaching losses.

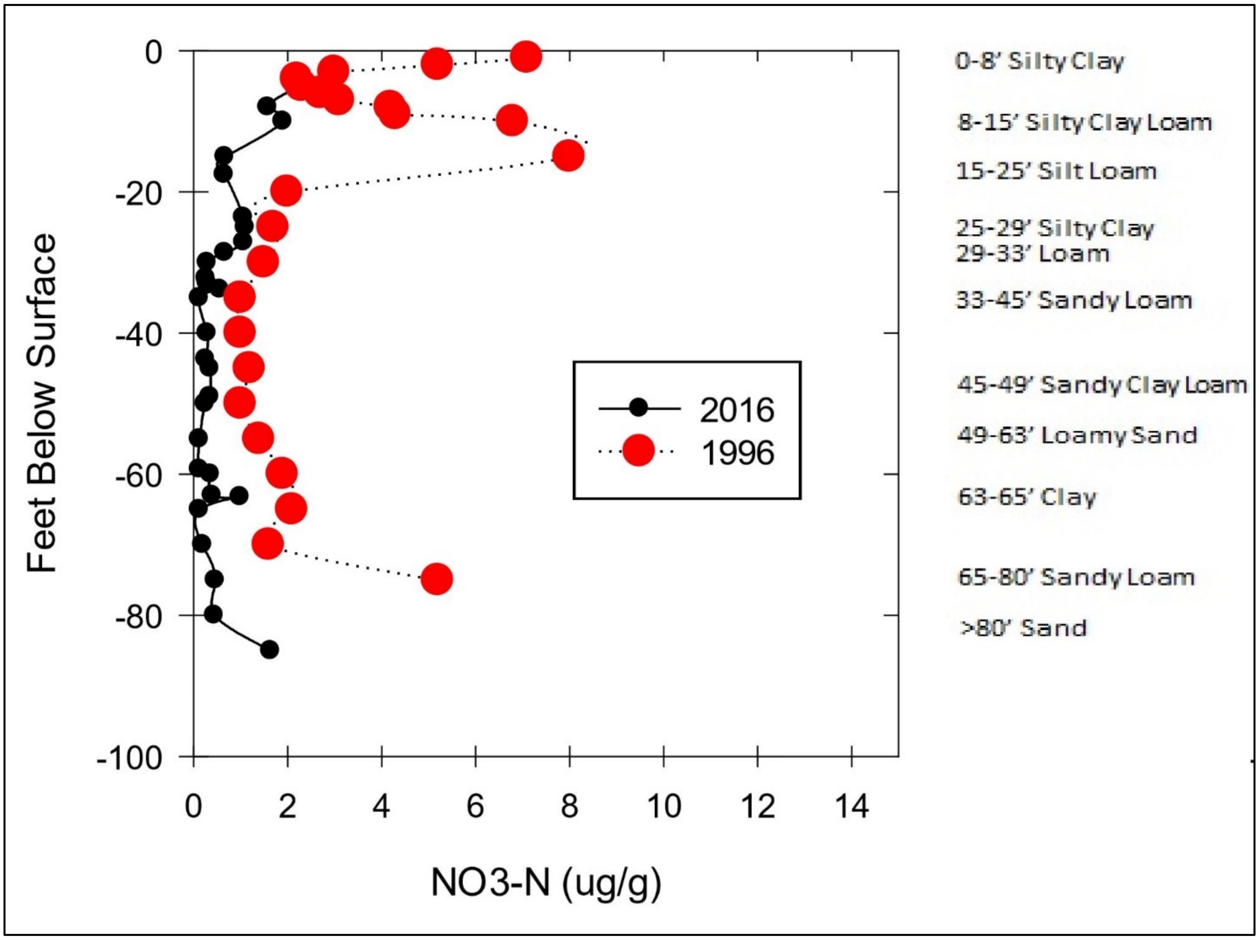


Figure VI-5. Deep soil nitrate coring and lag time to assess nitrogen and water management outreach and regulations.

Implications of the Residual Soil Nitrate Test for the proposed Rule

Use of the shallow residual soil nitrate test provided very good feedback for the Nebraska regulatory process. As previously mentioned, it worked in areas where the soils were coarse textured and the lag times where short because of shallow depth to groundwater. However, this method imposes some burdens: all Nebraska farmers in certain areas with elevated nitrates are required to provide shallow soil test results annually on fields receiving nitrogen fertilizer, and they are required to bear that additional cost. In addition, this testing requires access to a large number of acres. For this reason, the agency chose not to include this method in the rule, but it may be useful in some voluntary responses under the NFMP such as for townships with elevated nitrate.

The deep soil sampling method, the second approach used by the University of Nebraska, provides an accurate and useful approach and is included in the proposed Rule. In regions of the state where groundwater is located at much greater depths, it may be cost prohibitive to install monitoring wells. Similar to the Nebraska approach, deep soil samples would be obtained to establish a baseline inventory of the amount of inorganic nitrogen which has accumulated between the root zone and close proximity to the water table. Borings would be collected early in the Mitigation Level 2 process and then resampled on a predetermined sampling cycle. The number of sampling sites could be limited within the DWMSAs where this approach is used depending on available resources. MDA and the LATs would need to designate a small number of representative fields where the technique would be used.

This technique will provide useful metrics in terms of the initial levels of nitrogen currently in transport to the water table. The nitrogen levels should be reduced over time with improvements in nitrogen management practices. Once the resampling is conducted, the travel time of the nitrogen to groundwater can be quantified. The advantage of this approach is it is possible to determine if the implementation of BMPs and AMTs are effective by reducing the amount of nitrogen in the unsaturated profile without having to wait for extended lag times to actual reach (and ultimately impact) groundwater resources.

Subp. 6. Nitrogen fertilizer best management practices evaluation A.

BMP evaluation in mitigation level 2

According to Minn. Stat. § 103H.275, the MDA shall evaluate the nitrogen fertilizer BMPs based upon two components: 1) the evaluation of BMP implementation; and 2) the evaluation of BMP effectiveness. Each component must be evaluated individually, and their combined effect must be evaluated as well. Evaluation of either component will be a complex process. This section will discuss the tools used for assessing the implementation of nitrogen fertilizer BMPs.

The results of BMP implementation may not be discernible for a long period of time, as measured by the change in nitrate-nitrogen concentration of groundwater. Furthermore, changes in nitrate-nitrogen concentration observed over the course of a single year may or may not be related to BMP adoption. In view of these challenges, it is recognized that BMP adoption must be evaluated as well as BMP effectiveness in preventing or reversing the degradation of water quality.

On-Farm Nutrient Assessments: The ability of the MDA to document farmer adoption rates of voluntary nitrogen fertilizer BMPs is a critical component of the 1989 Minnesota Groundwater Protection Act (Minn. State. chap. 103H). The MDA has developed a diagnostic tool called FArm Nutrient Management Assessment Process (FANMAP) to get a clear understanding of existing farm practices regarding agricultural inputs such as fertilizers, manures and pesticides.

Although it is labor intensive, it provides a useful and accurate method of compiling data on BMP adoption. This approach was developed for DSWMAs and other small-scale water quality projects.

Results have been used to design focused water quality educational programs. Data collected in the program's infancy can be used as a baseline to assist in determining if the nitrogen fertilizer BMPs are being adopted. Over the past twenty years, hundreds of farmers have volunteered two to four hours of their time to share information about their farming operations. The complete compendium of FANMAP surveys is available on the MDA’s FANMAP website (n.d. (b)).

Phone Surveys: The MDA has partnered with the NASS and U of M researchers to collect information about fertilizer use and farm management on regional or statewide scales. Partners have pioneered a survey tool for characterizing fertilizer use and associated management. 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 farmer. The first attempt using this technique was in 2010. NASS enumerators surveyed approximately 1,500 corn farmers from across the state to gather information about commercial fertilizer use on corn (Bierman et al. 2011). Statewide nitrogen use surveys for grain corn production are now conducted every other year in partnership with NASS. During the alternate year, surveys on other crops and practices are conducted.

Evaluation for purposes of the proposed Rule will be conducted after a minimum of three growing seasons after the publication of the nitrogen fertilizer BMPs. Since the proposed Rule is focused on DWSMAs, the FANMAP approach previously described will be the likely tool. To determine if proper nitrogen rates are used, it will be necessary to look back at past years practices for the purposes of crediting all sources of nitrogen that are applied. The survey will take into consideration all cropland except soybean (i.e. corn, alfalfa, wheat, etc.)

Time period for BMP adoption

The MDA will inform farmers of the selected nitrogen fertilizer BMPs (and AMTs if funded in mitigation level 3, or for mitigation level 4) prior to the beginning of a growing season and give them adequate time before implementation is required and evaluated by the MDA. The MDA determined that three growing seasons should be used because this is the length of the most common corn-soybean crop rotation. The corn-soybean rotation for the past several years has covered approximately 16 million acres which represents over ¾ of Minnesota’s cropland acres.

It is reasonable that the MDA gives farmers time for implementing the nitrogen fertilizer BMPs (and AMTs if required) because after the selection and promotion of the nitrogen fertilizer BMPs, it may take some time for adoption. The MDA routinely finds that growers tend to use rates higher than the U of M recommendations in some parts of the rotations. Farmers will need time to experiment with these more conservative rates. In addition to farm management changes, there may be supplies (e.g., nitrogen fertilizer product availability), equipment (e.g., ‘specialized’ fertilizer application equipment), or other issues beyond the control of the farmer that may take time to resolve.

Exclude soybean acres

The MDA will not include soybean acres when evaluating compliance whether 80% of the cropland is following nitrogen fertilizer BMPs. Being a legume, soybeans fix their own nitrogen and therefore do not have a nitrogen recommendation except under unique circumstances. The proposed Rule is intended to apply to crops that apply nitrogen fertilizer; therefore it is reasonable that soybeans not be included. If soybeans were included, those acres would artificially increase the number of acres that followed the (non-existent for soybeans) nitrogen fertilizer BMPs. In addition (as noted above), soybeans are most often in rotation with corn, therefore those acres could be evaluated for compliance with required nitrogen fertilizer BMPs during the year corn is grown.

U of M research has shown that soybean loses appreciable amounts of nitrogen in comparison to other legume crops such as alfalfa. Beans frequently lose about 75% of the rate losses typically found under corn even though nitrogen fertilizer is seldom directly applied. Losses, in part, are due to the contributions from mineralized nitrogen along with lower crop water use (resulting in greater nitrogen flux). Alfalfa and other perennials are extremely effective in reducing nitrate losses through the root zone and when these crops are managed correctly, they can have extremely positive water quality benefits. For this reason, the introduction of these crops is considered an AMT and highly encouraged.

The MDA received some comments that suggested that it should not include soybeans in the 80% cropland calculation. Considering all of these factors, it is reasonable that the MDA does not include soybeans in the ‘80% cropland compliance’.

Justification for using 80% of cropland

Within any geographical region, it is reasonable to expect that some percentage of the agricultural landscape will experience climatic conditions or other conditions which will impede the producer’s ability to manage nitrogen inputs in accordance to the nitrogen fertilizer BMPs and corresponding Fertilizer Guidelines (MDA, n.d. (g) Kaiser et al., 2011, 2016, Lamb 2015). For example, one of the consequences of climate change is more localized thunderstorms resulting in wide variations of rainfall within small distances. Large differences are frequently observed within the boundaries of an individual farm. Localized saturated conditions, as well as drought conditions, can have a profound impact on time management and the producer’s ability to implement nitrogen management on these minor acres.

Additionally, making alterations to fertilizer management practices can also impact time management, labor costs, labor availability, and many associated equipment issues. For a variety of reasons, it is not realistic to assume that nitrogen fertilizer BMPs can be implemented across all acres for any particular growing season.

There was considerable discussion and eventual consensus across the NFMP Advisory Committee that this threshold level should not be 100%. A range of percentages were discussed and eventually the committee agreed that 80% would represent a balance between challenging producers to continue adopting the best available science yet reflecting that the forces of nature must always be considered.

Why is it needed and reasonable to allow periodic evaluations to monitor progress?
Periodic evaluations of nitrogen fertilizer BMP adoption will allow the agency to check on progress and compliance, and to make adjustments as needed. Over time, cropping systems and nitrogen fertilizer BMPs may change and the MDA will need to track these changes. In addition, evaluations indicate whether the practices needed to improve groundwater quality are in place. These periodic evaluations will allow the MDA to make sure that the desired nitrogen fertilizer BMPs/AMTs in mitigation levels 3 and 4 are being implemented. This type of feedback will also be informative for the LATs and other partners to evaluate the effectiveness of mitigation level 2 promotional activities. For these reasons, it is reasonable that the MDA conduct evaluations of nitrogen fertilizer BMP adoption.

The timeframes of these evaluations may be variable due to the mitigation level and DWSMA area as further discussed below.

Subp. 6. Nitrogen fertilizer best management practices evaluation. B – Evaluation criteria.
The proposed Rule has established several additional considerations when determining whether the nitrogen fertilizer BMPs (and AMTs) are being adopted. The MDA has determined that it is necessary for the rule to include additional circumstances that are relevant in determining compliance with the BMPs. These include:

> *Approved Alternative Management Tools (AMTs):* The AMTs are a replacement or improvement to the nitrogen fertilizer BMPs; therefore, it is reasonable that they be deemed in compliance with the nitrogen fertilizer BMPs. In the NFMP and in subsequent proposed Rule outreach activities, the MDA has repeatedly stated the goal of going beyond the nitrogen fertilizer BMPs and implementing AMTs. Therefore, in an effort to facilitate their use within the proposed Rule, the MDA will maintain a list of agency-approved AMTs so they are readily accessible for the MDA to promote and for farmers to implement. Therefore, it is needed to understand if farmers adopted approved AMTs in order to assess whether they are in compliance with the BMPs.
>
> *Minnesota Agricultural Water Quality Certification Program (MAWQCP):* A compliance determination for MAWQCP is needed because Minn. Stat. § 17.9891 states that enrollment in MAWQCP is deemed in compliance with any state regulation. This

includes the proposed Rule. In addition, in order to get certified under the MAWQCP, the nitrogen fertilizer BMPs as well as other fertilizer management practices will have been adopted on the certified acres.

Lack of Information: If a regulated party does not provide the MDA any information, or provides inadequate information, that party will be determined to not be in compliance with the proposed Rule. The MDA expects regulated parties to be forthcoming during compliance checks, and noncooperation by providing inadequate information will result in an assumption that nitrogen fertilizer BMPs have not been adopted. This is reasonable because the proposed Rule begins in a voluntary level, providing farmers adequate opportunity to comply before regulation. In the regulatory levels, it is reasonable to expect continued cooperation in compliance with regulatory requirements. In addition, determination of noncompliance is reasonable because it is equitable to all regulated parties in an area to require all to comply with the same regulatory requirements.

Waiver from non-compliance due to an agricultural emergency – In some cases, events will occur that are beyond the control of a farmer (e.g., weather events). The proposed Rule needs to account for agricultural emergency events, so that farmers are not deemed noncompliant due to an event that is unpreventable. It would not be uncommon for agricultural emergencies to impact more than one farmer in an area as well. Therefore, an exception for agricultural emergencies is needed and reasonable.

MPCA-approved and implemented manure management plan that include the required BMPs: Manure management plans are in place for feedlots of a defined size throughout Minnesota. These plans require proper management of manure based on the nutrient content including nitrogen. The plans provide a formal process for reviewing and approving the proper management of nutrients. In the comment process, the MDA received several recommendations that MDA use this existing process for approval of any required BMPs and practices so that farmers do not need two reviews of their practices. This provision has been included in the rule in response to those recommendations. A manure management plan that includes any required practices for the land in the DWSMA and has been approved by the MPCA or their designee will be considered to be implementing the required practices under the rule. This is reasonable, because a manure management plan requires that land application of manure be done in a manner that protects surface and groundwater. Therefore, including MPCA approve management plans is reasonable because feedlot rules (Minn. R. chap. 7020) require that nutrient applications be based on crop needs. This includes nitrogen from all sources including manure, fertilizer, crop credits and other sources; however, in addition the proposed Rule requires that the manure management plan is determined to be implemented (by MPCA staff or designee) as well. This is needed and reasonable because the plan must be implemented to reflect that actual manure (and associated nitrogen) management activities protective of water quality are being done.

Subps. 7-9. DWSMA mitigation levels. – Mitigation level 2, 3 and 4 designation review

The proposed Rule provides for a systematic process to determine the appropriate mitigation level. This process considers a review of water quality monitoring data and residual soil nitrate data below the root zone (if available) for all mitigation levels. In addition, for a mitigation level 2 site, it considers a survey on the adoption of designated nitrogen fertilizer BMPs.

The criteria for determining a site to be at a specific mitigation level are clearly defined. A site will move up a mitigation level if the criteria for a specific mitigation level are met. If the criteria for a mitigation level are no longer met because water quality is improving, then the site will be moved down.

The criteria for initial mitigation level 1 and mitigation level 2 determinations were previously discussed in Subp. 3. The criteria for moving a mitigation level 2 site to mitigation level 3 are if the recommended set of nitrogen fertilizer BMPs are not being adopted on 80% of the crop land acres (excluding soybean) or if water monitoring data or residual soil nitrate testing data indicates that nitrate-nitrogen concentrations are increasing.

The development of mitigation level criteria is needed to provide for a consistent approach and for ensuring that the goals of the regulation (reductions of nitrate-nitrogen concentrations in groundwater) are met. These mitigation level criteria are reasonable for two reasons. First, one of the primary goals of the Groundwater Protection Act is to ensure the adoption of nitrogen fertilizer BMPs. The criteria of 80% adoption of the recommended nitrogen fertilizer BMPs was selected because it means that most of the agricultural land with high nitrogen using crops in the DWSMA will be adopting the most important nitrogen fertilizer BMPs to ensure that nitrogen fertilizer is used appropriately and in a manner that will minimize nitrate leaching to groundwater. As is discussed elsewhere in the SONAR, the required percent of BMP adoption is not 100% because there are frequently practical limitations to 100% adoption of some practices and the Groundwater Protection Act clearly directs that any regulatory requirements must be practicable.

The 80% of cropland acres surveyed does not apply to soybean acres. This is reasonable because they do not generally receive significant applications of nitrogen fertilizer. In the case of soybean, it is generally grown in rotation with corn and proper crediting for nitrogen for soybean will be considered during other parts of the crop rotation. Other crops such as alfalfa and perennial crops are included in the assessment of cropland. This is reasonable because growing certain other crops such as perennials can have a significant beneficial effect on reducing nitrate losses. If these crops were not included in the assessment of cropland it might cause an unintended consequence of discouraging their adoption.

The other criteria for moving to mitigation level 3, and also for moving to mitigation level 4 for sites in mitigation level 3, is if nitrate-nitrogen concentrations in groundwater or in residual soil nitrate below the root zone are increasing. These criteria are intended to ensure that, at a minimum, the agricultural practices within the DWSMA are sufficiently protective to prevent water quality from getting worse and from eventually exceeding the HRL for nitrate-nitrogen of 10 mg/L. If nitrate-nitrogen concentrations are continuing to increase that indicates additional implementation actions beyond the widespread voluntary adoption of nitrogen fertilizer BMPs are necessary. In mitigation level 3 the commissioner – in consultation with a local advisory team – would require landowners to implement best management practices and may require other practices such as testing, educational programs and AMTs if they are funded. These actions would represent a significant increase in implementation activities to address the issue.

The timeline for review and possible redetermination of a mitigation level may vary depending upon the lag time for each DWSMA. The approach is to reevaluate the appropriate mitigation level after not less than three growing seasons or the estimated lag time, whichever is longer, following when the recommended practices are first published for mitigation level 2 or when the order is finalized and published for mitigation levels 3 and 4. The monitoring data and mitigation level will then be reviewed not less than every three years thereafter. The exception to this approach is if residual soil nitrate testing below the root zone is conducted in which case the timeline for evaluating these tests will be highly dependent upon the characteristics of the site and the procedures employed in the testing. Soil residual nitrate tests would be conducted in cases where the lag time is measured in decades. In such instances it is not feasible to wait until after the lag time and soil residual nitrate tests offer an alternative method to tracking the amount of nitrate moving to groundwater. However, these procedures will require an initial and one or more follow-up series of soil tests. In most cases the timeframe for evaluating these tests will be several years between tests at a minimum. For purposes of the rule it states that the time interval for review of residual soil nitrate tests will be not less than three years. Use of this test to assess changes in nitrate-nitrogen concentration is reasonable because it provides a more rapid alternative to groundwater monitoring in areas where there are very long lag times (which can be decades) or where it is very expensive to install monitoring wells. However, residual soil nitrate testing is highly resource intensive and still relatively new therefore it is anticipated that its application will be very limited. (see SONAR Supb. 5. Monitoring, Residual Soil Nitrate Monitoring).

Lag Time

Lag time is the period of time for nitrate to travel from the point of application on or near the land surface, through the unsaturated zone and reach the aquifer being monitored. This lag time can vary significantly in different locations across Minnesota from periods of less than a year in extremely vulnerable aquifers to decades or longer in some deeper aquifers. It is necessary to account for the lag time when evaluating if changes in land management practices are having an effect on water quality in an aquifer. The lag time can be estimated in several ways, including through models or calculations that estimate these travel times and/or through the use of a variety of tracers. Tracers are chemicals which are used in the environment at a known point in time so that when they are first detected in an aquifer they provide an estimate of the travel time to that aquifer. There are a number of commonly used tracers including the first use of a specific pesticide, pharmaceutical or compound linked to atmospheric deposition. The Minnesota Geologic Survey (MGS), the United States Geologic Survey (USGS) and the MN DNR have all provided technical advice, research publications, and conduct or support ongoing research to estimate travel times to different aquifers in Minnesota (Runkel et al, 2014, Steenberg et al, 2014, Puckett and Cowdery, 2002). The following references provide information on tracers. https://water.usgs.gov/lab/references/group/

These timelines provide clear guidance on expectations to the public regarding the MDA's process for review of water quality data, and expectations on when changes in water quality can reasonably be anticipated based on changes in practices. It is necessary to have some guidance in the proposed Rule on the evaluation process including timelines for moving to regulation or, if water quality improves, when regulatory requirements may be dropped. The timelines proposed in the proposed Rule are reasonable for several reasons. Three growing seasons is based on the three-year timeline that is frequently used for a crop rotation. This will provide a reasonable timeframe for all of the farmers in the DWSMA to learn about, evaluate and adopt any changes in practices that are necessary. During this time the MDA and partners in the agricultural community and local government will actively promote the nitrogen fertilizer BMPs, and at the same time discuss and encourage the adoption of AMTs. It is important to note that one of the primary goals of the NFMP is to educate on and promote the most effective and current agricultural practices that can minimize nitrate losses. The AMTs, which are described elsewhere in the SONAR, are intended to provide a highly flexible approach to engaging and sharing information across the entire agricultural community in Minnesota on new or proven strategies and technologies the can help reduce nitrate losses in vulnerable groundwater areas. Anyone can suggest AMTs and if they are suitable, they will be listed on the MDA website and may be considered for use in DWSMAs. The MDA is currently funding agricultural educator positions with U of M Extension specifically to promote nitrogen fertilizer BMPs and AMTs in targeted high-risk areas including DWSMAs. The three-year adoption period, especially in mitigation level 2, will be an important time for working with the local advisory committee, local farmers and agronomists to promote both the nitrogen fertilizer BMPs and AMTs in the DWSMA. This is reasonable and supports the goal of promoting practices that can improve water quality in the DWSMA.

As previously discussed, consideration of the lag time from when a change in practices will have an effect on groundwater quality is necessary and reasonable because we cannot know if changes in practices are having the desired effect until after the lag time (see 1573.0040, Supb. 5. Monitoring).

The timeline for mitigation review states that it will be “not fewer than” three cropping seasons or the lag time for water sampling, whichever is longer, or “not fewer than” three years for residual soil nitrate tests. The phrase “not fewer than” has been used because it is necessary and reasonable to use a longer timeline in some situations. For example, it is necessary to align the survey of BMP adoption in the DWSMA with the monitoring data, so they are assessed together. If the BMP adoption survey takes longer than anticipated, then it will be necessary to delay the review of the mitigation level until it is completed. In addition, there might be other factors which require a delay in the survey of BMP adoption. There could be extreme weather events such as a drought or extremely late planting due to heavy rainfall or late spring planting under which the Commissioner may allow wide spread exceptions to BMP adoption. In those years the MDA would postpone surveys until following a normal cropping year. The timelines for use of residual soil nitrate tests will vary by the test and may also be modified during periods of extreme weather. When working with agricultural systems, it is necessary to have some flexibility to adjust to weather conditions. An approach that provides this flexibility is reasonable and necessary to efficiently align different testing and survey methods into a single review cycle and to adjust or correct for extreme weather events.

The proposed Rule allows the commissioner to grant a one-time delay moving a mitigation level 2 or mitigation level 3 site up a mitigation level for a period equal to three growing seasons or the lag time, whichever is longer, or for a time period equal to the time used for the reviewing the level determination for residual soil nitrate tests, if the responsible parties have demonstrated progress in addressing nitrate in groundwater within the DWSMA. This provision has been included in the proposed Rule to recognize situations in which actions in the DWSMA have already been implemented that are comparable to, or go beyond, the actions that would likely be required in a mitigation level 3 or mitigation level 4 order. In this case the order would be unnecessary and even counter-productive. This provision might be applied in a situation where it took several years to implement practices that are much more extensive than mitigation level 2 nitrogen fertilizer BMPs or mitigation level 3 water resource protection requirements, such as a change in the cropping system to a perennial crop. This delay in implementation might be because it took a long time to obtain funding to implement the new practice, which is quite common when implementation funds are limited as they generally are. But since the new practices will have been implemented, it is appropriate to provide additional time to evaluate how effective they are. This provision in the proposed Rule is necessary because if the increased actions taken are effective the order would be unnecessary. Further, it might actually be counter-productive to issue the order because any regulatory action tends to provoke a defensive response from some members of a regulated community and an order that might reasonably be viewed as clearly unnecessary might offend and discourage further voluntary cooperative efforts. It is important to note that a goal of the Groundwater Protection Act and the NFMP is to address nitrate concerns through a voluntary approach and only move to a regulatory approach if the voluntary approach is not successful. This provision allows the commissioner to encourage and reward a strong voluntary response to elevated nitrate in the DWSMA.

The proposed Rule also allows the commissioner to make exceptions to increasing a mitigation level due to changes in land use. Some DWSMAs are very small and changes in land use might have a dramatic effect on water quality. In some cases there may be limited cropland left in a DWSMA. An example might be a DWSMA on the edge of an area where land is being converted from agriculture to suburban development.

The commissioner could not use the exceptions to increase the mitigation level faster than the other parts of the proposed Rule allow. However, the commissioner may make exceptions to the criteria and not increase a mitigation level based on a reduced risk of nitrate contamination to groundwater.

This provision in the proposed Rule is necessary because it allows the MDA to use resources efficiently and to be able to respond to situations where the source for elevated nitrate in a public well has been removed or greatly diminished even though, because of lag times and travel times within the DWSMA, it may take many years for high nitrate-nitrogen concentrations in the well to fall. It is reasonable for MDA to include provisions in the proposed Rule which allow flexibility for quickly adjusting to changes in nitrogen sources so that limited resources are not wasted.

A mitigation level 3 site will be moved to mitigation level 4 if nitrate water monitoring data or residual soil nitrate testing data shows nitrate-nitrogen concentrations are increasing as described above, or if the nitrate-nitrogen concentration in the sampling data from the public well exceeds 9 mg/L three times over the previous 10 years. The criteria indicate that the source water to the public well is at great risk of exceeding the nitrate-nitrogen MDH HRL of 10 mg/L and additional implementation activities than are required for mitigation level 3 are needed to prevent this from occurring. For mitigation level 4, the proposed Rule allows the commissioner, in consultation with the LAT, to order the implementation of any actions that are allowed under the Groundwater Protection Act. For a mitigation level 4 order the commissioner, in consultation with the LAT, would conduct a detailed site-specific assessment of the site, and then select practices that are likely to reduce nitrate-nitrogen concentrations in the source water to below the MDH HRL in consideration of the requirements in the Groundwater Protection Act. It is important to note the commissioner must consider economic and other practical factors for any requirements in the order. The specific statutory language (Minn. Stat. § 103H.275, subd. 2) regarding what the commissioner could require in the order is the following:

> "*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."

It is necessary to have clear criteria of when the concern for high nitrate-nitrogen concentration in groundwater or threatening groundwater justify moving to the highest regulatory requirements allowed by the Groundwater Protection Act and the proposed Rule. It is reasonable for the proposed Rule to adopt these specific criteria for moving to a mitigation level 4 because the criteria are reasonable indicators that there is a significant risk that the source water will exceed the MDH HRL if additional actions are not implemented than are currently being conducted under mitigation level 3.

If the criteria for a given mitigation level are no longer met, then a site will be moved to a lower mitigation level. The criteria for a specific mitigation level do not change. For a mitigation level 4 site it would be moved down one mitigation level to a mitigation level 3 site, and a mitigation level 3 order would be prepared in accordance with the mitigation level 3 requirements in the proposed Rule. For a mitigation level 3 site it would be moved down to mitigation level 1. This is because the water quality goal of not exceeding 8 mg/L nitrate-nitrogen over 10 years is the same for mitigation level 2 and 3. In addition, the site cannot have increasing nitrate-nitrogen concentrations as previously discussed.

It is necessary to have clear guidance in the proposed Rule for when a site will be removed from regulatory requirements. It is reasonable to use the same set of criteria for moving a site up or down since the criteria are based an increasing concern that nitrate-nitrogen concentrations are threatening to exceed the MDH HRL for source water in a public well, and if this concern no longer true, then regulatory requirements should be reduced. It is important to recognize that the water quality criteria are based on the nitrate-nitrogen concentrations observed over period of 10 years. It is felt that this is a sufficiently long period to provide confidence that the changes are likely to continue to be sustained over the long term

Subp. 10. DWSMA mitigation levels. - Limitation on change in designation

It is needed and reasonable for a DWSMA to only increase one mitigation level at a time in order to give regulated parties certainty about regulation. No less than every three growing seasons or the lag time, whichever is longer, DWSMAs with a mitigation level of 2 or higher will be reevaluated. If nitrate-nitrogen concentrations are increasing, the regulated party knows that they will only move up one mitigation level until the next re-evaluation cycle. This proposed Rule provides certainty for the responsible party and allows some certainty for the regulated party regarding the process of increasing mitigation levels.

E. 1573.0050 Water Resource Protection Requirements Order

Subp. 1. Commissioner's water resource protection requirements order

The MDA is required to lay out the procedures for notice to be given to persons affected by the water resource protection requirements order under Minn. Stat. § 103H.275, subd. 2(d). This provision of the proposed Rule is reasonable to identify who is subject to the water resource protection requirements order when it is issued for a DWSMA. Minnesota farms can be operated by an owner, a tenant, or other arrangements. Where neighboring DWSMAs are the same mitigation level and the cropping systems are similar, meaning that the implemented nitrogen fertilizer BMPs would be the same or similar, it is necessary and reasonable to use the MDA's limited resources to address these areas with one LAT and one mitigation level. This can reduce complications for those farmers that operate on land in more than one DWSMA and will not provide any additional regulations for those farmers that only operate in one DWSMA.

Subp. 1. Commissioner's water resource protection requirements order. A. – Mitigation level 3 and 4 DWSMAs

To address the most serious groundwater concerns, it is necessary and reasonable for the commissioner to issue a water resource protection requirements order, as described in Minn. Stat. § 103H.275, subd. 2(c), for DWSMAs that meet the requirements of mitigation levels 3 and 4 as described in this SONAR 1573.0040 Drinking Water Supply Management Areas; Mitigation Level Designations.

The water resource protection requirements in the proposed Rule are necessary to achieve the purpose of the Groundwater Protection Act, which is to ensure that groundwater is "maintained in its natural condition." Minn. Stat. § 103H.001.

Under the Groundwater Protection Act, the commissioner of agriculture is charged with, among other things, promoting the implementation of BMPs to prevent or minimize pollution from agricultural chemicals "to the extent practicable." Minn. Stat. § 103H.275, subd. 1. The commissioner of agriculture may issue water resource protection requirements if "the implementation of best management practices has proven to be ineffective." Minn. Stat. § 103H.275, subd. 1(b). Thus, if BMPs have not been implemented or if they have been implemented and found to be ineffective, the commissioner may issue water resource protection requirements. The proposed Rule addresses both the "implementation" factor and the "ineffectiveness" factor.

Implementation: Under the proposed Rule, the commissioner will issue water resource protection requirements if nitrogen fertilizer BMPs have been implemented on less than 80% of the cropland in the affected DWSMA. If nitrogen fertilizer BMPs are implemented on less than 80% of the cropland in the affected DWSMA, it is expected that nitrate-nitrogen concentrations in groundwater will continue to rise, making it necessary for the commissioner to issue a water resource protection requirements order. The use of 80% is a reasonable measurement to determine if nitrogen fertilizer BMPs have been implemented.

Ineffective: Under the proposed Rule, the commissioner also will issue a water resource protection requirements order if the nitrogen fertilizer BMPs have been proven ineffective. This will be assessed by measuring whether nitrate-nitrogen concentrations are increasing.

This is reasonable because, before moving to any water resource protection requirement, the MDA intends to use voluntary mitigation levels 1 and 2 to alert farmers to groundwater conditions, encourage farmers to voluntarily adopt the nitrogen fertilizer BMPs, and employ farmer-led strategies to protect groundwater. Farmers will have adequate time to implement the measures voluntarily, and adequate time will be allowed to take into account the travel time of the affected groundwater. It is also reasonable because the commissioner will assess whether the criteria have been met through scientifically accepted methods for testing for nitrate in groundwater (see 1573.0040 Drinking Water Supply Management Areas; Mitigation Level Designations). If the nitrate-nitrogen concentrations meet those objective criteria, it will be necessary for the commissioner to adopt water resource protection requirements in order to prevent the nitrate-nitrogen concentrations from becoming a broader public health issue by exceeding the MDH HRLs. It is also reasonable and satisfies the provisions of Minn. Stat. § 103H.275, subd. 2(c) because the water resource protection requirements order will be site-specific for each affected DWSMA.

Subp. 1. Commissioner's water resource protection requirements order. B. – Presence of groundwater monitoring networks or residual soil nitrate testing

It is necessary for the rule, as part of the mitigation level decision, to account for the time it takes for changes in agricultural or land management practices on the land surface to have an effect on water quality in the aquifer or in the public well. As noted in 1573.0060, subp. 5, the Commissioner may construction a groundwater monitoring network or conduct residual soil nitrate testing to evaluate if the water quality within a DWSMA is getting worse for purposes of designating a mitigation level. The groundwater monitoring network will be designed to evaluate water quality for groundwater considering the unique hydrogeology in each DWSMA. The installation of a monitoring network and use for mitigation level decisions is reasonable because it will provide a rapid and technically defensible assessment of changes in groundwater quality. The monitoring data from the monitoring network will be a direct reflection of the effectiveness of changes in agricultural or land management practices in reducing nitrate-nitrogen contamination in the aquifer. Residual soil nitrate testing below the root zone provides similar information on the increase or decrease of nitrate levels in soils below the root zone. Nitrate in soil below the root zone will not be taken up by the crop and is available for migration to the groundwater, and provides a useful indicator of future nitrate leaching into the aquifer.

For all aquifers there is a lag time before changes in agricultural or land management practices have a beneficial or harmful effect on water quality in the underlying aquifer. This is because it takes time for nitrate to migrate below the root zone of the crop where nitrate may be taken up by the plant, and through an unsaturated zone below the ground surface before it reaches an aquifer. An aquifer is a geologic formation that yields usable quantities of groundwater. This lag time can vary substantially from less than a year to decades or longer depending upon the depth to groundwater and ability of the soil or bedrock to rapidly conduct water (the hydraulic conductivity) (Adams, 2016, Struffert et al, 2016).

The DWSMA is a two-dimensional estimate of the area within an aquifer that would provide groundwater to a pumping well within a period of 10 years. The DWSMA is based on horizontal travel times within an aquifer (i.e. movement of nitrate once it has reached groundwater) and does not generally consider the lag time for nitrate or another contaminant to travel downward to reach the aquifer. The installation of a groundwater monitoring network or conducting residual soil nitrate testing will assess the changes in water quality across the entire DWSMA at once, without waiting 10 years for groundwater from the most distant part of the DWSMA to reach the public water supply well. Therefore it is reasonable, in areas where a groundwater monitoring network is installed or residual soil nitrate testing is conducted, for the order to apply to the entire DWSMA.

Subp. 1. Commissioner's water resource protection requirements order. C. – for areas where a groundwater monitoring network is not installed or residual soil testing is not conducted

It is necessary for the rule, as part of the mitigation level decision, to account for the time it takes for changes in agricultural or land management practices to have an effect on water quality in the public well. As described in subpart 1 (B), a DWSMA is calculated based on the two dimensional area in an aquifer that will provide water to a pumping well over a period of 10 years without consideration of lag time. In contrast to the situation described in subpart 1 (B), if a groundwater monitoring network is not installed, or residual soil nitrate testing is not conducted, then the monitoring information will not be available to assess the entire DWSMA at one time until a period equal to the lag time plus 10 years to account for the horizontal travel time across the entire DWSMA. However, the effectiveness of practices on water quality can be evaluated for those parts of the DWSMA that are having an impact on water quality in the public well based on estimated lag and horizontal travel times.

This provision in the rule provides that an order in a DWSMA may only apply to that part of the DWSMA for which practices on the land surface would impact water quality in the public well, considering both the lag time for nitrate to reach the aquifer and the horizontal travel time for water in the aquifer to reach the well. This is reasonable, because it ensures that the order will only apply to those fields where practices are impacting water quality in the public well based on a detailed assessment of the estimated travel time for nitrate-nitrogen to travel from the place of application to the well.

Subp. 1. Commissioner’s water resource protection requirements order. D. – Prioritizing issuance

Minnesota’s agricultural economy and its geology are very diverse and using a water resource protection requirements order is necessary as they allow the MDA to tailor groundwater improvement solutions to fit an affected area. The MDA has limited staff and resources, and the criteria described in part 1573.0040, Subp. 3 (A) of the proposed Rule allows the commissioner to prioritize the areas of greatest concern in order to use these resources most efficiently. Using the criteria described in the proposed Rule to prioritize water resource protection requirements orders are reasonable as it allows for areas with high groundwater nitrate concentrations that affect the largest populations to be prioritized over areas where nitrate-nitrogen concentrations are low and/or where there are higher levels of nitrogen fertilizer BMPs are adopted.

Subp. 1. Commissioner’s water resource protection requirements order. E. – Contents and application

Due process requires notice of a government action that may affect a private interest and provides a meaningful opportunity to be heard. The content of the water resource protection requirements order are needed and reasonable in order to inform the responsible parties in the DWSMA of the basis for its designation of a mitigation level 3 or 4. Including the information described in the proposed Rule is reasonable to sufficiently inform a responsible party why the DWSMA had been designated a mitigation level 3 or 4. This information includes letting responsible parties know of their mitigation level; providing responsible parties with the evidence as to why the mitigation level has been designated for their area;, informing regulated parties about the boundaries of the DWSMA that the order applies to, when the water resource protection requirements order will be effective, and their rights to contest the case. It is needed for the MDA to provide the responsible parties with the data that lead to the mitigation level designation. This data can help farmers understand that there is a groundwater problem in their DWSMA. It is reasonable and will help the regulated parties in that DWSMA understand the steps the MDA will take to work with the local area to reduce the concentration of nitrate-nitrogen in groundwater.

Subp. 1. Commissioner’s water resource protection requirements order. F. – DWSMA partial exclusions

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 certain requirements in the rule, and to allow MDA to consider other factors that may make implementation of a specific practice impracticable because of the unsuitability of the location for the specific practice.

An important consideration when working with agricultural systems is that one size or set of practices does not fit all landscapes and cropping systems. 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 DWSMAs, 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.

In addition for large DWSMAs there may be differences in soils types, land features, or groundwater vulnerability such that the practices that are highly desirable for one area may not be as beneficial or even practicable to implement across the entire DWSMA. This is especially important for level three orders that may require more complex AMTs (if fully funded) and for level four orders that can require any practices allowed under the Groundwater Protection Act. These practices could be much more difficult to implement then standard fertilizer BMPs and may not be suitable for all of the land area in a large DWSMA or their implementation in some parts of the DWSMA may provide little or no improvement in nitrate-nitrogen concentrations in the public well.

This provision is necessary to ensure that the commissioner does not impose requirements and related costs on individuals 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; implementing certain practices uniformly across a DWSMA including in areas where they may provide limited environmental benefits would not meet this requirement. It is necessary to be able to exclude parts of a DWSMA from a water resource protection requirements order so that they are not overly broad and do not include persons whose practices are not contributing significantly to the contamination. It is also reasonable to include only those responsible persons whose actions can affect the groundwater in the DWSMA.

Subp. 1. Commissioner’s water resource protection requirements order. G. – Exclusion.

This requirement is addressed under in the SONAR under 1573.0040, **Error! Reference source not found.**

Subps. 2-4 and 6. Commissioner's water resource protection requirements order – Notice, contested case hearings, final order effective date and judicial review

These provisions are necessary and reasonable because they provide due process and follow the requirements set forth at Minn. Stat. § 103H.275, subd. 2

Minn. Stat. § 103H.275, subd. 2(d) requires the MDA to provide procedural due process to persons affected by a commissioner's order. Procedural due process requires notice of a government action that may affect a private interest, and a meaningful opportunity to be heard. The MDA considered the question of how much process is due in issuing a water resource protection requirements order. *"[T]he requirements of due process must be measured according to the nature of the government function involved and whether or not interests are directly affected by the government action." Barton Contracting Company, Inc., v. City of Afton*, 268 N.W.2d 712, 715 (Minn. 1978). The MDA believes it is reasonable and necessary to provide sufficient notice of its proposed action and ample, meaningful opportunity for affected farmers to be heard. The process for issuing a water resource protection requirements order was drafted to follow the process outlined in the Public Waters Inventory because it involved similar due process challenges that are shared by the MDA (Minn. Stat. § 105.391). The procedural due process described in the public waters inventory has been upheld by the Supreme Court of Minnesota in *Application of Christenson*, 417 N.W.2d 607 (Minn. 1987).

Minn. Stat. 103H.275, subd. 2(d) authorizes the MDA to provide notice by personal service, publication, or other appropriate methods. While personal service will be the first priority, in large DWSMAs, the MDA may encounter significant difficulty and administrative burden in identifying potentially affected operators. In many cases, the landowner and the operator are different entities. Landowners may be living out of state and, while it might be possible to identify all landowners through tax records, not all landowners and operators are the same entity. It is possible that the task of comparing maps with land records to determine owners and addresses would only provide the MDA with partial information. The MDA would still not be aware of the operator on the land. Under these circumstances, providing published notice is the most efficient and effective way to provide notice to the actual operator of affected farmland. As the rule on the public waters inventory states, *"To provide personal notice to all interested persons in the public water inventory process throughout the state would be a nearly impossible administrative task."* For large DWSMAs, notifying each individual landowner and operator of that land could similarly be a nearly impossible administrative task.

The USDA Farm Service Agency (USDA-FSA) collects data about operators on agricultural land for federal grants and funding purposes. However, this information is federal and not available to the MDA.

The proposed Rule incorporates many procedural safeguards to prevent erroneous designation or mandatory practices that may a farmer may object to: there are required informational meetings, multiple publications in legal newspapers, public hearings, and notice to other governmental agencies, cities, counties and the township board. Judicial review pursuant to Minn. Stat. §§ 14.63-14.69, is also available to any person or entity subject to a final order. All of these measures are reasonable and necessary to provide meaningful opportunities to be heard about proposed action to interested parties.

Subp. 5. Commissioner's water resource protection requirements order. – Amended orders

A water resource protection requirements order may need to be amended for a variety of reasons. Research and agricultural practices are always changing and the LAT may recommend that new or additional nitrogen fertilizer BMPs or other practices are needed. An amendment process for the water resource protection requirements order is needed to order to update water resource protection requirements orders. The proposed Rule is reasonable as it outlines the amendment process, which requires due notice similar to the original issuance of a water resource protection requirements order, and will allow affected parties to seek beneficial changes.

Subp. 7. Commissioner's water resource protection requirements order. – Recording

This provision is needed and reasonable so that all affected persons will have notice of specific water resource protection requirement orders and amendments.

F. 1573.0060 Requirements for Water Resource Protection Requirements Orders

All water resource protection requirements orders will be site-specific for each DWSMA, and will be designed with input from a LAT and technical support from the MDA. This is needed so that the water resource protection requirements require a set of activities that are appropriate for the specific cropping systems, soils, hydrogeology, and the climate of the area. The one exception is a record keeping requirement applied to all orders for fertilizer-related records, which is reasonable and necessary in order determine if the required practices in the order have been adopted. This is also necessary to determine proper crediting for the nitrogen contribution or estimated losses due to agricultural practices that may include nitrogen or result in increased or decreased leaching losses of nitrate to groundwater. Many agricultural practices can have an influence on nitrate leaching and losses through runoff or atmospheric loss.

All responsible parties must comply with the requirements described in the proposed Rule and the final water resource protection requirements order. Minn. Stat. § 103H.275, subd. 2(f) states that a person who violates a water resource protection requirements order is subject to the orders under Minn. Stat. chap. 18D, which gives the MDA authority to enforce rules. This section of the proposed Rule is needed and reasonable because it gives the regulated party and the public knowledge and notice of the MDA's statutory authority.

G. 1573.0070 Water Resource Protection Requirements Order Contents

Subp. 1. Mitigation level 3.

This subpart outlines the categories of what might be included in the water resource protection requirements order. The order under mitigation level 3 may include nitrogen fertilizer BMPs formally approved by the MDA under Minn. Stat. § 103H.151 and any of the specific related practices that are listed under 1573.0070. Setting forth the practices that can be included in a mitigation level 3 order is necessary and reasonable to provide a transparent, consistent, and structured process for selecting technically defensible practices for a mitigation level 3 order. The general list of practices listed under 1573.0070 is reasonable and necessary because it is the result of a lengthy development process starting with the development of the NFMP and continuing into the development of the proposed Rule. It includes suggestions from a stakeholder advisory committee and input from three public comment periods - one on the NFMP and two discretionary comments periods on the draft rule. It includes activities that are widely accepted as being important to properly manage nitrogen fertilizer under different cropping systems and in different settings. It also includes an option for an education requirement which was an option strongly recommended by the advisory committee and has been generally supported as an important option by many commenters.

The nitrogen fertilizer BMPs that can be considered by the MDA for the order have been approved by the MDA under Minn. Stat. § 103H.151. This requirement is reasonable because it is based on the process for developing and approving nitrogen fertilizer BMPs, which is science-based and formal, with a public comment period. Nitrogen fertilizer BMPs are developed based on guidance in Minn. Stat. § 103H.005, subd. 4. They are developed with direct input from U of M scientists and consider economics and other practical considerations. In most cases, adopting the nitrogen fertilizer BMPs will increase a farmer's profitability. They are also flexible and can be amended through the above-stated process to address new studies, new practices, and other considerations such as climate change. Many of the practices are specific to the different regions across Minnesota. Because of the differences in nitrogen fertilizer BMPs for different soils and different regions, not all nitrogen fertilizer BMPs may be suitable for all locations. Therefore, some judgement in the selection of appropriate nitrogen fertilizer BMPs is needed and is an important part of the order development process. The nitrogen fertilizer BMPs are the foundation of good nitrogen management, which in turn is the most important step in minimizing nitrate losses. There is extensive research and many publications on their environmental and economic benefits. For all these reasons considering a requirement for appropriate nitrogen fertilizer BMPs in a mitigation level 3 order is both necessary and reasonable.

The MDA considered other options when drafting the list of water resource protection requirements for mitigation level 3. One of these options includes a fixed list of all possible options that could be considered a nitrogen fertilizer BMP now or in the future. The MDA concluded that this would not be a feasible requirement, as there is continuing research and advancement that may lead to updates of the nitrogen fertilizer BMPs. Practices that may be included on the list now may be outdated in a few years. In addition, new developments should be expected in the future that will likely be included on the recommended nitrogen fertilizer BMP list. Including these in the proposed Rule would make them static and would not allow the proposed Rule to follow future nitrogen fertilizer BMPs. It is necessary and reasonable for the list to be broad enough to cover practices that may be developed in the future, but specific enough so that LATs and responsible parties know what regulations could potentially become eligible nitrogen fertilizer BMPs included in the water resource protection requirements order. The water resource protection requirements order will be developed based on the recommendations of the LATs using the options included under 1573.0100 as the basis for the recommendations. All interested parties will have the opportunity to review the water resource protection requirements order before it goes into effect under the process described in 1573.0080.

Alternative management practices may be required for mitigation level 3 DWSMAs if there is a source of funding available to help offset the costs of implementing the practice. In mitigation level 4, alternative management practices that meet the requirements listed under Minn. Stat. § 103H. 275, subd. 2(a) shall be considered for inclusion in a water resource protection requirements order regardless of whether or not funding is available. As described in this SONAR Section I, 1573.0090 Alternative Management Tools; Alternative Protection Requirements, these practices will go above and beyond the nitrogen fertilizer BMPs and are locally optimized practices that will have been shown to reduce nitrate-nitrogen concentrations in groundwater. In the proposed Rule, AMTs are defined as “specific practices and solutions approved by the commissioner to address groundwater nitrate problems.” In areas with highly vulnerable groundwater, the use of nitrogen fertilizer at the recommended rate, timing, source and placement of the nitrogen fertilizer BMPs may not be enough to decrease the amount of nitrate leaching into groundwater to meet water quality goals. In these areas, the MDA will work with the LAT on locally developed solutions for addressing groundwater nitrate problems that are implemented on a site-specific basis. AMTs are needed because they are practices and activities designed to reduce nitrate leaching. AMTs represents an advanced level of groundwater protection that go beyond traditional nitrogen fertilizer BMPs.

Mitigation level 3 DWSMAs are areas where nitrates have exceeded or are projected to exceed the MDH HRLs within the next 10 years. These areas will affect large populations around the state and regulatory action is being taken to ensure the nitrogen fertilizer BMPs are being adopted. It is necessary for the MDA to be able to require the stronger practices of AMTs to reduce nitrate at this level. However, the MDA acknowledges that there may be additional costs associated with implementing AMTs and given that economic factors are one of the considerations the MDA must consider under Minn. Stat. § 103H.275, subd. 2(a), it is reasonable that these factors will only be required if there is additional funding available.

Mitigation level 3 DWSMA may include requirements for AMTs if funded. This is reasonable because farmers may need incentives to implement AMTs. AMTs may not be profitable, and funding could bridge this gap. Use of funding is reasonable, to ensure that farmers can implement these practices even during periods of very low crop prices. Sources of funding exist from Federal, state, and often also local sources (Lenhart et al., 2017). Funding would currently be available for some of the AMTs being considered, subject to funding levels and priorities within the local area.

Rules that include funding requirements to implement conservation practices to improve water quality are being applied in Wisconsin (Wisc. Stat. § 281.16; Wisc. R. NR 151.09(4)).

Subp. 2. Mitigation level 4.

A commissioner's order for a mitigation level 4 may contain any of the requirements for mitigation level 3, requirements for rate for nitrogen fertilizer, and any practices that meet the definition of water resource protection requirements in Minn. Stat. § 103H.005, subd. 15 (with two exceptions, see below, Subp. 3. Exceptions.) that meet the criteria set forth in Minn. Stat. § 103H.275, subd. 2(a). This is the highest mitigation level and it is reasonable that it would contain the most stringent requirements. It is necessary and reasonable to include these more stringent water resource protections requirements because DWSMAs will have had a minimum of six growing seasons to implement nitrogen fertilizer BMPs and will have had a minimum of three growing seasons under a mitigation level 3 water resource protection requirements order, yet specific indicators show that nitrate levels are not improving.

It is necessary and reasonable for the commissioner to implement more stringent water resource protection requirements in mitigation level 4, because the criteria set forth in the proposed Rule for moving to mitigation level 4 will be the indicators that nitrogen fertilizer BMPs have proven to be ineffective, which is the trigger for implementing more stringent water resource protection requirements under Minn. Stat. § 103H.275, subd. 1(b).

It is necessary and reasonable to include in a mitigation level 4 order any practice that meets Minn. Stat. § 103H.275, subd. 2(a) factors, rather than limiting the commissioner's authority (except as described below in Subp. 3. Exceptions.) to specific, enumerated practices at this time, because agricultural methods, scientific knowledge, treatment methods, and technology will have advanced significantly by the time a DWSMA gets to mitigation level 4, and it would be unreasonable to limit the commissioner's authority to what technology exists at the time a proposed Rule is passed. The commissioner will need to meet the statutory requirements set forth in Minn. Stat. § 103H.275, subd. 2(a) that require that any 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 MDA must consider these conditions in order to require a practice under mitigation level 4. In considering economic factors in mitigation level 4, it is reasonable and necessary to consider economic impacts both to affected farmers as well as to area residents who must bear the costs of treatment of public water supplies that have been contaminated with nitrate.

The proposed Rule states that the commissioner shall not restrict the selection of the primary crop in mitigation level 4. This part of the proposed Rule is needed and reasonable to clarify for farmers that the water resource protection requirements order will not dictate the main crop they should grow. Requiring farmers to grow the primary crop could put a huge burden on a farmer and have a significant effect on their livelihood. It is probable other crops that could be grown would not be as profitable as the primary crop. Also, other crop options may need other management than the primary crop; therefore farmers would need to alter their management. It would be unreasonable for the commissioner to prevent farmers from selecting which crop to raise in order to earn their livelihoods. The proposed Rule also states that the commissioner cannot require a nitrogen fertilizer application rate lower than the bottom of the rate range in U of M recommended nitrogen fertilizer BMPs. This is reasonable and necessary because requiring a rate that is lower than the bottom of the range would have the effect of restricting the primary crop raised by a farmer.

Subp. 3. Exceptions.

It is needed and reasonable for exceptions to the water resource protection requirements order to be allowed on a site-specific basis as there can be factors that can affect whether nitrogen fertilizer BMPs can be implemented. Weather plays an important role in agriculture, more so than many other industries. In the case of a severe weather event, where there has been damage to large amounts of a crop or a damaging storm that requires crops to be put in late, or other situations where the BMPs can't be followed, it is needed and reasonable for the MDA to grant an exception from a requirement of the water resource protection requirements order to a targeted area or even individual farmer.

H. 1573.0080 Minnesota Agricultural Water Quality Certification Program Exemption

Minn. Stat. § 17.9897 (a)(1) states that once a producer is certified, the producer *"retains certification for up to ten years from the date of certification if the producer complies with the certification agreement, even if the producer does not comply with new state water protection* *laws or rules that take effect during the certification period."* Proposed Rule language was added in order to provide certainty for those producers that are certified that they are deemed to be in compliance with the proposed Rule, for the length of their certification.

Agricultural producers certified in the Minnesota Agricultural Water Certification Program (MAWCP) shall be deemed to be in compliance with the proposed Rule so long as they are consistent with the Certification Agreement signed by the commissioner. As stated in Minn. Stat. § 17.9891 "*whereby a producer who demonstrates practices and management sufficient to protect water quality is certified for up to ten years and presumed to be contributing the producer's share of any targeted reduction of water pollutants during the certification period."* In order to be certified and meet the intent of the statute, producers need to be addressing the groundwater resource concern in areas subject to the proposed Rule. This means that they will be not only implementing the nitrogen fertilizer BMPs but exceeding them with conservation practices and management appropriate to their operation that reduces the risk of nitrate loss to both groundwater and surface water. It is necessary to include this exemption because it is required by Minn. Stat. § 17.9897.

I. 1573.0090 Alternative Management Tools; Alternative Protection Requirements

Alternative management tools (AMTs) are practices and activities designed to reduce nitrate leaching. AMTs represent an advanced level of groundwater protection that go beyond traditional nitrogen fertilizer BMPs. The MDA recognizes that implementation of nitrogen fertilizer BMPs may not be adequate to decrease the amount of nitrate leaching into groundwater to meet water quality goals in some areas or situations. In areas where groundwater is vulnerable, the MDA encourages farmers to consider AMTs to meet water quality goals.

In many cases AMT practices are developed and used by farmers and implemented in ways that are optimized for local conditions and opportunities. The tools are designed to be flexible and can be adjusted or tailored to local conditions to a greater extent than BMPs. The MDA will continue to work toward providing technical and financial resources regarding the effectiveness of these alternatives. The MDA will work with the local agricultural community to encourage and incentivize their use. The general benefits of AMTs have been documented in scientific studies.

At the present time, the AMTs fall into the following categories:

- Alternative cropping systems, including low nitrogen input crops or continuous cover,
- Advanced nitrogen fertilizer management, including variable rate application and use of advanced nitrogen requirement prescription tools,
- New technologies that can increase nitrogen use efficiency, including the use of advanced crop sensor technology,

- Enrollment in the Minnesota Agricultural Water Quality Certification Program (MAWQCP).

The AMTs are needed for the following reasons:

- Because the nitrogen fertilizer BMPs are relatively static and require a long process to change, the MDA needs AMTs to recognize new practices and technology that are developed to reduce nitrogen leaching as they evolve.
- The nitrogen fertilizer BMPs may not have sufficient flexibility to work under all conditions or situations. The AMTs provide this additional flexibility.
- Nitrogen fertilizer BMPs may not be sufficient to meet water quality goals in all areas or in all situations. The AMTs represent an advanced level of groundwater protection and are designed to go above and beyond the BMPs and improve water quality faster.
- AMTs allow the MDA to support and recognize a regulated party who wishes to implement practices that exceeds the nitrogen fertilizer BMPs.
- Including AMTs as an option in the proposed Rule will allow farmers to be recognized for practices and activities they have adopted that go beyond the nitrogen fertilizer BMPs.
- Including AMTs as an option in the proposed Rule will engage the agricultural community in problem solving and will provide an effective approach for the agricultural community to propose workable solutions and new technologies that can improve water quality on both the local and state level.
- Maintaining a list of approved AMTs will provide a rapid and effective means for sharing information on new and effective methods to address nitrate concerns.

Thus, it is needed and reasonable for the MDA to include AMTs in the proposed Rule.

Subp. 1. Alternative Management Tools. A and B.

The MDA will maintain a list of approved AMTs and make this list available on the website. This list will be updated on a regular basis as AMTs are evaluated and approved. The list of alternative management practices is needed to inform responsible parties of the recognized AMTs available to them. Publishing this list on the MDA's website and updating it annually is reasonable as it informs regulated parties of options available to them to reduce the risk of nitrate leaching into groundwater. If the regulated party is subject to a water resource protection requirements order this list will inform them of other practices that could be implemented and allow them to still meet the requirements of the water resource protection requirements order.

Subp. 1. Alternative Management Tools. C.

The list of AMTs on the MDA's website will state whether these practices can be used in addition to nitrogen fertilizer BMPs or if they can be substituted for a nitrogen fertilizer BMP. Substitutions are necessary as in some cases, an AMT might go above and beyond a particular

BMP and implementation of that BMP is no longer necessary, or the tool may be incompatible with the BMP. In some cases the AMT might be most effective when used in combination with a nitrogen fertilizer BMP. Keeping records of the practices used where an AMT was substituted for another required practice will allow for the AMTs to be counted during the evaluation of nitrogen fertilizer BMPs.

Subp. 1. Alternative Management Tools. D.

This proposed Rule is needed and reasonable because if a producer wants to go above and beyond the nitrogen fertilizer BMPs, the MDA supports this. In many cases, AMTs can be tailored to the local conditions to a greater extent than the nitrogen fertilizer BMPs.

Subp. 2. Alternative protection requirements.

Minn. Stat. § 103H.275, subd. 2(e) requires the MDA to allow persons subject to water resource protection requirements to be able to suggest alternative protection requirements. Therefore, it is needed and reasonable for the proposed Rule to lay out the process by which a responsible party could apply to the MDA for an alternative protection requirement.

J. Effective Date.

The effective date is necessary to give affected parties time to implement the necessary changes in their organizations before the restrictions go into place. January 1, 2020 is a reasonable start date as the MDA heard from several comments during the summer 2017 comment period that some of the larger affected parties can purchase fertilizer as much as a year ahead of time,. With the proposed Rule expected to be adopted in early 2019, giving that additional year to use the existing stock seemed reasonable. The proposed effective date is also reasonable because the MDA plans to use the fall of 2019 to conduct education and outreach to affected parties.

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VIII. Appendixes

1. Fertilizing Corn Grown on Irrigated Sandy Soils
2. Best Management Practices for Nitrogen Use in Minnesota
3. Best Management Practices for Nitrogen on Coarse Textured Soils
4. Best Management Practices for Nitrogen Use: Irrigated Potatoes
5. Best Management Practices for Nitrogen in Southeastern Minnesota
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9. Nitrogen Fertilizer Management Plan
10. Potential Nitrogen Sale Reduction

UNIVERSITY OF MINNESOTA EXTENSION

NUTRIENT MANAGEMENT

AG-NM-1501 (2015)

Fertilizing Corn Grown on Irrigated Sandy Soils

John A. Lamb, *Nutrient Management Specialist*
Carl J. Rosen, *Nutrient Management Specialist*
Phyllis M. Bongard, *Educational Content Development & Communications Specialist*
Daniel E. Kaiser, *Nutrient Management Specialist*
Fabian G. Fernandez, *Nutrient Management Specialist*
Brian L. Barber, *Director, Soil Testing Laboratory*

Most irrigated corn grown in Minnesota is on soils derived from sand and gravel outwash deposits. Sub-soils are sandy while the surface soil's textures can range from sand to silty clay loam. With irrigation, these soils are very productive but nutrient application is necessary to get the most economical production from them. These soils also require high levels of management to control nutrient loss and related environmental degradation and profitability concerns.

NITROGEN BEST MANAGEMENT PRACTICES

Currently, the use of best management practices (BMPs) for nitrogen (N) is voluntary. Corn growers on irrigated sandy soils should implement BMPs to optimize N use efficiency, profit, and protect against increased losses of nitrate-N to groundwater aquifers. The focus of this publication is to present recent findings for N fertilizer use, especially related to rate of application and time of application. For more detailed discussion on time of application, selection of N source, placement of fertilizer N, and decisions regarding the use of nitrification inhibitors please see Extension publications listed under Related Publications.

Rate of N Application

Because of environmental risks and profitability concerns, N is the most important nutrient input for irrigated corn. The corn fertilizer guidelines established in 2006 were based on the use of the Maximum Return To Nitrogen (MRTN) concept. This concept incorporates the productivity of the soil, the cost of N fertilizer, the price received for corn, and the grower's attitude towards risk associated with insufficient N for the crop and risk of environmental degradation.

When the MRTN concept was developed, there was relatively little current information for corn N response on irrigated sandy soils. A decision was made to use data from highly productive fine-textured soils for the irrigated sandy soils until an adequate amount of data was collected under irrigation. Here we discuss N rates based on field research conducted since 2007 on irrigated sandy soils. The corn market and fertilizer costs do affect the economic optimum N rate. To account for this, the ratio of the price of N fertilizer per pound to the value of a bushel of corn is used in the N rate decision. An example calculation of the price/value ratio is if N fertilizer costs $0.50 per lb N or $830 per ton of anhydrous ammonia, and corn is valued at $5.00 per bushel, the ratio would be 0.50/5.00 = 0.10. Once the soil productivity, in this case irrigated sandy soils, and price/value ratio have been determined, a producer's attitude towards risk must be factored into the process. The acceptable range listed in **Table 1**, was calculated as the difference in return of $1 per acre around the MRTN value. Choosing the lowest N rate in the acceptable range, a producer would only reduce profit $1 per acre compared to the MRTN N rate. A producer who is risk adverse and cannot tolerate risk associated with less-than-maximum yield in some years, even though economic return to N may not always be the greatest, may want to use the N rates near the high end of the acceptable range shown in **Table 1**. On the other hand, if input money is tight and/or other risk factors are a concern, producers may choose N rates near the low end of the acceptable range in Table 1. This acceptable range gives the producer flexibility in arriving at an acceptable and profitable N rate. The MRTN value shown in **Table 1** is the N rate that maximizes profit to the producer based on the results of experiments supporting these guidelines.

The N rate guidelines in **Table 1** are used if corn is grown in rotation with corn on irrigated sandy soils.

Table 1. Guidelines for use of N fertilizer for corn after corn grown on irrigated sandy soils.

N price/Crop value ratio	MRTN	Acceptable range
	------------- lb N/acre -------------	
0.05	233	214 – 252
0.10	209	192 – 225
0.15	191	177 – 206
0.20	177	164 - 190

To arrive at a guideline following other crops, an adjustment (credit) is made to the corn following corn guidelines. The adjustments can be found in Table 2. In **Table 2**, several crops are divided into Group 1 and Group 2. The crops for each group are listed in **Table 3**.

The N rates listed in **Table 1** define the total amount of fertilizer N that should be applied to maximize returns on the N investment. Any N applied in a starter fertilizer, weed and feed program, DAP (di-ammonium phosphate) or MAP (mono ammonium phosphate) should be included in the calculation of the total amount of N applied during the growing season.

Table 2. Nitrogen credits for different previous crops for first year corn.

Previous crop	1st year N credit
	lb N/acre
Soybean	30
Harvested alfalfa	100
Group 1 crops	75
Group 2 crops	0
Edible bean	20
Field pea	20

Table 3. Crops in Group 1 and Group 2.

Group 1 crops	Group 2 crops	
alsike clover	barley	potatoes
birdsfoot trefoil	buckwheat	rye
grass/ legume hay	canola	sorghum-sudan
grass/ pasture	corn	sugar beet
fallow	grass hay	sunflower
red clover	grass pasture	sweet corn
	oats	vegetables
		wheat

If your irrigation water has more than 10 ppm of nitrate-N in it, you should account for the amount supplied by the irrigation water above 10 ppm when determining the amount of N to apply. Irrigation water below 10 ppm nitrate-N is considered background N.

Table 4. Nitrogen credits for some forage legumes if corn is planted two years after the legume.

Legume crop	2nd year N credit
	lb N/acre
Harvested alfalfa	50
Red clover	35

It's generally accepted that legume crops provide N to the next crop in the rotation. Some forage legumes provide some N in the second year after the legume was grown. These second year N credits are listed in **Table 4.** If corn is grown in the second year following alfalfa and red clover, these N credits should be subtracted from the N rates in **Table 1.**

Time of N Application

The impact of timing of fertilizer N application for irrigated corn has been the focus of considerable research. Results of these research efforts lead to the conclusion that split applications are superior to a single application. Results from recent studies, **Table 5**, confirm this conclusion with modern corn production. The value of the split application is especially influenced by the amount and frequency of rainfall during the growing season. In 2012, there was considerable rainfall (5 to 6 inches) between planting and the first split application. Corn yield data confirms the superiority of split applications of urea in a wet year. While 2013 was not as wet, split application corn yields were still superior.

Table 5. The effect of split N applications on corn yields. Nitrogen was applied at 160 lb N/A. Rosen and Lamb 2014.

	2012		2013	
Method	Site 1	Site 2	Site 1	Site 2
	---- Corn grain yield (bu/A) ----			
Check (no N)	119	75	110	46
Urea pre-plant	164	106	190	172
BMP V2, V4	193	198	221	159
4 way split V2, V4, V6, and V8	210	220	228	190

When leaching is a potential problem, either a two or four equal side-dress N applications after emergence produced the greatest grain yields. Yields were low when all of the N fertilizer was applied before planting.

Based on the results of research trials conducted over the years, pre-plant applications are not recommended. There are several options for split applications on irrigated sands. These are:

- N in starter plus side-dress N
- N in the starter plus split side-dress N
- N in the starter plus side-dress N plus N injected in the irrigation water
- N in the starter plus N injected in the irrigation water
- N in the starter plus pre-emergence herbicide applied with UAN plus side-dress N
- N in the starter plus pre-emergence herbicide applied with UAN plus N injected with the irrigation water.

From both an agronomic and environmental perspective, split application of fertilizer N is a good management practice. There are many choices and the grower can choose the one that fits the farming enterprise. When planning a system for split application for corn, the last application of N should take place before the silks turn brown.

Nitrogen Sources and Additives

Responding to the recognition that loss of nitrate-N caused by leaching is a universal concern enhanced efficiency products have been developed to reduce the potential for loss. The use of these products can be especially important in irrigated sandy soils where N loss potential is great.

Table 6. The effect of N products applied pre-plant on corn grain yield that reduce potential for N loss in sandy soils. Nitrogen was applied at a 160 lb N/A rate. Rosen and Lamb 2014.

	2012		2013	
Product/Method	Site 1	Site 2	Site 1	Site 2
	Corn grain yield (bu/A)			
Check (no N)	119	75	110	46
ESN* preplant	165	160	232	187
Instinct**preplant	136	132	233	191
Super U***preplant	182	116	231	190
Urea preplant	164	106	190	172
BMP V2, V4	193	198	221	159
4 way split V2,V4, V6, V8	210	220	228	190

* ESN is urea coated with a polymer that slows N release.
** Instinct is a formulation of nitrapyrin for urea, UAN, and manure.
*** Super U is a combination of a nitrification inhibitor (DCD) and urease inhibitor (NBPT).

In a recent study comparing several different enhanced efficiency products, the products produced greater corn grain yields than untreated urea applied pre-plant, **Table 6**. When compared to a two or four way split in-season application of urea, the enhanced efficiency products were not superior. In only 1 of 9 site years, N products produced better corn yields than the 2 way split application and in the 9 site years, the products produced either equal or less corn grain yield than the 4 way split application of urea.

Application Below the Soil Surface

Although the risk is minimal with acid sandy soils, there can be some loss of N via volatilization if fertilizer N is placed on the soil surface and not incorporated. It is suggested to incorporate any N (28-0-0, 46-0-0, etc.) that is applied to the soil surface. Cultivation or irrigation water can be used for this incorporation. Application just prior to rain would also be acceptable. Studies conducted in other states in the Corn Belt have shown that 0.25 inches of irrigation water or rainfall is necessary to incorporate either 46-0-0 or 28-0-0 that has not been previous incorporated.

PHOSPHATE AND POTASH GUIDELINES

When needed, the use of phosphate and/or potash fertilizer can produce profitable increases in corn yields. The guidelines for phosphate use are summarized in **Table 7** and for potash in **Table 8**.

Phosphate

The phosphate guidelines provided in **Table 7** change with phosphorus (P) soil test level, expected yield, and placement. In general, the results of the Olsen test should be used if the soil pH is 7.4 or higher. Because at those pH levels the bray test tends to underestimate the amount of plant-available P. However, there are some situations when soil pH values are higher than 7.4 where the results of the Bray test are higher than the results of the Olsen test. In these cases, base the phosphate application off the higher value.

Measurement of P by the Mehlich-III procedure is not recommended in Minnesota. However, if the soil testing laboratory uses this analytical test, follow the category guidelines for the Bray procedure as long as the soil pH is less than 7.5. The Olsen test is suggested when the soil pH is higher than 7.4 because while the Mehlich-III test is correlated to the Olsen test, the Olsen P categories in **Table 7** do not match the Mehich-III test.

Table 7. Phosphate guidelines for corn production in Minnesota.*

Expected yield		Soil test P (ppm)									
	Category:	v. low		low		medium		high		v. high	
	Bray:	0-5		6-10		11-15		16-20		21+	
	Olsen:	0-3		4-7		8-11		12-15		16+	
	Placement:	Bdcst	Band	Bdcst	Band	Bdcst	Band	Bdcst	Band	Bdcst	Band
bu/acre		lb P_2O_5 per acre to apply									
175 – 199		110	55	75	40	45	30	15	10-15	0	10-15
200 – 219		130	65	90	45	55	30	20	10-15	0	10-15
220 – 239		145	75	100	50	60	3o	20	10-15	0	10-15
240 +		160	80	115	60	70	35	25	10-15	0	10-15

** Use one of the following equations to determine the amount of P_2O_5 if a specific soil test value and a specific expected yield is desired.*
lb P_2O_5 per acre = [0.700 - 0.035 (Bray P ppm)] (expected yield)
lb P_2O_5 per acre = [0.700 - (0.044 (Olsen P ppm)] (expected yield)
No phosphate fertilizer should be applied if the soil test for P is greater than 25 ppm (Bray) or 20 ppm (Olsen).

Rate Changes with Placement

A combination of band and broadcast applications is suggested when the soil test for P is very low (0-5 ppm for Bray; 0-3 ppm for Olsen). In these situations, use the suggested band rate in a band at planting, subtract this amount from the suggested broadcast rate, then broadcast and incorporate the remainder before planting.

Phosphate fertilizer can be applied either as a broadcast application or in a band if the soil test value for P is in the low (6-10 ppm for Bray; 4-7 ppm for Olsen) or medium (11-15 ppm for Bray; 8-11 ppm for Olsen) categories.

Broadcast applications of phosphate fertilizer have a low probability of increasing corn yields when the soil test or P is in the high category (16-20 ppm for Bray; 12-15 ppm for Olsen) but a banded application can be more advantageous. No phosphate fertilizer is needed (broadcast or banded) if the soil test is higher than 25 ppm (Bray), or 20 ppm (Olsen), in conventional tillage systems.

Potash

As with phosphate, the guidelines for potash vary with the potassium (K) soil test level, expected yield, and placement (**Table 8**). A combination of band and broadcast applications is suggested when the soil test for K is very low (0-40 ppm). In these situations, use the suggested band rate in a band at planting, subtract this amount from the suggested broadcast rate, then broadcast and incorporate the remainder before planting.

Potash fertilizer can be applied either as a broadcast application or in a band if the soil test value for K is in the low (41-80 ppm) or medium (81-120 ppm) categories.

Broadcast applications of potash have a low probability of increasing corn yields when the soil test value for K is in the high category (121-160 ppm), but a banded application can be more advantageous.

There is a low probability of response to broadcast applications of potash if the soil test for K is higher than 160 ppm. No potash fertilizer is needed (broadcast or banded) if the soil test is greater than 175 ppm in conventional tillage systems.

Potassium can be considered a mobile nutrient in very sandy soils that have low nutrient holding capacity. Split application of K has been proposed as a way to maintain K availability through the growing season. However, field studies over two growing seasons showed no yield advantage to split applied K in irrigated sandy soils.

Table 8. Potash guidelines for corn production in Minnesota.*

	Soil test K (ppm)									
Category:	**v. low**		**low**		**medium**		**high**		**v. high**	
Expected yield	**0-40**		**41-80**		**81-120**		**121-160**		**160+**	
	Bdcst	**Band**	**Bdcst**	**Band**	**Bdcst**	**Band**	**Bdcst**	**Band**	**Bdcst**	**Band**
bu/acre	--- lb K_2O per acre to apply ---									
175 - 199	**185**	**90**	**135**	**70**	**80**	**50**	**25**	**10-15**	**0**	**10-15**
200 - 219	**210**	**105**	**165**	**80**	**90**	**55**	**30**	**10-15**	**0**	**10-15**
220 -239	**235**	**120**	**165**	**85**	**100**	**60**	**30**	**10-15**	**0**	**10-15**
240 +	**255**	**130**	**180**	**90**	**110**	**65**	**35**	**15-20**	**0**	**10-15**

* *Use one of the following equations to determine the amount of* K_2O if *a specific soil test value and a specific expected yield is desired.*

lb K_2O per acre = [1.166 - 0.0073 (soil test K, ppm)] (expected yield)

No potash fertilizer should be applied if the soil test for K is 175 ppm or higher.

The study showed no differences in K availability in the soil or plant K uptake when K was applied in a single pre-plant application pre-plant, side-dress at V5, or in a split application at pre-plant and at V5. The study illustrated that targeting the appropriate rate of K_2O is more important than the timing of application.

Special Considerations

Because of the diversity in Minnesota's soils and climate, land rental and lease arrangements, and goals of individual growers, the phosphate and potash recommendations listed in **Tables 7 and 8** cannot be rigid across the entire state. There are some special situations where rates might be changed. Some, but not all, of these situations are described in the following paragraphs.

East Central Minnesota

Soils in this region of the state usually have high native levels of soil test P and strict interpretation of the recommendations suggests that no phosphate is needed in a fertilizer program. Yet, many have observed responses to phosphate when applied in a band at planting. Soils in this region are frequently cool and wet in the spring and these conditions can lead to a requirement for phosphate fertilizer early in the growing season. Therefore, regardless of soil P level, a rate of 10-20 lb. P_2O_5 per acre in a band close to the seed is suggested for corn production in these situations.

Broadcasting Low Rates

Some of the guidelines for phosphate and potash use listed in **Tables 7 and 8** are small and fertilizer spreaders cannot be adjusted to apply these low rates. In some situations, the suggested broadcast rate of phosphate can be blended with the suggested broadcast rate of potash and the mixture could then be applied with available equipment.

In other situations, broadcast applications of low rates of only phosphate or potash may be suggested. For these fields, it may be more practical to double the suggested broadcast rate and apply on alternate years.

Changes in Soil Test Values

Many growers would prefer to maintain soil test values for P and K in the medium to high categories. This is especially true if they own, rather than rent, the land. There is justified concern that soil test levels for either P or K will drop substantially if low rates of phosphate or potash fertilizers are applied year after year.

Research in Minnesota has shown that soil test levels for P and K do not change rapidly with time. Yearly decreases have been small for situations where no phosphate or potash fertilizer has been applied.

A small decrease in soil test levels for P and K can be expected when phosphate and potash are used repeatedly in a banded fertilizer application. Likewise, some reduction can be expected when low rates of phosphate and potash are used year after year. When soil test values drop, broadcast applications of higher rates of phosphate and/or potash fertilizers are justified if profitability and cash flow is favorable and the grower wants to maintain soil test values in the medium or high categories.

Unless long-term leases or rental arrangements are used, a banded application of phosphate and/or potash may be the most profitable management system for rented land. It is difficult to economically justify the use of high rates of phosphate and/or potash to build soil test levels on rented acres.

ADJUSTING FOR MANURE USE

The plant nutrients used in a fertilizer program for corn should be reduced if manure is used. The nutrient value of manure, however, varies with type of livestock, handling system, and method of application. Old general rules are no longer appropriate when calculating the nutrient value of manure. Manure nutrient credits should be subtracted from the fertilizer guideline. There are several extension publications that describe in detail the use of manure. These publications are listed at the end of this folder.

BANDING FERTILIZER

The use of a banded fertilizer at planting is an excellent management tool for corn production in Minnesota especially when soil conditions are cold and wet at planting. Yield increases are not always guaranteed with the use of a starter when soil test values are in the very high category. Recent research shows frequent response to banded fertilizer when soil test values for P and/or K are in the high category and yield potential is high. Banding P and/or K can be considered a good insurance policy.

The rate of fertilizer that can be applied in a band below and to the side of the seed at planting varies with the nutrient and type of fertilizer used, the distance between seed and fertilizer, and soil texture. See Use of Banded Fertilizer for Corn Production (FO-74250) for more information.

CAUTION! Do not apply urea (46-0-0), ammonium thiosulfate (12-0-0-26) or fertilizer containing boron in contact with the seed.

SULFUR USE

The addition of sulfur (S) to a fertilizer program should be a major consideration when corn is grown on sandy soils, reduced tillage systems or in a long continuous corn rotation.

The use of a soil test for S is not a reliable predictor of the need for sulfur in a fertilizer program. If the soil texture is a loamy sand or sandy loam, either apply 12 to 15 lb. S per acre in a banded fertilizer or broadcast and incorporate 25 lb. S per acre before planting. The optimal amount of S may vary based on the organic matter concentration in the top six inches of the soil surface. If organic matter concentrations are greater than 4.0% the amount of S required to maintain high yields may be as little as 10-15 lb S per acre.

There are several materials that can be used to supply S. Any fertilizer that supplies S in the sulfate (SO_4^{2-}-S) form is preferred. Elemental S is cost effective but must be oxidized to SO_4^{2-}-S to be available for corn uptake. The oxidation process is slow and is dependent on soil temperature. Elemental S should not be applied as the soil S source in situations where a deficiency is expected. Because the greatest need for S occurs early in the growing season, application of any needed S in a starter fertilizer is preferred. Keep in mind that ammonium thiosulfate should not be placed in contact with the seed. This material will not harm germination or emergence if there is 1 inch of soil between the seed and the fertilizer.

Is there a benefit from split application of S for irrigated corn?. Sulfate is mobile in the soil but the mobility depends on soil texture. Movement can be rapid on very sandy soils but decreases as the relative amount of clay in the soil increases. Research found no yield benefit from split applications of S on irrigated fields even in situations with heavy precipitation totals in May and June. This research also indicated that a significant portion of corn uptake, (10-20 lbs SO_4^{2-}-S per acre) could be applied through the irrigation water during the growing season. It is critical to have some available S early in the growing season when no irrigation water is applied.

MAGNESIUM NEEDS

Most Minnesota soils have an adequate natural supply of with magnesium (Mg), thus this nutrient is not usually needed in a fertilizer program. There are some exceptions, however. The very acid soils of east-central Minnesota might need Mg. There should be no need for the addition of Mg if dolomitic limestone has been applied for legume crops in the rotation. There is a soil test that can be used to predict the need for Mg. The guidelines for using Mg in a fertilizer program are summarized in **Table 9**.

Table 9. Guidelines for magnesium use for corn production.

Magnesium soil test	Relative level	Mg to apply	
		Band	Broadcast
ppm		------- lb per acre -------	
0 – 50	Low	10 - 20	50 - 100
51 – 100	Medium	Trial*	0
101 +	Adequate	0	0

*Apply 10 -20 lb. Mg per acre in a band only if a Mg deficiency is suspected or if a deficiency has been confirmed by plant analysis.

MICRONUTRIENT NEEDS

Table 10. Zinc guidelines for corn production in Minnesota.

	Zinc to apply	
Zinc soil test*	Band	Broadcast
- ppm -	------------- lb per acre -------------	
0.0 – 0.25	2	10
0.26 – 0.50	2	10
0.50 – 0.75	1	5
0.76 – 1.00	0	0
1.01 +	0	0

* Zinc extracted by the DTPA procedure.

Research trials conducted throughout Minnesota indicate that zinc (Zn) is the only micronutrient that may be needed in a fertilizer program for the corn production. This nutrient, however, is not needed in all fields. The soil test for Zn is very reliable and will accurately predict the needs for this essential nutrient. The guidelines for Zn are summarized in **Table 10.** Because corn is the only agronomic crop that will consistently respond to Zn fertilization, the use of Zn in a banded fertilizer is highly recommended. However, carryover to succeeding years will be better with broadcast applications. There are several fertilizer products that can be used to supply Zn. Except for large particles of zinc oxide, all commercially available sources of this nutrient are equally effective so cost should be a major consideration in product selection.

The use of iron (Fe), copper (Cu), manganese (Mn), and boron (B) is not suggested for corn fertilizer programs in Minnesota.

Additional information about nutrient management in all crops can be found at: www.extension.umn.edu/agriculture/nutrient-management.

The Corn Nitrogen Rate Calculator can be found at: http://extension.agron.iastate.edu/soilfertility/nrate.aspx

For more information:
www.extension.umn.edu/agriculture/nutrient-management/

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Best Management Practices for Nitrogen Use in MINNESOTA

BEST MANAGEMENT PRACTICES FOR NITROGEN APPLICATION

Best Management Practices for Nitrogen Use in Minnesota

John Lamb, Professor, Department of Soil, Water, and Climate; Gyles Randall, Soil Scientist and Professor, Southern Research and Outreach Center, Waseca; George Rehm, Nutrient Management Specialist (retired); Carl Rosen, Professor, Department of Soil, Water, and Climate, University of Minnesota

Introduction

Best Management Practices (BMP's) for management of nitrogen (N) were first developed for Minnesota in the late 1980's – early 1990's. These BMP's were based on University research. The objective of this series of publications is to update the BMP's with research information collected since that time. This publication will explain factors that were used to divide the state into specific regions, and the rationale for the BMP's in each region, and, finally, the process used to determine N recommendations appropriate for each region.

History

In response to the Comprehensive Groundwater Protection Act of 1989, a Nitrogen Fertilizer Management Plan was developed with the purpose of managing nitrogen (N) inputs for crop production so as to prevent degradation of Minnesota water resources while maintaining farm profitability. The central tool for achievement of this goal has been the adoption of Best Management Practices (BMP's) for fertilizer N. Fertilizer N is the primary focus of the BMP's, however, consideration of other nitrogen sources and agronomic practices is necessary for effective and practical total N management.

The focus in the majority of the publications is on N fertilization of corn. However, appropriate N management practices for small grain, sugarbeets, and edible beans are described in the appropriate publications. A separate BMP publication has been prepared for potatoes grown on irrigated soils.

BMP's for N are broadly defined as "economically sound, voluntary practices that are capable of minimizing contamination of surface- and groundwater with nitrate-nitrogen (NO_3^--N)." The BMP's recommended are based on research, particularly at the University of Minnesota and other land-grant universities, and practical considerations. This ensures that the BMP's are technically sound and likely to be easily adopted by growers.

BMP's are not universal across Minnesota. The combination of several factors lead to BMP's for each identified region of Minnesota. These factors are briefly described in the sections that follow.

Parent Material

Minnesota is a land of geologically young soils formed from many different parent materials (Figure 1). The common factor is that the soils were formed as a product of the last glacier occurrence in the Northern United States 11 to 14 thousand years ago. While to humans this is a long time period, it is considered recent in terms of geologic time. Figure 1 shows the distribution and extent of the five major parent materials (till, loess, lacustrine, outwash, till over bedrock) in Minnesota.

Till is predominant in the south central, west central and southwestern regions of the state. This material was deposited as the last glacier was melting and receding. Soils formed in this material generally have clay loam to silty clay loam textures at the surface, many different sizes of rocks throughout the root zone, and poor internal drainage. The poor drainage has a large influence on both N management practices and cultural practices.

Loess is wind blown silt-sized material that was blown in after the glacier melted. Silt deposits can range in thickness from a few inches to many feet.

The soils formed in loess generally have a silt loam texture and there are no rocks in the root zone. The majority of soils formed in loess occur in southeastern Minnesota. These loess deposits are on top of limestone or sandstone. Because of the porous state of these underlying parent materials in Minnesota, soils formed on loess are generally well drained. The loess materials in southwestern Minnesota are deposited over glacial till. The soils formed in this material in this region are generally poorly to somewhat poorly drained and N management practices are similar to those used for soils formed in glacial till.

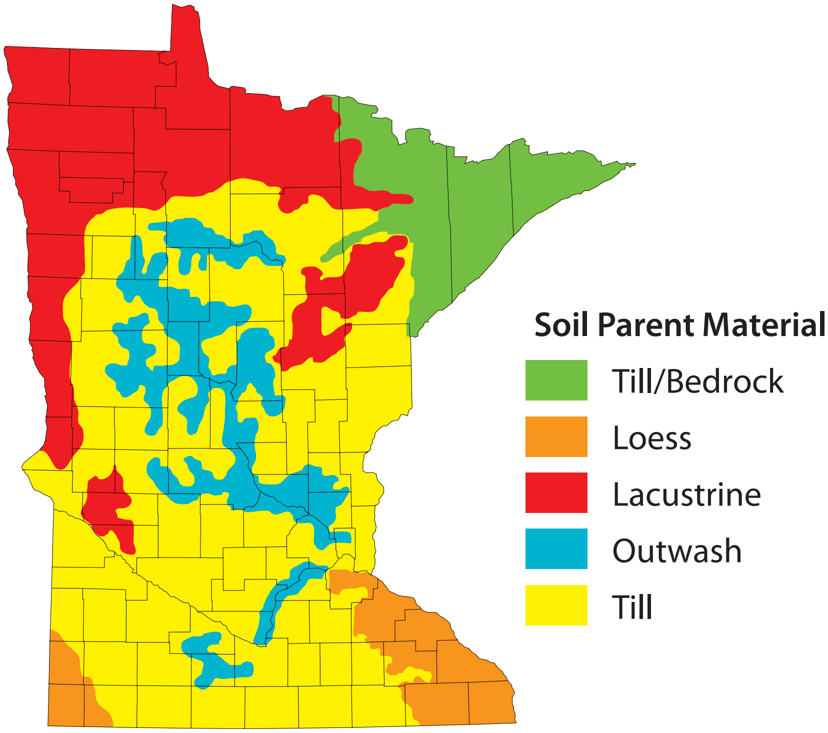


Figure 1. Parent materials of Minnesota.

Lacustrine parent materials are a result of material deposited in the bottom of a lake formed by the meltwaters of the glacier. In these lakes, the large particles such as rocks and sands were deposited immediately after the lake was formed while the smaller clay-size particles were deposited later. The soils formed under glacial Lake Agassiz in northwestern Minnesota and eastern North Dakota are good examples. There are smaller areas of soils formed in lacustrine material in other areas of Minnesota. Soils formed in lacustrine deposits have clay, clay loam, and silty clay loam textures, poor internal drainage, and no rocks.

Outwash material is the material deposited on the edges of fast running rivers of water from the melting ice of the glacier as it receded. These materials are large in size; rocks, gravel, and sand. These materials were large enough to drop out of the water flow while smaller particles continued to be transported in the current of the river. Soils formed in outwash materials are excessively well drained and have sand and sandy loam textures. Examples of areas in Minnesota with soils formed in outwash include the Anoka Sand Plain, North Central Sands, the Bonanza Valley and other parts of east central, north central, and central Minnesota.

Till/ bedrock deposits occur in northeastern Minnesota. Materials from the glacier were deposited over bedrock similar to south central Minnesota but material came from different glacial ice and there are significant areas where the soils were formed in bedrock. These soils tend to be shallow, allowing for limited root development and are not used extensively for crop production.

Climate

Since N movement in the soil is affected by the amount of soil water movement and soil temperatures, climate is an important factor in N management decisions. Precipitation is one of two factors that govern water movement in the soil. Average annual precipitation in Minnesota is the least in the northwest corner at 16 inches and greatest in the southeast corner where the average annual precipitation is 34 inches (Figure 2).

Evapotranspiration is the second factor that governs water movement through soils. Evapotranspiration is the combination of water evaporated from the soil surface and the amount of water transpired by growing plants. As air temperatures increase, evapotranspiration increases. If evapotranspiration is great, less water is available to cause loss of N by leaching or denitrification. In Minnesota, the greatest evapotranspiration occurs in the southwestern part of the state and least in the northeastern corner.

When combining these two factors (rainfall, evapotranspiration) one can calculate a leaching index or moisture index (Figure 3). This index is an indicator of average soil moisture conditions. The greater the index the more water present either in the soil or potentially percolating through the soil. There is a greater probability for N loss and greater need for careful N management as the index increases.

Chemical and biological reactions in the soil that involve N are related to temperature. Rates of various reactions increase as soil temperature increases. Normal average annual air temperatures in Minnesota ranges from 35 degrees F in the north to 46 degrees F in the south (Figure 4.). With a delay of about one day, soil temperatures fluctuate in the same way as air temperatures. Soil temperature affects N management because it has a direct impact on timing of soil sample collection and the application of N fertilizer. Lower soil temperatures are directly related to a reduced risk of the conversion of ammonium (NH_4^+), a less mobile form of N in the soil, to nitrate (NO_3^-) a very mobile form. The loss of N to denitrification, a biological process, is also related to soil temperature.

Combinations of soil parent material and climate parameters have led to the delineation of the BMP regions presented in Figure 5.

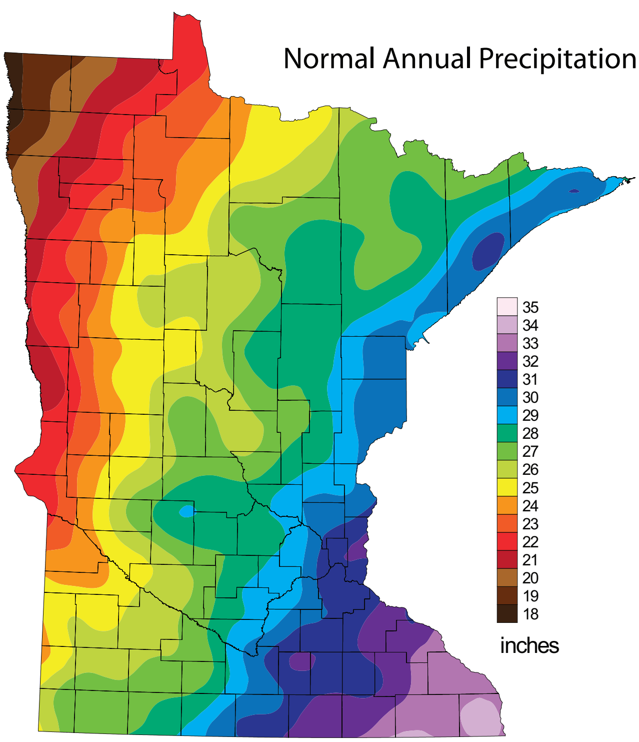


Figure 2. Normal annual precipitation in Minnesota

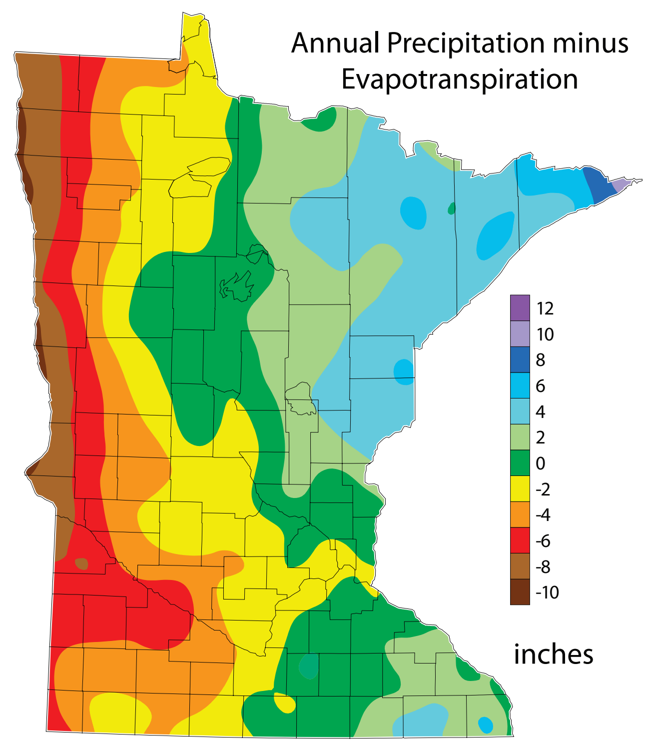


Figure 3. Annual precipitation minus estimated evaporation (leaching index) for Minnesota.

Minnesota BMP Regions

There are five BMP regions in Minnesota: Northwestern, Southwestern and West Central, South Central, Southeastern, and Irrigated and non-irrigated sands (Figure 5). The BMP's have been identified for coarse-textured soils that occur throughout the state.

The northwestern region is characterized by the least rainfall and evaporation. The parent material is predominantly lacustrine. While soils formed in lacustrine deposits are poorly drained, the reduced rainfall in this region decreases concerns for N losses from leaching and denitrification. Therefore, fall applications of nitrogen can be tolerated without a large concern about losses if soils do not have a sandy texture (sand, loamy sand, sandy loam).

The west-central and southwestern BMP region is characterized by a warmer and relatively drier climate. Glacial till and loess are predominate parent materials in this region. The loess materials are mainly found in the southwestern corner of the state. Most of the loess parent material was deposited on top of older glacial till; so soils formed in this parent material are also poorly drained. The drier climate reduces the risk of N losses; so fall N applications can be used in this region without a large concern for N loss.

The soils in the south-central region were formed in glacial till. The poor internal drainage and the increased precipitation in this region increases the chances for N losses though drainage tile or by denitrification. Fall N applications are discouraged because of these factors. The use of nitrification inhibitors should also be considered.

Southeastern region soils are formed in loess materials over a fractured limestone material. These soils have very good internal drainage. Compared to the rest of Minnesota, the precipitation is also the greatest in this region. Therefore, leaching of NO_3^--N is of great concern in this region. Spring or sidedress N application is strongly suggested.

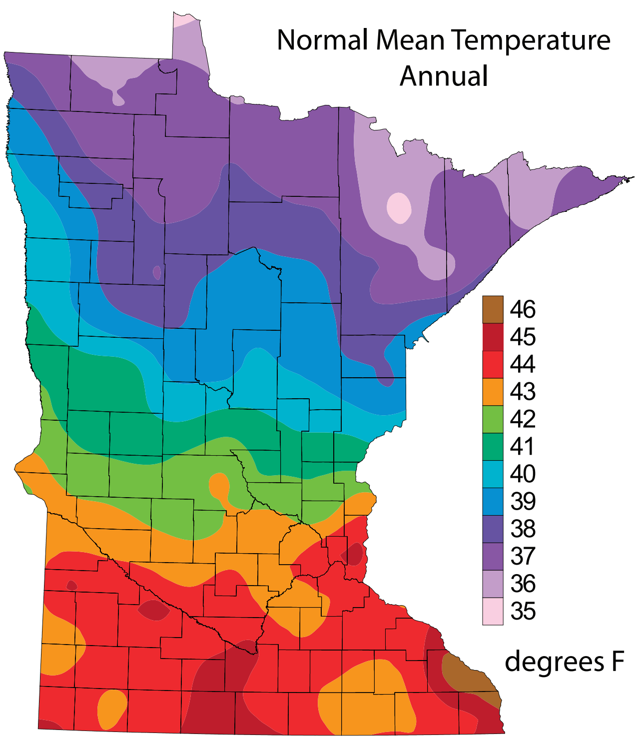


Figure 4. Normal mean annual temperatures for Minnesota.

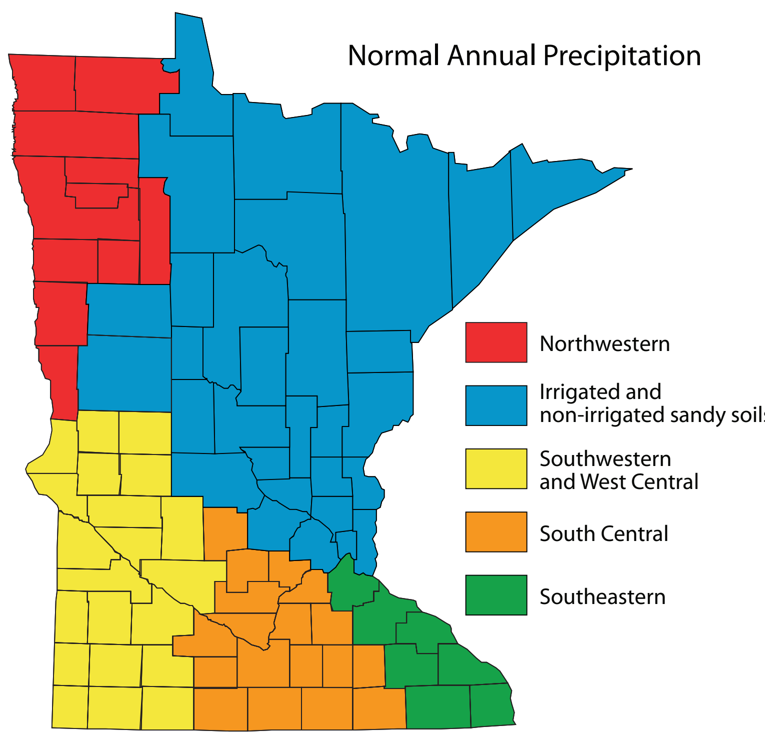


Figure 5. Minnesota NBMP regions.

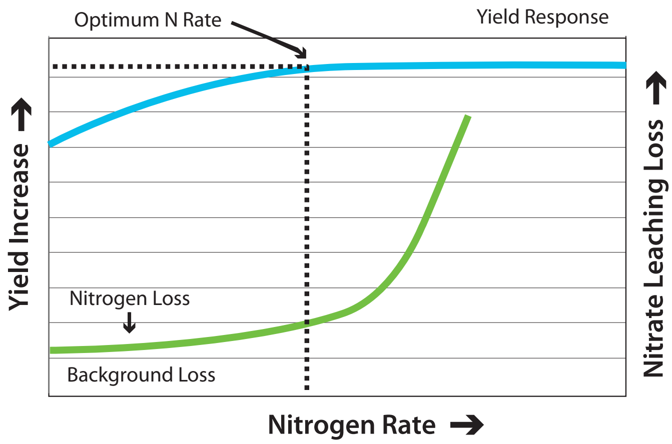


Figure 6. Importance of using optimum N rate for greatest profit and minimal nitrate-N loss.

How do we determine BMPS?

An understanding of regional differences and how they affect the N cycle is the basis of the research used to develop the BMP's. Choosing the correct rate is the number one factor in managing fertilizer N. As shown in Figure 6, N application rate is an optimization of yield increase versus N loss. Fortunately, under normal conditions, yield is optimized at the N rate where N loss is minimal. Use of the other best management practices suggested in the regional bulletins increases the probability of obtaining the most economic yield for the optimum N rate.

As mentioned earlier, the BMPs are based on University of Minnesota field research. They are the synthesis of results from research conducted from 1940 to the present day. The research has been conducted under the environmental conditions in each of the regions of Minnesota. Each field study was conducted using scientifically sound methods for making comparisons of management practices and interpreted with consideration of several other studies conducted at the same time or over years.

Summary

Best Management Practices (BMP's) for use of fertilizer N in Minnesota are diverse. There can be no "one size fits all" approach. The BMP's are different because soils and factors of soil formation are different. Recognition of these differences will result in more efficient management of fertilizer N, and maximum profit.

Related Publications

08557 (Revised, 2008) - Best Management Practices for Nitrogen Use in Southeastern Minnesota

08554 (Revised, 2008) - Best Management Practices for Nitrogen Use in South-Central Minnesota

08558 (Revised, 2008) - Best Management Practices for Nitrogen Use in Southwestern and West-Central Minnesota

08555 (Revised, 2008) - Best Management Practices for Nitrogen Use in Northwestern Minnesota

08556 (Revised, 2008) - Best Management Practices for Nitrogen Use on Coarse Textured Soils

AG-FO-5880 - Fertilizing Cropland with Dairy Manure

AG-FO-5879 - Fertilizing Cropland with Swine Manure

AG-FO-5881 - Fertilizing Cropland with Poultry Manure

AG-FO-5882 - Fertilizing Cropland with Beef Manure

AG-FO-3790 - Fertilizing Corn in Minnesota

AG-FO-3770 - Understanding Nitrogen in Soils

AG-FO-3774 - Nitrification Inhibitors and Use in Minnesota

AG-FO-2774 - Using the Soil Nitrate Test for Corn in Minnesota

AG-FO-2392 - Managing Nitrogen for Corn Production on Irrigated Sandy Soils

AG-FO-0636 - Fertilizer Urea

AG-FO-3073 - Using Anhydrous Ammonia in Minnesota

AG-FO-6074 - Fertilizer Management for Corn Planted in Ridge-till or No-till Systems

AG-FO-3553 - Manure Management in Minnesota

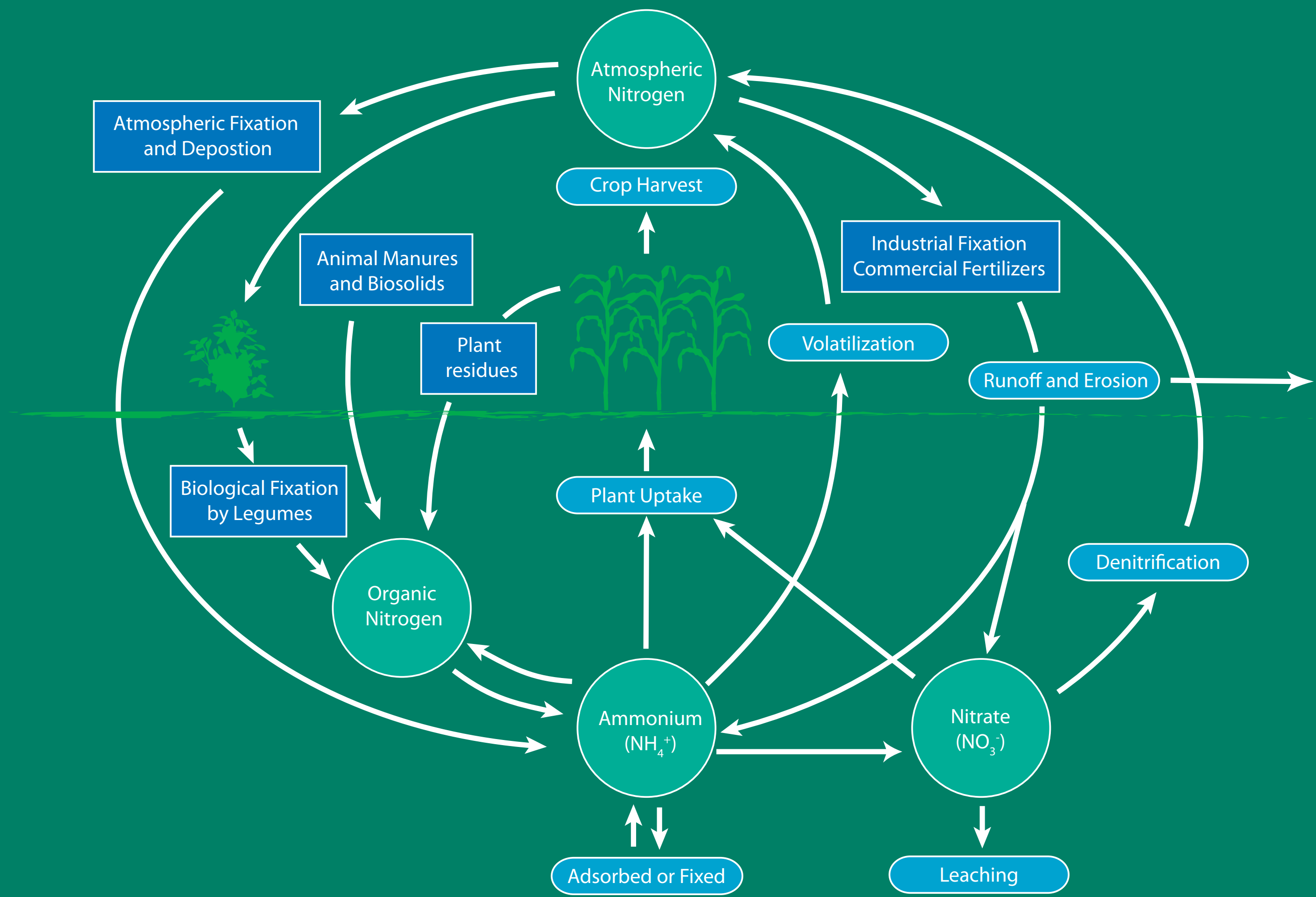
BU-07936 - Validating N Rates for Corn

Iowa State Univ. PM 2015 - Concepts and Rationale for Regional Nitrogen Rate Guidelines for Corn

FO-07715-C - Fertilizing Sugar Beet in Minnesota and North Dakota

FO-3772-C (Revised) - Fertilizing Wheat in Minnesota

FO-6572-B - Fertilizer Recommendation for Edible Beans in Minnesota



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Best Management Practices for Nitrogen Use in Minnesota

PUBLICATION # 08560

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Best Management Practices for Nitrogen on COARSE TEXTURED SOILS

BEST MANAGEMENT PRACTICES FOR NITROGEN APPLICATION

Best Management Practices for Nitrogen on Coarse Textured Soils

George Rehm, Nutrient Management Specialist (retired); John Lamb, Professor, University of Minnesota; Carl Rosen, Professor, University of Minnesota; Gyles Randall, Professor and Soil Scientist, Southern Research and Outreach Center, Waseca.

Introduction

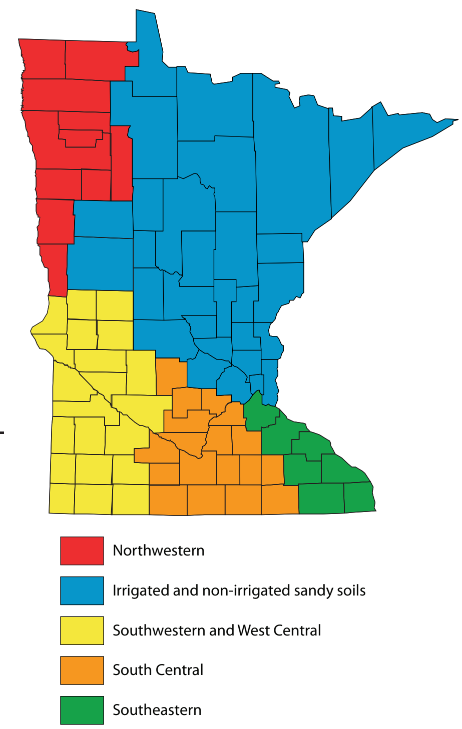
Nitrogen (N) is absorbed in large amounts by Minnesota crops. It is the major nutrient supplied in a fertilizer program. In addition, large quantities of nitrogen are part of the crop production ecosystem, including soil organic matter. Biological processes that convert nitrogen to its usable and mobile form (NO_3-N) occur continuously in the soil system. For details, see "***Understanding Nitrogen in Soils***", (**FO-3770, Minnesota Extension Service**). Nitrogen exists in several forms and conversion from one form to another can be complex.

Loss of nitrate-nitrogen (NO_3-N) from the soil system is a major environmental concern. This is especially true for irrigated sandy soils. Potential for leaching losses of NO_3-N, however, can be minimized if Best Management Practices are used. This publication describes those practices that are appropriate for corn and edible beans grown on sandy soils (see map). In Minnesota, sandy soils dominate the landscape in the central and east-central regions of the state. These coarse textured soils are also scattered throughout the remainder of the state. This publication also describes suggested Best Management Practices for corn and edible beans grown on coarse textured soils that are not irrigated.

The research-based Best Management Practices (BMP's) described in this publication are economically and environmentally sound. It is strongly suggested that they be used voluntarily.

What Are the Best Management Practices (BMP's)?

There's general agreement that BMP's are economically sound voluntary practices that, if used, are capable of minimizing contamination, of surface and ground water with NO_3-N while, at the same time, providing for profitable application of nitrogen fertilizers. The BMP's for corn and edible bean production described in this publication are based on research conducted by faculty of the University of Minnesota and other Land Grant institutions.



The BMP's relate to management of all sources of N used in crop production.

BMP's for Coarse Textured Soils

The BMP's described in this publication are appropriate for corn and edible bean production on sandy soils throughout Minnesota. While much of the discussion will focus on irrigated corn and edible beans, practices for non-irrigated crops growing on sandy soils will not be ignored. The BMP's are divided into three categories described as: 1) recommended, 2) acceptable, but with greater risk, and 3) not recommended. With respect to N management, risk can be either economic or environmental. Economic risk can be a consequence of added input costs without additional yield or reduced yield.

Environmental risk pertains to the potential for loss of nitrogen to either ground water or surface waters.

The BMP's for coarse textured soils are:

1) Recommended

- For corn, select an appropriate rate using U of M guidelines ("***Fertilizing Corn in Minnesota***" **FO-3790,** 2006 or newer) which are based on current fertilizer and corn prices, soil productivity, and economic risk.
- For edible beans, base N rate on expected yield and previous crop.
- Total N rate used for corn and edible beans should include any N supplied in a starter, in a weed and feed program, and contributions from phosphate fertilizers such as MAP and DAP.
- Use split applications of fertilizer N for both corn and edible beans.
- Use a nitrogen stabilizer (N-Serve) on labeled crops when early sidedress N is used.
- Take appropriate N credits for legumes and manure used in the crop rotation.
- If possible, apply N fertilizers below the soil surface or incorporate with light tillage or irrigation.

2) Acceptable, but with greater risk

- Spring preplant application with a nitrification inhibitor.
- Single sidedress application of anhydrous ammonia or urea early in the growing season without a nitrification inhibitor.
- Spring preplant application of ESN.

3) Not recommended

- Fall application of N regardless of source.
- Disregard for N supplied by legumes in rotation or the application of manure.
- Spring preplant N for corn without a nitrification inhibitor.
- N fertilizer applied to corn (fertigation) after tasseling.
- Application of ESN to edible beans after planting.

Choosing an Appropriate N Rate

Corn

Nitrogen rate guidelines for corn production in Minnesota have changed. Yield goal is no longer the major consideration. Instead, rate guidelines are based on 1) the productivity of the production environment, 2) the ratio of the cost of a pound of N divided by the value of a bushel of corn and, 3) the producer's attitude toward risk. The guidelines are the end product of numerous trials conducted by University of Minnesota faculty throughout Minnesota. The new guidelines agree with the concept for the approach to fertilizer N applications that will be used throughout the Corn Belt. This concept is described in detail in: **"*Concepts and Rationale for Regional Nitrogen Rate Guidelines for Corn.*" Bulletin PM 2015. Iowa State University. Ames, IA**. The N rate guidelines for corn for highly productive environments are provided in Table 1. Guidelines for this crop in environments that are considered to have medium productivity are provided in Table 2. Soil texture and availability of irrigation water are two major factors that separate highly productive environments from those that have medium productivity. Certainly, a non-irrigated soil with a loamy fine sand texture would be categorized as an environment with medium productivity. There are no specific measurable criteria that separate highly productive environments from those that are medium with respect to productivity. This choice can be made on a field by field basis by the grower with or without the advice of an ag-professional.

Table 1. Guidelines for use of nitrogen fertilizer for corn grown on soils considered to be highly productive.

N Price/Crop	corn/corn		corn/soybeans	
Value Ratio	MRTN*	Acceptable Range	MRTN	Acceptable Range
Ratio	- - - -	- - - lb. N to apply /acre	- - - -	- -
0.05	165	130 to 180	120	100 to 140
0.10	140	120 to 165	110	90 to 125
0.15	130	110 to 150	100	80 to 115
0.20	120	100 to 140	85	70 to 100

*MRTN = maximum return to nitrogen

Table 2. Guidelines for use of nitrogen fertilizer for corn grown on soils considered to have medium productivity potential.

N Price/Crop Value Ratio	corn/corn	corn/soybeans
	- - - - lb. N to apply/acre	- - - -
0.05	130	100
0.10	120	90
0.15	110	80
0.20	100	70

More details about the N guidelines can be found in ***Fertilizing Corn In Minnesota* (FO-3790-C, revised)**.

As part of a larger study conducted in 2006, various rates of fertilizer N were applied to corn following soybeans grown on an irrigated sandy soil. The response to N is shown in Table 3.

Table 3. Corn yield from an irrigated soil as affected by rate of fertilizer N.

N Applied*	Yield
lb./acre	bu. / acre
0	149
30	179
60	200
90	217
120	218
150	219
180	215

* N applied in starter fertilizer and irrigation water was approximately 30 lb. per acre

The economic optimum N rate was about 90 lb. per acre. This rate, combined with the N in starter and irrigation water totals 120 lb. N per acre which is within the acceptable range listed in Table 1.

In east central and central Minnesota, a substantial amount of corn is grown on non-irrigated soils that have a silt loam or loam texture. With adequate rainfall, this should be considered as a highly productive environment and N rate guidelines provided in Table 1 should be used.

Nitrogen credits for various crops that might be in the rotation are important. These credits are listed in Table 4.

The N credits for 2nd year corn following plow-down of a good stand of alfalfa are not well defined. The results from a study conducted with irrigated corn at the Staples Irrigation Center are summarized in Table 5. Following rye, the highest N rate (180 lb./acre) produced the highest yield. For 2nd year corn following alfalfa, the optimum N rate was 120 lb. per acre. So, the second year credit after alfalfa at this site was at least 60 lb. per acre. Additional research is needed to provide a more precise definition of the second year credits.

Table 4. Nitrogen credits for various legume crops that might preceed corn in the rotation.

Previous Crop	1st year nitrogen credit
	lb. N / acre
Harvested alfalfa	
4 or more plants/ft^2	150
2 to 3 plants/ft^2	100
1 or less plants/ft^2	40
Red clover	75
Grass/legume pasture	75

Table 5. Corn yield as affected by N rate for the second year of corn following rye and alfalfa.

	Previous Crop	
N Applied	rye	alfalfa
lb. N/acre	- - - bu./acre	- - -
0	89	96
60	158	151
120	174	178
180	182	179

Edible Beans

Unlike corn, fertilizer N guidelines for edible beans are adjusted for expected yield with some consideration for previous crop and soil organic matter content. These rates are summarized in Table 6. Specific recommendations for management of fertilizer N are in the sections that follow.

Table 6. Guidelines for use of nitrogen fertilizer for edible beans grown on coarse textured soils.

Previous Crop	Organic Matter Level	Expected Yield (lb. / acre)			
		1401-1900	1901-2400	2401-2900	2901+
		- - N to apply (lb. / acre) - -			
alfalfa (4+plants/ft^2)	low [1]	0	0	0	0
	medium and high	0	0	0	0
alfalfa (2 to 3 plants/ft^2)	low	0	20	40	60
	medium and high	0	0	10	30
red clover	low	0	0	25	45
	medium and high	0	0	0	25
non-legume crops	low	60	80	100	120
	medium and high	30	50	70	90

[1] low = less than 3.0%; medium and high = 3.0 % or more

Use Split Applications

The impact of timing of fertilizer N application for both irrigated corn and edible beans has been the focus of considerable research. Results of these research efforts lead to the conclusion that split applications are superior for both crops. The value of the split application for the two crops is influenced by amount and frequency of rainfall during the growing season. This is illustrated by the corn yields summarized in Table 7. Rainfall was high in 1981 and more normal in 1982. Therefore, leaching of NO_3-N was a problem in 1981.

With leaching as a potential problem, either a single sidedress or four equal N applications after emergence produced the highest yields. Yields were low when either all of the N or a major part of it was applied before planting.

In another study conducted in 1977, corn yields were higher when split applications of 46-0-0 were used (Table 8). For the split application situations, two applications were made after corn emergence. This is an indication that less N was lost when split applications were used.

Table 7. Yield of irrigated corn grown on sandy soil as affected by timing of the nitrogen application.

Method of Application	Year 1981	Year 1982
	- - - bu./acre	- - -
all preplant	92	197
all at the 12 leaf stage (sidedress)	168	192
4 equal applications prior to silking	159	202
1/3 preplant; 2/3 sidedress	134	194
2/3 preplant; 1/3 sidedress	105	194

N rate = 150 lb. /acre as 46-0-0

Based on the results from these and similar trials conducted over the years, preplant applications of N for corn production without a nitrification inhibitor are not recommended. There are several options for split applications on irrigated sands. These are:

- N in the starter plus sidedress N
- N in the starter plus split sidedress N
- N in the starter plus sidedress N plus N injected in the irrigation water
- N in the starter plus N injected in the irrigation water
- N in the starter plus preemergence herbicide applied with UAN
- N in the starter plus preemergence herbicide applied with UAN plus sidedress N
- N in the starter plus preemergence herbicide applied with UAN plus N injected with the irrigation water

From both an agronomic and environmental perspective, split application of fertilizer N is a good management practice. There are many choices and the grower can choose the one that fits the farming enterprise. When planning a system for split application for corn, the last application of N should take place before the silks turn brown.

Compared to corn, the edible bean crop has a shallow root system. Therefore, loss of NO_3-N below the root zone is a serious concern. This places even more importance on the use of split applications of N fertilizer.

Preplant applications of fertilizer N are not recommended for edible bean production. Recent trials to study N application frequency have shown three applications are not necessary; two are adequate (Table 9). The first application should take place following seedling emergence. For ease of field operation, the second should be made before bloom.

Table 8. Yield of corn grown on an irrigated sandy soil as affected by time of nitrogen application.

	Time of Application	
N Applied	preplant	split sidedress
lb. / acre	- - - bu. / acre	- - -
60	93	122
120	144	162
180	160	175

Yield of control (no N applied) = 37 bu. / acre
N Source = 46-0-0

Table 9. Yield of irrigated edible beans (red kidney) as affected by split application of fertilizer N.

N Applied At			Yield
post emergence	pre-bloom	post-bloom	
- - - - - -	lb. N / acre	- - - - - -	lb./acre
0	0	0	2608
30	30	30	2951
45	45	0	3042
45	0	45	3159
0	45	45	3088

It is doubtful if split applications of fertilizer N are beneficial for corn and edible bean production on non-irrigated sandy soils. A sidedress application would be the preferred timing. There is a fairly long window for completing this application beginning within a few days after emergence. The sidedress timing has several advantages. It is applied prior to the time of rapid N uptake by the corn or edible bean plant and usually after the time of heavy rains and subsequent greatest leaching potential.

Potential Helpful Products

Responding to the recognition that loss of NO_3-N due to leaching is a rather universal concern, products have been developed that, when used, could reduce the potential for loss. N-Serve is a nitrification inhibitor and will be described later. Agrotain is a urease inhibitor designed to be used in no-till or other production systems where urea remains on the soil surface without incorporation. ESN is urea coated with a polymer intended as a slow release product. Because of higher cost, use of this product falls into the category of "acceptable, but with greater risk."

Application of nitrification inhibitors, those products that delay the conversion of ammonium-N to nitrate-N, can be an important management practice in the production of corn on irrigated sandy soils. Trials have been conducted for the purpose of evaluating the effectiveness of this input.

In a comprehensive study, 46-0-0 was applied at rates to supply 60, 120,180, and 240 lb. N per acre. The 46-0-0 was applied with and without the inhibitor, N-Serve. In addition a single preplant was compared to split applications.

Use of the nitrification inhibitor produced a substantial increase in yield when the N was applied before planting (Table 10). Also, the split sidedress use of N without the inhibitor produced higher yields than the preplant application with the inhibitor. At the lower rates of applied N, the use of the inhibitor in the split application system was important.

Based on these results as well as results from other studies, the practice of applying N before planting with a nitrification inhibitor, and the practice of using a single sidedress application with a nitrification inhibitor are defined as acceptable, but with a greater risk.

Table 10. Corn yield as affected by time of nitrogen application with and without the use of a nitrification inhibitor.

	All Preplant		Split Application	
N Applied	no inhibitor	N-Serve used	no inhibitor	N-Serve used
lb. / acre	- - - - - - -	- bu. / acre	- - - - - - -	
0	59	--	59	--
60	89	119	117	127
120	105	150	147	181
180	136	169	191	191
240	170	181	191	190

N Source = 46-0-0

Appropriate Credit For Legumes and Manure

The importance of N supplied by either legume crops or manure used in the crop rotation cannot be ignored. The N credit for soybeans is 40 lb. per acre. The credits for other legumes are listed in Table 4 for corn production and are shown for edible beans in Table 6.

The N credits for manure will not be described in detail in this publication.

Application Below The Soil Surface

Although the risk is minimal with acid sandy soils there can be some loss of N via volatilization if fertilizer N is placed on the soil surface and not incorporated. Therefore, it is a good practice to incorporate any N (28-0-0, 46-0-0 etc.) that is applied to the soil surface. Cultivation or irrigation water can be used for this incorporation. Application just prior to rain would also be acceptable. Studies conducted in other states in the Corn Belt have shown that 0.25 in. of irrigation water or rainfall is necessary to incorporate either 46-0-0 or 28-0-0 that has not been previously incorporated.

Summary

Management of fertilizer nitrogen is a special challenge for crops grown on coarse textured soils, both irrigated and dryland. The research-based Best Management Practices (BMP's) described in this publication are agronomically, economically, and environmentally sound. They are voluntary. If these practices are followed, agriculture can be more profitable without the threat of regulation.

Related Publications

08560 (revised, 2008) - Best Management Practices for Nitrogen Use in Minnesota

08557 (revised, 2008) - Best Management Practices for Nitrogen Use in Southeastern Minnesota

08554 (revised, 2008) - Best Management Practices for Nitrogen Use in South-Central Minnesota

08558 (revised, 2008) - Best Management Practices for Nitrogen Use in Southwestern and West-Central Minnesota

08555 (revised, 2008) - Best Management Practices for Nitrogen Use in Northwestern Minnesota

AG-FO-5880 - Fertilizing Cropland with Dairy Manure

AG-FO-5879 - Fertilizing Cropland with Swine Manure

AG-FO-5881 - Fertilizing Cropland with Poultry Manure

AG-FO-5882 - Fertilizing Cropland with Beef Manure

AG-FO-3790 - Fertilizing Corn in Minnesota

AG-FO-3770 - Understanding Nitrogen in Soils

AG-FO-3774 - Nitrification inhibitors and Use in Minnesota

AG-FO-2274 -Using the Soil Nitrate Test for Corn in Minnesota

AG-FO-2392 - Managing Nitrogen for Corn Production on Irrigated Sandy Soils

AG-FO-0636 - Fertilizer Urea

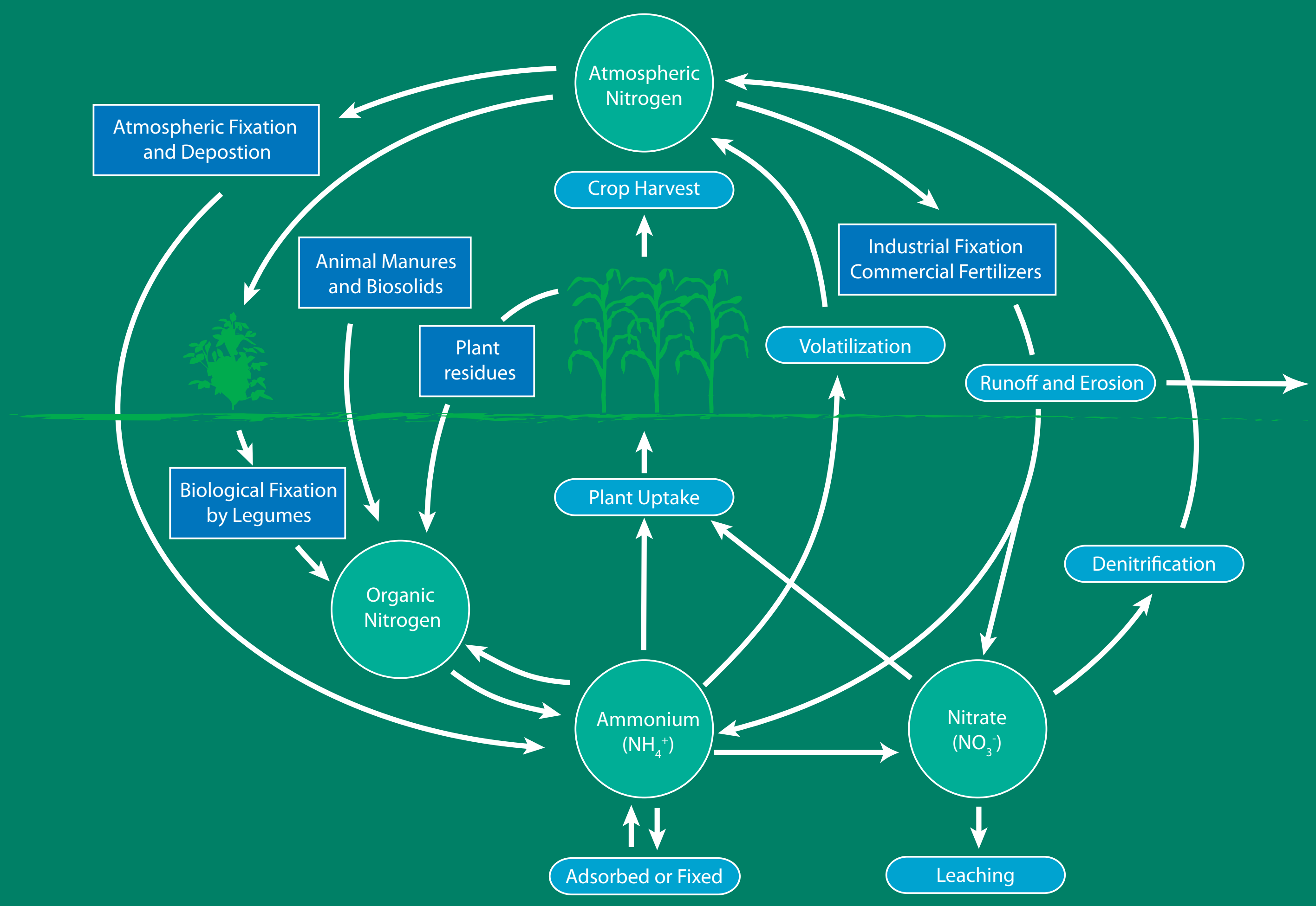
AG-FO-3073 - Using Anhydrous Ammonia in Minnesota

AG-FO-6074 - Fertilizer Management for Corn Planted in Ridge-till or No-till Systems

AG-FO-3553 - Manure Management in Minnesota

BU-07936 - Validating N Rates for Corn

Iowa State Univ. PM2015 - Concepts and Rationale for Regional Nitrogen Rate Guidelines for Corn



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Best Management Practices for Nitrogen on Coarse Textured Soils

PUBLICATION # 08556

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Best Management Practices for Nitrogen Use: IRRIGATED POTATOES

BEST MANAGEMENT PRACTICES FOR NITROGEN APPLICATION

Best Management Practices for Nitrogen Use: Irrigated Potatoes

Carl J. Rosen and Peter M. Bierman, Department of Soil, Water, and Climate, University of Minnesota

Summary

Nitrogen (N) is an essential plant nutrient that contributes greatly to the economic viability of irrigated potato production. Unfortunately, the nitrate form of N can leach into groundwater if N is not managed properly. Contamination of water resources by agricultural production systems will not be tolerated by the public and could lead to laws regulating the use of N fertilizers if this contamination is not minimized.

Research-based Best Management Practices (BMPs) have been developed specifically for irrigated potatoes and integrated into the BMPs that were developed previously for other agronomic crops on coarse-textured soils. Various strategies are provided that take into account N rate, timing of application, method of application, and N source. Optimum N management also depends on the variety grown and its harvest date, so basic principles are similar but specific recommendations differ for early, mid-season, and late-season varieties.

The main objectives of these BMPs are to maintain profitability and minimize nitrate leaching. By following these recommendations, the threat of fertilizer regulations can be avoided and a more profitable and better community can be attained.

Introduction

Nitrogen is an essential plant nutrient that is applied to Minnesota crops in greater quantity than any other fertilizer. In addition, vast quantities of N are contained in the ecosystem, including soil organic matter. Biological processes that convert N to its mobile form, nitrate (NO_3), occur continuously in the soil system. (For greater understanding see: ***Understanding Nitrogen in Soils*** **AG-FO-3770**). Unfortunately, nitrate can move (leach) below the rooting zone and into groundwater.

In response to the Comprehensive Groundwater Protection Act of 1989, a Nitrogen Fertilizer Management Plan was developed with the purpose of managing N inputs for crop production to prevent degradation of Minnesota water resources while maintaining farm profitability. The central tool for achievement of this goal is the adoption of Best Management Practices for Nitrogen. Best management practices for N are broadly defined as economically sound, voluntary practices that are capable of minimizing nutrient contamination of surface and groundwater. The primary focus of the BMPs is commercial N fertilizers; however, consideration of other N sources and their associated agronomic practices is necessary for effective total N management.

General BMPs for all Regions of the State

The use of BMPs is based on the concept that accurate determination of crop N needs is essential for profitable and environmentally sound N management decisions. General BMPs that apply to all cropping regions in the state are listed below:

- Adjust the N rate according to a realistic yield goal (for all crops except corn and sugar beets) and the previous crop
- Do not apply N above recommended rates
- Plan N application timing to achieve high efficiency of N use
- Develop and use a comprehensive record-keeping system for field specific information.
- If manure is used, adjust the N rate accordingly and follow proper manure management procedures to optimize the N credit:
    - Test manure for nutrient content
    - Calibrate manure application equipment
    - Apply manure uniformly throughout a field
    - Injection of manure is preferable, especially on steep sloping soils
    - Avoid manure application to sloping, frozen soils
    - Incorporate broadcast applications whenever possible

For more detailed information on making the most efficient use of manure nutrients and avoiding potential adverse effects on water quality, see the University of Minnesota Extension publications listed at the end of this bulletin.

The Need for Best Management Practices for Irrigated Potatoes

Most of the BMPs developed for crop production in Minnesota have been based on research with corn and small grains. Management strategies for coarse-textured soils can be found in: ***Best Management Practices for Nitrogen Use on Coarse Textured Soils*** (**08556, revised 2008**). In contrast to most agronomic crops, potatoes are a relatively shallow rooted crop and require intensive management to promote growth and yield. In addition, adequate N needs to be available to maintain both yield and tuber quality. The shallow root system of potatoes, the need for adequate N, and the extensive production on sandy soils greatly increase the potential of nitrate contamination of shallow aquifers under irrigated potato production. Fortunately, University of Minnesota research strongly suggests that environmental impacts can be minimized by using nitrogen BMPs specifically designed for potatoes.

While the general BMPs developed for corn and small grains listed above will also apply to irrigated potato production, BMPs focused on irrigated potato production are described within this bulletin so that more precise management practices can be followed. The research-based nitrogen BMPs discussed here, therefore, have been tailored specifically for potato production on irrigated, coarse-textured soils. These BMPs are not only environmentally sound, they are also potentially more profitable. When N leaches below the potato root zone, where it can degrade water quality, it also becomes a purchased input that is lost from the crop production system. Efficient N management that minimizes losses provides both economic and environmental benefits.

Specific Nitrogen Best Management Practices for Irrigated Potatoes

Nitrogen management considerations for irrigated potatoes include decisions regarding: 1) N rate, 2) timing of N application, 3) use of diagnostic procedures to determine N needs during the growing season, 4) effective water management, 5) sources of N, and 6) establishment of a cover crop after harvest. Suggested N management approaches for different varieties and harvest dates of irrigated potatoes are presented following the discussion on BMPs.

Selecting a Realistic Nitrogen Rate

The rate of N to apply to irrigated potatoes primarily depends on the cultivar and date of harvest, expected yield goal, amount of soil organic matter, and the previous crop. Rates of N recommended for potatoes can be found in ***Nutrient Management for Commercial Fruit and Vegetable Crops in Minnesota*** (**AG-BU-5886-F**) and in Appendix A of this document. Response to N by potato is typical of other crops in that the first increment of fertilizer usually brings about the greatest response in yield, followed by a more gradual increase with succeeding increments of N (Table 1). As the N rate increases, however, the potential for losses also increases. In addition to environmental concerns due to excessive N applications, high rates of N can detrimentally affect potato production by promoting excessive vine growth, delaying tuber maturity, reducing yields, decreasing specific gravity, increasing brown center, and inducing knobby, malformed, and hollow tubers. Selecting a realistic N rate is therefore important from both a production and an environmental standpoint. Unfortunately, the effect of excess N on tuber quality is dependent on soil moisture and temperature as well as the cultivar grown. This means that the N rate at which detrimental effects will occur is difficult to predict.

Base N rate on variety, harvest date, and realistic yield goals

Different potato varieties and differences in harvest date will have a pronounced effect on yields and yield goals. Because of lower yield and earlier harvest, early maturing varieties like Red Norland (Table 2) generally require less N than later maturing varieties, such as Russet Burbank (Table 1). A definition of harvest date is as follows: Early - vines are killed or the crop is green dug before August 1; Mid-season - vines are killed or the crop is green dug before September 1; Late –vines are killed or the crop is green dug September 1 or later. Unlike corn and sugar beets, the yield goal concept is still being used to guide N recommendations for potatoes, in conjunction with variety and harvest date, until a more complete measure of the N supplying capacity of the soil is available. Currently N recommendations are also adjusted for the amount of soil organic matter, with higher rates for low organic matter soils than for medium to high organic matter soils which have a greater capacity to release plant-available N. Yield goal for potatoes is based on the total yield obtained rather than the marketable yield, but the two are generally well-correlated. An overestimation of the yield goal will result in excessive applications of N, which can potentially result in nitrate losses to groundwater.

Table 1. Response of Russet Burbank potatoes to nitrogen rate at Becker MN, 2004-2005.

N rate	Marketable*	Total
lb N/A	------------ cwt/A	------------
0	299	377
30	326	485
80	423	550
120	547	651
160	531	629
180	583	667
240	611	690
320	594	663

*Marketable tubers are greater than 3 oz in size with no visible defects.

Table 2. Response of early harvested Red Norland potatoes to nitrogen rate at Becker MN, 1995-1997.

N rate	Total and Marketable
lb N/A	-- cwt/A --
125	336
165	325
205	324
245	317
285	303

Account for nitrogen from previous crops

Previous crop can also affect N needs. Legumes in a crop rotation can supply significant N to subsequent crops. Research in Wisconsin on sandy soils (Kelling, et al., 1991) found that maximum potato yields following sorghum sudangrass required 40 lb/A more N than following red clover and 80 lb/A more N than when following alfalfa. Similar results from a 20 year study in the Netherlands found that N requirements for optimum potato yield following oats were 60 lb N/A greater than following red clover and 90 lb N/A greater than following alfalfa (Neeteson, 1989). Failing to account for N supplied by legumes can lead to a buildup of soil N and increase the potential for nitrate leaching.

Test irrigation water for nitrogen content and adjust N fertilizer accordingly

The amount of N in the irrigation water should also be considered when adjusting N rates. Nitrate in irrigation water can supply a portion of the N required for crop production. In N calibration studies on potatoes at Becker MN, the nitrate-N concentration in irrigation water ranged from 7 to 10 ppm (parts per million). This concentration of N in the water should be considered as background, but amounts above 10 ppm should be credited as fertilizer N. Additionally, the time to credit N from irrigation water is when the plant is actively growing and taking up N. For late season potatoes this occurs from 20 to 60 days after emergence (Figure 1). Because nitrate-N levels in irrigation water can vary, samples of irrigation water need to be tested annually during the pumping season to determine approximate nitrate-N concentrations.

If nitrate-N in irrigation water is one ppm, then each inch of irrigation water applied is equal to 0.225 pounds of N applied per acre. As an example, if irrigation water is found to have 20 ppm nitrate-N and 9 inches of water are applied during the active part of the growing season, then about 40 lbs of N/A would be supplied with the water (0.225 * 9 * 20). After subtracting the background amount of 20 lb N/A, the remaining 20 lb N/A should be credited toward the total amount of N applied. In practice, you will not know how much N was applied in irrigation water until after the active growth period when all or most of the N fertilizer has already been applied, so for the current growing season you will have to estimate the N credit for irrigation water from records of previous years.

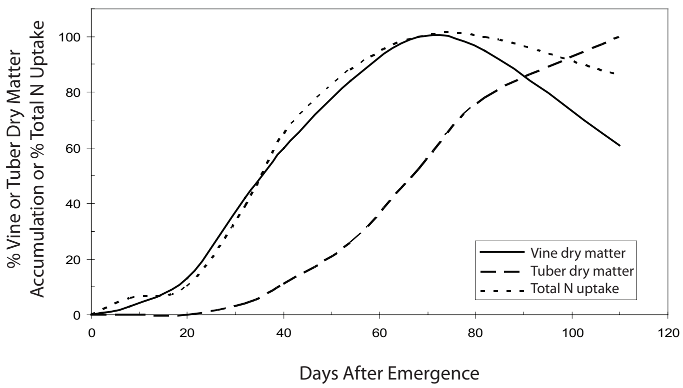

Figure 1. Relative tuber growth, vine growth and total nitrogen uptake by the potato crop. Based on data from the Russet Burbank variety.

Timing of Nitrogen Application: Match N Application with Demand by the Crop

One of the most effective methods of reducing nitrate leaching losses is to match N applications with N demand by the crop.

Do not fall apply N on sandy soils (sands, loamy sands, and sandy loams)

Do not use more than 40 lbs N/A in the starter for mid/late season varieties

Do not use more than 60 lbs N/A in the starter for early harvested varieties

Nitrogen applied through the hilling stage should be cultivated/incorporated into the hill

Plan the majority of soluble N inputs from 10 to 50 days after emergence

Nitrogen applications in the fall are very susceptible to leaching. Nitrogen applied early in the season when plants are not yet established is also susceptible to losses with late spring and early summer rains. Most nitrification inhibitors are not registered for potatoes and therefore cannot be recommended. Peak N demand and uptake for late season potatoes occurs between 20 and 60 days after emergence (Figure 1). Optimum potato production depends on having an adequate supply of N during this period. The recommendation is to apply some N at planting for early plant growth and to apply the majority of the N in split applications beginning slightly before (by 10 days) the optimum uptake period. This assures that adequate N is available at the time the plants need it and avoids excess N early in the season when plant growth is slow and N demand is low.

Research at the Sand Plain Research Farm at Becker, with full season varieties like Russet Burbank, demonstrates that nitrate movement below the root zone can be reduced by lowering the amount of N in the starter fertilizer without affecting yields (Table 4). Starter fertilizer should contain no more than 40 lb N/A for full season varieties. Uptake of N by the crop (vines plus tubers) increases when split N applications are used compared with large applications applied before emergence. Nitrogen applied through the hilling stage should be incorporated into the hill to maximize availability of the N to the potato root system.

Just as N fertilizer applied too early in the season can potentially lead to nitrate losses, so can N fertilizer applied too late in the season. Nitrogen applied beyond 10 weeks after emergence is rarely beneficial and can lead to nitrate accumulation in the soil at the end of the season. This residual nitrate is then subject to leaching.

For determinate early harvested varieties like Red Norland, higher rates of N in the starter may be beneficial (Table 5). These varieties tend to respond to higher rates of early N than indeterminate varieties, but the total amount of N required is generally lower because of lower yield potential and early harvest. In addition, late application of N to these varieties will tend to delay maturity and reduce yields, particularly if the goal is to sell for an early market. In many cases it is not possible to know when the exact harvest date will be as this will depend on market demands as well as weather conditions during the season. Because of these unknowns it is important to have some flexibility in both rate and timing of N application.

Table 4. Nitrogen starter effects on Russet Burbank potato yield and nitrate-N leaching to the 4½ ft depth. Means of 1991 and 1992.

Timing of N application			Yield		NO_3-N Leaching
Planting	Emergence	Hilling	Total	Marketable	
-----------	lb N/A	-----------	------	cwt/A ------	-- lb/A --
0	0	0	359.9	292.3	18
0	120	120	602.7	532.8	76
40	100	100	594.0	518.5	114
80	80	80	612.9	519.7	134
120	60	60	589.4	493.5	158

Errebhi et al., 1998.

Table 5. Nitrogen starter effects on Red Norland potato yield, Becker - 1995-1997.

Timing of N application			Total Yield
Planting	Emergence	Hilling	
-----------------	lb N/A	-----------------	-- cwt/A --
25	70	70	325
45	60	60	328
65	50	50	338
85	40	40	337

Use petiole analysis to aid in making post-hilling nitrogen applications

Increases in N use efficiency have been shown when some of the N is injected into the irrigation water after hilling (fertigation). Because the root system of the potato is largely confined to the row area during early growth, do not fertigate until plants are well established and potato roots have begun to explore the furrow area between rows. This is usually about three weeks after emergence. Nitrogen applications after this time are most beneficial in years when excessive rainfall occurs early in the growing season (Tables 6 and 7). In dry years with minimal leaching, N applications later than 16 days after emergence show little if any advantages from a production standpoint over applying all of the N by that stage (Tables 7 and 8). However, leaching losses can still be reduced.

Table 6. Effect of N applications later than 16 days after emergence on Russet Burbank yield, Becker – 1991 (high leaching year).

Timing of N application[1]				Tuber Distribution					
Plant.	Emerge.	Post Emerge.	Late PE	Culls	<3 oz	3-7oz	7-14oz	>14oz	Total
--------- lb N/A ---------				------------- cwt/A -------------					
40	40	40	0	23	51	240	158	5	477
80	80	80	0	28	47	224	179	8	486
40	40	40	80	36	42	221	200	13	512

[1]Planting, emergence, 16 days post-emergence, and two late post-emergence applications more than 16 days after emergence of 40 lb N/A per application.

Table 7. Effects of excessive irrigation and nitrogen rate, source, and timing on cumulative NO_3-N leaching to the 4 ft depth (Zvomuya et al., 2003).

N Rate	N Source	Irrigation	
		Standard	Excessive
		NO_3-N leaching	
--- lb N/A ---		----------- lb N/A -------------	
0	----	46	61
125	urea[1]	59	88
125	PCU[2]	55	84
250	urea[3]	75	204
250	PCU[2]	50	128
250	posthill[4]	80	121

[1]25 lb N/A at planting, 50 lb N/A at emergence, and 50 lb N/A at hilling.
[2]Polyolefin-coated urea in a single application at planting.
[3]25 lb N/A at planting, 112 lb N/A at emergence, and 112 lb N/A at hilling.
[4]25 lb N/A as urea at planting, 72 lb N/A as urea at emergence, 72 lb N/A as urea at hilling, and 40 lb N/A as equal amounts of N from urea and ammonium nitrate at 3 and 5 weeks after hilling.

Table 8. Effect of N applications later than 16 days after emergence on Russet Burbank yield, Becker – 1992 (low leaching year).

Timing of N application[1]				Tuber Distribution					
Plant.	Emerge.	Post Emerge.	Late PE	Culls	<3 oz	3-7oz	7-14oz	>14oz	Total
--------- lb N/A ---------				------------- cwt/A ------------					
40	40	40	0	32	58	267	158	3	518
80	80	80	0	31	53	281	223	12	601
40	40	40	80	29	58	246	195	14	541

[1]Planting, emergence, 16 days post-emergence, and two late post-emergence applications more than 16 days after emergence of 40 lb N/A per application.

If applications of N later than 16 days after emergence are used, then 2/3 to 3/4 of the recommended N fertilizer should be applied by that stage. Timing of the remainder of the N applications should be based on petiole nitrate-N levels determined on either a dry weight or sap basis. Table 9 shows suggested sufficiency ranges for Russet Burbank potatoes through the growing season. Other potato varieties may vary slightly in their sufficiency ranges. However, the ranges in Table 9 are still a suitable starting point to adjust post-emergence N applications for other varieties. Typically if N is needed, 20 to 40 lb N/A can be injected per application.

Another potential in-season monitoring tool is soil testing for plant-available inorganic N in the upper 12 to 18 inches of the soil. Samples should be collected from the hill area in sets of five soil cores and analyzed for nitrate-N and ammonium-N. One core should be from the top of the hill, one core from each side of the hill half-way up the side slope, and one core from each side at the base of the hill. Initial research on in-season soil testing suggests that sufficiency levels for total inorganic N (nitrate-N + ammonium N) in the 0-1 ft depth for Russet Burbank are about 140 lb N/A (35 ppm) during initial bulking (June) and 80 lb N/A (20 ppm) during early bulking (July). Additional research is necessary to calibrate in-season soil tests and determine how much N to apply at specific soil test levels. Soil testing should be viewed as a tool to help fine tune N management and used in conjunction with, not as a substitute for, petiole testing.

One danger of relying on N applications through the irrigation system occurs when rainfall patterns during the time for fertigation are adequate or excessive. Applying N through the system in this case may potentially lead to an increase in nitrate leaching if high amounts of irrigation water are also applied. In situations where there is a demand for N, but rainfall has been adequate or excessive, low amounts (less than 0.3 inch) of water should be applied with the N fertilizer. Another potential problem with delayed N application occurs when the potato crop dies back early due to insects or diseases. In this situation, N applied more than 16 days after emergence may not be used as efficiently and they may increase N leaching losses. It is essential therefore, that an integrated cropping approach be taken to minimize nitrate leaching losses.

Selecting Appropriate Nitrogen Sources

Do not use fertilizers containing nitrate in the starter

Each fertilizer N source used for potatoes has advantages and disadvantages, depending on how they are managed. However, because leaching often does occur in the spring, fertilizer sources containing nitrate (i.e. UAN-28 and ammonium nitrate) should be avoided at planting. Ammonium sulfate, diammonium phosphate, monoammonium phosphate, poly ammonium phosphate (10-34-0), or urea are the preferred N sources for starter fertilizer. Advantages of urea compared with ammonium nitrate are greater availability, lower cost, and delayed potential for leaching. Disadvantages of urea are that it is hygroscopic (attracts water), it must be incorporated after application or ammonia volatilization losses may occur, and its slow conversion to nitrate in cool seasons may reduce yields. Anhydrous ammonia may be beneficial in delaying the potential for leaching losses; however, positional availability of the N in relation to the hill may be a problem with sidedress applications. Further research needs to be conducted on the use of anhydrous ammonia for potato.

Table 9. Petiole nitrate-N sufficiency levels for Russet Burbank potatoes on a dry weight and sap basis.

Time of Season/ Stage of Growth	Sap NO_3-N	Dry wt. NO_3-N
	ppm	
Early Vegetative/tuberization (June 15 - June 30)	1200 – 1600	17,000 - 22,000
Mid Tuber growth/bulking (July 1 - July 15)	800 – 1100	11,000 - 15,000
Late Tuber bulking/maturation (July 15 - August 15)	400 – 700	6,000 - 9,000

Table 10. Effect of a controlled release N source on potato (Russet Burbank) yield, Becker – 2005.

N rate[1]	N source			
	Urea	ESN[2]	Urea	ESN[2]
	Total Yield		Marketable Yield	
lb N/A	cwt/A			
80	643	679	499	526
160	698	695	579	582
240	676	677	583	560
320	660	625	576	519
240 (ESN emergence)	-	737	-	631

1All treatments received 40 lb N/A from diammonium phosphate at planting.
2ESN was applied at planting, except for the second 240 lb N/A rate which was applied at emergence.

Substantial reductions in nitrate leaching can occur if controlled release sources of N are used (Table 7). Controlled release N sources include polymer coated urea that can be formulated to release N over various time intervals. These controlled release sources can also be applied earlier in the season without the fear of nitrate leaching losses. The main disadvantages of controlled release N fertilizer are delayed release to ammonium and nitrate when soil temperatures are cool and the higher cost of many of the products compared to conventional quick release N fertilizers. However, there are some newer slow release fertilizers on the market that are more economical and the cost savings of being able to make a single N fertilizer application rather than multiple applications is another factor to consider. Table 10 shows the yield response to ESN, a relatively low cost controlled release N fertilizer, compared to quick release urea applied using standard split application practices. When ESN was applied at planting there was a reduction in marketable yield at the higher N rates compared with urea, but ESN (240 lb N/A) applied at emergence produced the highest total and marketable yields in the study. Further research with low cost controlled release sources needs to be conducted to evaluate effects on tuber quality and nitrate leaching.

For mid to late season varieties, apply ESN no later than emergence.

ESN for early harvested potatoes (vines killed or green dug before August 1) is not recommended due to slow release of N.

Water Management Strategies

Follow proven water management strategies to provide effective irrigation and minimize leaching

Water management has a profound effect on N movement. While leaching of nitrate due to heavy rainfall cannot be completely prevented, following the N management strategies discussed above will minimize these losses. However over-irrigation, even with optimum N rate applied and proper timing of N application, can cause substantial leaching losses. Therefore, effective water scheduling techniques based on soil moisture content and demand by the crop should be followed to prevent such losses. For more information on irrigation scheduling, refer to: ***Irrigation Water Management Considerations for Sandy Soils in Minnesota***, **AG-FO-3875**.

Cover Crops Following Potatoes

Establish a cover crop following potatoes whenever possible

For early harvested potatoes (July/August), any nitrate remaining in the soil is subject to leaching with rainfall. Establishing a cover crop such as winter rye will take up residual N to minimize this potential loss. An additional benefit of the cover crop is to reduce wind erosion. After the cover crop is killed or plowed under, N will be released from the vegetation the following spring. Cover crops can also be planted after potatoes harvested in September/October, although the purpose here is more for erosion control than to reduce N losses.

Specific Best Management Practices for Irrigated Potatoes on Coarse-Textured Soils

Best management strategies for irrigated potatoes need to be somewhat flexible because of differences due to soil type, unpredictable weather, and the numerous potato cultivars grown. However, some general guidelines should be followed with the understanding that modifications may be necessary to fit specific situations and that fine-tuning BMPs for N is an ongoing process. Based on the research conducted with potatoes on sandy soils, the following best management options for N are suggested (these suggestions are based on research with Russet Burbank, an indeterminate late season variety and Red Norland, a determinate early season variety; response may vary with other varieties):

Mid/late season varieties - Vines killed or green dug August 1 or later

Option 1 - when fertigation is available:

- Apply up to 40 lb N/A in the starter (this amount should be included in meeting the total recommended N rate)
- Apply one-third to one-half of the recommended N at or around emergence and cultivate/incorporate the fertilizer into the hill; if ESN is used, apply no later than emergence and incorporate in the hill
- If hilling at emergence is the final hilling operation, begin fertigation 14-21 days later and apply the remainder of the recommended N in increments not exceeding 40 lb N/A
- If a final hilling operation is done 10-14 days after emergence, apply one-third of the recommended N at that time and cultivate/incorporate the fertilizer into the hill. On

heavier textured soils during rainy periods, it may not be possible to time this application properly due to row closure; in this situation, the N can be applied using fertigation
- Base timing of subsequent N applications on petiole analysis; apply up to 40 lb N/A per application through the irrigation system
- Establish a cover crop after harvest whenever possible

Option 2 - for mid/late season varieties when fertigation is not available:

- Apply up to 40 lb N/A in the starter (this amount should be included in meeting the total recommended N rate)
- Apply one-third to one-half of the recommended N at or around emergence and cultivate/incorporate the fertilizer into the hill; if ESN is used, apply no later than emergence and incorporate in the hill
- Apply the remainder of the recommended N rate at final hilling and cultivate/incorporate the fertilizer into the hill
- Establish a cover crop after harvest whenever possible

Option 1 has generally shown better N use efficiency, particularly during years when excessive rainfall has occurred before hilling. Remember that best management practices are based on the most current research available. As more information becomes available through research efforts, some modification of BMPs may be necessary.

Early season varieties, with or without fertigation - Vines killed or green dug before August 1

- Apply up to 60 lb N/A in the starter (this amount should be included in meeting the total recommended N rate)
- Apply one-third to two-thirds of the recommended N at or around emergence and cultivate/incorporate the fertilizer into the hill
- Apply the remainder of the recommended N rate at final hilling and cultivate/incorporate the fertilizer into the hill
- If fertigation is available, base timing of subsequent N application on petiole analysis; if needed, apply up to 30 lb N/A per application through the irrigation system; avoid late applications of N, because that will delay maturity
- Establish a cover crop after harvest

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Publications on Manure Management

Manure Management in Minnesota, FO-3553

Fertilizing Cropland with Swine Manure, FO-5879

Fertilizing Cropland with Dairy Manure, FO-5580

Fertilizing Cropland with Poultry Manure, FO-5881

Fertilizing Cropland with Beef Manure, FO-5582

Self-assessment Worksheets for Manure Management Plans

Appendix A

Nitrogen recommendations for irrigated potato production.

		Previous Crop and Organic Matter (O.M.) Level							
		alfalfa (good stand)[1] -O.M.[2]-		soybeans field peas -O.M.-		any crop in group 1 -O.M.-		any crop in group 2 -O.M.-	
Yield Goal[3]	Harvest Date[4]	low	medium to high	low	medium to high	low	medium to high	low	medium to high
cwt/A		N to apply (lb/A)							
<250	Early	0	0	80	60	60	40	100	80
250-299		25	0	105	85	85	65	125	105
300-349		50	30	130	110	110	90	150	130
350–399	Mid	75	55	155	135	135	115	175	155
400–449		100	80	180	160	160	140	200	180
450–499	Late	125	105	205	185	185	165	225	205
500+		150	130	230	210	210	190	250	230

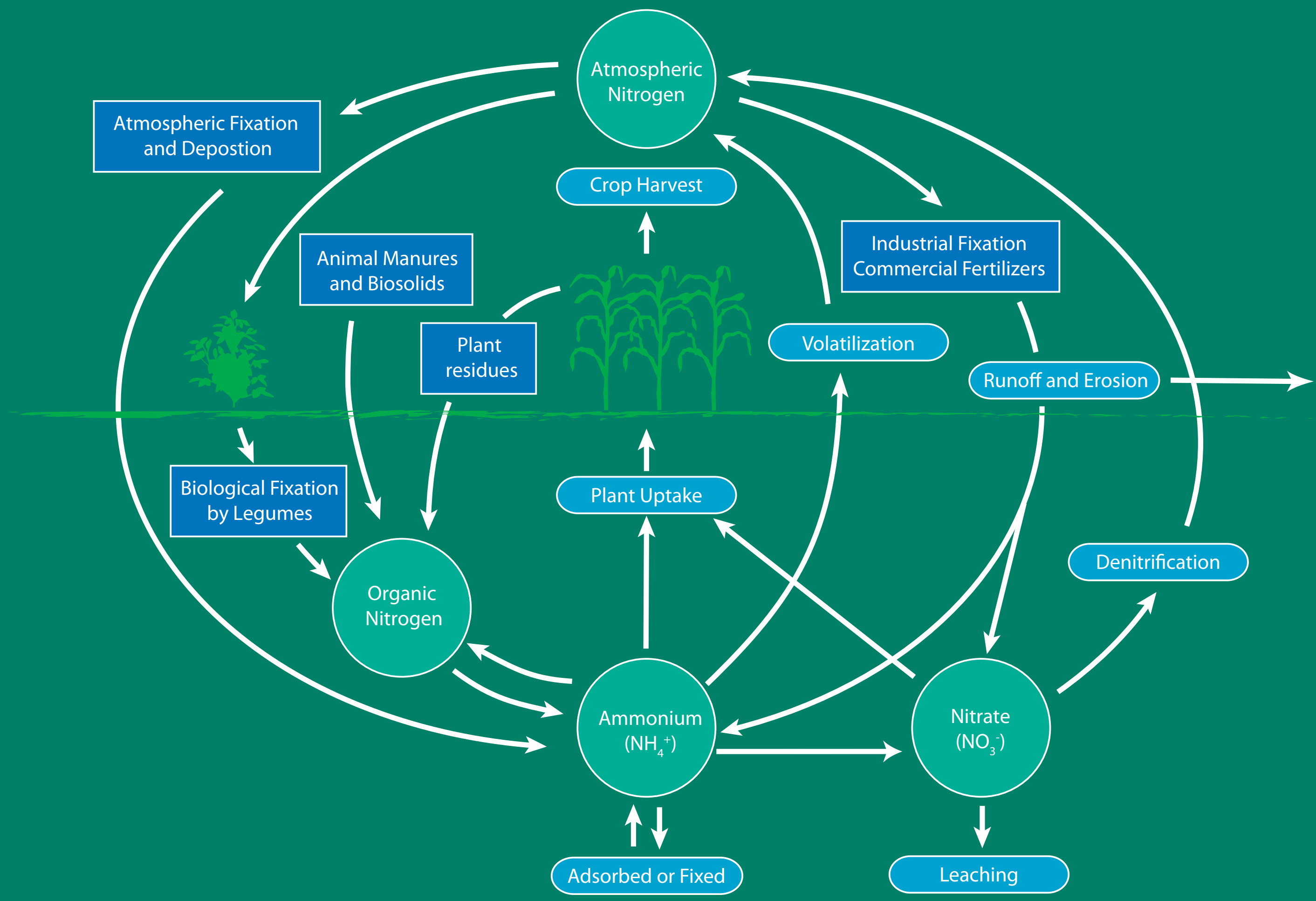
Crops in Group 1		Crops in Group 2	
alfalfa (poor stand)[1]	barley	grass hay	sorghum-sudan
alsike clover	buckwheat	grass pasture	sugarbeets
birdsfoot trefoil	canola	millet	sunflowers
grass-legume hay	corn	mustard	sweet corn
grass-legume pasture	edible beans	oats	triticale
red clover	flax	potatoes	wheat
fallow		rye	vegetables

[1]Poor stand is less than 4 crowns per sq. ft.

[2]Low = less than 3.1% O.M., medium to high = 3.1-19% O.M.; greater than 19% O.M. would be an organic soil and not a coarse-textured soil.

[3]Yield in this table refers to total yield not marketable yield.

[4]Early = vines killed or green dug before August 1; Mid = vines killed or green dug August 1-August 31; late = vines killed or green dug after Sept 1.



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PUBLICATION # 08559

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Best Management Practices for Nitrogen Use in SOUTHEASTERN MINNESOTA

BEST MANAGEMENT PRACTICES FOR NITROGEN APPLICATION

Best Management Practices for Nitrogen Use in Southeastern Minnesota

Gyles Randall, Professor and Soil Scientist, Southern Research and Outreach Center, Waseca; George Rehm, Nutrient Management Specialist (*retired*); John Lamb, Professor, Department of Soil, Water, and Climate, University of Minnesota

Introduction

Nitrogen (N) is an essential plant nutrient that is applied to Minnesota crops in greater quantity than any other fertilizer and contributes greatly to the agricultural economy of Minnesota crop producers. In addition, vast quantities of nitrogen are contained in the ecosystem, including in soil organic matter. Biological processes that convert nitrogen to its mobile form, nitrate (NO_3), occur continuously in the soil system. (For greater detail see "***Understanding Nitrogen in Soils"*** **AG-FO-3770**.) Unfortunately, nitrates can be leached from the root zone of the soil. Management guidelines have been developed to assist crop producers manage their nitrogen in ways that optimize profitability, reduce risk, and minimize losses of nitrate to surface and ground water.

What Are the Best Management Practices (BMP's)?

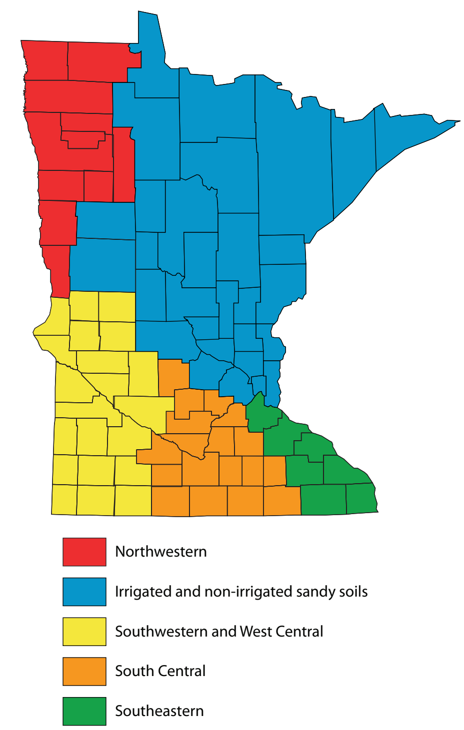
There's general agreement that BMP's are voluntary practices that are capable of minimizing nutrient contamination of surface and ground water. The BMP's recommended herein are based upon research conducted by the University of Minnesota from over 40 site-years of field research in southeastern Minnesota and upon practical considerations.

The BMP's are based, in part, upon the concept of total nitrogen management, which accounts for all forms of on-farm nitrogen in the development of crop management plans. BMP's were developed to be adopted on a statewide as well as a regional basis. Those developed for the unique soil and climatic conditions of southeastern Minnesota refine the recommendations of the statewide BMP's.

BMP's for Southeastern Minnesota

Southeastern Minnesota is characterized by permeable, silt loam soils with underlying fractured limestone bedrock. This "karst" region is very susceptible to ground water contamination. Average annual precipitation in the region is greater than 32 inches. Crops include corn, forages, oats and soybeans. Livestock production consists primarily of dairy, beef and hogs. BMP's for the counties shown in Figure 1 (Dakota, Goodhue, Fillmore, Houston, Olmsted, Wabasha and Winona) have been developed based on field research conducted in these counties.

The BMP's in this publication focus on nitrogen use for corn production. They are divided into three categories described as, 1) recommended, 2) acceptable but with greater risk, and 3) not recommended. With respect to N management, risks can be either economic or environmental. Economic risk can be a consequence of added input costs without additional yield or a reduction in yield. Environmental risks pertain to the potential for loss of nitrogen to either ground water or surface waters.



The nitrogen BMP's for southeastern Minnesota include:

1) Recommended

- Select an appropriate N fertilizer rate using U of M guidelines ("***Fertilizing Corn in Minnesota***" **FO-3790,** 2006 or newer) which are based on current fertilizer and corn prices, soil productivity and economic risks.
- Total N rate should include any N applied in a starter, weed and feed program, and contributions from phosphorus fertilizers such as MAP and DAP.
- Spring preplant applications of ammonia and urea or split applications of ammonia, urea, and UAN are highly recommended. (See Tables 2, 8, 9 and 10).
- Incorporate broadcast urea or preplant UAN within three days. (See Table 9).
- Under rain fed (non-irrigated) conditions, apply sidedress N before corn is 12 inches tall. (V7 stage).
- Take appropriate credit for previous legume crops and any manure used in the rotation.

- Inject or incorporate sidedress applications of urea or UAN into moist soil to a minimum depth of three inches.
- Minimize direct movement of surface-water to sinkholes.
- When soils have a high leaching potential (sandy texture), nitrogen application in a split-application or sidedress program is preferred. Use a nitrification inhibitor on labeled crops with early sidedressed N.

2) Acceptable, but with greater risk

- Spring preplant application of UAN (see Table 10)
- Spring preplant application of ESN

3) Not recommended

- Fall application of ammonia, urea, and UAN, with or without a nitrification inhibitor (N-Serve). (See Table 2).
- Sidedressing all N when corn follows corn.
- Fall application of N to coarse-textured (sandy) soils.
- Application of any N fertilizer including MAP or DAP on frozen soils.

Nitrogen Management Research in Southeastern Minnesota

Nitrogen management research for corn primarily involves determining the effects of rate and time of fertilizer N application, source of N, application methods, and additives (nitrapyrin, N-Serve) on corn production. In addition to measuring crop yield responses to various N treatments, many studies also evaluate crop quality (protein), economic return to N, carryover residual nitrate in the soil profile, and N use efficiency. In the following section, emphasis is placed on crop yield, economic return, and residual soil nitrate-N to determine economically and environmentally sound BMP's for southeastern Minnesota.

Rate of N Application

Using the correct amount of N optimizes crop yield while minimizing loss of N to the environment. Using excessive rates reduces profitability for the farmer and can result in excess nitrate being delivered to ground and surface water resources.

Determining the correct amount of fertilizer N to apply for a crop means first estimating how much N is available from the soil and second adding fertilizer N to meet the crop's total N need. Because uncontrollable factors like precipitation and temperature affect the release of N from the soil as well as the amount of N needed by the crop, the optimum amount of fertilizer N can change from area to area and year to year.

Dozens of field research studies have been conducted by University scientists in southeastern Minnesota to determine optimum N rates for corn. Data from 128 Minnesota sites were included in a massive effort to arrive at N recommendations for seven Corn Belt states (Iowa State Univ., PM 2015, 2006). Yield goal was found not to be a good predictor of the N rate needed. Instead, the recommended rate of N to apply was determined to be within a range of N rates, depending on the productivity of the soil, previous crop, manure applications, and the ratio of price of fertilizer N to corn price.

For southern Minnesota, the range of N rates for corn after corn and corn after soybeans is found in Table 1. Thus, for corn following soybeans, when N costs $0.25/lb and corn sells for $2.50/bu (a ratio of 0.10), the optimum N rate ranges from 90 to 125 lb N/A with the maximum economic return to N (MRTN) achieved at a rate of 110 lb N/A. In southeastern Minnesota, a rate of 110 to 120 lb N/A is recommended on those soils with the highest productivity and yield potential (Port Byron, Mount Carroll, Seaton, etc.), whereas, the 90-lb rate would be suitable for those soils of lower productivity where the yield potential is less due to limited water holding capacity (Frankville, New Glarus, Rockton, etc.).

A continuous corn study conducted in Olmsted County beginning in 1987 clearly demonstrates that nitrogen should not be applied above recommended rates and definitely not in the fall (Table 2). Highest four-year average yields occurred with the 150-lb N rate as ammonia; however, NO_3-N concentrations in the soil water at 5 feet also began to climb rapidly at this rate.

There may be fields in the region where production potential is limited by factors such as poor drainage, low water holding capacity, severe compaction and/or other restrictions to root and/or crop growth. For these fields or portions of fields, it is suggested that the rates listed to achieve MRTN and the N rates in the acceptable ranges listed in Table 1 be reduced by 20 lb. per acre.

Table 1. Nitrogen rate fertilization guidelines for highly productive soils in southern Minnesota based on N: corn price ratios and economic return for corn after corn and corn after soybean.

Price ratio	Previous Crop	
	Corn	Soybean
$/lb N: $/bu corn	lb N/A[1]	
0.05	130-180 (155)[2]	100-140 (120)
0.10	120-165 (140)	90-125 (110)
0.15	110-150 (130)	80-115 (100)
0.20	100-140 (120)	70-100 (85)

[1] N rates are to be reduced 20 lb/A on soils considered to have a medium yield potential due to yield-limiting factors.
[2] N rate that maximizes economic return to N (MRTN)

Table 2. Corn yield and NO_3-N concentration in the soil water at 5 feet as affected by rate and time of application in Olmsted Co., 1987-90.

Nitrogen Treatment		Grain Yield		Nitrate-N Conc. in Soil Water[1]
Rate	Time/Method	1990	1987-90	
lb N/A		---- bu/A ----		ppm
0	--	76	84	1
75	Spr., preplant	145	156	11
150	"	155	172	29
225	"	156	167	43
150	Fall	145	169	43
150	Fall + N-Serve	148	169	50
75 + 75	Spr. + SD (V7)	154	168	47

[1] Fall, 1990

Additional studies to define the optimum rate for continuous corn were conducted from 1992-2004 (Table 3). Corn grain yields were optimized at the 150-lb N rate during this 13-year period. Residual NO_3-N left in the soil profile in October greatly increased at N rates of 150 lb N/A and greater. These data clearly indicate the reduced profitability and increased potential for ground water contamination by nitrate when fertilizer N was applied at rates greater than needed.

Table 3. Continuous corn grain yield and residual NO_3-N in the soil profile in October in Olmsted Co., 1992-2004.

N Rate	Corn Yield 1992-2004	Corn Yield 2002-2004	Residual NO_3-N in 0-7' profile[1]
lb N/A	------ bu/A ------		lb/A
0	71	90	23
60	124	126	38
90	137	143	52
120	146	156	62
150	150	161	158
180	--	161	173

[1] October, 2003.

To determine if "extra-high" continuous corn yields could be achieved on a very high yielding Port Byron soil, very high fertilizer and seeding rates were used in an Olmsted Co. study in 2003-2005. Corn grain yields were increased about 6 bu/A with the very high fertilizer rates, but economic return was reduced by more than $120/A (Table 4). Moreover, potential nitrate leaching losses were increased by about 300 lb NO_3-N/A with the additional N that carried over in the soil profile after harvest from the 300-lb N rate. These results illustrate the negative consequences of very high total N rates for corn, which also can occur if N credits from legumes and manure are not properly taken and fertilizer N is applied.

Table 4. Influence of very high N rates and plant populations on continuous corn yield, economic return, and residual NO_3-N in the soil profile in Olmsted Co., 2003-2005.

N Rate	Final population	3-Yr. Average Yield	3-Yr. Average Return to Fert. & Seed	Residual[1] NO_3-N in soil
lb N/A	plants/A	bu/A	$/A	lb/A
180[2]	31,000	183	326	129
180[2]	41,900	184	313	167
300[3]	31,900	188	201	473
300[3]	41,900	192	192	420

[1] 0-5' profile in Oct. 2005.
[2] no additional P or K
[3] plus 200 lb P_2O_5 and 300 lb K_2O/A/yr

Nitrogen rate experiments for corn after soybeans were conducted on seven farmers' fields without a recent (10-yr) manure history from 1989-1999 (Table 5). The average economic optimum N rate (EONR), using a N price of $0.25/lb and a corn value of $2.50/bu—a 0.10 ratio) was 97 lb N/A for the six sites that responded to N. No fertilizer N was required to produce the 150 bu/A yield at the non-responding Dakota Co. site. Corn yield at the EONR averaged across all seven sites was 173 bu/A. Yield for the zero N treatment averaged across all seven sites was 147 bu/A, indicating that soil N supplied 85% of the N needed to optimize yield and profit while fertilizer N supplied 15% (26 bu/A). These results suggest that rates slightly lower than the MRTN rates shown in Table 1 can be used for corn after soybeans on highly productive soils in southeastern Minnesota.

Table 5. Corn yields for the zero N rate and for the economic optimum N rate (EONR) for seven sites following soybeans in southeastern Minnesota, 1989-1999.

Year	County	Corn grain yield at Zero N rate	Corn grain yield at EONR	EONR
		----- bu/A -----		lb N/A
1989	Dakota	150	150	0
1989	Olmsted	163	188	126
1992	Dodge	105	140	105
1992	Goodhue	115	147	92
1998	Dodge	175	202	89
1998	Dodge	175	200	82
1999	Olmsted	146	183	86
	Avg.	147	173	97[1]

[1] Six responding sites.

Nitrogen From Previous Legume Crops

Nitrogen can be supplied from legume crops used in the rotation. Nitrogen credits from these crops are listed in Tables 6 and 7 and should be subtracted from the nitrogen guidelines for corn following corn Table 1. The N credit for the soybean crop is 40 lb. per acre and has been accounted for in Table 1. The N credit for a corn crop in the second year following a forage legume is summarized in Table 7.

Table 6. Nitrogen credits for legumes preceding corn in the crop rotation.

Previous Crop	1st Year Nitrogen Credit
	---- lb. N per acre ----
Harvested alfalfa	
4 or more plants/ft^2	150
2-3 plants/ ft^2	100
1 or less plants/ ft^2	40
Red clover	75
Edible beans	20
Field peas	20

Table 7. Nitrogen credits for some forage legumes if corn is planted two years after the legume.

Previous Crop	2nd Year Nitrogen Credit
	---- lb. N per acre ----
Harvested alfalfa	
4 or more plants/ft^2	75
2-3 plants/ ft^2	50
1 or less plants/ ft^2	0
Red clover	35

Nitrogen in Manure

Nitrogen in livestock manure is just as important as nitrogen applied in commercial fertilizers. Therefore, any available N in manure should be used as a credit when determining the total amount of fertilizer N needed for corn. The process of determining the amount of N supplied by manure is described in other publications that are listed on page 6 of this bulletin. As with credits from legumes, manure N credits should be subtracted from the guideline values in Table 1 for corn following corn.

Nitrogen from Other Sources

When determining the total amount of fertilizer N needed, N supplied in other fertilizers cannot be ignored. This is true whether pre-emergence or post emergence herbicides are applied using 28-0-0 as a carrier or applying high rates of phosphate fertilizers using sources containing N (11-52-0, 18-46-0, 10-34-0). This N must be taken into consideration when the rate of fertilizer N to be applied for corn is determined.

Time of N Application and N-Serve

Fall application of nitrogen produces a greater risk of nitrate leaching in southeastern Minnesota because of high average annual precipitation, the well-drained and permeable nature of the soil, and the presence of fractured limestone (karst geology). Spring preplant or sidedress nitrogen applications provide more efficient use of nitrogen than fall application.

Fall application (Nov. 13) of anhydrous ammonia with and without N-Serve gave yields in 1990 that were 7 to 10 bushels per acre (bu/A) less than with the same nitrogen rate applied in the spring before planting (Table 2). Moreover, NO_3-N concentrations in the soil water were 50 to 70 percent higher with the fall applications. Nitrate-N concentrations in the soil water in October 1988 were also highest for the fall applications; however, yields were not affected that year. Examination of the four-year yield average does not show consistent yield decreases with fall-applied nitrogen, but in seasons with above-normal rainfall lower yields can be encountered with fall application of nitrogen.

Spring preplant (PP) applications of ammonia or urea have been found to yield as well as split and sidedress (SD) applications. Continuous corn studies conducted on Port Byron silt loam in 1987-90 in Olmsted Co. (Table 2) and Goodhue Co. (Table 8) showed no yield advantage for either split (PP + SD) or a single sidedress application of ammonia. Soil water obtained from a 5-foot depth after harvest in 1990 showed a significantly higher NO_3-N concentration with the split application in Olmsted Co. and the sidedress application at V5 in Goodhue Co.

Table 8. Effect of nitrogen application time and rate on corn yield and NO_3-N concentration in the soil water at a 5-foot depth in Goodhue Co., 1987-90.

Nitrogen Treatment		4-yr Average Yield	Nitrate-N Concentration in Soil Water[1]
Rate	Time/Method		
lb N/A		bu/A	ppm
0	--	89	6
50	Preplant (PP)	129	ND[2]
100	PP	143	22
150	PP	147	39
200	PP	148	ND
50+50	PP+SD (V5)	142	ND
50+100	PP+SD (V5)	146	ND
100+50	PP+SD (V5)	148	ND
100	SD (V5)	140	ND
150	SD (V5)	146	62

1/ Fall 1990
2/ ND-not determined

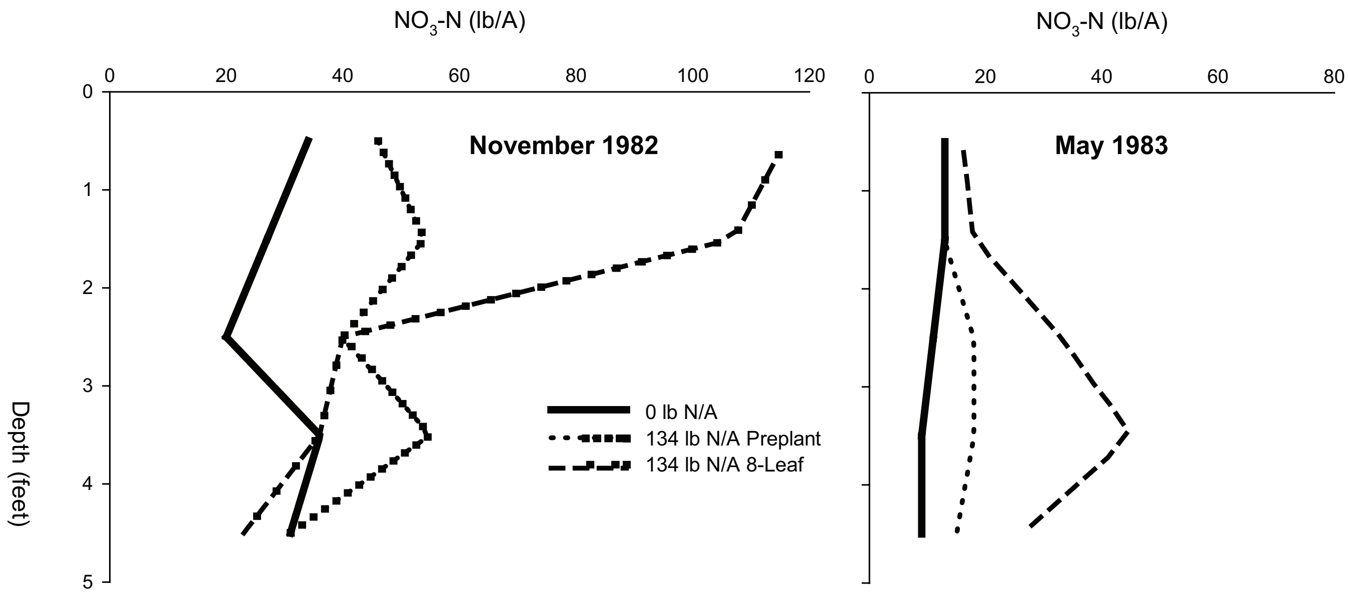


Figure 2. Effect of nitrogen rate and time of application on the NO_3-N in the soil profile in 1982-83.

Nitrogen not absorbed by plants often remains in the soil after harvest and thus is highly susceptible to leaching loss before the next year's crop can use it. Strong evidence of this occurred on a Mount Carroll silt loam in Goodhue Co. in 1982 and 1983 where substantial amounts of NO_3-N remained in the soil after harvest when the sidedress nitrogen was band-applied 2 inches deep at the 8-leaf stage (Figure 2). Most of this residual nitrate was not found in the 5-foot profile the following May. Excess levels of residual soil nitrate similar to those shown in Fig. 2 can also occur when preplant-applied N rates are greater than needed as shown in Tables 3 and 4.

Limiting sidedress applications to corn shorter than 12 inches will help ensure that nitrogen is available when the plants need it most, from late June through mid-August. This strategy also improves the chances that nitrogen will be available to the crop during extended dry weather. An Olmsted Co. study clearly showed that delayed nitrogen applications can result in significant yield reduction. On a Port Byron soil that had only received a 60-lb N rate the previous year, second year corn was grown to compare split application (PP + SD, V10) with preplant N application (Table 9). Grain yields of 194 bu/A were obtained at the 200-lb rate of preplant N at this "N-starved" site. Interestingly, yields for the split-applied 160-lb treatment were 19 bu/A lower than for the preplant treatment (166 vs. 185 bu/A). The sidedress urea treatments were applied on July 5 (V10 stage) and no precipitation occurred until after July 20 (R1). The roots did not take up the sidedressed N until after R1 as shown by the lower relative chlorophyll levels for the sidedress treatments.

Table 9. Corn grain yield and relative leaf chlorophyll content at R1 as influenced by N rate and time of application in Olmsted Co, 2005.

Time of Application		Total N Rate	Grain Yield	Rel. Leaf Chlorophyll
Preplant	V10			
- - - - - - - - - - - - lb N/A - - - - - - - - - - - -			bu/A	%
0	0	0	75	68
40	0	40	115	78
80	0	80	142	86
120	0	120	174	94
160	0	160	185	98
200	0	200	194	99
40	40	80	145	75
40	80	120	164	76
40	120	160	166	77

Time of Application and Source of N

For preplant applications, use ammonium forms of nitrogen fertilizer such as anhydrous ammonia and urea to reduce the potential for early-season nitrate loss. Urea-ammonium nitrate (UAN) contains 25% nitrate, which is immediately susceptible to leaching. Under normal spring conditions anhydrous ammonia and urea will take from two to six weeks to nitrify from ammonium to nitrate. This delay decreases the potential for leaching of nitrate during the last part of April and in May, when precipitation is highest and crop demand for nitrogen and water is low.

Urea broadcast on the surface should be mixed into the soil (incorporated) soon after application to reduce potential loss by volatilization and surface runoff. Volatilization is generally accelerated by crop residue and high soil pH. High soil pH is uncommon in southeastern Minnesota, but large amounts of surface residue are common because conservation tillage is used with continuous corn. In addition, fertilizer N injected or incorporated to a 4-inch depth is more likely to reach roots under dry conditions. Surface-applied fertilizers are less likely to reach roots under dry conditions, and yields may suffer.

Preplant-applied urea gave significantly greater continuous corn yields in a 3-year study on a Port Byron soil than did preplant-applied UAN (28%N) (Table 10). Yields for a split application of UAN were not significantly different from the preplant urea treatment.

Table 10. Continuous corn grain yield as affected by source and time of N application in Olmsted Co., 2002-2004

N Treatment		Corn Yield*
Source	Time	
		bu/A
Urea	Preplant	152
UAN	"	146
UAN	Split**	150

* Averaged across 60, 90, 120, 150, and 180-lb N rates.
** 30 lb N/A preplant and rest injected at V4 stage.

Urea and other fertilizers and manures left on the soil surface can easily be washed toward streams and sinkholes during intense rains. When nutrient-laden surface water runs directly into sinkholes, water quality over a large region can be harmed. Movement of those nutrients can be minimized through erosion control, berms, and filter strips around sinkholes. Incorporating fertilizer and manure into the soil, rather than leaving them on top, greatly reduces chances that they will wash into sinkholes and contaminate the groundwater.

Potential Helpful Products

There is general recognition that nitrogen can be lost from soils. Responding to that recognition, products have been developed that, when used, could reduce the potential for loss. N-Serve is a nitrification inhibitor used for the purpose of delaying the conversion of ammonium (NH_4-N) to nitrate (NO_3-N). The use of this product for corn production in southeastern Minnesota has been discussed previously in this publication.

Agrotain is a urease inhibitor designed to be used in no-till or other production systems where urea remains on the soil surface without incorporation. It reduces the potential for N loss due to volatilization. This product could be used in southeastern Minnesota where corn is planted using the no-till system.

ESN is a product that consists of urea coated with a polymer and, thus, is intended for use as a slow release nitrogen fertilizer. It is acceptable to use this product in the spring before planting in southeastern Minnesota. However, there is a risk. The cost is substantially higher than the cost of N supplied as urea. Mixtures of ESN and urea might be appropriate. However, mixtures have not been evaluated.

Summary

Effective and efficient management of nitrogen fertilizers is important for profitable corn production in southeastern Minnesota. The research based Best Management Practices (BMP's) described in this publication are agronomically, economically, and environmentally sound. They are voluntary. If these practices are followed, agriculture can be more profitable without the threat of regulation.

Related Publications

08560 (revised, 2008) - Best Management Practices for Nitrogen Use in Minnesota

08554 (revised, 2008) - Best Management Practices for Nitrogen Use in South-Central Minnesota

08558 (revised, 2008) - Best Management Practices for Nitrogen Use in Southwestern and West-Central Minnesota

08555 (revised, 2008) - Best Management Practices for Nitrogen Use in Northwestern Minnesota

08556 (Revised, 2008) - Best Management Practices for Nitrogen Use on Coarse Textured Soils

AG-FO-5880 - Fertilizing Cropland with Dairy Manure

AG-FO-5879 - Fertilizing Cropland with Swine Manure

AG-FO-5881 - Fertilizing Cropland with Poultry Manure

AG-FO-5882 - Fertilizing Cropland with Beef Manure

AG-FO-3790 - Fertilizing Corn in Minnesota

AG-FO-3770 - Understanding Nitrogen in Soils

AG-FO-3774 - Nitrification inhibitors and Use in Minnesota

AG-FO-2274 - Using the Soil Nitrate Test for Corn in Minnesota

AG-FO-2392 - Managing Nitrogen for Corn Production on Irrigated Sandy Soils

AG-FO-0636 - Fertilizer Urea

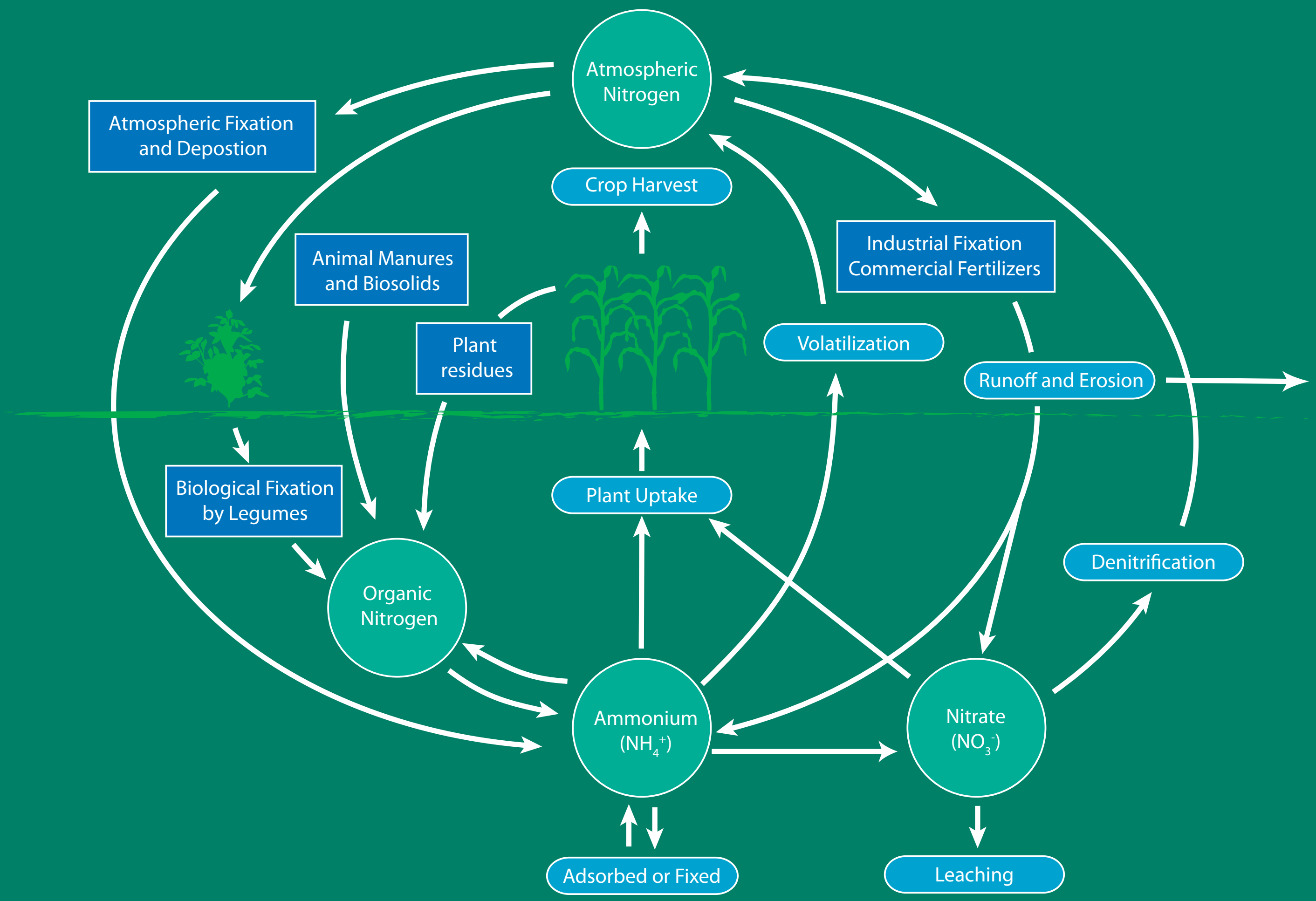
AG-FO-3073 - Using Anhydrous Ammonia in Minnesota

AG-FO-6074 - Fertilizer Management for Corn Planted in Ridge-till or No-till Systems

AG-FO-3553 - Manure Management in Minnesota

BU-07936 - Validating N Rates for Corn

Iowa State Univ. PM 2015 - Concepts and Rationale for Regional Nitrogen Rate Guidelines for Corn



UNIVERSITY OF MINNESOTA
EXTENSION

Best Management Practices for Nitrogen Use in Southeastern Minnesota

PUBLICATION # 08557

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UNIVERSITY OF MINNESOTA
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Best Management Practices for Nitrogen Use in SOUTH-CENTRAL MINNESOTA

BEST MANAGEMENT PRACTICES FOR NITROGEN APPLICATION

Best Management Practices for Nitrogen Use in South-Central Minnesota

Gyles Randall, Soil Scientist and Professor, Southern Research and Outreach Center, Waseca; George Rehm, Nutrient Management Specialist (*retired*); John Lamb, Professor; Carl Rosen, Professor, Department of Soil, Water, and Climate, University of Minnesota

Introduction

Nitrogen (N) is an essential plant nutrient that is applied to Minnesota crops in greater quantity than any other fertilizer and contributes greatly to the agricultural economy of Minnesota crop producers. In addition, vast quantities of nitrogen are contained in the ecosystem, including in soil organic matter. Biological processes that convert nitrogen to its mobile form, nitrate (NO_3), occur continuously in the soil system. (For greater detail see ***Understanding Nitrogen in Soils*** **AG-FO-3770**.) Unfortunately, nitrates can be leached from the root zone of the soil. Management guidelines have been developed to assist crop producers manage their nitrogen in ways that optimize profitability, reduce risk, and minimize the loss of nitrate to surface and ground water.

What Are the Best Management Practices (BMP's)?

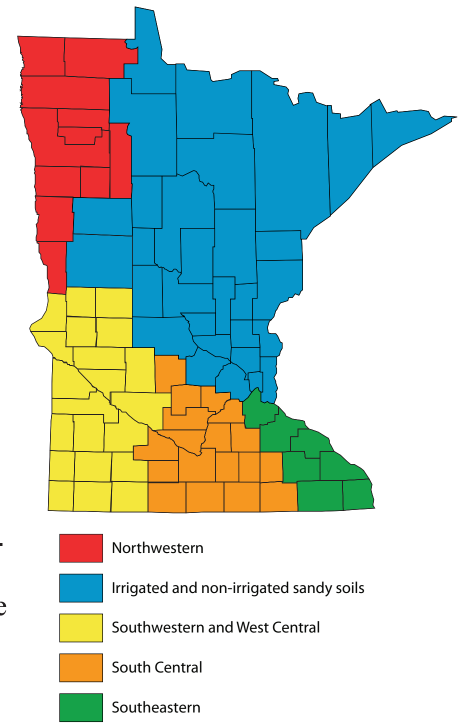
Best Management Practices (BMP's) for nitrogen are broadly defined as "economically sound, voluntary practices that are capable of minimizing nutrient contamination of surface and groundwater". The BMP's recommended herein are based upon research conducted by the University of Minnesota from over 70 site-years of field research in south-central Minnesota and upon practical considerations.

The BMP's are based, in part, upon the concept of total nitrogen management, which accounts for all forms of on-farm nitrogen in the development of crop management plans. BMP's were developed to be adopted on a statewide as well as a regional basis.

BMP's for South-Central Minnesota

South-central Minnesota is characterized by fine-textured soils formed in glacial till and sediments. Most south-central soils have naturally poor-to-moderate internal drainage and are tiled to improve drainage. Average annual precipitation in the region is 27 to 35 inches. Crops are predominantly corn and soybeans. BMP's for the area shown in the map (Blue Earth, Brown, Carver, Dodge, Faribault, Freeborn, LeSueur, Martin, McLeod, Meeker, Mower, Nicollet, Rice, Scott, Sibley, Steele, Waseca and Watonwan counties) have been developed based on field research conducted in some of those counties.

The BMP's in this publication focus on nitrogen use for corn. They are divided into three categories described as: 1) recommended, 2) acceptable but with greater risk, and 3) not recommended. With respect to N management, risks can be either economic or environmental. Economic risks can be either a consequence of added input cost without additional yield or a reduction in yield. Environmental risks pertain to the potential for loss of nitrogen to either ground water or surface waters.



For south-central Minnesota, the BMP's are:

1) Recommended

- Select an appropriate N fertilizer rate using U of M guidelines ("***Fertilizing Corn in Minnesota***" **FO-3790,** 2006 or newer) which are based on current fertilizer and corn prices, soil productivity and economic risks.
- Total N rate should include any N applied in a starter, weed and feed program, and contributions from phosphorus fertilizers such as MAP and DAP.
- Spring preplant applications of ammonia and urea or split applications of ammonia, urea, and UAN are highly recommended. (See Tables 2, 5, 6, 7, 8, 9, 11, 12 and 13)
- Incorporate broadcast urea or preplant UAN within three days to a minimum depth of 3 inches.
- Inject or incorporate sidedress applications of urea or UAN into moist soil to a minimum depth of 3 inches. (See Tables 12 and 13).
- Take appropriate credit for previous legume crops and any manure used in the rotation.
- Under rain fed (non-irrigated) conditions, apply sidedress N before corn is 12 inches tall. (V7 stage)
- When soils have a high leaching potential (sandy texture), nitrogen application in a split-application

or sidedress program is preferred. Use a nitrification inhibitor (N-Serve) on labeled crops with early sidedressed N.

2) Acceptable, but with greater risk

- Fall application of ammonia + N-Serve after soil temperature at the 6-inch depth is below 50°F. (See Tables 5, 6, 8, and 9).
- Spring preplant application of UAN (see Table 11)
- Late fall or spring preplant application of ESN

3) Not recommended

- Fall application of urea and ammonia without N-Serve. (See Tables 5, 6, 7, 8 and 9).
- Sidedressing all N when corn follows corn. (See Table 13).
- Fall application of N to coarse-textured (sandy) soils.
- Application of any N fertilizers, including MAP and DAP on frozen soils.
- Fall application of UAN (28-0-0).

Nitrogen Management Research in South-Central Minnesota

Nitrogen management research for corn primarily involves determining the effects of rate and time of fertilizer N application, source of N, application methods, and additives (Nitrapyrin, N-Serve) on corn production. In addition to measuring crop yield responses to various N treatments, many studies also evaluate crop quality (protein), economic return to N, carryover residual nitrate in the soil profile, nitrate losses to ground and surface (tile drainage) water and N use efficiency. In the following section, emphasis is placed on crop yield, economic return, N use efficiency, and nitrate losses in subsurface, tile drainage to determine economically and environmentally-sound BMP's for south-central Minnesota.

Rate of N Application

Using the correct amount of N optimizes crop yield while minimizing loss of N to the environment. Using the wrong amount reduces profitability for the farmer and can result in excess nitrate being delivered to ground and surface water resources.

Determining the correct amount of fertilizer N to apply for a crop means first estimating how much N is available from the soil and second adding fertilizer N to meet the crop's total N need. Because uncontrollable factors like precipitation and temperature affect the release of N from the soil as well as the amount of N needed by the crop, the optimum amount of fertilizer N can change from area to area and year to year.

Dozens of field research studies have been conducted by University scientists in south-central Minnesota to determine optimum N rates for corn. Data from 128 Minnesota sites were included in a massive effort to arrive at N recommendations for seven Corn Belt states (Iowa State Univ., PM 2015, 2006). Yield goal was found not to be a good predictor of the N rate needed. Instead, the recommended rate of N to apply was determined to be within a range of N rates, depending on the productivity of the soil, previous crop, manure applications, and the ratio of price of fertilizer N to corn price.

For southern Minnesota, the range of N rates for corn after corn and corn after soybeans is found in Table 1. Thus, for corn following soybeans, when N costs $0.25/lb and corn sells for $2.50/bu (a ratio of 0.10), the optimum N rate ranges from 90 to 125 lb N/A with the maximum economic return to N (MRTN) achieved at a rate of 110 lb N/A. In south-central Minnesota, a rate of 110 to 120 lb N/A is recommended on those soils with the highest productivity and yield potential (Nicollet, Webster, etc.), whereas, the 90-lb rate would be suitable for those soils of lower productivity where the yield potential is less due to limited water holding capacity (Clarion, Storden, etc.).

Table 1. Nitrogen rate fertilization guidelines for highly productive soils in southern Minnesota based on N: corn price ratios and economic return for corn after corn and corn after soybean.

	Previous Crop	
Price ratio	Corn	Soybean
$/lb N: $/bu corn	- - - - - - - - - - - lb N/A[1/]	- - - - - - - - - - -
0.05	130-180 (155)[2/]	100-140 (120)
0.10	120-165 (140)	90-125 (110)
0.15	110-150 (130)	80-115 (100)
0.20	100-140 (120)	70-100 (85)

[1/] N rates are to be reduced 20 lb/A on soils considered to have a medium yield potential due to yield-limiting factors.

[2/] N rate that maximizes economic return to N (MRTN)

The effect of N rate on corn yield, profitability, and nitrate loss to tile drainage is shown in Table 2. Compared with the standard 120-lb N rate applied in the fall, adding an additional 40 lb N/A (160-lb N rate) increased yields 6 bu/A (4%), increased profit by $2/A (3%), and increased NO_3-N concentration in the tile water by 4.9 mg/L (37%). On the other hand reducing the N rate to 80 lb/A reduced yield 22 bu/A (13%) reduced profit $34/A (47%), and reduced NO_3-N concentration in the water by 1.7 mg/L (13%). Greatest yield and profit with a minimal increase in NO_3-N concentration was found with the spring-applied 120-lb N rate. These data clearly demonstrate the importance of using the correct N rate as a cornerstone BMP from an economic and a water quality perspective.

Table 2. Corn production and nitrate loss to tile drainage as affected by rate and time of N application at Waseca, 2000-2003.

			4-Yr Average		
N Treatment			Grain	Net return	Flow-weighted
Time	Rate	N-Serve	yield	to N[1/]	NO_3-N Conc.[2/]
	lb N/A		bu/A	$/A	mg/L
--	0	--	111	--	--
Fall	80	Yes	144	38	11.5
"	120	"	166	72	13.2
"	160	"	172	74	18.1
Spr.	120	No	180	105	13.7

[1/] Based on corn = $2.00/bu, fall N = $0.25/lb, spring N = $0.275/lb, N-Serve = $7.50/A.

[2/] Across four C-Sb rotation cycles, i.e. four years of corn followed by four years of soybean.

Nitrogen From Previous Legume Crops

As with soybean discussed above, N can also be supplied from other legume crops used in the rotation. Nitrogen credits from these crops are listed in Tables 3 and 4 and should be subtracted from the nitrogen guidelines for corn following corn in Table 1. The N credit for a corn crop in the second year following a forage legume is summarized in Table 4.

Table 3. Nitrogen credits for legumes preceding corn in the rotation.

Previous Crop	1st Year Nitrogen Credit
	---- lb. N per acre ----
Harvested alfalfa	
4 or more plants/ft^2	150
2-3 plants/ ft^2	100
1 or less plants/ ft^2	40
Red clover	75
Edible beans	20
Field peas	20

Table 4. Nitrogen credits for some forage legumes if corn is planted two years after the legume.

Legume Crop	2nd Year Nitrogen Credit
	---- lb. N per acre ----
Harvested alfalfa	
4 or more plants/ft^2	75
2-3 plants/ ft^2	50
1 or less plants/ ft^2	0
Red clover	35

Nitrogen in Manure

Nitrogen in livestock manure is just as important as nitrogen applied in commercial fertilizers. Therefore, any available N in manure should be used as a credit when determining the total amount of fertilizer N needed for corn. The process of determining the amount of N supplied by manure is described in other publications that are listed on page 6 of this bulletin. As with credits from legumes, manure N should be subtracted from the guideline values in Table 1 for corn following corn.

Nitrogen from Other Sources

When determining the total amount of fertilizer N needed, N supplied in other fertilizers cannot be ignored. This is true whether pre-emergence or post emergence herbicides are applied using 28-0-0 as a carrier or applying high rates of phosphate fertilizers using sources containing N (11-52-0 or 18-46-0, 10-34-0). This N must be taken into consideration when the rate of fertilizer N to be applied for corn is being determined.

Time of N Application and N-Serve

A 4-yr study at Waseca, comparing a late-October application of anhydrous ammonia at three N rates plus N-Serve with spring-applied ammonia without N-Serve, showed a 14 bu/A yield response and $33/A economic return advantage for spring application when applied at the 120-lb rate with no difference in flow weighted NO_3-N concentration in the tile drainage (Table 2). Moreover, the 120-lb spring N treatment increased yields 8 bu/A and economic return to N by $31/A while decreasing NO_3-N concentration in the drainage from 18.1 to 13.7 mg/L (24%) compared with 160 lb N/A + N-Serve applied in the fall. Conversely, choosing to apply 160 lb N/A in the fall rather than 120 lb/A in the spring would have cost the grower a 4% yield and 30% economic reduction while increasing nitrate losses in drainage by 32%.

A long-term study, comparing late-October application of ammonia with and without N-Serve with a spring preplant application without N-Serve, showed distinct yield, economic, and environmental advantages for spring application, but not in all years (Table 5). Across the 15-yr period, corn yields averaged about 10 bu/A greater for the fall N + N-Serve and spring N treatments compared with fall N without N-Serve. Also, compared with fall application of N without N-Serve, NO_3-N losses in the drainage water were reduced by 14 and 15%, economic return to N was increased by $9 and $19/A, and N recovery in the grain was increased by 8 and 9% for fall N + N-Serve and spring N, respectively. However, corn yields were significantly affected by the N treatments in only 7 of 15 years. In those seven years, when April, May and/or June were wetter-than-normal, average corn grain yield was increased by 15 and 27 bu/A and average economic return was increased by $22.50 and $51.00/A for the fall N + N-Serve and spring N treatments, respectively. In summary, the 15-yr data suggest that applications of ammonia in the late fall + N-Serve or in the spring preplant were BMP's. However, when spring conditions were wet, especially in May and June, spring application gave substantially greater yield and profit than the fall N + N-Serve treatment. Therefore, fall N + N-Serve application is considered to be more risky than a spring, preplant application of ammonia. Moreover when N-Serve was not used, fall application of ammonia was more risky (lower yields) compared with spring application regardless of tillage system (no-till, strip-till, spring field cultivate, and fall chisel plow).

Table 5. Corn yield and economic return to nitrogen program as affected by time of application and N-Serve at Waseca, 1987-2001.

Parameter	Time of Application[1]		
	Fall	Fall + N-Serve	Spring
15-Yr Avg. Yield (bu/A)	144	153	156
15-Yr Avg. Economic return over fall N ($/A/yr)[2]	--	$9.30	$18.80
7-Yr Avg. Yield (bu/A)[3]	131	146	158
7-Yr Avg. Economic return over fall N ($/A/yr)[2]	--	$22.50	$51.00
Flow-weighted NO_3-N concentration in tile drainage from the corn-soybean rotation (mg/L)	14.1	12.2	12.0
Nitrogen recovery in the corn grain (%)[4]	38	46	47

[1] Rate of applications for 1987-1993 and 1994-2001 were 135 and 120 lb N/A, respectively.
[2] Based on corn = $2.00/bu, fall N = $0.25/lb N, spring N = $0.275/lb N, and N-Serve = $7.50/A.
[3] Only those seven years when a statistically significant yield difference occurred among treatments.
[4] Nitrogen recovery in the corn grain as a percent of the amount of fertilizer N applied.

A split application of ammonia with 40% applied preplant and 60% applied sidedress at the V8 stage was compared with late October and spring preplant applications of ammonia (Table 6). In this 7-yr period, grain yields were significantly greater (6 bu/A) for the split-applied treatments, resulting in slightly greater N recovery in the grain and economic return to N compared with the fall and spring treatments. However, NO_3-N concentrations in the tile drainage were also slightly higher with split-applied N than for the spring N and fall N + N-Serve treatments.

Table 6. Corn production after soybeans and nitrate loss as affected by time of N application and N-Serve at Waseca, 1987-93.

N Treatment		7-Yr Average			Flow-weighted NO_3-N conc. in tile drainage
Time	N-Serve	Corn yield	N recovery	Economic return to N[1/]	
		bu/A	%	$/A	mg/L
Fall	No	131	31	34	16.8
"	Yes	139	37	43	13.7
Spring	No	139	40	47	13.7
Split	No	145	44	56	14.6
LSD (0.10):		4			

1/ Based on corn = $2.00/bu, fall N = $0.25/lb, spring N = $0.275/lb, N-Serve = $7.50/A, and application cost = $4.00/A/time.

A 6-yr study comparing fall versus spring application of N-Serve with ammonia showed a statistically and economically significant 10 bu/A yield response to N-Serve applied in the fall (Table 7). The 4 bu/A yield increase to spring-applied N-Serve was not statistically significant and is considered economically neutral. However, a yield response to spring-applied N-Serve occurred in years when June rainfall was excessive. Because these data do not suggest a consistently significant and economical response to N-Serve applied in the spring and because excessive June rainfall can not be predicted at the time of spring ammonia application, adding N-Serve to spring-applied ammonia is not considered to be a BMP.

Table 7. Corn grain yield after soybeans as affected by fall and spring application of N-Serve with anhydrous ammonia at Waseca, 1994-99.

Time of application	N-Serve: No	N-Serve: Yes
	- - - - - 6-Yr Avg. Yield (bu/A) - - - - -	
Fall	161	171
Spring	172	176

Time of Application and N Source

The N source used must also be considered when selecting the proper time of application. Studies at Waseca in 1981 and 1982 compared fall application of anhydrous ammonia and urea, with and without N-Serve, to spring application of the same. Two-year average corn yields (Table 8) indicate: (a) broadcast and incorporated urea was inferior to anhydrous ammonia when fall-applied, (b) spring application of urea was superior to fall application, and (c) a slight yield advantage for spring-applied ammonia compared with fall application was found when averaged across N-Serve treatments.

Table 8. Corn yield as influenced by N source, time of application, and N-Serve at Waseca, 1981-82.

Nitrogen treatment		Time of Application	
Source	N-Serve	Fall	Spring
		- - - - - Yield (bu/A) - - - - -	
None	--	104	
Urea	No	157	164
"	Yes	155	167
An. Ammonia	No	162	168
"	Yes	170	173

A subsequent study evaluated late October application of urea (4" deepband) and anhydrous ammonia with and without N-Serve compared to spring preplant urea and anhydrous ammonia. Three-year average yields show a 33 bu/A advantage for urea and a 14 bu/A for ammonia when applied in the spring (Table 9). Nitrogen recovery in the corn plant ranked: spring ammonia = spring urea > fall ammonia > fall urea. The effect of N-Serve in this study was minimal. Yield responses to the spring treatments were greatest in 1998, when April and May were warm and late May was wet, and in 1999 when the fall of 1998 was warm and April and May, 1999 were very wet. Significant yield differences were not found in 1997 when the fall of 1996 was cold and the spring of 1997 was cool and dry.

Table 9. Corn yield and N recovery in the whole plant as influenced by time of application and N source at Waseca, 1997-1999.

Nitrogen Management			3-Yr Average	
Time	Source	N-Serve	Yield	N Recovery
			bu/A	%
Fall	Urea	No	152	43
"	"	Yes	158	47
"	An. Ammonia	No	168	60
"	"	Yes	170	63
Spr. Preplant	Urea	No	185	76
"	An. Ammonia	No	182	84
--	None	--	112	--
	LSD (0.10):		8	

Fourteen field studies were conducted on glacial till soils in south-central Minnesota to determine the effectiveness of split applications versus a single preplant application of N. Urea was applied preplant in 30-lb increments at rates of 0 to 180 lb N/A. Split applications consisted of preplant-applied urea at 30 or 60 lb N/A and urea injected 4" deep at rates of 30, 60, and 90 lb N/A at the V5 to V6 stage. Corn grain yields were equal between preplant and split-applied N at 7 of 14 sites. Yields from preplant-applied N were < or > yields from split-applied N at 4 and 3 sites, respectively, depending on spring rainfall. In 1991 when May-September rainfall was 56% above normal, yields were increased an average of 11 bu/A by the split-applied treatments (Table 10). In 1992, yields were decreased an average of 11 bu/A by the split applied treatments. Some N deficient corn was visible at the time of sidedressing, indicating the initial 30-lb preplant broadcast rate was insufficient. The plants never seemed to recover completely from this early-season deficiency, suggesting that a 40 to 60-lb rate of broadcast preplant N may be needed to reduce the risk of early-season N deficiency.

Table 10. Corn yield after soybeans as affected by method of application on fine-textured, glacial till soils in 1991 and 1992.

Time of application		Site	
Preplant	Sidedress (V6)	1991 Waseca Co.	1992 Blue Earth Co.
- - - - - N rate (lb N/A) - - - - -		- - - - - Yield (bu/A) - - - - -	
0	0	84	107
60	0	143	144
30	30	161	141
90	0	158	156
30	60	157	137
120	0	165	164
30	90	182	153
Advantage for split =		+11	-11

In summary, these "time of application" studies indicate:

- Spring preplant applications of N generally optimized grain yields and minimized nitrate losses to tile drainage water.
- Acceptability of fall applications (late October) depends on source of N and N-Serve.
- Urea should not be applied in the fall.
- Late-October applications of ammonia with N-Serve optimized corn yields in 10 of 15 years and reduced nitrate losses equal to those from spring-applied ammonia across the 15-yr period. Spring preplant-applied ammonia generated highest yields in years when May and June rainfall were excessive.
- Split applications of N produced yields similar to or greater than spring preplant N in most studies. However, yields were occasionally reduced by split application, suggesting the importance of adequate preplant N coupled with critical timing of sidedress N.
- Sidedress applications tended to generate slightly higher NO_3-N concentrations in the drainage water, especially in the following year when soybeans were planted.

Method of N Application

Split application studies were conducted at Waseca from 2001-03 to evaluate various methods for applying urea-ammonium nitrate solution (28%, UAN) at planting time in combination with a V3 sidedress treatment. The split treatments were compared with single fall and preplant applications of N in two tillage systems (spring field cultivate and strip-till) for corn after soybeans. Three-yr yield averages were generally greatest for the split treatments where UAN was either dribbled 2 inches from the row at planting or broadcast with a herbicide immediately after planting (weed and feed) in combination with 60 to 80 lb N/A sidedress injected midway between the rows at V3 to V4 stage (Table 11).

Lowest yields occurred with a single preplant application of UAN in the spring field cultivate system and either fall ammonia + N-Serve or 40 lb N/A dribbled as UAN at planting next to the seed row in the strip tillage system. Perhaps the 40-lb rate was too high when placed this close to the seed row in the strip-till system. Nitrogen recovery in the plant ranged from 56% for the fall ammonia treatments to 71% for the "weed and feed" UAN treatments when averaged across tillage systems. These results suggest substantial flexibility exists for combinations of preplant, planting, and sidedress applications of N as alternatives to traditional fall-applied ammonia.

Table 11. Corn yield following soybeans as affected by time/method of N application for two tillage systems at Waseca, 2001-2003.

Nitrogen treatment				Tillage system	
Time	Source	Rate	N-Serve	SFC[1/]	ST[1/]
		lb N/A		- Yield (bu/A) -	
--	--	0	--	122	111
Fall	AA	100	Yes	167	161
Spr.	AA	100	No	165	168
Spr.	Urea	100	"	167	166
Spr.	UAN	100	"	161	--
Plant [2/] + SD[1/]	"	20 + 80	"	--	170
Plant [2/] + SD[1/]	"	40 + 60	"	174	163
Plant [3/] + SD[1/]	"	40 + 60	"	172	174

1/ SFC = spring field cult., ST = strip-till, SD = sidedress at V3 to V4 stage.
2/ Dribbled 2 inches from the row at planting
3/ Broadcast pre-emergence with herbicide (weed and feed)

Incorporation

Incorporation of sidedress-applied urea and UAN has been a concern because of the possibility of volatilization losses if rainfall does not occur within a few days of application. Results from a 3-yr study conducted on moldboard plowed continuous corn at Waseca showed a 6 bu/A response to a 120-lb split application where anhydrous ammonia was applied at V6 (Table 12). However, yield reductions of 25 and 18 bu/A occurred where UAN was dribbled on the surface at rates of 120 and 180 lb N/A, respectively, and incorporated by cultivation within two days. In 1986 and 1987, another sidedress treatment consisting of UAN injected 4" deep at V6 gave yields that were 20 bu/A greater than those for the dribbled on the surface and cultivated in treatment.

Table 12. Continuous corn yield as affected by split applications of nitrogen at Waseca, 1985-87.

Application time		Total N rate (lb/A)	
Spr., preplant	Sidedress (V6)	120	180
		- - - - - Yield (bu/A) - - - - -	
None	None	68	
An. Ammonia	None	138	150
1/3 as UAN	2/3 as An. Ammonia	144	151
1/3 as UAN	2/3 as UAN (Drib)[1/]	113	132

1/ Dribbled on soil surface and incorporated by cultivation within 2 days.

Similar results were obtained in a ridge-plant study for continuous corn at Waseca in 1981-83. A single application of ammonia, urea, or UAN at 150 lb N/A was applied either spring preplant or sidedressed at V6. Preplant urea and UAN were broadcast on the soil surface prior to planting, whereas the sidedress treatments were dribbled on the soil surface and cultivated in within two days. Spring preplant applications of ammonia, urea and UAN yielded 5, 17, and 12 bu/A more than the sidedress application, respectively (Table 13). The large yield reductions for urea and UAN incorporated by cultivation suggest that sufficient N did not move down the soil profile and into the active root zone, thereby remaining positionally unavailable. The 5 bu/A reduction for sidedress ammonia also suggests that insufficient N was available to the plant early in the season when all of the N applied was delayed until the V6 stage (14-16" tall corn).

Table 13. Continuous corn yield in a ridge-plant system as affected by N source and time/method of application at Waseca, 1981-83.

N source[1/]	Time/Method	
	Spr., preplant	Sidedress (V6)
	- - - - - Yield (bu/A) - - - - -	
None	91	
An. Ammonia	146	141
Urea	146	129
UAN (28%)	145	133

[1/] Rate of application = 150 lb N/A

In summary, these data for south-central Minnesota support the recommendation of incorporating or injecting sidedress applications of urea and UAN to a depth of 3 to 4".

Managing N for Sandy Soils

Although sandy soils with a high leaching potential are not common in south-central Minnesota, it is extremely important for farmers to practice high-level management of their N inputs on these soils. The following recommendations should be practiced.

- Do not apply fertilizer N in the fall to coarse-textured (sandy) soils.
- Application of N in a sidedress or split-application program is preferred.
- Use a nitrification inhibitor (N-Serve) on labeled crops with early sidedressed N.

For greater detail on BMP's for coarse-textured soils see Best Management Practices for ***Nitrogen Use on Irrigated, Coarse-Textured Soils*** **AG-FO-6131** (revised, 2008).

Potential Helpful Products

Agrotain is a urease inhibitor designed to be used in no-till or other production systems where urea remains on the soil surface without incorporation. It reduces the potential for N loss due to volatilization. This product could be used in south-central Minnesota where corn is planted using the no-till system.

ESN is a product that consists of urea coated with a polymer and thus is intended for use as a slow release nitrogen fertilizer. Research conducted at Waseca from 2003-2006 has shown fall-applied (early November), 4" deep-band incorporated ESN to produce corn yields substantially greater than fall-applied urea and equal to spring-applied anhydrous ammonia. Thus, ESN is acceptable for late fall application or spring application in south-central Minnesota. However, there is a risk. The cost is substantially higher than the cost of N supplied as urea or ammonia. Mixtures of ESN and urea might be appropriate. However, mixtures have not been evaluated.

Summary

Effective and efficient management of nitrogen fertilizers is important for profitable corn production in south-central Minnesota. The research based Best Management Practices (BMP's) described in this publication are agronomically, economically, and environmentally sound. They are voluntary. If these practices are followed, agriculture can be more profitable without the threat of regulation.

Related Publications

08560 (revised, 2008) - Best Management Practices for Nitrogen Use in Minnesota

08557 (revised, 2008) - Best Management Practices for Nitrogen Use in Southeastern Minnesota

08558 (revised, 2008) - Best Management Practices for Nitrogen Use in Southwestern and West-Central Minnesota

08555 (revised, 2008) - Best Management Practices for Nitrogen Use in Northwestern Minnesota

08556 (Revised, 2008) - Best Management Practices for Nitrogen Use on Coarse Textured Soils

AG-FO-5880 - Fertilizing Cropland with Dairy Manure

AG-FO-5879 - Fertilizing Cropland with Swine Manure

AG-FO-5881 - Fertilizing Cropland with Poultry Manure

AG-FO-5882 - Fertilizing Cropland with Beef Manure

AG-FO-3790 - Fertilizing Corn in Minnesota

AG-FO-3770 - Understanding Nitrogen in Soils

AG-FO-3774 - Nitrification inhibitors and Use in Minnesota

AG-FO-2274 - Using the Soil Nitrate Test for Corn in Minnesota

AG-FO-2392 - Managing Nitrogen for Corn Production on Irrigated Sandy Soils

AG-FO-0636 - Fertilizer Urea

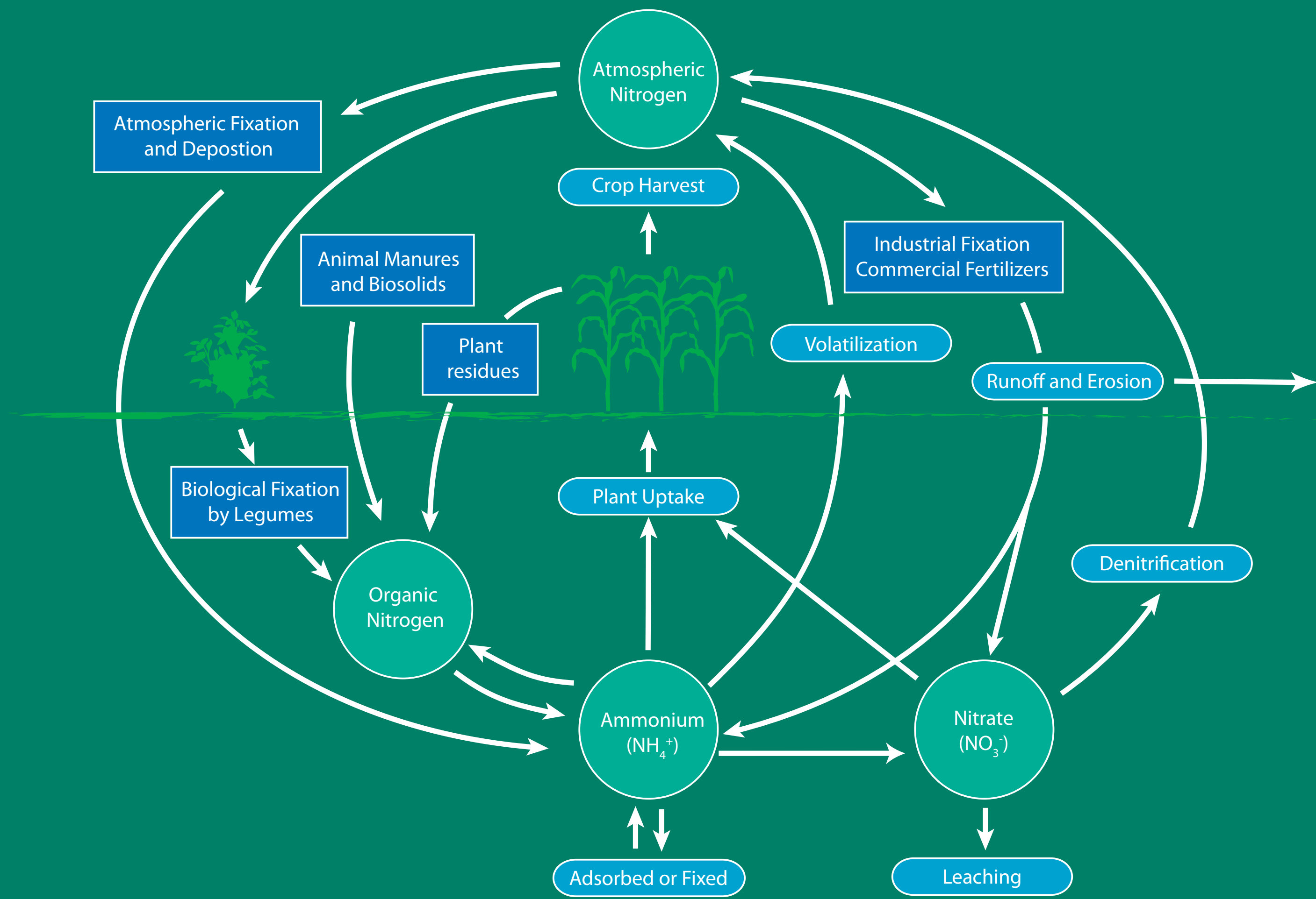
AG-FO-3073 - Using Anhydrous Ammonia in Minnesota

AG-FO-6074 - Fertilizer Management for Corn Planted in Ridge-till or No-till Systems

AG-FO-3553 - Manure Management in Minnesota

BU-07936 - Validating N Rates for Corn

Iowa State Univ. PM 2015 - Concepts and Rationale for Regional Nitrogen Rate Guidelines for Corn



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Best Management Practices for Nitrogen Use in South-Central Minnesota

PUBLICATION # 08554

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Best Management Practices for Nitrogen Use in SOUTHWESTERN AND WEST-CENTRAL MINNESOTA

BEST MANAGEMENT PRACTICES FOR NITROGEN APPLICATION

Best Management Practices for Nitrogen Use in Southwestern and West-Central Minnesota

George Rehm, Nutrient Management Specialist (retired); John Lamb, Professor; Jodi DeJong Hughes, Regional Extension Educator; Gyles Randall, Soil Scientist and Professor, Southern Research and Outreach Center, Waseca.

Introduction

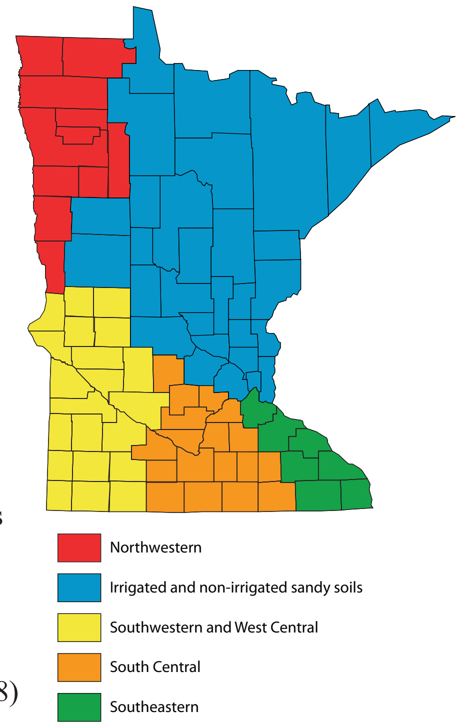
Nitrogen (N) is an essential plant nutrient that is a major input for profitable crop production in Minnesota. In addition, large quantities of nitrogen are part of the crop production ecosystem, including soil organic matter. Biological processes that convert nitrogen to its usable and mobile form (NO_3) occur continuously in the soil system. (For detail, see ***Understanding Nitrogen in Soils* - AG-FO-3770**). This nutrient has a substantial effect on the agricultural economy of the state. While the economic benefits are positive, nitrogen in the form of nitrate – nitrogen (NO_3-N) can be lost from the soil system. This loss is a major focus of public concern when the quality of both ground and surface waters is considered. There are appropriate management practices that can be used to minimize loss of NO_3- N to waters. This publication provides a description of the best management practices (BMP's) that optimize N fertilizer input efficiency while at the same time reducing the potential for loss of NO_3-N. The BMP's that are identified have evolved from the results of considerable research.

The research-based Best Management Practices (BMP's) described in this publication are economically and environmentally sound. It is strongly suggested that they be used voluntarily.

What Are the Best Management Practices (BMP's)?

BMP's for nitrogen use are broadly defined as "economically sound, voluntary practices that, when used, are capable of minimizing nitrogen contamination of both ground and surface waters." The recommended BMP's are based on research conducted at both the University of Minnesota and other land-grant universities. They are practical suggestions. The BMP's described in this publication were developed for the unique soil and climatic production environments of southwestern and west-central Minnesota. (see map)

Nitrogen BMP's for Southwestern and West-Central Minnesota



This region of the state is characterized by soils that have a medium to fine texture which were formed from loess, glacial till, or lacustrine deposits. The large majority of the soils have moderate to poor internal drainage and tile has been installed to improve production. Growers who manage coarse textured (sandy) soils are referred to publication **08556** (revised, 2008) entitled "***Best Management Practices for Nitrogen Use on Coarse Textured Soils***".

Corn, soybean, wheat and sugarbeet crops are dominant in the region. Therefore, the BMP's are focused on the production systems that include these crops. BMP's for wheat production are listed in the BMP publication for northwestern Minnesota, (**AG-FO-6130**, revised, 2008).

The BMP's for the region can be summarized as follows:

1) Recommended For Corn Production

- Select the appropriate N fertilizer rate using U of M guidelines ("***Fertilizing Corn in Minnesota***", **FO-3790-C**, 2006) which are based on current fertilizer and corn prices, soil productivity, and economic risk.
- Total N rate should include any N applied in a starter, weed and feed program, and contributions from phosphorus fertilizers such as MAP and DAP.

- Use a soil nitrate test when appropriate, by collecting soil samples to a depth of 24 inches in 0 to 6 and 6 to 24 inch increments. Collect fall soil samples after soil temperature at 6 inches stabilizes below 50°F.
- For urea (46-0-0) or anhydrous ammonia (82-0-0) applied in the fall, delay application until after soil temperature at 6 inches stabilizes below 50°F.
- Incorporate fall applied urea (46-0-0) as well as spring applied urea (46-0-0) and UAN (28-0-0) within 3 days to a minimum depth of 3 inches.
- Take appropriate credit for previous legume crops and manure used in the rotation.
- Under rain fed (non-irrigated) conditions, apply sidedress N before corn is 12 inches tall (V7 stage).
- When soils have a high leaching potential (sandy texture), a split application is preferred. Use a nitrification inhibitor with early sidedressed N applied to these soils.

2) Acceptable For Corn Production, But With Greater Risk

- Late fall or spring preplant application of ESN.
- Use of the products, Agrotain and N-Serve, with fall applied N.

3) Recommended For Sugarbeet Production

- Use a soil nitrate test by collecting soil samples to a depth of 4 feet after soil temperature at 6 inches stabilizes below 50°F.
- Apply ammonium based fertilizer N in the fall according to U of M guidelines (110 to 130 lb. N per acre). The N rate is a total of NO_3-N measured to a 4 foot soil depth plus fertilizer N.
- Apply fertilizer N in the fall after soil temperatures at the 6 inch depth stabilize below 50°F.
- Take first and second year credits for forage legumes that were part of the rotation.

4) Not Recommended For Corn and Sugarbeet Production

- Fall application of UAN (28-0-0) or any fertilizer containing nitrate-nitrogen.
- Shallow or no incorporation of urea (46-0-0) applied in the fall.
- Fall application of any N fertilizer to coarse textured (sandy) soils.
- Winter application of nitrogen fertilizers including MAP and DAP to frozen soils.

Choosing a Rate of N

Corn

Nitrogen rate guidelines for corn production in Minnesota have changed. Yield goal is no longer the major consideration. Instead, rate guidelines are based on: 1) the productivity characteristics of the production environment, 2) the ratio of the cost of a pound of N divided by the value of a bushel of corn, and 3) the producer's attitude toward risk. The guidelines are the end product of numerous trials conducted by University of Minnesota faculty throughout Minnesota. The new guidelines agree with the concept for the approach to fertilizer N applications that will be used throughout the Corn Belt. A more detailed description of these guidelines is provided in the publication, "***Concepts and Rationale for Regional Rate Guidelines for Corn***," **Bulletin PM2015**, **Iowa State University, Ames, Iowa**.

The guidelines for highly productive environments are provided in Table 1.

Table 1. Guidelines for use of nitrogen fertilizer for corn grown on soils considered to be highly productive.

N Price/ Crop Value Ratio	Corn/Corn		Corn/Soybeans	
	MRTN*	Acceptable range	MRTN*	Acceptable range
	- - - - - - N to apply (lb. per acre)1⊥ - - - - - -			
0.05	155	130 to 180	120	100 to 140
0.10	140	120 to 165	110	90 to 125
0.15	130	110 to 150	100	80 to 115
0.20	120	100 to 140	85	70 to 100

* MRTN = maximum return to nitrogen
1⊥ N rates are to be reduced by 20 lb. per acre on soils considered to have a medium yield potential due to yield-limiting factors.

It may be difficult to distinguish soils that are considered to be highly productive from those that have a medium productivity potential. In general, optimum yields on soils with a medium productivity potential are usually lower because of such factors as poor drainage, limited water holding capacity in the root zone, severe compaction, and other restrictions to root and/or crop growth.

Sugarbeet

As with corn, the fertilizer N guidelines are not adjusted for yield goal (expected yield). Extensive research with sugarbeet producers in southern Minnesota has led to the conclusion that a supply of 110 to 130 lb. N/acre is adequate for production of high yielding sugarbeets with good quality. This N total is the sum of fertilizer N and soil residual NO_3-N measured to a depth of 4 feet in late fall after soil temperature at the 6 inch depth has stabilized below 50° F.

Using Nitrogen Credits

Use of appropriate nitrogen credits is essential to avoid excessive application of fertilizer nitrogen. In general, suggested rates of fertilizer nitrogen are affected by:

1) carryover or residual nitrate – nitrogen (NO_3-N)
2) nitrogen from a previous legume crop in the rotation
3) manure applications
4) nitrogen from other fertilizer such as the N supplied in the application of 18-46-0

Carryover or Residual Nitrates

Corn

The use of the soil nitrate test is recommended when corn follows a crop other than soybeans in southwestern and west-central Minnesota. For this test, soil samples are collected in the fall to a depth of 24 inches after soil temperatures at a depth of 6 inches have consistently dropped below 50° F. For the fall sampling, increments of 0 to 6 and 6 to 24 inches are suggested. The 0 to 6 inch increment can be analyzed for NO_3-N, pH, phosphorus, potassium and other nutrients of interest. The 6 to 24 inch increment should be analyzed for NO_3-N only. The total amount of NO_3-N found in this test is used for a credit as follows.

NG = (Table 1 value for corn/corn – (0.60) STN_{0-24})

where:

NG = amount of fertilizer N needed, lb. /acre

STN_{0-24} = amount of nitrate – nitrogen (lb./acre) measured by using the soil nitrate test

More details regarding the use of the soil nitrate test are found in **FO-3790-C** (“***Fertilizing Corn in Minnesota***”) available from the Minnesota Extension Service.

Sugarbeet

As with corn, soil collected from below 6 inches should be analyzed for NO_3-N. The 0 to 6 inch increment can be analyzed for NO_3-N, phosphorus, potassium, etc. The soil from 6 to 24 and 24 to 48 inches is analyzed for NO_3-N only.

Nitrogen from Previous Legume Crops

Nitrogen can be supplied from legume crops used in the rotation. Nitrogen credits from these crops are listed in Tables 2 and 3 and should be subtracted from the nitrogen guideline for corn following corn in Table 1. The N credit for the soybean crop has been accounted for in Table 1. The N credit from alfalfa and clover for second-year corn is summarized in Table 3.

Table 2. Nitrogen credits for legumes preceding corn in the crop rotation.

Previous Crop	1st year Nitrogen Credit
	---- lb. N per acre ----
Harvested alfalfa	
4 or more plants/ft²	150
2-3 plants/ ft²	100
1 or less plants/ ft²	40
Red clover	75
Edible beans	20
Field peas	20

Table 3. Nitrogen credits for some forage legumes if corn is planted two years after the legume.

Legume Crop	2nd year Nitrogen Credit
	---- lb. N per acre ----
Harvested alfalfa	
4 or more plants/ft²	75
2-3 plants/ ft²	50
1 or less plants/ ft²	0
Red clover	35

Nitrogen in Manure

Nitrogen in livestock manure is just as important as nitrogen applied in commercial fertilizers. Therefore, any available N in manure should be used as a credit when determining the total amount of fertilizer N needed for both corn and sugarbeets. The process of determining the amount of N supplied by manure is described in other publications that are listed on the back of this bulletin. As with N credits from legumes, manure N credits are subtracted from the guideline values in Table 1 for corn following corn.

N from Other Sources

When determining the total amount of fertilizer N needed, N supplied in other fertilizers cannot be ignored. This is true whether pre-emergence or post emergence herbicides are applied using 28-0-0 as a carrier or applying high rates of phosphate fertilizers containing N (11-52-0 or 18-46-0). This N must be taken into consideration when the rate of fertilizer N to apply for both corn and sugarbeets is determined.

N Application Timing

Corn

When timing of the fertilizer N is considered, crop producers in southwestern and west-central Minnesota have several choices. Results from a comprehensive study at the Southwest Research and Outreach Center at Lamberton confirm this flexibility. Beginning in 1994 and continuing through 2000, two N sources (82-0-0, 46-0-0) were applied at three times (fall, spring preplant, summer sidedress) in continuous corn and a corn-soybean rotation. Several rates were applied.

For continuous corn, this study provided data for 7 years. Average yields for these 7 years are summarized in Table 4.

Table 4. Corn yield in a continuous corn production system as affected by time of application of two N fertilizers.

N Source	Time of Application		
	Fall	Spring Preplant	Sidedress
	- - - - - - - - - - - - - -	bu./acre	- - - - - - - - - - - - - -
82-0-0	165.7	175.0	177.0
46-0-0	164.8	167.9	170.1

There was no significant difference in yield between sources when fall application was used. Application was made after soil temperature cooled to 50°F and the 46-0-0 was incorporated as recommended.

For the spring preplant N application, yield was significantly higher when 82-0-0 was the N source. The lower yield from the use of 46-0-0 might indicate that there was some N loss when this source was used.

The use of 82-0-0 as a sidedress application produced a yield that was significantly higher when compared to the used of urea. Again, there may have been some volatilization loss from the application of 46-0-0.

In individual years, the ranking of sources for each time of application was not consistent. In some years, 82-0-0 was superior to 46-0-0; in other years, the use of 46-0-0 was superior for any application time. Considering the long term, both sources have a near equal effect on yield with no year-to-year consistency.

Continuous corn yields were slightly reduced for both N sources when applied in the fall. This indicates some loss of fall applied N. The data do not provide for an identification of the mechanism for the N loss.

Nitrogen management information for corn following soybeans is available for three years of this study (1995, 1997, 1999). Average yields for those years are summarized in Table 5. The optimum N rate was 120 lb. per acre for this rotation and yields listed are for that rate.

Table 5. Corn yields in a corn-soybean production system as affected by time of application of two N fertilizers.

N Source	Time of Application		
	Fall	Spring Preplant	Sidedress
	- - - - - - - - - - - - - -	bu./acre	- - - - - - - - - - - - - -
82-0-0	149.3	142.9	145.9
46-0-0	142.3	146.5	147.2

As with continuous corn, the ranking of the two N sources changed from year to year with very little difference among the three times of application. When averaged over time of application, yield was 146.0 bu. per acre when 82-0-0 was used and 145.5 bu. per acre when 46-0-0 was used.

When averaged over N source, yield was 145.8, 144.7, and 146.6 bu. per acre for the fall, spring preplant, and sidedress applications, respectively. Thus, time of application had no significant effect on yield in this crop rotation.

Considering both rotations that might be used in southwestern and west-central Minnesota and the year to year variability in results, there is flexibility in the optimum time of fertilizer application. Nitrogen fertilizer can be applied in the fall, as a spring preplant, or as a sidedress application.

The data summarized in Table 6. also show that the time of fertilizer N application can be flexible. When 46-0-0 was broadcast and incorporated as the N source, the optimum rate for corn following soybeans was 120 lb. per acre. At this optimum rate, there was very little difference in yield when fall and spring preplant applications are compared.

Table 6. Corn yield in west-central Minnesota as affected by time of application. Average of two locations.

N applied	Time of Application	
	fall	spring
lb. per acre	- - - - - - - - - - - - - - bu./acre	- - - - - - - - - - - - - -
0	173.9	169.5
30	175.7	182.5
60	189.5	194.8
90	192.4	193.9
120	200.7	198.4
150	197.6	206.6
180	192.8	195.5

For both corn and sugarbeet production, time of fall application should be dictated by soil temperature. The primary object in fall N application is to maintain the maximum amount of N in the ammonium (NH_4^+) throughout the winter and early spring. Ammonium N sources (46-0-0, 82-0-0) should be the fertilizers of choice. Soil temperature at a depth of 6 inches should be consistently at 50°F or less before fall application is considered. Otherwise, significant amounts of ammonium-N may convert to nitrate-N. This nitrate-N could potentially be lost via denitrification or leaching in the following spring.

Decisions about timing should also take the source of fertilizer N into consideration. Fall application of 28-0-0 is not recommended. The nitrate-N component of this material can be easily lost by the process of either leaching or denitrification.

When applied in the fall, urea should **not** be left on the soil surface without incorporation. Incorporation to a depth of at least 3 inches would be a better choice.

The application of anhydrous ammonia at a depth of 4 to 6 inches is an appropriate choice for a fall application. The placement at this depth reduces the potential for loss of nitrate-N due to denitrification in the following spring.

For several years, there has been an active discussion regarding the potential benefits of a urease inhibitor (Agrotain), and a nitrification inhibitor (N-Serve) for production systems where N is applied in the fall. The products have been evaluated and benefits have either not been documented or at best, are inconsistent in southwestern and west-central Minnesota. Use of these products should be put in the category of "acceptable for corn production, but with greater risk". The product, Agrotain may be of benefit in situations where urea is broadcast in early spring in no-till planting situations. However, these evaluations have not taken place in west-central and southwestern Minnesota. ESN is another product that has not been evaluated in this region.

Sugarbeet

Split applications of fertilizer N have not improved sugarbeet yield as well as recoverable sugar when this crop is grown on fine textured soils (Table 7). When comparing all combinations that could be used, none were superior to a single preplant application.

The results from the study summarized in Table 7 as well as other studies lead to the conclusion that split applications of fertilizer N are not recommended for this crop.

Table 7. Sugarbeet yield and sugar produced as affected by frequency of application of fertilizer nitrogen.

Time of N Application				Yield	Recoverable Sugar
preplant	4-leaf	4-leaf + 3 weeks	4-leaf + 6 weeks		
---------- lb. N / acre			----------	ton/acre	lb./acre
0	0	0	0	14.8	4769
20	20	20	20	17.2	5300
40	40	0	0	16.6	5546
40	0	40	0	17.1	5366
40	0	0	40	17.2	5231
0	40	40	0	17.4	5423
0	40	0	40	16.6	5123
0	0	40	40	16.9	5149
80	0	0	0	17.7	5470
			$LSD_{0.05}$	1.5	485

Incorporation of Fertilizer Nitrogen

In southwestern and west-central Minnesota, incorporation of fertilizer N applied for both corn and sugarbeet production is suggested. Since the majority of the soils in the region are calcareous, loss of N due to ammonia volatilization is a concern. This possible volatilization is a concern when urea or fertilizers containing urea remain on the soil surface without incorporation. Therefore, some incorporation of 46-0-0 and 28-0-0 is a recommended management practice. This incorporation can be achieved with some form of light tillage or cultivation if these materials are applied either in the spring or at sidedress time. Rainfall in excess of 0.25 inches is adequate if it falls within 24 hours of fertilizer application. Incorporation of urea to a greater depth is suggested if this material is applied in the fall.

Related Publications

08560 (Revised, 2008) - Best Management Practices for Nitrogen Use in Minnesota

08557 (Revised, 2008) - Best Management Practices for Nitrogen Use in Southeastern Minnesota

08554 (Revised, 2008) - Best Management Practices for Nitrogen Use in South-Central Minnesota

08555 (Revised, 2008) - Best Management Practices for Nitrogen Use in Northwestern Minnesota

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AG-FO-0636 - Fertilizer Urea

AG-FO-3073 - Using Anhydrous Ammonia in Minnesota

AG-FO-6074 Fertilizer Management for Corn Planted in Ridge-till or No-till Systems

AG-FO-3553 - Manure Management in Minnesota

BU-07936 - Validating N Rates for Corn

Iowa State Univ. PM 2015 - Concepts and Rationale for Regional Nitrogen Rate Guidelines for Corn

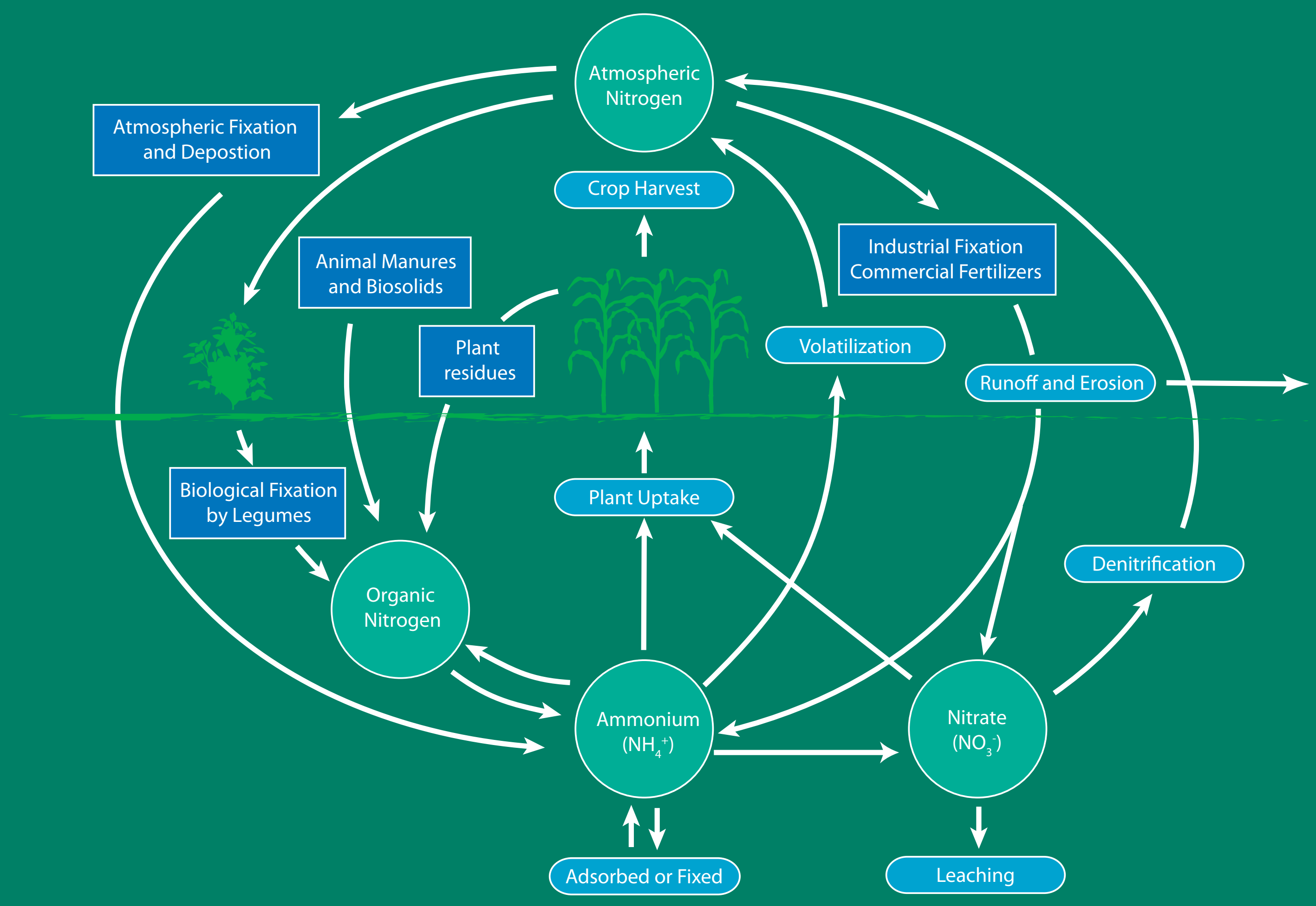
FO-07715-C - Fertilizing Sugar Beet in Minnesota and North Dakota

FO-3772-C (Revised) - Fertilizing Wheat in Minnesota

FO-6572-B - Fertilizer Recommendation for Edible Beans in Minnesota

Summary

Effective and efficient management of nitrogen fertilizers is important for profitable crop production in southwestern and west-central Minnesota. The research based Best Management Practices (BMP's) described in this publication are agronomically, economically, and environmentally sound. They are voluntary. If these practices are followed, agriculture can be more profitable without the threat of regulation.



University of Minnesota Extension

Best Management Practices for Nitrogen Use in Southwestern and West-Central Minnesota

PUBLICATION # 08558

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Best Management Practices for Nitrogen Use in NORTHWESTERN MINNESOTA

BEST MANAGEMENT PRACTICES FOR NITROGEN APPLICATION

Best Management Practices for Nitrogen Use in Northwestern Minnesota

Albert Sims, Associate Professor and Soil Scientist, Northwest Research and Outreach Center; George Rehm, Nutrient Management Specialist (retired); John Lamb, Professor, University of Minnesota.

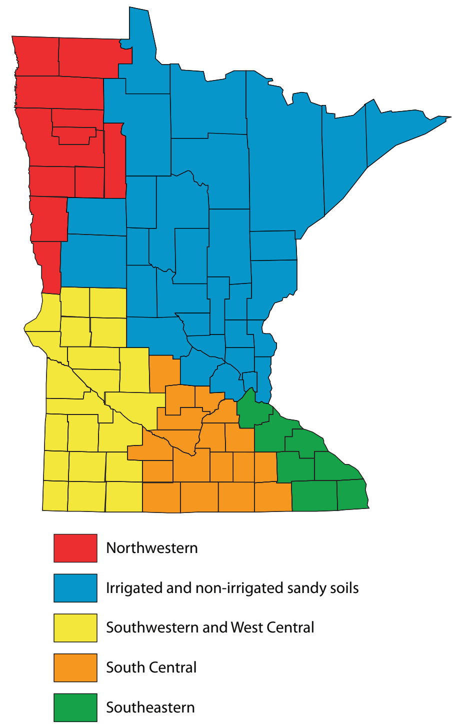
Introduction

Nitrogen (N) is absorbed in large amounts by Minnesota crops. It is the major nutrient supplied in a fertilizer program. In addition, large quantities of nitrogen are part of the crop production ecosystem including soil organic matter. Biological processes that convert nitrogen to its usable and mobile form (NO_3) occur continuously in the soil system, primarily in the soil organic matter. Nitrogen in soil exists in several forms and conversion from one form to another can be complex. For a more detailed description of the dynamics of nitrogen in soils see: "***Understanding Nitrogen in Soil***", **FO-3770**, **Minnesota Extension Service**.

While it is recognized that there is substantial diversity in crop production systems coupled with a wide variety of soils in northwestern Minnesota, this publication will focus on small grain production. The BMP's described in the publication "***Best-Management Practices for Nitrogen Use in Southwestern and West-Central Minnesota***" are appropriate for corn production in northwestern Minnesota. The BMP's listed in that publication are also appropriate for sugarbeet production in the region. For sandy soils in northwestern Minnesota, BMP's listed in the publication, "***Best Management Practices for Nitrogen on Coarse-Textured Soils***" are appropriate.

What are Best Management Practices (BMP's)?

There is general agreement that BMP's are economically sound voluntary practices that, if used, are capable of minimizing nitrogen loss to the environment and maximizing utilization by the crop. The BMP's listed in this publication are based on extensive research conducted by faculty of the University of Minnesota and neighboring Land Grant Institutions. The BMP's relate to management of all sources of nitrogen used in production of small grain in northwestern Minnesota.



BMP's for Northwestern Minnesota

The BMP's in this publication are focused on wheat production. The BMP's are also divided into three categories described as, 1) recommended, 2) acceptable but with greater risk, and 3) not recommended. With respect to N management, risks can be either economic or environmental. Economic risk can be a consequence of added input costs without additional yield or a reduction in yield. Environmental risks pertain to the potential for loss of nitrogen to either ground water or surface waters.

For northwestern Minnesota, the BMP's are:

1) Recommended

- Base rate of nitrogen applied on expected yield, with some general consideration of soil organic matter content and previous crop

- Total N rate should include all fertilizer sources including contributions from phosphate fertilizer, such as DAP or MAP.
- For ammonium based products (AA or urea), apply when soil temperatures at 6 inches stabilize below 50°F either broadcast or banded at planting.
- Take credit for nitrogen supplied by previous legume crops in the rotation.
- Take credit for available nitrogen supplied in manure or the nitrogen contained in sugarbeet tops based on leaf color prior to beet harvest.
- Adjust the nitrogen rate for measured residual nitrate-nitrogen in the surface 2 feet of the soil profile when wheat follows a non-legume crop in a rotation.
- Collect soil samples in increments of 0 to 6 and 6 to 24 inches after soil temperatures at 6 inches stabilizes at 50°F.
- Any broadcast urea, should be incorporated to a depth of 3 inches.

2) Acceptable, But With Greater Risk

- Limit rate to 40 lb. N per acre if a liquid source of nitrogen is applied to foliage at the boot stage or later.
- Application of urea in a band either with the seed or near the seed when an air seeder is used for planting.

3) Not Recommended

- Fall application of liquid nitrogen (28-0-0) or any fertilizer containing nitrate-nitrogen.
- Fall or spring application of urea without incorporation.
- Shallow (2 inches or less) application of 82-0-0 in either fall or spring.
- Foliar application of high rates of 28-0-0 (more than 40 lb. N per acre) at boot stage or later.
- Application of any N fertilizers including MAP or DAP on frozen soils.
- Fall application of N, regardless of source, to sandy soils in the fall.

Selecting a Nitrogen Rate

There are two ways to choose a rate of N for production of hard red spring wheat. The first is based on expected yield, previous crop and soil organic matter content (see Table 1). In using Table 1, the previous crops are grouped as follows:

Group 1	Group 2		
alsike clover	barley	grass pasture	sugarbeet
birdsfoot trefoil	buckwheat	millet	sunflower
grass/legume hay	canola	oats	triticale
grass/legume pasture	corn	potatoes	wheat
fallow	grass hay	rye	vegetables
red clover		sorghum-sudan	

Sampling soil for measurement of NO_3-N is not suggested when wheat follows a legume crop in the rotation. Legumes can extract considerable NO_3-N from the root zone leaving uniform amounts of NO_3-N that are relatively low.

Collection of soil samples from depths of 0 to 8 and 8 to 24 inches is suggested for cropping systems where wheat follows a crop other than a legume in rotation. The surface soil (0 to 8 inches) should be analyzed for pH, phosphorus, potassium, and zinc. This soil sample along with soil collected from 8 to 24 inches should be analyzed for nitrate-nitrogen.

If residual nitrate-nitrogen is measured, the suggested rate of nitrogen is derived from the following equation:

$$N_{Rec} = (2.5)\ EY\text{-}STN_{\ (0\text{-}24\ in)}$$

where: EY = expected yield (bu./acre)

STN = nitrate-nitrogen (NO_3-N) measured to a depth of 2 feet, lb./acre

Special attention should be given to the time of sample collection. These soil samples should be collected after soil temperature at a depth of 6 inches drops below 50°F. Nitrate-nitrogen in soil undergoes various transformations at higher temperatures. Therefore, accurate information may not be possible if soil samples are collected when soil temperatures are warmer.

Table 1. Nitrogen guidelines for hard red spring wheat where the soil nitrate test is not used.

Crop Grown Last Year	Organic Matter[1]	Expected Yield (bu./acre) 40-49	50-59	60-69	70-79	80+
		- - N to apply (lb. N/acre) - -				
alfalfa (4+ plants/ft^2)	low	0	30	55	80	95
	medium and high	0	0	35	60	75
alfalfa (2-3 plants/ft^2)	low	10	35	60	85	100
	medium and high	0	15	40	65	80
soybeans, alfalfa (1 or less plants/ft^2)	low	60	85	110	135	150
	medium and high	40	65	90	115	130
edible beans, field peas	low	70	95	120	145	160
	medium and high	50	75	100	125	140
group 1 crops	low	30	55	80	105	120
	medium and high	0	35	60	85	100
group 2 crops	low	80	105	130	155	170
	medium and high	60	85	110	135	150
organic soil		0	0	0	30	35

[1] low = less than 3.0%; medium and high = 3.0% or more

Tops of a previous crop of sugarbeets can supply nitrogen to the wheat crop. Some adjustment in rate of applied N should be made as indicated by the color of the tops (use Table 2). The values listed in Table 2 should be subtracted from the N guidelines in Table 1.

Table 2. Nitrogen adjustments when a sugarbeet crop precedes wheat in the rotation.

Color of Sugarbeet Tops	N Credit
	lb. N / acre
yellow leaves at harvest	0
light green leaves at harvest	30
dark green leaves at harvest	80

Nitrogen rate guidelines for corn can be found in the publication "***Best Management Practices for Nitrogen Use in Southwestern and West-Central Minnesota***", **AG-FO-6128 (revised)**.

Take Credit for Nitrogen Supplied from Previous Crops and Livestock Manure

The nitrogen credit for the previous crops is accounted for in Tables 1 and 2. It is also important to take credit for nitrogen supplied in livestock manure. The variability in the availability of nitrogen in manures is substantial and appropriate practices for sampling and application are discussed in bulletins listed at the end of this publication.

Method and Time of Application

Nitrogen fertilizers can be applied in either fall or spring. Two sources (AA, urea) are appropriate for fall application. If applied in a way to prevent N loss, both sources have an equal effect on yield (Table 3). With UAN, 25% of the N is present as nitrate-nitrogen. This nitrate-nitrogen is subject to loss - - primarily as denitrification. Therefore, fall application of UAN **is not** recommended.

Depth of placement is an important consideration for nitrogen applied in the fall. Incorporation or placement at depths less than 2 inches increases the probability of loss due to volatilization (application of AA) or denitrification (both AA and urea) if applied N is converted to nitrate-nitrogen in the fall. Therefore, placement of AA at a depth of 4 inches or greater is suggested. Likewise, incorporation of fall applied urea to a depth of 3 inches or greater is suggested.

When applied in the spring, all sources of fertilizer N have had an equal effect on yield (Table 4). Incorporation of urea and UAN is also suggested when these sources of nitrogen are applied in the spring before planting.

Suggestions for nitrogen application discussed in the previous paragraphs are appropriate when wheat is seeded with a drill. The use of air seeders for planting raises new questions about nitrogen placement and rate for production of hard red spring wheat. With this method of seeding, there are several options for placement of nitrogen fertilizers.

The wheat yields in Tables 3 and 4 are from research trials where the nitrogen was applied before planting. When drills are used, it is possible to apply urea with the seed. This is an acceptable practice if rates of applied nitrogen are not high (Table 5). Although yields increased with nitrogen rates up to 50 lb. per acre, the negative impact on emergence is a major concern. At nitrogen rates in excess of 50 lb. per acre, there was a negative effect on emergence.

Recently, a study was conducted in northwest Minnesota for the purpose of evaluating various placement options when urea was applied with an air seeder at planting. Wheat emergence and grain yields were measured (Figures 1 and 2). The urea was applied at rates to supply 25, 50, and 75 lb. nitrogen per acre.

Table 3. Yield of hard red spring wheat as affected by rate of application of two nitrogen sources applied in the field.

N Applied	Urea (46-0-0)	AA (82-0-0)
lb./acre	- - - - bu./acre	- - - -
50	39	40
75	40	40
100	41	41

yield of control = 30 bu. / acre

Table 4. Yield of hard red spring wheat as affected by three nitrogen sources applied in the spring.

N Applied	UAN (28-0-0)	Urea (46-0-0)	AA (82-0-0)
lb./acre	- - - - - -	bu./acre	- - - - -
100	76	78	80

yield of control = 58 bu./acre

Table 5. Emergence of hard red spring wheat and yield as affected by rate of nitrogen supplied as urea with the seed in a grain drill.

N Applied	Emerged Population	Yield
lb. / acre	plants / acre	bu. / acre
0	683,890	36
25	649,900	51
50	606,350	57
75	506,170	57
100	470,450	49

Some explanation of the various placements is needed. With the BB placement, the 46-0-0 was applied in a band to the side of the seed. The fertilizer and wheat seed were applied in the same band in the BM placement. With the air seeder, the seed and fertilizer mixed together are in a more concentrated band compared to seed and fertilizer mixed and a grain drill is used. The seed/fertilizer mixture was placed at the typical depth for planting wheat. For the TB placement, the seed was split into 2 rows about 3 to 4 inches apart and the fertilizer was placed in a band between the rows. Seed and fertilizer were mixed in a band that was about 3 inches wide in the SM placement. Emergence was reduced as the rate of N increased when the fertilizer and seed were mixed together (Figure 1). The reduction in emergence was less severe when the seed/fertilizer mixture was applied in a wide (SM) rather than a narrow (BM) band.

Measured yields are shown in Figure 2. A substantial reduction in yield was measured when the urea was applied at rates to supply 50 and 75 lb. nitrogen per acre in a narrow band with the seed. Otherwise, the wheat was able to tiller when there was a less severe reduction in emergence and yield was not negatively affected.

Spacing of rows is not constant on all air seeders. Therefore, it is logical to expect that limits to the rate of urea applied with the seed would vary with row spacing and the seeding implement used. North Dakota State University has proposed limits for various planter types and seed spread (Table 6). The lower end of the range is appropriate for coarse-textured soils. The upper end of each range is appropriate for fine-textured soils.

Table 6. Maximum urea-nitrogen fertilizer rates suggested with spring wheat at planting as affected by planter spacing, type, and seed spread.

Planter Type	Seed Spread	Planter Spacing (inches)			
		6	7.5	10	12
	inches	---- lb. urea-nitrogen / acre ----			
double disc	--	20-30	19-28	17-23	15-20
hoe opener	--	32-44	27-38	23-31	20-27
air seeder	4	56-72	46-58	37-48	32-42
	5	68-86	56-68	44-57	38-49
	6	80-100	66-79	51-55	44-56
	7	--	76-90	58-74	50-64
	8	--	--	66-83	56-71

Source: Extension Circular EB-62, North Dakota State University

Potential Helpful Products

There is general recognition that nitrogen can be lost from soils. Responding to that recognition, products have been developed that, when used, could reduce the potential for loss. N-Serve is a nitrification inhibitor used for the purpose of delaying the conversion of ammonium (NH_4^+-N) to nitrate (NO_3-N). When considering small grain production in northwestern Minnesota, there is no reason to delay this nitrification reaction. So, the use of this product is not part of the Best Management Practices.

Agrotain is a urease inhibitor designed to be used in no-till or other production systems where urea remains on the soil surface without incorporation. Unless hard red spring wheat is grown with no-till production practices, the use of Agrotain is not included in the Best Management Practices.

ESN is a product that consists of urea coated with a polymer and thus, is intended for use as a slow release nitrogen fertilizer. Trials to evaluate this product for grain yield and grain protein were just initiated and there are currently no conclusions.

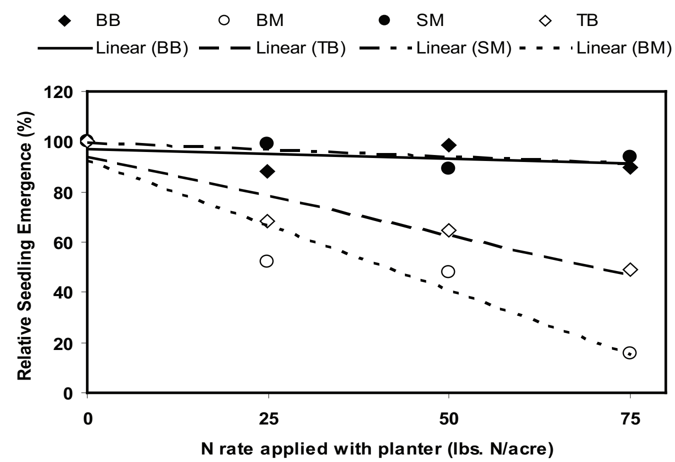


Figure 1. Relative Seedling emergence of hard red spring wheat as affected by rate and placement of urea nitrogen in 1998.

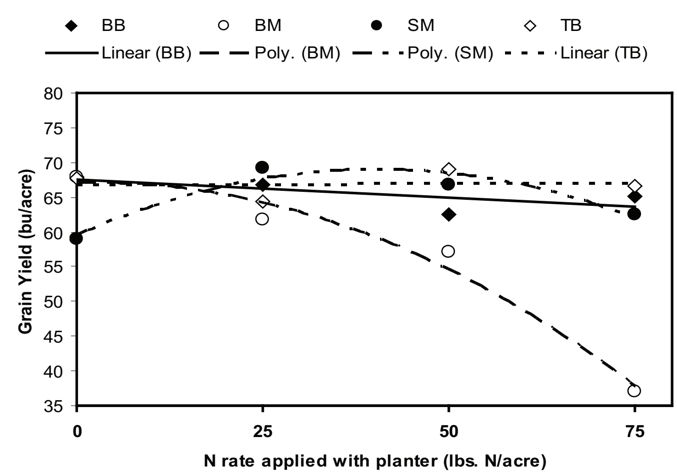


Figure 2. Grain yield of hard red spring wheat as affected by rate and placement of urea nitrogen in 1998.

Summary

Effective and efficient management of nitrogen fertilizers is important for profitable small grain production in northwestern Minnesota. The research based Best Management Practices (BMP's) described in this publication are agronomically, economically, and environmentally sound. They are voluntary. If these practices are followed, agriculture can be more profitable without the threat of regulation.

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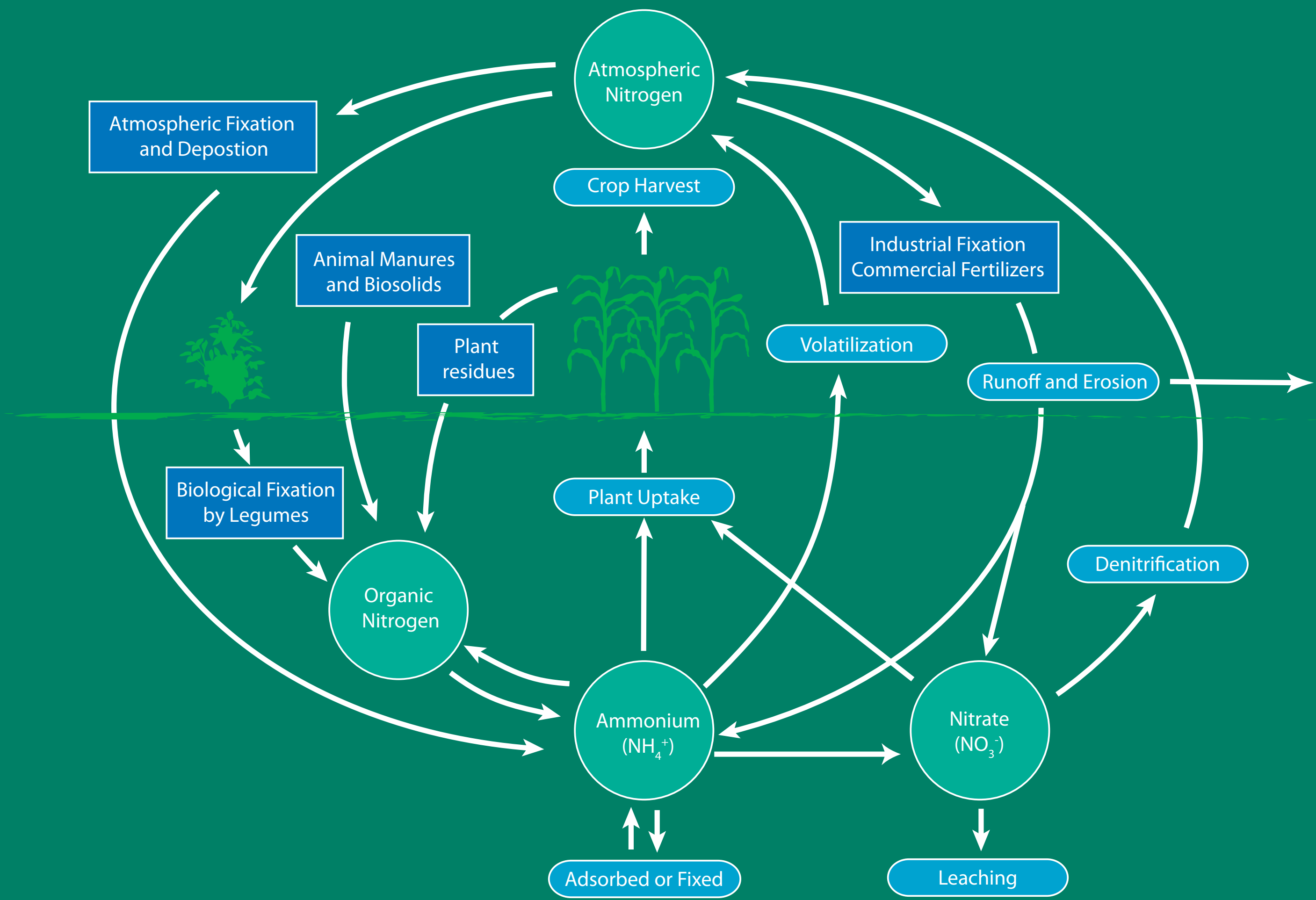

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Best Management Practices for Nitrogen Use in Northwestern Minnesota

PUBLICATION # 08555

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Minnesota Nitrogen Fertilizer Management Plan

March 2015

Minnesota Department of Agriculture
Pesticide and Fertilizer Management Division

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Acknowledgements

The Minnesota Department of Agriculture (MDA) would like to thank the Nitrogen Fertilizer Management Plan Advisory Committee for their thoughtful contributions, dedication and support throughout the plan revision process.

ADVISORY COMMITTEE

Agriculture
Steve Commerford - Minnesota Independent Crop Consultant Association
Brad Englund, alternates Jim Krebsbach, Sean Ness, Bill Bond, Tom Kladar - MN Crop Production Retailers
Pete Ewing, alternate Paul Gray - Minnesota Area II Potato Growers Council
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Skip Wright, alternate Dave Wright - Minnesota Department of Natural Resources

University of Minnesota
Carl Rosen, alternate John Lamb - Department of Soil, Water and Climate
Michael Schmitt - Extension
Faye Sleeper - Water Resources Center

MDA PRIMARY AUTHORS

Jeff Berg, Greg Buzicky, Annie Felix-Gerth, Larry Gunderson, Heather Johnson, Kimberly Kaiser, Bruce Montgomery, Heidi Peterson, Joshua Stamper, Dan Stoddard, and Ron Struss

MDA CONTRIBUTORS AND REVIEWERS

Denton Bruening, Jennifer Gallus, Janice Hugo, Aaron Janz, Jeppe Kjaersgaard, Kevin Kuehner, Ryan Lemickson, Margaret Wagner, and Brian Williams

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Executive Summary

The Groundwater Protection Act of 1989 (Minnesota Statutes, section 103H) significantly altered the direction of groundwater resource protection with regard to nitrogen fertilizer management. This was a result of three separate but related components of the law:

- Development of a groundwater protection goal;
- Enhanced regulatory authority for fertilizer practices within the Minnesota Department of Agriculture (MDA); and
- Development of a Nitrogen Fertilizer Management Plan (NFMP) by the MDA.

The NFMP is the state's blueprint for prevention or minimization of the impacts of nitrogen fertilizer on groundwater. By statute, the NFMP must include both voluntary components and provisions for the development of requirements if the implementation of the Best Management Practices (BMPs) is proven to be ineffective.

Background

Current agricultural crop production systems require the input of nitrogen fertilizer to increase food, fiber, feed and fuel production for consumption by humans and livestock. 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.

Nitrate in groundwater is a public health concern especially for pregnant women and infants under six months of age. The drinking water standard is 10 milligrams per liter (mg/L) nitrate-nitrogen (nitrate), referred to as the Health Risk Limit (HRL). Protecting our groundwater is important since approximately three out of four Minnesotans rely on groundwater for their drinking water supply.

Many aspects of the NFMP have been implemented since the plan was first developed in 1990. These include:

- The MDA, the University of Minnesota, and numerous partners have developed, promoted and evaluated the effectiveness of the BMPs and determined their potential impacts on the state's water resources;
- Survey tools to evaluate adoption of the BMPs have been developed and successfully implemented;
- Low cost methods for groundwater monitoring and private well testing have been developed and applied;
- Partnerships with other agencies, Soil and Water Conservation Districts and other organizations have been developed or strengthened; and
- A general approach to implement local response activities outlined in the NFMP has been extensively tested and refined at several locations, particularly in wellhead protection areas, with some important successes.

On the other hand, some parts of the 1990 NFMP were not fully implemented due to limited program funding as well as challenges that come with starting any new program.

In 2010 the MDA began a process to revise 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.

The revised NFMP is based on information and recommendations gathered from input from the NFMP Advisory Committee (primary source), past NFMP implementation experience, Nebraska's Central Platte Natural Resources District phased approach to groundwater management, the MDA's Pesticide Management Plan, documentation of nitrate concentration levels in groundwater and drinking water standard exceedances, and advances in agricultural technology and management practices.

Overview of the Nitrogen Fertilizer Management Plan

The purpose of the NFMP is to prevent, evaluate and mitigate nonpoint source pollution from nitrogen fertilizer in groundwater. The NFMP includes components promoting prevention and developing appropriate responses to the detection of nitrogen fertilizer in groundwater. Nitrogen BMPs are the cornerstone of the NFMP.

The nitrogen BMPs are tools to manage nitrogen efficiently, profitably and with minimized environmental loss. The BMPs are built on a four part foundation that takes into account the nitrogen rate, application timing, source of nitrogen, and placement of the application. If one of the above 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 BMPs.

The general approach used by the NFMP to address nitrate in groundwater consists of the following activities:

<u>Prevention</u>

It is the goal of the state that groundwater be maintained in its natural condition, free from any degradation caused by human activities. Prevention activities focus on promoting the nitrogen BMPs to protect groundwater from nitrogen fertilizer leaching in the most hydrogeologically vulnerable areas. Prevention activities within the NFMP are ongoing regardless of the status of mitigation for nitrate in groundwater. These efforts will be coordinated through a new statewide Nitrogen Fertilizer Education and Promotion Team (NFEPT). Implementation of education, outreach and demonstration activities will be accomplished through existing programs.

<u>Monitoring and assessment</u>

The goal of monitoring and assessment is to develop a comprehensive understanding of the severity and magnitude of nitrate in groundwater drinking water wells (public and private). The monitoring activities include identifying and selecting wells to be sampled for nitrate from a designated area, collecting and testing the water samples, obtaining and summarizing the results and conducting follow up site visits, if necessary, to confirm the results. Assessment involves establishing and reporting the overall pattern of nitrate levels in wells within designated areas. Monitoring and assessment initiates the NFMP process and forms a basis for determining the appropriate level of action (prevention or mitigation).

Nitrate concentration data from private and public wells will be assessed based on separate criteria described below in order to determine whether the area of concern continues in a “Prevention” mode or proceeds into a “Mitigation” mode. The NFMP Mitigation mode is comprised of four implementation levels. Each successive level represents an increase in implementation effort.

The determination of the mode and level is primarily based on nitrate concentrations, trends, and adoption of the BMPs. Consideration will also be given to significant changes in land use, the size of the area, the severity of the problem, and other factors that might be expected to influence nitrate levels. There are separate nitrate concentration criteria for private and public wells, as shown in the charts below.

Private well criteria used to determine Prevention and Mitigation Modes

Groundwater Nitrate Concentration Criteria	Unknown or Below Mitigation Level 1	5% of wells > HRL or 10% of wells > 7 mg/L	10% of wells > HRL	10% of wells >HRL	15% of wells > HRL
BMP Adoption Criteria	Unknown/NA	Unknown or BMPs Adopted	BMPs Adopted	BMPs not Adopted	
Mode	Prevention	Mitigation			
Level	NA	1	2	3	4
Status	Voluntary			Regulatory	

NOTE: The Health Risk Limit (HRL) for nitrate-nitrogen in Minnesota is 10 mg/L

Public well criteria used to determine Prevention and Mitigation Modes

Groundwater Nitrate Concentration Criteria	Unknown or Below Mitigation Level 1	Wells > 5.4 mg/L	Projected to exceed 10 mg/L in 10 years or less		Wells > 9 mg/L
BMP Adoption Criteria	Unknown/NA	Unknown or BMPs Adopted	BMPs Adopted	BMPs Not Adopted	
Mode	Prevention	Mitigation			
Level	NA	1	2	3	4
Status	Voluntary			Regulatory	

NOTE: The Health Risk Limit (HRL) for nitrate-nitrogen in Minnesota is 10 mg/L

Mitigation

The goal of mitigation is to minimize the source of pollution to the greatest extent practicable and, at a minimum, reduce nitrate contamination to below the HRL so that groundwater is safe for human consumption. The mitigation strategy is based on the prevention strategy, but implemented over a defined area and at a higher level of effort and intensity. Mitigation will be accomplished by intensifying and targeting education and outreach (preventative) efforts via a multi-level approach, using/refining the existing nitrogen BMPs, developing and implementing Alternative Management Tools (AMTs); considering the cost versus benefit and technical feasibility of mitigation measures; developing incentives and, when necessary; exercising regulatory authority provided in the Groundwater Protection Act.

The mitigation process is the same for addressing nitrate in both private and public wells. All sites will start in a voluntary level (Level 1 or 2), determined using the mitigation criteria discussed in Chapter 9, and will only move to a regulatory level (Level 3 or 4) if the BMPs are not being adopted. The mitigation process generally consists of the following activities listed in the likely chronological order of implementation:

1. Form local Advisory Team (Advisory Team);
2. Select a project lead and develop a work plan;
3. Establish a local nitrate monitoring network capable of producing long term trends;
4. Hold a public information meeting(s) for farmers and other interested parties;
5. Select the right set of nitrogen BMPs to implement in the area using U of M guidance;
6. Conduct an initial survey of BMP adoption;
7. Consider Alternative Management Tools (AMTs) in high risk areas;
8. Assess the need for demonstration projects based on results from BMP adoption survey;
9. Develop a plan for educational activities based on results from BMP adoption survey;
10. Assist with obtaining funding for implementing the selected BMPs and AMTs;
11. Work with farmers to implement selected BMPs;
12. Conduct a follow up survey of BMP adoption after three growing seasons of implementation;
13. Evaluate BMP adoption; and
14. Determine appropriate mitigation level using nitrate concentration and BMP adoption criteria.

The NFMP emphasizes engaging key groups who are involved with crop production and the use of nitrogen fertilizers. Target groups include crop advisors/consultants, fertilizer retailers, and professional organizations that provide information on planning and guidance to farmers. These individuals and organizations have specialized knowledge and are in a position to influence the adoption of the nitrogen BMPs. A significant effort will be conducted to coordinate with these professionals to protect groundwater resources in a responsible and effective manner.

Structure of the Nitrogen Fertilizer Management Plan

The NFMP is organized into ten chapters. Chapter one provides a general introduction to the plan. Chapters two through six include background and technical information about nitrogen and groundwater. Chapters seven through ten outline the NFMP process, with detailed information about prevention, monitoring and assessment and mitigation. Appendices A-J supplement the chapter material.

Chapter 1 : Introduction to the Nitrogen Fertilizer Management Plan

Current agricultural crop production systems require the input of nitrogen fertilizer to increase food, fiber, feed and fuel production for consumption by humans and livestock. When applying fertilizer nitrogen to crops, the goal is to maximize its use by a crop while minimizing its loss to the environment.

Nitrogen fertilizer is typically applied in different forms, such as nitrate or ammonium. These forms of nitrogen are easily absorbed by the plants. The nitrate form of nitrogen is very soluble in water and may escape plant uptake and may leach into the groundwater.

Nitrate in groundwater is a public health concern, especially for pregnant women and infants under six months of age. This is a concern since approximately three out of four Minnesotans rely on groundwater for their drinking water supply.

When groundwater resources become contaminated with nitrate, efforts to remove or mitigate the contamination are challenging and expensive.

"Groundwater" is defined in Minnesota Statutes, section 115.01, subdivision 6 as:

…water contained below the surface of the earth in the saturated zone including, without limitation, all waters whether under confined, unconfined, or perched conditions, in near-surface unconsolidated sediment or regolith, or in rock formations deeper underground.

GROUNDWATER PROTECTION ACT OF 1989

The Groundwater Protection Act of 1989 (Minnesota Statutes, section 103H) significantly altered the direction of groundwater resource protection with regard to nitrogen fertilizer management. This was a result of three separate but related components of the law:

- Development of a groundwater protection goal;
- Enhanced regulatory authority for fertilizer practices within the Minnesota Department of Agriculture (MDA); and
- Development of a Nitrogen Fertilizer Management Plan (NFMP) by the MDA. The NFMP is a strategy for preventing, evaluating, and mitigating non-point sources of nitrogen fertilizer in Minnesota's groundwater.

Because of the complexity of how nitrogen fertilizer affects water resources and the controversial nature of associated management decisions, the 1989 Legislature authorized the MDA to establish a Nitrogen Fertilizer Task Force to make recommendations to the Commissioner of Agriculture on the structure of the NFMP. Task Force membership was established by statute to include a diverse group of representatives from agriculture, environmental groups, local and state government.

The Nitrogen Fertilizer 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. As the result of their work and the work of the MDA staff, a NFMP was adopted by the Minnesota Commissioner of Agriculture in August 1990.

PURPOSE OF THE NITROGEN FERTILIZER MANAGEMENT PLAN

The purpose of the NFMP is to carry out requirements of the Groundwater Protection Act of 1989 as written in Minnesota Statutes, section 103H.001, which discusses the degradation prevention goal:

> 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 (Minnesota Statutes, section 103H.275) lays out a framework for the response to the identification of contamination and introduces the concept of Best Management Practices (voluntary) and Water Resource Protection Requirements (regulatory), key components of the Nitrogen Fertilizer Management Plan:

> (a)... If groundwater pollution is detected, a state agency or political subdivision that regulates an activity causing or potentially causing a contribution to the pollution identified shall promote implementation of best management practices to prevent or minimize the source of pollution to the extent practicable. (b) The pollution control agency, or for agricultural chemicals and practices, 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.

Best management practices (BMPs) are voluntary and are defined in Minnesota Statutes. Section 103H.005, subdivision 4:

> “Best management practices” means practicable voluntary practices that are capable of preventing and minimizing degradation of groundwater, considering economic factors, availability, technical feasibility, implementability, effectiveness, and environmental effects. Best management practices apply to schedules of activities; design and operation standards; restrictions of practices maintenance procedures; 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.

Water resource protection requirements (WRPRs) may be adopted by the Minnesota Commissioner of Agriculture if the implementation of the BMPs has proven to be ineffective. The water resource protection requirements are defined in Minnesota Statutes, section 103H.005, subdivision 15:

> ... 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, operations and maintenance procedures, practices to prevent releases, spills leaks and incidents, restrictions on use and practices and treatment requirements.

In summary, the NFMP is the state's blueprint for prevention or minimization of the impacts of nitrogen fertilizer on groundwater. By statute, the NFMP must include both voluntary components (BMPs) and provisions for the development of restrictions (WRPRs) if the implementation of the BMPs is proven to be ineffective.

THE MDA'S AUTHORITY TO PROTECT GROUNDWATER

The NFMP is intended to address nitrate in groundwater resulting from the legal application of nitrogen fertilizer. The MDA is the lead state regulatory agency in Minnesota for nitrogen fertilizer and has authority to regulate the use of nitrogen fertilizer, if necessary, to protect groundwater quality. The MDA does not have comparable authority to regulate the use of nitrogen fertilizer to protect surface water or for regulating the use of manure.

The Minnesota Pollution Control Agency (MPCA) is the lead state agency in responding to elevated nutrients including nitrate in surface waters and the lead agency for regulating the use of manure The MPCA's responsibilities include monitoring and assessing water quality, listing impaired waters, and establishing Total Maximum Daily Loads (TMDLs). The NFMP will, to the extent practicable, align or integrate its processes with the impaired waters processes.

The NFMP supports the concept that surface water and groundwater be managed as holistically as possible. This can be done by integrating surface and groundwater strategies. Some activities such as promoting certain nitrogen BMPs might benefit both surface water and groundwater.

One area of potential concern is nitrate losses through subsurface agricultural tile drainage systems. Areas with tile drainage are generally artificially drained because they have heavy soils with poor internal drainage, and tend to be less prone to nitrate leaching to the groundwater. It is likely that most areas with a significant amount of tile drainage will not be a high priority for a localized response to groundwater contamination.

1990 PLAN IMPLEMENTATION SUMMARY

Many aspects of the NFMP have been implemented since the plan was first developed in 1990. These include:

- The MDA, the University of Minnesota, and numerous partners have developed, promoted and evaluated the effectiveness of the BMPs;
- Survey tools to evaluate adoption of the BMPs have been developed and successfully implemented;
- Low cost methods for groundwater monitoring and potable well testing have been developed and applied;
- Pilot response strategies including field demonstrations, educational events, and some pioneer approaches with land use changes within early Wellhead Protection Areas (public groundwater suppliers).

Partnerships with other agencies, Soil and Water Conservation Districts and other organizations have been developed or strengthened. A general approach to implement local response activities outlined in the NFMP has been tested and refined at several locations, particularly in wellhead protection areas, with some important successes. On the other hand, some parts of the 1990 NFMP were not fully implemented due to limited program funding.

REVISION OF THE 1990 NFMP

In 2010, the MDA began a process to revise 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.

In 2011, 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, nitrogen research, and implementation. They also received an overview of the status of existing state and federal programs. The Committee, after reviewing information and considering expert testimony, made recommendations about the plan structure, content, and roles.

The revised NFMP is based on information and recommendations gathered from the following sources:

- Input from the NFMP Advisory Committee (primary source);
- Past NFMP implementation experience;
- Existing FANMAP and NASS survey information;
- Nebraska's Central Platte Natural Resources District phased approach to groundwater management;
- The MDA's Pesticide Management Plan;
- More detailed documentation of nitrate concentration levels in groundwater and drinking water standard exceedances; and
- Advances in agricultural technology and management practices.

A draft revised NFMP was completed by the MDA in August 2013. The MDA then conducted a public comment period including six listening sessions across Minnesota to solicit public review and comment on the draft between August and November 2013. The MDA received 32 formal comments from a variety of stakeholders and replied to the comments in two response documents. Based on stakeholder input, the draft NFMP was finalized and approved by the Minnesota Commissioner of Agriculture on March 26, 2015.

It is the intent of the MDA to review and revise the NFMP every ten years or more frequently if needed in order to ensure that it remains current. The revision process will be initiated by the MDA.

CONCEPTUAL GOALS OF THE NFMP

The MDA has incorporated a number of practical and conceptual goals into the revised NFMP. These goals have been developed from past experience working on implementation activities in the field; feedback from cooperators, farmers, crop advisors and agricultural professionals; and ongoing interagency planning and coordination efforts. The goals include:

1. Build upon lessons learned over the past 20 years in implementing the original NFMP. Examples of these lessons come from the process developed by the MDA for responding to local nitrate problems which includes: using a single credible contact person for all interactions with farmers; adopting field tested survey tools for evaluating local on-farm nutrient management practices; involving crop advisors and farmers in a primary role for developing solutions; forming local advisory teams with farmers, local government and other local stakeholders; and following the MDA protocols for low cost approaches for local groundwater monitoring to determine nitrate trends. A discussion of lessons learned is presented in Appendix A: MDA Lessons Learned in Responding to Elevated Nitrate in Groundwater. Three case studies are presented in Appendix B: City of Perham, City of St. Peter, Lincoln-Pipestone Rural Water.

2. Provide clear guidance and direction when establishing key decision-making steps of the NFMP.

3. Support and be aligned with other state water plans and programs, and capitalize on existing resources and activities. Examples include the Minnesota Department of Health (MDH) wellhead protection program; the MPCA watershed restoration and protection strategy; the Department of Natural Resources (DNR) efforts to develop groundwater management areas, and the Board of Water and Soil Resources (BWSR) comprehensive local water management program.

4. Consider the potential for unintended environmental consequences due to interactions between agricultural practices and surface and groundwater.

5. Provide guidance, strategies, and tools to maximize implementation efforts by local government.

6. Outline approaches to engage farmers, land owners, government and other stakeholder groups in resolving nitrate problems in local groundwater.

7. Be executed effectively given available MDA staff and resources.

8. Provide direction to the MDA for prioritizing the use of available staff and resources.

9. Support decision making based on factual information, particularly with respect to characterizing local agricultural practices and using this data to develop farm specific recommendations for protecting groundwater and to obtain funding for implementing these recommendations.

10. Have a significant emphasis on prevention. Once groundwater is contaminated, it can be extremely difficult, expensive and very slow to remediate.

11. Consider strategies that go beyond the BMPs in targeted high risk areas. It is recognized that the nitrogen fertilizer BMPs may not reduce nitrogen losses sufficiently to achieve groundwater quality goals in some highly vulnerable areas. Potential strategies include using new technologies, continuous cover and/or retiring land, for example.

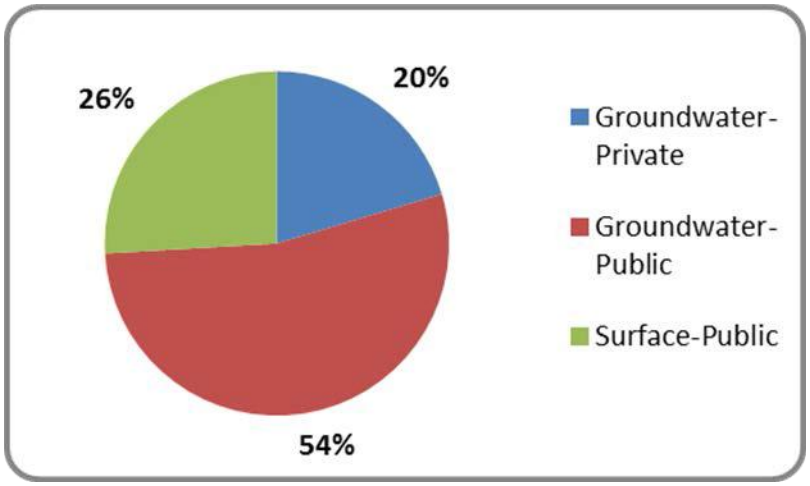
STRUCTURE OF THE NFMP

The NFMP is organized into ten chapters. Chapter one provides a general introduction to the NFMP. Chapters two through six include background and technical information about nitrogen and groundwater. Chapters seven through ten outline the revised NFMP process, with detailed information about prevention, monitoring and assessment and mitigation. Appendices A-J supplement the chapter material.

Chapter 2 : Impacts of Nitrate Contamination

Water contamination from nitrate presents a potential health risk to human populations which rely on it for drinking water. Approximately 75% of Minnesotans (4 million) rely on groundwater for their drinking water (Figure 1). These residents are served by either private wells or public water supplies. If elevated nitrate levels are detected in drinking water, there may be an increased probability that other contaminants, such as bacteria or pesticides, may also be present. Livestock and aquatic ecosystems may also be impacted by nitrate contaminated groundwater.

Figure 1. Drinking Water Sources in Minnesota



PUBLIC HEALTH RISKS

The U.S. Environmental Protection Agency (EPA) has established a drinking water standard of 10 milligrams per liter (mg/L) nitrate-nitrogen (nitrate) for public water supply systems. The MDH uses the EPA standard as a state Health Risk Limit (HRL) for public water supply systems, and as a guideline for private drinking water systems (MDH 1998). The drinking water standard has been established to protect against adverse human health impacts from ingesting the water, including methemoglobinemia, or “blue baby syndrome.”

Elevated nitrate in drinking water poses a risk to infants less than six months of age. Nitrate is reduced to nitrite in the gastrointestinal tract of infants (the high pH characteristic of the infant gastrointestinal system permits nitrate-reducing bacteria to thrive). The nitrite is then absorbed into the blood stream where it reacts with hemoglobin (oxygen carrying molecule) to produce methemoglobin, thus impairing the blood's ability to carry oxygen. Infants afflicted with methemoglobinemia actually suffer from an oxygen deficiency, and consequently their extremities may become blue, particularly around the eyes and mouth. If nitrate levels in the water are high enough and prompt medical attention is not received, death can result.

As an infant ages, its stomach acidity increases, reducing the numbers of nitrite-producing bacteria. After six months the conversion of nitrate to nitrite in the stomach no longer occurs. Most adults can consume large amounts of nitrate with no ill effects. In fact, the average adult in the U.S. consumes about 20-25 milligrams of nitrate every day in food, largely from vegetables (Carpenter 2012). Pregnant women, people with reduced stomach acidity, and people with certain blood disorders may be susceptible to nitrate-induced methemoglobinemia.

The MDH uses the following classification system to evaluate human health impacts on nitrate (expressed as mg/L NO_3-N) concentrations in groundwater:

- Background: Less than 1.0 mg/L – assumed to represent natural background nitrate concentration (ambient conditions without human impact);
- Transitional: 1.0 to less than 3.0 mg/L – transitional nitrate concentrations that may or may not represent human influence;
- Elevated: 3.0 to less than 10 mg/L – may indicate elevated nitrate concentrations resulting from human activities; and
- Exceeding standards: 10 mg/L and higher – exceeds nitrate drinking water standards for public and private drinking water supplies.

LIVESTOCK HEALTH RISKS

Livestock can also be affected by ingesting high levels of nitrate present in certain plants or drinking water. However nitrate poisoning is usually associated with animals ingesting forage or feed containing high nitrate. Ruminants (cattle, goats and sheep) are most susceptible to nitrate, whereas horses and pigs are more resistant (Aiello 2012). Nitrate in plants or water is converted by the digestion process to nitrite, and in turn the nitrite is converted to ammonia. The ammonia is then converted to protein by bacteria in the rumen. If ruminants rapidly ingest large quantities of plants that contain very high levels of nitrate, nitrite will accumulate in the rumen. Nitrite is absorbed into the animal's red blood cells and combines with hemoglobin to form methemoglobin. Methemoglobin cannot transport oxygen as efficiently as hemoglobin, so the animal's heart rate and respiration increases, the blood and tissues of the animal take on a blue to chocolate brown color, muscle tremors can develop, staggering occurs, and the animal eventually suffocates. This is commonly called "nitrate poisoning."

Although usually short term, the effects of nitrite or nitrate toxicity may exist long term and are reported to include retarded growth, lowered milk production (cows), vitamin A deficiency, minor transitory goitrogenic effects, abortions and fetotoxicity, and increased susceptibility to infection (Aiello 2012). Chronic nitrate toxicosis remains a controversial issue and is not as well characterized, but most evidence does not support allegations of lowered milk production in dairy cows due to excessive dietary nitrate exposure alone.

Groundwater can be a potential source of toxic levels of nitrate for livestock if it becomes contaminated. The National Academy of Sciences set the guideline for the safe upper limit of nitrate-N in water at 100 mg/L for livestock (National Academy of Sciences 1974).

RISKS TO AQUATIC ECOSYSTEMS

Many of Minnesota's streams, lakes, and wetlands (surface waters) depend on the inflow of groundwater to maintain water levels, pollution assimilative capacity, and temperature. Aquatic life in surface waters receiving nitrate contaminated groundwater may be at risk. Research shows that nitrate can be toxic to certain aquatic life at concentrations lower than values found in some surface waters of the state. The MPCA is currently developing nitrate surface water quality standards to address aquatic life toxicity.

Eutrophication, or the growth of plant biomass due to excess nutrients, potentially threatens the health of aquatic ecosystems. When aquatic plants die and decay, bacteria use the oxygen in the water leaving inadequate amounts for the needs of other aquatic organisms. While nitrogen is not usually considered to be the nutrient which controls the extent of plant growth in Minnesota lakes or streams, it can contribute to eutrophication of downstream coastal waters, such as the Gulf of Mexico. When excessive nutrients from the Mississippi River reach the Gulf of Mexico, a “dead zone” or area of hypoxia or low dissolved oxygen develops (MPCA 2014).

DRINKING WATER TREATMENT COSTS OF NITRATE CONTAMINATION

Preventing nitrate contamination from occurring in drinking water supplies is typically much more cost effective than removing the contamination. Private and public well nitrate contamination problems can be mitigated through a variety of solutions. The University of Minnesota conducted two studies in 2006 to determine how private and public well owners respond to elevated nitrate and to quantify their costs (Lewandowski et al. 2008). The following sections on public and private wells provide information on the results of the two studies.

PUBLIC WELL STUDY

Seven Minnesota community water supply managers were interviewed in the summer of 2006 (Lewandowski et al. 2008). The managers were sent extensive questionnaires, and then they participated in open-ended, in-person interviews to clarify answers to the questionnaire and to discuss wellhead protection issues.

The study found that public water suppliers can take one or more of the following actions to address elevated nitrate in their wells: 1) install a new well(s) in a non-vulnerable location if there is sufficient quality and quantity of water available; 2) blend existing water supplies; or 3) remove nitrate in existing water supplies (treatment). The following describes each of these actions in greater detail:

- Install a new well: In some cases, a new well may need to be installed in a deeper, uncontaminated aquifer. Siting, construction and pumping costs associated with these new wells can frequently double the water cost to the customer. According to the study, installing a new well can cost a community $75,000 to $500,000 depending on depth and size of the well. Deep aquifers contain older water, which frequently contains high levels of iron, manganese, sulfur, or other elements. The costs associated with the removal of these elements must also be considered.

- Blend: Water suppliers commonly “blend” water from wells with higher and lower nitrate concentrations to provide drinking water with nitrate levels below the safe drinking water standard. However some communities currently do not have the proper facilities to blend water.

- Treatment: Nitrate removal (treatment) may be the only feasible option in situations where adequate quantity or quality of water is not available. In many cases, the study found that the installation and maintenance of municipal nitrate removal systems has increased the cost of water delivery by fourfold or more. This translates into $100 to $200 in increased water costs per customer per year. Nitrate removal systems used by public water suppliers include:
    - Reverse Osmosis Process - Pressure forces water through a semi-permeable membrane leaving behind most contaminants and a portion of the rejected solution. The membranes

need to be replaced on a regular basis. Typically, reverse osmosis can reduce nitrate by 85 to 95% but actual removal rates vary depending on the initial water quality, system pressure, and water temperature.

- Anion Exchange Process - An anion exchange system works by passing contaminated water through a resin bead filled 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 backwashing with a sodium chloride solution. The presence of sulfates can reduce the efficiency of the nitrate removal.

PRIVATE WELL STUDY

In 2006, a survey of private well owners in the 11 county "Central Sand Plains" area of Minnesota was conducted (Lewandowski et al. 2008). The objective of the study was to quantify actual amounts spent by private well owners when nitrate levels were elevated, regardless of whether the owners were aware of the contamination. The survey included questions about well characteristics, nitrate testing, and costs of actions taken in response to elevated nitrate concentrations, if identified.

Of the 483 returned surveys, the study concluded that 1) at least 33% of the wells could be considered susceptible to contamination because they were of sand point construction, more than 30 years old, or less than 50 feet deep; 2) at least 40% of the wells could be considered less susceptible because they were drilled and either less than 15 years old or greater than 100 feet deep; 3) nitrate concentrations did not differ among the well types, but the odds of elevated nitrate concentrations were significantly higher in wells where the principal land use within one-quarter mile was agricultural (cropland, pasture, and grassland).

Private well owners with a nitrate contaminated well have several options: 1) install a new well; 2) remove nitrate in existing well; or 3) buy and use bottled water. According to the study, the average remediation costs for private well owners were $190 per year to buy bottled water, $800 to buy a nitrate removal system plus $100 per year for maintenance, and $7,200 to install a new well. Homeowners must drill deeper wells in high nitrate areas in order to avoid nitrate contaminated groundwater. The cost of installing a new well is based on the depth (linear foot) of the well, which can be cost prohibitive.

Chapter 3 : Groundwater Contamination and Vulnerable Areas

The susceptibility of an area to groundwater contamination is referred to as the "sensitivity" of the region. Several environmental factors determine the sensitivity 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 sensitivity very site-specific.

Further complicating the nature of sensitivity is nitrogen mobility. The dominant pathways for nitrogen movement include plant uptake, volatilization (gaseous losses as ammonia or as nitrogen gas through denitrification), adsorption, leaching below the root zone, and surface runoff. The prevailing environmental and management conditions at a given site may favor one of these pathways over another. For example, sandy soils may lose nitrogen primarily through leaching while heavy, poorly drained soils may lose nitrogen mainly through denitrification.

PHYSICAL AND CHEMICAL PROPERTIES OF SOIL AND GEOLOGICAL MATERIALS

The primary geologic, soil and biochemical factors affecting groundwater susceptibility to contamination are:

Depth to Groundwater: The depth to groundwater directly affects the time required for the nitrate to travel from the root zone to groundwater. Shallow groundwater has a greater potential for contamination compared to deep groundwater.

Soil Characteristics: Soil texture, structure, organic matter content and bulk density contribute to the amount of nitrate that is available to leach to groundwater and the ease with which it can leach. The presence of channels from earthworms or plant roots, or cracks within the vadose zone may also influence the flow of water. These characteristics vary with parent material type. For example, soils with a high sand content tend to have low organic matter, large pore sizes and high permeability. All of these factors increase water infiltration and nutrient leaching.

Vadose Zone Materials and Aquifer Materials: The unsaturated zone, often called the vadose zone, is the portion of the subsurface above the water table. It contains, at least some of the time, air as well as water in the pores.

Two properties of geologic materials determine the ability of aquifers to store and transmit water: porosity and permeability (Geologic Sensitivity Workgroup 1991). Porosity is the amount of space that is void in a material (rock or soil). Permeability is the measure of connections between the pore spaces. The greater the porosity and permeability, the shorter the time required for water to travel a given distance within the aquifer.

The presence of cracks and fissures can alter the ability of an aquifer to hold and transmit water. Special mention must be made of karst geology, which is a condition of fractured limestone bedrock and sinkholes. Karst areas are highly susceptible to groundwater contamination because the fractures and sinkholes act as conduits for rapid surface-to-subsurface movement of water and dissolved contaminants. These factors all vary widely throughout the state. In addition, these factors can vary significantly in a limited geographic area; because of this variability, maps such as those presented in this chapter can have limitations regardless of scale.

Denitrification: Denitrification is a process that can occur where there is organic matter but no oxygen present, such as under saturated conditions (e.g. in wetlands) or oxygen-free pockets within the unsaturated zone. During the denitrification process, bacteria remove nitrate by converting it to nitrogen gas. This makes the process an important factor to consider when assessing aquifer sensitivity and susceptibility to contamination. Shallow groundwater generally has low amounts of organic carbon so denitrification is limited. In some aquifers denitrification may be an important process with nitrate concentrations decreasing significantly and rapidly with increasing depth in the saturated zone.

TOOLS TO DETERMINE VULNERABLE AREAS IN MINNESOTA

There are various tools available to assess aquifer sensitivity. A statewide geomorphology GIS layer was produced by the Minnesota Geological Survey (MGS) and the University of Minnesota Duluth (UMD), providing an updated interpretation of geologic materials at a higher level of resolution than previous statewide maps (Minnesota DNR, UMD and MGS 1997). The geomorphology layer includes generalized categories of the sediments or bedrock types that are associated with landforms (Figure 2). The Sediment Association layer of the Geology of Minnesota was used to classify the state into aquifer sensitivity ratings. There are three ratings for aquifer sensitivity: low, medium and high (Figure 3). The ratings are based upon guidance from the Geologic Sensitivity Project Workgroup's report "Criteria and Guidelines for Assessing Geologic Sensitivity in Ground Water Resources in Minnesota" (Geologic Sensitivity Workgroup 1991). The high sensitivity rating is given to materials such as glacial outwash and bedrock associations. Glacial outwash, which is found extensively in Central Minnesota, contains sand and gravel with lesser amounts of fine grained materials. In Southeast Minnesota, the hydrogeology is dominated by limestone, dolomite and sandstone bedrock. Karst features and fractures in the bedrock create direct pathways from activities on the surface to groundwater and are vulnerable to contamination.

Other tools that may be used to understand aquifer sensitivity are the MGS and the DNR County Atlas – Regional Assessment Program, the MDH's Nitrate Probability Map Program and the Wellhead Protection Program.

Figure 2. Geomorphology of Minnesota - sediment association (data source: DNR, UMD and MGS 1997)

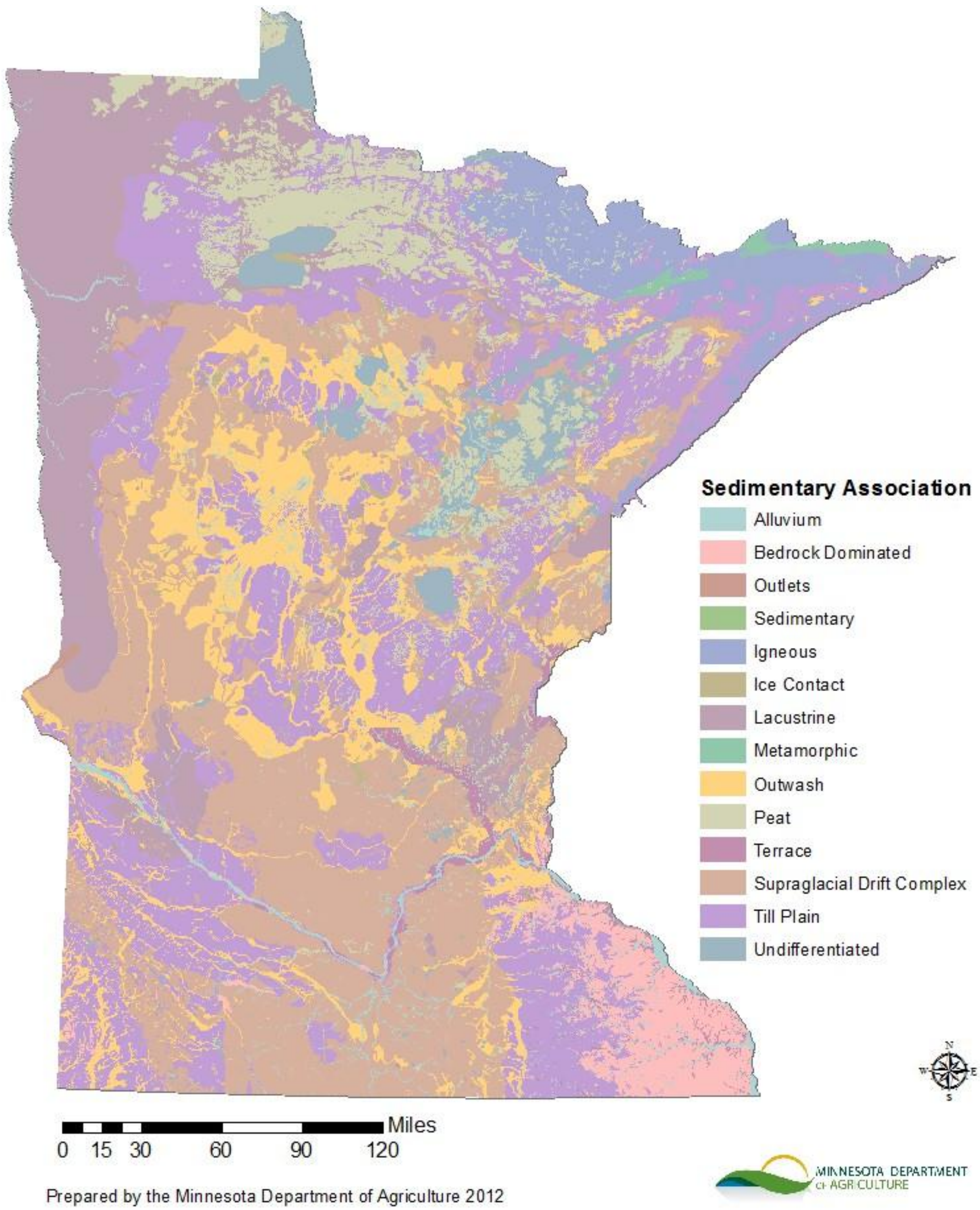
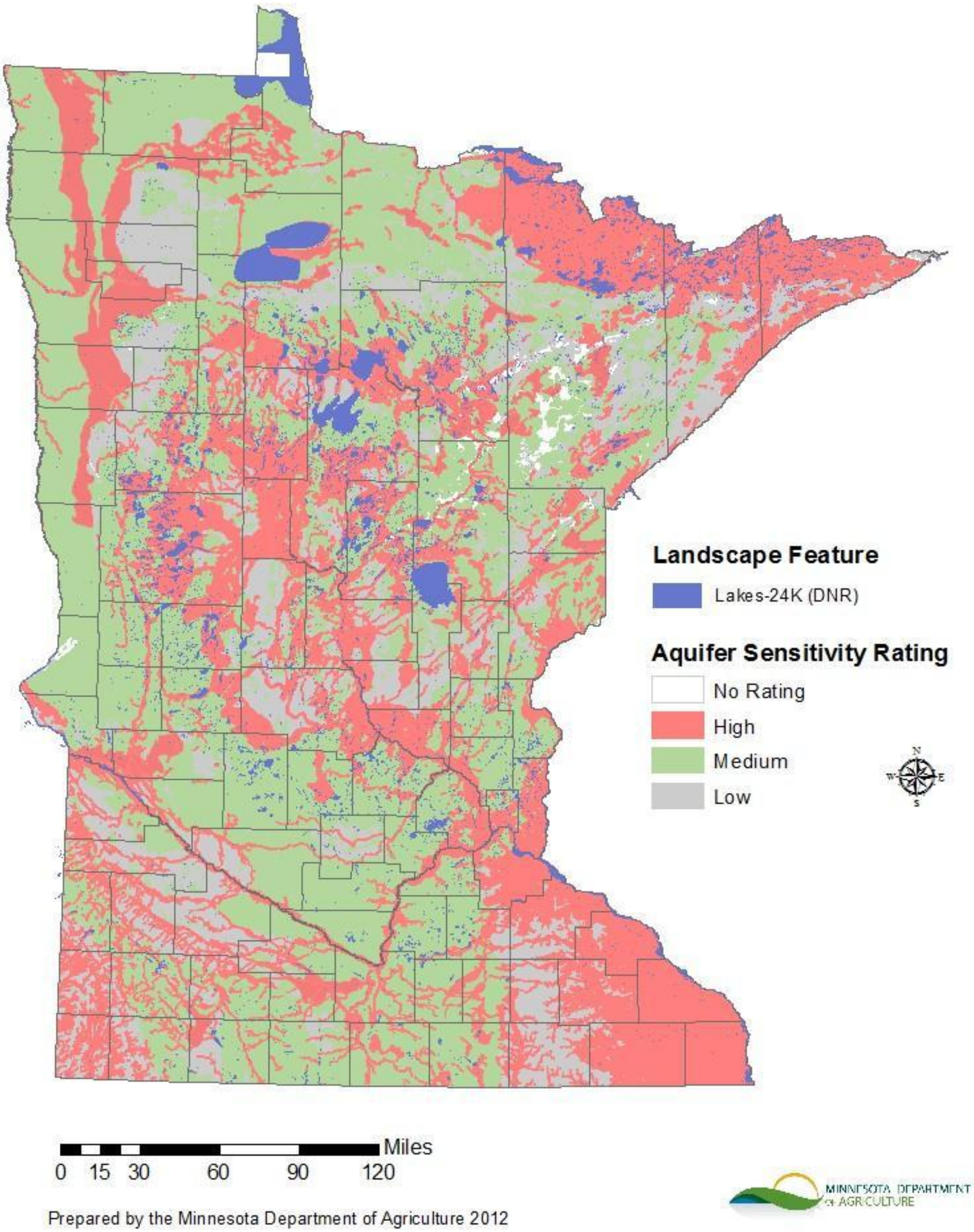


Figure 3. Water table sensitivity



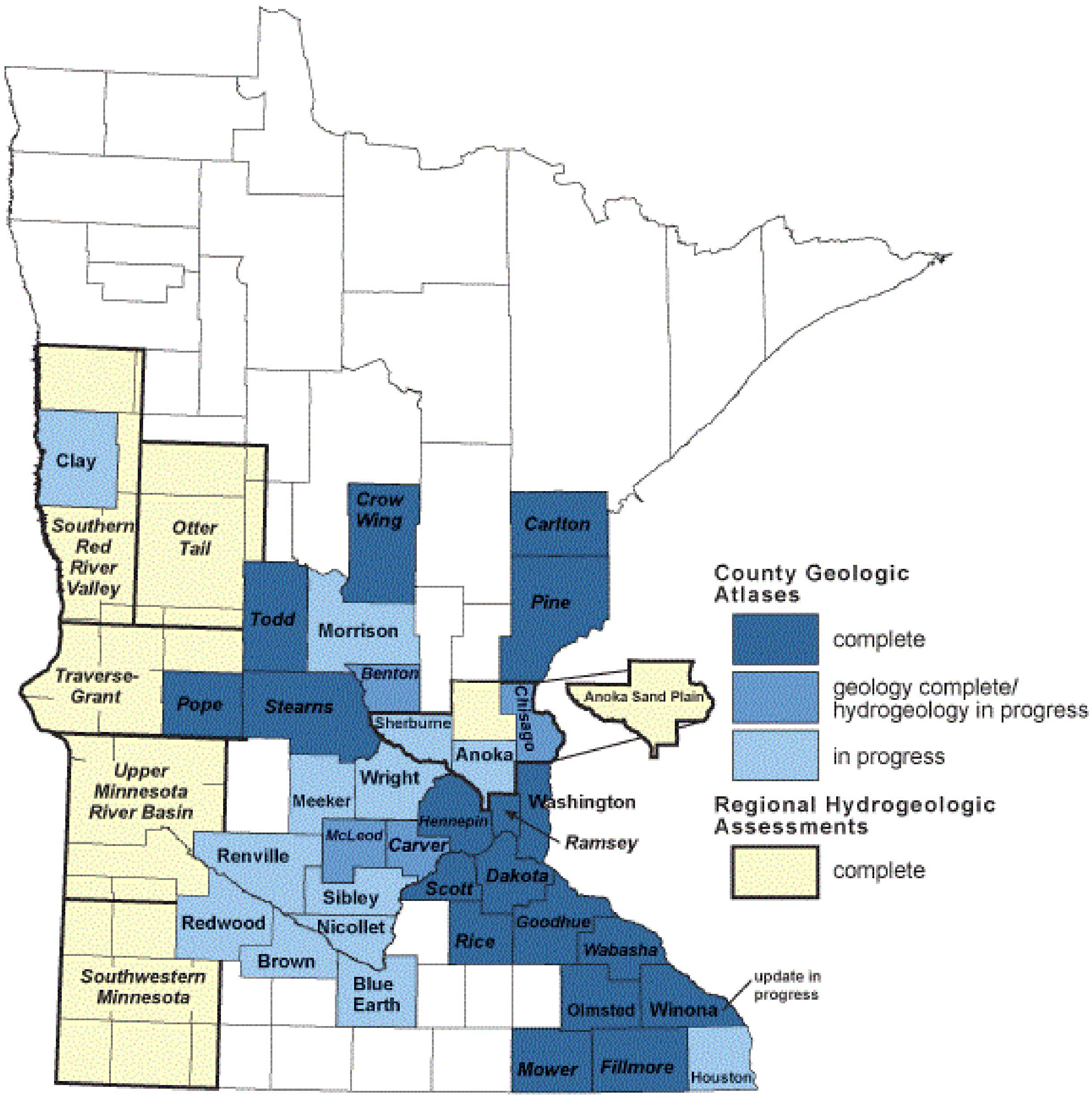
COUNTY GEOLOGIC ATLAS-REGIONAL ASSESSMENT PROGRAM

Together, the DNR and the MGS prepare map-based reports of counties (County Geologic Atlases) and multicounty regions (Regional Hydrogeologic Assessments) to convey geologic and hydrogeologic information and interpretations to governmental units at all levels, but particularly to local government. This information contributes to sound planning and management of the state's land and water resources (MGS 2012; DNR 2013).

County geologic atlases provide information essential to sustainable management of groundwater resources, for activities such as monitoring, water allocation, permitting, remediation, and well construction. They define aquifer properties and boundaries, as well as the connection of aquifers to the land and to surface water resources. The atlases also provide a broad range of information on county geology, mineral resources (including construction materials) and natural history.

A complete geologic atlas consists of two parts. Part A is prepared by the MGS and includes the water well database and 1:100,000 scale geologic maps showing properties and distribution of sediments and rocks in the subsurface. Part B is constructed by the DNR Division of Ecological and Water Resources and includes maps of water levels in aquifers, direction of groundwater flow, water chemistry, and sensitivity to pollution. Atlases are usually initiated by a request from a county and an offer to co-fund or provide in-kind service. The MGS is committed to the expeditious completion and periodic updating of atlases statewide (Figure 4) (MGS 2012).

Figure 4. Status of geologic atlases and regional assessments (DNR 2013)



NITRATE PROBABILITY MAPPING

The MDH has developed nitrate probability maps to assist in state and local water quality planning efforts. These maps identify areas with relatively high, moderate, and low probability of elevated nitrate concentrations in groundwater. The goal of nitrate probability mapping is to help protect public and private drinking water supplies and to prevent further contamination by raising awareness and assisting in local planning and prevention.

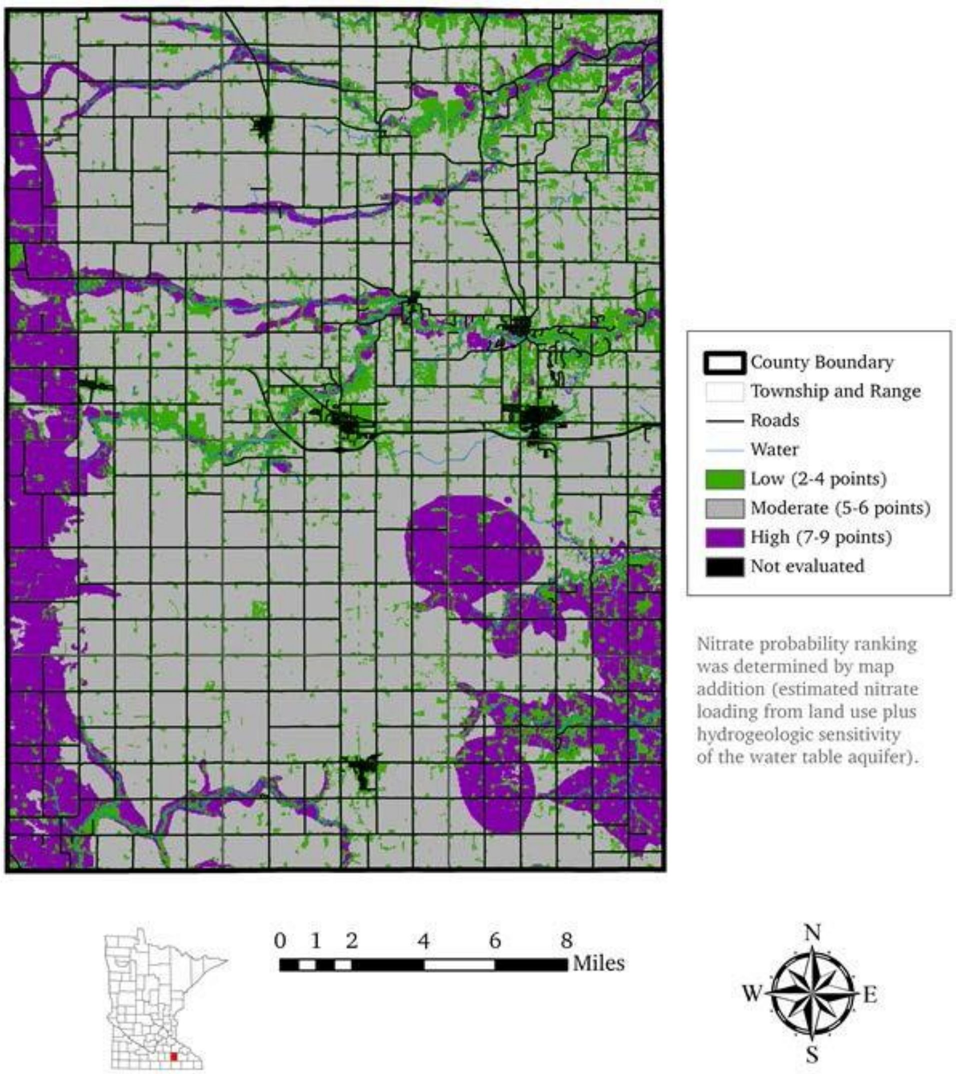
Wells with elevated nitrate concentrations will most likely be located in areas ranked as high or medium probability; however, wells in these areas also may provide drinking water without nitrate. Localized problems such as poor well construction, improper drainage, surface water entering the well bore, or onsite wastewater contamination, can lead to elevated nitrate levels anywhere in the state and may not be predicted using the probability maps.

Each probability map is accompanied by an explanatory report which describes the data layers used to develop the map. Figure 5 is a nitrate probability map created by the MDH for Dodge County in Minnesota.

To generate a nitrate probability map, the MDH uses geologic and soil data to produce a Geographic Information System (GIS) map depicting the hydrogeologic sensitivity of a water table aquifer. Next, the MDH uses cropland and urban land use data to generate a map of estimated nitrate loading to the subsurface. Finally, the hydrogeologic sensitivity and estimated nitrate-loading maps are compiled to create a nitrate probability ranking map.

The data layers used to prepare the map may vary between counties, as different databases are available for various counties. See the [MDH Nitrate-Nitrogen (Nitrate) Probability Maps and Reports](http://www.health.state.mn.us/divs/eh/water/swp/nitrate/nitratemaps.html) website to find a specific county: http://www.health.state.mn.us/divs/eh/water/swp/nitrate/nitratemaps.html.

Figure 5. Nitrate probability map for Dodge County, Minnesota (Lundy 2011)



WELLHEAD PROTECTION

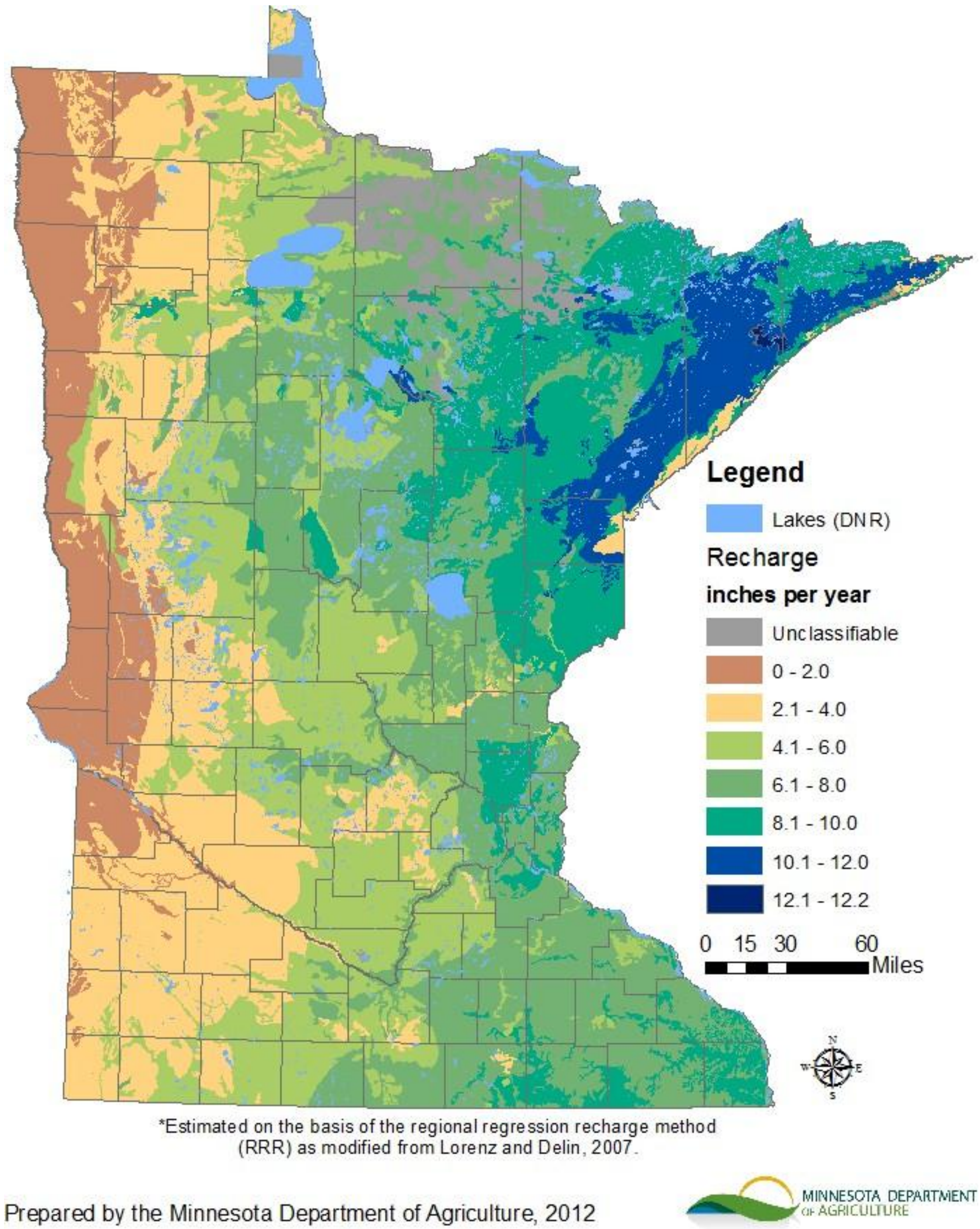
Wellhead protection programs are designed to protect groundwater that is used as a public water supply. States are required to have wellhead protection programs under the provisions of the 1986 amendments to the federal Safe Drinking Water Act. A capture zone for the well (called the wellhead protection area) is designated and a plan is developed for managing potential contamination sources within the wellhead protection area. The MDH assigns staff to assist public water suppliers with preparing and implementing wellhead protection plans. The MDH administers the state wellhead protection rule (Minnesota Rules, Part 4720.5100 - 4720.5590) that sets standards for planning.

CLIMATIC CONDITIONS AND GROUNDWATER RECHARGE

The term groundwater recharge describes the addition of water to the groundwater system. The timing and intensity of spring snowmelt, rain, and evapotranspiration during the growing season all play a role in the recharge process. Recharge may be altered by pumping, land use or climate changes resulting in increased or decreased recharge (Delin and Falteisek 2007).

Statewide estimates of annual recharge rates in Minnesota are based on the regional regression method (Lorenz and Delin 2007)(Figure 6). Recharge rates to unconfined aquifers in Minnesota typically range between 20 to 25% of the annual precipitation, recharge rates to glacial clays or till is typically less than 10% of precipitation and recharge to confined aquifers is typically less than 1% of precipitation (Delin and Falteisek 2007).

Figure 6. Annual recharge rate to surficial materials in Minnesota, 1971-2000 (Lorenz and Delin 2007)



Chapter 4 : Nitrate Conditions in Minnesota Groundwater

Monitoring provides information to resource managers and the public about nitrate concentrations and trends in groundwater. It is important to have sufficient, reliable data on groundwater quality in order to protect human health and to make appropriate land management decisions. Most results discussed in this section are from reports and data sets completed through 2012, with one through 2013. Additional assessment has been accomplished since then, and small summaries of those efforts are included at the end of this chapter.

To learn about the history of groundwater monitoring in Minnesota see Appendix C: History of Groundwater Monitoring in Minnesota; and Appendix D: Challenges of Monitoring Groundwater Quality.

NITRATE CONDITIONS IN VULNERABLE GROUNDWATER IN AREAS OF THE STATE UNDER AGRICULTURAL ROW CROP PRODUCTION

This section focuses on nitrate data collected from wells located in shallow, vulnerable groundwater aquifers in agricultural areas of the state. Due to the variation in geology and extent of Minnesota's groundwater resources, it is not practical to attempt a comprehensive evaluation of all the agriculture-related impacts on groundwater. It is also highly unlikely that the routine use of nitrogen fertilizer would significantly impact all of Minnesota's groundwater systems.

SHALLOW GROUNDWATER

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.

MDA Nitrate Data Summary

The MDA's Monitoring and Assessment Unit provides information on impacts to the state's water resources from the routine application of agricultural chemicals. Although the MDA's current groundwater monitoring program was 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.

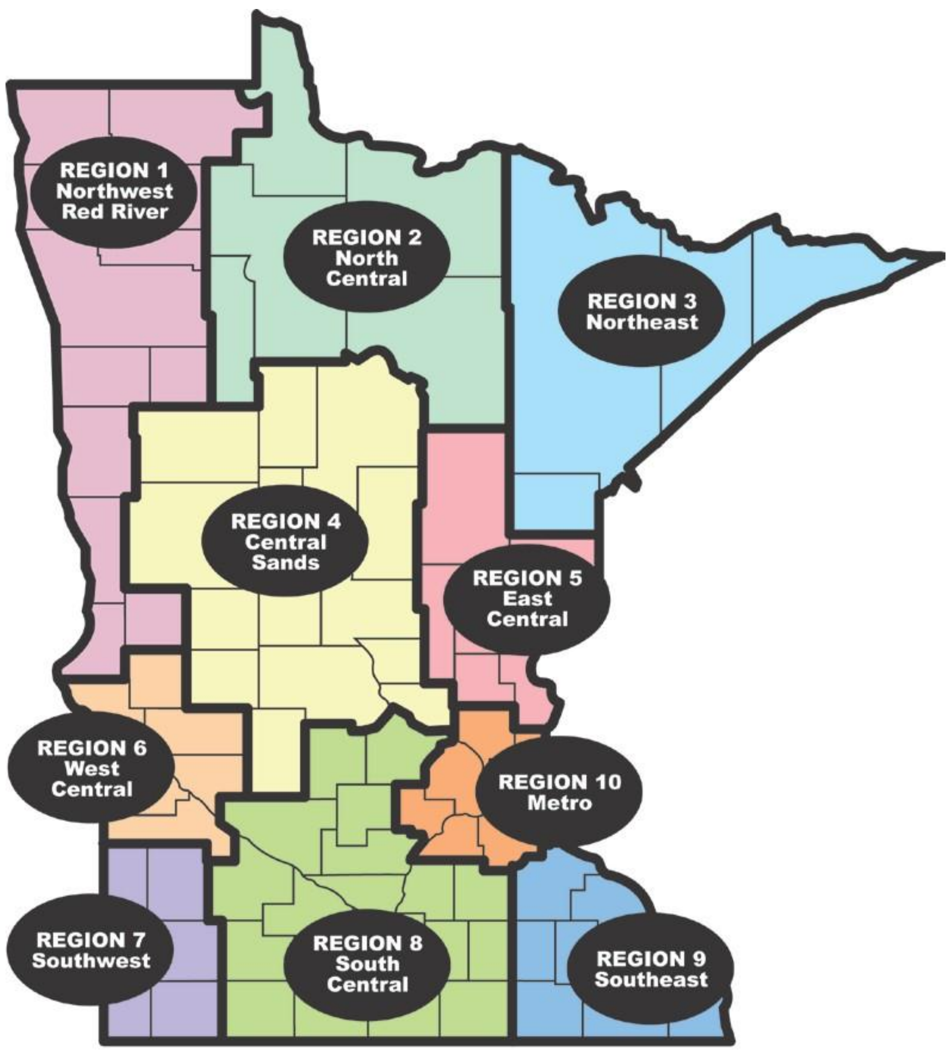
The MDA began monitoring in 1985 and developed a monitoring well network (referred to as the "former network") which consisted of monitoring wells, observation wells, and private drinking water wells that, depending on the region, were placed in either the Quaternary aquifer, till, or karst bedrock. This former network operated from 1987 to 1996. After 1996, the MDA completed a formal evaluation of its groundwater monitoring network and determined that many of the wells were, or soon would be, past their useful life span. Following three years of development, the MDA began installing a new network of monitoring wells starting in 2000 focused areas of the state (known as the Central Sands network or the current network). Most of the wells in the current network are located at the edge of fields, many of them irrigated, in shallow "water table" conditions. The Central Sands network consisted entirely of water quality monitoring wells designed to sample the very top portion of the shallowest aquifers in the state's major sand plain region. This current network was designed specifically as an early warning, edge of field monitoring network for pesticides. Nitrate concentrations in groundwater can vary significantly over short distances, short time frames and with changes in depth. It should be noted that this current network was not designed to address this nitrate variability. To assess nitrate in groundwater, additional wells at multiple depths would be required. To learn more about designing a monitoring network to test for nitrate concentration, please refer to Appendix E: Evaluating the Presence of Nitrate-Nitrogen in Groundwater.

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) (Figure 7).

PMR's 4, 9, and 10 (urban) have unique monitoring designs based on their distinctive land use, hydrogeologic, or other important characteristics. Groundwater in PMR 9 has been sampled via naturally occurring springs since 1993 and private drinking water wells since 2009 (MDA 2009). PMRs 2 and 3 are not currently monitored for groundwater due to very limited agricultural production in these heavily forested regions.

To learn about nitrate trends in groundwater in springs, see Appendix F: Nitrate Trends in Groundwater at Selected Springs in Southeast Minnesota.

Figure 7. Minnesota Pesticide Monitoring Regions (MDA 2012b)



The MDA Nitrate Report Findings

In 2012, a report was completed that provided a summary of the MDA's nitrate groundwater monitoring activities through the Monitoring and Assessment Unit at the MDA (MDA 2012b). The nitrate data were compiled and analyzed on an annual basis by network (former versus current) 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 data collected around the state showed that, when comparing the former and current networks, there was a significant step increase in nitrate concentration in a majority of the regions (Table 1). The reasons for this step change are not known and are likely to be varied but may be related to changing well locations and depth. Nitrate concentrations in the very shallow, highly vulnerable groundwater monitoring wells sampled in this program exceed the Health Risk Limit (HRL) at many locations. However, this is not the situation with every well or all of the regions monitored. There were many wells that have shown no detections or very low nitrate levels. Nitrate concentration data also showed significant fluctuation over both short-term and long-term time frames. In addition to the trends over time, there are significant spatial differences showing that concentrations and trends may be different between and within various monitoring regions.

Table 1. Summary of nitrate results from former and current MDA monitoring networks

	Former Network (1985-1996)				Current Network (2000-2013)			
Pesticide Monitoring Region	Detections/ # of Samples	% Detections	Median (mg/L)	% of samples above HRL	Detections/ # of Samples	% Detections	Median (mg/L)	% of samples above HRL
1	2/31	6	0	0	59/114	52	0.45	8
4	1150/1580	73	6.5	38	1582/1634	97	14.4	62
5	49/66	74	8.2	44	88/92	96	10.5	52
6	16/63	25	0	8	59/111	53	0.59	12
7	13/25	34	0	6	51/90	57	5.10	27
8	15/84	18	0	7	88/142	62	1.69	20
9	280/337	83	7.4	35	590/592	99	6.09	23
The detection method reporting limit for nitrate-nitrogen is 0.4 mg/L. This means all detections reported from the laboratory are at or above this level.								

It should be noted again that the MDA's pesticide groundwater monitoring program was not designed to determine nitrate detection or concentration status and trends. These wells were constructed at the water table, and nitrate concentrations can change significantly with depth. The network does not represent concentrations in drinking water wells. Identification of the causes and factors involved in the changing trends in nitrate concentrations may require a different monitoring design dedicated to understanding nitrate in groundwater.

Figure 8 shows concentration over time in the Central Sands region of Minnesota in the former network (1985 – 1996). It indicates that monitoring well nitrate concentrations generally increased. The rate of increase was statistically significant in four out of the six trend tests performed on the former network (MDA 2012a). There was some nonseasonal fluctuation in the data. This fluctuation has occurred at all levels (median, 75th percentile, and 90th percentile).

Figure 8. Nitrate concentration time series from PMR 4 groundwater monitoring wells former network

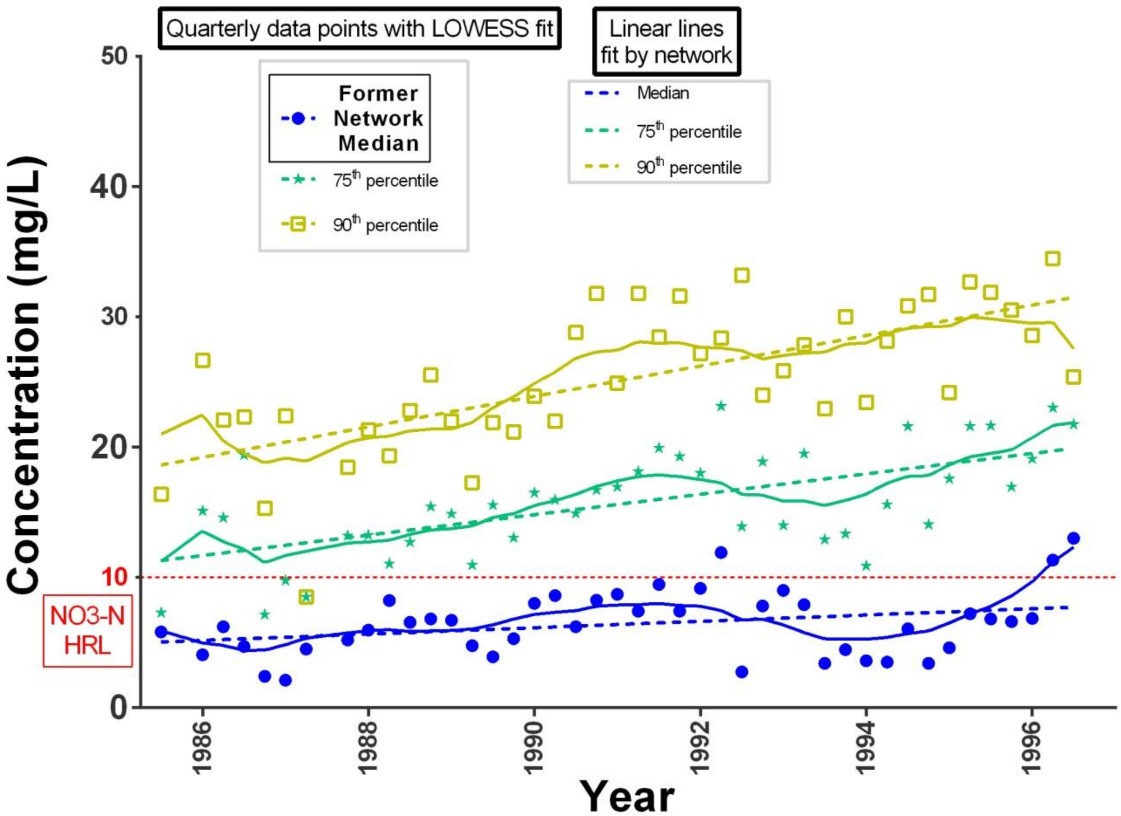
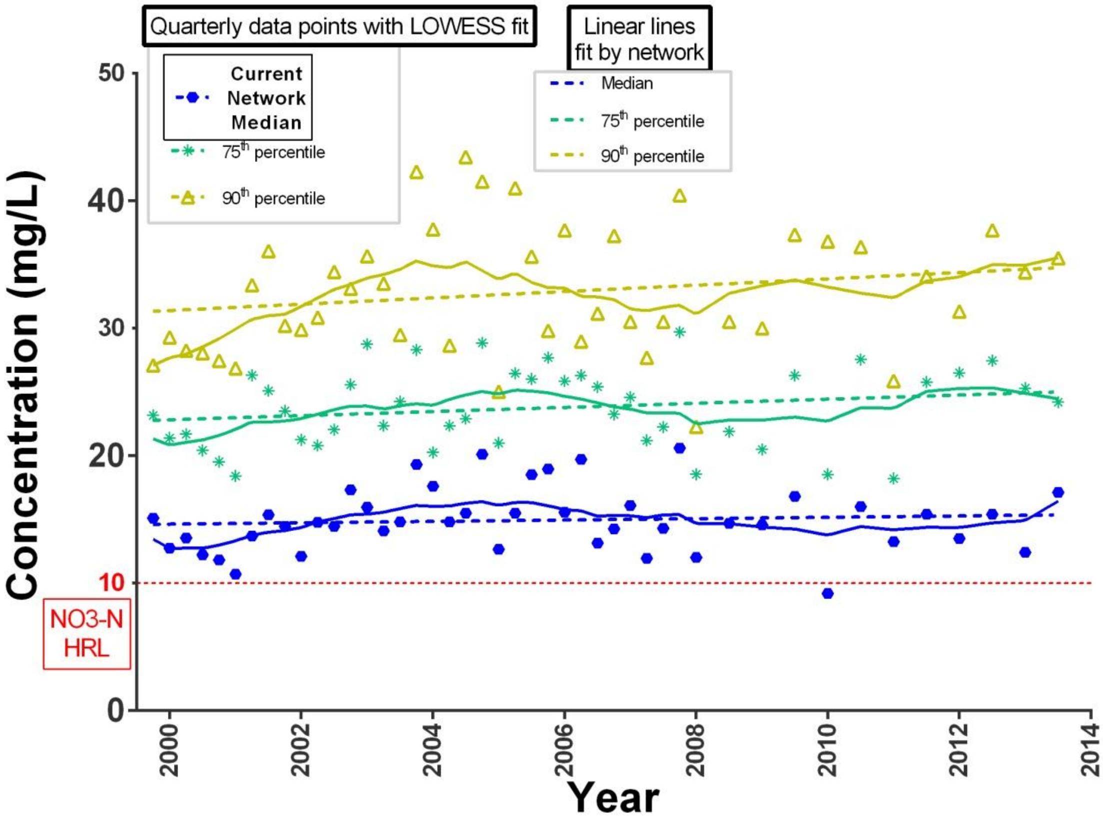


Figure 9 shows concentration over time in the Central Sands region of Minnesota in the current network (2000 - 2013). It suggests that monitoring well nitrate concentrations have generally increased since 2000. However, the rate of increase was not statistically significant in five out of the six trend tests performed on the current network (MDA personal communication 2014). It appears that the nitrate concentrations in the current network may have reached a maximum around 2005 and have dropped slightly since then, although there is significant annual variability in the data. Median nitrate concentrations in the current network were consistently higher than the HRL of 10.0 mg/L, whereas median concentrations in the former network were, in their majority, below the HRL. Due to the differences in these networks, data can not be extrapolated between the former and the current networks.

Figure 9. Nitrate concentration time series from PMR 4 groundwater monitoring wells current network



Sixty-two of samples from the MDA monitoring wells (PMR 4) were above 10 mg/L nitrate-N and only 14% of samples were below 3 mg/L (Table 2). The median concentration for the MDA PMR 4 monitoring wells was 14.4 mg/L while the CSPWN median concentration is 0 mg/L. The high nitrate concentrations observed in the MDA PMR 4 monitoring wells were not seen in the private drinking water wells.

Table 2. Nitrate-N concentration results summary for the MDA PMR 4 monitoring wells from 2000-2013

MDA PMR 4 Monitoring Wells	Nitrate –N Parameters							
	# Samples	Minimum (mg/L)	Median (mg/L)	75th Percentile (mg/L)	90th Percentile (mg/L)	Maximum (mg/L)	% ≤ 3 (mg/L)	% ≥ 10 (mg/L)
2000-2013	1,687	0.0	14.4	23.5	33.3	115	15	62

PRIVATE WELLS

MDA and partners have worked with private well owners to sample their wells for nitrates, and has found there can significant variability in monitoring data in individual wells from year to year. In addition, participation by homeowners is voluntary and some may drop out or not provide samples some years. However the data is useful for evaluating long term trends and indicates a concern for nitrate in groundwater from vulnerable aquifers in central and southeast Minnesota.

SOUTHEAST VOLUNTEER NITRATE MONITORING NETWORK RESULTS 2008-2012

Drinking water quality is a concern across southeastern Minnesota, where nitrate loading to the subsurface can be significant and hydrogeologic sensitivity is highly variable within short distances. In 2008, the Southeast Minnesota Water Resources Board (SEMNWRB), and several partners (MPCA, MDA, MDH) began collecting data from the "volunteer nitrate monitoring network" (VNMN). This region was selected as a pilot because of its vulnerable and complex geology.

This network of 675 private drinking water wells, representing a stratified-random distribution across the nine counties (Dodge, Fillmore, Goodhue, Houston, Mower, Olmsted, Rice, Wabasha and Winona) and several aquifers, was designed to provide nitrate concentration data.

Before data collection began, well network coordinators (county staff) enrolled volunteers (well owners) into the program by collecting detailed information about well location, well construction, and nearby nitrate sources. Volunteers collected six rounds of samples, between February 2008 and August 2012.

Based on the 3,245 samples collected and analyzed, the percentage of wells exceeding the HRL for each sampling round ranged between approximately 7.6 and 14.6% (Table 3) (MDH 2012; Aug. 2012-unpublished data from MDA).

Table 3. Median nitrate-N and wells exceeding the Health Risk Limit (HRL)

	February 2008	August 2008	February 2009	August 2009	August 2010	August 2011	August 2012
Median Nitrate-N (mg/L)	0.3	0.3	0.2	0.3	0.7	0.5	0.4
Exceed HRL (%)	14.6	11.4	11.1	11.0	9.3	10.4	7.6

The study evaluated several factors related to well construction and hydrogeology, and found them to influence groundwater quality. Well construction (the documented presence or absence of casing grout) and overlying geologic protection (shale or at least ten feet of clay above the open interval of the well) had the strongest influence on groundwater quality. Low nitrate concentrations were measured in 97.7% of wells with the most-desirable construction and hydrogeologic characteristics. The results are only applicable to the nine counties in the study area.

MDA CENTRAL SANDS PRIVATE WELL MONITORING NETWORK RESULTS 2011-2014

Due to the success of the southeast volunteer nitrate monitoring network, as well as the availability of newly acquired funding from the Clean Water Legacy Amendment, the MDA launched a similar project in the Central Sands area of Minnesota. The MDA determined that because high levels of nitrate have been measured in Central Sands monitoring wells, it was important to expand nitrate monitoring to private drinking water wells to determine if the concentrations were similar to concentrations found in the monitoring wells. In the spring of 2011, the MDA began the Central Sands Private Well Monitoring Network (CSPWN). The first goal of this project was to look at current conditions across the Central Sands region and the second long term goal was to determine long term nitrate concentration trends using a subset of this monitoring data

By July 1, 2011 the MDA had analyzed 1,555 samples for nitrate (MDA 2012a). Over 88% of the wells sampled had nitrate-N concentrations below 3 mg/L, 6.8% of the wells ranged from 3-10 mg/L of nitrate-N and 4.6% were greater than the nitrate-N HRL (Table 4).These results were similar to findings from a 2010 U. S. Geological Survey (USGS) report on nitrate concentrations in private wells in the glacial aquifer systems across the upper US (Warner and Arnold 2010). The USGS report found that less than 5% of sampled private wells had nitrate-N concentrations greater than or equal to 10 mg/L nitrate-N. Nitrate concentrations from the CSPWN 2011 results varied widely over short distances (Figure 10). This was also the case in the USGS report on glacial aquifer systems.

Table 4. Summary of nitrate-N concentrations for the Central Sands Private Well Network (2011)

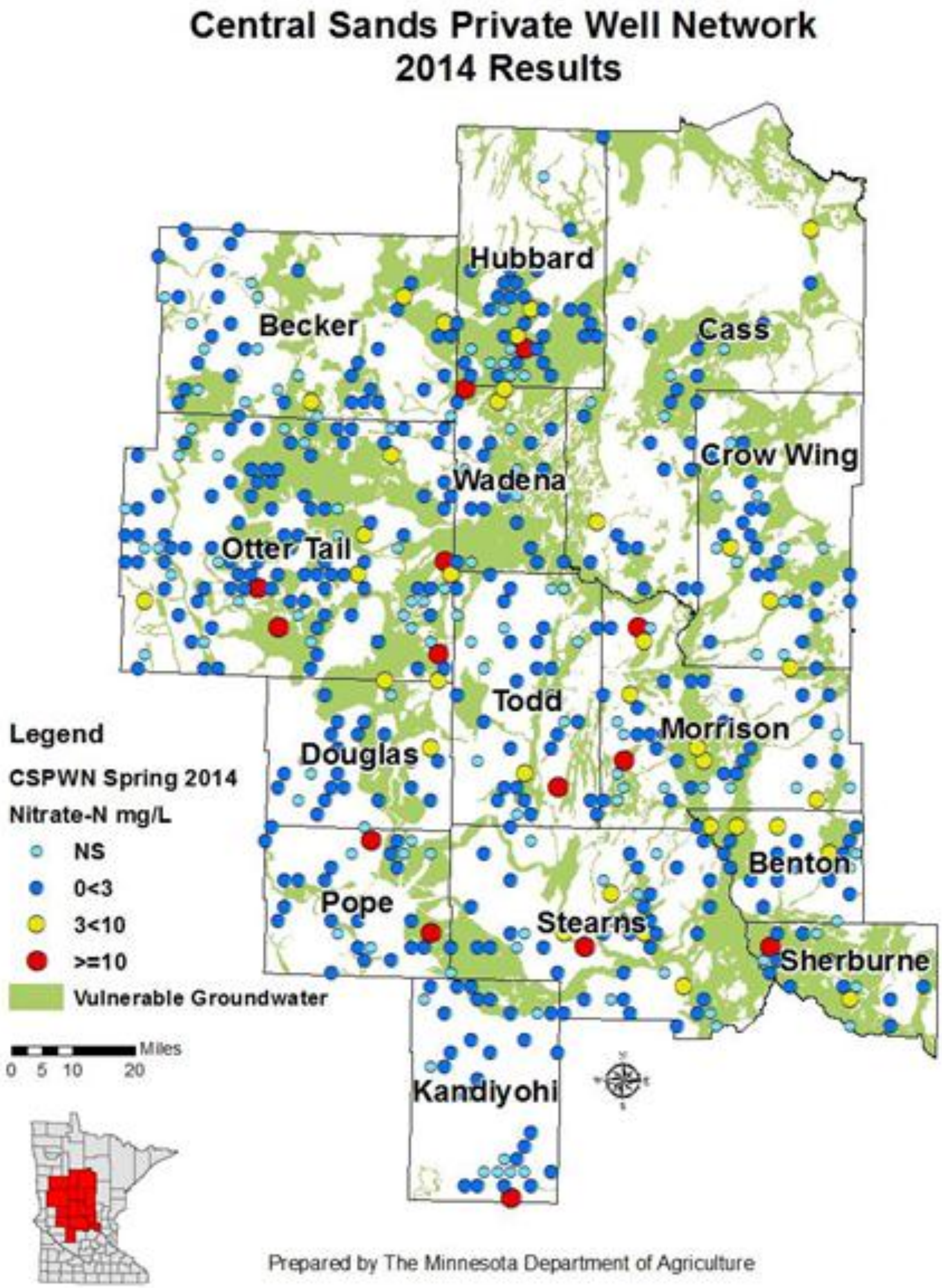
	# of Samples	Minimum (mg/L)	Median (mg/L)	75th Percentile (mg/L)	90th Percentile (mg/L)	Maximum (mg/L)	% ≤ 3 (mg/L)	% 3-10 (mg/L)	% ≥10 (mg/L)
Average	1,555	<0.03	0.01	0.66	4.15	31.9	88.6	6.8	4.6

Starting in 2012, approximately 550 homeowners volunteered to participate in annual sampling of their private wells. Results from 2012 and 2013 indicated a similar response to 2011, with 89% of the wells in both years having less than 3 mg/L of nitrate-N concentration. 2014 results show: 89% of sampled wells were < 3 mg/L, 8% were 3-10 mg/L, and 3% were ≥10 mg/L. (Table 5). Work on this project is ongoing. For further information on this sampling project, see http://www.mda.state.mn.us/en/protecting/cleanwaterfund/gwdwprotection/characterizingnitrates.aspx

Table 5. Summary of nitrate-N concentration results for the Central Sands Private Well Network (2011 – 2014)

		Sample Distribution by Year			
		2011	2012	2013	2014
Nitrate-N (mg/L)	Total # of Samples	534	510	487	434
0 < 3		478	454	433	388
3 < 10		35	40	41	32
≥ 10		21	16	13	14
Percent of Samples ≥ 10		4%	3%	3%	3%

Figure 10. Central Sands Private Well Network distribution of nitrate-N concentrations in individual wells



Analysis of well owner surveys demonstrates a relationship between nitrate concentrations and well construction type, well depth and to a lesser extent, well age. However, because well information was provided by the well owners, it may be approximate or erroneous.

The results are applicable to the Central Sands counties and are based on a one-time sampling event, used to determine areas of concern. The second stage of this project is to continue sampling approximately 600 wells on an annual basis to determine long term nitrate trends of nitrate concentrations.

PUBLIC WATER SUPPLY WELLS

MINNESOTA DEPARTMENT OF HEALTH DRINKING WATER INFORMATION SYSTEM DATABASE

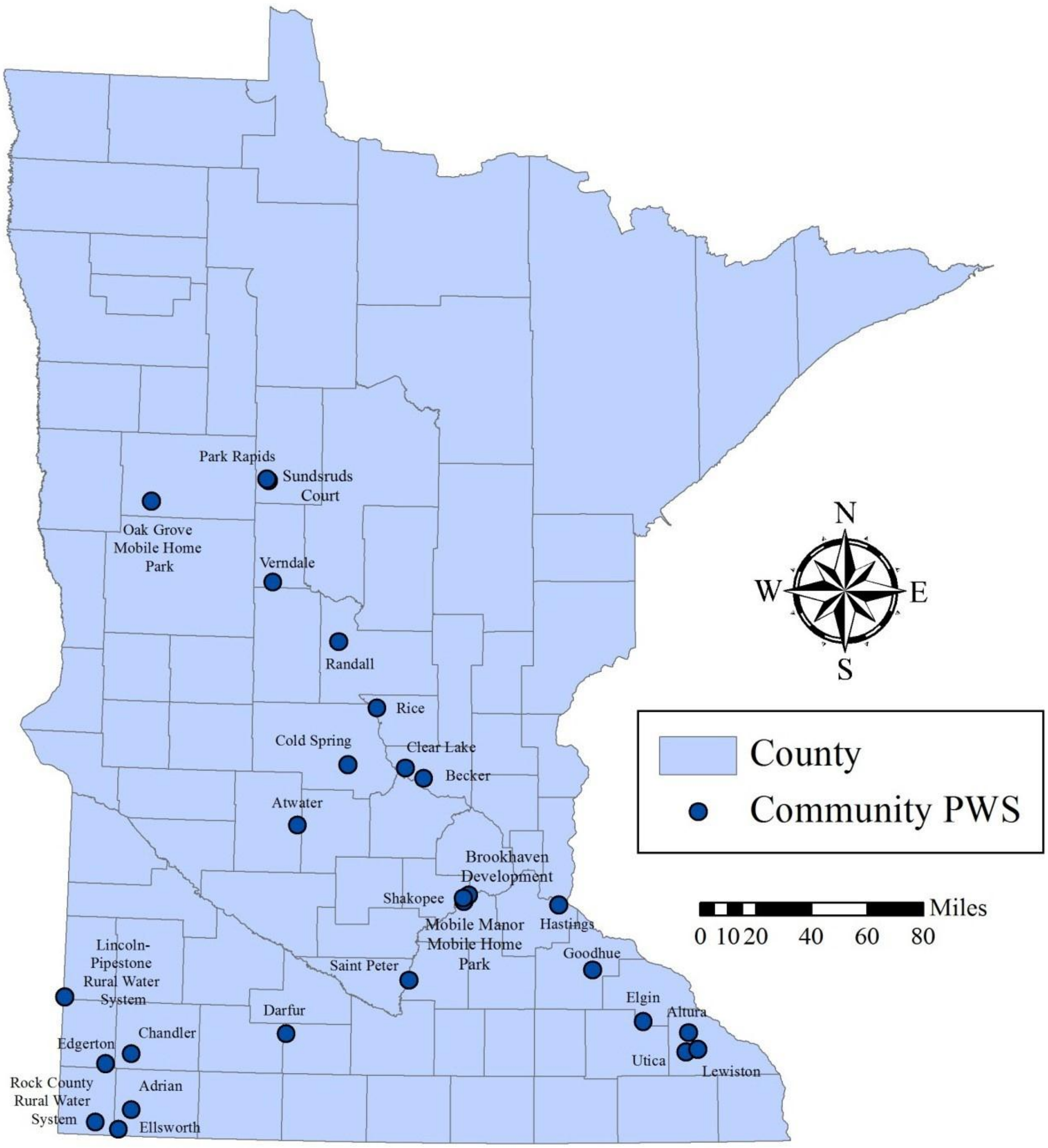
The MDH operates and manages the Minnesota Drinking Water Information System (MNDWIS) database, which stores and tracks information about each public water supply's distribution components (e.g. wells, treatment plant, water storage) and water quality monitoring and compliance data regulated by the federal Safe Drinking Water Act (SDWA). Presently, there are 7,091 PWS in Minnesota, ranging from churches, schools, day care centers, resorts, restaurants, mobile home parks, prisons, and municipal water supplies that provide drinking water to the public. Of the total PWS in Minnesota, 963 PWS are classified as "community" water suppliers in Minnesota (i.e., cities, prisons, schools). Most cities have multiple wells and any raw (source) water pumped from these wells that exceeds the HRL is either treated or blended with water having a lower concentration of nitrate in order to attain the standard prior to being distributed to users.

Nitrate is one of several annual general compliance contaminants required to be tested under the SDWA. Regulated monitoring and testing of a public water supply occurs after treatment or at the point where the water enters the distribution system and is available to the public for consumption. Raw water data also is available in MNDWIS. The same general contaminant information is required to be made public by the PWS through a "Consumer Confidence Report" so citizens have the opportunity to know about the quality of their drinking water.

To protect public health and help public water suppliers avoid exceeding the regulated contaminant levels under the federal SDWA, the MDH requires quarterly water quality monitoring when certain contaminant thresholds are reached. Public water suppliers are required to submit quarterly monitoring results when wells exceed 5.4 mg/L nitrate-N to more closely monitor, evaluate and identify ways to reduce nitrogen levels in their water supply. The goal in wellhead protection areas is to prevent the raw water from exceeding the drinking water standard. Also, all PWS that are treating for nitrate are required to continue to submit quarterly monitoring results to ensure the water produced for consumption is maintained below the drinking water standard of 10 mg/L nitrate-N. The MDA supports the MDH requirements to monitor wells that exceed 5.4 mg/L nitrate-N in PWS systems. This is the value at which additional monitoring is currently required under the SDWA.

There are presently 27 community public water supply systems that are conducting quarterly monitoring for nitrate (Figure 11). See Appendix B: Case Studies: City of Perham, City of St. Peter, Lincoln-Pipestone Rural Water to learn more about selected communities that the MDA and the MDH have worked with to address elevated nitrate in their PWS.

Figure 11. Community public water supply systems monitoring nitrate quarterly (MDH 2013)



Blue dots show locations for 27 community PWS (groundwater) systems currently monitored quarterly for exceeding 5 mg/L nitrate.

MINNESOTA DEPARTMENT OF HEALTH WELL WATER QUALITY DATABASE (NEW WELLS)

Since 1990, when a new well is constructed, the well driller is required to collect a water sample and have the water tested by a certified lab for coliform bacteria and nitrate. Additionally a requirement to analyze for arsenic was added in 2008. The test results are provided to the property owner and also entered into the MDH Well Management "Wells" database. As described in the 2012 Clean Water Fund Performance Report, the percentage of new wells with nitrate-N exceeding 5 mg/L was around 2% over this twenty year period, and those wells exceeding the drinking water standard was around 0.5% (Minnesota Agencies 2012).

Twenty years of water quality data collected from newly constructed private wells shows that the percentage of new wells above 5 mg/L nitrate-N is small. It is important to note that the data does not account for differences in geology and aquifer vulnerability in Minnesota. The data also does not reflect the fact that well drillers will avoid drilling new wells in aquifers known to be contaminated by nitrate by drilling into deeper aquifers or different locations, therefore the dataset is of limited usefulness in tracking the impacts of nitrate on drinking water.

ADDITIONAL MONITORING RESOURCES AND REPORTS

MINNESOTA'S CLEAN WATER ROADMAP

Minnesota's Clean Water Roadmap is a set of goals for protecting and restoring Minnesota's water resources during the 25-year life of the Clean Water, Land and Legacy Amendment. This document was created through a collaborative process with an interagency team made up of personnel from seven agencies (BWSR, MDH, MPCA, MDA, DNR, MN Public Facilities Authority, and the Metropolitan Council). The MDA will work together with the other agencies to help achieve the indicators set forth. One of the four high-level indicators describes goals for groundwater quality. The statewide 2034 goal for drinking water standards for nitrate is to reduce nitrate levels in groundwater by 20%, which will decrease the percentage of wells exceeding the drinking water standard by approximately 50%.

TOWNSHIP TESTING PROGRAM

The MDA has established a Township Testing Program to determine current nitrate concentrations in private wells on a township scale. This program is discussed in Chapter 9.

Chapter 5 : Nitrogen Cycle, Sources and Trends

This chapter is a simplified version of Appendix G: Nitrogen Cycle, Sources and Trends.

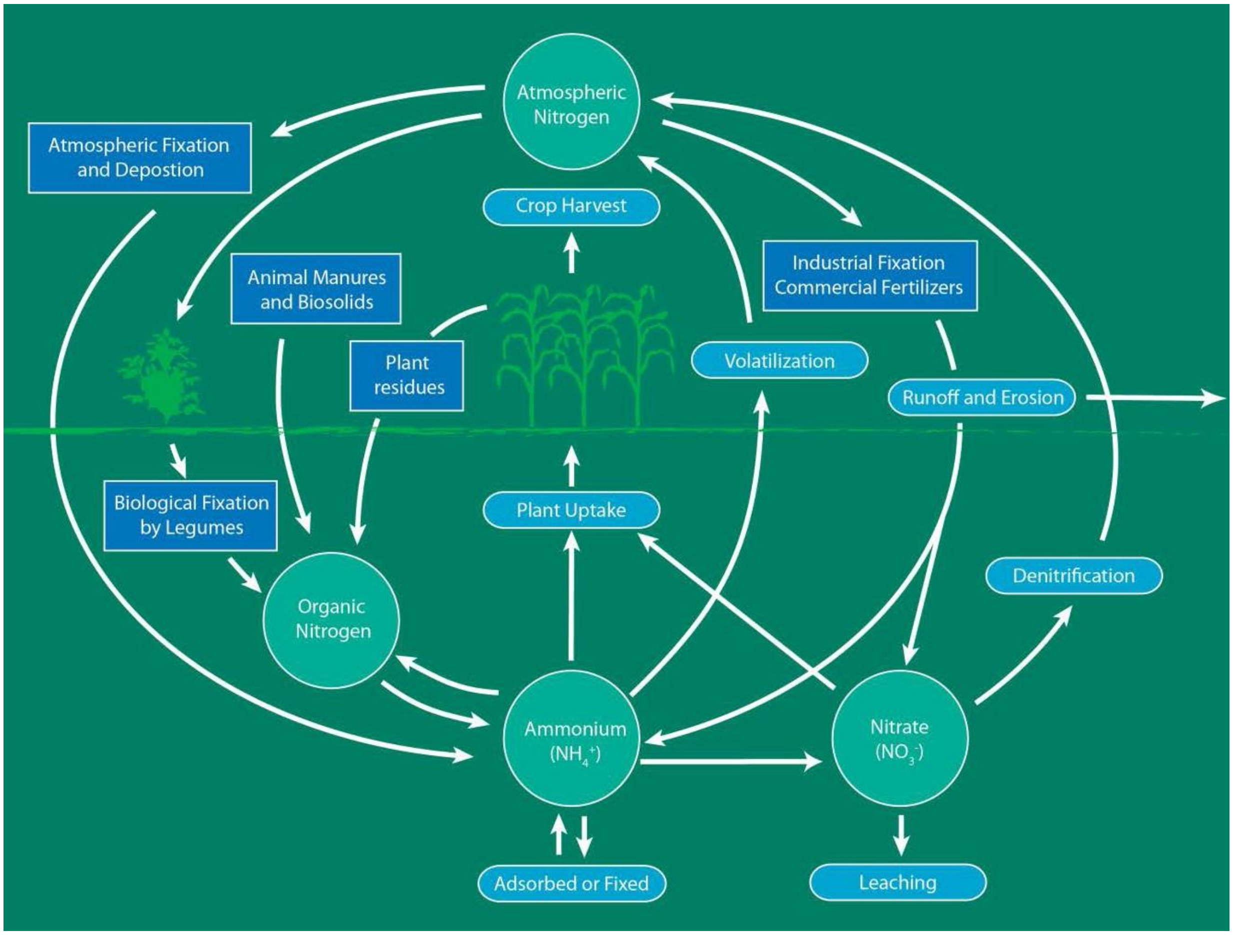
THE NITROGEN CYCLE AND TERMINOLOGY

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". The nitrogen cycle, depicted in Figure 12, describes the inputs, pools, pathways, transformations, and losses of nitrogen in the environment.

Although several nitrogen species are involved in the cycle, the species which are of primary importance 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 posing economic and environmental concerns. The characteristics of these species and related processes are summarized in Appendix G.

Two notes should be made on the subject of nitrogen sources. First, 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. Secondly, it is important to recognize that nitrate occurs naturally in the soil system. Nitrate losses, although typically minor, can occur under natural vegetative conditions. Losses, although generally temporal, 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 following by prolonged wet cycles.

Figure 12. The nitrogen cycle (Lamb et al. 2008)



AGRONOMIC AND EXTERNAL SOURCES OF NITROGEN

In a recent report, it is estimated that the statewide balance of inorganic nitrogen is 2.7 million tons per year (Figure 13) (MPCA 2013). Eighty percent of those contributions are applied on or derived from Minnesota's cropland. Contributions from soil organic matter, fertilizer, manure and legume crops are very important inputs for optimizing yields and it is imperative that these inputs are managed to minimize environmental impacts (Figure 14). Nitrogen sources to cropland are highly diverse and relative contributions vary substantially on both regional and local scales. It would be highly relevant to conduct similar types of nitrogen source contribution assessments to specific areas of Minnesota where groundwater supplies are either impacted or threatened by excessive nitrogen loading.

Figure 13 illustrates the major sources of nitrogen inputs to Minnesota cropland from a statewide perspective. It is important to note that the relative percentage from any category may not directly relate to amounts reaching groundwater or surface waters. Some processes, such as mineralization, can only be managed or manipulated to a small degree. Key nitrogen sources that can be managed to a significant degree include: fertilizer (through selection of proper rates, sources, timing, etc.), manure (proper crediting, rates, incorporation, etc.) and legumes (crediting).

Figure 13. Major sources of nitrogen inputs to Minnesota soils (MPCA 2013) Note that categories for soil mineralization denote "net" mineralization on an annual basis

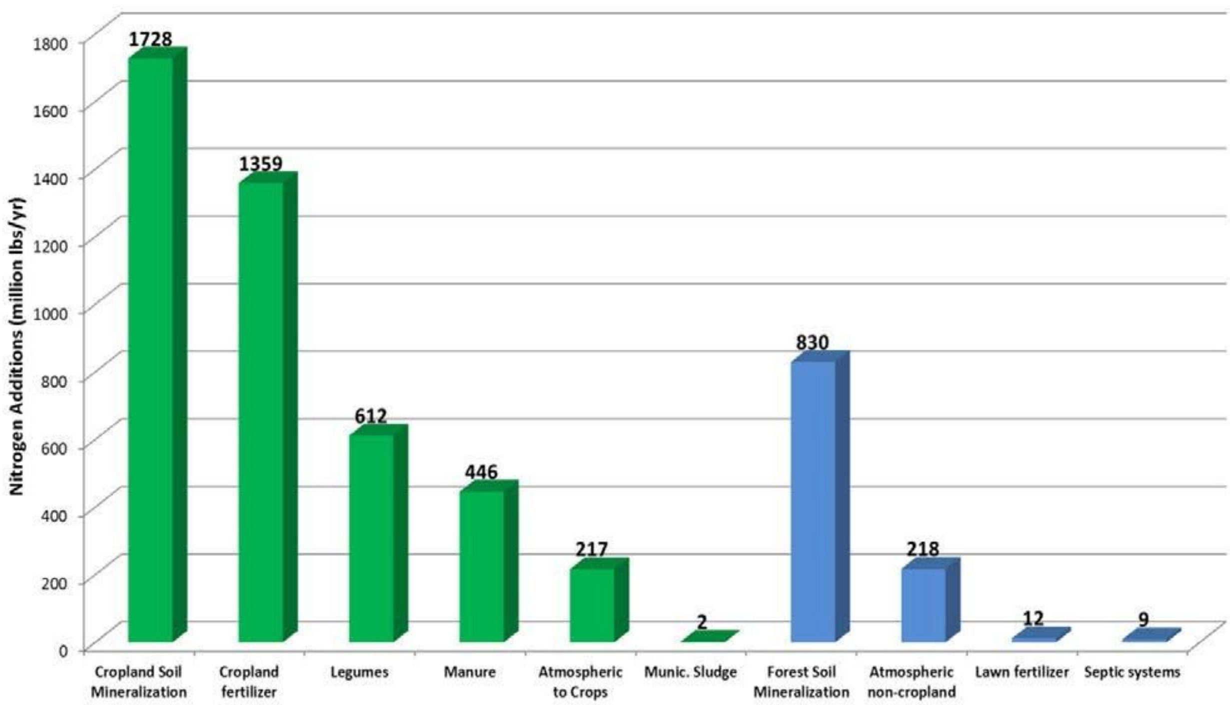
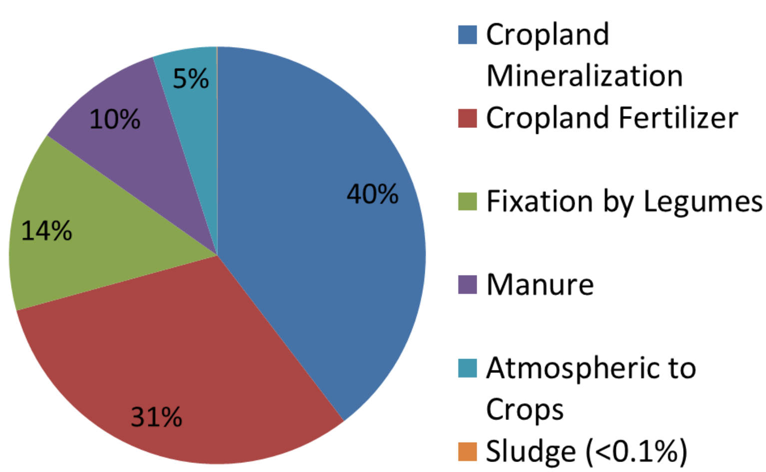


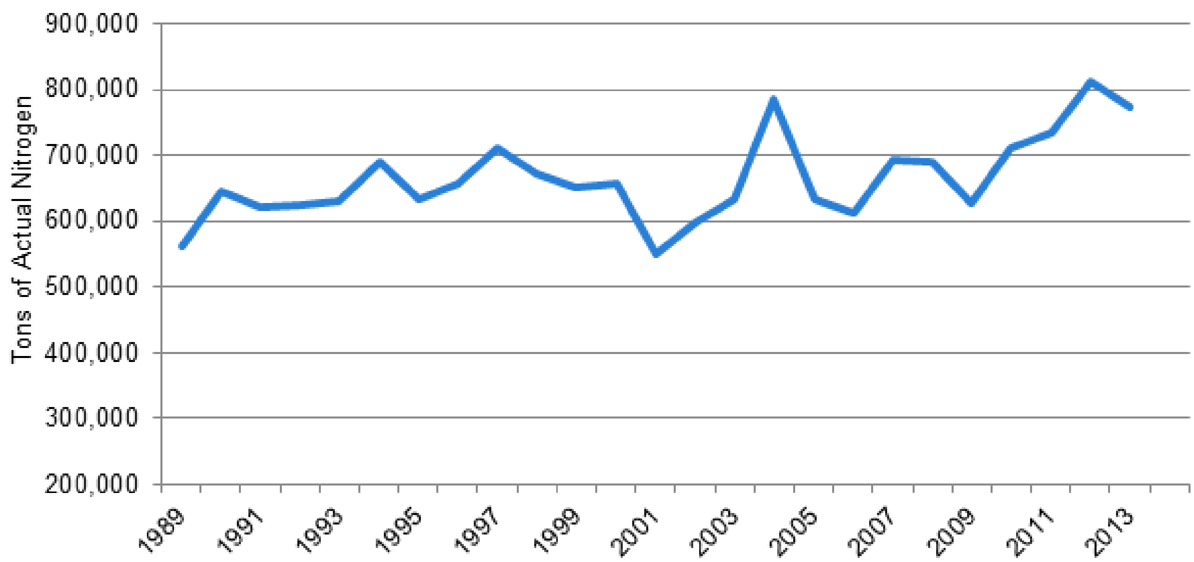
Figure 14. Major agricultural nitrogen sources in Minnesota (MPCA 2013). Cropland "mineralization" denotes the annual net mineralization between the total nitrogen released minus the amount going back into the organic fraction (immobilized)



NITROGEN FERTILIZER SALES AND SOURCES

Commercial nitrogen fertilizer use in Minnesota grew quickly between the late 1960s and 1970's, then began to stabilize in the early 1980's. Since 1990, statewide sales have averaged 669,000 tons per year and are trending slightly upward (Figure 15). Recent sales increases (12% higher than the long-term average) during the past five years are strongly linked to both increased corn acres and slightly higher application rates. Appendix G examines similar annual nitrogen sales information on a national and Midwest level.

Figure 15. Commercial nitrogen fertilizer sales trends in Minnesota from 1990 to 2013; ten year averages 1991-2000: 654,988; 2001-2010: 653,481; 2011-2013: 772,564 tons, based on MDA data

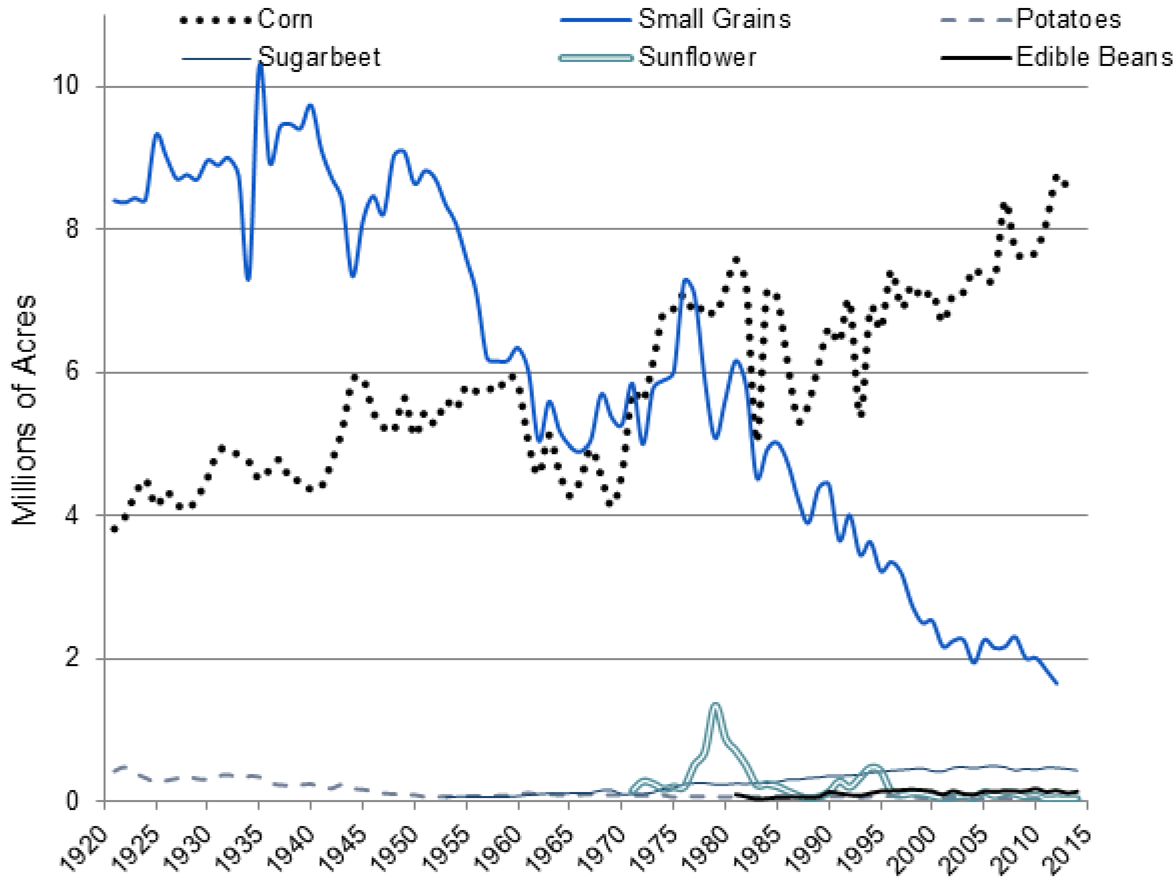


CROPPING TRENDS AND POTENTIAL NITROGEN LOSSES OF MINNESOTA'S MAJOR CROPS

Crop type is one of the most profound drivers influencing nitrate leaching losses and it is extremely important to understand these relationships. A summary of typical nitrogen fertilizer crop requirements, characteristics, and relative nitrate leaching losses can be found in Table G 1 in Appendix G.

Crop selection, as reported by the National Agricultural Statistics Service (NASS) over the past ninety years, has changed dramatically. Minnesota once routinely raised over 8 million acres of small grains each year (Figure 16). Acres dropped significantly in the 1950's and again during the 1980's and 1990's. Over the past decade, there are approximately 2 million acres of small grains 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; typically grown in areas of low groundwater vulnerability; and moderate nitrogen inputs due to lodging concerns.

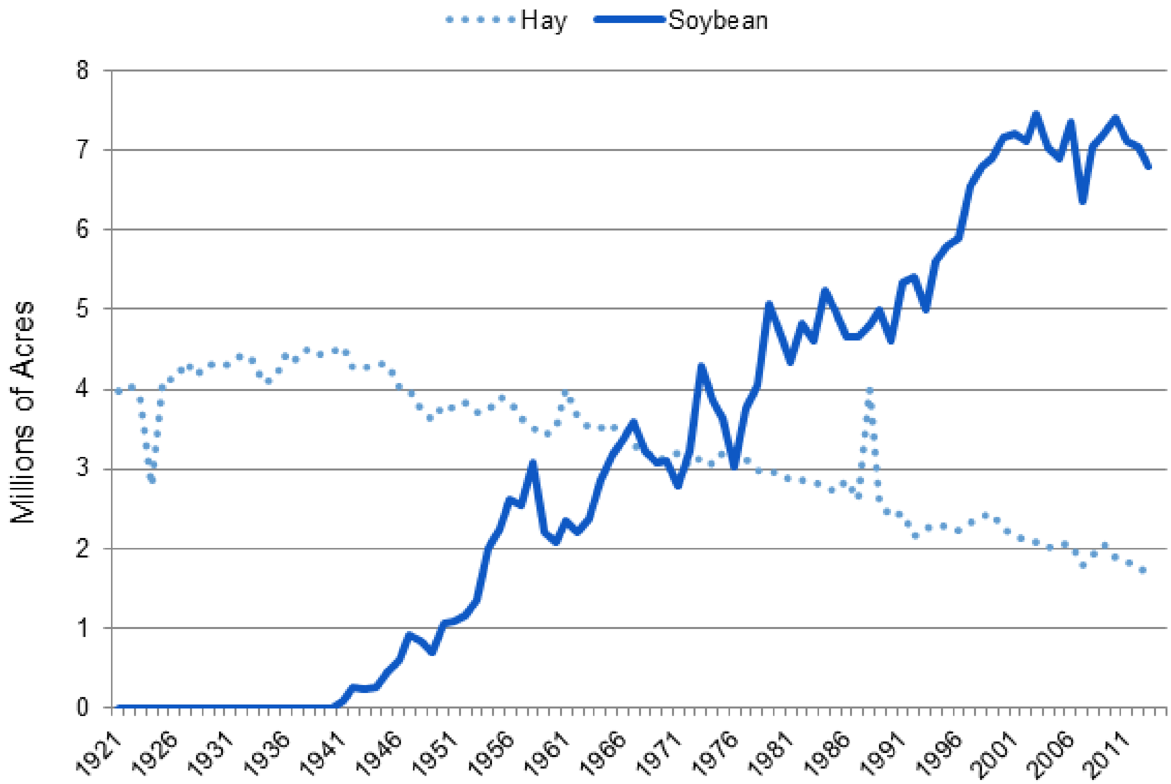
Figure 16. Acreage trends for Minnesota's nitrogen demanding crops from 1921 through 2012



Corn acres have been steadily increasing for the last ninety years. This crop has a high nitrogen-demand and has a narrow uptake period. Minnesota's nitrogen BMPs have a number of options to insure that this crop has the nutrients needed during its critical uptake period while minimizing the amount of inorganic nitrogen in the soil profile during other portions of the growing season. Other nitrogen-demanding crops, such as sugar beets and potatoes, are relatively small on a state acreage perspective but can have significant impacts (both economic and environmental) on a local area.

Looking back at the trends in "legume" crops since the 1920's (Figure 17), there has been a very steady decline of alfalfa and clover acres. Acreage declines in perennial legumes can be partially explained by both overall reductions in both number of milk cows and milking operations. Minnesota also imports a significant amount of these forages from the Dakotas where it can be grown at lower production costs and less prone to spoilage losses. These crops have strong, positive effects 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.

Figure 17. Acreage trends in Minnesota's legume and hay crops from 1921 through 2012

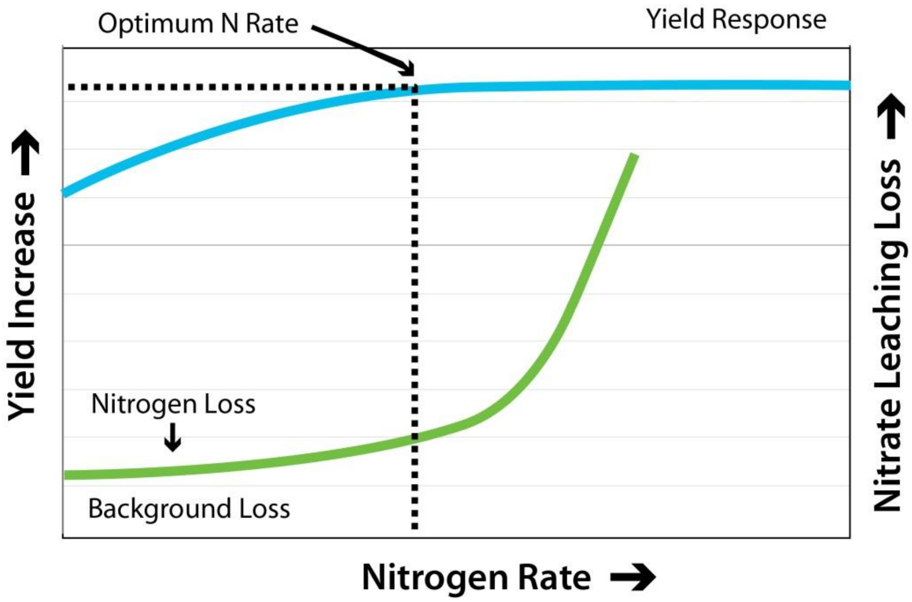


TRENDS IN NITROGEN FERTILIZER USE ON MAJOR CROPS, PRODUCTION AND FERTILIZER USE EFFICIENCY

Nitrogen fertilizer rate selected by farmers is a critical factor in understanding potential environmental consequences. Figure 18 is a conceptual illustration showing the important relationship between nitrogen fertilizer rates, crop response, and nitrate leaching losses. Identifying the optimum nitrogen rate is an important step in balancing the production aspects with environmental concerns associated with water quality. For simplicity sake, this illustration assumes that other important BMPs, such as timing and source, are already implemented.

It is important to note that there will almost always be some level of nitrate losses under row crop production regardless of nitrogen rates. Leaching loss contributions from non-fertilized corn typically range from 10 to 15 pounds per acre per year under highly productive Minnesota soils during normal rainfall conditions. These "background" losses are well documented from multiple tile drainage studies across diverse climatic conditions over the past 40 years at the University of Minnesota (U of M) Research and Outreach Centers across southern Minnesota. These losses can be limited to a 10 to 20% increase when using the optimum nitrogen rates in partnership with other BMPs such as the right timing, right source and placement. Nitrate leaching losses can increase dramatically when applying rates significantly greater than the optimum rates which are provided by the U of M.

Figure 18. Conceptual relationship between nitrogen inputs, crop response and nitrate leaching loss (Lamb et al. 2008)



Analysis of annual fertilizer sales combined with crop acres (NASS) suggests that corn (grain) consumes approximately 70-75% of the commercial nitrogen fertilizer each year (Figure G 4 in Appendix G). Additional MDA analysis of statewide use suggests that the average nitrogen fertilizer rate (regardless of crop rotations, legume crediting and manure applications) on corn tends to be between 120 to 140 pounds of nitrogen per acre (Figure G 5 in Appendix G). Average rates also appear to be increasing very slightly (4%) over the past 20 years. Average rates between the time periods of 1992-2001 and 2002-2011 were 124 and 129 pounds per acre per year, respectively. Additionally, the nitrogen rates estimated for 2012-2013 appeared to jump 5 to 10 pounds per acre and are likely to be directly linked to high corn prices. Information on commercial fertilizer rates on other Minnesota crops is not robust enough to examine trends.

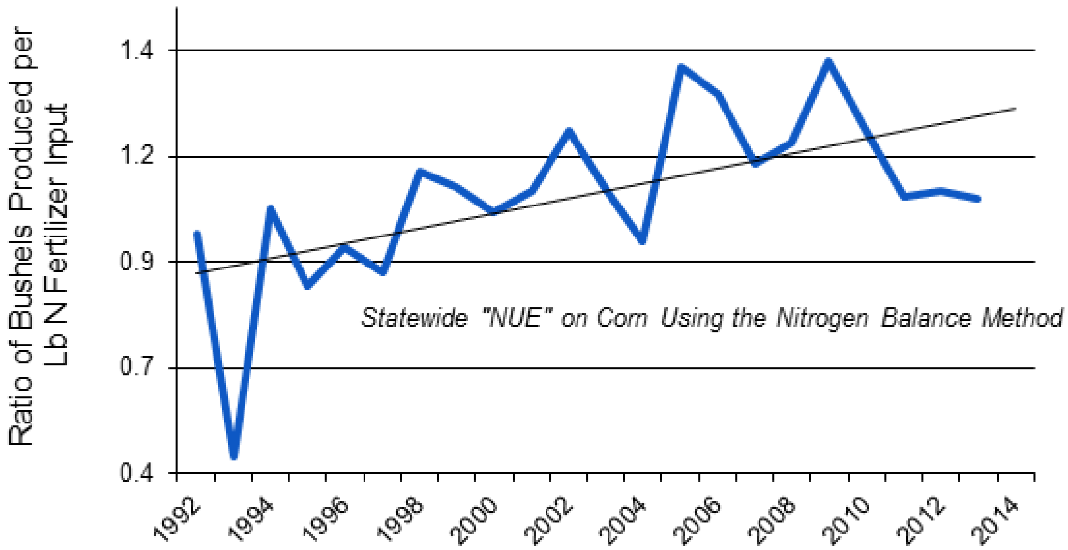
There are some other interesting trends that have developed over the last 20 years between inputs and outputs. Statewide nitrogen fertilizer consumption on corn has increased about 13%[1]; corn acres have steadily increased by 8%[2] (Figure 19). However, the interesting outcome is that the corresponding yield (bushels produced) has increased about 40%[3] over the same time period.

[1] Annual consumption by corn between 1992-2001 and 2002-2011 were 435,100 and 490,100 tons, respectively.

[2] Average corn (grain) acres between 1992-2001 and 2002-2011 were 7.0 and 7.6 million acres, respectively.

[3] Average bushels of corn grain produced between 1992-2001 and 2002-2011 were 822,390 and 1,150,280 million, respectively.

Figure 19. Ratio of corn grain produced per pound of nitrogen fertilizer applied to Minnesota corn acres from 1992 to 2013



This relationship suggests that corn farmers are successfully getting more production from each pound of nitrogen fertilizer. From the environmental perceptive, this trend is positive. However at this time, the causative factors or the direct environmental implications are not clear. Currently there is limited long-term research to demonstrate that increased nitrogen use efficiency (NUE) has a direct and positive impact on groundwater resources. The strongest evidence suggesting that this relationship exists comes from the Central Platte and other Natural Resources Districts in Nebraska where nitrogen regulations, which include mandatory fertilizer use reporting, have been in place for the last forty years (Ferguson 2013, personal communication). One of the complicating factors in this type of assessment is the fact that corn protein levels have been declining over the past decade or two with the newer corn hybrids. Simply stated, increased corn yields due to hybrid improvements may not be removing as much nitrogen from the soil system as in the past and the NUE trends may not necessarily reflect long-term improvements in water quality.

Figure 19 illustrates the improvements in nitrogen fertilizer use efficiency. Bushels produced per pound of nitrogen fertilizer have steadily increased from roughly 0.8 to 1.3 over the past twenty years. Lower NUE values in 2011, 2012 and 2013 are clearly related to moderate to severe moisture stress during the critical pollination and grain filling stages.

Many researchers suspect that there are multiple reasons for these trends with improved plant genetics being a significant driver. Root systems are larger, deeper and denser resulting in more effective nitrogen uptake and utilization. General adoption of the "4R" concept (right rate, right source, right timing and right placement) is another reason.[4] Improved weed control and the use of different hybrids in different parts of the landscape are other important improvements. Additionally, the NUE trends can also reflect improvements in manure and legume crediting. Regardless of the reason, it is very clear that farmers are producing significantly more grain with each unit of nitrogen fertilizer input.

[4] This concept, currently promoted by the agricultural industry as the "4Rs" (Right Rate, Right Timing, Right Source, and Right Placement), is a systems approach to fertilizing crops promoted by the International Plant Nutrition Institute, Canadian Fertilizer Institute, and The Fertilizer Institute.

Chapter 6 : Best Management Practices

BMPs have been discussed previously throughout this document. The term “Best Management Practices” is defined in Minnesota Statutes (Chapter 1). Minnesota has officially recognized nitrogen BMPs (Chapter 5). BMPs are the basis for the Nitrogen Fertilizer Management Plan’s (NFMP) prevention goal (Chapter 8). This chapter will provide information about the MDA’s past and future efforts to address BMP development, education and promotion, and evaluation.

The Groundwater Protection Act provides more detailed requirements for BMPs in Minnesota Statutes, section 103H.151, subdivision 2-4.

Subdivision 2 requires that:

> The commissioner of agriculture, in consultation with local water planning authorities, shall develop best management practices for agricultural chemicals and practices. The commissioner shall give public notice and contact and solicit comment from affected persons and businesses interested in developing the best management practices.

Subdivision 3 requires that:

> The commissioners of the Pollution Control Agency and agriculture, in conjunction with the Board of Water and Soil Resources, soil and water conservation districts, and the University of Minnesota Extension, must promote best management practices and provide education about how the use of best management practices will prevent, minimize, reduce, and eliminate the source of groundwater degradation. The promotion and education shall include demonstration projects.

Subdivision 4 requires that:

> The commissioners of agriculture and the Pollution Control Agency shall, through field audits and other appropriate means, monitor the use and effectiveness of best management practices developed and promoted under this section. The information collected must be submitted to the Environmental Quality Board, which must include the information in the report required in section 103A.43, paragraph (d).

INTRODUCTION

BMPs for the management of nitrogen were first developed for Minnesota in the late 1980’s and early 1990’s by the U of M and are based upon many decades of crop response research. The BMPs are our best tools to manage nitrogen efficiently, profitably and with minimized environmental loss. BMPs are a reflection of our understanding of the nitrogen cycle, and are predicated on hundreds of site years of agronomic and environmental research. While acknowledging that no generalized recommendations are relevant all of the time, the BMPs represent a combination of practices that will reduce risk of excessive nitrogen loss in a normal year.

The 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.

RISK

Minnesota's nitrogen BMPs are predicated on the concept of managing and reducing risk. A farmer's decisions regarding nitrogen fertilizer management integrate many factors. Because of the numerous trade-offs in optimizing all of the farm level factors, nitrogen fertilizer management is often an extension of overall farm risk management. The nitrogen BMP recommendations focus on managing the "agronomic risk," but there other types of risk that farmers also consider when making nitrogen fertilizer management decisions including economic, psychological, environmental, societal, and logistical risks (Beegle et al. 2008). Below are examples of how these risks might be considered in making nitrogen management decisions within each category.

Agronomic: "Am I applying the correct amount of supplemental nitrogen, at an appropriate time, in an appropriate form and by appropriate methods?"

Economic: "What is the economic optimum nitrogen rate for my fields?"

Psychological: "How good of a job do I need to do with nitrogen application?"

Environmental: "Do my nitrogen management practices minimize the potential for negative impacts on water quality?"

Societal: "Do my neighbors value the role I play in protecting water quality which impacts human, animal and environmental health?"

Logistical: "Do I, either myself or through the service providers who apply fertilizer for me, have enough time and the appropriate equipment to meet my nitrogen fertilizer application needs?"

Considering only one category of risk can be misleading. The U of M and the farmers can have a much better conversation when they acknowledge these factors jointly, which is why the U of M has revised the nitrogen BMPs to include a range of rates.

BMP DEVELOPMENT

The original nitrogen BMPs that were established for Minnesota in the 1990 NFMP have been adapted to account for most cropping systems within the state of Minnesota. The generalized statewide nitrogen BMPs are listed below:

- Adjust the nitrogen rate according to a realistic yield goal (for all crops except corn and sugar beets) and the previous crop.
- Do not apply nitrogen above recommended rates.
- Plan nitrogen application timing to achieve high efficiency of nitrogen use.
- Develop and use a comprehensive record-keeping system for field specific information.

- If manure is used, adjust the nitrogen rate accordingly and follow proper manure management procedures to optimize the nitrogen credit.
  - Test manure for nutrient content.
  - Calibrate manure application equipment.
  - Apply manure uniformly throughout a field.
  - Injection of manure is preferable, especially on steep sloping soils.
  - Avoid manure application to sloping, frozen soils.
  - Incorporate broadcast applications whenever possible.

Due to major differences in geology, soils and climate across the state, there are also regional recommendations (Figure 20). These regional recommendations give specific instructions on how to utilize the most appropriate nitrogen rate, source, timing, and placement. Regional and specialized nitrogen BMPs can be found in the following documents on the MDA website: http://www.mda.state.mn.us/nitrogenbmps.

- 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

Minnesota nitrogen rate BMPs for corn are based on a grouped economic approach that determines nitrogen rates by applying economics to large sets of nitrogen response data. This is due to the fact that there is a very weak relationship between Economic Optimum Nitrogen Rate (EONR) and corn yield in the North-Central region of the United States. Prior to 2006, nitrogen rates were based on yield goal, but a group of researchers in the North-Central region showed that the relationship between the price of nitrogen fertilizer and the price of corn was actually a better predictor of the EONR than yield goals. The concepts and rationale for this approach to nitrogen recommendation development is further explained by Sawyer et al. 2006. Nitrogen BMPs that pertain to timing, placement and source of nitrogen fertilizer are specific for each region and are supported by empirical agronomic research data from that area of Minnesota.

Figure 20. Minnesota nitrogen BMP regions

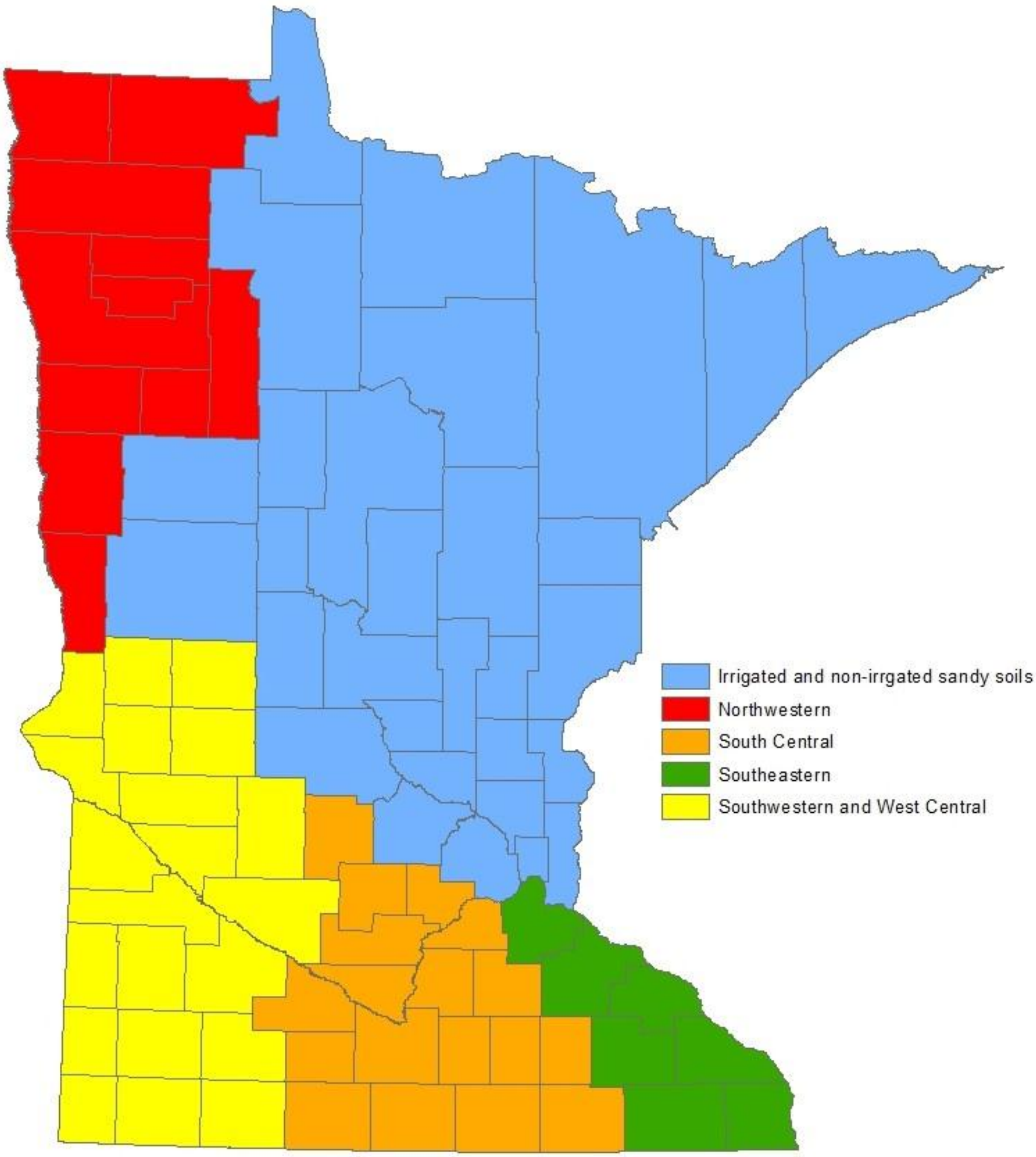


Table 6 summarizes how nitrogen sources and timing interact across state regions. For example, practices that may work well in southwestern Minnesota may not be appropriate for southeastern Minnesota. Nitrogen rate recommendations do not change across regions except for lower productivity soils.

Table 6. Summary of the major nitrogen timing and source recommendations for corn by region

	Minnesota Recommended Application Timing for Corn		
Nitrogen BMP Region	Fall*	Spring Preplant	Split or Sidedress
Southeast	Not Recommended	Highly Recommended: AA or Urea	Highly Recommended: AA, Urea, or UAN
		Acceptable with Risks: Preplant with UAN or ESN	
South-Central	Acceptable with Risks: AA or Urea with N-Serve	Highly Recommended: AA or Urea	Highly Recommended: Split Applications of AA, Urea, or UAN
	Not Recommended: Fall Application of Urea or UAN	Acceptable with Risks: Preplant with UAN or ESN	
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	Recommended: Urea, AA, or UAN	Recommended: Sidedress Prior to V7 Growth Stage
	Acceptable with Risk: Late Fall ESN or use of N-Serve or Agrotain		
	Not Recommended: Fall UAN or Any Fertilizer Containing Nitrate		
Northwest	Recommended: Fall Application of AA or Urea	Recommended: Urea, AA, or UAN	Recommended: Sidedress Prior to V7 Growth Stage
	Acceptable with Risk: Late Fall ESN or Use of N-Serve or Agrotain		
	Not Recommended: Fall UAN or Any Fertilizer Containing Nitrate		

*Only after six inch soil temperatures fall below 50 ºF

Note: AA=Anhydrous Ammonia, ESN=Environmentally Smart Nitrogen, UAN=Urea Ammonium Nitrate Solution

Each BMP region of Minnesota has specific risks, BMPs, acceptable practices, and practices that are not recommended. In addition to the practices listed above, a short summary of each region is listed below.

BMP REGION: SOUTHEAST

Physical Features and Cropping Systems: Characterized by permeable, silt loam soils with underlying fractured limestone bedrock. Highly productive soils with greater than 32 inches of average annual rainfall. Major crops include corn, soybeans, forages and oats.

Groundwater Concerns and Localized Problematic Areas: This region is very susceptible to groundwater contamination, particularly in close proximity to sink holes. Elevated nitrate levels are common in this region as discussed in Chapter 3. Current community water suppliers with elevated nitrate are: Hastings; Lewiston; Plainview; Utica; and several wells within the Rochester wellhead protection area. Hastings installed a nitrate removal system and plans to install a second system in the near future.

Recommended BMPs: Include accounting for nitrogen in ammoniated phosphorus products, spring preplant (PP) or split applications (PP+ sidedress) of nitrogen, utilizing appropriate legume and manure credits, minimizing direct surface water movement to sinkholes, incorporating nitrogen fertilizer and using a nitrification inhibitor on early applied sidedress (SD) nitrogen.

Practices that are acceptable with a higher degree of risk include PP applications of UAN (urea and ammonium nitrate) and ESN (Environmentally Smart Nitrogen, a slow release, urea nitrogen fertilizer).

Practices that are not recommended include any fall application of any form of nitrogen fertilizer, applying ammoniated phosphorus fertilizers to frozen ground (due to risk of runoff), and sidedressing all of the nitrogen fertilizer in continuous corn production (risk of stunting early season crop growth).

BMP REGION: SOUTH-CENTRAL MN

Physical Features and Cropping Systems: Characterized by fine-textured soils formed in glacial till and sediments. Most south-central soils have naturally poor-to-moderate internal drainage and have subsurface drainage systems to improve drainage. Average annual precipitation in the region is 27 to 35 inches. Crops are predominantly corn and soybeans.

Groundwater Concerns and Localized Problematic Areas: Due to the fine-textured till soils commonly found in this region, groundwater resources are generally well protected. However, there are some exceptions where coarse-textured soils are found on a localized level. The City of St. Peter, for example, has been dealing with elevated nitrate for the past 20 years and recently installed a nitrate removal system.

Recommended BMPs: Include accounting for the nitrogen in ammoniated phosphorus products, spring PP applications of nitrogen, utilizing appropriate legume and manure credits, incorporating nitrogen fertilizer and using split applications of nitrogen on sandy soils.

Practices that are acceptable with a higher degree of risk include fall applications of anhydrous ammonia (AA) with a nitrification inhibitor, spring preplant applications of UAN, and late fall or early preplant applications of ESN.

Practices that are not recommended include fall application of urea or AA fertilizer without a nitrification inhibitor, applying ammoniated phosphorus fertilizers to frozen ground (due to risk of runoff), sidedressing all of the nitrogen fertilizer in continuous corn production (risk of stunting early season crop growth), fall application of UAN, and fall applications of nitrogen to sandy soils.

BMP REGION: SOUTHWESTERN AND WEST-CENTRAL MINNESOTA

Physical Features and Cropping Systems: This region of the state is characterized by soils that have a medium to fine texture which were formed from loess, glacial till, or lacustrine deposits. The large majority of the soils have moderate to poor internal drainage, and tile has been installed to improve production.

This region also has a vast difference in the soils from north to south with heavier soils located in the southern portion of the region and often irrigated sandier soils located in the northern portion of the region. Average annual precipitation in the region is often below 30 inches, and as low as 25 inches in some areas. Corn, soybean, wheat and sugar beet are dominant crops in the region.

Groundwater Concerns and Localized Problematic Areas: Due to the medium to fine textured soils found in this region coupled with lower annual precipitation, groundwater resources are generally adequately protected. However, water availability can be a problem in southwest Minnesota. Rural water systems, such as Lincoln-Pipestone, Rock and Red Rock, are essential in providing adequate supplies to rural Minnesota. Water from these important alluvial channels is commonly impacted by nitrate. The Holland well field (part of the Lincoln-Pipestone Rural Water System), along with a number of small communities (Edgerton, Adrian, Ellsworth, etc.) have found it necessary to install nitrate removal systems.

Recommended BMPs for Corn: Include accounting for nitrogen in ammoniated phosphorus products, utilizing appropriate legume and manure credits, utilize a deep nitrate soil test in the fall as a nitrogen credit, incorporating nitrogen fertilizer, and split apply nitrogen on sandy soils.

Recommended BMPs for Sugar beet: Include using a 4 foot deep soil nitrate test to credit nitrogen applications, a total nitrogen rate (including credits) of 110 to 130 pounds per acre, and applying ammonium nitrogen fertilizers in the fall after soil temperatures have dropped below 50° F.

Practices that are acceptable with a higher degree of risk include late fall and PP applications of ESN and the use of urease and nitrification inhibitors with fall applied nitrogen (research has not shown a high degree of efficacy for these products at this time.

Practices that are not recommended for corn or sugar beets include any fall application of fertilizers containing nitrate, applying ammoniated phosphorus or any nitrogen fertilizers to frozen ground (due to risk of runoff), and not incorporating fall applied urea (fall applied urea is subject to very high nitrogen loss to volatilization if unincorporated on high pH soils).

BMP REGION: NORTHWESTERN MINNESOTA

Physical Features and Cropping Systems: This region of the state is characterized by soils that have a medium to fine texture which were formed from loess, glacial till, or lacustrine deposits. The large majority of the soils have moderate to poor internal drainage and tile has been installed to improve production.

Because of the flatness of the region, water often has to be pumped from the field and flooding is also common in areas within this region. This region also has a shorter growing season than other regions. Average annual precipitation in the region is often below 25 inches in many areas. Wheat is the dominant crop although corn, soybean and potatoes are also grown. Corn and sugar beets grown in Northwest Minnesota should use the nitrogen BMPs for Southwest and West-Central Minnesota.

Groundwater Concerns and Localized Problematic Areas: Due to the medium to fine textured soils found in this region coupled with lower annual precipitation, groundwater resources are generally adequately protected. There are very limited documented areas of nitrate contaminated hotspots in this region. Areas of concerns would the coarse-textured soils found along the beach ridges of the Red River Valley.

Contaminated wells due to surface water intrusions from spring flooding are a significant problem.

Recommended BMPs for small grain production: Include an initial nitrogen rate based on expected yield, adjust nitrogen rate according to fall 2 foot deep soil nitrate test results and legume credits, accounting for nitrogen in ammoniated phosphorus fertilizers, incorporating or banding any fall applied urea, apply AA or urea after soil temperatures are below 50° F, incorporating nitrogen fertilizer, and taking credit for nitrogen contained in previous sugar beet crop tops.

Practices that are acceptable with a higher degree of risk are applying up to 40 pounds of liquid nitrogen to foliage at boot stage or later and banding urea with or near the seed at planting.

Practices that are not recommended include fall applications of any nitrogen fertilizers containing nitrate, not incorporating spring or fall applied urea (high soil pH exacerbates urea nitrogen loss to volatilization), shallow applications of AA, foliar applications of greater than 40 pounds of nitrogen at boot stage or later, applying ammoniated phosphorus or any nitrogen fertilizers to frozen ground (due to risk of runoff), and fall applications of nitrogen (regardless of source) to sandy soils.

BMP REGION: COARSE-TEXTURED SOILS IN MINNESOTA

Physical Features and Cropping Systems: Sandy soils dominate the landscape in the central and east-central regions of the state. These coarse-textured soils are also scattered throughout the remainder of the state. Groundwater is often located 30 feet or less below many of these sandy soils. Average annual precipitation in the region is often below 25 inches in western area while in the eastern areas 30 inches or more is common. Corn, soybean, edible beans, wheat, potatoes and some vegetables are grown in the region. Irrigation is common on the sandy soils in this region. The nitrogen BMPs for the coarse-textured soils in Minnesota are aimed specifically at irrigated and dry land corn and edible beans. Nitrogen rate recommendations take into account the productivity of the soil, which in most cases is a function of irrigation and soil water holding capacity. Non-irrigated crops, grown on coarse-textured soils, tend to be classified as medium productivity, and will have a lower nitrogen rate recommendation than a soil that is classified as highly productive. It should be noted that the irrigated nitrogen recommendations are currently being revised, and this revision will be complete in 2015.

Groundwater Concerns and Localized Problematic Areas: Nitrate contamination can be a significant localized problem (Chapter 3) due to the coarse-textured soils, shallow distance to groundwater, and most of the state's irrigation development can be found in the Central Sands and the Dakota/Goodhue/Washington County area. Additionally, crop failure and water stress under dry land conditions can have significant ramifications on nitrate leaching losses.

Many public water suppliers dealing with nitrate issues are found under coarse-textured soil conditions. Examples are the cities of Perham, Park Rapids, Verndale, Hastings, and Cold Spring.

Recommended BMPs: Include accounting for nitrogen in ammoniated phosphorus products, split applications of nitrogen for corn and edible beans, utilizing appropriate legume and manure credits, incorporating nitrogen fertilizer, and using a nitrification inhibitor on early applied SD nitrogen.

Practices that are acceptable with a higher degree of risk include using just a single SD application of AA, spring PP application of ESN and use of nitrification inhibitors with spring PP applications.

Practices that are not recommended include any fall application of nitrogen fertilizer, not accounting for legume credits, fertigation of nitrogen after corn has tasseled, and application of ESN after planting edible beans (nitrogen will not be available soon enough due to the slow release).

To learn about Regional Issues and Opportunities for Advancements in Nitrogen Management see Appendix H.

BMP PROMOTION

As part of its statutory mandate to demonstrate and promote the effectiveness of the BMPs, the MDA has also instrumented several edge-of-field monitoring and demonstration sites to monitor or evaluate nitrogen loss through tile drainage, monitoring wells, and root zone monitoring. The sites known as Red Top Farm, Clay County Drainage site, and Highway 90 are tile drained and the MDA staff have instrumented these sites to collect water quality data on the effectiveness of the BMPs in reducing nitrate loss through tile drainage. The Red Top and Highway 90 sites have been retired due to changes in land management, but a wealth of information has been garnered about nitrogen and its fate in Minnesota crop production.

In the coarse-textured irrigated sands of Minnesota, suction cup lysimeters have been utilized at the Rosholt Farm 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 the rate BMPs for irrigated coarse-textured soils. The MDA staff have also instrumenting similar demonstration sites in the coarse-textured soils of Dakota, Lyon, Otter Tail, Stearns, and Wadena Counties.

On-farm nitrogen rate demonstration sites like the MDA's Nutrient Management Initiative (NMI) has also been a tool to allow farmers to compare the nitrogen BMP rate range to higher nitrogen rates in order to increase farmer acceptance of the rates. At the end of the season farmers are provided with an economic analysis based on their actual nitrogen costs and yields. Since 2006, over 190 farmers have participated in the NMI program.

Minnesota Discovery Farms, a farmer led program that is led by the Minnesota Agricultural Water Resource Center and supported by the MDA, is also contributing to the promotion of the BMPs and our understanding of the field scale impact of the nitrogen BMPs and conservation practices. Minnesota Discovery Farms encompass numerous farm enterprises across Minnesota, and will inform our understanding of the baseline effects of these practices.

The Root River Partnership is designed to help southeastern Minnesota farmers and policy-makers better understand the relationship between agricultural practices and water quality. 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 BMPs.

The MDA will continue to dedicate time and resources towards understanding and promoting new and emerging practices that can improve nitrogen use efficiency and advance conservation in agriculture.

TOOLS FOR THE EVALUATION OF BMP ADOPTION

According to Minnesota Statutes, BMP evaluation has two components, the evaluation of BMP adoption, and the evaluation of BMP effectiveness. Each component must be evaluated individually, and their combined effect must be evaluated as well. Evaluation of either component will be a complex process. This section will discuss the tools used for determining the adoption of practices.

The results of BMP implementation may not be discernible, as measured by the level of change in nitrate concentration of ground or surface water, for a long period of time. Furthermore, changes in nitrate concentration observed over the course of a single year may or may not be related to the adoption of the BMPs. In view of these challenges, it is recognized that BMP adoption must be evaluated as well as BMP effectiveness in preventing or reversing the degradation of water quality.

Interviews: The ability for state agencies and Extension to document farmer adoption rates of voluntary BMPs is a critical component of the 1989 Minnesota Groundwater Protection Act. The MDA has developed a diagnostic tool called FArm Nutrient Management Assessment Process (FANMAP) to get a clear understanding of existing farm practices regarding agricultural inputs such as fertilizers, manures and pesticides. Although it is labor intensive, it provides a useful and accurate method of compiling data on BMP adoption.

Results have been used to design focused water quality educational programs. Data collected in the program's infancy can be used as a baseline to assist in determining if the 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. The complete compendium of FANMAP surveys is available on the MDA website: http://www.mda.state.mn.us/protecting/soilprotection/fanmap.aspx.

Phone Surveys: The MDA has partnered with the USDA National Agricultural Statistics Service (NASS) and U of M researchers to collect information about fertilizer use and farm management on regional or statewide scales. Partners have pioneered a survey tool for characterizing fertilizer use and associated management. 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 farmer. The first attempt using this technique was in 2010. NASS enumerators surveyed approximately 1,500 corn farmers from across the state to gather information about commercial fertilizer use on corn (Bierman et al. 2011). Statewide nitrogen use surveys for grain corn production are now conducted every other year in partnership with NASS. During the alternate year, surveys on other crops and practices are conducted.

Currently reports can be found on the MDA website: http://www.mda.state.mn.us/.

BMP EVALUATION: CURRENTLY IMPLEMENTED PRACTICES

This most recent assessment of nitrogen management practices provide metrics for understanding the status of nitrogen BMP adoption on Minnesota corn acres. Table 7 compares the recommended timing and fertilizer sources with the actual timing reported by farmers in that region. In general, many of the timing BMPs are followed but there may be opportunities for Minnesota farmers to improve their nitrogen management by incorporating more split and sidedress applications.

Table 7. Overview of nitrogen recommendations and distributions of nitrogen application timings (Bierman et al. 2011)

	Recommended Timing of the Primary Nitrogen Application Minnesota Recommended Application Timing for Corn			Actual Timing of the Primary Nitrogen Application (Reported as % of Primary Nitrogen Source)		
Nitrogen BMP Region	Fall*	Spring Preplant	Split or Sidedress	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	5%	88%	5%
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	43% with a Very High % as AA, 51% of AA included N-Serve. Minimal Fall Applied Urea (<5%) or UAN	53%	7%
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	5% Note: There are Some Fine Textured Soils with the Counties Designated as Coarse-Textured	70% , Urea is Dominant Source	25%, UAN is the Probable Dominant Source on Irrigated Split Applications
Southwest/ West-Central	Recommended: Fall Application of AA or Urea Acceptable with Risk: Fall ESN or N-Serve with Agrotain Not Recommended: Fall UAN	Recommended: Urea, AA, or UAN	Recommended: Sidedress Prior to V7 Growth Stage	47%	47%	7%
Northwest	Recommended: Fall Application of AA or Urea Acceptable with Risk: Fall ESN or N-Serve with Agrotain Not Recommended: Fall UAN	Recommended: Urea, AA, or UAN	Recommended: Sidedress Prior to V7 Growth Stage	11%	89%, Urea is Dominant Source	0%

*Only after six inch soil temperatures fall below 50 degrees F

Note: AA=Anhydrous Ammonia, ESN=Environmentally Smart Nitrogen, UAN=Urea Ammonium Nitrate Solution

Detailed analysis supporting this table is provided in Appendix H.

Nitrogen rates are also a major concern and component of good nitrogen management, and are probably the first part that comes to mind for most farmers when nitrogen management is discussed. Table 8 presents the range of nitrogen rate recommendations for corn, and the average nitrogen rates for each region. For corn following corn acres, the nitrogen rates fell squarely within an acceptable range. The nitrogen rates that were used for corn following soybeans tended to be toward the higher end of the range, and for South-Central Minnesota, rates were actually outside of the acceptable range. This is partly due to the largest percentage of nitrogen rates in the South Central region being from 140 to 154 pounds per acre. Survey data suggests that there is a need to improve crediting for all nitrogen sources such as corn following soybeans, alfalfa and especially manure. Additional work also needs to be done to provide appropriate recognition and guidance for variable rate applications of fertilizer.

Table 8. Minnesota nitrogen BMPs and mean nitrogen rates (Bierman et al. 2011)

	Acceptable Range of Nitrogen Rates for Nitrogen Fertilizer on Corn (pounds per acre)		Mean Nitrogen Rate Reported by Minnesota Corn Farmer (pounds per acre)	
Nitrogen BMP Region	Corn Following Corn	Corn Following Soybeans	Corn Following Corn	Corn Following Soybeans
Southeast	100-180	70-140	143	138
South-Central	100-180	70-140	160	145
Irrigated Coarse-Textured Soils	100-180	70-140	146	151
Coarse-Textured Soils	100-180	70-140	128	137
Southwest/West-Central	100-180	70-140	145	138
Northwest	100-180	70-140	NA	126

FUTURE BMPS AND REFINEMENT OF EXISTING BMPS

As science and technology rapidly evolve, agriculture has often been on the cutting edge with continual changes in practices. Therefore it is important that the nitrogen BMPs also stay current with evolving agricultural technology and actual changes in practices on the farm. Some current examples of agricultural practices or new technology that need revision or development of formal state BMPs include the following:

- Optical reflectance of crop canopy to evaluate in-season nitrogen stress from active sensors and remote sensing is widely viewed in the academic and industry world as the next frontier in nitrogen management. The current challenge is to demonstrate that these tools can do a better job of quantifying nitrogen stress and addressing variability than our current nitrogen rate BMPs due to spatial and temporal variability. The MDA has currently proposed using Clean Water Fund research dollars to evaluate the efficacy of these tools.

- Research is currently being conducted to update the BMP recommendations for corn grown on irrigated sands, and is expected to be completed in 2015. An outcome of this study will also be emphasizing the role that irrigation water management will play in reducing the impact of nitrogen fertilizer on groundwater in irrigated sands.

- Improving the understanding of variables influencing nitrogen mineralization rates on a field scale is critical as precision agriculture moves forward. The Minnesota Corn Growers Association as well as the Agricultural Fertilizer Research and Education Council (AFREC) have recently invested significant resources in U of M research programs to insure that this research moves forward in a timely fashion.

- It is also acknowledged that in some irrigated, coarse-textured areas of Minnesota, nitrogen BMPs alone may not be enough to reverse the effects of groundwater contaminated by nitrate. Resources may be allocated to evaluate the feasibility of transitioning to alternative cropping systems that have lower nitrogen inputs, greater water use efficiency, and or the ability to assimilate nitrogen more efficiently.

TECHNICAL ADVISORY COMMITTEE FOR BMP DEVELOPMENT

One of outcomes of the NFMP revision will be the development of a technical advisory team that will serve several functions. The first role will be in assisting local advisory groups in establishing prioritized BMPs, based on the best available science and reasonable considerations for local conditions and cropping systems, for nitrate impacted areas. Prioritization of site specific BMPs will play an important role in making sure that targeted and impacted groundwater areas respond positively, both environmentally and agronomically. This committee will also assist the MDA in prioritizing the development and revision of the nitrogen BMPs.

Chapter 7 : Nitrogen Fertilizer Management Plan Process Overview

The purpose of the NFMP is to prevent, evaluate and mitigate nonpoint source pollution from nitrogen fertilizer in groundwater. The NFMP includes components promoting prevention and developing appropriate responses to the detection of nitrogen fertilizer in groundwater. The prevention strategy utilizes officially recognized Minnesota nitrogen fertilizer BMPs, as well as education, outreach, demonstration and training to accomplish the prevention goal. The mitigation strategy, which also includes all of the prevention strategies, necessitates a higher level of effort and intensity. Both the prevention and mitigation strategies are intended to engage local communities in the development and implementation of activities to protect groundwater from nitrate contamination.

The NFMP is designed to allow for evaluation and response to nitrogen contamination on a state, regional, or local basis. The structure of the NFMP must be flexible in order to address the site specific nature of groundwater contamination problems. Additionally the structure must be dynamic, in order to allow for advancements in soil and crop management as well as groundwater monitoring technology.

GENERAL APPROACH OF THE NFMP

The general approach used by the NFMP to address nitrate in groundwater consists of the following activities:

- Identify areas of elevated nitrate in groundwater;
- Promote nitrogen BMPs and low nitrogen cropping systems to protect groundwater statewide but with greater efforts in hydrogeologically vulnerable areas;
- Monitor private drinking water wells (or use existing monitoring data) on a township scale over a 10-year cycle and use the best available data from public wells in wellhead protection areas to identify areas with nitrate concerns;
- Conduct a detailed assessment of groundwater nitrate conditions in these areas to determine the severity and priority of the problem;
- Involve the agricultural community in problem solving at the local level; and,
- Conduct mitigation in high priority areas using a phased approach starting with voluntary actions and progressing to regulatory actions if necessary.

Each of the activities listed above are discussed in detail in subsequent chapters. A brief overview is provided below.

PREVENTION

Prevention activities focus on promoting the nitrogen BMPs to protect groundwater from nitrogen fertilizer leaching . Prevention activities within the NFMP are ongoing regardless of the status of mitigation for nitrate in groundwater. These efforts will be coordinated through a new statewide Nitrogen Fertilizer Education and Promotion Team (NFEPT). Implementation of education, outreach and demonstration activities will be accomplished through existing programs.

MONITORING AND ASSESSMENT OF GROUNDWATER

The goal of monitoring and assessment is to develop a comprehensive understanding of the severity, magnitude, and long term trends of nitrate in groundwater as measured in public and private wells. Assessment of nitrate levels in private and public wells initiates the NFMP process and aids in determining the activity level in an area.

MITIGATION

The mitigation framework is comprised of four implementation levels (Levels 1-4). The mitigation process consists of planning activities, an implementation period, followed by an evaluation of the adoption of nitrogen BMPs and verification of nitrate concentration data to determine next steps.

The NFMP emphasizes engaging key groups who are involved with crop production and the use of nitrogen fertilizers. Target groups include farmers, certified crop advisors, fertilizer retailers, crop advisors/consultants, and professional organizations that provide information on planning and guidance to farmers. These individuals and organizations have specialized knowledge and are in a position to influence BMP adoption. A significant effort will be conducted to coordinate with these professionals to protect groundwater resources in a responsible and effective manner.

Chapter 8 : Prevention

GOAL AND STRATEGY

PREVENTION GOAL

The prevention goal in the NFMP is the groundwater degradation prevention goal of the Groundwater Protection Act (cited in Chapter 1). Prevention is significantly emphasized because once groundwater is contaminated, the remediation process can be extremely slow, difficult, and expensive. Prevention activities within the NFMP are ongoing regardless of the status of mitigation for nitrate in groundwater. It is intended that prevention be accomplished by promoting Nitrogen Fertilizer BMPs, which are defined in the Groundwater Protection Act as practices that consider economic factors, availability, technical feasibility, implementability, effectiveness, and environmental effects.

PREVENTION STRATEGY

The MDA must promote BMPs and provide education about how their use will prevent, minimize, reduce, and eliminate the source of groundwater degradation. The objective of education and promotion in the NFMP is to assist farmers in the adoption of nitrogen fertilizer BMPs to the fullest extent possible for their given operation. For the purposes of the NFMP, education is the process where people become aware of a BMP and then acquire the needed knowledge and skills to successfully use it. Promotion is the process where an individual or a group supports or encourages others to consider a BMP and incorporate it into their cropping system. Promotion can also involve removing barriers to BMP adoption, such as assuring specialized nitrogen fertilizer products are available in an area, or providing financing for equipment purchases.

MDA and partners such as the U of M will provide BMP education and promotion to farmers and to those who provide farmers with crop nutrient management services and support, including crop advisors/consultants and Soil and Water Conservation District (SWCD) staff, and suppliers of fertilizer, farm equipment, and agricultural technology. In addition, education is provided to residents and local government officials and staff in areas susceptible to nitrate groundwater contamination so they are aware of the nitrogen fertilizer BMPs and their role in protecting groundwater quality.

PREVENTION IMPLEMENTATION

Since 1990, the NFMP prevention efforts have included implementing a variety of activities at a statewide, regional and on-farm level (Table 9). Providers of nitrogen BMP education and promotion in Minnesota have varied over time. The once predominate role of U of M Extension has been supplanted by others following Extension's move from a county-based to a regional-based program delivery model in the early 2000's. Extension still plays an important role, especially in developing educational materials and providing statewide and regional training for farmers and agricultural professionals, but now a larger role is played by crop consultants, agribusiness, SWCDs, state agencies, and non-profit organizations. Moreover, the wide availability of accurate yield monitors, global positioning systems (GPS) and remote sensing technology has allowed farmers to conduct their own on-farm demonstrations and to provide peer-to-peer consultation. Internet access has given farmers much more information at their fingertips as well.

Table 9. Examples of nitrogen BMP education and promotion activities implemented since 1990

STATEWIDE	
Type	**Examples**
Publication	U of M Extension's Best Management Practices for Nitrogen Use in Minnesota
Media	MDA and U of M press releases in agricultural newspapers, radio and television
Internet	MDA and U of M nutrient management websites, MDA soil temperature website, U of M and agricultural industry crop production blogs
Conference	U of M Extension Short Course, Minnesota Ag Expo
Exhibit	MDA exhibits at Minnesota Crop Production Retailers Trade Show and Minnesota Ag Expo
REGIONAL	
Type	**Examples**
Communications	Newsletters and e-mail updates from agricultural industry and SWCDs.
Conference	Nutrient Management Efficiency Conferences, U of M Winter Crop Days, Irrigation Management Workshops
Demonstration	MDA's tile drainage demonstration sites, U of M Extension and MDA's nitrogen management on coarse-textured soils demonstrations
ON FARM	
Type	**Examples**
Demonstration	Nutrient Management Initiative demonstrations, adaptive nitrogen demonstrations, manure management demonstrations, Discovery Farm sites, WinField Answer Plots

PREVENTION PRACTICES AND TOOLS

A variety of practices and tools can be utilized in order to achieve the NFMP prevention goal. Each is described in detail below.

BEST MANAGEMENT PRACTICES

According to Minnesota Statutes, the NFMP must include components promoting prevention. The primary tool for achievement of this objective is the adoption of nitrogen BMPs, which are discussed in detail in Chapter 6. The MDA will work with various partners to educate and promote BMPs for nitrogen fertilizer use.

Alternative Management Tools

In areas with highly vulnerable groundwater, the use of nitrogen fertilizer at the recommended rate, timing, source and placement of the nitrogen BMPs may not be enough to decrease the amount of nitrate leaching into groundwater to meet water quality goals. It is difficult to prevent nitrate from leaching to groundwater when growing high nitrogen demanding crops in vulnerable areas, and under unfavorable weather conditions the losses can be quite high. Even without adding fertilizer there are nitrogen losses from the mineralization of organic matter that can be significant. For these reasons, nitrate in groundwater is a very complex and difficult issue to address.

In these cases, the MDA encourages farmers to consider other options such as Alternative Management Tools (AMTs). AMTs go beyond the nitrogen BMPs through the use of other alternatives. The MDA can encourage and support the adoption of AMTs in targeted high risk areas (such as areas with sandy, coarse-textured soil or shallow bedrock). AMTs are defined as locally developed solutions for addressing groundwater nitrate problems that are implemented on a site-specific basis. The MDA will work toward selecting and/or developing tools to determine BMP effectiveness so that the information is available for consideration. If the BMPs can be shown to be inadequate, possible AMTs should be proposed by the local farmers and considered by the Advisory Committee.

AMTs implemented on a site specific basis for groundwater protection can be divided into four categories: utilizing new technologies (including precision agriculture); improving genetic diversity; increasing continuous cover (including diversifying crop rotation, perennial crops,& cover crops); and retiring crop land. Each of these categories will be discussed in further detail below. This summary does not include all the AMTs available, but rather provides examples to capture the range of options. The MDA has found that local stakeholders can suggest unique and effective AMTs, which can be successful in decreasing nitrate pollution in groundwater.

Utilizing New Technologies

Inefficient fertilizer use reduces economic returns for the farmer. Controlled (i.e. slow or delayed) release nitrogen fertilizer products have been available since the early 1970s and were developed to release nutrients gradually into the soil to improve crop use efficiency. When used correctly, this reduces the likelihood of environmental nitrogen loss via volatilization, denitrification, leaching or runoff and can result in greater yields compared to applying conventional nitrogen sources prior to planting (Blaylock et al. 2005). This technology can be beneficial to cropping systems in coarse-textured soils susceptible to leaching. For example, results from a Minnesota based study suggested that the use of polymer-coated urea on potatoes grown in coarse-textured soils improved recovery of applied nitrogen and reduced nitrate leaching (Zvomuya et al. 2003, Wilson et al. 2010).

Precision Agriculture

Precision agriculture is a method of farm management that uses site specific information on soils, crops, nutrients, pests, and/or moisture to adjust practices to reflect in-field variability. It encourages better management of agricultural inputs including fertilizers, herbicides, seed and fuel, and is already practiced in some form by at least one-third of Midwestern farmers (Mulla 2013). The use of precision agriculture has the potential to increase production and nutrient use efficiency, thereby reducing nutrient leaching potential and/or over application (Hedley, 2014). Precision agriculture techniques often incorporate GPS technology to spatially reference the observed field variability. Research has shown that the use of GPS alone can increase nutrient use efficiency by 5 to 10%, and when combined with geographic information system (GIS) prescription maps, the efficiency can increase an additional 10 to 20% (Hedley 2014). Using variable rate fertilizer application technology, a field can be divided into management zones and different fertilizer rates can be applied based on soil nutrient concentrations, crop response, landscape position, soil moisture and soil type.

Variable rate irrigation is a type of precision agriculture technique that combines GPS technology with GIS field maps to increase irrigation efficiencies. This technique not only improves water use and reduces cost, but can also be used to minimize nutrient leaching losses by adjusting the frequency and duration of irrigation based on soil texture and moisture. Research has shown that drainage and runoff can be reduced by as much as 55% during the period of irrigation, decreasing the risk of nitrate leaching (Hedley 2014). This approach could be further expanded to apply nutrients to crops through irrigation water (i.e., fertigation), which also has the potential to provide highly efficient uniform or variable application to meet site-specific crop needs over the field area within the pivot. Although additional research should be pursued to confirm benefits to water quality within Minnesota, preliminary research has shown that soluble nitrogen fertigation of potatoes may reduce nitrate leaching in coarse textured soils; however, this may need to be used in conjunction with a cover crop to minimize fall leaching (Wilson et al. 2010).

Improving Genetic Diversity

Genetically engineered crops provide environmental benefits in addition to the economic benefits (NRC, 2010). Selection of crop varieties engineered with genes that have been shown to use nitrogen more efficiently, or that allow greater nitrogen uptake (e.g., larger root systems, quicker establishment) can reduce the amount of nitrogen susceptible to environmental loss, including leaching. On average, depending on the crop species and cultivar, at least half of the nitrogen fertilizer applied to the soil is lost to the environment (McAllister et al. 2012). Although additional research is needed for the continued development of new solutions to increase yields while maintaining or decreasing nitrogen fertilizer requirements, the agricultural industry can be the biggest contributor to the education and promotion of varieties that have successfully demonstrated lower nitrogen input requirements or loss reductions. By working together with crop advisors, consultants and seed dealers, farmers can evaluate the appropriate seed varieties for improved nitrogen use efficiencies within their soil types and management practices.

Increasing Continuous Cover

Landscapes have become increasingly homogenized over the last decade as fields formerly in small grains, grassland or pasture have been converted to corn and soybean (Wright and Wimberly 2013). Increased conventional row crop acreage and aggressive management can result in bare soils during periods of high runoff and precipitation; resulting in increased nutrient loss and a larger opportunity for nitrate leaching. Identifying methods of adding continuous cover to portions of the landscape can reduce nitrogen inputs and/or increase uptake of soil nitrogen. Increasing continuous cover can be accomplished by diversifying crop rotations, adopting perennial cropping systems and incorporating cover crops.

Diversifying Crop Rotations

A majority of Minnesota farmers typically have a corn-corn or corn-soybean rotation. There are environmental benefits, including the prevention and reduction of nitrate leaching, to having crop rotations that incorporate crops other than corn and soybean. In addition to the environmental benefits, multi-year crop rotations can have net returns per acre as high as or higher than typical two-year rotations (Olmstead and Brummer 2008; Riedell et al. 2009; Coulter et al. 2011; Davis et al. 2012).

Alternative annual crops, such as small grains (e.g., oats, wheat, rye, barley) and oilseed crops (e.g., flax, canola, safflower, sunflower), can be included into crop rotations. These crops require less nitrogen and have greater nitrogen use efficiencies than corn and most other row crops. The incorporation of legume crops, such as alfalfa or clover into rotations, benefits soil health by increasing biomass and fixing atmospheric nitrogen into the soil, resulting in greater income stability once established (Davis et al. 2012). Although benefits may not be observed instantly, diverse cropping systems are valuable tools for improved net returns and soil health.

Perennial Crops

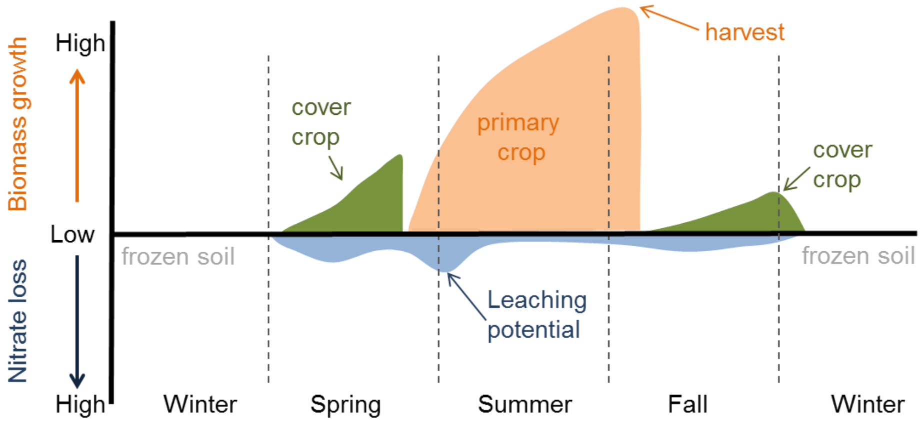
Perennial vegetation has been shown to be effective at scavenging nitrogen from the soil, as well as requiring lower nitrogen inputs. Perennial crops encompass perennial biomass or forage crops, and woody perennials, including shrubs and trees.

Unlike most row crops, perennial biomass or forage crops are not cultivated each year, which is beneficial for soil health and water quality, because it builds organic matter and reduces weed, insect and disease pressure. Long-term perennial forage used for haying or grazing can be economically competitive with corn and soybean production (Olmstead & Brummer 2008). However, in addition to being more labor intensive, it is important to acknowledge that hay production may require different planting and harvesting equipment. Perennial forages combined with grazing provide another option for farmers with livestock. Grazing lands are the principal source of forage for domestic livestock in Minnesota; therefore, managed grazing can be a profitable, productive, and an environmentally beneficial land use. In addition legumes fix nitrogen that will provide nitrogen credits to the next crop.

Cover Crops

When agricultural fields would otherwise be bare prior to crop emergence in spring or after fall harvest, cover crops can be planted to increase landscape diversity and provide seasonal soil cover. Cover crops include annually seeded grasses, small grains, legumes or forbs. Common cover crops conducive to Minnesota’s colder climate include rye and other small grains, buckwheat, hairy vetch, radishes and brassicas. Cover crops improve water and soil quality by adding soil organic matter and reducing the opportunity for nitrogen leaching by increasing biomass production when the primary crop is not yet established or has been harvested (Figure 21; concept adopted from Heggenstaller et al. 2008).

Figure 21. Conceptual diagram representing nitrate loss in response to cover crop use



An obstacle for successful cover crop adoption in Minnesota is the small window of opportunity for establishment following the primary row crop harvest. Because of the short time frame between harvest and killing frost, cover crop adoption by Minnesota farmers using shorter season crop rotations have a greater likelihood of success. These short season crops, including corn silage, small grains, and vegetable crops like peas and sweet corn, are harvested early enough in the growing season to allow sufficient time for successful cover crop establishment in the fall. Successful cover crop stands may also be achieved by over-seeding into a standing corn and soybean field. Currently with existing cover crop technology, only 1/3 of cover crops are successfully established, though current Clean Water Funded research projects and U of M Forever Green Initiative are trying to change this.

Retiring Cropland

In Minnesota's most highly vulnerable groundwater areas, retiring cropland is an option for minimizing the nitrate leaching risk. Working together with local communities, the MDH and the MDA have had success in exchanging vulnerable cropland located within wellhead protection areas with less vulnerable land, allowing the land within the wellhead protection areas to be temporarily or permanently retired.

Retiring targeted portions of cropland into conservation easements may be the most environmental and economically beneficial option. Programs such as the Board of Water and Soil Resources Reinvest in Minnesota (RIM) Reserve Program and the Natural Resources Conservation Service (NRCS) Conservation Reserve Program (CRP) provide the landowner payment(s) to retire the land from production. The MDA will collaborate with other partners to identify specific areas where retiring cropland would be most appropriate. In addition, the Environmental Quality Incentives Program (EQIP) Source Water Protection (SWP) Initiative is a new NRCS funding and technical assistance opportunity (in partnership with the MDH) dedicated to protect and improve the quality of Minnesota's vulnerable drinking water resources used by public water suppliers.

Alternative Management Tool Implementation

The MDA encourages the exploration and use of Alternative Management Tools (AMTs) in highly vulnerable areas in order to protect and/or mitigate groundwater nitrate concerns. There are many options to consider when selecting the appropriate AMT, most importantly economics and site conditions. Farmers and their advisors/consultants will have the best insight on which AMTs might fit their farming operation. The MDA will continue to work toward providing knowledge and developing resources regarding the effectiveness of the AMTs so that proper information is available for consideration.

Research on cropping systems that encourage the use of the nitrogen BMPs and AMTs has been funded by the MDA since 1989 through the Sustainable Agriculture Demonstration Grant Program, Specialty Crops Block Grants, the Agriculture BMP Loan Program, and more recently, the Clean Water Legacy Amendment funded Technical Assistance and Research programs. Recent attention, both locally and nationally, on the environmental benefits gained through the use of cover crops has increased the interest and funding for innovative cover crop projects. The MDA will continue to lead the state effort to explore, research, and promote new technology and improved crop diversity to protect our groundwater resources.

The MDA will identify opportunities to collaborate with other agencies, industry, and non-governmental organizations through existing programs and develop new partnerships. This includes internal MDA collaboration between divisions to determine where perennial cropping systems may support the development of biofuel and other progressive industry development efforts. The MDA will continue to work with other state and federal projects and programs.

Additionally, there is opportunity to explore partnerships with agricultural industry and organizations in order to foster the development and establishment of AMTs. One avenue could be investigating the potential for and development of markets that support implementation of the continuous cover practices discussed above. This could be pursued as a statewide effort or through the local Advisory Team process. Any and all of these avenues may be explored to advance the diversification of our cropping systems and promotion of new technologies.

PREVENTION PROGRAMS AND ACTIVITIES

Although the NFMP focuses on groundwater, the prevention implementation efforts will benefit surface water as well. A recent study evaluated nitrogen sources and loads to surface waters and found that agricultural contributions are a significant factor in many watersheds within Minnesota (MPCA 2013). It is recognized that there may be significant overlap of efforts to protect groundwater and surface water from nitrate and other agricultural non-point source contaminants; therefore prevention activities under the NFMP will be integrated to the greatest extent possible with other state, federal, local or private sector water protection programs.

Nitrogen Fertilizer Education and Promotion Team

As a first step in developing an integrated education and promotion program to prevent water resource degradation, the MDA will establish a Nitrogen Fertilizer Education and Promotion Team (NFEPT). The NFEPT will assist the MDA with the coordination of prevention activities and programs. The NFEPT provides expertise and advice on education and promotion activities the MDA should undertake.

The NFEPT should include the organizations listed in the statute (the MDA, MPCA, BWSR, SWCDs and Extension), as well as, University of Minnesota researchers and private sector agronomists, fertilizer retailers and/or crop consultants and advisors. Other agencies, such as the MDH, the DNR, the Minnesota Rural Water Association and the Natural Resource Conservation Service will be invited to participate as well. Additional interested parties are welcome to attend NFEPT meetings and contribute to discussions and planning activities. NFEPT meetings will be informal and facilitated by the MDA.

The NFEPT will meet at least once annually to review and design targeted educational and promotional prevention activities for water resource protection, including activities associated with the BMPs required as part of Minnesota Statutes, section 103H.151 or as part of the MDA's activities in response to groundwater areas of concern. The MDA and the NEFPT will:

- Look for ways to ensure an appropriate message about nitrogen BMPs and the risk to groundwater is integrated into education and outreach activities;
- Strive to ensure that available resources are used wisely to minimize any potential overlap between programs; and
- Support an adaptive management strategy where the recommended BMPs may change over time based on newly available information on potential sources or practices and tradeoffs between practices where there are multiple water quality concerns.

These efforts will make coordination and communication essential. It is anticipated that frequent, informal communications and interaction will occur between NFEPT members and MDA staff to plan and implement outreach activities.

Prevention programs and activities are delivered on statewide, regional, and local scales. Those activities that are the most effective in educating and promoting nitrogen BMPs and AMTs will vary over time and between locations. The NFEPT, or a regional or local team will identify education and promotion activities considered to be the most effective for a given time and set of conditions. These teams will operate on different scales (statewide, regional or local). In identifying education and promotion activities, these teams will specify the: 1) target audience, 2) educational and/or promotional objective, 3) delivery method, and 4) evaluation method. The NFEPT suggestions for education and promotion activities will be considered subject to available resources to be provided by the MDA as well as other partner contributions. Opportunities for cooperation among state agencies, representative NFEPT organizations, and other interested parties will be explored, as will opportunities for joint grant writing. Programs and activities that MDA is currently involved with are described below.

Local Water Management Planning

Local Water Management Plans (LWMPs), including comprehensive local water plans, county water plans, watershed district management plans, SWCD yearly work plans, watershed management organization plans, etc., are major tools for addressing water resource concerns at the local level. LWMPs will serve as a key vehicle for implementing the NFMP prevention activities. The BWSR has oversight to ensure that LWMPs are prepared and coordinated with existing local, and state efforts and that plans are implemented effectively. The MDA, via input on LWMPs, seeks to provide guidance to support the process, including nitrogen fertilizer management planning.

At the beginning of the LWMP update process, state agencies, including the MDA, are invited to provide input to the local government unit (LGU). The MDA has redeveloped a process to provide comment on LWMPs to LGUs and has identified nitrogen fertilizer management as a priority concern for groundwater in the state. The MDA provides guidance on recommended prevention activities to address this concern, as well as maps of counties depicting vulnerable areas. MDA staff are available to provide technical support for developing the plans. The LGU reviews all agency and public input, and then selects the concern(s) of highest priority to include in their LWMP. The county includes activities for each of the selected concerns and gives an estimated cost and timeline to implement. Once the plan is approved, these activities become eligible for funding. The LGU may then apply for grants and other funding opportunities based on activities in their plan.

Groundwater Protection Programs

Groundwater protection is a shared responsibility between the MDA, MDH and DNR. The MDA's involvement in each of the agency's programs are described below.

Wellhead Protection

The MDH is responsible for administering the State's Wellhead Protection (WHP) program (Minnesota Rules, Part 4720) designed to prevent human caused contaminants from entering wells used by a public water supply. Community and non-community non-transient public water suppliers are required to develop a WHP plan to protect their source of drinking water based on the scientifically delineated recharge area of their well(s) and the vulnerability of the aquifer they use. The vulnerability of the wells and aquifer is based on well construction, geologic information and well water chemistry results. This information is used locally by the public water supplier to help them identify potential concerns, issues and activities that will be effective in protecting the water supply wells and aquifers from potential sources of contamination.

To gather local support, WHP teams are organized by the public water supplier (PWS) to discuss concerns and identify activities and resources needed to help protect the public water supply. WHP plans are updated every 10 years. Depending on the vulnerability of the public water supply and local concerns, WHP Teams can include a combination of local, state and federal government and others needed to develop and implement effective WHP plans. Public water suppliers are required to implement activities identified in the WHP Plan as part of on-going implementation efforts to protect their groundwater.

Through participation on WHP teams, the MDA provides expertise to local technical staff and farmers regarding the promotion and use of the nitrogen BMPs and other practices that can help reduce nitrogen loss to groundwater in WHP areas. Some examples of previous WHP area work includes on-farm test plots to try new technologies and nitrogen rates, development of nutrient management plans, promotion of nitrification inhibitors and time release fertilizers such as Environmentally Smart Nitrogen® (ESN), new crop varieties and alternative cropping systems, etc. These activities are frequently conducted in consultation with the U of M.

The MDA and the MDH will continue to coordinate and prioritize prevention activities to minimize nitrogen impacts in vulnerable WHP areas where agriculture land uses are present. Staff will meet on an on-going basis to regionally prioritize efforts based on local needs and water quality and agriculture land use changes that may warrant accelerated promotion and implementation of the nitrogen BMPs. Further priority will also be given to vulnerable WHP areas where groundwater quantity or quality is limited and there is a considerable population served by the PWS. The NFEPT may be able to provide assistance in the development of outreach materials to local WHP teams and county resource staff in the promotion of the nitrogen BMPs to farmers.

Groundwater Management Areas

The Minnesota legislature created groundwater management areas (GWMAs) as a tool for the DNR to address groundwater quantity issues. The program is currently in a pilot project status. NFMP implementation will be coordinated with the DNR-led GWMA projects where water supply and groundwater quality (nitrate) are concerns.

SURFACE WATER PROTECTION PROGRAMS

The MPCA is the lead state agency for implementing the federal Clean Water Act and state statutes to protect surface water quality in Minnesota. The MDA, in cooperation with the MPCA and other stakeholders, will ensure that nitrogen BMP education and promotion activities under the NFMP are coordinated with and support MPCA-based prevention and impaired waters response efforts. This will be accomplished by developing an integrated strategy to coordinate and prioritize prevention plans and activities for the NFMP and Watershed Restoration and Protection Strategy (WRAPS).

The State of Minnesota has adopted a Watershed Approach to address the water quality in each of the state's 81 major watersheds on a ten-year cycle. In the first four years of the cycle, a WRAPS document is drafted that includes water quality assessments, impairments, pollutant and stressor identification, total maximum daily load allocations, public participation and restoration and protection strategy development. Groundwater information and vulnerable areas will also be integrated into the discussions. A team is formed in each major watershed that includes local partners to provide input on the development of this document. The MDA will share nitrate data and other information available on research and existing practices.

Nitrate Total Maximum Daily Loads (TMDLs)

The MPCA, in cooperation with other agencies and organizations, implements a process for monitoring surface waters to determine if the waters are impaired (do not meet standards). The process establishes the total maximum daily load (TMDL) of a contaminant that a water body can carry without becoming impaired and allocates pollutant loads (commonly referred to as the TMDL process). The process also includes the development of an implementation plan to achieve necessary pollutant reductions.

The MPCA incorporated the Safe Drinking Water Act standard for nitrate-N (10 mg/L) into the State's Water Quality Standards. The nitrate standard is applied to Class 1 waters (groundwater and designated surface waters) in Minnesota. A number of Class 1 surface waters in the state are currently impaired due to high nitrate. The MPCA is currently preparing a draft standard for the protection of aquatic life in cold surface waters (Class 2). For nitrate impairments in surface water, the MDA will support the MPCA's investigation and planning efforts and promote the prevention activities in the NFMP.

There are instances where discharge of nitrate contaminated groundwater can be a significant source in surface water nitrate impairments. This is especially a concern in karst areas in southeastern Minnesota, outwash sand deposits in central Minnesota and in alluvial valleys across the state. In these vulnerable areas, groundwater is the primary source of flow during much of the year for many streams and rivers. In these cases, the MDA will continue to promote the prevention activities in the NFMP and will also support the MPCA in investigating and planning efforts to address nitrate impairments.

If a TMDL plan identifies specific nitrate concentration goals for groundwater in order to meet surface water standards, the MDA will work to the fullest extent possible with the MPCA, local government and other groups to survey current agricultural practices and promote the selected BMPs. The MDA will work with the MPCA to provide information related to the costs, benefits and limitations of the nitrogen BMPs to support modeling and development of TMDL allocations and implementation plans.

Nutrient Reduction Strategy

The Minnesota Nutrient Reduction Strategy (NRS) is the state's plan for addressing nitrogen (and phosphorous) contamination in surface water (MPCA 2014). The Nutrient Reduction Strategy sets Phase I nitrogen targets of a 35% reduction in the Mississippi River basin and a 10% reduction in the Red River Basin by 2025. Working together on implementing the NFMP and the Nutrient Reduction Strategy will help to reach these targets and to decrease nitrogen in groundwater and surface water. The Strategy notes that progress on nutrient efficiency and cover crops, among other areas, is key to decreasing nitrogen in surface water. As the Minnesota Nutrient Reduction Strategy and NFMP are implemented, the MDA and MPCA will collaborate to ensure that mutual goals and strategies are coordinated.

Chapter 9 : Monitoring and Assessment of Groundwater in Sensitive Areas

Nitrate monitoring and assessment of groundwater is targeted to sensitive groundwater areas of the state as identified in Chapter 4. The goal of monitoring and assessment is to develop a comprehensive understanding of the severity and magnitude of nitrate in groundwater drinking water wells (public and private). Nitrate monitoring activities include identifying and selecting wells from a designated area, collecting and testing the water samples, obtaining and summarizing the results and conducting follow up site visits, if necessary, to confirm the results. Nitrate assessment involves establishing and reporting the overall pattern in wells within designated areas. Monitoring and assessment initiates the NFMP process and forms a basis for determining the appropriate level of action (Prevention or Mitigation).

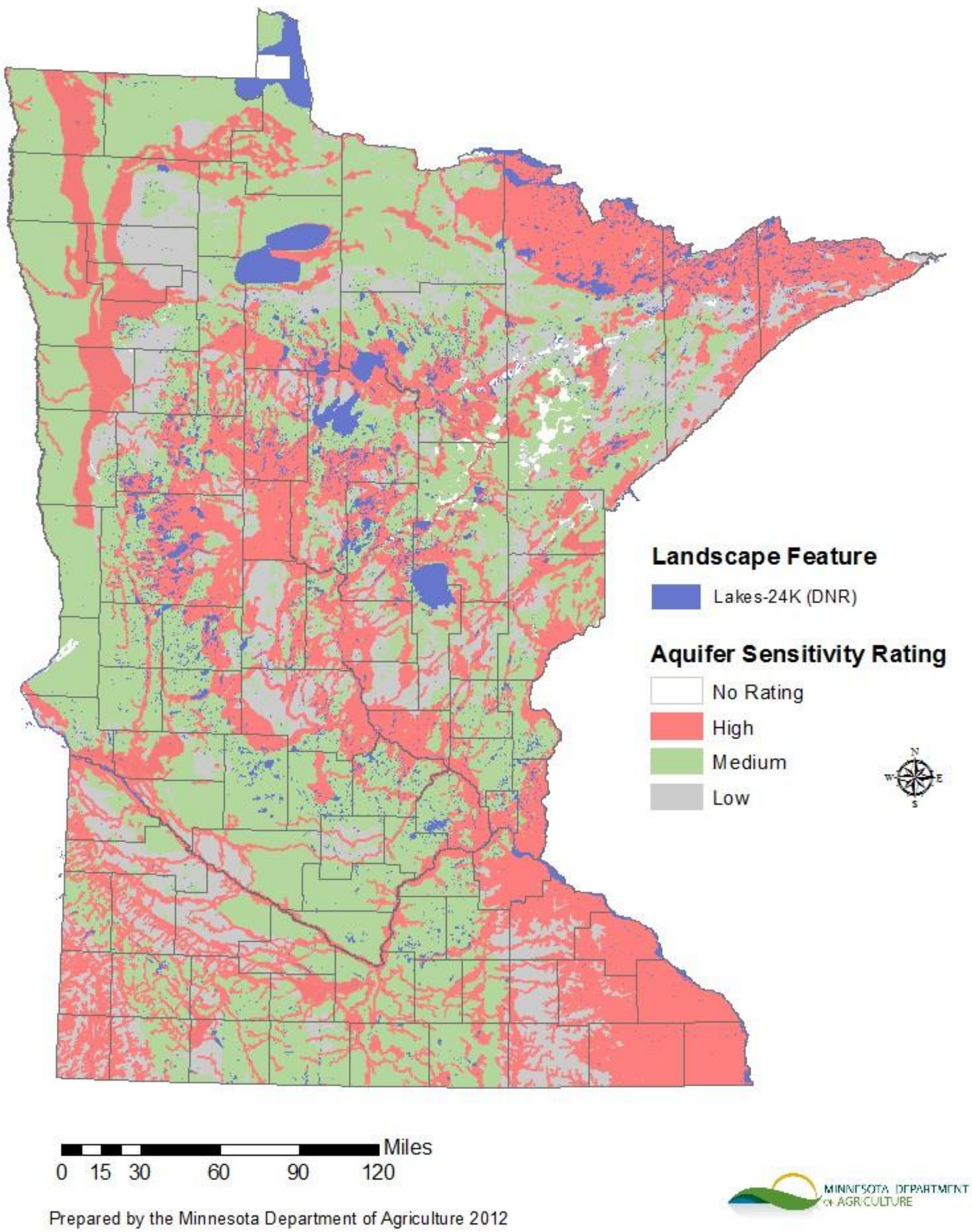
MONITORING STRATEGY

There are separate nitrate monitoring strategies for private and public wells due to the fact that the MDA administers the private well monitoring program and the MDH administers the public well program.

PRIVATE WELL MONITORING

The MDA has established a Township Testing Program to determine current nitrate concentrations in private wells on a township scale. Monitoring will focus on areas of the state where groundwater nitrate contamination is more likely to occur. The MDA will perform the initial search based on all available private drinking water wells in hydrogeologically vulnerable areas, generally using the township as the primary geographic boundary for sampling. The selection of townships will be based on groundwater vulnerability information, the proportion of land in row crops and other data which may indicate an increased or decreased risk of nitrate in water wells. Figure 22 illustrates potential groundwater vulnerable areas. The MDA estimates 250-350 townships may be targeted for nitrate testing. This number may change based on site specific conditions determined after additional investigation. It is anticipated that over 70,000 private wells will be offered nitrate testing as a part of this assessment.

Figure 22. Water table sensitivity



During the township selection process, the MDA will consult with the local government unit(s) (county, Soil and Water Conservation District, water management organization, rural water authority, etc.), consider all relevant information (described in Chapter 3) and review any existing groundwater nitrate data from private and public wells. If nitrate data is already available, recent and meet the well screening requirements, the MDA will consider the information on a case-by-case basis to decide if it can be used for the NFMP process. Based on the review of this information, the MDA may decide that collecting additional groundwater nitrate data is necessary in order to accurately characterize the drinking water quality in an area. If additional water sampling and testing is needed, the MDA will partner with the local government unit to conduct private well testing via the homeowners.

Well owners will be contacted via letter, inviting them to participate in a free analysis for nitrate concentrations in their wells. If the well owner agrees to participate, they will be asked to fill out a survey about their well (construction type, well depth, age, etc.) and mail it in. Each participant will then receive a sample kit with instructions on how to take the sample and where to send it for analysis.

Samples will be analyzed for nitrate concentration using a certified lab if the financial resources are available. Otherwise, UV spectrophotometers will be used and local government staff will be trained to perform the analysis. (MDA has 15 units scattered across the state and encourages local partners to use them) A Quality Assurance Quality Control (QA/QC) protocol will be established and utilized.

Follow up site visits will be conducted for wells with high nitrate-N results (> 5mg/L). Site visits will include resampling and a potential nitrate source inventory to confirm well construction information and to assess whether nitrate in the well is likely from a nitrogen fertilizer and agricultural non-point source (see Appendix I: MDA Private Well Sampling and Site Inventory for details). Wells that may be vulnerable to other nitrogen sources, such as feedlots, should be screened and removed from consideration.

The MDA will notify and consult with other agencies (DNR, MDH, MGS) and local government unit(s) about the project. The MDA will request available technical data related to land use, hydrogeologic sensitivity, groundwater flow, capture zones and travel times, etc. to determine scope and extent of the problem area and potential source areas. Age dating of the aquifer(s) or other similar tests may be conducted if necessary.

PUBLIC WELL MONITORING

The MDH is responsible for monitoring contaminants in public wells within wellhead protection areas (WHPAs), including nitrate, as discussed in Chapters 3, 4, and 8. The MDA will coordinate with the MDH to obtain monitoring data from public water suppliers that are already conducting quarterly nitrate monitoring. Water samples collected from these wells will be evaluated by the MDA and the MDH to determine if they meet the screening criteria (i.e. the monitoring well data is determined to be representative of nitrogen fertilizer use within the WHPA) and are the most representative of the raw water. The samples could include raw water, finished water, or water from other area wells; however raw water is more appropriate for understanding actual nitrate conditions. If the opportunity exists, monitoring of private wells within WHPAs will be considered as well.

STATEWIDE AQUIFER MONITORING NETWORK

The MDA has initiated discussions through the State Interagency Groundwater Team about developing a statewide groundwater monitoring network of permanent, non-private wells which could be used to evaluate water quality for each vulnerable aquifer across the state. The goal of this network will be to provide statistically defensible water quality concentration and trend data which can be used for evaluating nitrate impacts. However, it will be several years before this information would be available.

ASSESSMENT STRATEGY

Following the assembly of nitrate monitoring data, the MDA will conduct an assessment based on data in areas of concern. Nitrate concentration data from private and public wells will be assessed based on separate criteria described below in order to determine whether the area of concern continues in a "Prevention" mode or proceeds into a "Mitigation" mode. The NFMP Mitigation mode is comprised of four implementation levels. Each successive level represents an increase in implementation effort.

The determination of the mode and level is primarily based on nitrate concentrations, trends, and adoption of the BMPs. Consideration will also be given to significant changes in land use, the size of the area, the severity of the problem, and other factors that might be expected to influence nitrate levels. It is important to recognize that there can be significant variability in nitrate concentrations over time and distance as a result of the complexity and unique characteristics of each site. Therefore, decision makers will need to use best professional judgment and may deviate from this guidance if deemed appropriate based on site specific conditions and circumstances.

PRIVATE WELL ASSESSMENT

The assessment of private wells will be based on existing data and/or the results of the MDA well water monitoring efforts. The initial assessment will result in determining the proper mitigation level as shown in the tables below.

Private Well Assessment Criteria:

- The area will be determined to be in Prevention mode if the groundwater nitrate concentrations are unknown or below the Level 1 Mitigation mode criteria.
- Mitigation Level 1 is reached when 5% of the wells have nitrate concentrations greater than the Health Risk Limit (HRL) or 10% of the wells have groundwater nitrate-N concentrations greater than 7 mg/L.
- Mitigation Level 2 is reached when 10% of the wells have nitrate concentrations greater than the HRL and, the BMPs are being adopted or the response effort will be initially promoting BMP adoption.
- Mitigation Level 3 is reached when 10% of the wells have nitrate levels greater than the HRL and BMPs are not being adopted.
- Mitigation Level 4 is reached when 15% of the wells have nitrate levels greater than the HRL and BMPs are not being adopted.

Table 10 depicts the private well Prevention and Mitigation modes and criteria. After the first round of private well monitoring is completed, the results will be evaluated using the criteria listed under Prevention and Mitigation Levels 1 and 2 only. The criteria for Mitigation Levels 3 and 4 will be considered in subsequent monitoring and assessment rounds.

Table 10. Private well criteria used to determine Prevention and Mitigation modes and levels

Groundwater Nitrate Concentration Criteria	Unknown or Below Mitigation Level 1	5% of wells > HRL or 10% of wells > 7 mg/L NO_3-N	10% of wells > HRL	10% of wells > HRL	15% of wells > HRL
BMP Adoption Criteria	Unknown/ NA	Unknown or BMPs Adopted	BMPs Adopted	BMPs Not Adopted	BMPs Not Adopted
Mode	Prevention	Mitigation			
Level	NA	1	2	3	4
Status	Voluntary	Voluntary	Voluntary	Regulatory	Regulatory

NOTE: The Health Risk Limit (HRL) for nitrate-nitrogen in Minnesota is 10 mg/L.

Following the determination decision, the boundaries of the area(s) of concern may need to be reevaluated. The MDA may consider combining townships for the purpose of developing an effective and efficient response.

Following the initial round of monitoring and assessment for private wells, the MDA will attempt to organize subsequent monitoring and assessment rounds in parallel to MPCA's 10 year water quality assessment cycle and revisit the areas that have not developed a long term monitoring or mitigation plan, or updated it the past ten years.

PUBLIC WELL ASSESSMENT

The assessment of public wells in wellhead protection areas will be based on nitrate data that has been collected by the public water supplier. These areas may include only one or very few public wells; therefore, the percentage criteria used for private wells is not applicable. The MDA and the MDH will assess the data using the nitrate criteria described below. The criteria are based on Safe Drinking Water Act standards. Using the available data, the MDA will use best professional judgment in determining the mitigation level, in consultation with the MDH.

Public Well Assessment Criteria:

- The wellhead protection area will be determined to be in Prevention mode if the groundwater nitrate-N concentrations are unknown or below 5.4 mg/L (Level 1 Mitigation mode criteria), which is the value at which additional monitoring is currently required under the Safe Drinking Water Act.
- Mitigation Level 1 is reached when the well(s) are above 5.4 mg/L nitrate-N.
- Mitigation Levels 2 and 3 are reached when the nitrate contamination in the raw water is projected to exceed the drinking water standard of 10 mg/L nitrate-N in 10 years or less. Consideration will also be given to significant changes to land use, the size of the wellhead protection area and other local factors which might be expected to increase or decrease groundwater nitrate levels. Where possible, trend studies will be conducted by doing statistical analysis of time series data. In cases where limited or conflicting data exist, best professional judgment will also be applied.

- If the BMPs are being adopted, the area will be in a Level 2.
- If BMPs are not being adopted the area will be in a Level 3.

- Mitigation Level 4 is reached when the well(s) are above 9 mg/L and the BMPs are not being adopted.

Table 11 depicts the public well Prevention and Mitigation modes and criteria. After the first round of public well monitoring is completed, the results will be evaluated using the criteria listed under Prevention and Mitigation Levels 1 and 2 only. New sites may be assessed at Level 1 or 2. The criteria for Mitigation Levels 3 and 4 will be considered in subsequent monitoring and assessment rounds.

Table 11. Public well criteria used to determine Prevention and Mitigation modes and levels

Groundwater Nitrate Concentration Criteria	Unknown or Below Mitigation Level 1	Wells > 5.4 mg/L NO_3-N	Projected to exceed 10 mg/L NO_3-N in 10 years or less		Wells > 9 mg/L NO_3-N
BMP Adoption Criteria	Unknown/NA	Unknown or BMPs Adopted	BMPs Adopted	BMPs Not Adopted	BMPs Not Adopted
Mode	Prevention	Mitigation			
Level	NA	1	2	3	4
Status	Voluntary	Voluntary	Voluntary	Regulatory	Regulatory

NOTE: The Health Risk Limit (HRL) for nitrate-nitrogen in Minnesota is 10 mg/L.

Chapter 10 : Mitigation

MITIGATION GOAL, STRATEGY AND PRIORITIZING EFFORTS

MITIGATION GOAL

The goal of mitigation is to minimize the source of pollution to the greatest extent practicable and, at a minimum, reduce nitrate contamination to below the Health Risk Limit (HRL) so that groundwater is safe for human consumption.

MITIGATION STRATEGY

The mitigation strategy is based on the prevention strategy, but implemented over a defined area and at a higher level of effort and intensity. Mitigation will be accomplished by:

- Intensifying and targeting education and outreach (preventative) efforts via a multi-level approach;
- Using/refining the existing nitrogen BMPs, developing and implementing Alternative Management Tools (AMTs) in areas where conventional BMPs may not provide enough protection;
- When appropriate, exercising regulatory authority provided in the Groundwater Protection Act.

This strategy will be implemented considering regional and local conditions. Geology, crop type, groundwater vulnerability and the type of wells (public or private) vary throughout the state. Both BMPs and AMTs can be used at each and every mitigation level.

The mitigation process is designed with two goals in mind. First, to ensure that the appropriate nitrogen fertilizer BMPs are adopted, using either a voluntary, or, if necessary, a regulatory approach. Second, to actively involve local farmers and the local community in problem solving to develop effective solutions to local nitrate problems. Figure 23 provides an illustration of how the combination of nitrate levels and BMP adoption results in identification of the appropriate mitigation level.

The mitigation criteria is different for private wells versus public water supplies. Specific criteria are shown in in Figure 24 and Figure 25 as well as Table 12 and Table 13 (repeated from Chapter 9). Additional narrative is provided in Chapter 9.

Figure 23. Mitigation levels based on nitrate levels and BMP adoption

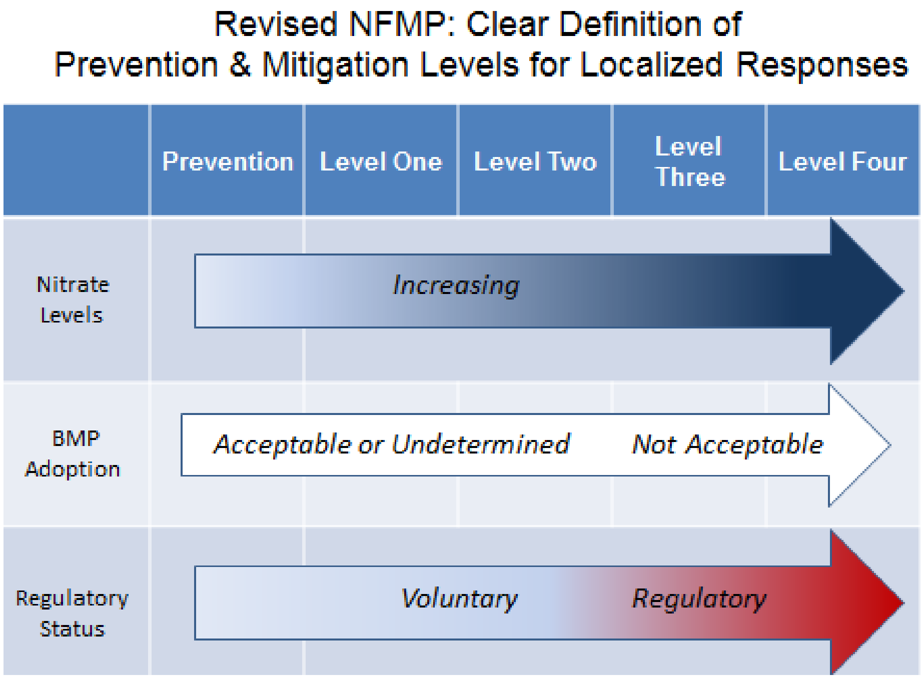


Figure 24. Mitigation process for private wells

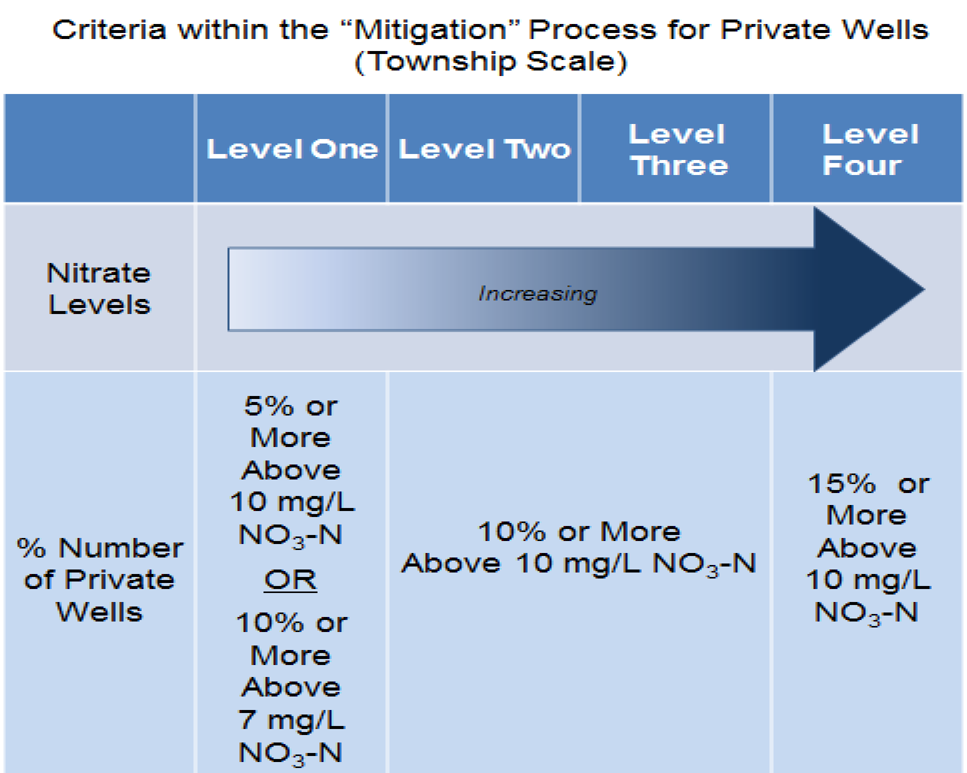


Figure 25. Mitigation process for public water supplies

Criteria within the "Mitigation" Process for Public Water Supplies

	Level One	Level Two	Level Three	Level Four
Nitrate Levels	*Increasing* →			
Nitrate Conc. mg/L	5.4 mg/L NO_3-N	Nitrate Levels Expected to Exceed 10 mg/L NO_3-N in 10 Years or Less		9.0 mg/L NO_3-N

Table 12. Private well criteria used to determine Prevention and Mitigation modes and levels

Groundwater Nitrate Concentration Criteria	Unknown or Below Mitigation Level 1	5% wells > HRL OR 10% wells > 7 mg/L NO_3-N	10% wells > HRL	10% wells > HRL	15% wells > HRL
BMP Adoption Criteria	Unknown/ NA	Unknown or BMPs Adopted	BMPs Adopted	BMPs Not Adopted	BMPs Not Adopted
Mode	Prevention	Mitigation			
Level	NA	1	2	3	4
Status	Voluntary	Voluntary	Voluntary	Regulatory	Regulatory

NOTE: The Health Risk Limit (HRL) for nitrate-nitrogen in Minnesota is 10 mg/L.

Table 13. Public well criteria used to determine Prevention and Mitigation modes and levels

Groundwater Nitrate Concentration Criteria	Unknown or Below Mitigation Level 1	Wells > 5.4 mg/L NO_3-N	Projected to exceed 10 mg/L NO_3-N in 10 years or less		Wells > 9 mg/L NO_3-N
BMP Adoption Criteria	Unknown/NA	Unknown or BMPs Adopted	BMPs Adopted	BMPs Not Adopted	BMPs Not Adopted
Mode	Prevention	Mitigation			
Level	NA	1	2	3	4
Status	Voluntary	Voluntary	Voluntary	Regulatory	Regulatory

NOTE: The Health Risk Limit (HRL) for nitrate-nitrogen in Minnesota is 10 mg/L.

PRIORITIZING MITIGATION EFFORTS

Mitigation activities require significant staff resources to implement and the MDA and partners may need to prioritize its work load in consideration of the following:

- Private wells in areas with the highest nitrate concentrations, and with the greatest numbers of wells exceeding the HRL;
- Public wells (in wellhead protection areas) with the highest concentrations of nitrate relative to the HRL, and the trend analysis before exceeding the HRL;
- Size of population potentially affected;
- Significant changes to land use, the size of the area and other factors, which might be expected to increase or decrease nitrate levels; and
- Local government units and agricultural communities with demonstrated willingness and capacity to participate and provide support, as well as the probability that successful implementation of mitigation activities will cause the groundwater nitrate concentrations to decrease in a reasonable amount of time.

The MDA will consider input from other agencies in developing priorities.

MITIGATION IMPLEMENTATION

Based on past experience implementing the NFMP over the last twenty years (see Chapter 1, Appendix A and B), the MDA has developed a process for responding to local areas with elevated nitrate. The mitigation process is the same for addressing nitrate in both private and public wells. All sites will start in a voluntary level (Level 1 or 2), determined using the mitigation criteria discussed in Chapter 9, and will only move to a regulatory level (Level 3 or 4) if the BMPs are not being adopted.

MITIGATION PROCESS OVERVIEW

The mitigation process generally consists of the following activities listed in a typical chronological order of implementation; however each site is unique and actual activities may vary depending upon specific considerations for each site. This is intended for general guidance rather than instructional. This process begins once a nitrate problem has been identified and a potential problem confirmed;

1. Form local Advisory Team (Advisory Team);
2. Select a project lead and develop a work plan;
3. Establish a local nitrate monitoring network capable of producing long-term trends;
4. Hold a public information meeting(s) for farmers and other interested parties;
5. Select the right set of nitrogen BMPs to implement in the area using U of M guidance;
6. Conduct an initial survey of BMP adoption;
7. Consider Alternative Management Tools (AMTs) in high risk areas;

8. Assess the need for demonstration projects based on results from BMP adoption survey;
9. Develop a plan for educational activities based on results from BMP adoption survey;
10. Assist with obtaining funding for implementing the selected BMPs and AMTs;
11. Work with farmers to implement selected BMPs;
12. Conduct a follow up survey of BMP adoption after three growing seasons of implementation;
13. Evaluate BMP adoption; and
14. Determine appropriate mitigation level using nitrate concentration and BMP adoption criteria.

MITIGATION PROCESS IN DETAIL

The following provides details of each of the above steps for the localized areas where groundwater is impacted by nitrate have been identified.

1. Form local Advisory Team (Advisory Team).

   The role of the Advisory Team is to advise the MDA regarding appropriate response activities for the area and to support implementation of these activities. The team(s) will help develop and implement locally viable solutions to address elevated nitrate.

   The Advisory Team will consist of people who are from the area, including farmers, representatives of local groups/organizations, public water supply systems (in wellhead protection areas), and government staff and/or professionals who can provide technical or financial support. The majority of members will be local farmers and their crop advisors/consultants. The size and composition of the team will vary depending upon the size of the area, the nature of the problem and availability of local stakeholders; however it will likely be no more than 15 -20 people. The MDA will develop guidance that outlines the roles and responsibilities of the Advisory Team.

   Local farmers and their crop advisors/consultants are critical in helping develop and implement appropriate activities to address elevated nitrate in their groundwater because they control the land use. The mitigation strategy is constructed specifically to involve the local agricultural community in problem solving with the opportunity to avoid regulations if voluntary actions are taken.

   Advisory Team decisions will not be determined by majority vote, but rather the team will seek consensus and common ground. The team will advise the MDA in an open process. All members' comments and recommendations will be considered. The MDA will be responsible for final determinations of potential regulatory actions and will seek to provide consistency in decision making for similar situations/areas.

   It is highly recommended that one member of the Advisory Team be selected to be the point person for the project. This person would be the liaison between the agricultural community and the technical/government staff and should be present for on-farm communications with farmers. It is vital that they be agriculturally literate and possess excellent communication skills.

The MDA will form the team(s) in level 2 or above in consultation with local leaders. The MDA will support the formation of Advisory Teams in level 1. A formal determination of level will be placed on the MDA's website as data become available.

2. Select a project lead and develop a work plan.

   There are two options for project leadership in mitigation. One option is for the MDA to administer and lead the process. The other option is for a local entity to lead the process with the MDA as the project administrator. A local entity could be a county, Soil and Water Conservation District, watershed management organization, or township in a private well contamination situation or a municipality (city) in a public well contamination situation. These governing bodies have proven to be the most effective and efficient way to accomplish the prevention and mitigation goals of the NFMP. The leadership role determination will be based on several factors including the capacity and resources at the local level and willingness to participate.

   The MDA, in cooperation with the local government unit and the Advisory Team, will develop a work plan to define and guide expectations, tasks, responsibilities, timelines, funding needs, etc. for the project. Work plan templates will be provided to local government units.

3. Establish a local nitrate monitoring network capable of producing long-term trends.

   A long term local nitrate monitoring network will be established based on the set of private wells (or possibly public wells in wellhead protection areas) sampled during the Monitoring and Assessment Process (Chapter 9) using the same sampling procedures and analytical protocol. This network will be used to collect routine nitrate samples from private wells. The Advisory Team will propose monitoring network recommendations to the MDA. Monitoring data from this network will be maintained by the MDA and made available through reports, data requests and on the MDA website.

4. Hold a public information meeting for farmers and other interested parties.

   It is important to create awareness about nitrate issues; therefore hosting a public meeting is a critical early step. Based on the Advisory Team findings, the meeting will provide as many facts as are known about the current situation. An expected outcome for the meeting will be a dialogue regarding appropriate BMPs for the area, barriers to adopting those BMPs and possible solutions. There may be significant economic or operational barriers to adopting the BMPs. Adopting new BMPs might require a substantial change in practices with significant costs or risks for implementation. These barriers may vary significantly between regions and individual farming operations.

5. Select the right set of nitrogen BMPs to implement in the area using U of M guidance.

   The Advisory Team will provide input to the MDA on the BMPs that are appropriate for the area. The BMPs will be selected by reviewing the appropriate U of M nitrogen BMP recommendations, information from the public meeting(s), and local soils and cropping systems data. This set of BMPs will be the basis for measuring BMP adoption.

6. Conduct an initial survey of BMP adoption.

   An initial survey of the selected BMPs will be completed by the MDA to determine adoption rates for nitrogen fertilizer rate, timing, source and placement. These practices are interrelated and each should be evaluated in the context of the other three. Other practices may be considered in the survey. It will also be important to assess barriers to adopting the BMPs.

There are a number of survey options, ranging from resource intense in-person interviews to less resource intense mail surveys. The type of survey used will be subject to available resources and priority.   The survey type and intensity may be different based on the mitigation level with a level 1 survey being the least intense. One possible survey format could be a simplified version of the MDA's FArm Nutrient Management Assessment Program (FANMAP), which is a method for conducting in-person field-by-field surveys of fertilizer management practices. The MDA has also developed other regional survey techniques and is investigating remote sensing and field scale assessment methods for evaluating appropriate nitrogen fertilizer use practices.

Farmer participation in surveys is important to ensure complete and accurate data. In situations where farmer participation is limited, the Advisory Team should evaluate whether the available information supports a conclusion that the BMPs are being adopted. There should be sufficient survey or other technical data to support this conclusion.

Information collected by the MDA in relation to the practices on a specific farm is confidential and protected by Minnesota Statutes (section 13.643, subdivision 7). The information will be aggregated by the MDA and reported publically unless it would reveal the practices on an individual farm. Whether reported or not, the information can be used to support site specific decisions. This initial survey of practices will be reviewed by local farmers and the Advisory Team for accuracy.

7. Consider Alternative Management Tools (AMTs) in high risk areas.

The critical challenge for addressing nitrate in groundwater from agricultural fertilizer is that even the most responsible management practices result in some nitrogen loss. It is difficult to prevent nitrate from leaching to groundwater when growing high nitrogen demanding crops in vulnerable areas, and under unfavorable weather conditions the losses can be quite high. Even without adding fertilizer there are nitrogen losses from the mineralization of organic matter that can be significant. For these reasons, nitrate in groundwater is a very complex and difficult issue to address.

Various sources strongly suggest that the full adoption of the current nitrogen BMPs (rate, timing, source and placement of fertilizer) will reduce nitrate leaching losses by 15 to 25% (under normal climatic conditions). It is important to note that farmers have already integrated many of these practices into their operations over the past twenty years. Under Minnesota soils and field conditions, nitrate concentrations can exceed the 10 mg/L drinking water standard under row crop agricultural fields even when no commercial nitrogen fertilizer is applied. Nitrate losses of 8 to 20 pounds per acre per year are typical under non-fertilized corn-soybean rotations. Nitrate losses under alfalfa or conservation land (Conservation Reserve Program) are typically 1 pound per acre which is a 95% or greater reduction in nitrate leaching (Sawyer and Randall 2008; Randall and Sawyer 2008; MPCA 2013; Upper Mississippi Sub-basin Hypoxia Nutrient Committee 2008).

The MDA does not have the authority, nor do we believe it is appropriate, to require farmers to grow certain crops. But the MDA can encourage and support the adoption of AMTs in targeted high risk areas (such as areas with sandy, coarse-textured soil or shallow bedrock). AMTs (discussed in detail in the Chapter 8) are defined as locally developed solutions for addressing groundwater nitrate problems that are implemented on a site-specific basis.

The MDA will work toward selecting and/or developing tools to determine BMPs effectiveness so that the information is available for consideration. If the BMPs can be shown to be inadequate, possible AMTs should be proposed by the local farmers and considered by the Advisory Committee.

Mitigation level activities must include the use of BMPs, but AMTs are not required. However, the distinction is made between BMPs and AMTs since BMPs are the general basis for potential regulations under the Groundwater Protection Act, while AMTs are not. Therefore BMPs and AMTs are given separate standing, even though both may be important contributors in addressing groundwater degradation.

8. Assess the need for demonstration projects based on results from BMP adoption survey.

   The MDA, in cooperation with the Advisory Team will consider the need for demonstration projects. On-farm nitrogen rate demonstration projects like the MDA's Nutrient Management Initiative establish nitrogen rate strips that maintain a minimum of 30 pound nitrogen rate difference and also require a short check strip where little or no nitrogen is applied. At the end of the season farmers are provided with an economic analysis based on their actual nitrogen costs. AMT demonstration projects should also be considered.

9. Develop a plan for educational activities based on results from BMP adoption survey.

   The Advisory Team will assist the MDA in developing an educational plan to target the selected BMPs and address barriers. The Advisory Team will specify its target audience, educational and/or promotional objectives, as well as the delivery and evaluation methods to be used. The Advisory Team will also help identify and determine who will be responsible for implementing the education program. At the state level, the Nitrogen Fertilizer Education and Promotion Team (NFEPT) may address targeted educational opportunities that can be tailored to local areas by the Advisory Teams. The education plan can include activities listed in the Prevention Chapter.

   The MDA will provide guidance to the Advisory Team and the local government unit such as technical assistance, factsheets, links to information on the MDA website, and other materials.

10. Assist with obtaining funding to implement the selected BMPs and AMTs.

    The MDA staff and/or qualified representatives will help farmers and the local government unit to obtain funding to implement the selected BMPs and AMTs. Funding such as grants, loans and cost share from local, state and federal sources may be pursued. Detailed information on selected practices, estimated cost to implement, schedule of work, etc. will be prepared.

11. Work with farmers to implement selected BMPs.

    MDA will inform farmers of the selected BMPs prior to the beginning of the growing season, preferably in the summer or fall of the year before implementation. Farmers should be allowed three growing seasons (length of a typical crop rotation) following the selection and promotion of selected BMPs to adopt them. The MDA staff and/or qualified representatives will work with farmers to implement selected BMPs. One-on-one meetings between farmers and technical staff (SWCD, Natural Resources Conservation Service, county, etc.) and/or the project point person will be conducted to discuss mitigation level goals and review their farming operation in the context of the selected BMPs.

12. Conduct a follow up survey of BMP adoption after three growing seasons of implementation.

    After three growing seasons of BMP implementation has occurred, the MDA will conduct a follow up survey of BMP adoption.

13. Evaluate BMP adoption.

One of the most challenging components of the NFMP is evaluating BMP adoption. This is because each farm operation is unique and the selected BMPs may vary depending upon the soils, topography, cropping system, economic risk and individual preferences of farmers. Nevertheless, with careful review, it is possible to assess reasonable and appropriate BMPs for a particular crop, setting and rotation. The review can also identify practices which are clearly inappropriate for protecting water resources.

Each of the BMPs will be evaluated as pass-fail, in context of the other practices. There can be a great deal of variability in farm management decisions from year to year, depending on the weather, so there are challenges to consistently implementing the practices. Few farm operations can realistically implement all of the practices every year. Therefore, the selected BMPs need to be implemented on approximately 80% of the available row crop land in order to meet the BMP adoption criteria. This value provides a benchmark for BMP implementation and allows for evaluation on a site specific basis. There must be information to support that BMPs are being adopted.

14. Determine appropriate mitigation level using nitrate concentration and BMP adoption criteria.

In order to evaluate mitigation level activities the following conditions must be met:

- Complete at least two rounds of private well sampling (sample rounds must be from different years). Within wellhead protection areas, public well data will be used in coordination with the MDH;
- Allow three growing seasons to implement the selected BMPs;
- Complete BMP adoption surveys prior to and after implementation and prior to considering a regulatory level (Level 3 or 4).

The MDA will review available nitrate concentration (and trend data, if available) and BMP adoption survey data to determine if the area moves up or down a level. When evaluating the change in nitrate in groundwater, the MDA will consider lag time to determine if the BMPs implemented have been effective. Lag time is the period from when a practice is adopted to when a change in groundwater quality could be expected. Over a short time period it is very unlikely that groundwater monitoring data would be sufficient to link results to BMP effectiveness; demonstration site and modeling are much more likely to answer that question. The lag time can be less than a year to decades depending upon a number of factors including soil type, geology, depth to groundwater, the volume, intensity and timing of precipitation, as well as field practices such as tillage and crop type. In dry years, there may be virtually no nitrate leaching to groundwater, while heavy precipitation after several dry years could result in a large quantity of nitrate leaching past the root zone. The lag time should be based on a technical assessment of water travel times from the land surface to the water table using modeling, soil sampling, age dating of groundwater or other suitable methods. The estimated lag time should be based on the best available data, with consideration of historical local weather events. Nitrate leaching models may be helpful as well as monitoring residual soil nitrogen in the root zone.

The MDA recognizes the need to better understand the relationship between land-use practices and changes in groundwater nitrate levels. The MDA may utilize or develop tools such as models, field hydrologic tests, field sampling, tracers, etc. that can provide the information to show the link between

BMP implementation and water quality. The MDA is supportive of continuing research on accurate quantification and prediction of nitrogen leaching losses to groundwater under field conditions.

Downgrading the mitigation level will be conducted using similar considerations. A site may be downgraded to a lower level if nitrate monitoring results indicate that nitrate has continuously improved to below the nitrate criteria for the current level. Once a site has been categorized as Level 3 or 4, it generally should not be removed unless nitrate data are below the minimum nitrate criteria with an appropriate margin of assurance. A site may be downgraded to a lower level if the 90th percentile from the monitored wells show a stable or downward trend for three consecutive sampling events over a period of a least three years and sustained nitrate monitoring results are at least 10% below the nitrate criteria. This will help to ensure the reduction is stable. The MDA will use best professional judgment in making a final determination.

ADDITIONAL MITIGATION ACTIVITIES TO CONSIDER

The mitigation process described above provides a layout of the basic activities. The Advisory Team may explore additional activities to implement in the mitigation process. The MDA has provided a set of examples below for Levels 2-4; Level 1 is not listed because the effort needed is less than for the other levels. The Advisory Team may offer other alternatives for consideration by the MDA.

ACTIVITIES TO CONSIDER FOR LEVEL 2

- Collect irrigation well water samples to augment the long-term private well monitoring network data and to provide information on nitrogen crediting for determining proper nitrogen fertilizer application rates;
- Proper crediting for all nitrogen sources;
- Record keeping of nitrogen use, including rates, crediting of nitrogen sources, timing, placement and source;
- Recommend and support developing irrigation, water management or nutrient management plans;
- Demonstration sites;
- Annual farmer updates.

ACTIVITIES TO CONSIDER FOR LEVEL 3 (IN ADDITION TO LEVEL 2 ACTIVITIES)

- The MDA or approved representative collects irrigation well water samples;
- Farmers report on their fertilizer management practices to the MDA, including nitrogen fertilizer and/or manure application rates, timing, sources, crediting and placement;
- Require irrigation, water management and/or nutrient management (including manure) plans developed and/or certified by a qualified professional;

- Farmers attend at least one MDA approved education activity such as a meeting, field day, clinic and/or workshop.

ACTIVITIES TO CONSIDER FOR LEVEL 4 (IN ADDITION TO LEVEL 3 REQUIREMENTS)

- Mandate specific nitrogen management practices.

DEVELOPMENT OF WATER RESOURCE PROTECTION REQUIREMENTS (WRPRS, OR RULES)

If it is determined that an area will move to a regulatory mitigation level (Level 3 or 4), the MDA will implement a rule(s).The Groundwater Protection Act grants the MDA authority to develop formal rules called Water Resource Protection Requirements (WRPRs) (Minnesota Statutes, section 103H.275).

Actions should be carefully targeted to restrict practices which are clearly inappropriate, or mandate practices that are very effective at protecting groundwater, can be successfully enforced at a reasonable cost, and are economically viable. Any regulatory activity should be implemented only after a reasonable period of time has been allowed for notification, education and voluntary adoption of the selected BMPs.

There are currently no rules (WRPRs) in place. Beginning in 2015, the MDA will develop a rule to address statewide and area specific nitrate issues. Appendix J provides some guidance in development of these rules. The Administrative Procedures Act (Minnesota Statutes, section 14) identifies requirements for rule development and implementation.

The new rule will generally be based on the Minnesota nitrogen BMPs. There will be increased restrictions/requirements when going from Mitigation Level 3 to Level 4. It is intended that Level 3 will allow farmers significant freedom to control their agronomic practices. However, Level 3 regulations are intended to send a clear message that groundwater contamination is a significant concern in the area; it is critical to actively work with crop advisors/consultants and the Advisory Team to help develop and implement reasonable and effective methods for addressing elevated nitrate. The goal of Level 3 regulation is to attain the widespread adoption of the BMPs and, to the extent possible, involve stakeholders in identifying solutions that will be effective in addressing the problem. In some cases other options may be needed such as those outlined in the AMT section in Chapter 8.

The process for developing rules in the Groundwater Protection Act (Minnesota Statutes, section 103H.275, subdivision 2) provides for two options, one is applying a rule statewide and the second is developing a rule which would be applied to specific geographic areas by Commissioner's Order. The MDA has decided to use both options. General information on what these proposed rules will contain is outlined below. Greater detail will be provided in the proposed rules.

PROPOSED STATEWIDE RULES

Part 1 of the proposed rule will restrict the fall application of nitrogen fertilizer and application of nitrogen fertilizer to frozen soils in areas that are vulnerable to groundwater contamination when it is listed under "not recommended" in the nitrogen BMPs. The MDA believes that these practices are clearly inappropriate and that the vast majority of Minnesota farmers and their crop advisors do not fall apply or apply fertilizer to frozen ground when it is not recommended by the U of M.

If there are exceptions where fall application or application to frozen ground is appropriate, the MDA will include those exceptions in the rule. Exceptions could include things such as agronomic products or practices where nitrogen fertilizer use may be acceptable. The MDA will work with the U of M and the agricultural community to define or refine nitrogen BMPs and exceptions.

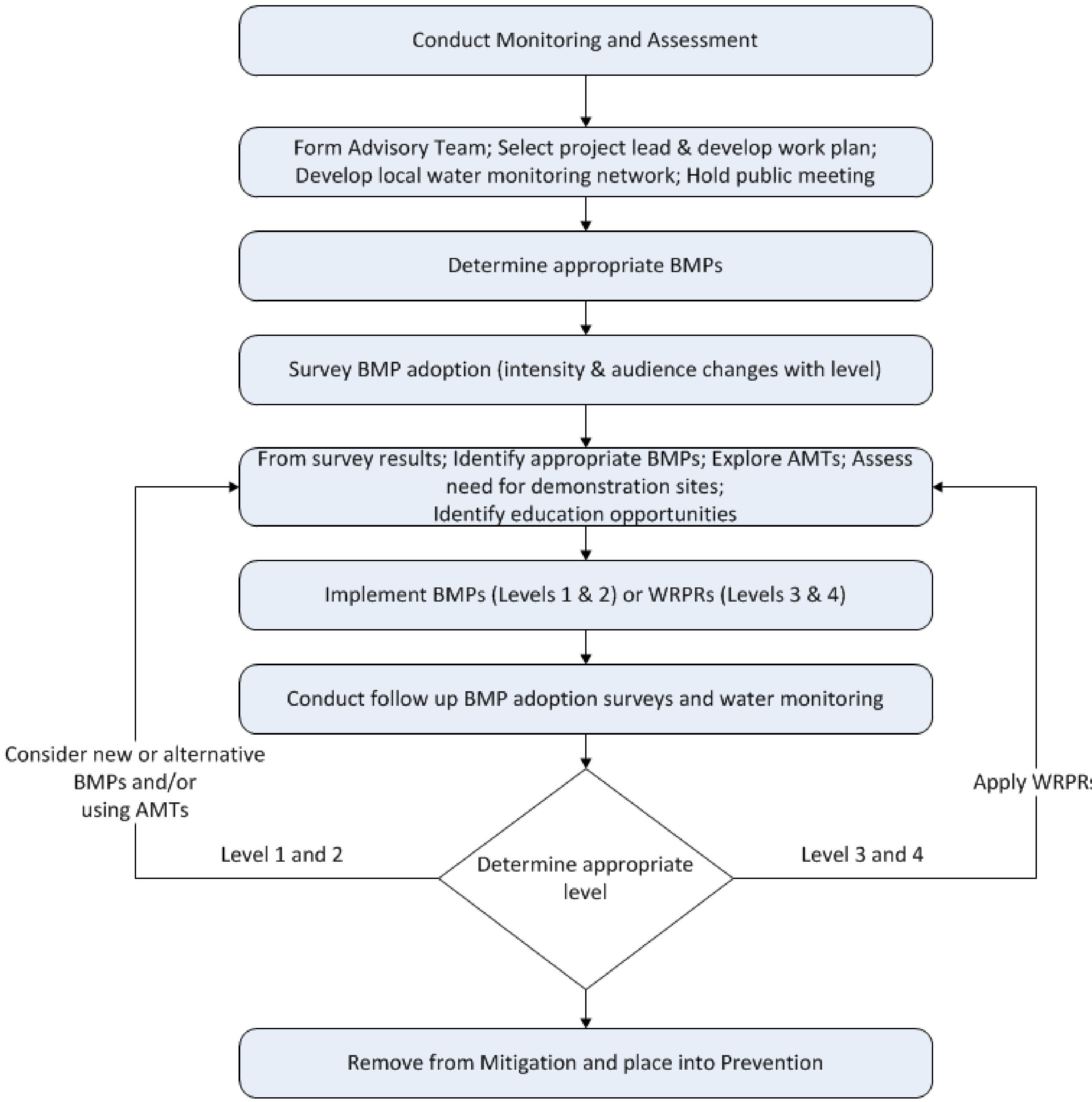
Part 2 of the proposed rule will adopt a process for moving to regulation based on the mitigation process outlined in this chapter. This includes implementing regulations at Levels 3 and 4. Site specific regulations would be selected from a menu of options that will be in the rule, with specific requirements applied to a local area (such as a township or wellhead protection area) through a Commissioner's Order as outlined in the Minnesota Statutes, section 103H.275, subdivision 2. Commissioner's Orders are exempt from rulemaking under the Administrative Procedures Act.

The menu of options would be based primarily on the existing regional nitrogen BMPs. Other options could include those listed in the 'Additional Mitigation Activities to Consider' section of this chapter. This menu of options will be reviewed at the local level in consultation with a local advisory team to select the option(s) appropriate for the specific setting.

MITIGATION DIAGRAM

Figure 26 depicts the mitigation process. It is a cyclical process, consisting of reoccurring nitrate monitoring and assessment, planning, pre- implementation BMP adoption surveys, a period of implementation, post-implementation BMP adoption surveys, and final assessment. This process begins after nitrate testing has occurred and impacted areas have been identified at the township or WHPA scale.

Figure 26. Simplified Nitrogen Fertilizer Management Plan (NFMP) Mitigation process.



BENCHMARKS

The MDA will develop benchmarks and performance goals for implementing the NFMP. This will be used for MDA work planning and also as an information tool for other state agencies and local partners. These will include timelines for evaluating private wells in townships with vulnerable groundwater and conducting the first round of nitrate sampling. The long term goal will be to survey every available private well in vulnerable townships at least once every 10 years in synch with the MPCA 10 year watershed monitoring cycle. This will allow local government units to integrate actions to protect groundwater into their local water management plans as well as coordinate potential shared monitoring efforts.

The MDA will estimate the staff resources required to implement a response effort in all areas designated as a Level 2 or higher over a period of 10 years and will seek funding to do so. The MDA will annually measure its performance against this 10 year plan and project likely implementation timelines into the future. The MDA will also evaluate and report on the progress implementing the BMPs and other mitigation actions in areas designated as a Level 2 or higher.

SURFACE WATER IMPAIRMENTS AND THE NFMP MITIGATION PROCESS

The MDA involvement in surface water impairments via the NFMP in a Prevention mode was discussed in Chapter 8. The following section describes how the MDA could become involved in surface water impairments via the NFMP in a mitigation mode.

GROUNDWATER TO SURFACE WATER DISCHARGE TOTAL MAXIMUM DAILY LOADS (TMDLS)

The MDA may implement a mitigation response in TMDL areas if the groundwater nitrate concentrations meet the criteria outlined in the NFMP. Regulatory actions may be considered in accordance with the NFMP and guidance in the Groundwater Protection Act. There must be clear attribution in the TMDL of the impact of nitrogen fertilizer management practices on groundwater quality, and the subsequent impact on surface water quality. These decisions will be made on a site specific basis subject to available resources. However, these projects will be prioritized following the process outlined in the “Prioritizing Mitigation Efforts” section of this chapter.

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Abbreviations

AGENCIES AND ORGANIZATIONS

BWSR	Minnesota Board of Water and Soil Resources
DNR	Department of Natural Resources
EPA	Environmental Protection Agency
MDA	Minnesota Department of Agriculture
MDH	Minnesota Department of Health
MDNR	Minnesota Department of Natural Resources
MGS	Minnesota Geological Survey
MPCA	Minnesota Pollution Control Agency
SWCD	Soil and Water Conservation District
U of M	University of Minnesota
USGS	United States Geological Service

TECHNICAL TERMS

BMP	Best Management Practices (voluntary)
ET	Evapotranspiration
HRL	Health Risk Limit
MCL	Maximum Contaminant Level
mg/L	Milligrams Per Liter
N	Nitrogen
NFMP	Nitrogen Fertilizer Management Plan
PMR	Pesticide Monitoring Region
UAN	Urea Ammonium Nitrate (fertilizer)
WRPR	Water Resource Protection Requirements (regulatory)

Appendices

A. MDA Lessons Learned in Responding to Elevated Nitrate in Groundwater

B. Case Studies: City of Perham, City of St. Peter, Lincoln-Pipestone Rural Water

C. History of Groundwater Monitoring in Minnesota

D. Challenges of Monitoring Groundwater Quality

E. Evaluating the Presence of Nitrate-Nitrogen in Groundwater

F. Nitrate Trends in Groundwater at Selected Springs in Southeast Minnesota

G. The Nitrogen Cycle, Sources and Trends

H. Regional Issues and Opportunities for Advancements in Nitrogen Management

I. MDA Private Well Sampling and Site Inventory Guidance

J. Regulated Mitigation Guidance

A. MDA LESSONS LEARNED IN RESPONDING TO ELEVATED NITRATE IN GROUNDWATER

The Minnesota Department of Agriculture (MDA) has been working on responding to areas with elevated nitrate in groundwater for over 20 years. Most activities have been focused on responding to public water supply issues. However, our staff resources have always been severely limited, generally only a few staff to address the issue statewide. Therefore we focused our efforts on developing a process for responding to locally high nitrate, primarily through working with the Minnesota Department of Health (MDH) in wellhead protection areas with nitrate problems. Based on this experience, we have developed a general approach to addressing nitrate problems and have also learned a number of lessons regarding these efforts. This approach and some of the lessons learned are briefly discussed below:

Major Steps

1. Review monitoring data to confirm there is a problem and to understand the extent and scope of the problem.
2. Consult with other agencies on their understanding of the problem, especially the use of hydrogeologic sensitivity and groundwater flow maps to understand potential source areas for targeted implementation of practices.
3. Form a local advisory team.
4. Begin a long term private well monitoring network. This is not always possible within a wellhead protection area because most residents will be on public water. The same may be true for rural water systems.
5. Hold a public information meeting early in the process specifically for farmers; otherwise the subsequent survey of practices may not be successful.
6. Conduct a detailed survey of agricultural practices (FArm Nutrient Management Assessment of Practices - FANMAP) and other local issues such as lawn care, golf courses, etc.
7. Review the FANMAP data and identify recommended Best Management Practices (BMPs) for local soils and cropping systems.
8. Develop an educational response targeting key weaknesses (if any).
9. Work with farmers to implement recommended BMPs.
10. Use FANMAP data to support obtaining implementation and cost sharing funding if needed.
11. Foster industry and local agricultural dealership support and awareness.
12. Conduct edge of field demonstrations, such as the Red Top and Highway 90 demonstration sites. These sites were essential to opening doors to farmers and demonstrating BMPs that needed to be implemented.
13. Promote the Nutrient Management Initiative (NMI), BMP Challenge and other programs that address the economic risk for the farmers.
14. Consider alternative management practices such as alfalfa or Conservation Reserve Program (CRP) on high risk lands as early as possible in the process.
15. Continue monitoring and BMP promotion.
16. Conduct a post BMP adoption FANMAP survey (after appropriate time period) and adjust the response as needed.

Lessons Learned

1. Local government units may be very hesitant to work with state agencies and other outside potential players.
2. Most local government units may need a lot of help. They don't have the expertise to do this effort without considerable assistance.
3. Funding – we need to be realistic about funding needs and have many options based on funding availability.
4. Recognize that groundwater quality may be one of many issues facing any given area. Don't expect that locals will be there with open arms to take on new work, especially if there is not associated funding.
5. Be careful of local politics or long-standing sour relationships. There may be hard feelings to overcome that have nothing to do with the current situation.
6. There may be friction between the local government unit and area residents already. Sometimes to avoid confrontation, the local government unit may not want specific residents on the advisory team.
7. Intentionally build trusting relationships. Understand that it will take a long time to build these relationships. This is no different than how all of us act. Very few of us will put our business and future prosperity into the hands of a stranger.
8. The key people needed on the local advisory team are: the city and/or county; the water supplier; state agency technical staff, hydrogeologists and agricultural scientists; University of Minnesota Extension (if available); the local agricultural dealership(s) and, local farmers and their crop advisors.
9. Include as many farmers and local agricultural consultants/crop advisors on the advisory team as possible.
10. Keep people with difficult personalities off the team. One hostile person can ruin everything.
11. An objective non-accusatory attitude within the advisory team is the most important factor in the success of the project. This can be accomplished through strong, preferably local, leadership.
12. Don't waste farmers' time. They are busy. Make sure your meetings are well run and useful.
13. Find an effective facilitator if at all possible.
14. The project needs a liaison - a person who is trustworthy, reliable, and understands farming. Only this person should be allowed to speak to farmers outside of the advisory team meetings. Frequent visits, especially from unqualified people, may quickly wear out the welcome for everyone else. Sometimes it may be best to have the one contact person conduct shuttle diplomacy to negotiate between individuals or local government units to overcome hard feelings. Be flexible.
15. There can be a huge communications gap between the local advisory team and area farmers - this gap needs to be addressed early in the project.
16. Because groundwater issues are local, they tend to be relevant and important to people. Make sure everyone can understand the causes and effects of local nitrate problems.
17. Local needs - Be ready to address local concerns even when the best literature and science tells you otherwise, such as the golf course example. It was important to the area farmers that MDA investigate sources of nitrate from an area golf course. The demonstration helped address their concerns.
18. Many cities will not have their monitoring data compiled by individual well or may be reluctant to share the data with you. If possible obtain it. Long term water quality trend data is very useful. Rarely is there an abundance of monitoring data, and it is not uncommon for existing data required by MDH to be in paper form and unorganized.
19. MDA has developed a standard approach to conducting a field-by-field survey of actual nutrient management practices (FANMAP). While this tool is available to everyone, most people will have great difficulty conducting the survey without help. Individuals without a suitable agricultural background will not be able to conduct the survey.

20. The FANMAP survey of practices is extremely important. It provides hard facts on local farm practices, both good and bad. These facts change the whole tone of the discussion from one of defensiveness to one of shared problem solving. Without facts all you have are opinions and assumptions, which are usually incorrect. Present FANMAP results back to the farmers and ask them "did we get it right?" This will add enormous credibility to the program by collectively identifying weaknesses and possible reasons for current practices.
21. Information on the practices for a specific farm or piece of land must be kept completely confidential or no one will participate. Farmers are very proud and competitive and watch their neighbors, so be careful not to embarrass anyone. Further, sharing information on rental land and individual farm practices can put farmers at a local competitive disadvantage and cost them money.
22. FANMAP data generally makes it much easier to obtain implementation funding since you can be very specific in a grant or loan application about what needs to be implemented and why, and the request will be supported by the members of the advisory team.
23. Local farmers have repeatedly come up with the ideas that work best.
24. Consider Alternative Management Tools (AMTs) early (Chapter 8). These generally are by far the most beneficial actions that can be taken to address groundwater quality issues. They might be very costly to implement, but we have seen farmers implement these practices at their own cost in order to help their neighbors and their community.
25. Don't expect passive, indirect methods of communication to change practices. Mail outs, news releases, etc. may be very good at raising awareness but rarely result in behavioral changes.
26. Crop advisors/crop consultants are especially influential in many farmers land management and fertilizer use decisions.
27. Make it a priority to provide farmers with updates and question/answer opportunities. Some of our best meetings have been over a meal sponsored by the community and served more as a trust building exercise rather than an informational meeting.
28. Give farmers credit for being reasonable, caring, people who want to be good neighbors. With very few exceptions they are.
29. Edge of field demonstrations, such as the Red Top and Highway 90 demonstration sites and the Nutrient Management Initiative are essential to opening doors to farmers and demonstrating BMPs that need to be implemented in a location.
30. Land swapping and rentals can add numerous complications to water quality efforts. Rental lands can be a challenge since the owner may not be local and may have little interest in the local situation. Alternatively, a land owner has the ability to require BMPs or implement alternative management strategies on their property.
31. Methods for evaluating progress on a project may include indicators such as 1) edge of field demonstration response time; 2) early adoption by cutting edge farmers; 3) adoption by "average" farmers; 4) changes in deep residue soil nitrate from bottom of root zone to the water table; 5) observation wells or sand points, etc.
32. Water quality monitoring data will determine success or failure of the effort. We will know if our efforts are being successful. However there may be a long lag time between implementing practices and improvements in water quality. Rarely will improvements in groundwater quality be observed in public water supplies within a year; it may take many years, even decades to see improvements.
33. Vigilance. Once you start working on a local nitrate problem you can never stop. Unless someone is paying attention, the land use practices may revert back to the old ways.

B. CASE STUDIES: CITY OF PERHAM, CITY OF ST. PETER, LINCOLN-PIPESTONE RURAL WATER

CITY OF PERHAM

Perham is located in the heart of Minnesota's west-central lakes region in Ottertail County. The city boasts an impressive business community based upon industry, agriculture, and tourism. Approximately 325 million gallons of water are supplied each year to businesses, industry, and its 2600 residents. Elevated nitrate levels in the community's drinking water supplies have forced the city to take immediate and long-term corrective actions. Providing quality drinking water is an important component for future growth and viability of this region.

Water Quality and Challenges

- Five supply wells vary in depth from 95 to 120 feet deep. Two supply wells were recently idled due to low output and will only be used under emergency or backup situations. A new well, yielding high quality water, was put online in 2000 to replace them.
- Individual city wells have sporadically exceeded the safe drinking water standard of 10 mg/L. Currently city staff blends water to keep the levels of the finished drinking water between 6 to 8 mg/L nitrate. Deeper aquifers with lower nitrate levels contain high levels of iron. More than likely, finding adequate supplies of low nitrate water will become more and more difficult.
- A nitrate removal system was considered, but not put into practice because of the very high costs involved.
- Water quality is impacted by factors such as land use activities from a combination of growing high nitrogen consuming crops, large areas being irrigated, coarse-textured soils which allow rapid water movement, and relatively shallow wells.
- Perham's wellhead protection area covers approximately 11,500 acres. Within this area, 1,600 acres are of significant importance, because surface water can reach the aquifer within 10 years.
- In the remaining protection area it typically takes between 10 to 30 years for water to reach the aquifer. This means that we may not enjoy many of the environmental benefits of improved nitrogen management for years to come.

Successful Action Steps

- A wellhead protection plan was completed to address the amount of nitrogen escaping from cropland, lawns, septic tanks, and feedlots. Management goals and strategies in the plan define implementation steps to protect and improve drinking water quality. This approach was highly successful due to cooperation among community residents, farmers, businesses, industry, and state/local agencies.
- Residents in the wellhead protection area, including farmers, businesses and city homeowners, are being provided with information on specific actions they can take to protect drinking water. Information is being distributed through public meetings, press releases, utility bill inserts, demonstration projects and curriculum being taught in local schools.

- Signs have been installed identifying the boundaries of the wellhead protection area. Residents, landowners, and farmers have a better understanding of the size of the protection area when they can visually see it.
- In 1993, the Perham wellhead protection team partnered with the MDA to establish a volunteer groundwater monitoring network using about 100 privately owned wells. Nitrate trends are monitored in outlying areas and within the water supply management area.
- In 1999 and 2000, most farmers who farm in the wellhead protection area participated in a study to evaluate their current nutrient management practices, fertilizer, manure rates, and review associated management. This information helped educators design appropriate programs and served as the baseline to determine where improvements have been achieved.
- Farmers are trying a new variety of potato that produces good crop yields with less nitrogen fertilizer.
- Livestock farmers are improving the way they manage manure by developing nutrient management plans and taking nitrogen credits for those applications.
- Landowners have been encouraged to take sensitive land out of crop production where nitrate leaching is a risk. This land is enrolled in long-term easements through the Conservation Reserve Program (CRP). Native grasses planted on this land are helping to filter out pollutants moving into groundwater.
- Homeowners are learning efficient ways to manage nitrogen fertilizer applications on their lawns. Regular maintenance of septic systems is encouraged and failing systems are upgraded.

CITY OF ST PETER

St. Peter is located in south-central Minnesota nestled in the beautiful Minnesota River valley. Substantial growth and development are projected for the future of St. Peter and supplying quality drinking water is very important for long-term economic growth and stability of the city. Approximately 350 million gallons of drinking water are supplied annually to over 10,000 residents.

Water Quality and Unique Challenges

- Seven supply wells, varying in depth from 130 to 670 feet, pump water from three separate aquifers. Of these, four shallow wells are considered vulnerable to land use activities.
- Nitrate levels in the vulnerable wells have been steadily increasing since the 1980's. In response to this threat, a planned approach was developed on how to minimize risks from nitrate and other contaminants.
- City staff blend water from various wells to produce a finished water supply which typically contains nitrate levels between 4 to 5 mg/L, the health standard is 10 mg/L. In 2011 the City of St. Peter did construct a reverse osmosis treatment system to treat for nitrates, radium and other minerals.
- St. Peter's wellhead protection area covers over 4,600 acres. Over 80% of the protection area is cultivated cropland consisting of corn, soybeans, and canning crops.

- Drainage water derived from tile-drained cropland on the western edge of the management area is discharged onto coarse-textured soils near the city limits. The rapid infiltration of water through these coarse soils allows rapid movement of contaminants into the aquifer.

Successful Action Steps

- Community residents, farmers, businesses, and state/local agencies developed a wellhead protection plan to protect the city's water supply. Management goals and strategies in the plan define implementation steps to address nitrate contamination from cropland, lawns, and septic systems. This plan was approved in 1998 and was one of the first of its type in Minnesota.

- Local units of government were instrumental in obtaining funding through state and federal grant programs. Assessing the extent of the problem and implementing numerous educational activities were made possible through these grants.

- City residents, farmers, and businesses are provided with information on specific actions they can take to protect drinking water. Information is distributed through public meetings, media, direct mailings, utility bill inserts, demonstration projects, and curriculum being taught in local schools.

- An inventory of potential contaminants was compiled by interviewing property owners. Personal interviews provided an excellent "one on one" opportunity to explain the importance of protecting their drinking water resource.

- A well sealing campaign was initiated for inactive private wells. This campaign successfully sealed numerous wells and identified some previously unrecorded ones.

- In 1996, an "on-farm" study was conducted to evaluate farmer's current nutrient management practices, fertilizer/manure rates, and review associated management decisions. This information helped target educational programs focused on reducing nitrogen application rates and promote nitrogen Best Management Practices (BMPs).

- Rural residents are encouraged to upgrade failing septic systems through low interest loan, cost share programs, and upgrades through property transfer requirements.

- Homeowners are learning about efficient ways to manage nitrogen fertilizer applications on their lawns. Lawn and garden care demonstrations are held at local parks. Lawn management information is supplied to the homeowner through monthly water statements.

- The "Red Top" demonstration farm was established in 1995 as a means for evaluating the University of Minnesota fertilizer recommendations, associated nitrogen BMPs, and subsequent water quality. This site has been a highly successful demonstration tool.

- Informational handbooks were developed and distributed to farmers and agricultural professionals within the wellhead protection area. These handbooks emphasize activities producers and landowners can implement to reduce groundwater contamination.

- Numerous nitrogen validation trials have been established on farmer's fields. Results from these trials have consistently proven that farmers can produce maximum economic corn yields and reduce nitrogen inputs. Farmers in the protection area are beginning to implemented positive management changes on their own farms after seeing these results.

- Crop consultants and agricultural retailers are taking a leadership role in promoting nitrogen BMPs and developing nutrient management plans. Some farmers in the area are taking advantage of cost share incentives for developing these plans through the Environmental Quality Incentive Program (EQIP).

LINCOLN-PIPESTONE RURAL WATER

Water quality and quantity in southwest Minnesota are significant concerns. Protection of limited water supplies is important to the long-term economic stability and growth of this area. Most drinking water supplies in the region are obtained from shallow groundwater aquifers which are frequently contaminated with nitrate. Deeper aquifers are not suitable for use as drinking water because of sulfur contamination and inadequate recharge. Past agricultural land use practices have played a large role in defining today's water quality issues.

Water Quality and Unique Challenges

- Lincoln-Pipestone Rural Water (LPRW) supplies water to 27 communities and 3000 rural households in southwestern Minnesota.
- The recharge area of the three major well fields– Burr, Verdi, and Holland covers over 32,000 acres. Water from the Burr well fields is low in nitrate due to the geology of this area.
- Raw water from some of the Verdi and Holland supply wells have elevated nitrate levels and in some cases exceeded the federal drinking water quality standard of 10 mg/L. These higher levels are due to the fact that wells are shallow and vulnerable to contamination from activities taking place on the land.
- Wells containing various nitrate concentrations are blended to produce a safe finished product.
- A $2,000,000 nitrate removal system was installed in the Holland well field. (Hopefully over time improved water quality will make the system unnecessary).
- Few locations in the area have a dependable backup source of drinking water. It is critical that existing supplies are adequately protected.

Successful Action Steps

- The LPRW project is an example of how water suppliers, crop and livestock farmers, ag-dealerships, University of Minnesota, and local/state/federal organizations can work together to develop and implement a wellhead protection plan. Management goals and strategies in the plan define implementation steps to protect and improve drinking water quality.
- A chain reaction of grant writing and obtaining sources of funding occurred after the initial state grant was obtained. Local units of government were responsible for later bringing in $235,000 in EQIP 319 and Clean Water funding, and a $60,000 continuation gift from the Lincoln-Pipestone Rural Water Board, to support local initiatives.
- When nitrogen BMPs are properly administered, and adequately funded with cost share dollars, significant behavioral changes in nutrient management can be achieved in a narrow window of time.

- Channeling communications from all of the various partnerships through the LPRW project coordinator significantly reduced much of the confusion, redundancy, and apprehension commonly shared by most farmers in these types of projects.

- Local Natural Resource Conservation Service and Soil and Water Conservation District staff are historically swamped with existing workloads. Hiring a dedicated nutrient plan writer/coordinator to work solely with farmers to develop nutrient, pesticide and tillage management plans was a huge boost to the project.

- Research was conducted to fine-tune existing fertilizer and manure recommendations for the unique soils and geology found in this area. Area farmers were highly receptive to having research conducted by USDA-ARS and University of Minnesota (U of M) on their farms. This research confirms that U of M recommendations for applying nitrogen are accurate.

- Farmers were extremely receptive to changing management practices when provided knowledge as to: 1) how their nutrient management decisions affect groundwater quality, and 2) how changes in their nutrient management decisions can result in favorable profit margins.

- Similar to most areas of Minnesota, farmers frequently enjoy a cost savings of anywhere from $4 to $8 per acre through reduced nitrogen inputs. Savings on manured fields can be substantially higher.

- Personal on-farm visits and “one on one” technical assistance were critical in clearly explaining the benefits of conservation easement programs and nitrogen BMPs.

- Portions of the most sensitive land have been taken out of agricultural production and have been placed into the Conservation Reserve Program (CRP) where groups such as local hunting clubs can lease the land.

- Innovative, cost effective solutions are frequently developed on a very localized scale. In this case, a lease agreement between an area hunting club and LPRW was highly beneficial in taking some of the most sensitive land out of production and replacing it with perennial grasses and legumes.

C. HISTORY OF GROUNDWATER MONITORING IN MINNESOTA

The Groundwater Protection Act of 1989 provided funding for the Department of Natural Resources, Minnesota Geological Survey, Minnesota Pollution Control Agency, Minnesota Department of Agriculture and Minnesota Department of Health to conduct various types of groundwater monitoring. Because of the Act, Minnesota has made great strides in advancing its groundwater data collection programs. This accomplishment is due in part to a study completed in 1991 by the Legislative Water Commission, titled "Nitrogen in Minnesota Groundwater." This report clearly identified the void in not having a statewide groundwater monitoring program to specifically assess the extent and trends of nitrate concentrations.

Since the 1990s, Minnesota has evolved to use a multi-agency approach to monitoring groundwater quality and quantity. Multiple state, local, and federal entities collect groundwater samples for nitrate analysis throughout Minnesota. Each entity has differing statutory and regulatory authority, purposes, goals and roles in groundwater monitoring based on their respective responsibilities (Figure C 1). Some of these entities are listed below, along with their related web link (is not an exclusive list):

- Minnesota Department of Agriculture (MDA) – Monitors water quality to identify the concentration and frequency of agricultural chemicals in Minnesota's groundwater and surface water.

  http://www.mda.state.mn.us/chemicals/pesticides/maace.aspx

- Minnesota Department of Health (MDH) – Monitors public drinking water supplies in the state. The web link provides monitoring and statistical information on nitrate nitrogen levels found in community water supply systems in relation to the number of community systems in Minnesota and population served.

  https://apps.health.state.mn.us/mndata/nitrate-messaging

- Minnesota Department of Natural Resources (DNR) – Monitors groundwater levels via a statewide network of water level observation wells.

  http://www.dnr.state.mn.us/waters/groundwater_section/obwell/index.html

- Minnesota Pollution Control Agency (MPCA) – Monitors ambient groundwater quality conditions in urban areas around the state.

  http://www.pca.state.mn.us/index.php/water/water-types-and-programs/groundwater/groundwater-monitoring-and-assessment/groundwater- monitoring-and-assessment.html

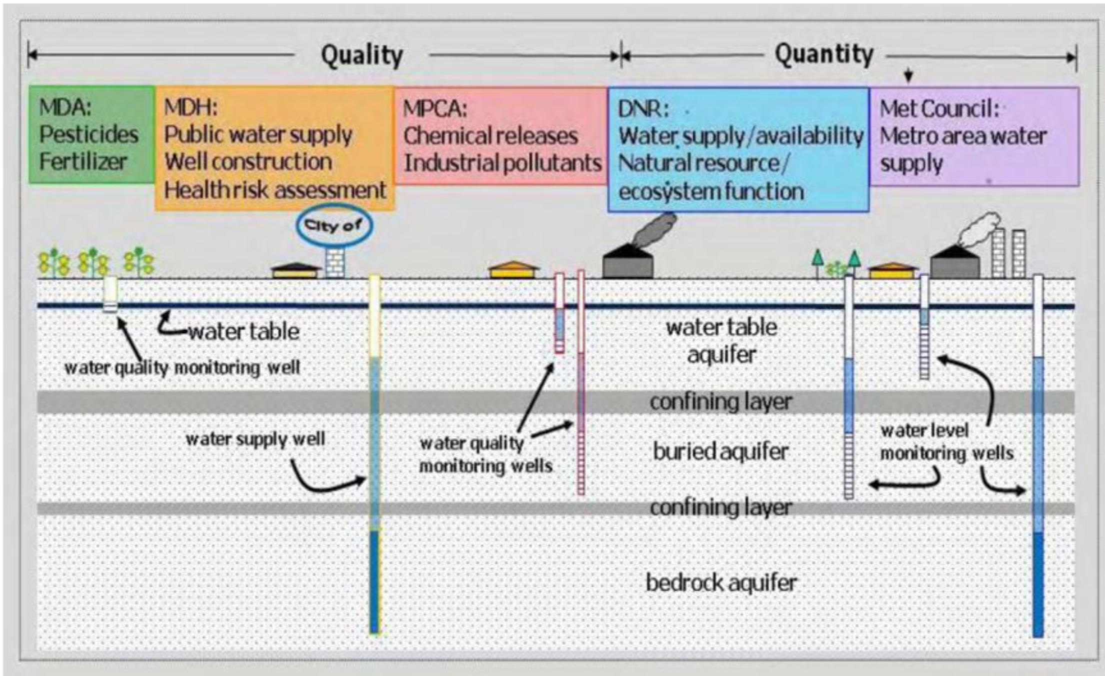
- United States Geological Survey (USGS) – Monitors groundwater quality and quantity in special project areas or at regional-scales throughout the nation.

  http://water.usgs.gov/ogw/programs.html

- County agencies, such as Soil and Water Conservation Districts (SWCDs) – Manage natural resources at the local-scale.

  http://www.maswcd.org/SWCDs_On_The_Web/swcds_on_the_web.htm

Figure C 1. Minnesota agencies responsible for water monitoring and the well types used



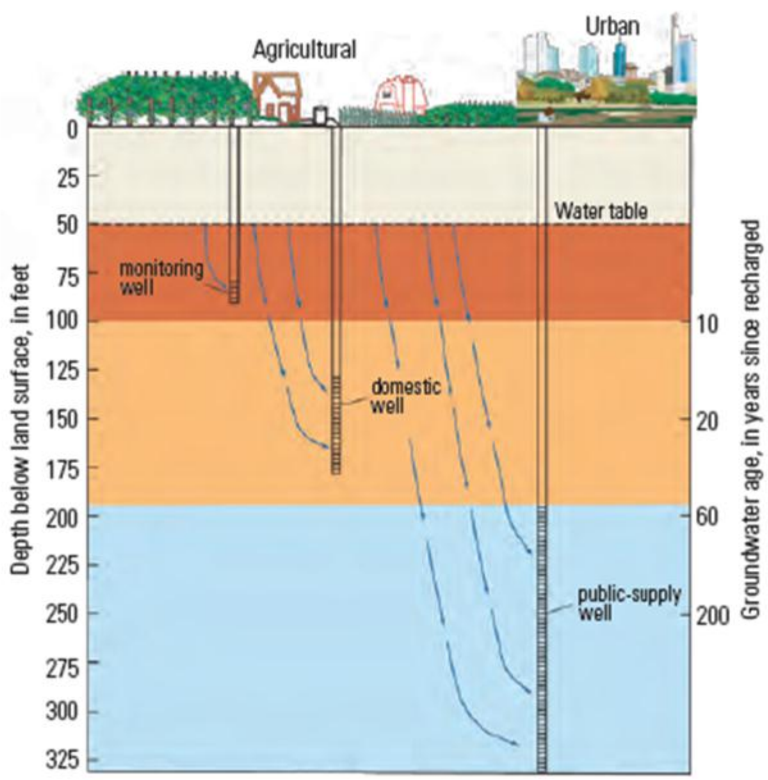
D. CHALLENGES OF MONITORING GROUNDWATER QUALITY

There are many complicating factors to monitoring and assessing groundwater nitrate data. Nitrate concentrations in the groundwater will depend upon the amount of the nitrogen loading into the system, transport time to groundwater, and where and when the sample is collected (Minnesota Department of Health 1998). Specifically, the nitrate concentration will depend upon, 1) nitrogen input as a result of land use (e.g., grassland, forest, dry land cultivation, irrigated crop land, residential, industrial or commercial) and how that land use is managed; 2) short-term and long-term precipitation, or recharge; 3) physical and chemical properties (Chapter 3), and 4) associated management of nitrogen fertilizer inputs.

In addition to land use, climatic and other variables influence the nitrogen cycle and the release of nitrate into the water table. Well type, construction and placement can have huge implications on nitrate monitoring results. Nitrate is typically highly stratified, with much higher concentrations at the top of the aquifer, so it is important to monitor water quality in various depths.

Typically, each type of well—monitoring, private (domestic), or public—taps a different depth interval in the aquifer system, so that samples collected from each type of well reflect a different part of the history of nitrogen input in that region (Figure D 1).

Figure D 1. Well types, associated depths and rate of groundwater recharge (Dubrovsky 2010)



Because the well type, construction and depth can affect groundwater quality results, it is important to be aware of how the wells differ.

Monitoring wells are installed for the sole purpose of monitoring groundwater quality and do not provide drinking water. The intake, or screen, of a monitoring well is located to evaluate a specific type of contaminant. Groundwater samples collected from monitoring wells are very sensitive to groundwater quality changes caused by infiltrating recharge. This makes monitoring wells ideal for evaluating impacts to groundwater quality caused by the overlying land use (Minnesota Pollution Control Agency 2007). Because of the these factors, monitoring well nitrate results are typically much higher than private and public wells and should not be used to infer drinking water quality.

Private (domestic) wells are installed to supply drinking water to homes and small businesses. The intake or screen for a private well is generally installed ten or more feet below the water table and typically ten or more feet in length to maximize the volume of water that can be extracted from the aquifer. Because the intake of a private well is separated by distance and time of travel from the water table, groundwater samples collected from private wells tend to be insulated from rapid water quality changes occurring at the water table. Consequently, private wells can provide a more integrated picture of ambient water quality in the aquifer (Minnesota Pollution Control Agency 2007).

Public supply wells are installed to supply drinking water to the public, the most prominent being a municipal system, operated by a city to provide water to its citizens. However, schools, churches, mobile home parks and apartment complexes may also have public water supply wells. Public water supply wells are installed at varying depths depending on geology and water quantity needs. Typically public supply wells are deeper than private wells.

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E. EVALUATING THE PRESENCE OF NITRATE-NITROGEN IN GROUNDWATER

Water resource managers must have high quality data for making sound decisions to protect groundwater from nitrate-nitrogen (hereafter referred to as nitrate) impacts. Collecting high quality nitrate data requires an appropriately designed water monitoring program. Methods for evaluating nitrate in groundwater must consider the time it takes for water to travel from a point of origin (for example, a septic system or a farm field) to an aquifer and subsequently within the aquifer. The transformation of nitrate (via chemical reactions) within the aquifer needs to be understood in order to determine proper well placement, data collection needs and to ensure appropriate evaluation of the resulting data. Monitoring groundwater for nitrate is multi-faceted, time consuming and expensive to do correctly, but proper monitoring design is absolutely necessary in order to ensure accurate and informative data are collected.

One of the key issues in developing a nitrate monitoring program and understanding the data is denitrification. Denitrification results in the transformation of nitrate into harmless nitrogen gas ($NO_3^- \rightarrow NO_2^- \rightarrow NO + N_2O \rightarrow N_2$ (gas)). Denitrification is an important process in groundwater and occurs when oxygen is either absent or is present at very low levels in the aquifer. These low oxygen conditions are known as reducing conditions and can effectively remove the nitrate from groundwater. Knowledge on where these reducing conditions are present in groundwater is critical in developing monitoring strategies and for interpreting the data from monitoring samples.

Another critical piece of information needed to develop a nitrate groundwater monitoring program is the age of the water in the aquifer. Water enters the ground to become groundwater at various times prior to when a sample is collected (days, weeks, years or decades). The time lapse between when the water entered the ground and when the sampling occurs may be critically important in determining the significance of nitrate results. Typically, water that entered the ground 50 or more years ago tends to have very low nitrate levels. It is also very common for this water to occur at greater depths in the aquifer. Groundwater age and reducing conditions, combined, lead to the explanation why deeper groundwater within the same aquifer has little or no nitrate present even when there are high nitrate levels near the top of the aquifer.

What makes an aquifer more susceptible to nitrate impacts?

In Minnesota, surficial aquifers are recharged annually. This means the time it takes water to move from a point of origin to the water table (the very top portion of the aquifer) is less than one year. These surficial aquifers are generally considered susceptible to nitrate contamination at the water table; however, deeper portions of these surficial aquifers may not be susceptible because nitrate will be denitrified or the water is older, having entered the ground before the increase in nitrogen fertilizer application during the past 50 years. Another reason that deeper portions of a surficial aquifer may be less susceptible to nitrate is the presence of a thick confining layer, which creates a physical barrier so nitrate cannot move from the top to deeper portions of the aquifer.

How does an aquifer in a reducing condition decrease nitrate levels?

The nitrogen cycle in groundwater is complex and dependent on many variables. Nitrogen generally moves into an aquifer as nitrate. Once within an aquifer, nitrogen will stay as nitrate as long as there is an adequate supply of oxygen. Conversely, when oxygen is depleted bacteria within the aquifer will begin to use, or consume, nitrate as an energy source. These “denitrifying” bacteria will use up available nitrate by converting it to nitrogen gas and thus create areas of low nitrate.

What is the best way to monitor for nitrate?

When monitoring groundwater for nitrate, samples should be collected in all dimensions within the aquifer of concern; both horizontally and vertically. The upper portion of an aquifer may be susceptible to nitrate contamination but the lower portion may not be. A transition zone of low oxygen content, where nitrate is used by bacteria and converted to gas, frequently occurs between upper and lower aquifer zones. The transition zone may be susceptible to nitrate reaching the zone but the nitrate rapidly disappears, ultimately resulting in low sensitivity to nitrate.

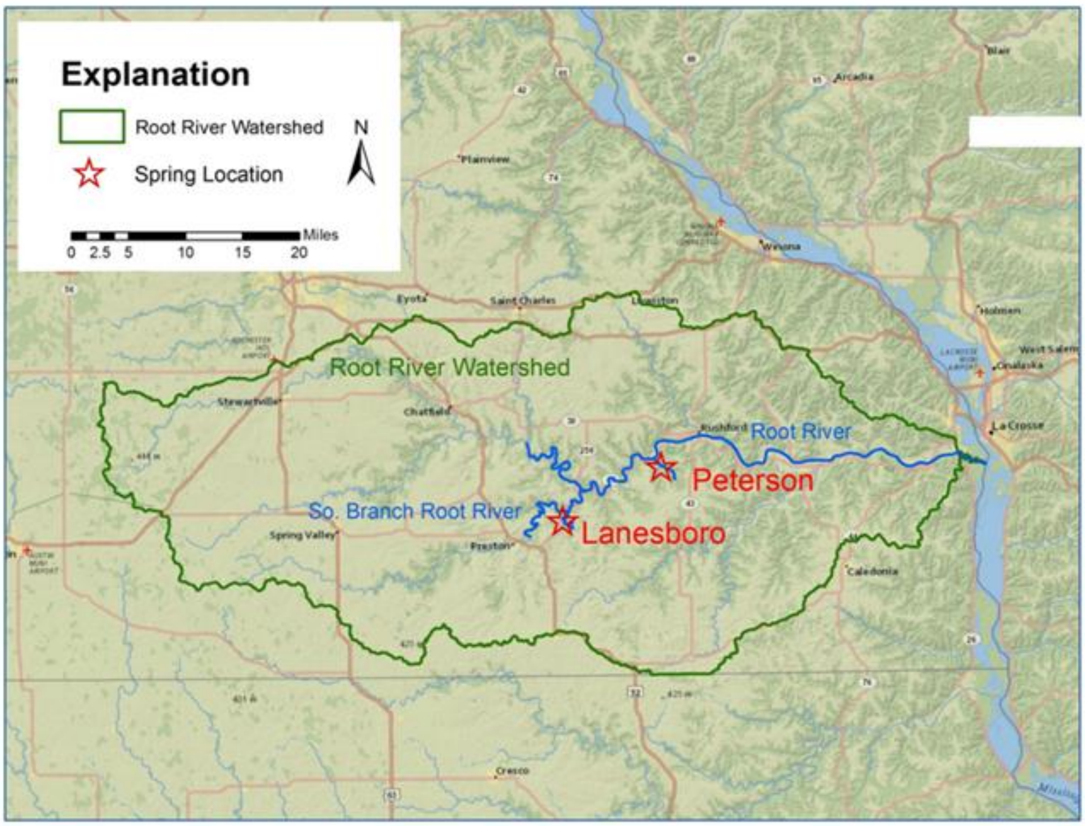
Samples collected from wells in a nitrate monitoring program should be analyzed for other parameters to more completely understand the fate of nitrogen in the aquifer. Samples may be tested for different forms of nitrogen, including nitrogen gas and ammonia, as well as dissolved oxygen and other common groundwater constituents (such as, dissolved iron, sulfur, and manganese). There are many other groundwater quality concerns related to nitrate that will need their own specific monitoring design, ranging from relatively basic to extremely complex. In the end, the cost and complexity of a nitrate monitoring program is directly related to how the resulting data will be used. The main costs associated with an appropriately designed nitrate monitoring program are drilling multiple wells at varying depths, sample collection and analysis, and subsequent data analysis and summarization.

F. NITRATE TRENDS IN GROUNDWATER AT SELECTED SPRINGS IN SOUTHEAST MINNESOTA

Minnesota Pollution Control Agency (MPCA) Root River Watershed Study 2000-2010

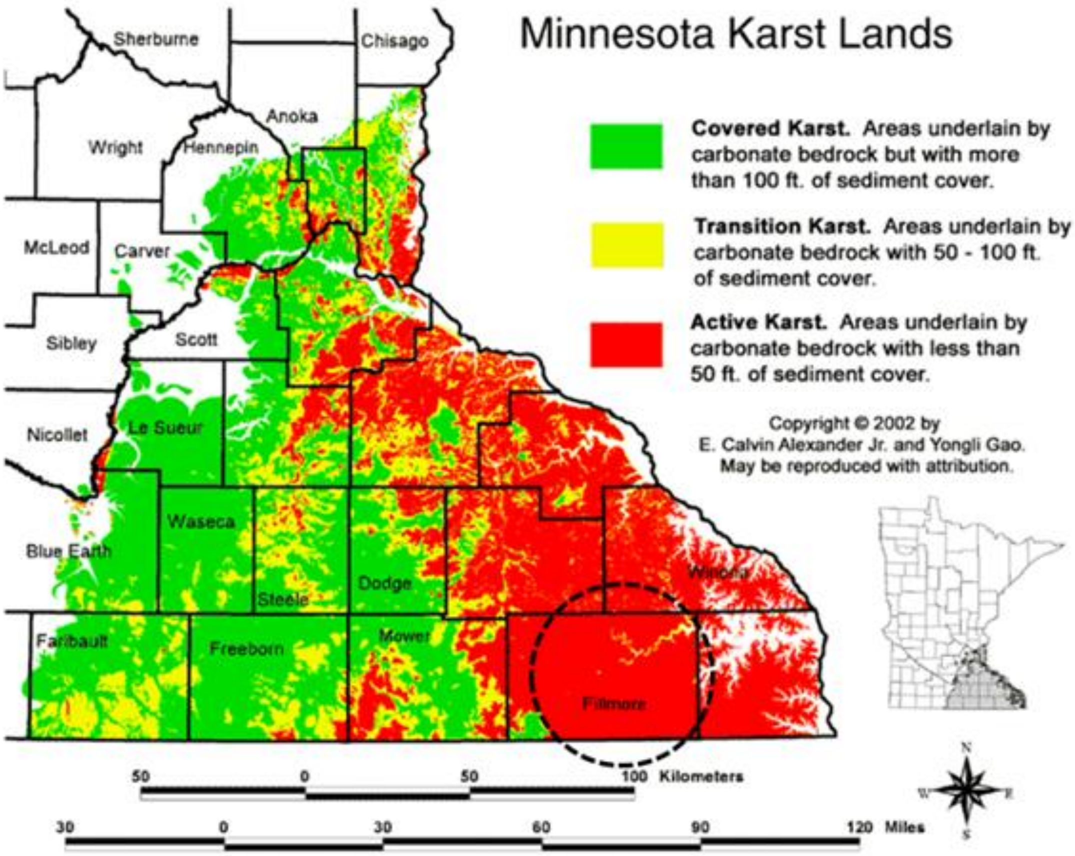
Due to its unique karst geology (fractured limestone bedrock overlaid with shallow soil, often with sinkholes), much of southeastern Minnesota represents a sensitive region for contamination of groundwater and surface waters. As part of an effort to understand the groundwater-surface water interaction on the karst landscape, the MPCA investigated flow and nitrate concentration trends in three springs in the Root River Watershed in southeastern Minnesota from 2000-2010 (Figure Figure F 1) (Streitz 2012).

Figure F 1. Root River Watershed Study Area



The Root Watershed is located in an active karst region of Minnesota (Figure F 2). Karst landforms are concentrated in southeastern Minnesota and consist primarily of limestone. The springs included in the study were Lanesboro, Peterson and Crystal springs. Crystal Springs, located on the Whitewater River in northern Winona County was dropped due to a lack of data. Lanesboro and Peterson springs are both integrated into the Minnesota Department of Natural Resources fish hatchery operations. Because of this connection, discharge and nitrate concentrations have been monitored for over 20 years.

Figure F 2. Study Area and Hydrogeology of Southeast Minnesota



Spring discharge is controlled by the interaction between precipitation, topography, geology and climate. To understand these interactions, precipitation, water appropriations (withdrawals), and stream flow data was analyzed. Below are some basic conclusions:

- Based on average areal precipitation, rainfall in the Southeast region displays no significant trend over the last 20 years.
- Groundwater and surface water withdrawal trends have been increasing at statistically significant rates over the last 20+ years, with $p = 0.01$ for both trends.
- The average annual flow of the Lanesboro spring shows no trend over the period of the last 20 years.
- The Lanesboro spring average annual nitrate concentration shows a statistically significant increasing trend (Figure F 3).
- The Lanesboro spring shows a rising trend in nitrate load that is statistically significant, at $p<0.05$ (Figure F 4).
- The flow data for the main spring at Peterson spring shows no statistically significant trend, but it appears that flow was in a long term decline until 2007, when flow increased dramatically.

- The Peterson spring average annual nitrate concentration shows a statistically significant increasing trend (Figure F 5).
- The Peterson spring exhibits a strong rising trend in nitrate load that is statistically significant, at p=0.001 (Figure F 6).

Figure F 3. Lanesboro Spring nitrate-nitrogen average annual concentration (MPCA 2012)

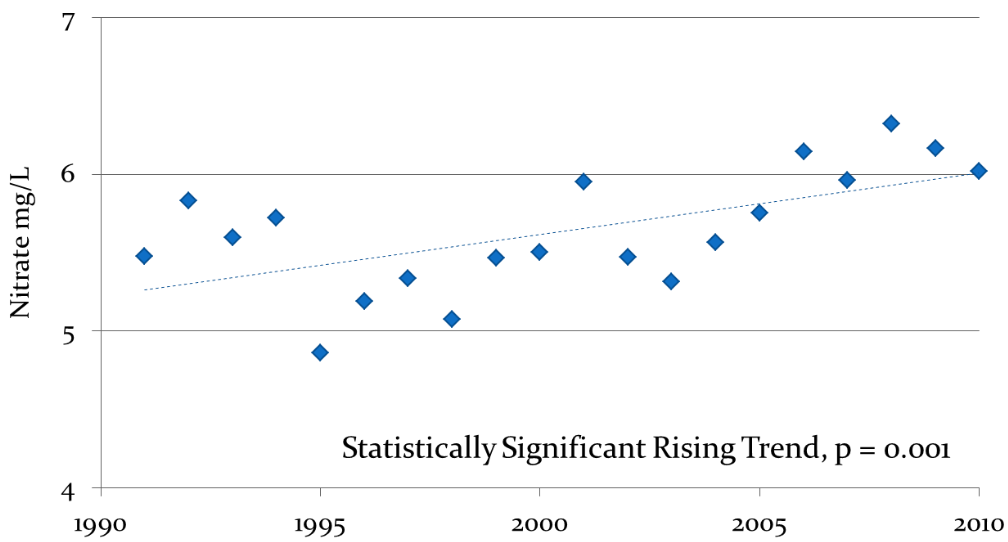


Figure F 4. Lanesboro Spring nitrate-nitrogen load (MPCA 2012)

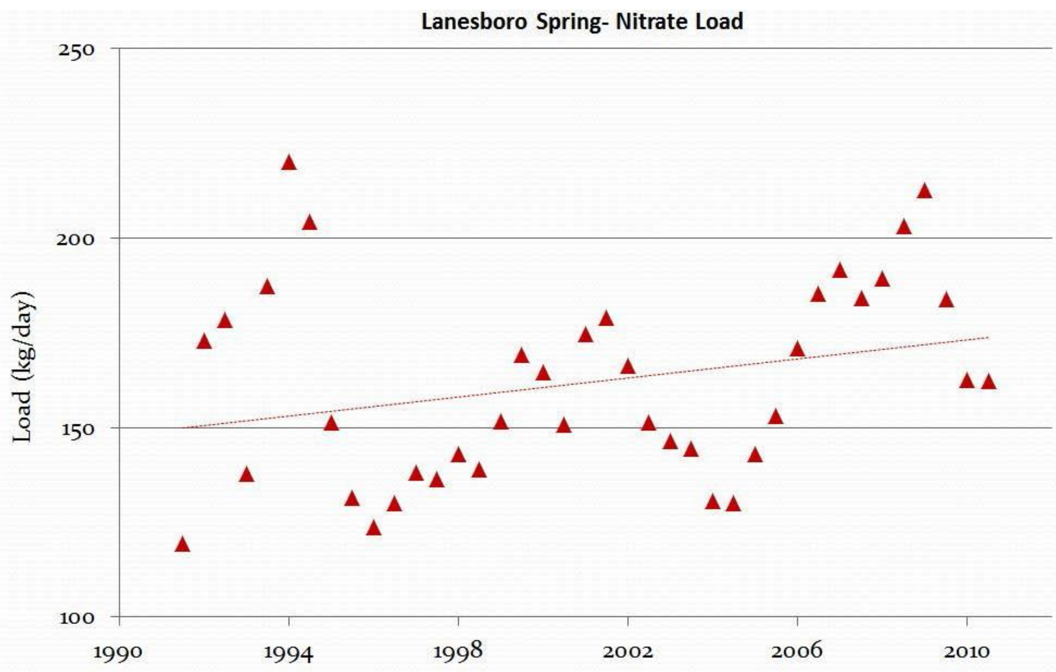


Figure F 5. Peterson Spring nitrate-nitrogen average annual concentration (MPCA 2012)

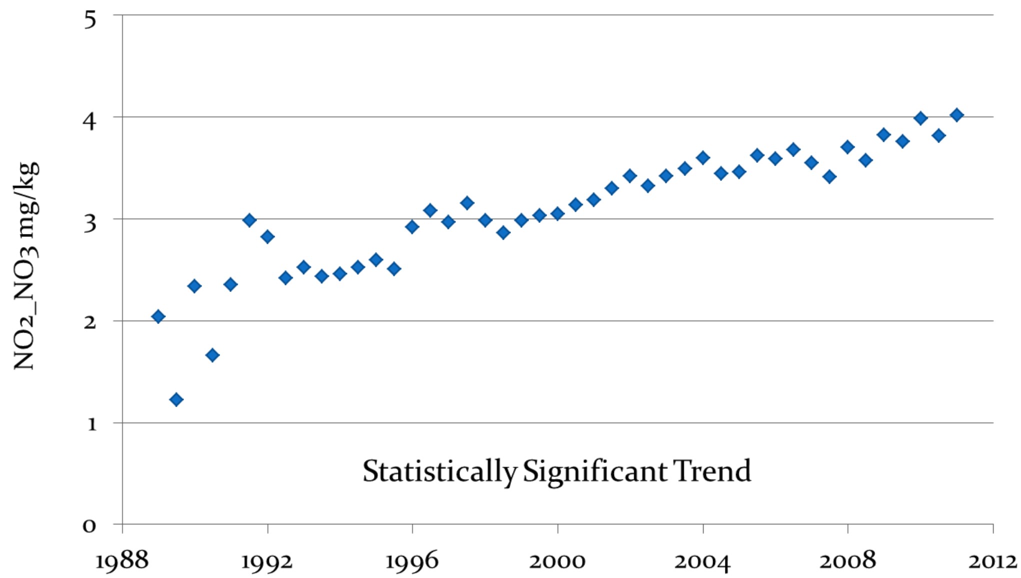
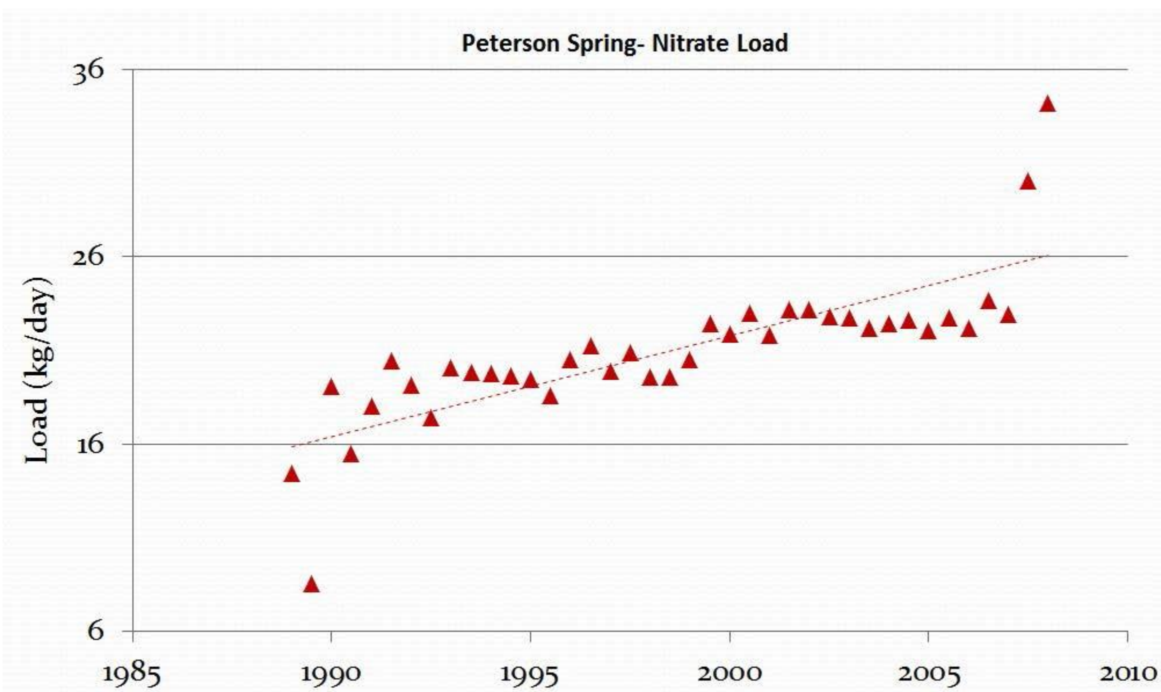


Figure F 6. Peterson Spring nitrate-nitrogen load (MPCA 2012)



References

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G. THE NITROGEN CYCLE, SOURCES AND TRENDS

The behavior of nitrogen in the environment is governed by a complex set of interrelated chemical and biological transformations. These reactions are summarized in the “nitrogen cycle” (Figure 12). The nitrogen cycle describes the inputs, pools, pathways, transformations, and losses of nitrogen in the environment.

The nitrogen cycle reactions are influenced by the interaction of numerous chemical, biological, environmental and management factors. The dynamic interplay of these factors complicates predictions of the behavior of nitrogen introduced into the environment. Knowledge of the dynamics of the nitrogen cycle is important to help understand how these multiple factors will interact to influence nitrogen behavior at a given site. Sound nitrogen management decisions can then be made based upon this knowledge.

Although several nitrogen species are involved in the cycle, the species which are of primary importance in the soil are nitrate-nitrogen (NO3-), ammonium nitrogen (NH4+), and organic nitrogen. The characteristics of these species and related processes are summarized below:

- **Organic nitrogen:** Organic nitrogen is the predominant nitrogen species in the soil profile. Organic nitrogen is not readily available for release into solution but must first be transformed to inorganic forms by microbial action (mineralization). Organic nitrogen may be the primary source of nitrogen in surface runoff but rarely contributes to groundwater contamination.

- **Nitrate (NO3-):** Nitrate is extremely soluble in water and its negative charge excludes it from adsorption onto sites in the soil colloid exchange complex. These characteristics render it highly susceptible to leaching and subsequent groundwater contamination.

- **Nitrite (NO2-):** Nitrite is an intermediate product in the conversion of ammonium to nitrate in the soil and is the species 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 (NH3) / ammonium (NH4+):** Ammonia (gas) is the primary form of nitrogen feedstock applied in fertilizers. It reacts to form ammonium immediately upon contact with water. Ammonium binds tightly to soil colloid surfaces and clay interlayers; it 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:

- **Mineralization**: The microbial degradation of organic nitrogen to produce the inorganic forms of nitrogen.

- **Net Mineralization**: The cumulative balance at the end of the growing season between mineralization and immobilization. Net mineralization is used frequently within this document when discussing nitrogen budgets and comparing quantitative amounts to other nitrogen sources.

- **Nitrification**: The microbial mediated oxidation of ammonium to nitrite and then to nitrate. This is the primary nitrate-producing reaction in the cycle. It is also a key to potential nitrogen loss in the cycle since nitrate can be lost from the root zone by leaching or by denitrification.

- **Immobilization:** The assimilation of inorganic forms of nitrogen by plants and microbes, producing various organic nitrogen species.

- **Denitrification:** The biochemical reduction of nitrate and nitrite to gaseous molecular nitrogen (N2) or a nitrogen oxide form nitrous oxide (N2O), nitric oxide (NO), or nitrogen dioxide (NO2). This is a primary volatile loss pathway to the atmosphere. Over 78% of the atmosphere is comprises of N2.

- **Volatilization:** The loss of ammonia to the atmosphere. This occurs primarily in the case of surface-applied urea fertilizers, animal wastes (which also contain urea), and during the application of anhydrous ammonia under conditions when the soils do not properly seal.

- **Leaching:** The process of mass and diffusive transport of solutes in water percolating through the soil. Nitrate is the principal nitrogen species 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.

AGRONOMIC AND EXTERNAL SOURCES OF NITROGEN

The potential sources of nitrogen to the soil system are many and varied. In an agronomic context, all nitrogen sources applied to a field should be taken into account in determining the appropriate nitrogen fertilizer rate. This multitude of potential sources greatly complicates the calculation of a nitrogen budget. For the purposes of this discussion, nitrogen sources will be defined in terms of agronomic (crop growth) inputs and external sources. The agronomic inputs are those sources which may be considered in a nitrogen budget for the purposes of crop production. The external sources are nitrogen sources which may contribute to groundwater contamination but are dissociated from agricultural production.

Agronomic Inputs:

- Soil organic matter and crop residue;
- Commercial fertilizers;
- Atmospheric deposition;
- Atmospheric fixation (legumes);
- Land-applied manure and other organic residues.

External Sources:

- Municipal Wastes;
- Septic systems;
- Feed lots (concentrated animal wastes);
- Turf grass (golf course, parks, private and public lawns);
- Landfills;
- Wildlife excretions.

Two notes should be made on the subject of nitrogen sources. First, 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. Secondly, it is important to recognize that nitrate occurs naturally in the soil system.

Theoretically, this means that the threat of nitrate contaminated groundwater is ubiquitous regardless of external inputs. However, in Minnesota there are no known cases of elevated nitrate levels in groundwater in an undisturbed situation. Background nitrate concentrations are generally considered to below 3 mg/L.

The University of Minnesota (U of M) and other land grant universities have conducted numerous research projects and subsequently produced numerous reports on nitrogen management and its relationship to environmental outcomes (Randall and Mulla 2001; Randall and Goss 2001; Laing 2008). These research efforts have primarily focused on cropland soils and its associated agronomic inputs.

At the time of this report writing, a highly related research project between the U of M, U.S. Geological Survey, and the Minnesota Pollution Control Agency (MPCA) reached its final completion (Minnesota Pollution Control Agency 2013). Researchers did an exhaustive investigation of nitrogen sources and contributions to surface and groundwater.

Project goals were:

- Assess soil nitrogen budgets for combinations of soils, climates, and land uses representative of the most common conditions in Minnesota;
- Assess nitrogen contributions to Minnesota rivers from primary land use sources and hydrology pathways; and
- Determine the watersheds which contribute the most nitrogen to the Mississippi River.

Figure 13 (Chapter 5) illustrates the major sources of nitrogen inputs to Minnesota cropland. It is noted that farmers don’t have direct control over some of the major pathways. Mineralization contributions account for greater than 40% of the inputs but due to the complexities of the nitrogen cycle, this source is the least understood. Similarly atmospheric deposition, although significantly less important, also needs to be considered. Mineralization rates are strongly influenced by many factors including soil type, organic matter content, climatic conditions and landscape position. In a very general sense, average mineralization and deposition credits are already built into the U of M’s nitrogen fertilizer recommendations. Due to mineralization variability, nitrogen fertilizer rate recommendations tend to be a range based on regional research rather than an absolute number.

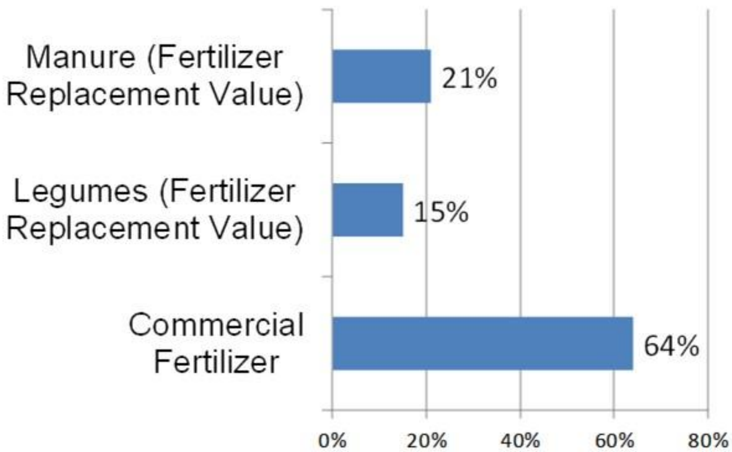
Alternatively, farmers have considerable management control over the fertilizer source characteristics, timing, placement and rate of commercial fertilizer. Complicating factors include the successful management of manure and legume sources. However, a sound science-based nutrient management approach can successfully account for many of the complicating factors under most cropping conditions.

MAJOR AGRICULTURAL SOURCES OF NITROGEN

Figure G 1 examines the same data set as Figure 13 but only looks at those sources that farmers have direct control over. Estimates of the relative contributions from the primary agricultural nitrogen sources including fertilizer, manures, and legumes are 64%, 21% and 15%, respectively. For comparative purposes, contributions from manure and legumes[1] are expressed in terms of “fertilizer replacement” values. Previous estimates (Minnesota Pollution Control Agency 2008) were 68%, 14%[2] and 18%, respectively, based on data from the 2002 Census of Agriculture. The importance of manure was slightly different in the two studies due to some minor differences in nutrient availability assumptions. Animal densities were similar, but the more recent study by the MPCA (2013) considered a much wider set of variables.

It is also important to note that the relative contributions of these three key nitrogen sources vary drastically from farm to farm and in many cases, from field to field.

Figure G 1. Controllable nitrogen sources applied to agricultural land (Modified from Wall et al. 2012)



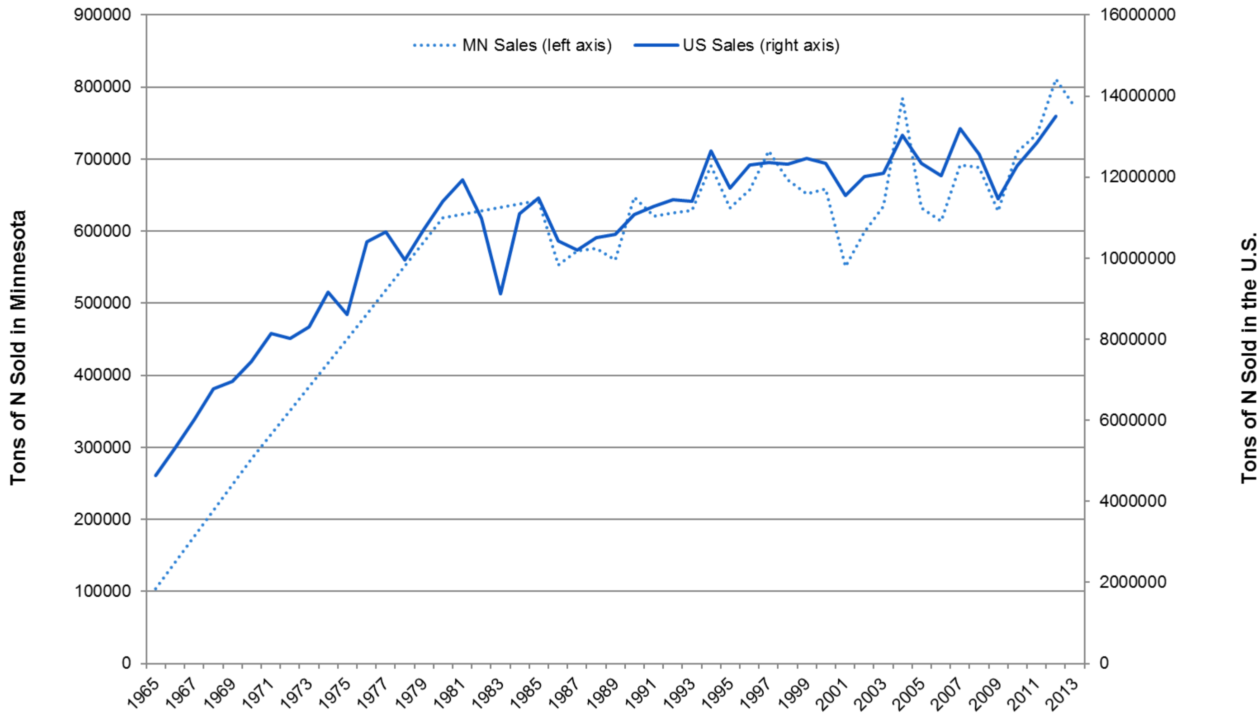
NITROGEN FERTILIZER SALES AND SOURCES

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 until the early 1960’s. The Tennessee Valley Authority
(TVA) and cooperative research programs in many U.S. agricultural colleges helped promote the adoption of fertilizer use. Commercial nitrogen fertilizer use eventually catapulted in the United States during the 1960’s and 1970’s as a result of educational efforts, lower costs, and the introduction of improved plant genetics.

[1] In the 2013 MPCA report, the amount of nitrogen which cropland legumes fixed from the atmosphere was estimated to be 612 million pounds (306,000 tons per year). When converting to “fertilizer replacement” value, it was assumed that the past soybean acres contributed 140,000 tons per year (7 million acres at 40 pounds per acre) and the alfalfa-clover acres would be terminated after the fourth year of production contributing 19,000 tons per year (2 million acres at 75 pounds per acre) for a legume “fertilizer replacement” value of 159,000 tons per year).
[2] Manure nitrogen contributions were calculated based upon the 2002 animal census for various species of livestock and poultry using nutrient output estimates from the Midwest Planner (Midwest Plan Service 1985). Output numbers are then reduced by 50% recognizing that there are significant storage and application losses due to gas emission losses of ammonia, uncollected manure under pastured conditions and other losses. These adjusted values represent the land-applied portion of manure that ultimately becomes available for plant uptake and is referred to as the “fertilizer replacement value of manure.”

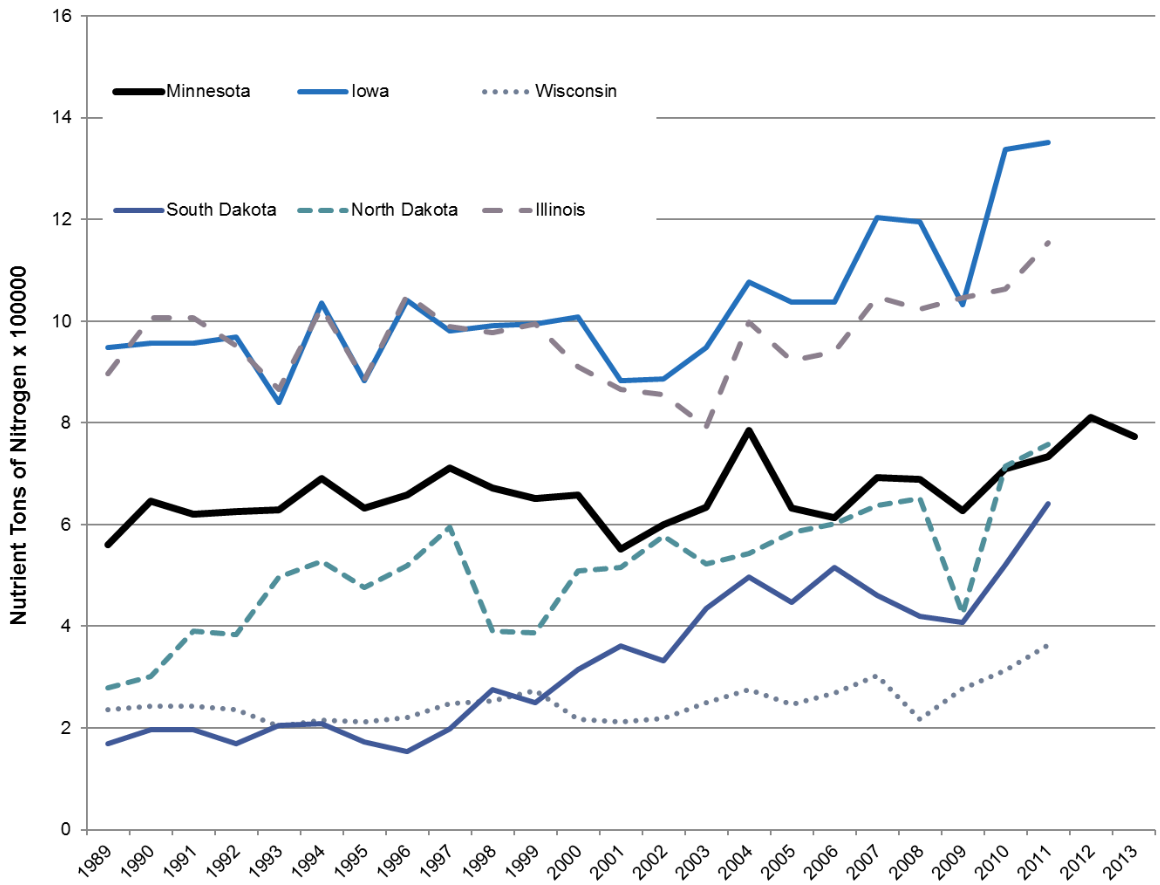
Minnesota’s historic nitrogen use (Figure G 2) tracks similar to the national trends.

Figure G 2. Commercial nitrogen fertilizer sales trends in Minnesota and U.S., 1965-2013



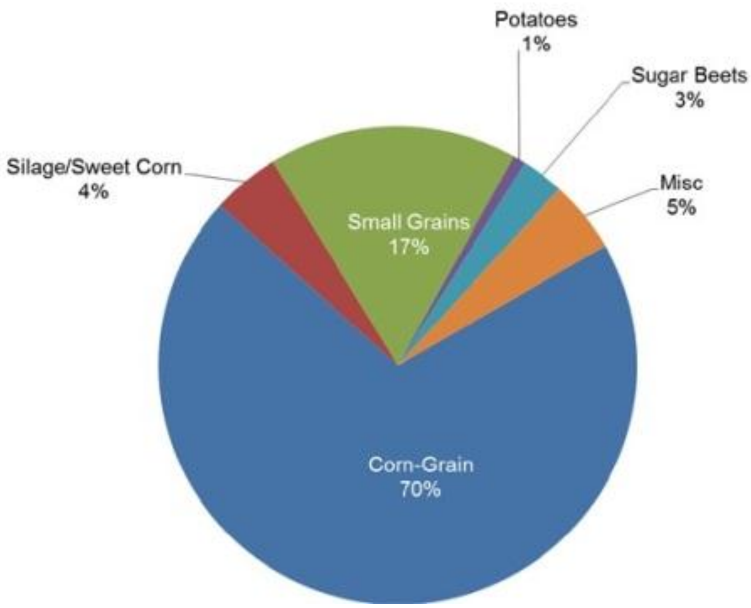
Minnesota's nitrogen fertilizer sales began to stabilize in the early 1980's. Over the past 20 years, statewide sales have averaged 660,000 tons per year and are trending slightly upward (Figure G 3). Fertilizer sales in other Upper Midwestern Corn Belt states have also shown slight upward trends. Both North and South Dakota have seen some rapid increases in nitrogen fertilizer sales which are most likely due to large increases in corn acres.

Figure G 3. Nitrogen fertilizer sales trends in neighboring states, 1989-2011



In order to better understand the potential fate of nitrogen fertilizer, it is important to establish a basic understanding of the usage and associated management. Obtaining accurate fertilizer use information directly from farmers can be problematic and therefore frequently limited. Consequently the statewide nitrogen fertilizer information reported here are approximations (Figure G 4). The key pieces of information needed to make these estimates are derived from the Minnesota Department of Agriculture's (MDA) annual statewide sales and the reported crop acres from the National Agricultural Statistics Service (NASS).

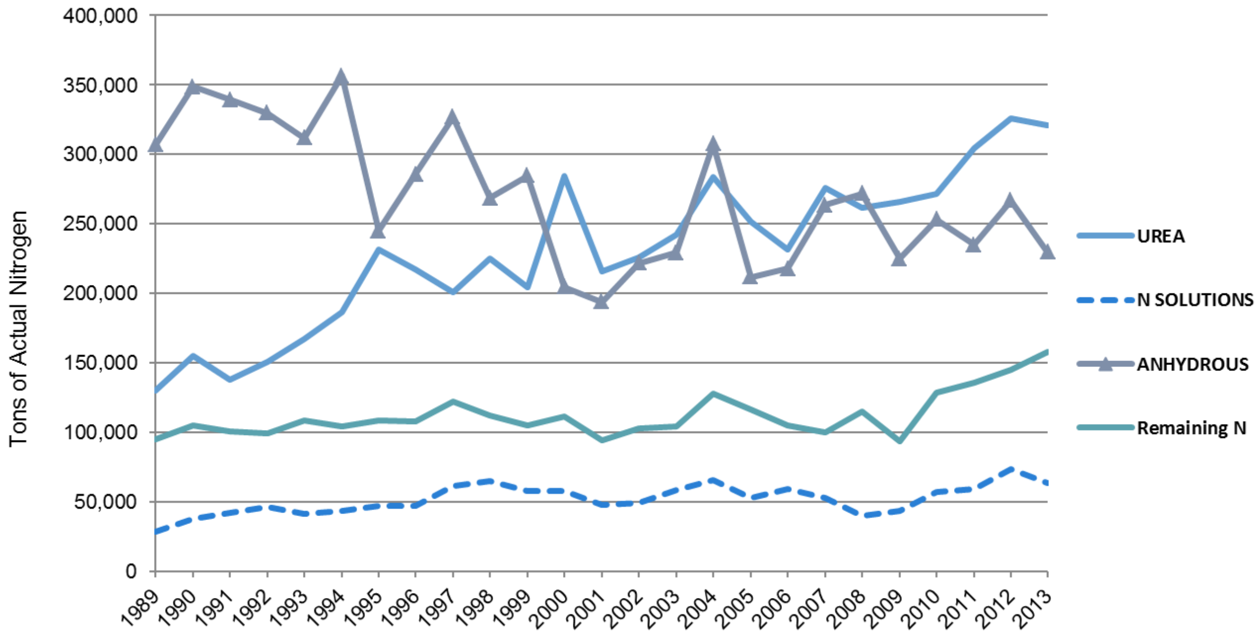
Figure G 4. Estimated nitrogen fertilizer distribution by crop type (MDA sales data and NASS reported acres from 1992-2011)



It is estimated that grain corn consumes approximately 70% of the nitrogen fertilizer sold in the state. With the recent increases in corn acres (2010 to 2013), those percentages have recently grown to 76 to 77%. Small grain consumption (defined here to include spring and winter wheat, oats, durum, barley, and rye) accounts for another 15 to 20%; this acreage can vary significantly from year to year. Silage corn and sweet corn (fresh market and canning) uses another 4 to 5%. Minnesota is a national leader in sugar beet production (0.5 million acres) which consumes another 3%. Statewide, the amount of nitrogen fertilizer used on irrigated and dry land potatoes is a very small percent although the per acre rate on irrigated potatoes is generally the highest compared to any other crop. Miscellaneous crops (5%) include edible beans, sunflowers, peas and some other minor crops.

Selecting the right nitrogen source is an important consideration. Minnesota's nitrogen best management practices (BMPs) recognized the importance in selecting the right source in partnership with timing, placement, rate and other factors. Anhydrous ammonia (82-0-0) was the dominant source throughout the 1970's, 80's and early 90's (Figure G 5). Historically, anhydrous has been the cheapest source. It also has been an excellent option for many farmers in a fall-application program because anhydrous is less prone to off-season leaching losses compared to other sources. However, because of safety concerns and increased regulations, the number of fertilizer dealerships offering anhydrous has steadily decreased during the 1990's.

Figure G 5. Trends in major nitrogen sources used in Minnesota, 1989-2013



In many cases, urea (46-0-0) has taken up the slack in anhydrous ammonia sales. For most applications in Minnesota, urea can be an excellent substitute when properly applied for most farmers. However, it does not have the versatility of anhydrous for fall application in the south-central part of the state. For the last decade, anhydrous and urea each supply approximately 35 to 40% of the state's nitrogen fertilizer. Liquid nitrogen fertilizer (28-0-0 and 32-0-0) account for another 9 to 10% of the sales. Miscellaneous sources, which include a very wide variety of dry fertilizer products, make up the balance.

These major nitrogen fertilizer sources have unique characteristics and require different management in terms of timing, placement, and methods for stabilizing. Minnesota's regionally-based nitrogen BMPs provide farmers with this type of information. For more information, please review the complete set of nitrogen BMPs by going to the University of Minnesota Extension Nutrient Management website: http://www.extension.umn.edu/agriculture/nutrient-management/nitrogen-best-management-practices/.

CROPPING TRENDS AND POTENTIAL NITROGEN LOSSES OF MINNESOTA'S MAJOR CROPS

Crops vary widely in their physiological nitrogen needs, timing of uptake, and their ability to capture nitrogen inputs before it becomes a water quality concern. Crop type is one of the most profound drivers influencing water quality and it is extremely important to understand these relationships. Numerous research studies by the U of M and other land grant universities have clearly documented the importance of crop selection on the potential impacts on nitrate leaching losses. A collection of outstanding summaries have been compiled as a result of the relatively recent concerns associated with the hypoxic zone in the Gulf of Mexico (Laing 2008).

Some general guidelines found in Table G 1 provide a listing of the major crops grown in Minnesota, the typical nitrogen requirements, unique characteristics of that crop, and the relative nitrate leaching losses.

Table G 1. Typical nitrogen requirements and potential impacts on nitrate leaching losses for crops/cover in Minnesota (MDA and MDH)

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	Spring Applied: M-H; Fall Applied: H-VH; Irrigated: M-H; Manured: M-VH
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 inputs	NA	Dependent upon grazing pressure; Generally L
CRP Mixtures	Application at establishment	Mixtures vary but diverse systems tend to be the most conservative	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

*Very High=VH, High=H, Medium=M, Low=L, Very Low=VL

Crop selection, as reported by the NASS over the past ninety years, has changed dramatically. Minnesota once routinely raised over 8 million acres of small grains each year (Figure 16). Acres dropped significantly in the 1950's and again during the 1980's and 1990's. Over the past decade, there are approximately 2 million acres 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; typically grown in areas of low groundwater vulnerability; and moderate nitrogen inputs due to lodging concerns.

Corn acres have been steadily increasing for the last ninety years. This crop has high nitrogen requirements and has a narrow uptake period. Minnesota's nitrogen BMPs have a number of options to insure that this crop has the nutrients needed during this critical uptake period. Other nitrogen-demanding crops are relatively small on a state perspective but can have significant impacts (both economic and environmental) on a local level.

Looking back at the trends in "legume" crops since the 1920's (Figure 17), 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.

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 1940's and has steadily increased to about 7 million areas. Provided with the proper nitrogen-fixing bacteria (via inoculum), soybeans are highly capable of supplying its own nitrogen needs as well as utilizing residual soil nitrate from the previous crop.

Between the 1920's and 1960's, amounts of nitrate leaching below the root zone were probably relatively small compared to recent years. The major changes over the past ninety years are: 1) the additional influx of commercial fertilizers (Figure 15); 2) substantial more acres of nitrogen demanding crops (Figure 16); and 3) replacement of nitrogen conserving crops, such as alfalfa, clovers, pasture and hay grasses, with soybeans (Figure 17). These changes in aggregate contribute to an increased risk of nitrate entering groundwater. If these changes continue on the landscape, it suggests an ongoing increased risk nitrate loading to groundwater.

TRENDS IN N FERTILIZER USE ON MAJOR CROPS, PRODUCTION AND FERTILIZER USE EFFICIENCY

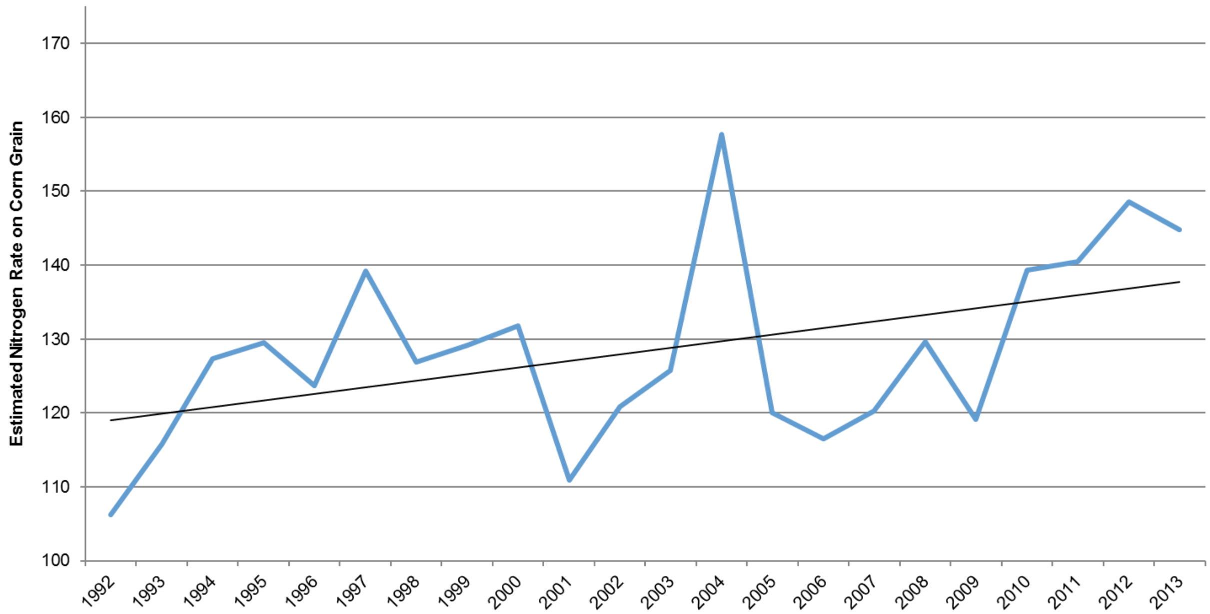
Generally, nitrogen fertilizer rate is the most important factor in understanding potential environmental consequences. Figure 18 illustrates the important relationship between nitrogen fertilizer rates, crop response, and nitrate leaching losses. Identifying the optimum nitrogen rate is critical in balancing the production aspects with environmental concerns associated with water quality.

Since the writing of the original Nitrogen Fertilizer Management Plan (1990), there has a been significant advancements made in understanding nitrogen fertilizer use and the associated management practices that Minnesota farmers implement to optimize economic and environmental returns. Chapter 6 discusses these survey studies, and other methods for understanding current fertilizer practices.

Establishing credible data quantifying nitrogen rates that farmers typically use on their farming operation can be extremely complicated. Factors such as crop rotation, mineralization rates, and manure applications need to be understood for the reported rates to be meaningful. Additionally, it is not uncommon for farmers to use different rates for specific fields based upon years of past experience. Making things even more complex is the fact that a significant number of farmers are now applying multiple nitrogen rates within a given field through soil zoning or other variable rate techniques.

The MDA has been estimating nitrogen fertilizer use on grain corn since 1992. The MDA's approach used the reported annual statewide sales data as the starting point. Sales included both primary and secondary nitrogen sources such as nitrogen contributions from MAP and DAP. Using the verified NASS reported acres for all crops, MDA staff then used the best available use information from other existing surveys and university input for all crops other than grain corn. The remaining balance was then divided across all reported corn acres. Rates over time are provided in Figure G 6.

Figure G 6. Statewide estimates of nitrogen fertilizer rates on grain corn, 1992-2013

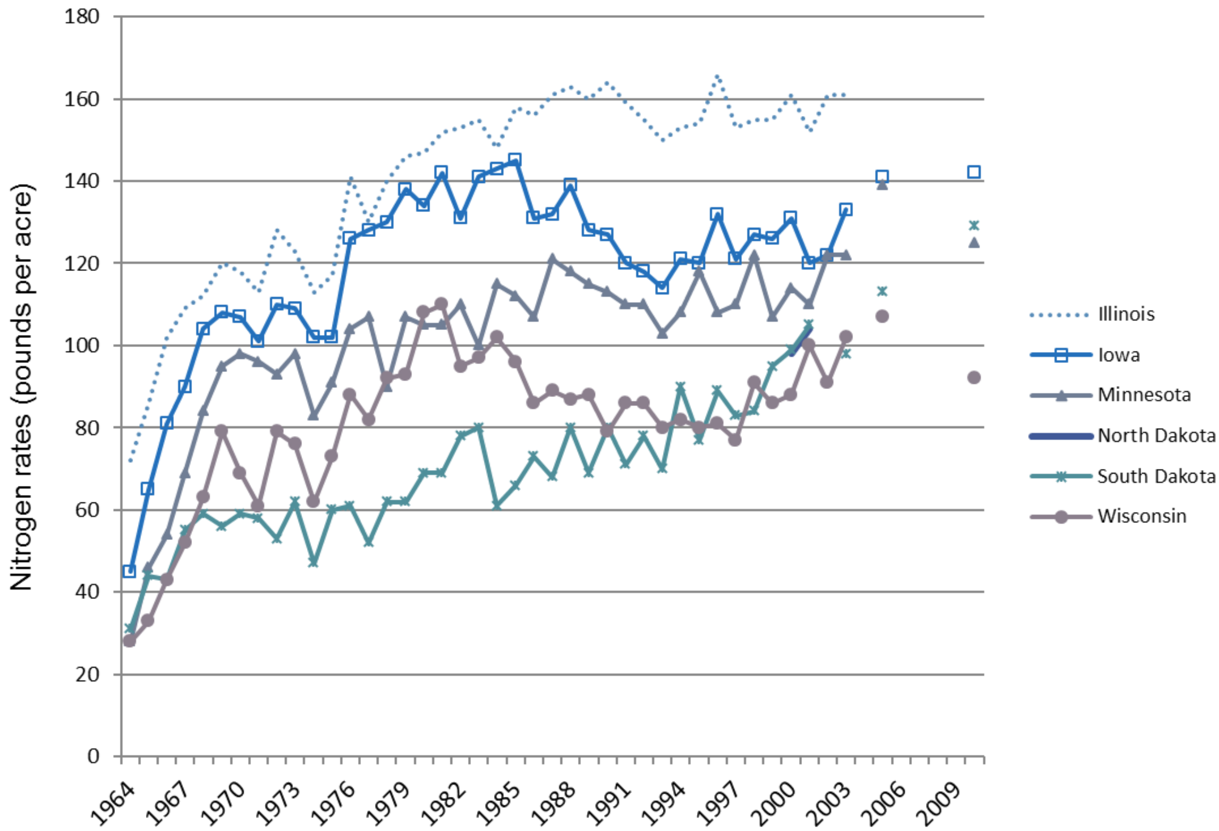


Due to the fact that the relationship shown in Figure G 6 is based upon sales data, there tends to be considerable year to year variability. Spikes such as shown in 2004, followed by subsequent slump, were probably caused by the short term occurrence of buying fertilizers on the futures market. The actual product more than likely did not get applied until one to three years after the recorded sale. Based upon the MDA estimates, it appears that across all corn acres, the typical nitrogen fertilizer rate on corn tends to be between 120 to 140 pounds per acre. Rates increased very slightly (4%) from 1992 to 2011. Average rates between the time periods of 1992 to 2001 and 2002 to 2011 were 124 and 129 pounds acre per year, respectively. Estimated nitrogen fertilizer rates since 2010 increased 5 to 10 pounds per acre and were likely to be directly linked to high corn prices.

The NASS has also made estimates of fertilizer rates over the past fifty years. The nitrogen fertilizer rate estimates for corn shown Figure G 7 are from the ARMS [3] survey program. The NASS collected this information annually until 2003. Because of federal budget cuts, ARMS activities have become highly sporadic. It is very important to note that the sampling population used in ARMS is used primarily for economic analysis and is heavily weighted on factors such as farmer age, income and demographics. The resulting sampling population used by ARMS is approximately 150 individual corn fields which is intended to represent 7 to 8 million acres across the state. Additionally, the NASS does not collect any information on crop rotation, manure application, etc. It is believed that the NASS approach generally underestimated nitrogen rates and similar observations were reported in Iowa. Typically using the NASS rates and reported acres, it was very difficult to account for 10 to 20% of the nitrogen fertilizer sold statewide.

[3] Agricultural Resource Management Survey. This survey is USDA's primary source of information of the financial condition, production practices, resource use, and economic well-being of America's farm households.

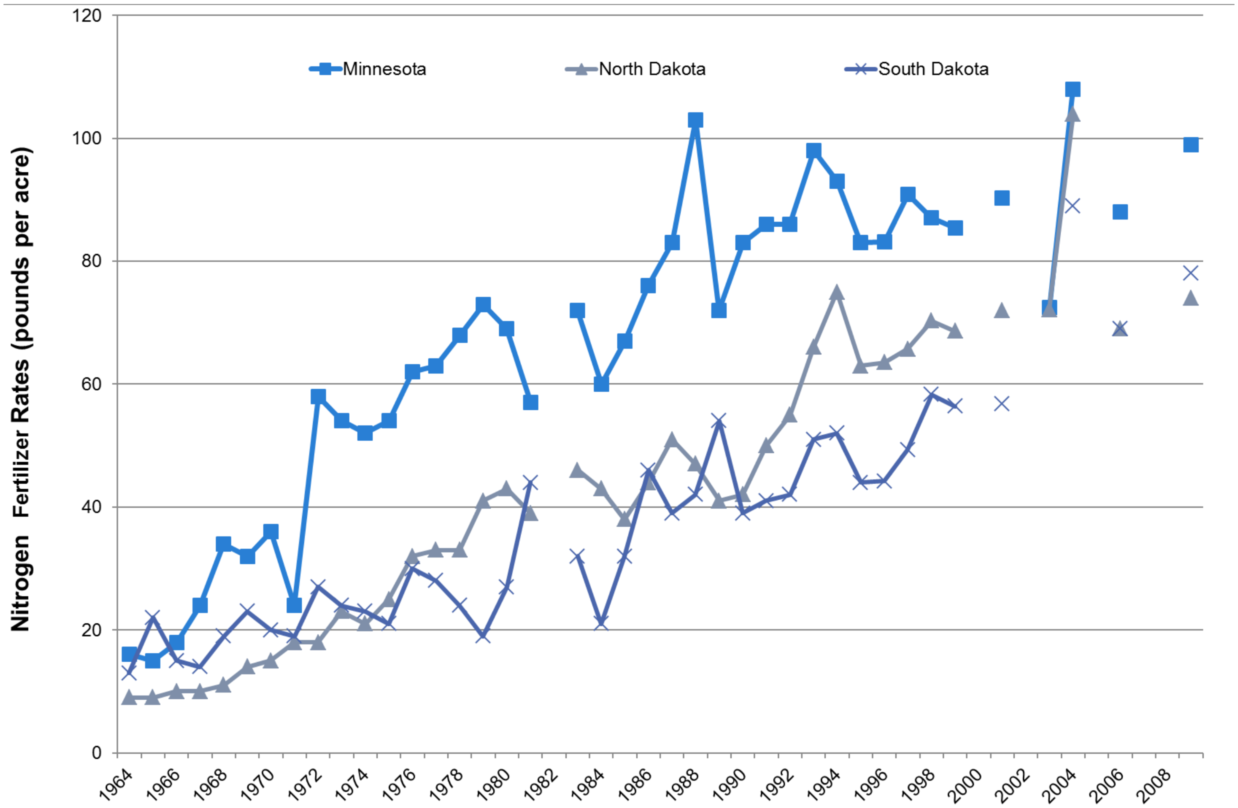
Figure G 7. Nitrogen rates on corn in neighboring states, 1964-2010. Note that the data set from North Dakota is very limited.



The NASS/USDA fertilizer use information, because of the already discussed limitations, is probably the most useful with general trends over time. When comparing trends on estimated nitrogen rates on corn, it appears that Minnesota rates follow somewhat similar patterns to neighboring states (Figure G 7). Similar to the rate estimates provided in Figure G 6, this data also suggests that rates on corn are trending slightly upward over the past twenty years.

The NASS/ERS included wheat in their annual surveys since the 1960's (**Error! Reference source not found.**). This information suggests that rates, similar to corn, rose rapidly and then stabilized over the past 10 to 15 years. Lodging from too much nitrogen can cause excess top growth, weakened stems, and subsequent harvesting problems from wind damage.

Figure G 8. Nitrogen rates on wheat in neighboring states, 1964-2010



Sugar beets are an excellent example of the need for balancing production with product quality. The sugar beet industry, with the assistance of North Dakota State University and the U of M, determined that there is a very significant negative relationship between nitrogen fertilizer rates and the amount of extractable sugar produced per acre. Extensive research has led to the conclusion that 110 to 130 [4] pounds of nitrogen per acre is adequate for production of high yielding sugar beets with good quality (BMPs for Nitrogen Use in Southwest and West Central MN). Information on commercial fertilizer rates on other Minnesota crops is very limited.

There are some other interesting trends that have developed over the last 20 years between inputs and outputs. Nitrogen fertilizer consumption on corn has increased about 13%[5] corn acres have steadily increased by 8% [6](Figure G 8). However, the interesting outcome is that the corresponding outcome (bushels produced) has increased about 40% [7]over the same time period.

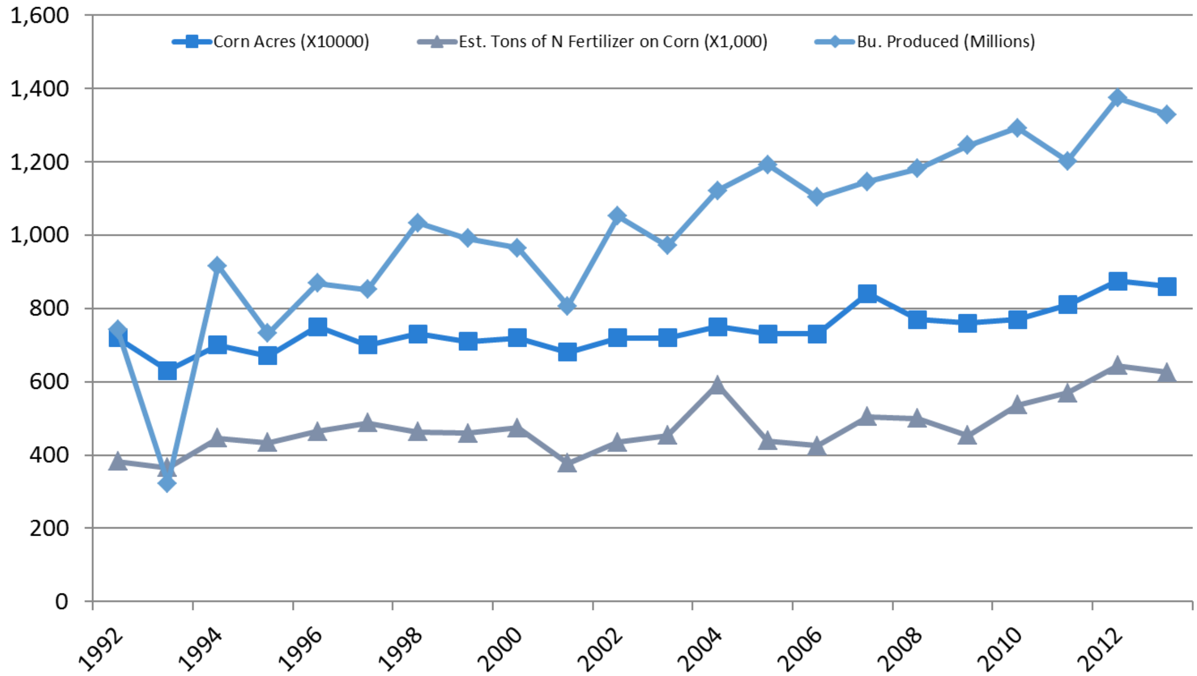
[4] Total nitrogen is the sum of fertilizer nitrogen and soil residual nitrate measured to a depth of four feet in late fall.

[5] Annual consumption by corn between 1992-2001 and 2002-2011 were 435,100 and 490,100 tons, respectively

[6] Average corn (grain) acres between 1992-2001 and 2002-2011 were 7.0 and 7.6 million acres, respectively.

[7] Average bushels of corn grain produced between 1992-2001 and 2002-2011 were 822,390 and 1,150,280 million, respectively.

Figure G 8. Relationship between grain corn production, corn acreage and nitrogen fertilizer inputs



This relationship suggests that corn farmers are successfully getting more production from each pound of nitrogen fertilizer. From the environmental perceptive, this trend is positive. However at this time, the causative factors or the direct environmental implications are not well understood.

Figure 19 illustrates the improvements in nitrogen fertilizer use efficiency. Bushels produced per pound of nitrogen fertilizer have steadily increased from roughly 0.8 to 1.3 over the past twenty years. Many researchers suspect that genetics is a significant driver for the increases. Root systems are larger, deeper and denser resulting in more effective nitrogen update and utilization. General adoption of the 4R concept (right rate, right source, right timing and right placement) is another reason. Improved weed control and the use of different hybrids in different parts of the landscape are other important improvements.

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H. REGIONAL TRENDS AND OPPORTUNITIES FOR ADVANCEMENTS IN NITROGEN MANAGEMENT

The nitrogen best management practices (BMPs) developed by the University of Minnesota (U of M) vary by region, discussed in Chapter 6. This appendix explores regional trends and opportunities for advancement in nitrogen management.

BMP REGION: SOUTHEAST

Marketplace Trends Over the Past 20 Years: The dairy industry has changed significantly over this time period in this region. Since the early 1990's, there has been an 11% reduction in dairy cows, a 42% reduction in alfalfa acres, and a 60% reduction in the number of dairy operations. Many of the small operations, commonly referred to as "scrape and hauls" (no manure storage structures), have been greatly reduced. With the loss in dairy numbers, significant amount of alfalfa, clover, and pasture land acres have been converted to corn/soybean systems. Corn acres have risen 16% over the past 20 years. This has put additional pressure on protecting groundwater resources from nitrate loading.

There are over 55,000 irrigated acres in Dakota and northern Goodhue Counties and this number continues to slowly expand. This will increase the acreage of high nitrogen demanding crops such as potatoes and corn.

Opportunities for Advancements in Nitrogen Management: A recent survey found that the vast majority of nitrogen fertilizer was applied as a spring preplant and the average application rate on corn was 140 pounds per acre (Bierman, et al. 2011). Most of these reported fields were following soybeans with no recent manure applications (past 5 years). Farmers could potentially reduce fertilizer inputs by 20 to 30 pounds per acre through additional soybean crediting.

There have been significant concerns about fall applications in this area. Fall application is a highly visible operation that area farmers and non-farmers are very sensitive to and occasionally complaints are reported to either Minnesota Department of Agriculture (MDA) or county staff. The most recent report (Bierman et al. 2011) indicated that 5% of the nitrogen going onto corn is fall applied. Additional follow-ups with dealerships confirmed that there is a small percentage that does get applied on the heavier soils outside of the traditional karst regions. Early fall applications of manure is probably a much more significant threat.

Proper manure crediting has historically been one of the greatest opportunities for advancements in nutrient management. Several projects, such as within the Whitewater River watershed, has made significant advances in crediting. Future MDA/National Agricultural Statistics Service (NASS) surveys will help better understand the current crediting level.

BMP REGION: SOUTH-CENTRAL

Marketplace Trends Over the Past 20 Years: The hog industry has changed dramatically over this time period. Most of the small operations are no longer in existence, having been replaced by up to 4000 head confinement barns. Many counties in this region have doubled or tripled the hog numbers in the past 20 years. With the increase in hog numbers, manure has become an important nitrogen resource. This region is also the location of many of the counties with the highest production of corn and soybeans.

Opportunities for Advancements in Nitrogen Management: Fertilizer rates on corn are the highest (146 pounds per acre) in the state (Bierman et al. 2011). Nitrogen rates (pounds per acre) ranged from 128 (Rice) to 159 (Faribault). Rates on corn following soybeans frequently exceeded the U of M recommendations by 20 to 30 pounds per acre. Future educational programs are needed to insure that farmers can enjoy the fertilizer savings while reducing nitrate losses to surface waters via tile drainage. Improvements in management will probably have minimal impacts on groundwater resources in the majority of South-Central Minnesota but could be important in subsurface drainage waters.

Over 40% of the primary nitrogen goes on in the fall making this a very important regional practice. Fall nitrogen in this region needs the additional protection from nitrification inhibitors. Based on the Bierman report, half the acreage is using an inhibitor with anhydrous ammonia. Future educational efforts should strive to reduce acres not being treated with inhibitors. Expanded use of inhibitors should help reduce "insurance nitrogen." Based on expanded analysis[1] of the Bierman (2011) report, fall applications are 12 pounds per acre greater than spring applications in a corn-soybean rotation.

Soil temperatures are also a critical consideration when fall-applying. Currently there is a minimal understanding of how closely temperatures are being considered prior to fall applications. Future educational efforts should focus on identifying ways to make this type of information readily available and considered prior to fall applications.

Fall application of urea is not recommended in this region. In some areas, crop retailers have discontinued selling anhydrous ammonia because of safety concerns. Where this happens, localized education efforts need to focus on the promotion of spring applications.

Lack of proper manure crediting is a statewide issue. Over the past several decades, there has been some critical research completed on nutrient availability especially on hog manure. Through improved recommendations and attention to spreader calibration and technology, livestock farmers have been able to realize the benefits from manure crediting. Many of the spreading challenges have been resolved through the use of certified commercial manure applicators.

BMP REGION: SOUTHWEST AND WEST-CENTRAL

Marketplace Trends Over the Past 20 Years: Relative acres of the major crops has been relatively stable in this region. Perhaps one of the large improvements in terms of fertilizer efficiencies has been in the sugar beet area (includes the Northwest BMP Region). Rates and management have changed drastically when the interaction between beet quality and nitrogen inputs was understood. Large increases in the number of hog systems over the past two decades has changed some of the nutrient management challenges on a localized level. Most of the small operations are no longer in existence having been replaced by confinement barns, often of 6000 head or greater. Many counties in this region have doubled or tripled the hog numbers in the past 20 years. With the increase in hog numbers manure has become a common resource for nitrogen fertilizer. This region is also the location of many of the counties with high production of corn and soybeans. Turkey operations are also a common place in this region with modest growth over the past twenty years.

Opportunities for Advancements in Nitrogen Management: Nitrogen rates (pounds per acre) on corn averaged 139 pounds per acre ranging from 117 (Douglas) to 155 (Redwood). Rates on corn following soybeans frequently exceeded the U of M recommendations by 20 to 40 pounds per acre. Future educational programs are needed

[1] Personal Communication with Denton Bruening, MDA.

to insure that farmers can enjoy the fertilizer savings while reducing nitrate losses to surface waters via subsurface drainage. Improvements in management will probably have minimal impacts on groundwater resources in the majority of this region but could have significant impacts in recharge areas.

Roughly 50% of the primary nitrogen goes on in the fall making this a very important regional practice. Unlike the South-Central Region, the nitrogen BMPs do not recommend nitrification inhibitors or Environmentally Smart Nitrogen (ESN) because there is lower probability of seeing a crop response factoring in the additional economic costs.

Soil temperatures are also a critical consideration. Currently it is difficult to determine how closely temperatures are being considered prior to applications. Future educational efforts should focus on identifying ways to make this type of information readily available and considered prior to fall applications.

In this region, farmers have several nitrogen source options for fall application with either anhydrous ammonia (AA) or urea being acceptable; urea ammonium nitrate (UAN) is not recommended. It is very likely that farmers would attempt to switch to this highly soluble source.

Lack of proper manure crediting is a statewide issue. Over the past several decades, there has been some critical research completed on nutrient availability especially on hog manure. Through improved recommendations and attention to spreader calibration, livestock farmers have been able to realize the benefits from manure crediting. Many of the spreading challenges have been resolved through the use of certified commercial manure applicators.

BMP REGION: NORTHWEST

Marketplace Trends Over the Past 20 Years: Similar to the West-Central Region, perhaps one of the large improvements in terms of fertilizer efficiencies has been in the sugar beet area. Rates and management have changed drastically when the interaction between beet quality and nitrogen inputs was understood. This area has seen a significant change from wheat to more corn and soybeans.

Opportunities for Advancements in Nitrogen Management: Nitrogen rates on corn were the lowest in the state (131 pounds per acre, (Bierman et al. 2011)) with a very large percentage (89%) going on in the spring. Due to the high pH soils, atmospheric losses from non-incorporated urea may pose the biggest economic threat to farmers. Soil testing for nitrogen, especially on wheat and beets, is also common. Wheat was the dominate crop in this region. Farmer's practices for nitrogen management are not well documented in regards to wheat. Likewise nitrogen management for potatoes is not well documented in this region.

Documenting nitrogen management for wheat and potatoes would provide a basis to analyze nitrogen use. Providing nitrogen management education for farmers adapting corn and other southern crops in their rotations would also be beneficial. Future MDA/NASS surveys will help better understand the current crediting level.

BMP REGION: COARSE-TEXTURED SOILS

Marketplace Trends Over the Past 20 Years: Irrigation development has had a profound impact on localized areas within the Central Sands and Dakota/Goodhue Counties. Statewide, irrigated acres have increased by 9% over the last decade. Some counties, such as Morrison, have shown irrigated acreage increases over 20%.

Opportunities for Advancements in Nitrogen Management: Nitrogen rates ranged from 112 pounds per acre in Isanti County to 162 pounds per acre in Chisago County. Timing indicated that 95% of nitrogen fertilizer was applied either in the spring (70%) or as a split application (25%). The area that warrants the greatest education resources in the coarse-textured soil will undoubtedly be irrigation water management. As irrigation acres continue to expand, it is imperative that farmers are provided with the knowledge and tools to accurately manage water and nitrogen as they transition from low input, dry land management into highly managed irrigated crops.

I. MDA PRIVATE WELL SAMPLING AND SITE INVENTORY GUIDANCE

GROUNDWATER NITRATE-NITROGEN TOWNSHIP SAMPLING

Private well and/or irrigation well water samples will be collected from townships in sensitive areas.

Groundwater Monitoring Data Analysis:

1. Summary statistics of groundwater nitrate-nitrogen results.
2. Summarize survey information which includes well depth, well age, and well construction. Wells that are of hand-dug construction will not be included in the statistical data analysis.
3. Collection of all relevant groundwater information including, but not limited to:
    - Has a geologic county atlas been conducted?
        - If yes, many well logs are available and may be linked to the County Well Index.
    - What is the drinking water profile of the community? What is the ratio of well types?
    - Age dating information available?

NITROGEN FERTILIZER SOURCE CONFIRMATION

Nitrogen fertilizer source will be confirmed before a township moves into Level 3, which is regulatory. Wells with high (>5 mg/L) nitrate-nitrogen results will be screened with the following possible sources:

1. Septic Sources of Nitrate:
    - Are there septic systems in the immediate vicinity of the well(s) that may be impacting groundwater?
    - Is the area served by a municipal sanitary sewer?
    - What is the general condition of septic systems in the area? Percent failing? Are they required to be checked at point of sale?
    - Are there other parameters that may suggest septic systems could be a nitrate contamination source; e.g. fecal coliform, caffeine, etc.
2. Feedlot Sources of Nitrate:
    - Are feedlots in the area?
    - Is manure commonly applied in the area?

3. Land Use Practices:

    - What percent of the land is in corn, potatoes, sod farms, or other crops that may have significant nitrate applications in the area of concern?

    - Is irrigation taking place in the area?

4. Other Nitrate Sources:

    - Are significant quantities of wastewater applied in the area of concern?

J. REGULATED MITIGATION GUIDANCE

This guidance document describes the circumstances under which regulations may be adopted to accomplish mitigation goals. The following are the key elements from Minnesota Statutes, section 103H.275 regarding the adoption by rule of Water Resource Protection Requirements (WRPRs) to protect groundwater:

1. WRPRs may only be adopted if best management practices (BMPs) are proven to be ineffective;
2. WRPRs must be commensurate (proportional) with the groundwater pollution;
3. WRPRs must be consistent with the degradation prevention goal of the Groundwater Protection Act, and be designed to prevent and minimize the pollution to the extent practicable;
4. WRPRs must be designed to prevent the pollution from exceeding Health Risk Limits (HRLs); and
5. WRPRs must be based on –
    a. Use and effectiveness of BMPs
    b. Nitrogen fertilizer use and practices contributing to the pollution detected
    c. Economic factors
    d. Availability
    e. Technical feasibility
    f. Implementability
    g. Effectiveness

Based on these statutory requirements, the following is general guidance that will be used by the Minnesota Department of Agriculture (MDA) when evaluating the need for proposed adoption of WRPRs by rule:

1. WRPRs may be adopted by the commissioner if:
    a. BMPs are proven to be ineffective; and
    b. The commissioner determines that regulatory action is required because of significant or widespread exceedances of the HRLs.

OR

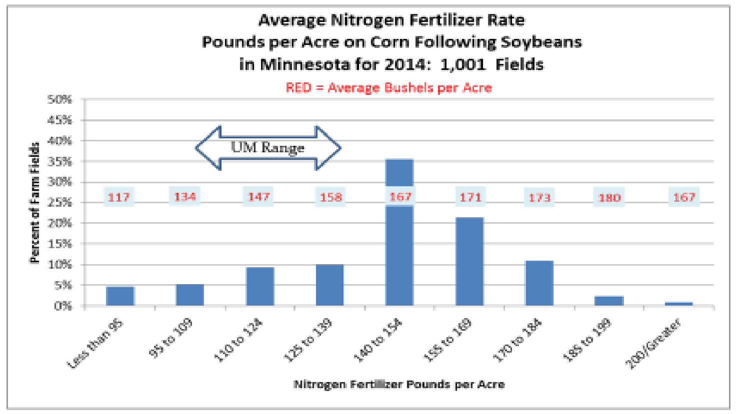
2. WRPRs may be adopted by the commissioner if:
    a. BMPs are proven to be ineffective; and
    b. One of the following conditions exist:
        i. The pollution exceeds, or is at risk of exceeding, the HRLs; or
        ii. The WRPRs would be proportional with the groundwater pollution.
    c. If the BMPs are, or appear to be, ineffective, and BMP adoption data supports that the BMPs are being adopted, then other tools will be explored and considered in order to achieve the goals of the Groundwater Protection Act.

While prevention of groundwater degradation (i.e., zero pollution) is a goal of the act, it is not a requirement. The act repeatedly uses the term “to the extent practicable” and directs the MDA to recognize potential limitations to achieving non-degradation, and that non-degradation may not in some circumstances be practicably achievable. This is further reemphasized by the requirement that WRPRs must be proportional with the groundwater pollution.

If successful, the BMPs will provide for the minimum amount of nitrogen fertilizer to be used while still achieving economic profitability. It is possible that some contamination of groundwater at concentrations below the HRLs will occur. Under the Groundwater Protection Act, it is recognized that for some human activities the degradation prevention goal cannot be practicably achieved; however, pollution should be prevented and minimized to the extent possible.

The act directs similar goals and considerations for the development of both BMPs and WRPRs. Both are intended to prevent and minimize pollution to the extent practicable in consideration of several specific and similar criteria. Therefore, if required, WRPRs should be similar to the BMPs.

NASS Corn Grower N Survey-2014
% of Fields Within UM Recommended N Ranges
for Corn Following Soybeans---Statewide



UM N Guidelines Using 0.1 MRTN: 105-130 lb/A DATA: NASS Corn Grower N Survey-2014

Non-Manure Corn within a C/S Rotation (Using the Upper Rate)

Used 2014 Corn acres and assumed 75% in a corn-soybean rotation — 2014 N Sales

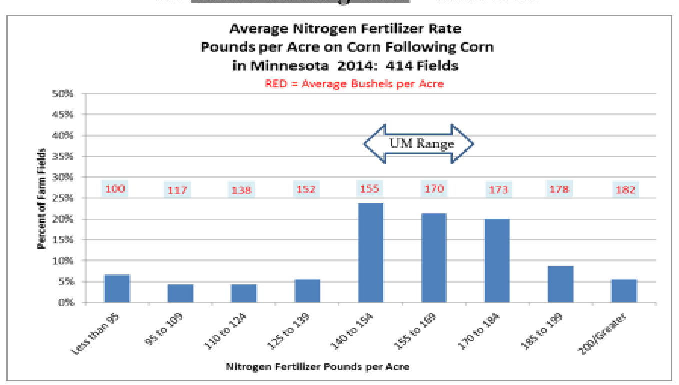
	8200000	75%	6150000		779199
	Non-Manure	80%	4920000		
N Rate Range	Midrange	140	% Acres	Acres	Excess Tons
140 to 154	147	7	36%	1771200	6199
155 to 169	161	21	21%	1033200	10849
170 to 184	177	37	11%	541200	10012
185 to 199	192	52	2.5%	123000	3198
Over 200	207	67	1.0%	49200	1648
total					31,906
					4.1%
					0.0091
				Weighted	18.1

Non-Manure Corn within a C/S Rotation (Using the Mid-Range)

Used 2012 Corn acres and assumed 75% in a corn-soybean rotation — N Sales for 2014

	8200000	75%	6150000		779199
	Non-Manure	80%	4920000		
N Rate Range	Midrange	120	% Acres	Acres	Excess Tons
140 to 154	147	27	36%	1771200	23911
155 to 169	161	41	21%	1033200	21181
170 to 184	177	57	11%	541200	15424
185 to 199	192	72	2.5%	123000	4428
Over 200	207	87	1.0%	49200	2140
total					67,084
					8.6%
					0.0191
					38.1

NASS Corn Grower N Survey-2014
% of Fields Within UM Recommended N Ranges
for Corn Following Corn---Statewide



UM N Guidelines Using 0.10 MRTN: 145-170 lb/A DATA: NASS Corn Grower N Survey-2014

Non-Manure Continuous Corn (Using the Upper Rate)

Used 2012 Corn acres and assumed 10% in a corn-corn rotation

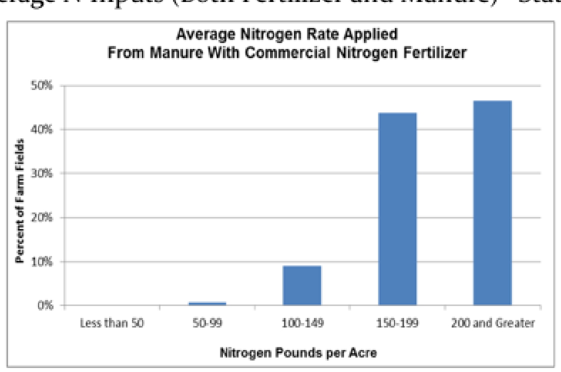
	8200000	10%	820000		
	Non-Manure	80%	656000		
N Rate Range	Midrange	170	% Acres	Acres	Excess Tons
170 to 184	177	7	20%	131200	459
185 to 199	192	22	8%	52480	577
Over 200	207	37	6.0%	39360	728
total					1,765
					0.2%
				Based on Upper UM	

Non-Manure Continuous Corn (Using the Mid-Range)

Used 2012 Corn acres and assumed 10% in a corn-corn rotation

	8200000	10%	820000		
	Non-Manure	80%	656000		
N Rate Range	Midrange	155	% Acres	Acres	Excess Tons
170 to 184	177	22	20%	131200	1443
185 to 199	192	37	8%	52480	971
Over 200	207	52	6.0%	39360	1023
total					3,437
					0.4%
				Based on Upper UM	

NASS Corn Grower N Survey-2012
Average N Inputs (Both Fertilizer and Manure)--Statewide



Details: Analysis included 144 fields. Average N inputs from manure and commercial N were 120 and 76 lb/A, respectively. Additional details on page 149.

Manure Corn following Soybeans (Using the Upper Rate and 0.05 ratio)

Used 2012 Corn acres and assumed 75% in a corn-soybean rotation — N Sales for 2012

	8200000	75%	6150000		811051
	Manured	20%	1230000		
N Rate Range	Midrange	160	% Acres	Acres	Excess Tons
155 to 199	177	17	43%	528900	4496
200+	220	60	46%	565800	16974
total					21,470
					2.6%
				Acres	Excess Tons
					Based on Upper UM
Totals for These Three Corn Rotations				4835540	**55,140**

In Excess of UM (% of Sales)

7%

Manure Corn following Soybeans (Using the Upper Rate and 0.05 ratio)

Used 2012 Corn acres and assumed 75% in a corn-soybean rotation — N Sales for 2012

	8200000	75%	6150000		811051
	Manured	20%	1230000		
N Rate Range	Midrange	145	% Acres	Acres	Excess Tons
155 to 199	177	32	43%	528900	8462
200+	220	75	46%	565800	21218
total					29,680
					3.7%
				Acres	Excess Tons
					Based on Upper UM
Totals for These Three Corn Rotations				4835540	**100,202**

In Excess of UM (% of Sales)

12%

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.

DEPARTMENT OF AGRICULTURE