MINNESOTA WELL OWNERS ORGANIZATION
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Rochester, MN 55904

01 November 2013

Ms. Annie Felix-Gerth
Minnesota Department of Agriculture
625 Robert St. North
St. Paul, MN 55155

Via e-mail to Annie.felix-gerth@state.mn.us

Dear Madam,

The following are Minnesota Well Owners Organization's (MnWOO) comments for the record on the Draft Minnesota Department of Agriculture (MDA) Nitrogen Management Plan (Plan). MnWOO finds sufficient inconsistencies and contradictions in the Plan that lead us to conclude that the Plan fails to propose appropriate and timely action to protect groundwater from degradation in areas of historic and well known groundwater contamination risks.

First, but not least, the proposed nitrogen in groundwater monitoring/prevention/mitigation strategy cannot protect groundwater when the trigger for action is contamination above the Health Risk Limit (HRL), and when it takes ten years to conduct redundant studies and repetitive assessments that have already established the imminent risk. Taking preventative action only when a new round of well samples show five percent of wells exceeding the HRL of 10 milligrams nitrate per liter water (mg/L) undermines the statutory mandate that "groundwater be maintained in its natural condition, free from any degradation caused by human activities." The approach presented in the Plan does not actually make prevention of contamination a priority, nor does the Plan ensure mitigation actions can ever be taken to bring back the health of our water supply. In other words, as further explained, the MnWOO thinks that the Plan fails to set definitive proactive prevention and mitigation actions at levels far below HRLs and that this failure ultimately results in groundwater being polluted before the MDA takes action.

MnWOO further considers the Plan's recommendation to start again with monitoring and risk assessments is another in a round of repeated shortcomings of effective groundwater management throughout large areas of the state; the MDA need not begin anew every time a commodity group or political action committee questions the data about groundwater risks. This leads to a second criticism of the Plan: the Plan either ignores or fails to give credence to important historic data and existing risk assessments in making the management recommendations. For example, in the southeastern Karst and Central Sands the groundwater risk has been evident since the mid 1980s and both areas have been the focus of accelerated monitoring and the widespread promotion of Best Management Practices (BMPs). Despite the 25-30 year awareness of the nitrate problem, data still provides evidence of widespread nitrate contaminated groundwater above the HRLs, and an unknown rate of farmer BMP adoption and compliance for prevention or mitigation. It is undisputed that the risks are known, have been studied and published proving that shallow groundwater is contaminated throughout wide areas of the southeastern

Karst and Central Sands; these areas require immediate action. MnWOO believes it is necessary to immediately designate large areas of Minnesota as Nitrogen Management Areas as prescribed in the 1990 Nutrient Management Plan. The southeastern Karst and Central Sands must have accelerated initiatives for prevention and mitigation in the new Plan.

There are additional concerns: aside from the local and State government representatives, we question the qualifications of some of the task force members to advise the State on serious health risks. Given the increased nitrate pollution in Minnesota, the Plan does not provide a meaningful vocabulary or timely action to prevent widespread nitrogen loss in porous and leaky aquifers. As mentioned above, the Plan does a poor job of communicating the scale of the risk throughout Minnesota, and especially in the southeastern Karst and Central Sands.

MnWOO also questions the proposed assumption that farmer- led Advisory Teams can be effective environmental risk managers; is this a case of the fox guarding the hen house? For example, no where does the Plan emphasize the importance that farmers (or their crop consultants) understand and estimate how much nitrogen in applied fertilizer is lost and how much water will be contaminated for every ton of fertilizer that leaches into the ground. Farmers must know, accept and internalize the science that soluble nitrogen resulting from the application of fertilizer is a potent contaminant, with a relatively low HRL. MnWOO considers it necessary for every farmer to calculate the annual nitrogen loss in terms of pollution potential; if so, we would all have a common beginning to prevent continued groundwater degradation. But especially, Minnesota farmers alone cannot be expected to manage the risks of fertilizer application, let alone restore the quality of groundwater in aquifers that are already beyond the brink of safety. Farmers are more concerned with their crop, yield, profits or losses and should not be the environmental risk managers for the entire population of Minnesota.

In the following comments MnWOO has addressed specific concerns and made recommendations for actions that are appropriate to the risks. We have made our comments in the order presented in the Plan, making it easier for the MDA staff to respond with specific points of agreement or justification for their rejection of our proposals. MnWOO encourages the MDA to recognize and institutionalize its statutory mandate to maintain groundwater in its natural condition. Prevention of contamination is better than the loss of healthy water or mandated mitigation.

Sincerely:

Minnesota Well Owners Association (MnWOO)

Minnesota Well Owners Organization's comments to the
Minnesota Nitrogen Fertilizer Management Plan, Public Comment Draft, August 2013,
Minnesota Department of Agriculture

Chapter 3: Groundwater Contamination and Sensitive Areas

The Plan, at Chapter 3, pages 24 through 30 identify many appropriate tools for defining the groundwater risk but these factors seemed to be dropped from consideration in the implementation of the Plan. For example, areas already known to be at high risk or already contaminated are ignored and not specifically addressed in the proposed Assessment Process. Heedless of thirty years of data and research which created a historic baseline, and an ever improving ability to assess groundwater risk, the studies and work of Federal, State and local government units are essentially ignored when the Plan treats all of the state the same. The failure to immediately designate the known high-risk hydro-regions for immediate prevention and mitigation actions forfeits the ability to prevent further degradation.

Chapter 5 Best Management Practices (BMPs)

Minnesota Statute 103H.151 subd. 4 states in part that "[t]he 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 [emphasis added]." This section was passed by the Minnesota Legislature in 1994. Since then, MDA has not undertaken a regional or statewide effort to either evaluate the effectiveness of nitrogen BMPs or the adoption rates. Although it has developed and promoted statewide and region nitrogen BMPs for over 20 years, MDA has not completed field audits to fulfill its responsibility under this section of the Groundwater Protection Act.

As an example, BMPs for nitrogen use in southeastern Minnesota were developed and promoted in 1993 and again in 2008. Minnesota Statute 103H.151 subd. 4 requires that MDA evaluate the implementation and effectiveness of its best management practices. MDA has not published a report evaluating the effectiveness of and the adoption rates by farmers of its nitrogen BMPs that were developed and promoted since 1993. MDA has undertaken Farm Nutrient Management Assessment Program studies in the region (Hastings and Whitewater

Watershed), but these studies cover small geographical areas, involve a small number of farmers and rely on voluntary participation by farmers. No effort has been made by MDA to design a FANMAP sampling of farmers that would be representative of a larger geographical area or population. The FANMAP studies conducted in these small areas, however, have revealed that farmers are generally following nitrogen BMPs. **The most troubling conclusion to be drawn from theses studies is that despite farmers following nitrogen BMPs, nitrate concentrations in private and municipal wells, springs and base flow in streams are all increasing. (emphasis added)** Thus, if the BMPS are being followed but there is no resulting decrease in high nitrate contamination of groundwater, it is reasonable to conclude that the nitrogen BMPs are not working. herefore, in the well-studied areas throughout southeastern Minnesota, MDA should immediately move to adopt water resource protection requirements under Minnesota statutes 103H.275.

Chapter 6 Nitrate Conditions in Minnesota Groundwater & Appendix F Challenges of Monitoring Groundwater Quality

The Plan properly cites the fact that monitoring shallow groundwater is protective, is a proactive means of protecting the groundwater, and properly recognizes that nitrate loading to the subsurface can be significant in the Minnesota's southeastern Karst geology; however, the Plan fails to recommend timely action to address these known risks. The plan further fails to recognize that many samples from older wells in the southeastern Karst and Central Sands, including samples from the poorly constructed wells referenced in the Southeast Minnesota Water Resources Board Volunteer Nitrate Monitoring Program (SEMNWRB) findings, are essentially sampling the nitrate contaminated shallow groundwater that cascades down the well bore. Shallow contamination puts the deeper aquifers at risk. The trigger for prevention and mitigation should be on the shallowest water, springs and base flow in groundwater fed streams. If shallow water is being contaminated, protective and mitigation efforts are immediately warranted to prevent further degradation.

The attached VNM Analysis of water from the SEMNWRB shows the importance of immediate designating southeast Minnesota a Nitrogen Management Area. Tables 3 and 4 of the southeastern Minnesota groundwater quality study show that 20 to 40 percent of the wells in the

southeast Karst have more than 3 mg/L nitrate and that 5 percent to 24 percent of the wells have more than 10 mg/L. The analysis of matrix type as an influence on nitrate level shows that shallow bedrock, clastic bedrock and solution weathered bedrock as the first encountered rock already have groundwater with significant nitrogen contamination impacts. The existing data is adequate to determine that southeastern Karst should be immediately designated as a Nitrogen Management Area with accelerated protection and mitigation. A long delay with additional groundwater sampling is not necessary to define the high risk areas or to define the southeastern Karst watersheds where the need for action is immediate.

Similarly in the Central Sands both private and public water supplies are known to be sensitive and easily degraded, even when BMPs are promoted and utilized. For example, in recent legislative hearings held on October 7 and 8, 2013, MDA employee Bruce Montgomery touted the high level of BMP adoption by potato growers; however, when questioned, he admitted there was high nitrogen loss with irrigated potatoes (see Table 7 of BMPs for Nitrogen Use: Irrigated Potatoes by the U of M Extension). The same problems exist for corn and other annual crops in the Central Sands region. Mr. Montgomery, moreover, was unable to advise the Minnesota legislature on the amount of water contaminated above the HRLs for the "standard" potato leaching loss of eighty pounds nitrogen per acre per year.

It is significant that the Plan notes that the Minnesota Health Department requires 27 Minnesota public water suppliers to sample wells four times a year if wells exceed 5 mg/L but MDA does not propose taking preventive action until wells exceed the 10 mg/L HRL or are at 7 mg/L. MnWOO asserts that the MDA must adopt a more protective standard of 3mg/L if the Plan is to prevent further degradation. Statewide well sampling from the MDA shows a strong correlation between the mapped Water Table Aquifer Sensitivity and the occurrence of both public and private wells exceeding the nitrate HRL. The large numbers of wells with nitrate detections above 3 mg/l in Figure 18 of the Plan show the imminent risk of inaction and the certainty of wider groundwater degradation if the new Plan does not provide for immediate prevention and mitigation. The Minnesota Department of Health (MDH), Minnesota Pollution Control Agency (MPCA), local well drillers and water professionals should be engaged in selecting the watersheds where protection and mitigation plans will be immediately developed.

Minnesota laws provide an existing nitrate standard for the protection of human health at 10 mg/L, which applies to surface waters designated for drinking water uses (class 2A and 2Bd which includes all designated trout streams). MPCA is in the process of drafting a new nitrate water quality standard for surface waters based on aquatic life toxicity. The proposed chronic standard is 3.1 mg/L for 2A streams and 4.9 mg/L for cool-warm water streams (MPCA wq-s6-23). With this proposed change, the numbers of streams exceeding this standard will increased dramatically and include nearly all trout streams for which there is nitrate concentration data. Because high nitrate concentrations in trout streams occur exclusively during base flow conditions which are from groundwater contributions, MDA needs to include these proposed nitrate water quality standard rule changes in their nitrogen management planning efforts.

MDA's proposal to conduct private drinking water well sampling in vulnerable areas with townships being the primary boundary to evaluate current nitrate conditions is flawed in several respects. The township scale chosen by MDA to monitor is arbitrary and ignores all of the groundwater sensitivity and probability mapping done by other State agencies. The Plan should consider the existing maps developed specifically for groundwater contamination purposes to direct its nitrate mitigation and monitoring efforts. These recommendations point to the fundamental flaw that the Plan fails to build on existing monitoring programs that have established increasing nitrate trends in groundwater over the last twenty years and thereby waste millions of dollars of taxpayer funded monitoring efforts. The Plan fails to recognize the value of Minnesota Department of Natural Resources' (MDNR) mapping groundwater sensitivity, MDH's nitrate probability mapping, the SEMWRB and MPCA's comprehensive watershed water quality monitoring efforts. It would be to the benefit of the citizens of Minnesota if MDA integrated their groundwater monitoring with these ongoing efforts of other state agencies and citizens groups to eliminate redundancy and wasteful duplication of water quality monitoring efforts.

MnWOO encourages MDA to build on existing monitoring networks of springs, private and municipal wells, and base flow in streams rather than begin a new sampling effort of private wells. The 20+ years of monitoring trends at existing sites indicate an increasing trend of nitrate concentrations at geographic scales from springshed to major watershed. MDA, moreover, has a

network of 193 wells located in ten counties in the Central Sands and eleven springs in southeastern Karst to build on for future nitrogen management efforts. MDA's failure to integrate this data in current nitrogen management planning efforts could be construed to purposely delay meaningful action to reduce nitrate contamination of the State's water resources and ignore provisions of the Groundwater Protection Act.

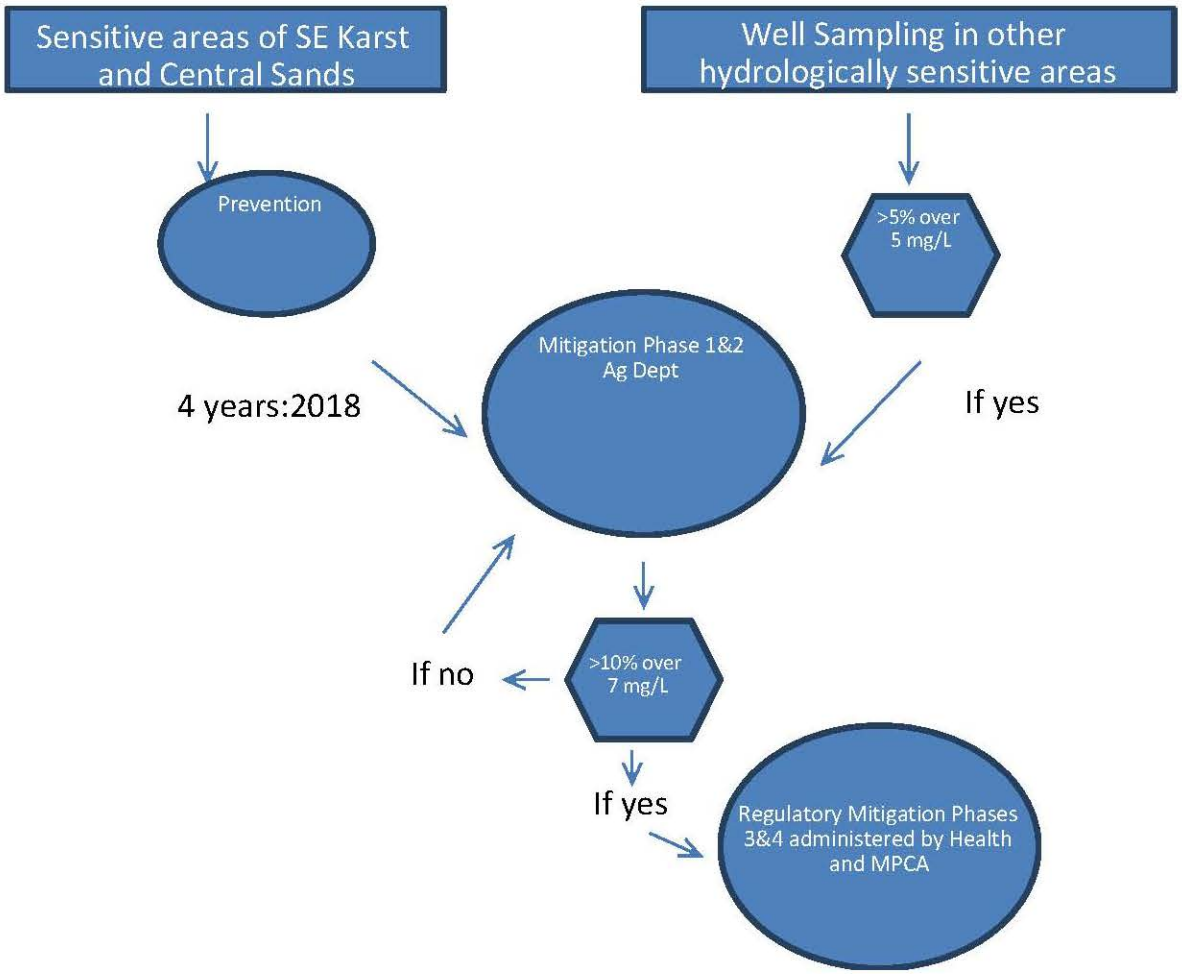
For 25 years MDA has avoided using private drinking water wells for regulatory purposes. The only explanation for the change in position can be delay of any meaningful regulatory action until wells can be located, permission obtained, sources of contamination ascertained, and many rounds of sampling evaluated to determine nitrate concentration trends and seasonal variability. The SEMWRB voluntary nitrate monitoring network sampling on private wells that was done during 2008-2012, had a wide variability 33-99 percent in the numbers of wells it was able to sample during any given round, *see* MnWOO's Appendix A attached with these comments. In addition, in some counties over fifty percent of the well owners with concentration greater than 10 ppm dropped out of the network. Voluntary networks cannot be relied upon to give samples at a predetermined time or for a long period of time.

Chapter 7: Overview of the Nitrogen Plan Process

The Plan in Chapter 7 proposes to start sampling yet again and conduct another decade of monitoring and assessment in the southeastern Karst and Central Sands without accelerated action to protect and mitigate groundwater in the known high-risk hydro regions. This proposal is imprudent in these regions because they are very high-risk and the proposal to monitor and access provides a low-return to the health of our water supply for human and animal consumption. The passive notion that more sampling will satisfy the statutory requirements to prevent groundwater degradation is a denial of fact. If the known groundwater risks referenced in Chapter 3 and discussed in Chapter 6 are heeded in the least, all the areas with rapid recharge rates and high aquifer sensitivity would be addressed much differently than the Plan proposes. Groundwater protection in areas dominated by row crops and known to be highly sensitive, require immediate protection **AND** mitigation measures. The same immediate actions should be taken where shallow aquifers have been proven to be contaminated, where springs and base-flow

in streams are above the HRL, and even where poorly constructed wells are already contamination above 3 mg/L. These conditions indicate an imminent risk of nitrate contamination that requires rule-making action under the old 1990 plan and begs for consideration for accelerated action in the new Plan. The known highly susceptible areas should not be sent back to the beginning with more monitoring. The immediate needs cannot be dismissed or ignored in this prevention and mitigation strategy.

MnWOO proposes an alternative assessment process that relies more heavily the Minnesota Geological Survey, the US Geological Survey, the MDH and MDNR data and models for sensitive areas and relies on new monitoring in the less sensitive areas. Adequate assessment has been done in the southeastern Karst and Central Sands regions and these areas should be automatically designated for prevention and be given four years to adopt mitigation strategies. To prevent degradation, water quality testing everywhere else should trigger prevention and mitigation when more than five percent of wells exceed 5 mg/L, following the lead of the MDH. In the southeastern Karst and Central Sands or any other area with springs and streams exceeding 7 mg/L or more than ten percent of wells exceed 7mg/L, Phase 2 mitigation and regulation of nitrogen use should be implemented by statute or rule to prevent further degradation.


Sensitive areas of SE Karst and Central Sands
Well Sampling in other hydrologically sensitive areas
Prevention
>5% over 5 mg/L
Mitigation Phase 1&2 Ag Dept
4 years:2018
If yes
If no
>10% over 7 mg/L
If yes
Regulatory Mitigation Phases 3&4 administered by Health and MPCA

Chapter 8: Prevention

The prevention and education strategies are inadequate in the southeastern Karst and Central Sands unless they are immediately adopted and implemented. MnWOO proposes that in any area where nitrate groundwater contamination is endemic with ten percent of springs, streams or wells above 7mg/L the responsibility for communication and action should be immediately transferred to the MDH and the MPCA.

The Plan's proposed prevention strategy lacks an important component: making farmers understand the water quality impact of nitrogen loss. MnWOO proposes that it is necessary to provide farm scale estimates of annual, or even seasonal, nitrogen loss followed by a calculation or estimate of how much water is contaminated above the HRL for each farm operation. Farmers and their service providers cannot appreciate the impact of nitrogen loss without a meaningful and trustworthy estimate of the flux of nitrogen into the water as part of a farm conservation or nutrient management plan. Nitrogen flux, added to knowledge of groundwater sensitivity, would allow farmers the ability to assess their individual water quality impact. The traditional MDA approach of highlighting the tangible cost of fertilizer overuse is the most quoted farmer defense against over application but few operators actually calculate or understand the impact of their nitrogen loss. Because the University of Minnesota nutrient management recommendation calculations are a function of fertilizer price, crop price, soil productivity and economic risk all the fertilizer decisions are based only economic factors; there is no recognition of the environmental risk. The knowledge and a simple tool for estimating water contaminated per 100 pounds of nitrogen lost would be a reasonable factor to assess farm-to-farm pollution reduction efforts.

Unfortunately we never hear any farm service providers say "my nutrient management efforts preserved 25,000 acre feet of water from nitrate contamination this year"; it is not part of the paradigm, culture or even language of agriculture and farming to assess the farm-to-farm or acre-to-acre impact of nutrient loss. MnWOO strongly asserts that the Plan cannot be effective unless people understand, in common terms, the impact nutrient loss has on groundwater and surface water. If farmers could calculate potential water contamination in acre feet or gallons

they could orientate themselves better toward the task of reducing nitrate loss to the groundwater, especially in the highly sensitive Central Sands and southeastern Karst. MnWOO proposes to teach the farmers and service providers how to calculate nitrate impact on water with the same manner and ease that service providers calculate soil loss. MnWOO would like to require that farm rental agreements and eligibility for farm programs require calculating and reporting nitrogen loss much in the same way erosion control is applied to farm leases or program eligibility.

Having the metrics for field-to-field and farm-to-farm nitrogen loss and water pollution should become one of the benchmark BMPs. The historic watershed nitrate yields published recently by the MPCA can be used as a benchmark to start the conversation for the nitrate flux and historic yield if every operator would answer the question, "how many gallons of water will be contaminated above the HRL when I lose (x) pounds of nitrogen per year on my farm?" If, for example, a farmer living in the Whitewater valley sees that on average his watershed yields eight pounds nitrogen per acre per year his on-farm efforts would be measured against the average. For another simplified example, a farmer cultivating a 640 acre farm in a watershed yielding nine pounds nitrogen per acre per year would lose 5,760 pounds of nitrogen per year. A reduction goal of thirty percent could retire rows crops from 192 acres of nitrogen-reducing land cover to reduce the nitrogen load to 1,728 pounds of nitrogen per year.

The Plan speaks of the difficulty of getting fertilizer use data directly from farmers, admitting the task is difficult and frequently limited. After thirty years of doubling down on BMPs, even after thirty years of accelerated and concentrated efforts in areas like Garvin Brook and the Whitewater Watershed, it is known that nitrate loads cannot be effectively reduced without retiring land from corn and soybeans. Annual row crops lose nitrogen disproportionately to almost all other land use and many current studies link nitrogen contamination to the percentage of annual row crops in a watershed. For the last twenty years, intensified row cropping has avoided having crop rotations of small grains or grasses to remove excess nitrogen. During the same period Minnesota farmers have also accelerated the removal of thousands of acres of perennial vegetation converting grasslands, pastures, fencerows, woodlots, wetlands and forests. Because nitrogen loss is directly proportional to the percentage of land in row crop, **the simplest and most effective start to abating nitrogen loss is to stop the loss of grasslands, wetlands and forests.** This could be accomplished if nutrient loss is monitored and regulated

and/or it can be accomplished if each farm is allowed to claim the ecological service benefits from grasslands, wetlands and forests.

If nutrient management focused on total nitrogen loss measured or estimated every year farmers would have a yardstick to measure water quality impacts and to plan nitrogen reduction strategies. Additionally if nutrient management plans could account for the benefits of non-cropland a farmer could have a mix of cropland and non-cropland to meet a nitrogen loss target. Attributing a nitrogen benefit to non-cropland needs to be a top priority for abating nitrogen loss. Nitrogen loss measured as a watershed yields will correlate to annual row crops. Without coupling nitrogen use, nitrogen loss and water pollution the nutrient management will only focus on the annual cost.

MnWOO recommends that the nutrient management plans and training programs for farmers and farm service providers sanctioned by the MSA provide better guidance in sensitive areas and should demonstrate and provide resources on how to calculate water pollution from nitrogen loss tables. Water quality certified farmers should be required every winter to analyze last year's nitrogen loss and water pollution contribution. A simple use of existing nutrient curves can estimate water quality impact by assessing the farm yield, nutrient input and the regional standards infiltration and runoff.

Every farmer in the southeastern Karst and Central Sands should be required to assess their individual impact on water quality at the end of the year, starting immediately with every protection plan. The Plan should require a water quality impact analysis at a farm scale, every year.

The Plan's prevention efforts rely a great deal on BMPs but these BMPs don't adequate address the water quality risk communication problem. We recommend a change in language for the nutrient BMP:

> "*Select appropriate N Fertilizer Rate using U of M guidelines and calculate the water quality impact of nutrient loss on the farm using fertilizer price, corn price, soil productivity, economic risk and environmental impact to water quality.*"

Additionally BMP language should include special language for southeastern Karst with similar appropriate language for the Central Sands:

> *"Minimize the movement of surface water and infiltration of nutrients and farm chemicals into karst and alluvial sands. Karst features include areas where there is less than 50 feet of soil over carbonate bedrock, sinkholes, shallow bedrock or sandy soils in cultivates fields, drainage to bedrock valleys and losing streams, springs and groundwater fed streams."*

Chapter 9: Mitigation

The mitigation goal is adequate only if action is taken before aquifers are above the nitrate HRLs. In this regard, the Plan actually allows, rather than prevent water degradation. Unless the limits are set far below the HRLs, similar to the MDH standard of 5 mg/L, the chance keeping healthy water may be impossible to achieve in the southeastern Karst and Central Sands.

When Phase 1 and 2 voluntary mitigation is required, the MDA needs to lead and try to recruit or compel effective reduction measures; however, if after this last attempt to get ag-interest cooperation in sensitive or impaired areas fails, Regulatory Mitigation, Phase 3 and 4 should be established by statute or rule. Regulations to regulate nitrogen loss in sensitive areas should be administered by the MDH and MPCA.

Because of the known imminent risk of nitrate contamination in the southeastern Karst and Central Sands, significant staff resources of qualified water quality specialists should immediately be deployed to mitigate the existing nitrogen impacts and dramatically lower farm nitrogen loss. The MDA must take the lead to assure effective prevention and mitigation in the sensitive areas regardless of whether the local agriculture community and government units demonstrate willingness and capacity to reduce nitrogen loss. Based on 25 years of history in the southeastern Karst region, it is unlikely that local farm and ag-industry interests will support water protection and are more likely to try to thwart any action to abate nitrogen loss. Therefore, advisory councils in sensitive watersheds should be managed by qualified health risk and environmental risk professionals who should take and hold control and veto power over local advisory comments and actions. It is nice to say that farmer led groups can solve the nitrate loss

problems, but thirty year of history in known sensitive areas have shown that the locals are simply not quaffed to assess or manage environmental water quality risks on farms or at the scale necessary to prevent further water degradation of major aquifer systems.

Historically neither the commodity groups nor local farmers have demonstrated the will to act or take responsibly for existing and ongoing water quality management in the southeastern Karst and Central Sands. MDA 's prioritization concept of relying on local agricultural community support is inappropriate and contrary to the statutory mandate that MDA protect our water from degradation.

Appendix A – MDA Lessons Learned in Responding to Elevated Nitrates in Groundwater:

Appendix A omits the first two fundamental steps in any response to environmental risks:

(1) Rely on historical data and "don't recreate the wheel"; and

(2) Communicate in terms and at a scale that is understandable.

MnWOO understands the hard lessons learned about difficult public forums but it is incumbent on the MDA to assure that the process is open to the public and includes people with dissenting and opposing viewpoints. The Lessons Learned section seems to indicate that MDA and farmer's work best together when dealing with agreeable farmers; groundwater, however, is a critical public resource where the public has a vested interest and a right to participate in government sponsored farm programs. MnWOO strongly considers the safety of the water supply to be a public resource and current statutes do not allow willful degradation. All citizens should participate in the process of protecting groundwater and managing nitrogen fertilizers.

The Phased Approach is flawed. The Plan should address areas with known and established contamination and high risk, such as the Central Sands and southeastern Karst. The top priority should be addressing Minnesota's most sensitive areas first. Make it known that the MDA/MDH/MPCA/MDNR know, understand and are willing to address the risks in the southeastern Karst and glacial-alluvial aquifers based on current knowledge. Any delay will assure continuing the nutrient practices that are known to contaminate groundwater above the HRLs in both the southeastern Karst and the Central Sands.

MnWOO proposes changing the priority and details of the Plan in order to demonstrate a legitimate attempt to prevent degradation of groundwater and to carry out the goals and responsibilities of the Minnesota Groundwater Protection Act.

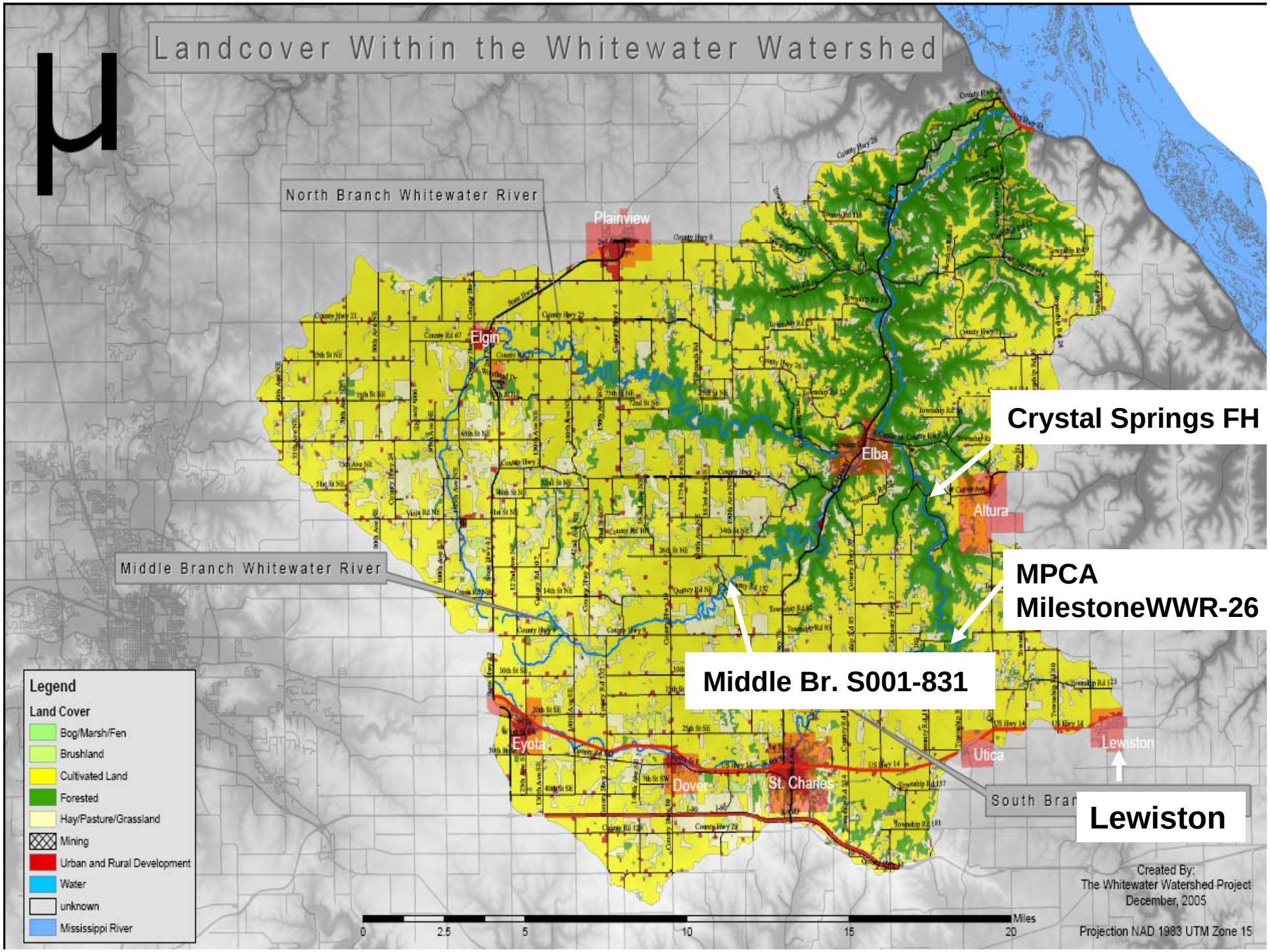
1. Conduct protective actions on high priority areas that should be designed by formal rule-making ule as Nitrogen Management Areas including the southeastern Karst, the Central and Northwest "irrigated and non-irrigates sandy soils." Require immediate implementation of BMPs that address water quality risks, calculate the potential impact of nitrogen loss on groundwater and advise operators on the means to prevent the loss of nitrogen to water.
2. Define the Mitigation Phase 1 and 2 action levels for water quality in any area of the state as five percent of wells with more than 5 mg/L (ppm).
3. Assign programmatic difference between the southeastern Karst, Central Sands and the other agricultural areas of the state.
    a. In the southeastern Karst and Central Sands aquifer Nitrogen Management Areas will use existing water quality data from wells, springs and stream base flow and develop a network of water monitoring sites to build on existing data to develop baseline background conditions. Monitoring will concentrate of the shallowest and most venerable aquifers and sensitive areas as outlined in Chapter 3 "Groundwater Contamination and Sensitive Areas" including the areas defined by the maps that were used to make Figure 3 Water Table Aquifer Sensitivity, the County Geologic Atlas Program, the Department of Health Nitrate Contamination Probability maps (Chapter 3 and figures 3 to 5). Conduct a detailed assessment of water quality in the southeastern Karst and Central Sands watersheds.
    b. For the Northwest, South West and South Central cropland areas monitor groundwater wells at a HUC 8 watershed scale for ten years to identify additional areas with nitrate concerns.
    c. Conduct Phase 1 and 2 mitigation actions administered by the MDA for the southeastern Karst and Central Sands Nitrogen Management Areas and any areas exceeding five percent of springs, streams or wells greater than 5mg/L nitrate;

i. set a goal for 50% nitrogen loss reduction.

d. Set a four year schedule for improvement with a requirement of annually calculating and reporting farm scale nitrogen loss.

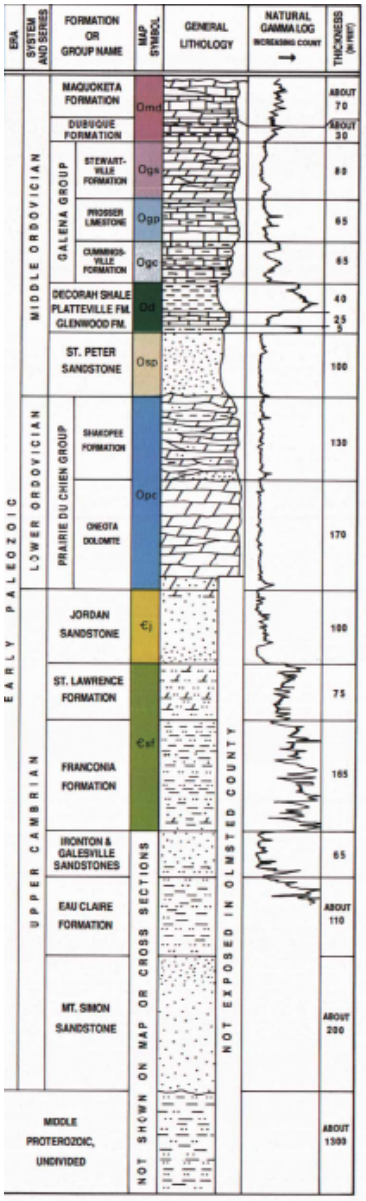
e. Areas with more than ten percent of wells exceeding 7mg/L shall have regulatory Phase 3 and 4 Mitigation Plans required by statute or rule and administered by the MDH and MPCA.

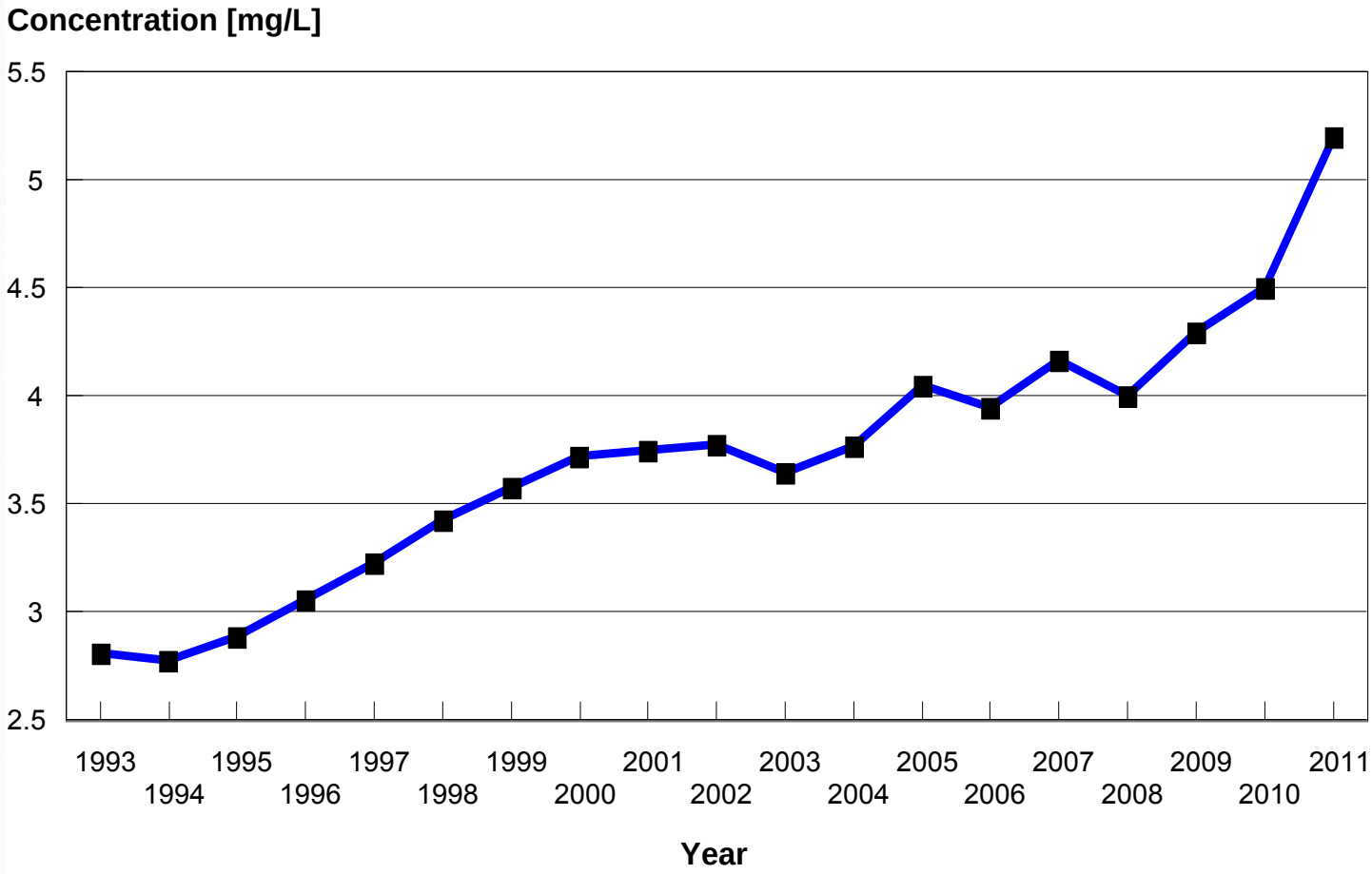
MnWOO Appendix A: Submitted by the Minnesota Well Owners Organization as comments to the Minnesota Department of Agriculture's Minnesota Nitrogen Fertilizer Management Plan, Public Comment Draft, August 2013

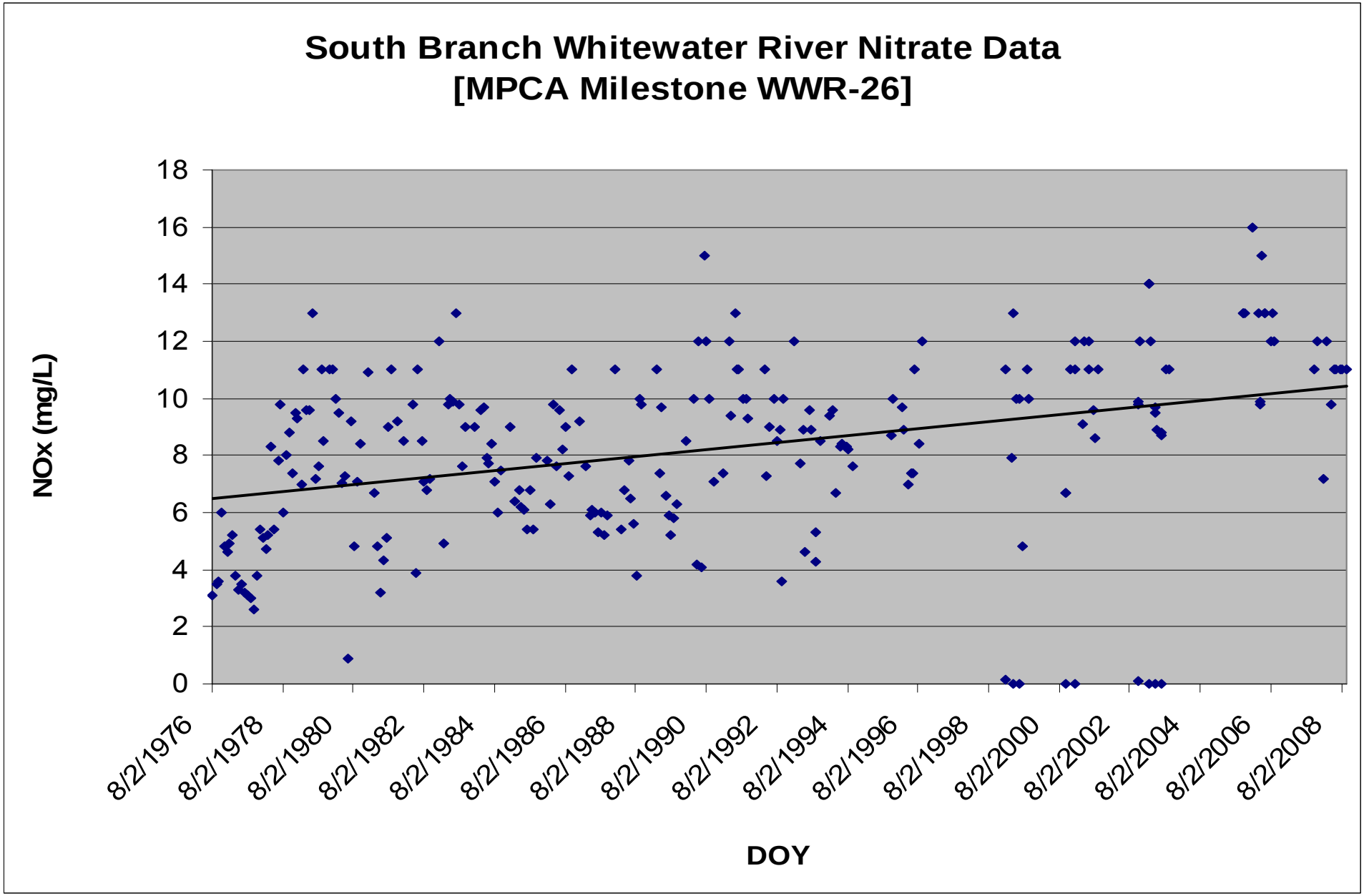

Landcover Within the Whitewater Watershed
North Branch Whitewater River
Middle Branch Whitewater River
South Bran
Plainview
Elgin
Elba
Altura
Eyota
Dover
St. Charles
Utica
Lewiston
Crystal Springs FH
MPCA
MilestoneWWR-26
Middle Br. S001-831
Lewiston
Legend
Land Cover
Bog/Marsh/Fen
Brushland
Cultivated Land
Forested
Hay/Pasture/Grassland
Mining
Urban and Rural Development
Water
unknown
Mississippi River
0
2.5
5
10
15
20
Miles
Created By:
The Whitewater Watershed Project
December, 2005
Projection NAD 1983 UTM Zone 15

Crystal Springs NO3-N Concentrations 1993-2011

St. Lawrence Formation






South Branch Whitewater River Nitrate Data
[MPCA Milestone WWR-26]
NOx (mg/L)
18
16
14
12
10
8
6
4
2
0
8/2/1976
8/2/1978
8/2/1980
8/2/1982
8/2/1984
8/2/1986
8/2/1988
8/2/1990
8/2/1992
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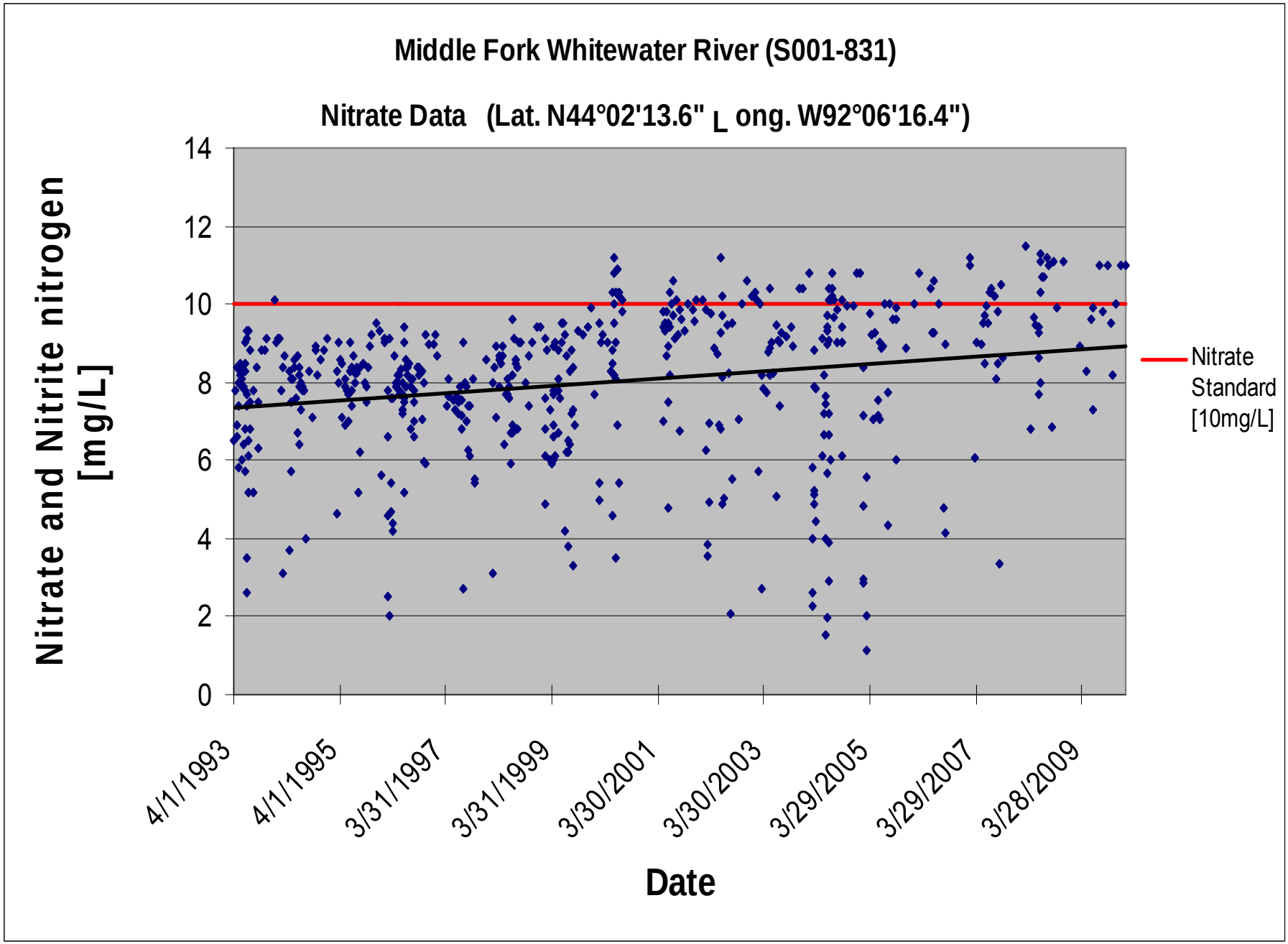
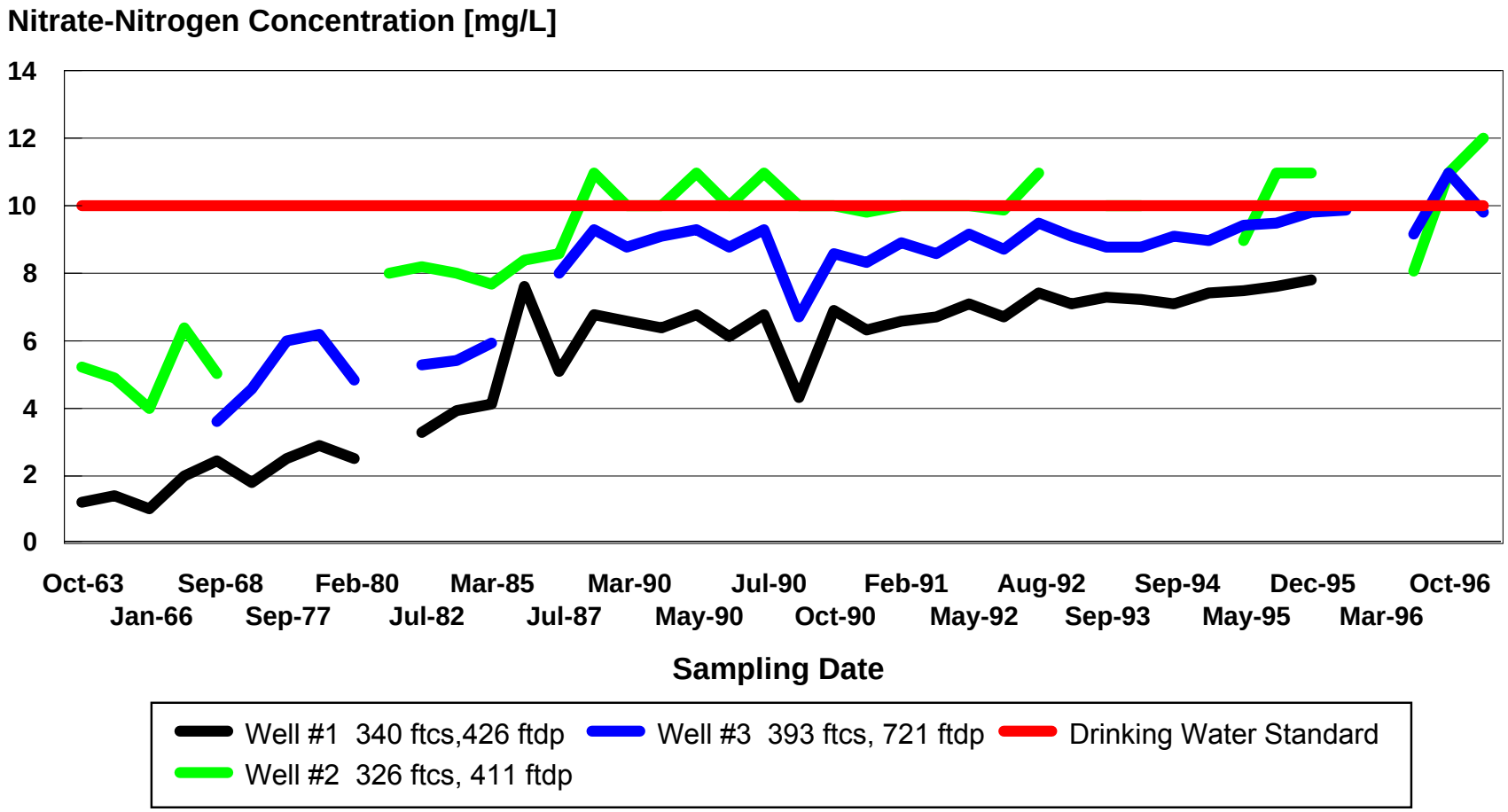
8/2/2004
8/2/2006
8/2/2008
DOY


Middle Fork Whitewater River (S001-831)
Nitrate Data (Lat. N44°02'13.6" L ong. W92°06'16.4")
Nitrate and Nitrite nitrogen [mg/L]
14
12
10
8
6
4
2
0
4/1/1993
4/1/1995
3/31/1997
3/31/1999
3/30/2001
3/30/2003
3/29/2005
3/29/2007
3/28/2009
Date
Nitrate Standard [10mg/L]

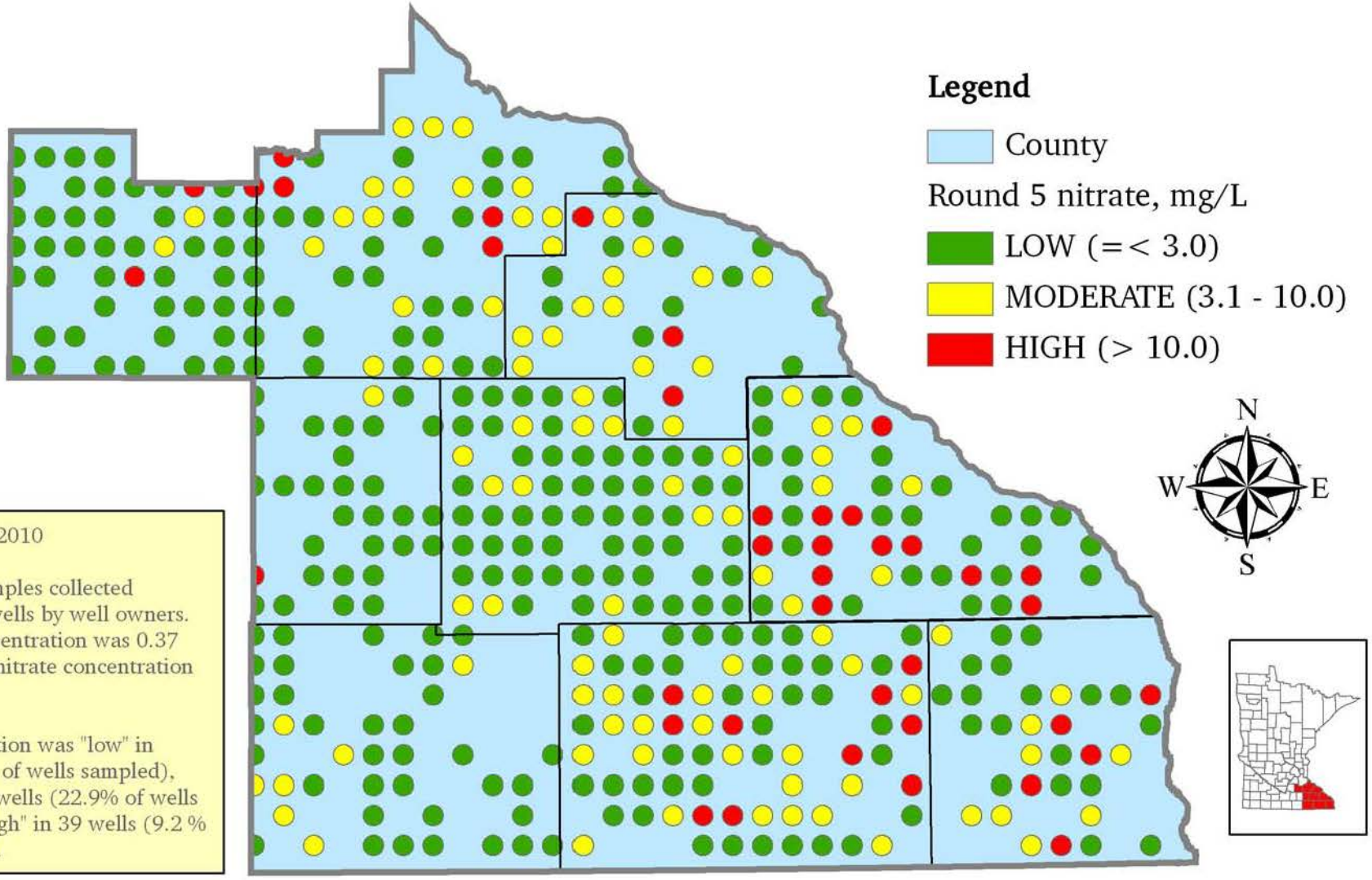
Lewiston Municipal Water Supply Nitrate Data

for years 1963-1996



Southeast Minnesota Volunteer Nitrate Monitoring Network
Round 5 Nitrate Concentrations, August 2010

Prepared by Minnesota Department of Health, February 2011



Round 5--August 2010

Ground water samples collected at 424 domestic wells by well owners. Mean nitrate concentration was 0.37 mg/L, maximum nitrate concentration was 37 mg/L.

Nitrate concentration was "low" in 288 wells (67.9% of wells sampled), "moderate" in 97 wells (22.9% of wells sampled), and "high" in 39 wells (9.2 % of wells sampled).

0 4.5 9 18 27 36 Miles

Nitrate Contamination of Private Wells SE MN

- Grid-based sampling conducted from 2008 to 2012 by the Southeast Minnesota Water Resources Board
  - 30% of wells in Wabasha County above HRL
  - 25% of wells in Fillmore County above HRL
  - 22% of wells in Winona County above HRL
  - 12% of wells in Olmsted County above HRL

USGS 2011 Study of flow normalized nitrate concentration and flux in the Mississippi River Basin

- Flow normalized concentration and flux of nitrate increased 76% and 67%,respectively, during the years 1980 to 2008 at the Mississippi in Clinton Iowa. This site had the greatest increase of the 8 sites studied. The increase in concentration at low stream flows during all seasons is a strong indication that increasing nitrate concentrations in groundwater are having a substantial effect on river concentrations in the basin.

VNMN Project Analysis

Tisha Hooks and Corey Smith, Winona State University Statistical Consulting Center

May 28, 2013

The database used for this analysis consisted of 675 wells across southeastern Minnesota. The nitrate levels (NO3) of each well were potentially measured at each of the following time periods:

- Time 1 – February 2008
- Time 2 – August 2008
- Time 3 – February 2009
- Time 4 – August 2009
- Time 5 – August 2010
- Time 6 – August 2011
- Time 7 – August 2012

The original data set also included a Time 0; however, this time period did not control for date and included an overwhelming number of missing values. So, for this analysis, we consider only Time Periods 1 through 7. Note that even for Times 1-7, some well samples were not submitted. Table 1 summarizes the sampling coverage by county. For example, the database includes 56 wells from Dodge County. Of these 56 wells, only 30 were sampled in Round 1, only 31 were sampled in Rounds 2 and 3, etc. Table 2 contains the same information, with the results expressed as percentages rather than counts.

Table 1. Number of Wells Sampled in each Round by County.

County	Round1	Round2	Round3	Round4	Round5	Round6	Round7
Dodge (n=56)	30	31	31	29	29	28	27
Fillmore (n=96)	95	94	91	91	73	73	64
Goodhue (n=92)	72	72	64	65	47	52	53
Houston (n=66)	48	36	39	38	32	39	36
Mower (n=88)	58	55	51	51	43	40	36
Olmsted (n=72)	52	62	65	66	65	63	63
Rice (n=67)	63	63	60	52	53	50	51
Wabasha (n=64)	44	37	34	21	28	27	22
Winona (n=74)	57	60	59	58	50	53	54
Total (n=675)	519	510	494	471	420	425	406

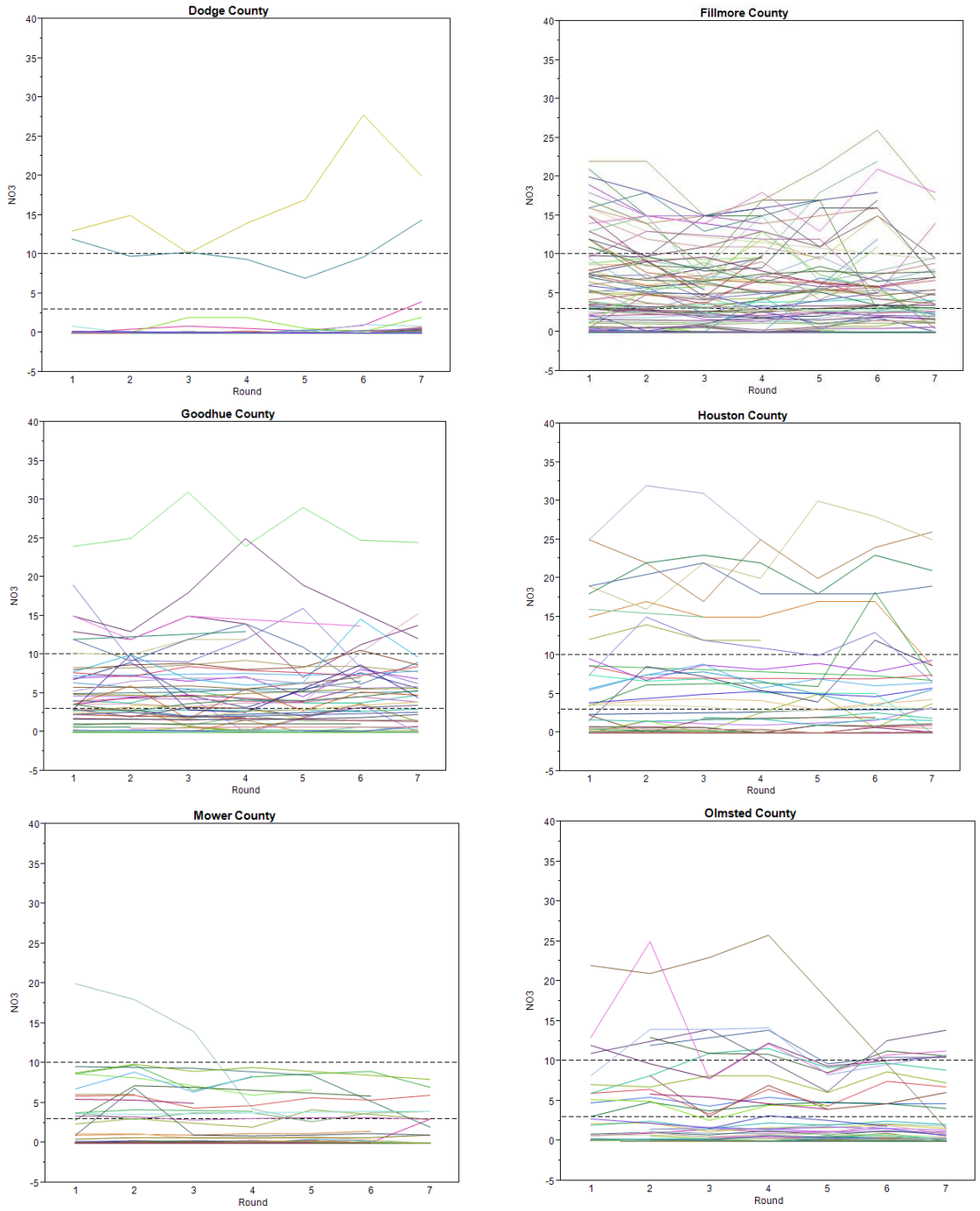
Table 2. Percentage of Wells Sampled in each Round by County.

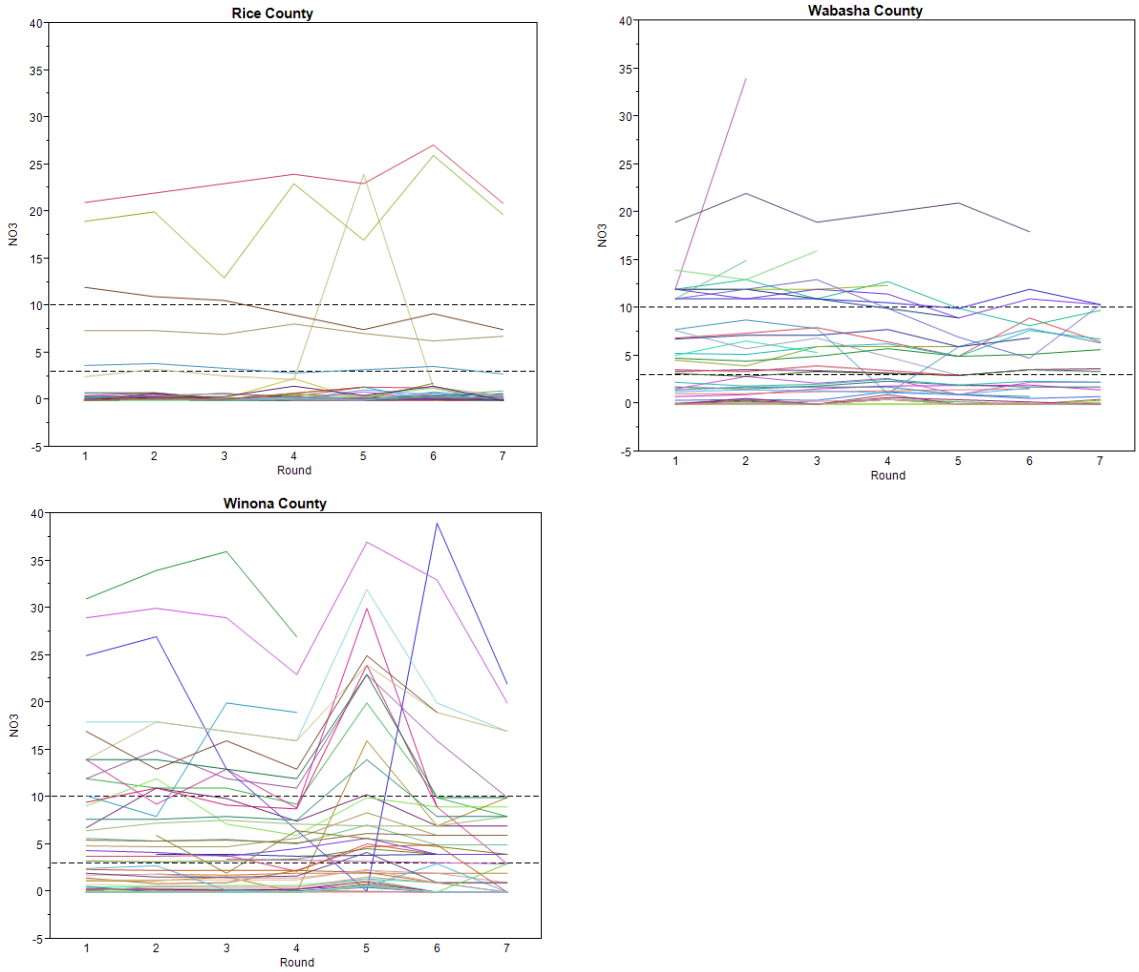
County	Round1	Round2	Round3	Round4	Round5	Round6	Round7
Dodge (n=56)	54%	55%	55%	52%	52%	50%	48%
Fillmore (n=96)	99%	98%	95%	95%	76%	76%	67%
Goodhue (n=92)	78%	78%	70%	71%	51%	57%	58%
Houston (n=66)	73%	55%	59%	58%	48%	59%	55%
Mower (n=88)	66%	63%	58%	58%	49%	45%	41%
Olmsted (n=72)	72%	86%	90%	92%	90%	88%	88%
Rice (n=67)	94%	94%	90%	78%	79%	75%	76%
Wabasha (n=64)	69%	58%	53%	33%	44%	42%	34%
Winona (n=74)	77%	81%	80%	78%	68%	72%	73%

NO3 Levels Compared across County

The plots in Figure 1 display the trends for the NO3 measurements over time for each county. Each line on these plots represents one well in that particular county. Note that some counties have many more wells than others. The two dashed horizontal lines represent NO3 measurements of 3 and 10 mg/L. From these plots, we can see that Winona County, for example, has many wells that have NO3 measurements above 10 mg/L. We see a similar trend in Fillmore County. Conversely, we see that Mower County had only one well that was ever at an elevated level, and that well is now below 10 mg/L.

Figure 1. NO3 Measurements by County.

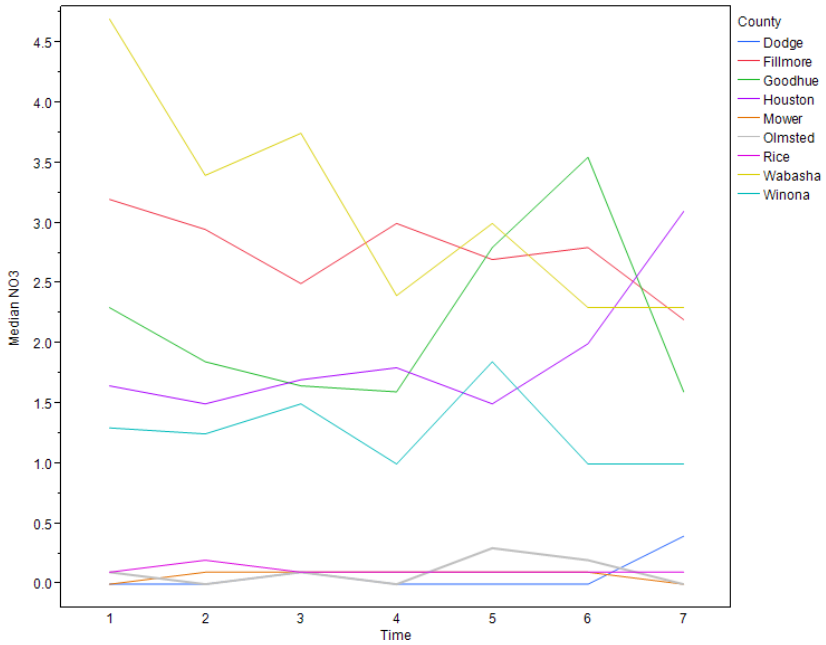




Instead of displaying the measurements for each well, Figure 2 shows the median NO3 level for each County across time (recall that the median is defined as the middle number in a list of sorted numbers). Note that the wells in Wabasha, Fillmore, Goodhue, and Houston Counties tend to have higher NO3 concentrations than do the other counties. Winona County tends to be the next highest. Dodge, Mower, Olmsted, and Rice Counties tend to have lower NO3 concentrations.

<u>Comment</u>: Values of nitrate levels reported as 0 may actually be non-detects. These were left coded as 0 for this analysis, which would not affect the median.

Figure 2. Median NO3 Levels across Time by County.



Tables 3 and 4 also allow for comparisons of nitrate levels across counties. Table 3 shows the percentage of wells in each county that have elevated nitrate levels (NO3 > 3 mg/L) during each of the seven rounds. Similarly, Table 4 shows the percentage of wells in each county that have nitrate levels exceeding the standard (NO3 > 10 mg/L) during each of the seven rounds.

Table 3. Percentage of Wells in each Round with Elevated Nitrate Levels (> 3 mg/L) by County.

County	Round1	Round2	Round3	Round4	Round5	Round6	Round7
Dodge	6.7%	6.5%	6.5%	6.9%	6.9%	7.1%	11.1%
Fillmore	52.6%	48.9%	47.2%	48.4%	46.6%	46.6%	42.2%
Goodhue	38.9%	38.9%	39.1%	38.5%	44.7%	53.9%	43.4%
Houston	43.8%	44.4%	43.6%	39.5%	34.4%	43.6%	52.8%
Mower	24.1%	25.5%	21.6%	19.6%	16.3%	17.5%	13.9%
Olmsted	23.1%	22.6%	20.0%	22.7%	21.5%	19.1%	19.1%
Rice	7.9%	9.5%	8.3%	5.8%	9.4%	10.0%	7.8%
Wabasha	59.9%	51.4%	55.6%	38.1%	42.9%	44.4%	45.5%
Winona	40.4%	40.0%	40.7%	37.9%	44.0%	43.4%	37.0%

Table 4. Percentage of Wells in each Round with Nitrate Levels Exceeding 10 mg/L by County.

County	Round1	Round2	Round3	Round4	Round5	Round6	Round7
Dodge	6.7%	3.2%	6.5%	3.5%	3.5%	3.6%	7.4%
Fillmore	21.0%	13.8%	11.0%	17.6%	13.7%	15.1%	4.7%
Goodhue	12.5%	5.6%	9.4%	10.8%	8.5%	11.5%	7.6%
Houston	18.9%	19.4%	23.1%	18.4%	12.5%	20.5%	11.1%
Mower	1.7%	1.8%	2.0%	0%	0%	0%	0%
Olmsted	7.7%	8.1%	7.7%	10.6%	0%	7.9%	9.5%
Rice	4.8%	4.8%	5.0%	3.9%	5.7%	4.0%	3.9%
Wabasha	31.8%	24.3%	23.5%	19.0%	3.6%	11.1%	13.6%
Winona	21.0%	20.0%	18.7%	13.8%	24.0%	11.3%	7.4%

These trends also indicate that wells in Dodge, Mower, Olmsted, and Rice Counties tend to have lower NO3 concentrations.

Comparisons across Matrix

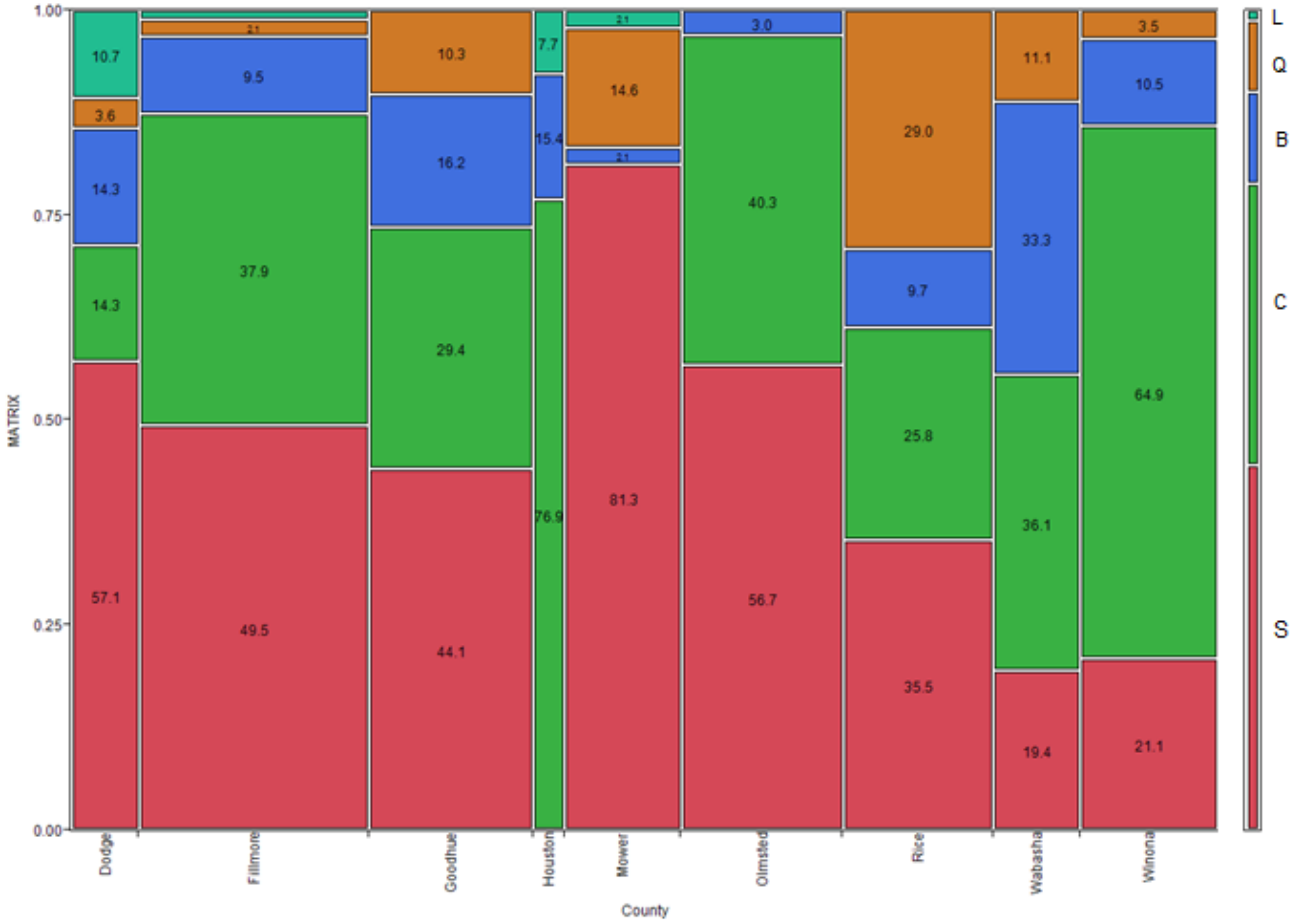
The previous summaries indicate that the NO3 levels vary across county. Note that this could be due to differences in geology from one site to the next. The land around each well in the study was classified using the following matrix types:

- B = solution weathered & clastic bedrock
- C = clastic bed rock (sandstone)
- L = low permeability material
- Q = clastic unconsolidated material
- S = solution weathered bedrock

Figure 3 shows the breakdown of these matrix types by County in a graphic known as a mosaic plot. Each column in this plot shows the percentage of wells contained in each matrix type by county. For example, of all wells in Dodge County, 57.1% are in solution weathered bedrock, 14.3% are in clastic bedrock (sandstone), 14.3% are in solution weathered & clastic bedrock, 3.6% are in clastic unconsolidated material, and 10.7% are in low permeability material.

Some columns are wider than others in this plot because the width of the column is proportional to the amount of wells with Matrix Type data available in each county. For example, for all wells with Matrix type data available, only 13 were in Houston County; conversely, 95 were in Fillmore County.

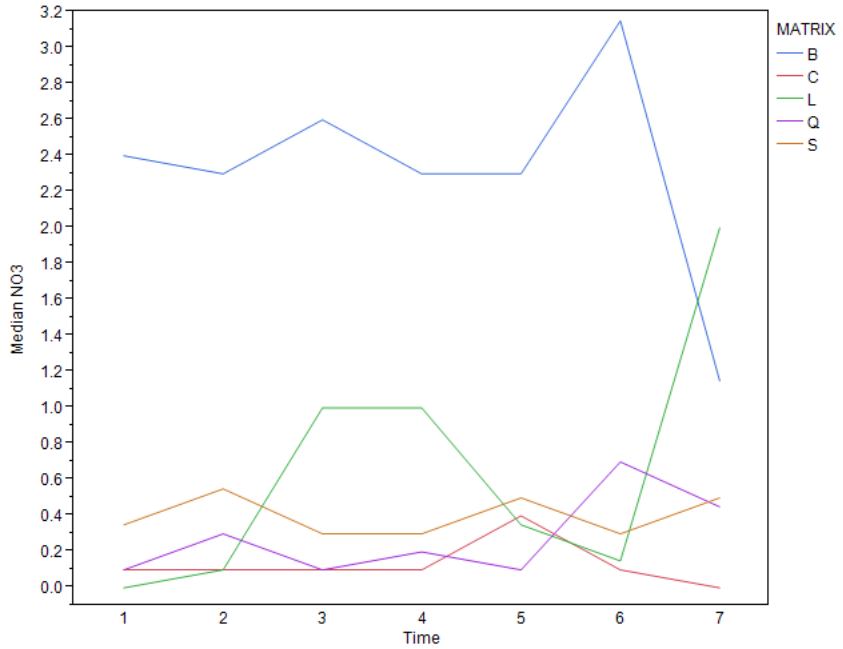
Figure 3. The Percentage of Wells Contained in Each Matrix Type by County.



Note that there are differences in Matrix type across counties. For example, 33.3% of the wells in Wabasha County were in Matrix type B, whereas only 2.1% of the wells in Mower County were in Matrix type B. If there are differences in NO3 levels across these Matrix types, then this could potentially help to explain the differences in NO3 levels across counties.

Figure 4 shows the median NO3 level for each matrix type across time. Note that in general, Matrix Type B (solution weathered & clastic bedrock) typically has much higher NO3 levels than the other types. For at least some time periods, Matrix Type L (low permeability material) also appears to have higher NO3 levels than Matrix Types Q, S, and C.

Figure 4. Median NO3 Levels across Time by Matrix Type.



Statistical Comparisons: Using the mixed-distribution model described in Appendix A, we first tested for differences in the probability of a well yielding a non-zero NO3 level between each of the Matrix types. The significant pairwise differences are summarized below in Table 5. Traditionally, p-values below .10 provide weak evidence for a difference, whereas p-values below .05 provide strong statistical evidence for a difference.

Table 5. Significant Differences Across Matrix Type When Comparing the Probabilities of a Non-Zero N03 level.

Matrix Type Comparisons	p-value
B vs. C	< .0001
B vs. Q	.0394
B vs. S	.0543

Next, as also described in Appendix A, we tested for differences in the means of the log-transformed NO3 levels between each Matrix type. The statistically significant differences are summarized in Table 6.

Table 6. Pairwise Differences Across Matrix Type When Comparing N03 levels.

Matrix Type Comparisons	p-value
B vs. C	<.0001
B vs. Q	.0055
B vs. S	.0277

The results confirm what was seen in Figure 4; the wells found in Matrix Type B (solution weathered & clastic bedrock) tend to yield higher nitrate levels than wells found in Matrix Types B, C and S.

An alternative analysis for making comparisons across Matrix Types was also completed. Instead of considering actual nitrate values, this analysis modeled the probability of a well either (1) having elevated nitrate levels (above 3 mg/L) or (2) exceeding the standard (above 10 mg/L) in each round. The percentage of wells in each of these categories for each Matrix Type are shown in Tables 7 and 8.

Table 7. Percentage of Wells in each Round with Elevated Nitrate Levels (> 3 mg/L) by Matrix Type.

Matrix Type	Round1	Round2	Round3	Round4	Round5	Round6	Round7
B	47.2%	45.1%	47.8%	40.9%	44.2%	50.0%	34.2%
C	23.0%	20.7%	22.0%	18.8%	19.9%	20.4%	20.5%
L	33.3%	16.7%	33.3%	33.3%	16.7%	33.3%	40.0%
Q	15%	20.5%	16.2%	11.8%	11.8%	17.2%	20.0%
S	40.3%	39.8%	36.2%	38.4%	36.1%	36.4%	33.8%

Table 8. Percentage of Wells in each Round with Nitrate Levels Exceeding 10 mg/L by Matrix Type.

Matrix Type	Round1	Round2	Round3	Round4	Round5	Round6	Round7
B	18.9%	15.7%	17.4%	9.1%	11.6%	13.6%	7.9%
C	4.7%	4.5%	5.2%	4.9%	3.1%	5.9%	3.2%
L	16.7%	16.7%	16.7%	16.7%	16.7%	16.7%	20.0%
Q	7.5%	7.7%	8.1%	8.8%	11.8%	6.9%	10.0%
S	19.9%	14.3%	12.8%	15.9%	10.1%	10.5%	8.0%

Note that Matrix Types B and S tend to have a higher percentage of wells with nitrate values either exceeding 3 mg/L or 10 mg/L.

Statistical Comparisons:
Logistic regression models accounting for the repeated measures structure of the data was used to test whether the probability of a well either having elevated nitrate levels (above 3 mg/L) or of exceeding the 10 mg/L standard differed across Matrix Type or time. PROC GENMOD in SAS version 9 was used to fit the appropriate models.

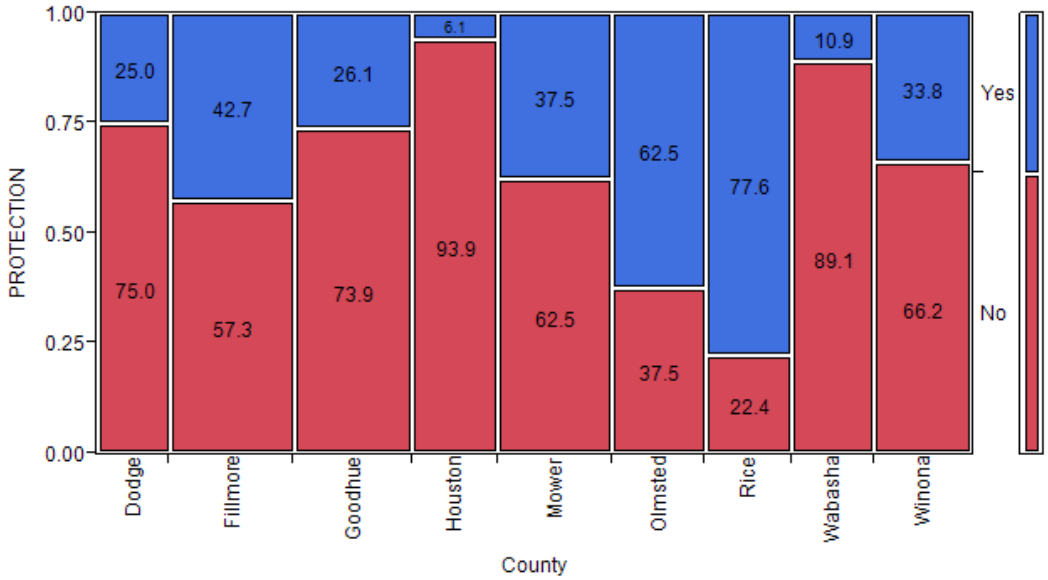
Comparing the Probability of a Well Having Elevated Nitrate Levels: The results indicate that the probability of a well having an elevated nitrate level was significantly different across Matrix Type ($p < .0001$); however, there were no differences across time ($p = .0723$). Further tests revealed which pairwise comparisons were significant: the probability was found to be significantly higher for Matrix Type B than Matrix Type C ($p = .0005$) and Matrix Type Q ($p = .0024$). Also, the probability was found to be significantly higher for Matrix Type S than Matrix Type C ($p = .0003$) and Matrix Type Q ($p = .0051$).

Comparing the Probability of a Well Exceeding the 10 mg/L Standard: The results indicate that the probability of a well having nitrate levels above 10 mg/L was significantly different across Matrix Type ($p = .0015$) and also across time ($p = .0045$). Further tests revealed which pairwise comparisons were significant: the probability of exceeding the standard was found to be significantly higher for Matrix Type B than Matrix Type C ($p = .0076$). Also, the probability was found to be significantly higher for Matrix Type S than Matrix Type C ($p = .0008$). Regarding comparisons across time, the probability was found to be significantly higher in Round 1 than in Round 2 ($p = .0177$), Round 3 ($p = .0121$), Round 5 ($p = .0017$), Round 6 ($p = .0043$), and Round 7 ($p < .0001$). Finally, the probability of exceeding the standard was found to be significantly lower in Round 7 than in Round 1 ($p=.0177$), Round 2 ($p=.0087$), Round 3 ($p = .009$), and Round 4 ($p = .0027$).

Comparisons across Protection Status

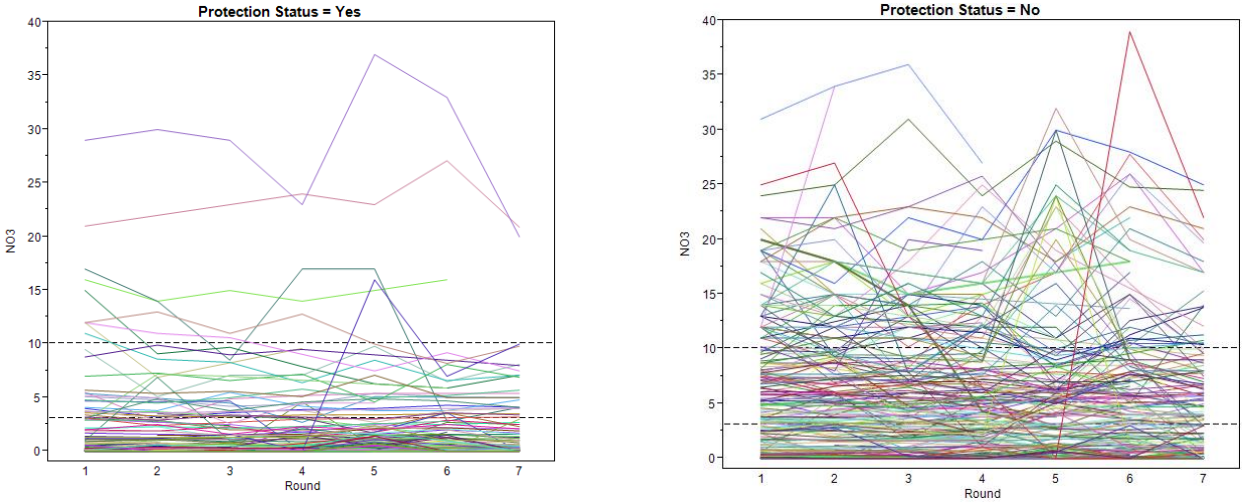
Note that the differences in NO3 levels could also be due to differences in protection status. Each well in the study was classified as either having an overlying protection layer present or not. Figure 5 shows the breakdown of Protection Status by County. For example, of all wells in Fillmore County in this data set, 43.2% are protected and 56.8% are not.

Figure 5. The Percentage of Wells Protected by County.



A chi-square test reveals that there are significant differences in Protection Status across County ($p < .0001$). For example, note that only 10.9% of the wells in Wabasha County are protected, whereas 62.5% of the wells in Mower County and 77.6% of the wells in Rice County are protected. This could also potentially explain why the nitrate levels in Wabasha County were higher. Figure 6 shows the trends for the NO3 measurements over time for both protected and non-protected wells.

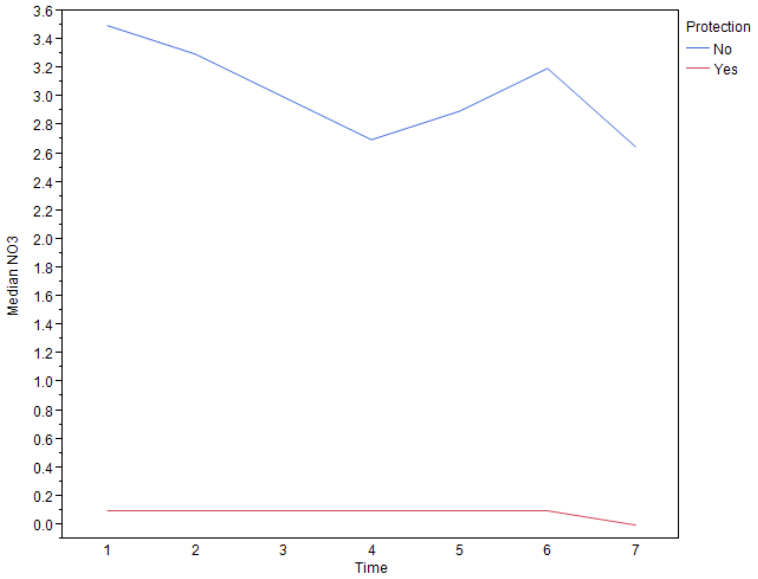
Figure 6. NO3 Measurements by Protection Status.



The two dashed horizontal lines represent NO3 measurements of 3 and 10 mg/L. We see that in both cases, many wells have NO3 measurements near 0. However, for the unprotected wells, we see many more wells that have measurements above 10 mg/L and above 3 mg/L when we compare them to the protected wells. For protected wells only, we see a vast majority lie below the cutoff of 3 mg/L, but when we look at the unprotected wells, we see many more wells scattered above both cutoff lines.

Figure 7 shows the median NO3 level for both protected and non-protected wells across time. Note that wells that are protected (red) have much lower median NO3 measurements than the wells that are not protected (blue).

Figure 7. Median NO3 Levels across Time by Protection Status.



<u>Statistical Comparisons</u>: Once again using the mixed-distribution model described in Appendix A, we first tested for differences in the probability of a well yielding a non-zero NO3 level between the protected and non-protected wells. This difference was statistically significant ($p < .0001$). The non-protected wells have a significantly higher probability of yielding a non-zero NO3 value than do protected wells.

Next, as described in Appendix A, we tested for differences in the means of the log-transformed NO3 levels between protected and non-protected wells. This difference was also statistically significant ($p < .0001$). That is, there is statistical evidence that that the NO3 values are significantly higher for non-protected wells.

An alternative analysis for making comparisons across Protection Status was also completed. Instead of considering actual nitrate values, this analysis modeled the probability of a well either (1) having elevated nitrate levels (above 3 mg/L) or (2) exceeding the standard (above 10 mg/L) in each round. The percentage of wells in each of these categories for each Protection Status are shown in Tables 9 and 10.

Table 9. Percentage of Wells in each Round with Nitrate Levels Above 3 mg/L by Protection Status.

Protection	Round1	Round2	Round3	Round4	Round5	Round6	Round7
Yes	13.9%	11.4%	11.9%	11.5%	11.3%	12.3%	12.2%
No	52.3%	52.3%	50.0%	48.0%	47.1%	50.3%	46.3%

Table 10. Percentage of Wells in each Round with Nitrate Levels Above 10 mg/L by Protection Status.

Protection	Round1	Round2	Round3	Round4	Round5	Round6	Round7
Yes	4.0%	2.6%	2.3%	2.4%	2.6%	1.5%	1.1%
No	23.2%	18.7%	18.4%	19.3%	13.8%	16.9%	13.0%

Statistical Comparisons:

Logistic regression models accounting for the repeated measures structure of the data was used to test whether the probability of a well either having elevated nitrate levels (above 3 mg/L) or of exceeding the 10 mg/L standard differed across Protection Status or time. PROC GENMOD in SAS version 9 was used to fit the appropriate models.

Comparing the Probability of a Well Having Elevated Nitrate Levels: The results indicate that the probability of a well having an elevated nitrate level was significantly different across Protection Status ($p < .0001$). Wells that are not protected have a much higher chance of having elevated nitrate levels. The probability of having an elevated nitrate level did not differ significantly across time ($p = .0680$).

Comparing the Probability of a Well Exceeding the 10 mg/L Standard: The results indicate that the probability of a well having a nitrate level exceeding the standard was significantly different across Protection Status ($p < .0001$). Wells that are not protected have a much higher chance of exceeding the standard. The probability of exceeding the standard also differed significantly across time ($p = .0058$). These results were quite similar to what was observed in the earlier analysis involving matrix types: the probability was found to be significantly higher in Round 1 than in Rounds 2, 3, 5, 6, and 7. Also, the probability of exceeding the standard was found to be significantly lower in Round 7 than in Rounds 1, 2, and 3.

Comparisons across WellCode

Note that the differences in NO3 levels could also be due to differences in WellCode. Each well in the study was classified as either being built to code or not. Figure 8 shows the breakdown of WellCode by County. For example, of all wells in Fillmore County in this data set, 31.3% were built to code and 68.8% were not. A chi-square test reveals that there are significant differences in WellCode across County ($p < .0001$).

Figure 8. The Percentage of Wells Built to Code by County.

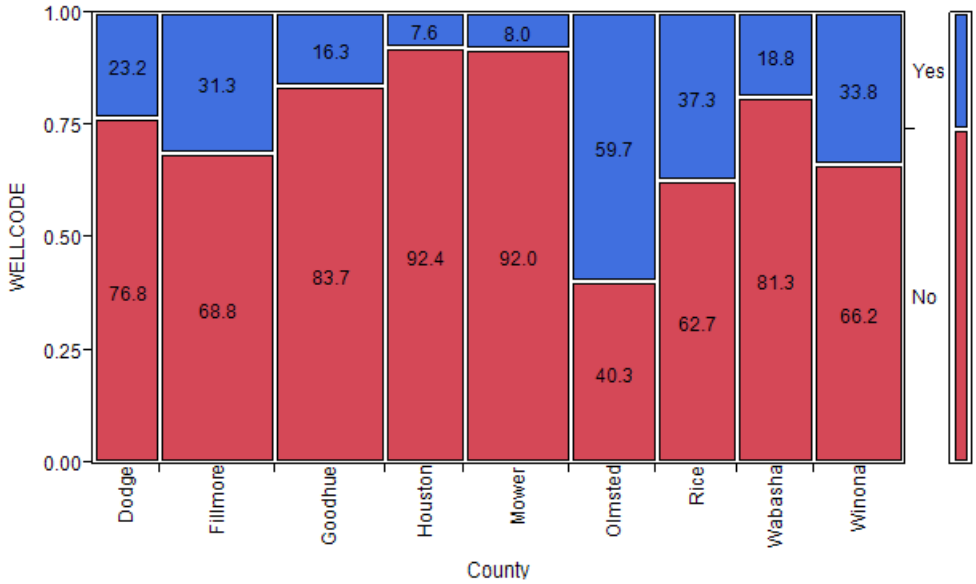
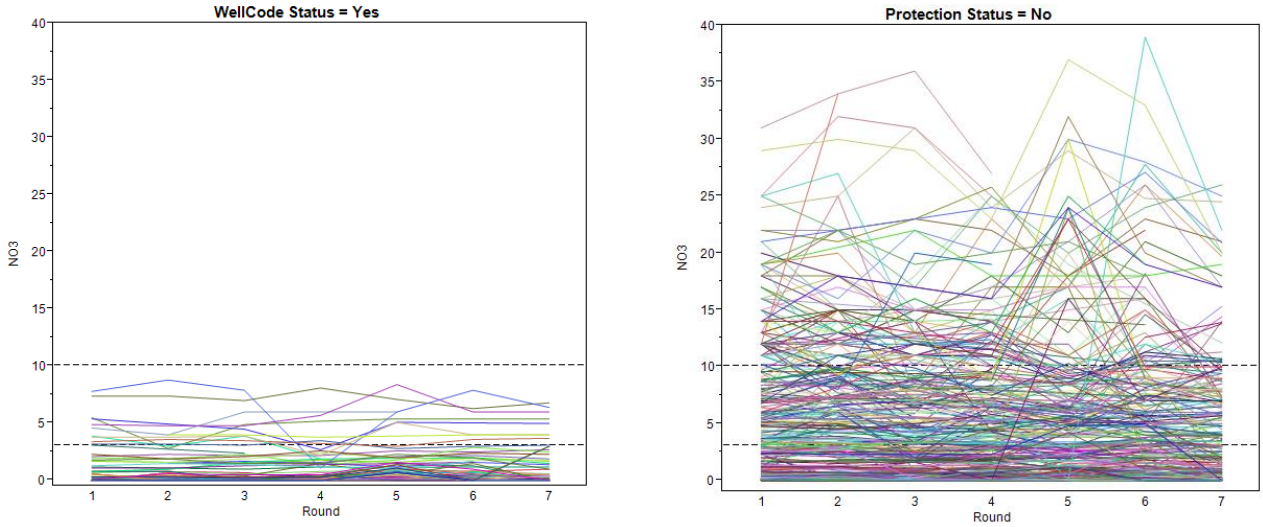


Figure 9 shows the trends for the NO3 measurements over time for both levels of WellCode status.

Figure 9. NO3 Measurements by WellCode Status.

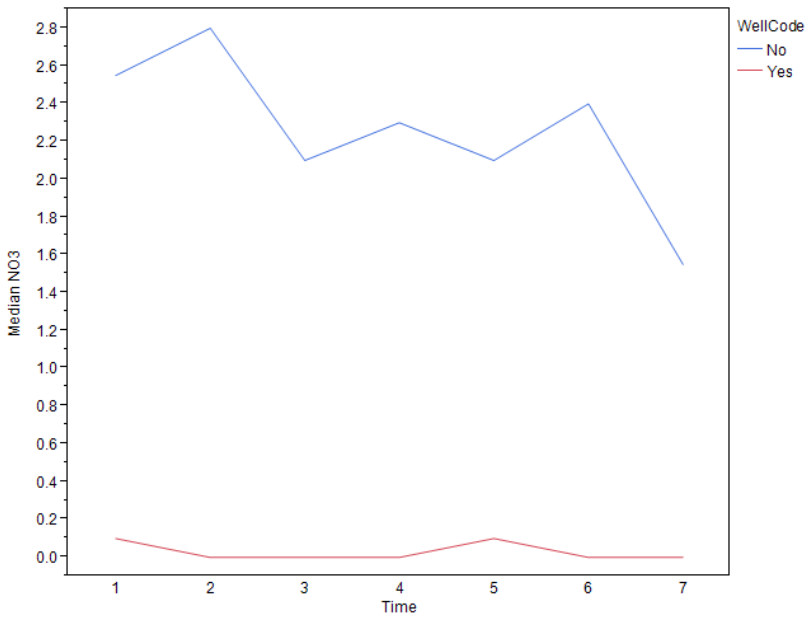


We can see from these plots that we had many more wells that were not built to code than wells that were. We also see that when examining only wells that were built to code (Wellcode Status = Yes), we did not have

any wells that were at elevated NO3 levels (above 10 mg/L). We did, however, see many wells at an elevated level when examining the wells that were not built to code.

Figure 10 shows the median NO3 level for both wells that were and were not built to code across time. Note that wells that were built to code (red) have much lower median NO3 measurements than the wells that were not (blue).

Figure 10. Median NO3 Levels across Time by WellCode Status.



Statistical Comparisons: Once again using the mixed-distribution model, we first tested for differences in the probability of a well yielding a non-zero NO3 level between the wells that were and were not built to code. This difference was statistically significant ($p < .0001$). The wells not built to code have a significantly higher probability of yielding a non-zero NO3 value than do wells that were built to code.

Next, we tested for differences in the means of the log-transformed NO3 levels between wells that were and were not built to code. This difference was also statistically significant ($p < .0001$). In other words, there is statistical evidence that that the NO3 values are significantly higher for wells not built to code.

An alternative analysis for making comparisons across WellCode Status was also completed. Instead of considering actual nitrate values, this analysis modeled the probability of a well either (1) having elevated nitrate levels (above 3 mg/L) or (2) exceeding the standard (above 10 mg/L) in each round. The percentage of wells in each of these categories for each Well Code Status are shown in Tables 11 and 12.

Table 11. Percentage of Wells in each Round with Nitrate Levels Above 3 mg/L by WellCode Status.

Protection	Round1	Round2	Round3	Round4	Round5	Round6	Round7
Yes	46.7%	46.7%	44.6%	44.0%	43.8%	47.7%	42.4%
No	7.1%	4.9%	6.8%	3.2%	4.9%	4.8%	6.6%

Table 12. Percentage of Wells in each Round with Nitrate Levels Above 10 mg/L by WellCode Status.

Protection	Round1	Round2	Round3	Round4	Round5	Round6	Round7
Yes	0%	0%	0%	0%	0%	0%	0%
No	20.6%	15.9%	16.6%	16.5%	12.7%	15.1%	10.4%

Statistical Comparisons:

Logistic regression models accounting for the repeated measures structure of the data was used to test whether the probability of a well either having elevated nitrate levels (above 3 mg/L) or of exceeding the 10 mg/L standard differed across WellCode Status or time. PROC GENMOD in SAS version 9 was used to fit the appropriate models.

Comparing the Probability of a Well Having Elevated Nitrate Levels: The results indicate that the probability of a well having an elevated nitrate level was significantly different across Well Code Status ($p < .0001$). Wells that are not protected have a much higher chance of having elevated nitrate levels. The probability of having an elevated nitrate level did not differ significantly across time ($p = .1313$).

Comparing the Probability of a Well Exceeding the 10 mg/L Standard: Because there were no protected wells with nitrate levels exceeding the standard, the logistic regression could not be fit for this case. It is clear, however, that non-protected wells are much more likely to have nitrate levels exceeding the 10 mg/L standard.

Comparisons across Recharge2W

Finally, note that the differences in NO3 levels could also be due to differences in whether the ground sloped toward a well or away from a well. Each well in the study was classified as either Recharge2W = Yes (when the ground sloped toward the well) or Recharge2W = No (when the ground did not slope toward the well). Figure 11 shows the breakdown of Recharge2W status by County. A chi-square test reveals that there are significant differences in Recharge2W status across County ($p < .0001$).

Figure 11. The Percentage of Wells toward Which the Ground Slopes by County.

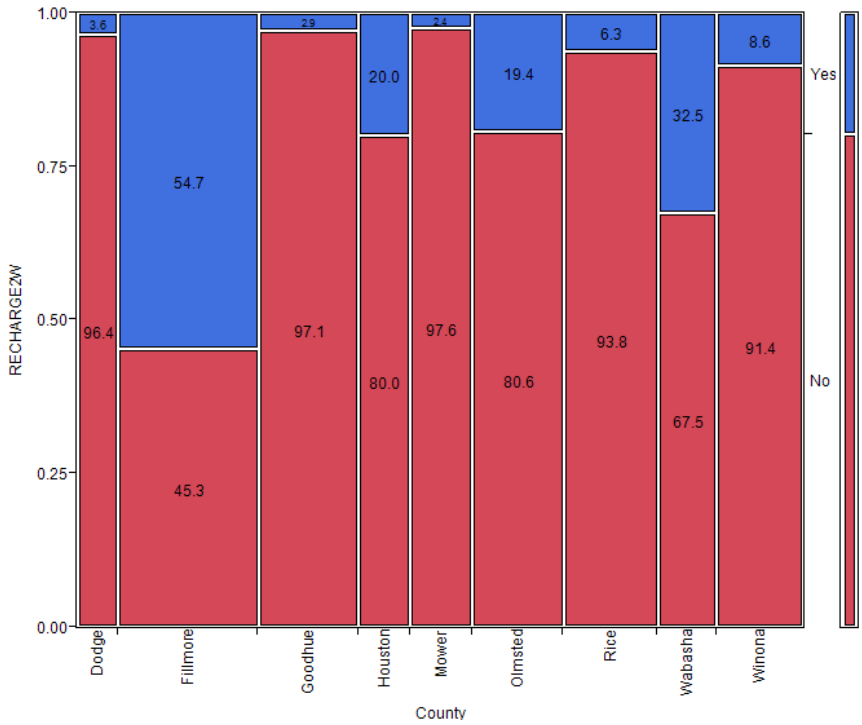
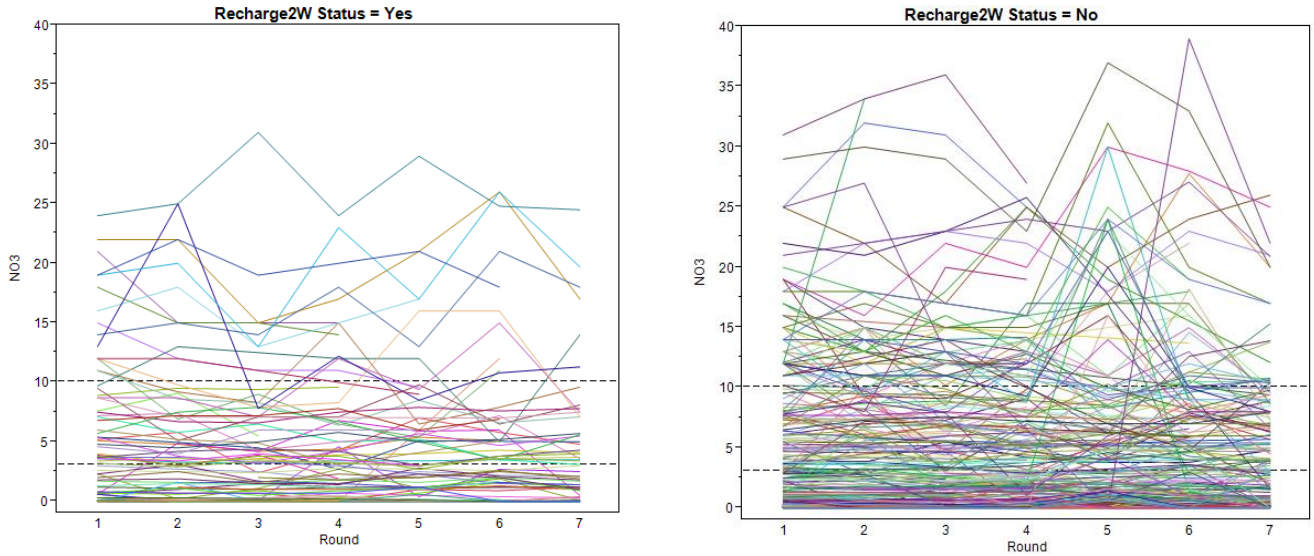


Figure 12 shows the trends for the NO3 measurements over time for both levels of Recharge2W status.

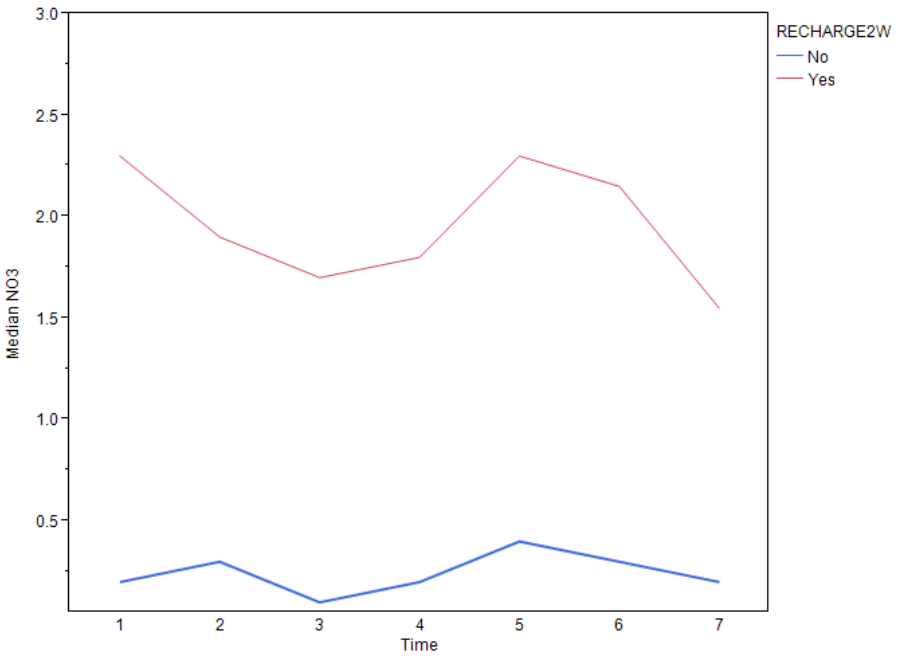
Figure 12. NO3 Measurements by Recharge2W Status.



We see that we have more wells without the ground sloping towards them than those that do. No general trend is evident when comparing the two levels of this variable (Recharge2w), as we see similar distributions of NO3 measurements for both cases.

This trend is more evident when we summarize the distributions with the median NO3 value. Figure 13 shows the median NO3 level for both wells that did and did not have the ground slope towards them across time. Note that wells that did not have the ground sloping towards them (blue) have much lower median NO3 measurements than the wells that did (red).

Figure 13. Median NO3 Levels across Time by Recharge2W Status.



<u>Statistical Comparisons</u>: Once again using the mixed-distribution model, we first tested for differences in the probability of a well yielding a non-zero NO3 level between the wells that did and did not have the ground sloping towards them. This difference was not statistically significant (p = .1161).

Next, we tested for differences in the means of the log-transformed NO3 levels between wells that did and did not have the ground sloping towards them. This difference was statistically significant (p = .0068). That is, there is statistical evidence that that the NO3 values are significantly higher for wells that have the ground sloping towards them.

An alternative analysis for making comparisons across Recharge2W Status was also completed. Instead of considering actual nitrate values, this analysis modeled the probability of a well either (1) having elevated nitrate levels (above 3 mg/L) or (2) exceeding the standard (above 10 mg/L) in each round. The percentage of wells in each of these categories for each Recharge2W Status are shown in Tables 13 and 14.

Table 13. Percentage of Wells in each Round with Nitrate Levels Above 3 mg/L by Recharge2W *Status.*

Protection	Round1	Round2	Round3	Round4	Round5	Round6	Round7
Yes	47.3%	43.0%	44.9%	40.2%	38.0%	43.2%	39.4%
No	32.0%	31.1%	29.8%	28.1%	28.6%	29.8%	28.1%

Table 14. Percentage of Wells in each Round with Nitrate Levels Above 10 mg/L by Recharge2W *Status.*

Protection	Round1	Round2	Round3	Round4	Round5	Round6	Round7
Yes	17.6%	12.9%	11.2%	14.6%	10.1%	13.5%	9.1%
No	14.0%	11.4%	11.9%	11.2%	8.7%	9.5%	6.8%

Statistical Comparisons:
Logistic regression models accounting for the repeated measures structure of the data was used to test whether the probability of a well either having elevated nitrate levels (above 3 mg/L) or of exceeding the 10 mg/L standard differed across Recharge2W Status or time. PROC GENMOD in SAS version 9 was used to fit the appropriate models.

Comparing the Probability of a Well Having Elevated Nitrate Levels: The results indicate that the probability of a well having an elevated nitrate level was significantly different across Recharge2W Status ($p = .0211$). Wells that have the ground sloping towards them have a much higher chance of having elevated nitrate levels. The probability of having an elevated nitrate level did not differ significantly across time ($p = .2215$).

Comparing the Probability of a Well Exceeding the 10 mg/L Standard: The results indicate that the probability of a well having a nitrate level exceeding the standard did not differ significantly across Recharge2W Status ($p = .4276$). The probability of exceeding the standard did differ significantly across time, however ($p = .0003$). Once again, these results were quite similar to what was observed earlier: the probability was found to be significantly higher in Round 1 than in Rounds 2, 3, 5, 6, and 7. Also, the probability of exceeding the standard was found to be significantly lower in Round 7 than in Rounds 1, 2, and 3.

Examining Matrix, Protection, WellCode, and Recharge2W Simultaneously

Earlier analyses consider the factors separately. To consider these factors jointly, a single logistic regression model was fit to examine the effects of Matrix, Protection, WellCode, Recharge2W, and Round on the probability of a well either (1) having elevated nitrates (above 3 mg/L) or (2) having nitrates that exceed the standard (above 10 mg/L). This model accounted for the repeated measures nature of the data and was fit using PROC GENMOD in SAS version 9.

The results presented in Table 15 indicate that all factors were significant except for time. This indicates that each factor is still a significant predictor of the probability of having elevated nitrate levels even after adjusting for the effects of the other variables.

Table 15. Results of Logistic Regression Model for Predicting the Probability of Nitrates Exceeding 3 mg/L.

Variable	p-value
Matrix	.0087
Protection Status	<.0001
WellCode Status	<.0001
Recharge2W Status	.0004
Round	.1775

The probability was found to be significantly higher for Matrix Type B than Matrix Type Matrix Type Q (p = .016). Also, the probability was found to be significantly higher for Matrix Type S than Matrix Type Q (p = .0007). Non-protected wells, wells not up to code, and wells with the ground sloping towards them were found to have significantly higher chances of having elevated nitrate levels than their counterparts.

A similar model was fit to predict the probability of exceeding the 10 mg/L standard. The results are presented in Table 16. Note that WellCode status was not included in this model since no protected wells exceeded the 10 mg/L standard (including this variable in the analysis would not allow for successfully fitting a logistic regression model). The results indicate that all factors were significant except for Recharge2W status. Once again, this indicates that Matrix, Protection Status, and Time are all significant predictors of the probability of having nitrate levels above 10 mg/L even after adjusting for the effects of the other variables.

Table 16. Results of Logistic Regression Model for Predicting the Probability of Nitrates Exceeding 10 mg/L.

Variable	p-value
Matrix	.0016
Protection Status	<.0001
Recharge2W Status	.1527
Round	.0152

The probability of exceeding the standard was found to be significantly higher for Matrix Type B than Matrix Type C (p = .0491). Also, the probability was found to be significantly higher for Matrix Type S than Matrix Type C (p = .0005). Wells not up to code and wells with the ground sloping towards them were found to have significantly higher chances of having elevated nitrate levels than their counterparts. Regarding comparisons across time, the probability was found to be significantly higher in Round 1 than in Round 2 (p = .0227), Round 3 (p = .0166), Round 5 (p = .0044), Round 6 (p = .0115), and Round 7 (p = .0005). Finally, the probability of exceeding the standard was found to be significantly lower in Round 7 than in Round 1 (p=.0277), Round 2 (p=.0347), Round 3 (p = .0319), and Round 4 (p = .0074).

Comparisons across Aquifer

It may also be of interest to compare nitrate levels across aquifer. Figure 14 shows the median NO3 levels across time for each aquifer. Note that there are 7 aquifers that have elevated median scores (above 3 mg/L) for one (if not all) time periods. These aquifers are as follows: CJFR (which contained only 2 wells), DCLP (which contained 7 wells), OGCM (which contained 3 wells), OPCJ (which contained 30 wells), OPGW (which contained only 2 wells), OPNR (which contained only 1 well), and OPOD (which contained 10 wells). Table 17 shows the number of wells that were measured in each round by aquifer.

Figure 14. *Median NO3 Levels across Time by Aquifer (the number of wells in each aquifer is indicated in parentheses).*

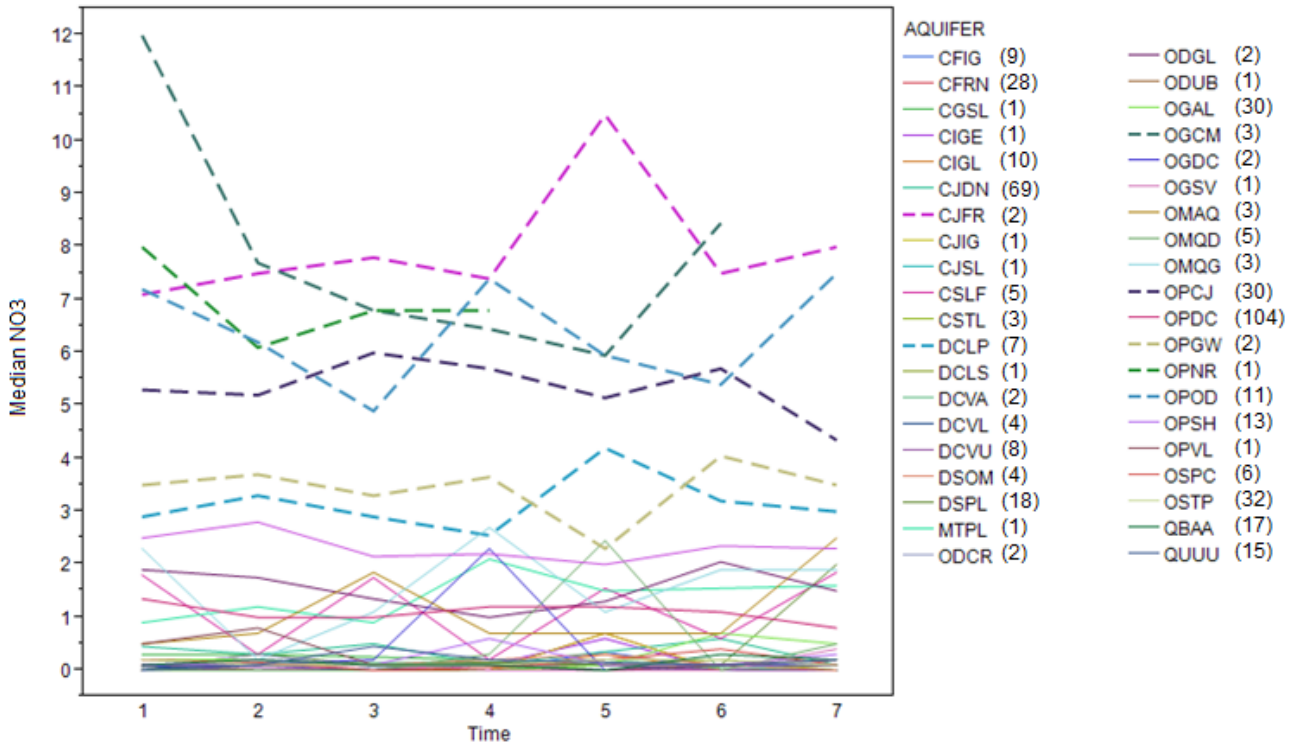


Table 17. The Number of Wells Measured in Each Round by Aquifer.

Aquifer	Round1	Round2	Round3	Round4	Round5	Round6	Round7
CFIG	9	9	8	8	8	9	7
CFRN	27	28	27	25	21	23	23
CGSL	1	1	0	1	0	1	1
CIGE	1	1	1	1	1	1	1
CIGL	9	9	9	8	8	8	7
CJDN	62	64	67	63	56	58	51
CJFR	2	2	2	2	2	2	2
CJIG	1	1	1	1	1	1	1
CJSL	1	1	1	1	1	1	1
CSLF	4	5	4	3	4	3	2
CSTL	3	3	3	3	3	3	3

Aquifer	Round1	Round2	Round3	Round4	Round5	Round6	Round7
DCLP	7	7	7	6	5	5	5
DCLS	1	1	1	1	1	1	1
DCVA	2	2	2	2	2	2	2
DCVL	4	4	4	4	4	4	4
DCVU	8	8	5	7	5	6	5
DSOM	3	4	3	3	3	3	3
DSPL	18	17	17	16	13	10	11
MTPL	1	1	1	1	1	0	1
ODCR	2	2	2	1	1	1	2
ODGL	2	2	2	2	2	2	2
ODUB	1	0	1	0	0	1	0
OGAL	29	29	27	27	25	24	24
OCGM	3	3	3	2	2	2	0
OGDC	1	1	1	1	1	1	1
OGSV	1	1	1	1	1	1	1
OMAQ	3	3	2	3	3	3	2
OMQD	5	5	5	5	4	5	5
OMQG	3	3	3	3	3	3	2
OPCJ	30	29	26	24	24	25	20
OPDC	94	93	93	88	82	78	71
OPGW	2	2	2	2	2	2	2
OPNR	1	1	1	1	0	0	0
OPOD	10	10	9	10	8	9	8
OPSH	12	13	11	11	13	13	12
OPVL	1	1	1	1	1	0	1
OSPC	6	6	5	4	5	4	4
OSTP	27	30	30	28	27	28	28
QBAA	16	16	15	14	15	11	12
QUUU	15	14	14	13	12	12	10

Appendix A. Description of Statistical Methods Used to Test for Differences Across Matrix Type

To test whether the differences in NO3 levels from one Matrix type to another are statistically significant, traditional repeated measures analyses are not appropriate because of the abundance of zeros in the data set and fact that the NO3 measurements are highly positively skewed. To account for this, we used a mixed-distribution model with correlated random effects. First, a "logistic" response component estimates the probability of obtaining a non-zero NO3 value for each Matrix type. Second, for those non-zero NO3 measurements, a "lognormal" response component estimates the mean of the log-transformed positive NO3 values and allows us to test for differences in the actual NO3 values across Matrix type.

We conducted these analyses using a SAS macro, MIXCORR, which is referenced below.

Note that similar analyses were conducted to make comparisons across Protection Status, whether the wells were up to code, and whether the ground sloped toward a well.

Source: Tooze JA, Grunwald GK, Jones RH. Analysis of repeated measures data with clumping at zero. Stat Methods Med Res. 2002;11:341–355.

University of Minnesota
EXTENSION

Best Management Practices for Nitrogen Use:
IRRIGATED POTATOES

BEST MANAGEMENT PRACTICES FOR NITROGEN APPLICATION

Best Management Practices for Nitrogen Use: Irrigated Potatoes

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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.

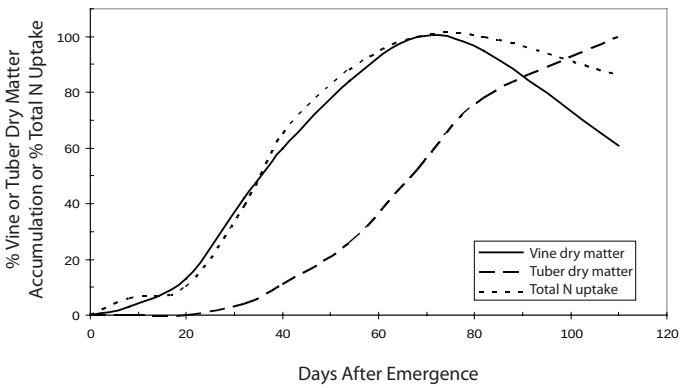

Figure 1. Relative tuber growth, vine growth and total nitrogen uptake by the potato crop. Based on data from the Russet Burbank variety.

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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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

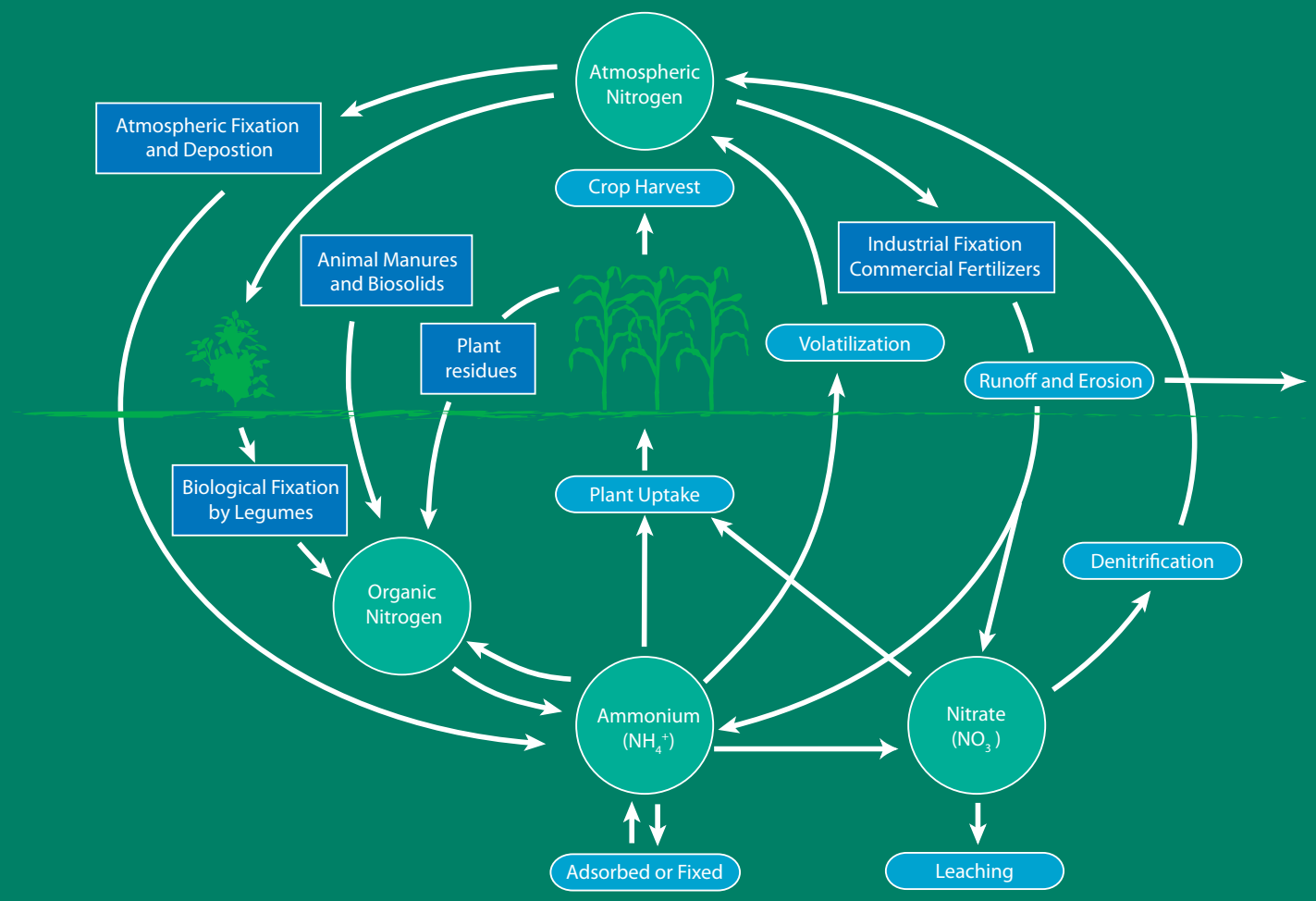
Nitrogen recommendations for irrigated potato production.

		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.



UNIVERSITY OF MINNESOTA
EXTENSION

Best Management Practices for Nitrogen Use: Irrigated Potatoes

PUBLICATION # 08559

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Long-term fate of nitrate fertilizer in agricultural soils

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Edited by Peter M. Vitousek, Stanford University, Stanford, CA, and approved September 9, 2013 (received for review March 26, 2013)

Increasing diffuse nitrate loading of surface waters and groundwater has emerged as a major problem in many agricultural areas of the world, resulting in contamination of drinking water resources in aquifers as well as eutrophication of freshwaters and coastal marine ecosystems. Although empirical correlations between application rates of N fertilizers to agricultural soils and nitrate contamination of adjacent hydrological systems have been demonstrated, the transit times of fertilizer N in the pedosphere–hydrosphere system are poorly understood. We investigated the fate of isotopically labeled nitrogen fertilizers in a three–decade-long in situ tracer experiment that quantified not only fertilizer N uptake by plants and retention in soils, but also determined to which extent and over which time periods fertilizer N stored in soil organic matter is rereleased for either uptake in crops or export into the hydrosphere. We found that 61–65% of the applied fertilizers N were taken up by plants, whereas 12–15% of the labeled fertilizer N were still residing in the soil organic matter more than a quarter century after tracer application. Between 8–12% of the applied fertilizer had leaked toward the hydrosphere during the 30-y observation period. We predict that additional exports of ^{15}N-labeled nitrate from the tracer application in 1982 toward the hydrosphere will continue for at least another five decades. Therefore, attempts to reduce agricultural nitrate contamination of aquatic systems must consider the long-term legacy of past applications of synthetic fertilizers in agricultural systems and the nitrogen retention capacity of agricultural soils.

nitrogen cycle | nitrate leaching | isotopic biogeochemistry

Increasing anthropogenic nitrogen inputs have recently been identified as one of the two major issues potentially compromising a safe operating space for humanity (1). In many regions, the amount of human-activated reactive nitrogen, primarily via application of synthetic fertilizers and cultivation of leguminous crops, exceeds now the amount of natural nitrogen as a result of population growth and the associated need for food production (2, 3). These anthropogenic nitrogen inputs have significantly impacted the nitrogen cycle in terrestrial and aquatic ecosystems (4, 5).

Increasing diffuse nitrate loading of surface waters and groundwaters has emerged as a major problem in many agricultural areas of the world resulting in contamination of drinking water resources abstracted from aquifers and eutrophication of freshwaters (6–8) and coastal marine ecosystems (9) despite the implementation of several diffuse pollution control directives (10, 11) and best management practices (12). Empirical correlations relating increased use of synthetic fertilizers, their application rates, land use change, and nitrate leaching suggest that the increased application of synthetic fertilizers is strongly connected with the increase of nitrate concentrations in groundwater and surface waters (13, 14), but quantitative data on transfer rates of fertilizer N into the hydrosphere are elusive. There is also considerable uncertainty regarding the transit time of anthropogenic nitrogen applied to agricultural soils between the topsoil and groundwater due to a poor mechanistic understanding of the timelines governing nitrogen cycling and nitrate transfer through soils (3, 15–17).

Previous studies on the fate of synthetic fertilizers and other nitrogen amendments in agricultural soils have been carried out at various long-term agricultural research sites (18–26). In several cases, fertilizer compounds artificially enriched in ^{15}N have been used to successfully follow the uptake of fertilizer N by crops and retention of fertilizer N in soil organic matter. These tracer studies with labeled ^{15}N compounds demonstrated that 40–60% of the fertilizer N is rapidly taken up by crops and is removed via harvest, whereas the remainder of the fertilizer N is incorporated into the soil organic matter pool and soil microbial biomass. From this fertilizer-derived soil N pool, nitrate may be formed and leached out of the soil zone especially outside of the growing season (27–29). To our best knowledge, no in situ studies have investigated the long-term fate of this fertilizer-derived N in soil organic matter and quantified to which extent and over which time periods fertilizer N stored in soil organic matter is rereleased for either uptake in crops or is exported toward the hydrosphere.

We investigated the long-term fate of isotopically (^{15}N) labeled fertilizer nitrate in the plant–soil–water system of two intact lysimeters under rotating sugar beet and winter wheat cultivation at a site in France over a period of three decades (1982–2012). The objectives were *i*) to determine the extent to which fertilizer nitrate was taken up by crops, *ii*) to assess the mean residence time of fertilizer nitrogen in soil organic matter, and *iii*) to measure the rates at which fertilizer-derived nitrogen was exported as nitrate to the hydrosphere in the three decades after application of isotopically labeled fertilizer. The goal was to establish a complete 30-y mass balance of the fate of fertilizer N in an agricultural system and to quantify to which extent and over which time periods fertilizer N stored in soil organic matter is rereleased for either uptake in crops or export toward the hydrosphere.

Significance

Fertilizers are of key importance to sustain modern agriculture, but the long-term fate of fertilizer-derived nitrogen in the plant–soil–water system is not fully understood. This long-term tracer study revealed that three decades after application of isotopically labeled fertilizer N to agricultural soils in 1982, 12–15% of the fertilizer-derived N was still residing in the soil organic matter, while 8–12% of the fertilizer N had already leaked toward the groundwater. Part of the remaining fertilizer N still residing in the soil is predicted to continue to be taken up by crops and to leak toward the groundwater in the form of nitrate for at least another five decades, much longer than previously thought.

Author contributions: M.S., B.N., and A.M. performed research; M.S., B.M., B.N., G.P., and A.M. analyzed data; and M.S., B.M., B.N., G.P., and A.M. wrote the paper.

The authors declare no conflict of interest.

This article is a PNAS Direct Submission.

Freely available online through the PNAS open access option.

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This article contains supporting information online at www.pnas.org/lookup/suppl/doi:10.1073/pnas.1305372110/-/DCSupplemental.

ENVIRONMENTAL SCIENCES

Details about the experimental design are provided in the *SI Methods*. Two large (2 × 2 × 2 m) soil monoliths containing agricultural topsoils underlain by mineral soil were converted into lysimeters. For both lysimeters, the annual crop rotation was sugar beet–winter wheat with annual N fertilization rates of 120 kg $N \cdot ha^{-1} \cdot y^{-1}$ except in 1982. In the year of the tracer application (1982), Lys S was cropped with sugar beet whereas winter wheat was grown on Lys W. In 1982, both crops received a one-time ^{15}N-labeled tracer application (635.3 mg $^{15}N \cdot m^{-2}$ on March 11 for wheat, 633.8 mg $^{15}N \cdot m^{-2}$ on April 7 for sugar beet) equivalent to a typical fertilizer application rate of 120 and 150 kg $N \cdot ha^{-1} \cdot y^{-1}$ for wheat and sugar beet, respectively. Nitrogen exports occurred annually by harvesting of wheat and sugar beets and via seepage water outflow in 2-m depth. Soils, harvest products, and seepage waters were sampled repeatedly, and chemical and isotopic analyses were conducted. Mass and isotope balances were conducted to assess the fate of the fertilizer applied in 1982 in the agricultural soils and its export via harvest products and toward the underlying aquifers (see *SI Methods* for further details).

Results and Discussion

Before tracer application, $\delta^{15}N$ values of nitrate in lysimeter outflow were on average 2.5‰. Following the application of the $K^{15}NO_3^-$ solution sprinkled uniformly on the surface of the two lysimeters in 1982, $\delta^{15}N$ in seepage water nitrate steadily increased to peak values of 473‰ after 19 mo (577 d) in lysimeter W (Lys W) under wheat and 535‰ after 55 mo (1,653 d) in lysimeter S (Lys S) under sugar beet (Fig. 1*A*). Tritium measurements indicated that infiltration rates for precipitation water vary from 35 to 55 cm/y consistent with expected tracer migration times calculated based on water infiltration rates. Thereafter, $\delta^{15}N$ values in seepage water nitrate decreased steadily reaching values of circa +200‰ in 1990, and +100‰ by 1996. During the last 14 y, $\delta^{15}N$ values of seepage water nitrate in 2-m depth decreased slowly to values of +32‰ (Lys S) and +53‰ (Lys W) in 2008, indicating that isotopically labeled tracer N is still exported from the lysimeters almost three decades after tracer application. The elevated $\delta^{15}N$ values and their sluggish decrease in seepage water nitrate are indicative of significant tracer retention in the soil–plant system, because the pore-space of the lysimeters had been flushed more than 10 times during the observation period. Nitrate collected in outflow from both lysimeters between 2001 and 2009 was also analyzed for oxygen isotope ratios yielding an average $\delta^{18}O_{nitrate}$ value of -0.5 ± 2.8‰ ($n = 16$).

Before application of the ^{15}N tracer, the $\delta^{15}N$ value of total nitrogen in plants was 0‰. The $\delta^{15}N$ values of total N in the harvest products increased to +230‰ (Lys S) and +340‰ (Lys W) after the first growing season (Fig.1*B*), indicating that a considerable portion of the labeled ^{15}N was taken up by the crops in the first growing season. The $\delta^{15}N$ values of total N in the harvested crops decreased markedly in the following years to +67‰ (Lys S) and +119‰ (Lys W) in 1987 and to +28‰ (Lys S) and +38‰ (Lys W) in 2009. Even 27 y after tracer application, the $\delta^{15}N$ values of the crops were still significantly higher than natural abundance nitrogen isotope ratios observed before tracer application suggesting continued availability of isotopically labeled N applied in 1982.

Before application of the ^{15}N tracer (1976–1981), $\delta^{15}N$ values of total N in soils ranged between 4.4 and 5.4‰. Three years after tracer application (1985), $\delta^{15}N$ of total nitrogen in soil organic matter had maximum values of +98‰ (Lys S) and +105‰ (Lys W) (Fig. 1*C*). Thereafter, $\delta^{15}N_{total}$ values of soil organic matter decreased exponentially to +52.2‰ (Lys W) and +41.5‰ (Lys S) in 2009. This indicates significant retention of isotopically labeled fertilizer N more than a quarter century after application, with slightly higher tracer contents in the lysimeters cropped with sugar beets (Lys S) compared with those planted with wheat (Lys W).

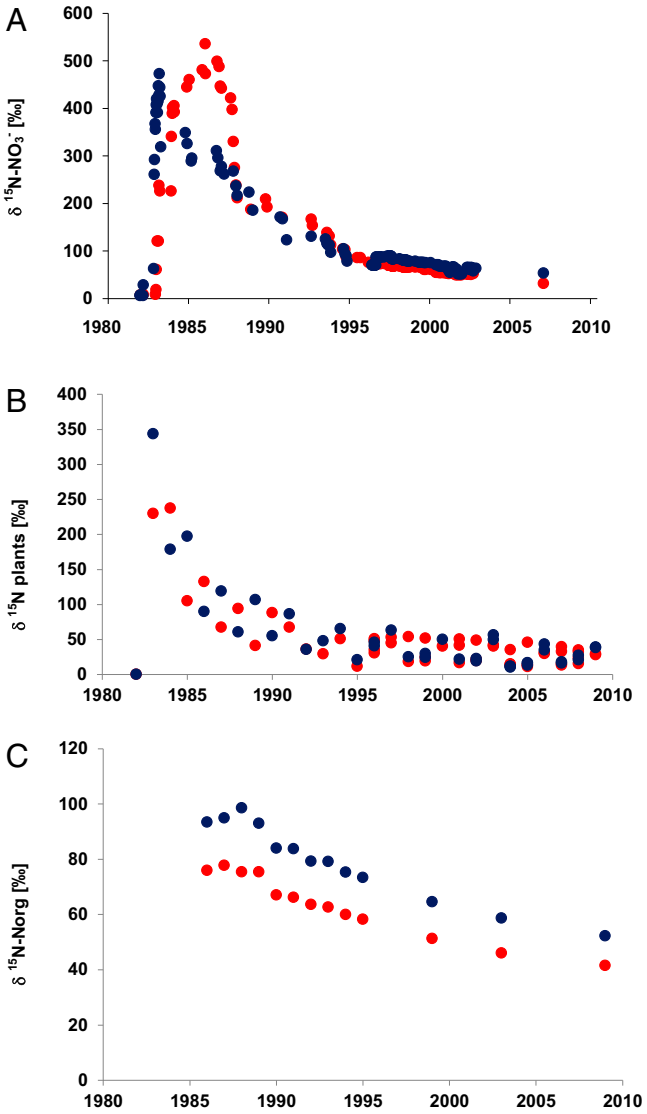

Fig. 1. The $\delta^{15}N$ values for seepage water nitrate (*A*), plants (*B*), and soil organic matter (*C*) for the two types of lysimeters under sugar beet (Lys S in red) and under wheat (Lys W in blue).

Isotope and mass balances were used to determine the extent to which fertilizer nitrate was taken up by crops, to assess the mean residence time of fertilizer nitrogen in soil organic matter, and to measure the rates at which fertilizer-derived nitrogen was exported to the hydrosphere over an observation period of almost three decades. In the first year of the experiment, between 45.2% (Lys W) and 50.4% (Lys S) of the ^{15}N-labeled fertilizer nitrate-N was taken up by the winter wheat and sugar beet crops, respectively (Fig. 2). In subsequent years, additional crop uptake of ^{15}N-labeled fertilizer N was observed at average annual rates between 0.3% (lysimeter S) and 0.5% (lysimeter W) of the labeled fertilizer N applied in 1982. Twenty-seven years after tracer application, between 65.3% (Lys S) and 61.3% (Lys W) of the applied tracer had been cumulatively taken up by the crops and was exported from the soil–plant system via harvest (Fig. 2).

Three years after tracer application, between 32.3% (Lys S) and 37.4% (Lys W) of the ^{15}N-labeled fertilizer were detected in the soil organic matter (Fig. 2). Subsequently, the amount of tracer ^{15}N recovered in the soils decreased by circa 0.9% per annum. At the end of the observation period in 2009, between

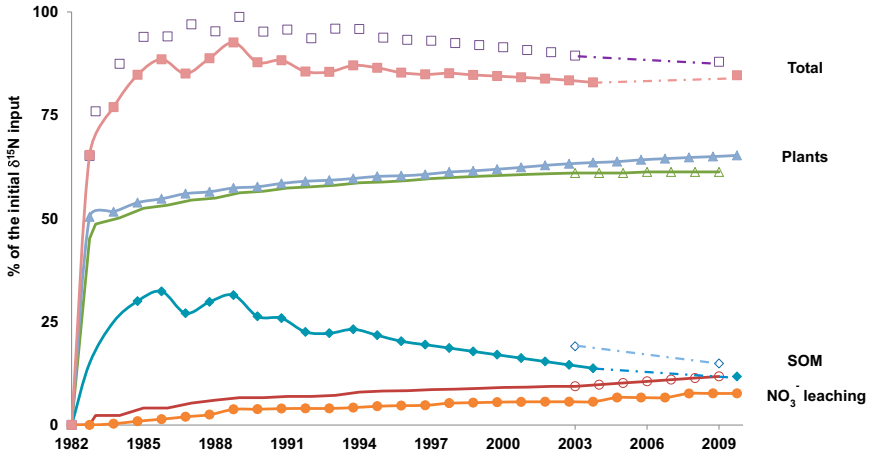

Fig. 2. Cumulative budget of ^{15}N-labeled fertilizer nitrogen based on mass and isotope balances for plants, soil organic matter (SOM), and nitrate in lysimeter outflows for Lys S (full symbols) and Lys W (empty symbols).

11.8% (Lys S) and 14.9% (Lys W) of the ^{15}N-labeled N still resided in the soil organic matter (Fig. 2). The observed decrease of the ^{15}N tracer in soil organic matter between 1985 and 2009 is partially explained by plant uptake (4.9 and 5.5% in 27 y after the 1982 growing season) and nitrate leaching as seepage water outflow from the lysimeters, as described below.

Three years after tracer application, i.e., in 1985, between 1.4% (Lys S) and 4.1% (Lys W) of the applied ^{15}N-labeled nitrate had been exported with the seepage water outflow in 2-m depth. During the following 24 y an average of 0.4% of the applied tracer was exported annually with the seepage water nitrate flux from the plant–soil system with comparatively little variability of hydrological ^{15}N exports between wet and dry years. The cumulative nitrate exports toward the hydrosphere accounted for 7.6% (Lys S initially cropped with sugar beets) and 11.8% (Lys W, initially wheat) of the ^{15}N-labeled fertilizer N applied in 1982 throughout the 27-y observation period (Fig. 2). $\delta^{18}O$–NO_3^- values of lysimeter outflow nitrate collected for both lysimeters in 2001, 2003, 2005 (only Lys W), 2008, and 2009 (only Lys W) averaged -0.5 ± 2.8‰ ($n = 16$). Nitrate-containing fertilizers (i.e., +22–25‰) and atmospheric nitrate deposition (>50‰) have $\delta^{18}O$ values typically >20‰ (30, 31). The observed low $\delta^{18}O$–NO_3^- values indicate that the exported nitrate was not directly derived from the applied fertilizer, but from nitrification of soil organic matter (32, 33). During ammonification of soil organic matter followed by nitrification, three new atoms of oxygen

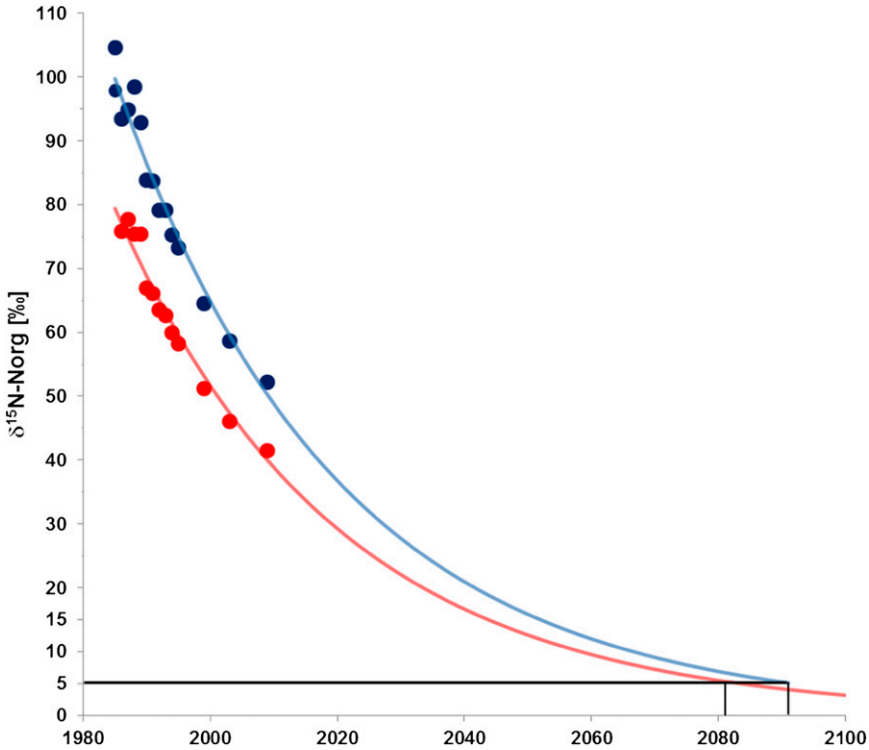

Fig. 3. Decay functions fitted to observed δ^{15}N values of soil organic matter from Lys S (red) and Lys W (blue). The model suggests that it will take circa 100 y to reach the background δ^{15}N values of circa +5‰ observed before tracer application.

are incorporated into the newly formed nitrate molecule, two of which are derived from water resulting in low $\delta^{18}O$ values of nitrate typically around 0‰ (34). Therefore, the combination of $\delta^{15}N$ and $\delta^{18}O$ measurements indicates that a significant portion of the ^{15}N-labeled fertilizer nitrate was first incorporated into the soil organic matter either directly by uptake in the soil microbial community or via plant root decomposition after harvest. Subsequently, the ^{15}N-labeled organic N was remineralized and some of this newly formed nitrate is continuously exported toward the hydrosphere.

In summary, between 61 and 65% of the applied fertilizer N was taken up by plants during this three-decade experiment (Fig. 2). A significant part of the applied nitrate that was not taken up by the crops after ^{15}N-labeled fertilizer application was rapidly incorporated into the soil organic matter pool (initially between 32 and 37%), and between 12 and 15% of the tracer remained in the soil organic matter pool 28 y after fertilizer application (Fig. 2). Oxygen isotope measurements on seepage water nitrate collected at 2-m depth below the root zone confirmed that ^{15}N enriched nitrate was derived from mineralization of soil organic matter. These soil-internal processes resulted in a continuous leaching of circa 0.4% of the applied fertilizer N per year as labeled nitrate toward the groundwater for more than a quarter of a century after fertilizer application. Throughout the observation period, between 8 and 12% of the labeled fertilizer N was exported toward the hydrosphere (Fig. 2).

Overall mass balances for ^{15}N detected in crops, soils, and seepage water accounted in the first years of the experiment for between ∼88% (Lys S) and ∼95% (Lys W) of the labeled fertilizer N. Throughout the experiment, the mass balance calculations revealed a slightly increasing deficit of ^{15}N of up to 15.3% for Lys S and 12.1% for Lys W in 2009 (Fig. 2). This discrepancy is not thought to be due to unaccounted losses to the hydrosphere, because all of the seepage water exported from the lysimeters was quantitatively recovered and regularly analyzed. Therefore, we hypothesize that the mass balance deficit for ^{15}N was caused by gaseous losses of N via volatilization (NH_3) and/or denitrification (e.g., N_2, N_2O) of either fertilizer N after tracer application or labeled N released from the soil organic matter pool. The observed percentage of gaseous loss of fertilizer nitrogen is in good agreement with values reported in the literature (35).

These results provide evidence that a significant portion of fertilizer N is incorporated in the soil organic matter pool, which constitutes a temporary nitrogen reservoir for the fertilizer N. In 2003, 21 y after ^{15}N application, between 13.7% (Lys S) and 19.0% (Lys W) of the ^{15}N-labeled N was still residing in the soil organic matter pool. Remineralization of fertilizer-derived N incorporated into the soil organic matter pool gradually releases ^{15}N-labeled N that is then taken up by plants, is lost to the atmosphere via volatilization or denitrification, or is leached toward aquifers in low doses over more than 25 y after application of the ^{15}N-labeled fertilizer.

Using a simple decay function fitted to the isotope data for soil nitrogen shown in Figs. 1*C* and 2 it is predicted that it will take circa 100 y to reach the background $\delta^{15}N$ values of +5‰ measured for soil N before tracer application (Fig. 3). Hence, the model suggests that it will take at least another five decades until the remaining tracer N is removed from the soil system. Assuming similar proportions of N transformation in the plant–soil–water system as in the last three decades, the remaining fertilizer-derived ^{15}N in the soil organic matter (12–15%) will be subject in approximately equal proportions to plant uptake (4–5%), seepage water export as nitrate (4–5%), and removal via soil-internal processes such as volatilization and denitrification (2–7%). It is estimated that seepage water export of labeled ^{15}N applied with a nitrate fertilizer in 1982 will continue for at least another five decades. This suggests that between 12 and 17% of the initially applied ^{15}N-labeled fertilizer are subject to low-dose continuous release with seepage water nitrate toward the hydrosphere over a time period of more than eight decades.

It is often assumed that most of the nitrate contained in fertilizers is used by plants for their growth or quickly leached out of the root zone (3, 4, 36, 37). Using ^{15}N-labeled tracer techniques combined with the determination of oxygen isotope ratios of nitrate this long-term lysimeter study demonstrates that a significant portion of nitrate fertilizer applied in 1982 was incorporated (32–37% in 1985) and partly retained for more than a quarter century (14–19% in 2009) in the soil organic matter pool of an agricultural soil. Hence, a significant part of the applied nitrate fertilizer is incorporated in the soil organic matter entering the soil nitrogen cycle with an estimated mean residence time of circa three decades. Mineralization of this ^{15}N-labeled soil organic matter pool continuously produced nitrate available for uptake by plants in the growing season and for export to the hydrosphere in approximately equal proportions. Our 30-y study demonstrates that a portion of the nitrogen applied as nitrate fertilizer is available for decades after application. This long-term retention and recycling of fertilizer N and release of nitrate has several implications. Soil organic matter management is crucially important for maximizing the long-term benefit of fertilizer applications for crop yields and for minimizing nitrate export to the hydrosphere. For example, bypassing the retention capacity of the soil organic matter pool by intensive tile drainage systems increases significantly the transfer of fertilizer-derived nitrate to rivers, aquifers, and estuaries (38–40). Also, due to the long mean residence time of fertilizer N in soils the effects of changes in soil management practices on nitrate loading of the hydrosphere may be considerably delayed. For instance, studies of the Mississippi River Basin have revealed a decrease in anthropogenic N inputs without any concurrent reductions in riverine nitrate loading (41–43).

Our findings reinforce the importance of soil organic matter management in agricultural soils as a buffer to mitigate diffuse nitrogen pollution of surface waters and groundwaters. They stress the need to take into account this long-term N-recycling component in soil N and catchment models to better understand and simulate nitrate-leaching lag times often observed between fertilizer N applications to soils and nitrate transfers in drainage basins. Our data also imply that the current trends of nitrate concentration increases observed in hydrological systems associated with many agricultural areas of the world are the result of both current and past activities throughout the last decades. Therefore, mitigation or restoration measures must take into account the delay resulting from legacies of past applications of synthetic fertilizers in agricultural systems.

Methods

The study was carried out over a 30-y period since 1981 using two lysimeters in the chalk area located under in situ environmental conditions near Châlons en Champagne, France (48°58′N, 4°19′E). Each lysimeter consisted of an intact unaltered soil monolith (2 × 2 × 2 m) surrounded by a lysimetric tank. Soil organic matter and harvest products of wheat and sugar beets were sampled annually, air dried, ground and sieved through a 1 mm mesh for soils and 80-μm for plants, and total N contents were determined using an elemental analyzer. Isotope abundance ratios of total nitrogen for plant materials and soil organic matter were determined by continuous flow isotope ratio mass spectrometry coupled to an elemental analyzer (EA-CF-IRMS). Nitrate concentrations in the lysimeter seepage water were determined by automated colorimetry (44). Nitrogen isotope ratios of nitrate in lysimeter seepage water were determined either with the Kjeldahl distillation procedure or with the ammonium diffusion technique using Devarda reagent (45, 46). Oxygen isotope ratios of seepage water nitrate were determined using an adaptation of the method described by Silva et al. (47). $\delta^{18}O\text{-}NO_3^-$ values were determined after conversion of nitrate to pure silver nitrate, which was converted to CO via pyrolysis in a glassy carbon reactor (TC/EA) at 1350 °C followed by mass spectrometric measurements. $\delta^{18}O$ values of nitrate are reported with respect to Standard Mean Ocean Water.

ACKNOWLEDGMENTS. We thank the Institut National de Recherche Agronomique (INRA), Gonzague Alavoine, Jean-Louis Ballif, Danièle Denys, Bruno Mary, Christian Herre, Marie-Jeanne Herre, Francis Millon, and Sylvie Millon for providing the set up of the Fagnières Lysimetric experimental site, the field assistance, the collection and analysis of plant, soil, and water samples or the data collection, and Micheline Grably for isotopic measurements.

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MDH List of community water supply wells with nitrate contamination

NAME	PWS_ CODE	OWNER_ CODE	POPULATION_ SERVED	Facility_Name	OBJECTIVE_D ESC	PROCESS_MECHANISM_DESC
Hastings	COMM	Municipal	22652	TREATMENT PLANT #1	Nitrate removal	Anion exchange
Elmore	COMM	Municipal	663	TREATMENT PLANT	Other	Blending
Lincoln-Pipestone Rural Water System	COMM	Municipal	11521	HOLLAND FIELD TREATMENT PLANT	Nitrate removal	Fixed barrier technologies/Reverse Osmosis
Lincoln-Pipestone Rural Water System	COMM	Municipal	11521	VERDI FIELD TREATMENT PLANT	Nitrate removal	Blending
Saint Peter	COMM	Municipal	10884	BROADWAY AVENUE TP	Nitrate removal	Fixed barrier technologies/Reverse Osmosis
Saint Peter	COMM	Municipal	10884	ST. JULIEN STREET TP	Nitrate removal	Fixed barrier technologies/Reverse Osmosis
Adrian	COMM	Municipal	1209	TREATMENT PLANT	Nitrate removal	Blending
Adrian	COMM	Municipal	1209	TREATMENT PLANT	Nitrate removal	Anion exchange
Ellsworth	COMM	Municipal	463	TREATMENT PLANT	Nitrate removal	Blending
Ellsworth	COMM	Municipal	463	TREATMENT PLANT	Nitrate removal	Anion exchange
Edgerton	COMM	Municipal	1189	TREATMENT PLANT	Nitrate removal	Anion exchange
Clear Lake	COMM	Municipal	414	TREATMENT PLANT	Nitrate removal	Anion exchange
Lewiston	COMM	Municipal	1620	COMBINED DISCHARGE Entry Point	Nitrate removal	Blending
Sundsruds Court	COMM		40	Well #1 Entry Point	Nitrate removal	Anion exchange
Brookfield 1 Complex	NTNC		90	Nitrate Removal	Nitrate removal	Anion exchange
Old Fire Hall/Crosslake Community School	NTNC		150	Community School Anion Exchange	Nitrate removal	Anion exchange
Northland Bible Baptist Church	NTNC		200	Nitrate Treatment Anion Exchange 2 - New Addition	Nitrate removal	Anion exchange
Northland Bible Baptist Church	NTNC		200	Nitrate Treatment Anion Ex 1, Original Building	Nitrate removal	Anion exchange
Holy Cross School	NTNC		60	Softener/Tannin Removal	Other	Anion exchange
MN Valley Nat'l Wildlife Refuge-Rapid L.	TNC		25	Nitrate Removal - Anion Exchange	Nitrate removal	Anion exchange
Two Rivers Campground and Tubing	TNC		300	Nitrate Treatment - Anion Exchange	Nitrate removal	Anion exchange
Sugar Daddy's	TNC		200	Nitrate Treatment - Anion Exchange	Nitrate removal	Anion exchange
NUSS Truck and Equipment	TNC		25	Anion Exchange	Nitrate removal	Anion exchange
Landsburg Landscape and Nursery	TNC		25	Reverse Osmosis	Nitrate removal	Fixed barrier technologies/Reverse Osmosis
AASA Coates Corner Mart	TNC		25	Nitrate Treatment - Reverse Osmosis	Nitrate removal	Fixed barrier technologies/Reverse Osmosis
Alexis Bailly Vineyard	TNC		25	Nitrate Treatment - Reverse Osmosis	Nitrate removal	Fixed barrier technologies/Reverse Osmosis
Bellwood Oaks Golf Course	TNC		250	Nitrate Treatment - Anion Exchange	Nitrate removal	Anion exchange

Stanton Sport Aviation	TNC	25	Nitrate Treatment - Reverse Osmosis	Nitrate removal	Fixed barrier technologies/Reverse Osmosis
Y Steak House	TNC	25	Anion Exchange-Nitrate Removal	Nitrate removal	Anion exchange
West Forty Restaurant	TNC	500	Nitrate Treatment - Anion Exchange	Nitrate removal	Anion exchange
Bradford Township Hall	TNC	25	Reverse Osmosis POU - Nitrate Removal	Nitrate removal	Fixed barrier technologies/Reverse Osmosis
Knotty Pine Supper Club	TNC	70	Nitrate Treatment	Nitrate removal	Fixed barrier technologies/Reverse Osmosis
Knotty Pine Supper Club	TNC	70	Nitrate Treatment	Nitrate removal	Anion exchange
Hilmerson Sports Center	TNC	30	Nitrate Removal	Nitrate removal	Anion exchange
Tiny's Tavern	TNC	50	Anion Exchange	Nitrate removal	Anion exchange
Sportsman's Bar	TNC	30	Nitrate Treatment - Reverse Osmosis	Nitrate removal	Fixed barrier technologies/Reverse Osmosis
Mrs. B's Restaurant	TNC	40	Nitrate Treatment - Anion Exchange	Nitrate removal	Anion exchange
The Landing	TNC	25	Well #1 Treatment	Nitrate removal	Anion exchange
Palmer House	TNC	50	Nitrate Removal	Nitrate removal	Anion exchange
Oaks on the River Campground	TNC	400	Sites 6-23 Nitrate Removal	Nitrate removal	Anion exchange
Holiday Stationstore No. 598	TNC	800	Nitrate Treatment - Anion Exchange	Nitrate removal	Anion exchange
Stearns Scout Camp	TNC	25	Nitrate Treament - Anion Exchange	Nitrate removal	Anion exchange
Corky's Bar	TNC	100	Anion Exchange	Nitrate removal	Anion exchange
Sunfish Resort	TNC	30	Nitrate Removal	Nitrate removal	Anion exchange
Sidewalk Bar and Grill	TNC	50	Well #1 Treatment	Nitrate removal	Anion exchange
Long Drive In	TNC	150	Nitrate Treatment	Nitrate removal	Anion exchange
Rock Tavern and Eatery	TNC	100	Treatment Plant	Nitrate removal	Anion exchange
R & J Cafe	TNC	25	Nitrate Treatment-Anion Exchange	Nitrate removal	Anion exchange
Carpenter Nature Center	TNC	25	Visitor Center Anion Exchange	Nitrate removal	Anion exchange
Greenwood Campground	TNC	25	Nitrate Treatment	Nitrate removal	Anion exchange
Kingdom Hall of Jehovah's Witnesses	TNC	25	Nitrate Treatment - POU	Nitrate removal	Fixed barrier technologies/Reverse Osmosis
Arendahl Lutheran Church	TNC	130	Nitrate Treatment - Anion Exchange	Nitrate removal	Anion exchange
Immanuel Lutheran Church of West Florenc	TNC	200	Nitrate Treatment Point-of-Use Anion Exchange	Nitrate removal	Anion exchange
Stanton United Methodist Church	TNC	150	Nitrate Treatment - Reverse Osmosis	Nitrate removal	Fixed barrier technologies/Reverse Osmosis
Evergreen Church	TNC	25	Nitrate Removal	Nitrate removal	Anion exchange
Park Rapids Assembly of God Church	TNC	150	Nitrate Treatment - Anion Exchange	Nitrate removal	Anion exchange
Silver Rapids Lodge	TNC	75	Nitrate Treatment - Anion Exchange	Nitrate removal	Anion exchange

Faaberg Lutheran Church	TNC	25	Nitrate Treatment - Anion Exchange Unit	Nitrate removal	Anion exchange
Glenwood Lodge	TNC	50	Nitrate Treatment - Anion Exchange	Nitrate removal	Anion exchange
Concordia Evangelical Lutheran Church	TNC	100	Nitrate Treatment - POU	Nitrate removal	Fixed barrier technologies/Reverse Osmosis
Paynesville Evangelical Free Church	TNC	70	Nitrate Treatment - Reverse Osmosis	Nitrate removal	Fixed barrier technologies/Reverse Osmosis
Community Country Church	TNC	100	Anion Exchange-Nitrate Removal	Nitrate removal	Anion exchange
Cottage Grove United Church of Christ	TNC	380	Anion Exchange	Nitrate removal	Anion exchange
Tri-County Alliance Church	TNC	110	Nitrate Treatment - Anion Exchange	Nitrate removal	Anion exchange
Fuller Lake Wayside Rest MNDOT	TNC	1175	Nitrate Treatment - Anion Exchange	Nitrate removal	Anion exchange

Executive Summary

Minnesota Nutrient Reduction Strategy

The draft *Minnesota Nutrient Reduction Strategy* (Strategy) will be available for public review and comment from October 7, 2013, to December 18, 2013. The conversation which begins during this comment period will be integrated to strengthen the recommendations contained in the Strategy. Once finalized, this initial iteration of the Strategy will serve as a guide for the reduction of nutrients in waters throughout Minnesota, providing additional data and information for future improvements.

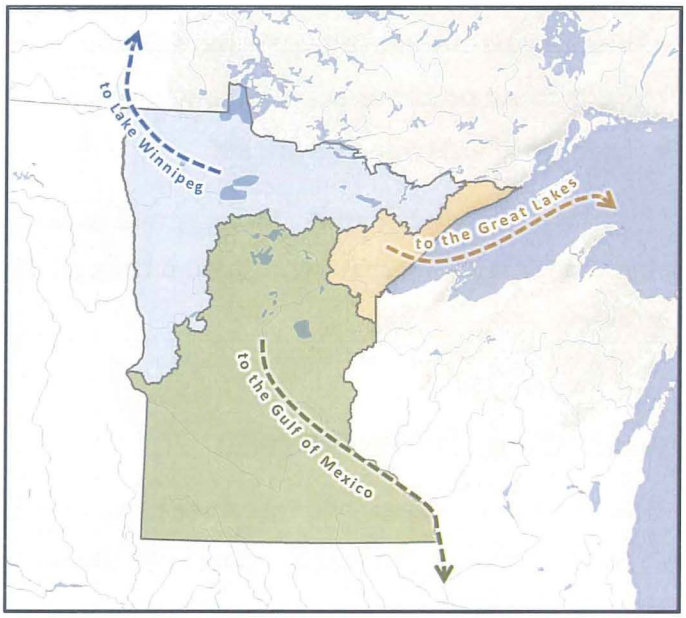


Figure 1. Major drainage basins in Minnesota.

Excessive nutrient levels pose a substantial threat to Minnesota's lakes and rivers, as well as downstream waters including the Great Lakes, Lake Winnipeg, the Mississippi River, and the Gulf of Mexico. A number of federal, regional, and state initiatives drive the need for a statewide nutrient reduction strategy in Minnesota.

At the federal level, the U.S. Environmental Protection Agency (EPA) focus on statewide nutrient reduction planning served as a key driving force for Minnesota's Strategy development. Regionally, Minnesota's involvement in the Mississippi River/Gulf of Mexico Watershed Nutrient Task Force also served as a driving force. In recent decades, nutrient issues downstream of Minnesota have reached critical levels, including the effect of nutrients in the Gulf of Mexico which resulted in a dead zone, eutrophication issues in Lake Winnipeg, and algal blooms in the Great Lakes. Several state-level initiatives and actions highlighted the need for a statewide strategy that ties separate but related activities together to further our progress in making nutrient reductions.

The Strategy guides state-level programs to achieve nitrogen and phosphorus reductions within Minnesota water bodies to enhance the health of aquatic life, improve public health and safety, and increase the recreational potential of Minnesota's numerous lakes, rivers, and streams, as well as the

health of the groundwater supply. In addition, nutrient reductions will also benefit the Gulf of Mexico hypoxia problem and other waters downstream of Minnesota, including Lake Winnipeg and Lake Superior. The theme of the overall Strategy is *A Path to Progress in Achieving Healthy Waters*, which includes the following:

- Defining progress with clear goals
- Building on current strategies and success
- Prioritizing problems and solutions
- Leading to local implementation

Successful implementation of the Strategy will require broad agency support, coordination, and collaboration. An interagency coordination team (ICT), representing ten state agencies, helped develop the Strategy.

Goals and Milestones

The Strategy includes goals and milestones for nutrient reduction at multiple scales including basin (e.g., Mississippi River Basin at the state line) and watershed (e.g., 8-digit hydrologic unit code [HUC 8] watersheds) (Table 1). Progress towards goals and milestones can be tracked over time to determine if strategies are successful and where additional work is needed. Several existing efforts establish nutrient reduction targets for large drainages within Minnesota and provide a suitable framework for load reduction goals. In addition, the Strategy includes a groundwater/source water protection goal to address groundwater as a drinking water source.

Table 1. Basin-wide nutrient reduction goals

Basin	Phosphorus reduction goal	Nitrogen reduction goal
Lake Superior [a]	Maintain 1979 conditions	Qualitative – continued implementation of specific nutrient management programs
Lake Winnipeg [b]	10 percent reduction from 2003 conditions	13 percent reduction from 2003 conditions
Mississippi River [c]	45 percent reduction from average 1980–1996 conditions	45 percent reduction from average 1980–1996 conditions
Statewide Groundwater/ Source Water [d]	No goal identified	Qualitative – achieve and maintain drinking water standards

a. Great Lakes Water Quality Agreement of 1978, amended by a protocol signed November 18, 1987.
b. 2003 Lake Winnipeg Action Plan (Manitoba Water Stewardship Division, 2003); Provisional goal, to be revised once the Red River/Lake Winnipeg strategy is complete. Lake Winnipeg Goals are expected to change in the near future, resulting in additional load reduction needs.
c. 2008 Gulf Hypoxia Action Plan; Provisional goal; Includes drainage associated with Missouri, Des Moines, and Cedar rivers.
d. Based on 1989 Minnesota Groundwater Protection Act.

In addition to goals, milestones serve as interim measures of progress. Milestones provide a step-wise approach to meeting basin goals for nutrient reduction and can take into account the changing landscape, regulatory environment, and available best management practices (BMPs). Milestones are an important component of the Strategy due to a variety of factors:

- Adoption of future water quality standards will drive point source reductions in some watersheds; the timing of standards adoption is critical to long-term planning.
- Additional research and successful pilot demonstrations are required for several types of point and nonpoint source BMPs before widespread adoption can be expected.
- Effective nitrogen reductions at wastewater treatment facilities require several years of planning.

The milestones are phased over time, depending on parameter and basin. Table 2 presents the milestones, which are based on reducing basin outlet loads to eventually achieve the goals. Strategies and target dates will be adjusted through an adaptive management process.

Table 2. Milestones

Basin	Pollutant	Phase 1 Milestone	Phase 2 Milestone	Phase 3 Milestone
Mississippi River (Includes the Cedar, Des Moines, and Missouri Rivers)	Phosphorus	Achieve 35% reduction from baseline by 2025 [a]	Achieve 45% reduction goal	Meeting goals, no net increase
	Nitrogen	Achieve 20% reduction from baseline by 2025 [b]	Achieve 30% reduction from baseline	Achieve 45% reduction goal
Lake Winnipeg [c] (Red River Only)	Phosphorus	Achieve 10% reduction goal by 2025	Adapt goals, if necessary, based on international joint efforts with Canada	
	Nitrogen	Achieve 13% reduction goal by 2025	Adapt goals, if necessary, based on international joint efforts with Canada	
Lake Superior	Phosphorus	Achieve 3% reduction goal by 2025	Meeting goals, no net increase	
	Nitrogen	Maintain protection		
Statewide Groundwater/ Source Water	Nitrogen	Meet goals of 1989 Groundwater Protection Act		

a. It is important to note that active phosphorus reduction began with the completion of the *Detailed Assessment of Phosphorus Sources to Minnesota Watersheds* (Barr Engineering 2004) and Phosphorus Strategy adopted by MPCA's Citizens' Board in 2000.
b. While the baseline for nitrogen reduction is established as prior to 2000, no active strategy has been established since that time to coordinate actions.
c. Milestones to be revised upon completion of the Red River/Lake Winnipeg strategy.

This Strategy emphasizes the need to base HUC8 watershed nutrient goals on the downstream needs outside of the HUC8 watersheds, in addition to needs within the HUC8 watershed. HUC8 watershed milestones are derived from the basin milestone, and apply to all HUC8 watersheds within the respective basin (e.g., all HUC8 watersheds in the Mississippi River Basin should reduce nitrogen by 20 percent from baseline conditions). In the future, additional data and analysis might support local milestone goals that are specific for each watershed.

Headwaters to the Mississippi River
Photo Credit: MPCA

Water Quality Standards

Nitrate and eutrophication water quality standards for protection of Minnesota's water resources are important components of the Strategy. Both the existing lake and proposed river eutrophication standards (RES) in Minnesota include phosphorus, but they do not include nitrogen. Eutrophication standards were promulgated for lakes in 2008, and finalization of the RES should occur in 2014. Nitrate toxicity standards to protect aquatic life in surface waters of the state are expected by about 2015.

Phosphorus loading is often directly related to total suspended solids (TSS) in rivers, especially during moderate to high flow events. Minnesota has existing standards for turbidity and plans to replace the turbidity standards with TSS standards. Current turbidity total maximum daily loads (TMDLs) have a TSS surrogate to facilitate the calculation of load allocations.

An evaluation of the data indicates that meeting in-state lake and proposed RESs will likely result in meeting the basin-wide goals for phosphorus reduction. For example, Lake Pepin, a riverine lake on the Mississippi River, requires an approximate 43 percent phosphorus load reduction compared to pre-2006 conditions to meet a proposed site-specific standard for the lake. Lake Pepin's watershed includes over half of Minnesota.

Downstream reduction needs will drive nitrogen reductions (e.g., Gulf of Mexico and Lake Winnipeg). At this time, existing local surface and groundwater nitrogen standards will not drive enough change to protect out-of-state waters due to limited nitrogen impairments in the state.

Promulgation of numeric water quality standards will provide more tools to protect and restore Minnesota's waters and make progress toward meeting goals to reduce Minnesota's contribution of nutrients into downstream waters such as the Gulf of Mexico and Lake Winnipeg. Minnesota's Strategy is being developed in consideration of the state-level programs, efforts, and goals which can aid local governmental units in addressing nutrients within their HUC8 watersheds and thereby achieve these multipurpose goals.

Evaluating Recent Progress

Understanding the progress made since the baseline conditions is a key component of the Strategy. *Recent Progress* is quantified through available program data and helped to define meaningful Phase 1 Milestones.

Sixteen regional, state, or federal programs were identified as key nutrient-reducing programs in Minnesota. Each of these programs provided input on quantifying outputs or outcomes associated with program implementation. Data from the Natural Resource Conservation Service (NRCS) Environmental Quality Incentives Program (EQIP), the Reinvest in Minnesota Program (conservation easements), and Minnesota's eLINK database, which tracks state-funded nonpoint source BMPs, were compiled from 2000 to present. Reductions in wastewater nutrients were also quantified. These programs and the BMPs chosen for quantification are indicators of program implementation and are thus applied as Recent Progress against the reductions needed to meet basin goals and milestones (Figure 2 and Figure 3).

This Strategy addresses the gap between Recent Progress and Phase 1 Milestones.

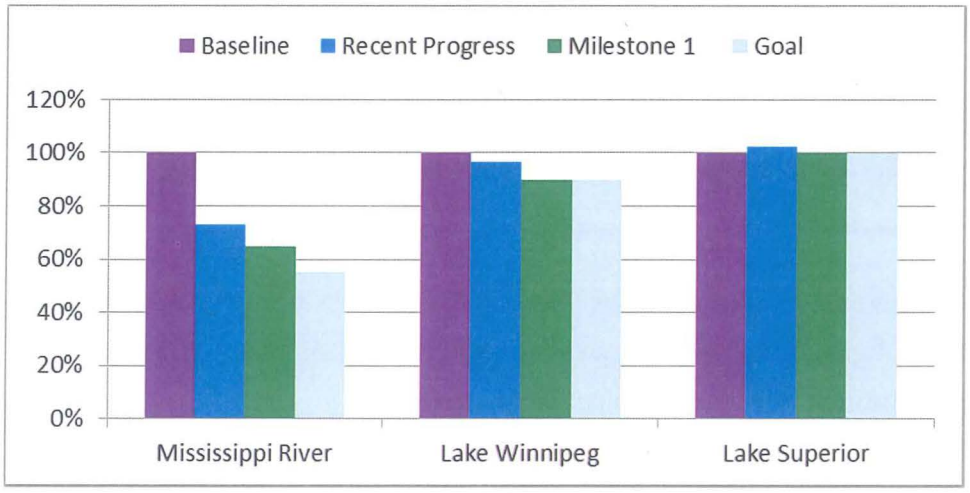


Figure 2. Summary of recent trends in phosphorus source loads by major basin.

Notes:
Recent Progress is the percent of baseline load remaining after accounting for estimated reductions since 2000.
The Lake Winnipeg Milestone 1 and Goal are expected to change in the near future, resulting in additional load reduction needs.

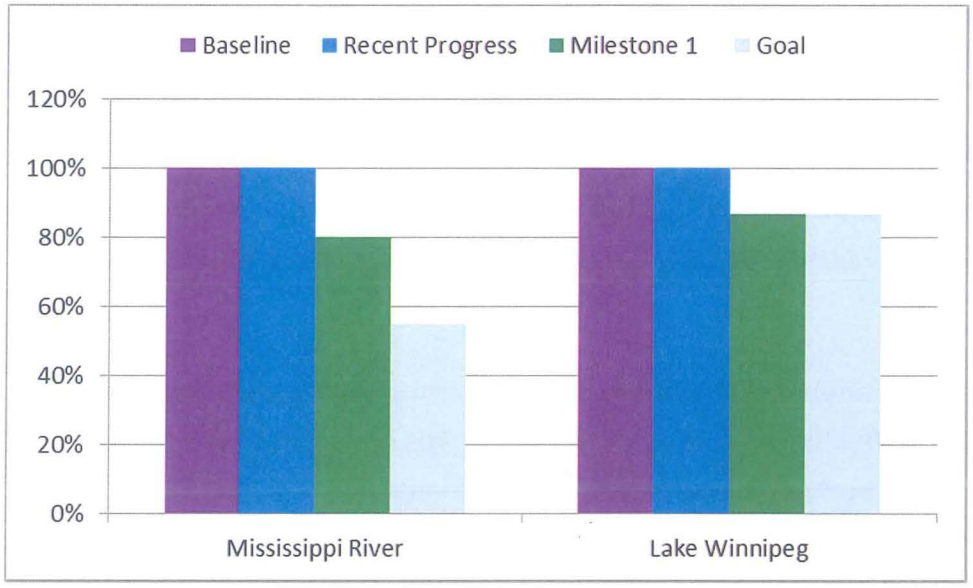


Figure 3. Summary of recent trends in nitrogen source loads by major basin.

Notes:
There is not a reduction goal for nitrogen assigned in the Lake Superior Basin.
Recent Progress is the percent of baseline load remaining after accounting for estimated reductions since 2000.
The Lake Winnipeg Milestone 1 and Goal are expected to change in the near future, resulting in additional load reduction needs.

Priority Management Areas

Priority management areas are based on priority sources and watersheds. Targeting implementation activities to priority sources in high-priority watersheds is a potential cost-effective approach to achieve initial nutrient reductions. It is important to recognize that while prioritization is an effective management tool for directing limited resources, significant reduction targets to meet the Strategy goals cannot be achieved through implementation in a limited number of high-priority watersheds.

Priority sources are based on studies that identified the sources of nutrients in Minnesota water (Barr Engineering 2004; MPCA 2013). Priority sources are determined on the basin scale, although it should be noted that different sources might be more or less important at the local scale. Priority sources could differ depending on the scale at which reductions are needed and could be adjusted through local and regional planning processes. There are also sources that cannot be reliably reduced by local or regional scale implementation activities, including atmospheric deposition and loads from forested areas. Therefore, this initial iteration of the Strategy does not consider these sources as priority sources.

Table 3. Priority sources

Basin	Priority phosphorus sources	Priority nitrogen sources
Mississippi River	Cropland runoff, permitted point sources, and streambank erosion	Agricultural tile drainage and cropland groundwater [b]
Lake Superior	Nonagricultural rural runoff [a], permitted point sources, and streambank erosion	Permitted point sources
Lake Winnipeg	Cropland runoff and nonagricultural rural runoff	Cropland groundwater

a. Includes natural land cover types (forests, grasslands, and shrublands) and developed land uses that are outside the boundaries of incorporated urban areas.
b. Refers to nitrogen leaching into groundwater from cropland land uses.

Priority watersheds represent those watersheds with the highest nutrient yields (loads normalized to area) or contain a large proportion of potentially impaired segments based on the proposed RES. Figure 4 identifies these watersheds.

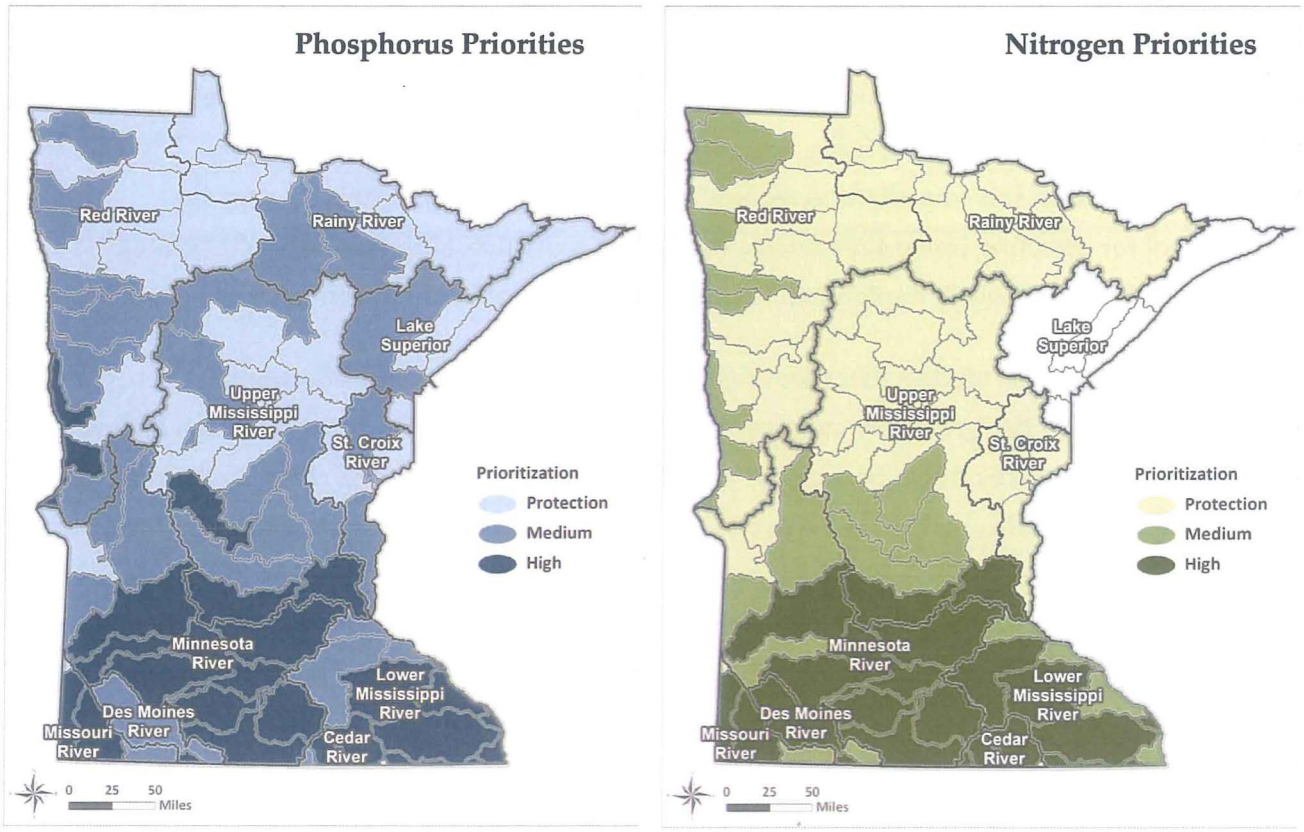


Figure 4. HUC8 watershed priorities (Lake Superior Basin not evaluated for nitrogen).

Nutrient Reduction Strategies

Development of the Strategy builds on previous implementation efforts in the state. Working toward the milestones over time requires a significant amount of coordination and communication at a statewide level. Infrastructure will be necessary to support coordination and communication among the various partners. The first set of recommended strategies focus on developing and sustaining the necessary infrastructure to support coordinated implementation and communication on progress over time. These recommendations include the following:

- Create accountability team and coordinating mechanism to integrate Strategy with other efforts.
- Develop a statewide Strategy education/outreach campaign.
- Integrate basin reduction goals with watershed planning efforts.
- Integrate Strategy tracking considerations into key program databases and tracking tools.
- Create new statewide nutrient reduction incentives for voluntary or industry-led BMP adoption.
- Develop mechanisms to improve state agency and federal agency data sharing and coordination.
- Commit to an adaptive management plan for the Strategy.

Specific strategies are necessary to increase agricultural BMP adoption, achieve wastewater reductions, address miscellaneous sources, and provide protection to areas under pressure.

Wastewater Strategies

The current Phosphorus Rule has and will continue to address phosphorus reductions in wastewater. The adoption of RES in 2014 is expected to result in additional wastewater phosphorus reductions in certain watersheds.

The history of phosphorus management at wastewater treatment facilities in Minnesota starting in 2000 is a relevant example of a successful program to reduce a pollutant of concern. Several successful techniques utilized in the Phosphorus Strategy (MPCA 2000) are proposed for nitrogen:

- Influent and effluent nitrogen monitoring at wastewater treatment facilities
- Nitrogen Management Plans for wastewater treatment facilities
- Nitrogen effluent limits
- Add nitrogen removal capacity with facility upgrade
- Point source to nonpoint source trading

A 20 percent reduction in wastewater nitrogen loads is anticipated to reach the Phase 1 Milestones for the Mississippi River.

Agricultural BMP Adoption Strategies

To reach the Phase 1 Milestones in 2025, and eventually reach basin-wide goals, additional BMPs, wastewater treatment, and other nutrient-reducing activities will be necessary. The Strategy includes select BMPs and treatment options to guide implementation; however, any combination of BMPs and treatment options which achieve the load reduction goals can be used. As new research is conducted, additional BMPs and treatment options are expected to become part of the Strategy.

Potential agricultural BMPs for this Strategy were identified from the Nitrogen Study (MPCA 2013), the Iowa Strategy (Iowa State University 2013), the AgBMP Handbook (Miller et al. 2012), literature on the Minnesota Phosphorus Index (Moncrief et al. 2006), and the Lake Pepin implementation planning work (Tetra Tech 2009). The Watershed Nitrogen Reduction Planning Tool (Lazarus et al. 2013) was also used to derive various BMP inputs. BMPs were evaluated to determine which would be most likely to help achieve the Strategy nutrient reduction goals. BMPs are grouped into the following four categories:

1. Increase fertilizer use efficiencies (nutrient management practices)

2. Increase and target living cover
3. Field erosion control (for phosphorus reduction)
4. Drainage water retention for water quality treatment (for nitrogen reduction) and for control of erosive flows (to help address phosphorus loads from near channel erosion, ravines, and streambanks)

Suitable acres for each BMP type are determined on a HUC8 watershed scale, and existing BMP implementation is taken into account as part of this analysis. A spreadsheet analysis was conducted to evaluate various BMP scenarios.

Example BMP scenarios to achieve the phosphorus Phase 1 Milestones were developed, paying attention to both effectiveness and cost of BMPs. In general, the conceptual strategy for phosphorus has the following priority order:

1. Optimize fertilizer and manure rates based on soil test-phosphorus (estimated to provide a net savings to producers).
2. Increase use of conservation tillage with 30 percent residue where not already applied (estimated to provide a net savings to producers).
3. Use precision application techniques such as subsurface banding (net cost uncertain).
4. Add living cover BMPs such as riparian buffers, grass waterways, and cover crops that currently have a net cost to producers.

Residue Management Using Strip Till
Photo Credit: NRCS

Table 4. Example BMP scenario for achieving the phosphorus Phase 1 Milestones through cropland BMPs

BMP category	Example BMP	*Mississippi River*		*Lake Winnipeg (Red River Only)*	
		Future adoption rate	Total new acres (million acres)	Future adoption rate	Total new acres (million acres)
Increasing Fertilizer Use Efficiencies	Achieve target soil test phosphorus and use subsurface banding	90%	1.9	0%	0
Increase and Target Living Cover	Riparian buffers	25%	0.3	60%	0.3
	Cover crops	10%	0.3	20%	0.2
	Conservation reserve	3%	0.2	0.6%	0
Field Erosion Control	Conservation tillage	85% of available area; 90.7% net	7.2	53% of available area, 63.5% net	1.4

Notes:

Adoption rates are expressed as a percentage of the total area on which a practice is applicable, with the exception of conservation tillage, which is expressed as a fraction of the area not currently in conservation tillage. A cumulative adoption rate for conservation tillage is also shown.

Acreage from program quantification for 2000–2013 is excluded from total future acres where applicable. Adoption rate percentages are relative to suitable areas and represent the percentage of land in total that would require the BMP. The SPARROW model is assumed to reflect 2000 agricultural conditions.

For the Lake Superior Basin, the goal is a 3 percent decrease in phosphorus loads. Agriculture is estimated to contribute only 6 percent of the total phosphorus load in this basin, and many agricultural BMPs for phosphorus are not particularly useful because of low soil phosphorus concentrations. The needed reduction in the Lake Superior Basin is expected to come from a combination of point source reductions and miscellaneous nonpoint runoff reductions.

Example BMP scenarios to achieve the nitrogen Phase 1 Milestones were also developed. In general, the conceptual strategy for nitrogen includes increasing fertilizer use efficiency through nutrient management, treating tile drainage, and implementing living cover BMPs, which are consistent with the phosphorus evaluation. Table 5 summarizes the results of this analysis.

MN has 18.7 million acres row crops

Table 5. Example BMP scenario for achieving nitrogen Phase 1 Milestone through cropland BMPs

BMP category	Example BMP	Mississippi River		Lake Winnipeg (Red River Only)	
		Future adoption rate	New total acres (million acres)	Future adoption rate	New total acres (million acres)
Increasing Fertilizer Use Efficiencies	Use recommended fertilizer application rates	80%	13.2 71%	95%	6.0
Increase and Target Living Cover	Cover crops	10%	0.3	20%	0.2
	Riparian buffers	25%	0.3	60%	0.3
	Conservation reserve	3%	0.2	0.10%	0
Drainage Water Retention and Treatment	Wetlands and controlled drainage	18%	1.1	25%	0.001

Notes:
Adoption rates are expressed as a percentage of the total area on which a practice is applicable.
Acreage from program quantification for 2000–2013 is excluded from future acres where applicable. Adoption rate percentages are relative to the area for which a given practice is suitable and represent the percentage of land in total that would require the BMP. The SPARROW model is assumed to reflect 2000 agricultural conditions.

Increased adoption of agricultural BMPs is critical to implementing the Strategy and achieving goals and milestones. Recommended strategies to achieve the Phase 1 Milestones include the following:

- Optimization Strategies
  - Develop state and federal program Step Up Plans for select programs.
  - Increase delivery and track implementation of industry-led BMPs.
- Economic Strategies
  - Evaluate potential nutrient-based crop yield insurance program.
  - Develop markets and technologies for use of perennials.
  - Quantify cost-effectiveness of reducing nutrient levels in water.
  - Enhance partnerships with federal partners.
- Education and Involvement Strategies
  - Implement targeted outreach and education campaign.
  - Encourage participation in the Agricultural Water Quality Certification Program.
  - Focus education and technical assistance to co-op agronomists and certified crop advisors
  - Involve agricultural producers in identifying feasible strategies.

  - Share nutrient reduction success stories and make awards to watershed heroes.
  - Work with soil and water conservation districts, University of Minnesota Extension, and community engagement initiatives to improve education and involvement.
  - On-farm trials and demonstration projects.
  - Focus demonstration initiatives on soil health, including cover crops.
- Research
  - Improve success rate for cover crop establishment and continue to develop the best and most profitable cover crops.
  - Research on forages for livestock.
  - Increase knowledge base regarding fertilizer use efficiency.
  - Continue to research innovative approaches for removing nutrients from tile drainage waters, including use of saturated buffers, two-stage ditches, etc.
  - Develop approaches that will reduce soluble phosphorus, as well as BMPs which can address both phosphorus and nitrogen.
  - Research use of remote sensing for nitrogen and phosphorus losses to the environment to help develop nutrient-efficient cropping systems.
  - Further development of the Watershed Nitrogen Reduction Planning Tool, including adding a phosphorus component.

Lake Superior
Photo Credit: MPCA

Miscellaneous Source Strategies

New strategies are not suggested at this time to reduce loads from miscellaneous sources; however, existing programs have strategies in place that allow for systematic reductions in loads from sewage treatment systems, stormwater, and feedlots. A statewide strategy is also under development to address sediment reduction. The statewide strategy will help address sediment-related nutrient load reductions. In addition, implementation of TMDLs, particularly for turbidity-impaired streams, will likely address sediment-bound phosphorus sources that are a result of bank and channel erosion.

Protection Strategies

Protection strategies are needed in watersheds facing development pressures and changes in agricultural and land use practices, as well as vulnerable groundwater drinking water supplies. The Watershed Approach, as described in Chapter 1, requires protection strategies as part of watershed restoration and protection strategy (WRAPS) development, and therefore should address the potential for increased nutrient loads at a watershed scale. Ensuring that nitrogen and phosphorus reductions are addressed as part of WRAPS development is important. In addition, protection strategies are necessary to address increases in Red River watershed tile drainage and nitrogen loads to Lake Superior.

Strategy Summary

The following figures for the Mississippi River summarize the overall strategies to achieve nutrient reduction milestones. Chapter 5 includes strategy summary figures for all basins. Each of the figures includes suggested reductions by source for each of the BMP categories, as described previously.

20% Reduction Milestone — Mississippi River Nitrogen

	Source			
	Agricultural	Wastewater	Miscellaneous	Total
Baseline Load (1980–1996) Units = 1,000 metric tons (MT) per year	98.7	7.9	7.0	113.6
Progress Since Baseline	1.5	-1.5	0	0
Recommended Strategy Reductions				
Increasing Fertilizer Use Efficiencies on 13.2 Million Acres ▪ Recommended fertilizer rates ▪ Placement and timing of application ▪ Nitrification inhibitors	15 (13.2%)			
Increase and Target Living Cover on 800,000 Acres ▪ Cover crops ▪ Perennial buffers ▪ Forage and biomass planting ▪ Perennial energy crops ▪ Conservation easements and land retirement	3.1 (2.7%)			
Drainage Water Retention and Treatment for 1.1 Million Acres ▪ Constructed wetlands ▪ Controlled drainage ▪ Bioreactors ▪ Two stage ditches	3.7 (2.4%)			
Wastewater Treatment		1.9		
Total Reductions	20.8 +	1.9 +	0 +	0 = Total 22.7

Milestone Target **20%** from Baseline Load = 22.7 Metric Tons Reduced

Progress Since Baseline 0 + **Additional Reductions** 22.7 = **Milestone** 22.7 MT Reduced = **20%** by **2025**

1,000 kg = 1 MT

35% Reduction Milestone — Mississippi River Phosphorus

	Source			
	Agricultural	Wastewater	Miscellaneous	Total
Baseline Load (1980–1996) Units = 100 metric tons (MT) per year	24	22	12	58
Progress Since Baseline	5	11	0	16
Recommended Strategy Reductions				
Increasing Fertilizer Use Efficiencies on 1.9 Million Acres ▪ Recommended fertilizer rates ▪ Placement and timing of application ▪ Reducing soil P levels ▪ Livestock feed management	1.8 (3.1%)			
Increase and Target Living Cover on 800,000 Acres ▪ Cover crops ▪ Perennial buffers ▪ Forage and biomass planting ▪ Perennial energy crops ▪ Conservation easements and land retirement	1.0 (1.7%)			
Field Erosion Control on 7.2 Million Acres ▪ Conservation tillage and residue management ▪ Terraces/grassed waterways ▪ Sediment control basins	0.5 (0.9%)			
Urban Stormwater + Other Sources			0.6 (1.0%)	
Wastewater Treatment		0.3 (0.5%)		
Total Reductions	3.3 +	0.3 +	0.6 +	16 = Total 20.2

Milestone Target **35%** from Baseline Load = 20.2 Metric Tons Reduced

Progress Since Baseline 16 + **Additional Reductions** 4.2 = **Milestone** 20.2 MT Reduced = **35%** by **2025**

1,000 kg = 1 MT

Adaptive Management and Tracking Progress

Establishing a coordinated strategy that provides an efficient and effective pathway to achieving statewide goals is the first step in an iterative process of planning, implementing, assessing, and adjusting. This iterative process is often referred to as *adaptive management*. The Strategy sets out goals and milestones for nutrient load reductions, as well as recommended approaches for achieving the milestones (Figure 5). To ensure that on-the-ground implementation is on pace with the Strategy milestones and goals, it is imperative to have an adaptive management plan that will guide an evaluation of the Strategy's progress over time. The basic components of the Strategy's adaptive management plan are as follows:

- Identify data needed to track progress toward Strategy goals and milestones.
- Create a system or approach for collecting data and information needed to track progress toward Strategy goals and milestones.
- Evaluate trends.
- Adjust the Strategy as necessary.

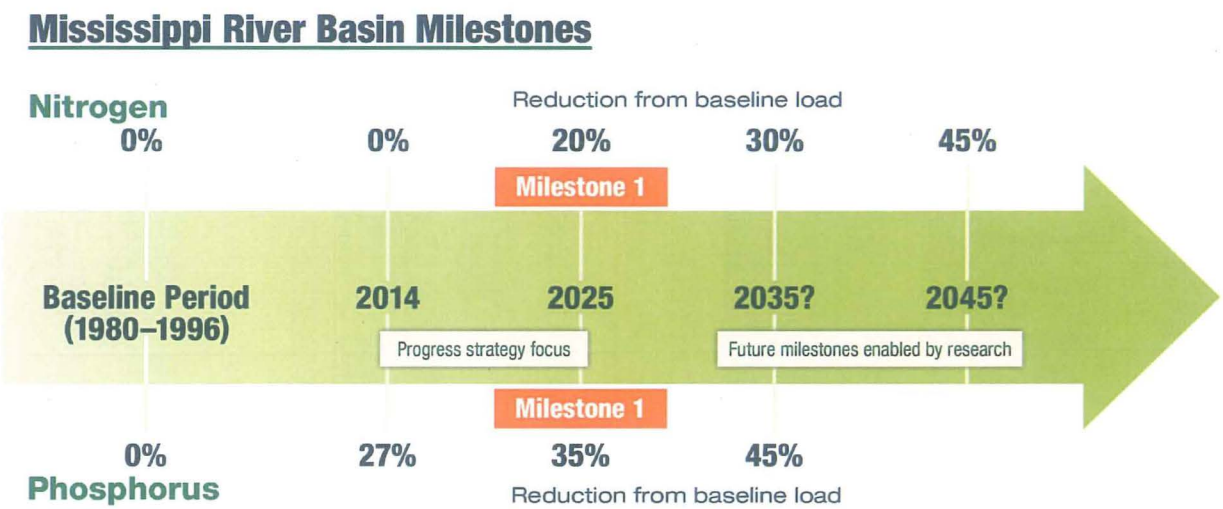


Figure 5. Example adaptive management schedule for the Mississippi River basin.

Implementation tracking will be done through both program implementation and in-stream data. Program implementation data provides early indicator information about nitrogen and phosphorus reductions that, over time, should translate to in-stream nutrient reductions.

Several key programs in Minnesota implement a variety of structural and nonstructural BMPs. Quantifying nutrient reductions for BMPs associated with each program would not be a sustainable and replicable approach to show progress toward Strategy goals over time. A streamlined approach quantifies implementation progress over time, which involves the development and tracking of program measures. The Strategy contains a suite of program measures:

- Implementation of nonpoint source BMPs tracked via eLINK and estimated nutrient load reductions
- Implementation of permanent easements and associated nutrient load reductions
- Implementation of nitrogen fertilizer management BMPs
- Implementation of priority Conservation Reserve Program (CRP) conservation practices and estimated nutrient load reductions
- Implementation of priority EQIP management practices and estimated nutrient load reductions
- Implementation of conservation tillage funded through Agricultural BMP (AgBMP) Loans
- Municipal wastewater phosphorus trends (excerpted from the Clean Water Fund performance measures)

It is important to note that the selected program measures reflect government programs and do not capture industry-led conservation activities. As a result, while the selected program measures are strong indicators of program implementation trends, they are conservative indicators of statewide BMP adoption.

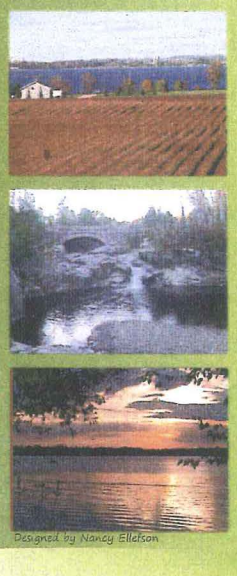
Future water quality evaluations will rely upon the Watershed Pollutant Load Monitoring Network (WPLMN) and efforts to complete statewide water quality modeling. There are many other local, regional, statewide, and national level monitoring programs that will inform water quality evaluations, including those that the new Mississippi River Monitoring Collaborative is conducting. The Mississippi River Monitoring Collaborative is made up of federal and state agencies along the Mississippi River between the Gulf of Mexico and Minnesota.

Although the annual program measures will provide an indication of implementation progress, the water quality outcome measures will provide a more significant yardstick for measuring progress toward Strategy interim milestones over time. Water quality outcome measures include the following:

- Trend in actual load
- Trend in flow weighted mean concentration
- Progress toward meeting eutrophication standards
- Statistical comparisons of baseline loads/concentrations at low, medium, and high flow periods with comparable flow periods during recent years

- Progress toward reducing groundwater nitrate in high-nitrate areas, including those watersheds where nitrate coming from groundwater currently impairs surface waters

The Strategy centers on a series of goals and milestones and targeted actions identified to achieve those goals and milestones over time, with periodic reevaluation and reassessment through adaptive management (Figure 5). Milestone tracking and reporting will occur at 2-year, 5-year, and 10-year intervals. There is currently no integrated tool that will allow for automated tracking of Strategy output and outcome information to assess progress over time. The approach for tracking progress requires the development of a tool to ensure the efficiency and reliability of progress tracking. Developing a tool of this nature will be a multi-agency undertaking that must take into consideration the existing data management approaches used by numerous programs within several agencies.



Minnesota's DRAFT Nutrient Reduction Strategy

Rebecca Flood
Minnesota Pollution Control Agency Assistant Commissioner
Interagency Coordination Team Chair

October 2013

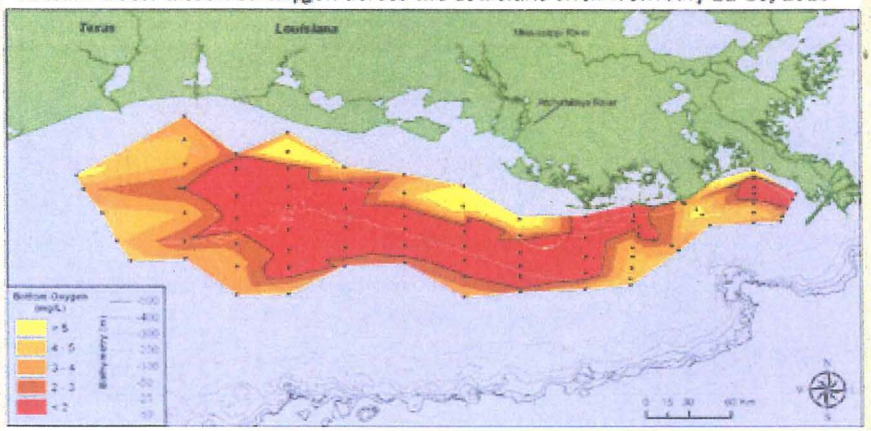
released today to start public comment process

What is Hypoxia?

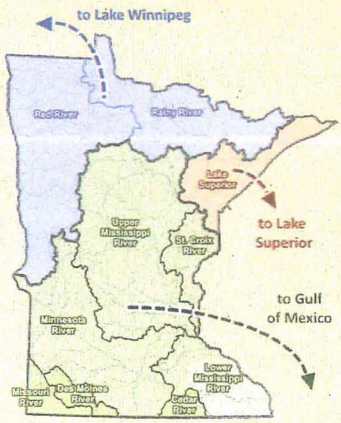
- Nutrient-rich water causes excessive algae growth
- When algae die, oxygen is depleted from the water as algae sink and decompose
- Not enough oxygen to support aquatic life
- Reduce hypoxia by reducing nutrients

Gulf Hypoxia Action Plan - 2008

Bottom-water dissolved oxygen across the Louisiana shelf from July 22-28, 2013



Reduce nutrients to ensure healthy waters



Start of the strategy discussion

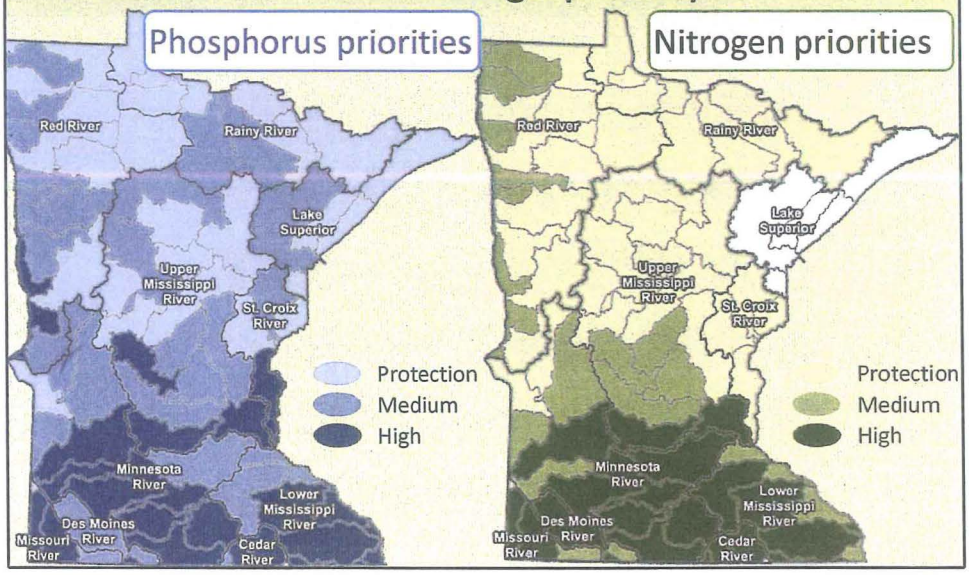
Foundation

- Partner with stakeholders
- Use current data
- Assess new technology/research
- Work within regulatory framework
- Fit into existing programs
- Set realistic goals and milestones
- Seek quantifiable results

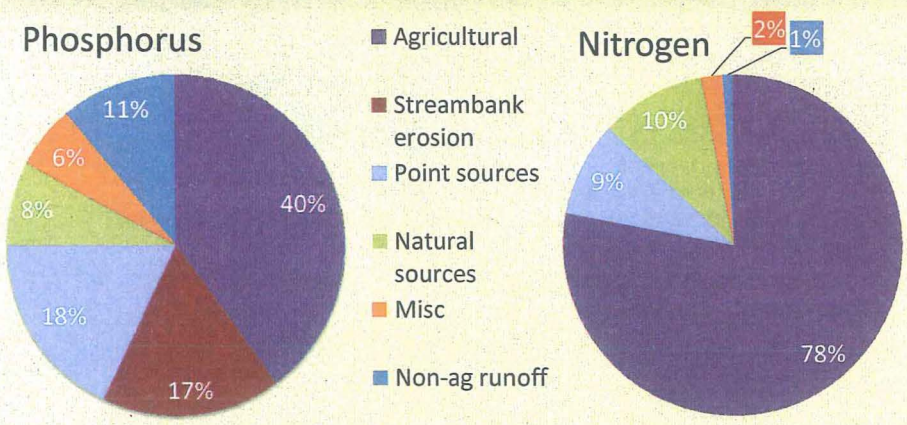
Purpose

Guide state-level programs to reduce nitrogen and phosphorus

We rely on data
Southern Minnesota high priority



Data identify nutrient sources



We work within regulatory framework & existing programs

In-state local & regional WQ standards	Downstream & out-of-state Goals
• Lake eutrophication & turbidity/TSS standards in place • River eutrophication standards expected by 2015	• Nitrate drinking water standards in place • Nitrate aquatic toxicity standards under development

We set goals and milestones

Goals

Long term target that complements existing state level water quality approaches

Milestones

Interim achievable plans of progress

Reduction goals based on basin plans

35% TP reduction to the Mississippi by 2025

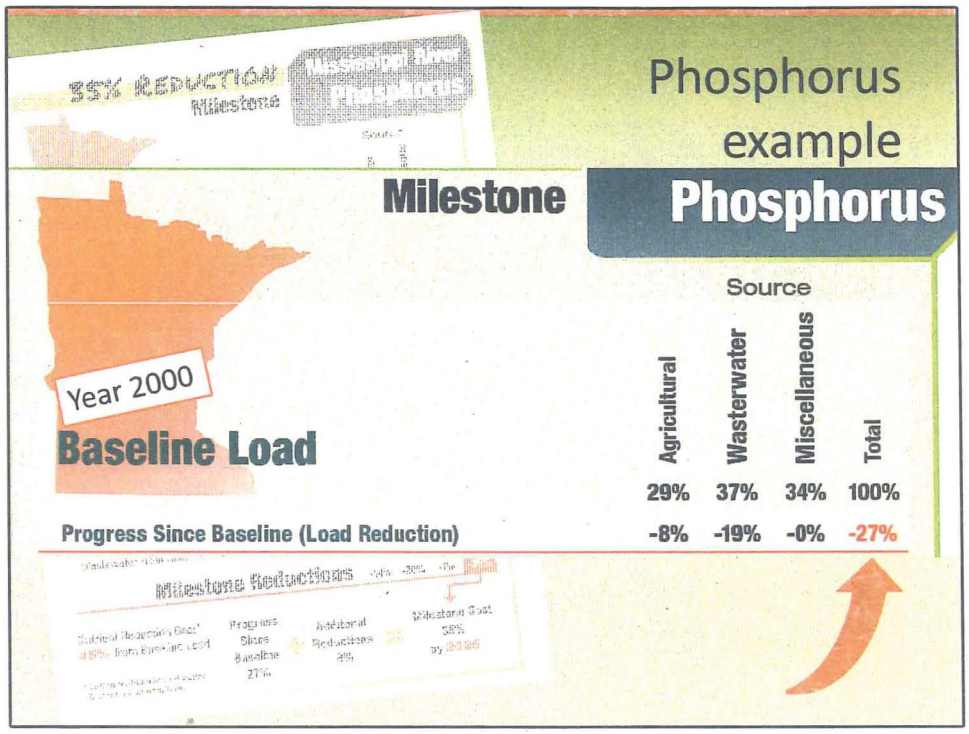
20% TN reduction to the Mississippi by 2025

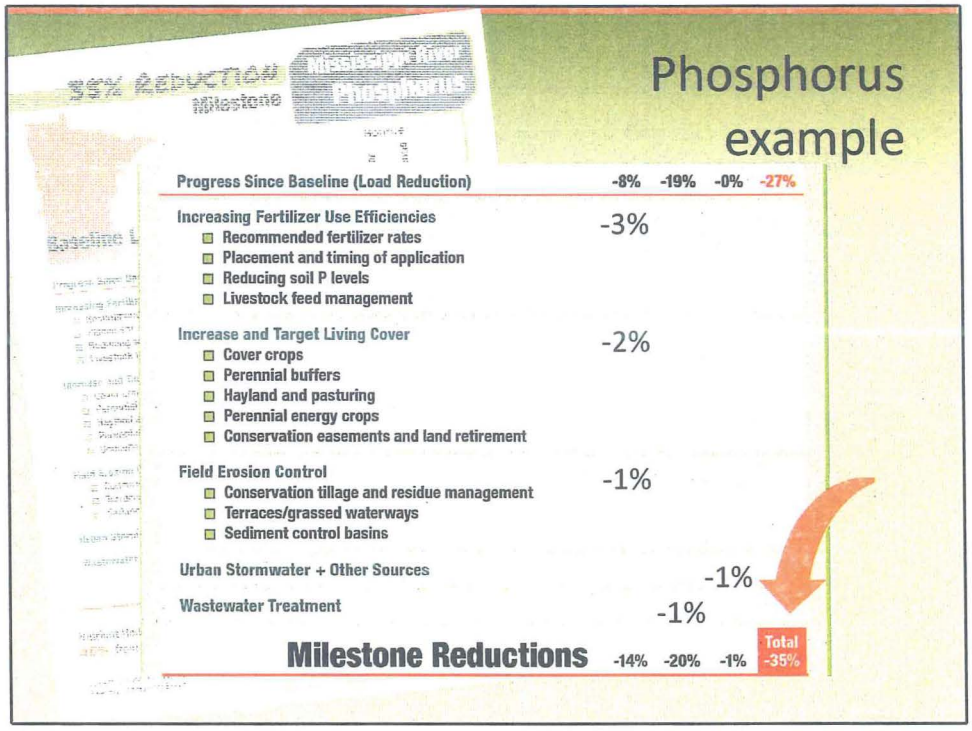
We have a plan to reach the milestones

- Use BMPs to address priority sources in key watersheds
- Identify load reductions and scale of actions needed
- Task programs to step up to support reductions
- Create new programs, initiatives, and incentives
- Leverage local watershed planning & implementation
- Track progress through adaptive management

Milestone

Reduce P in Mississippi River by 35%


Phosphorus example
Milestone
Phosphorus
Source
Year 2000
Baseline Load
Agricultural
Wasterwater
Miscellaneous
Total
29%
37%
34%
100%
Progress Since Baseline (Load Reduction)
-8%
-19%
-0%
-27%


Phosphorus example
Progress Since Baseline (Load Reduction)
-8%
-19%
-0%
-27%
Increasing Fertilizer Use Efficiencies
Recommended fertilizer rates
Placement and timing of application
Reducing soil P levels
Livestock feed management
-3%
Increase and Target Living Cover
Cover crops
Perennial buffers
Hayland and pasturing
Perennial energy crops
Conservation easements and land retirement
-2%
Field Erosion Control
Conservation tillage and residue management
Terraces/grassed waterways
Sediment control basins
-1%
Urban Stormwater + Other Sources
-1%
Wastewater Treatment
-1%
Milestone Reductions
-14%
-20%
-1%
Total -35%

Milestone

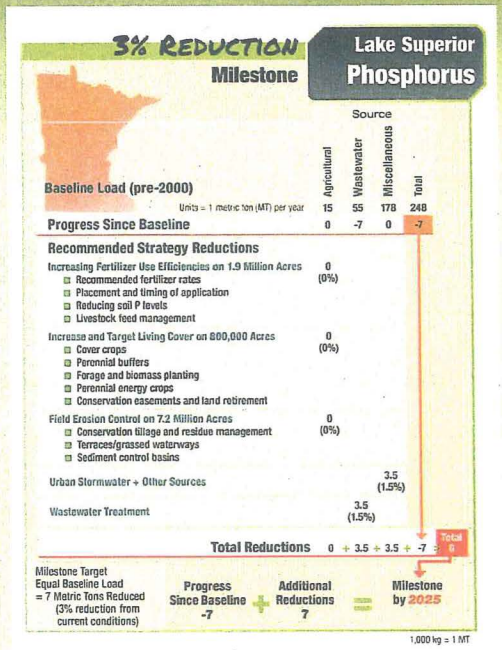
Reduce N in Mississippi River by 20%

Nitrogen example

Increasing Fertilizer Use Efficiencies	-13%			
▪ Recommended fertilizer rates				
▪ Placement and timing of application				
▪ Nitrification inhibitors				
Increase and Target Living Cover	-3%			
▪ Cover crops				
▪ Perennial buffers				
▪ Hayland and pasturing				
▪ Perennial energy crops				
▪ Conservation easements and land retirement				
Drainage Water Retention and Treatment	-2%			
▪ Constructed wetlands				
▪ Controlled drainage				
▪ Bioreactors				
▪ Two stage ditches				
Wastewater Treatment		-2%		
Milestone Reductions	-19%	-1%	0%	Total -20%

Lake Superior Milestone

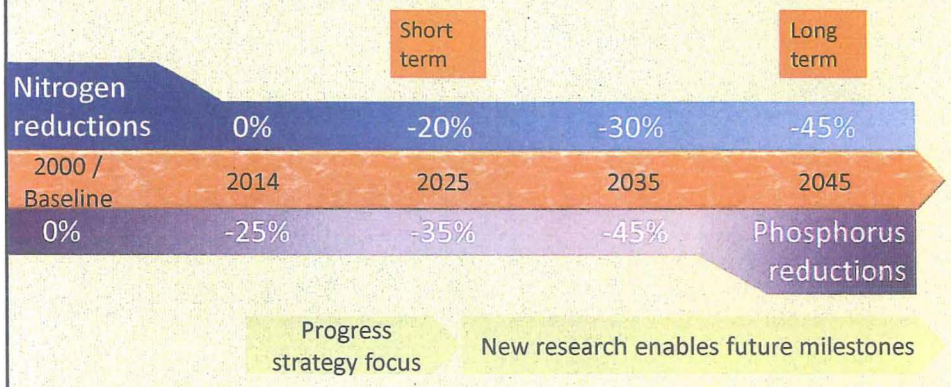
- 3% reduction by 2025 for phosphorus



Red River Milestones

- 10% reduction by 2025 for phosphorus
- 13% reduction by 2025 for nitrogen

Mississippi River goals & milestone Progress Evaluation



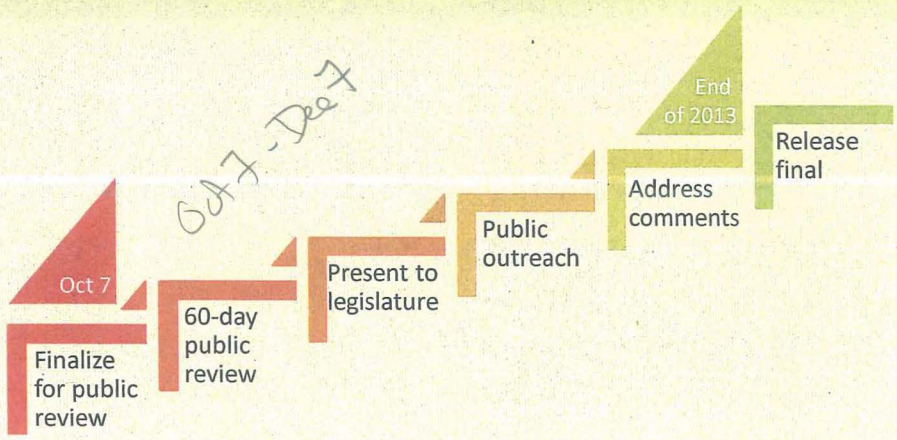
We're accelerating existing strategies. . .

- Increase agricultural BMP adoption
- Fully integrate watershed approach
- Trading
- Accountability

. . .and developing new ideas

- Track industry-led BMP implementation
- Develop markets/ technologies for use of perennials
- Explore nutrient focused crop yield insurance program
- MAWQCP

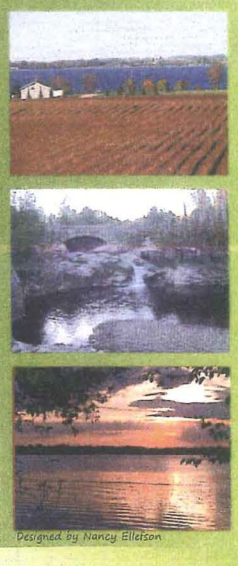
Conversation starts now



Acknowledging

Interagency Coordination Team

- Minnesota Pollution Control Agency
- Minnesota Department of Agriculture
- Minnesota Department of Natural Resources
- Minnesota Board of Water and Soil Resources
- Minnesota Department of Health
- USDA Natural Resources Conservation Service
- Metropolitan Council
- University of Minnesota
- Minnesota Public Facilities Authority
- United States Geological Survey



Minnesota's DRAFT Nutrient Reduction Strategy

http://www.pca.state.mn.us/zihy1146

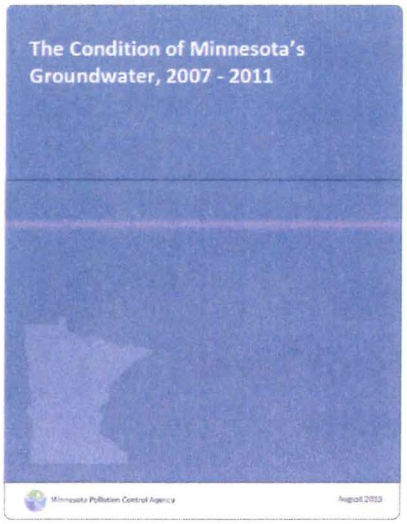
MPCA's 2013 Groundwater Condition Report

October 7, 2013

Sharon Kroening
Research Scientist
Environmental Outcomes and Analysis Division

Minnesota Pollution Control Agency

Released in August 2013



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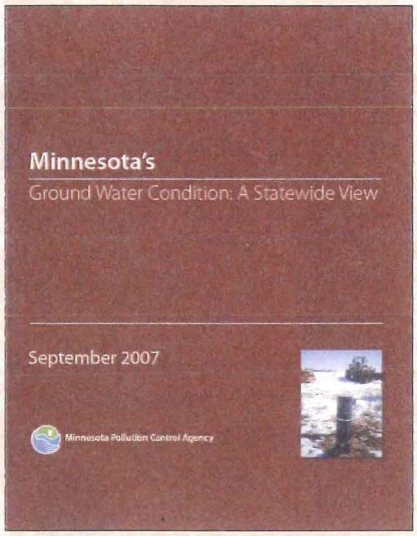
Updates Previous Report



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Chemicals Assessed

- Nitrate
- Chloride
- Arsenic
- Iron, Manganese
- VOCs
- Phosphorus
- Sulfate
- New or Emerging Contaminants

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Report Focus

- Ambient Groundwater Quality Conditions
- Monitoring Data
  - MPCA
  - MDA
  - Southeast Minnesota Volunteer Network
- Published Studies

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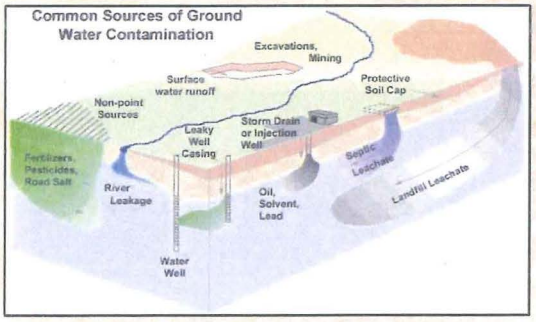
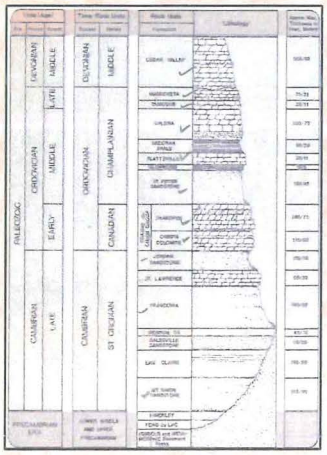
Groundwater Susceptible to Contamination





14 water-supply aquifers

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MPCA's Network

- [illegible] network
- <40' shallow GW w/ bw a [illegible]
- bedrock sp. [illegible]

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Urban Residential Sewered and Unsewered

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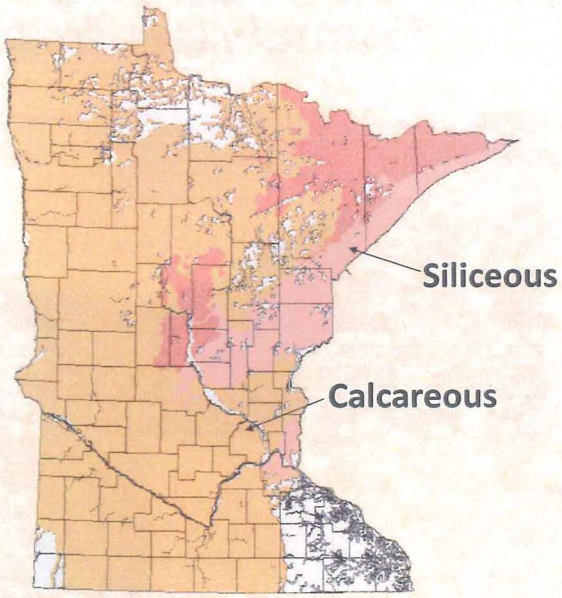
Commercial/Industrial

Minnesota Pollution Control Agency

Undeveloped

Control Agency

Glacial Deposit Types



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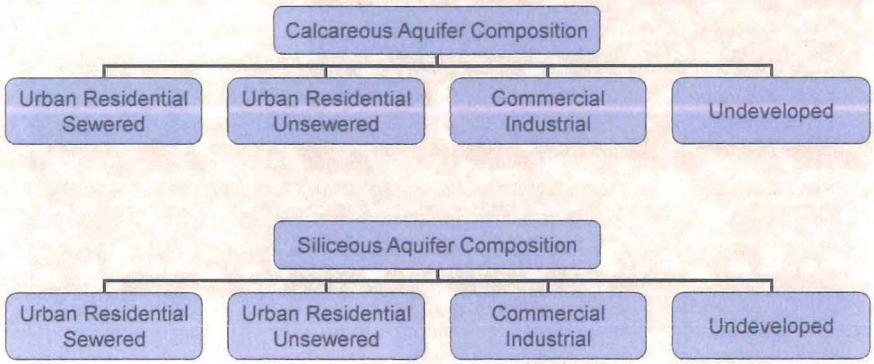
Network Structure



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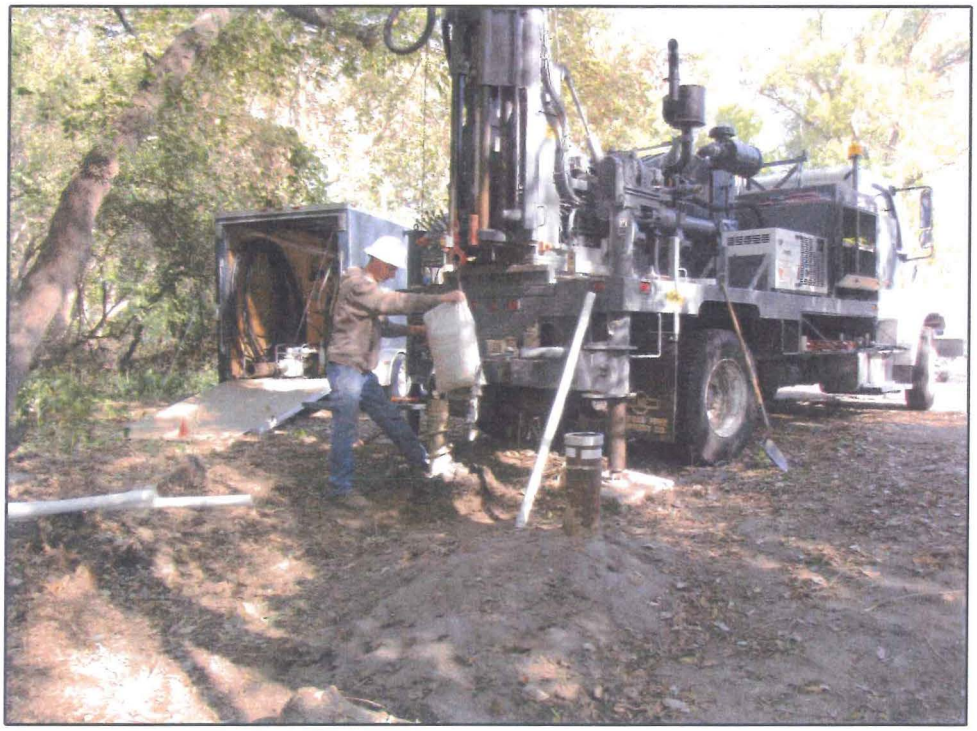

FINDINGS

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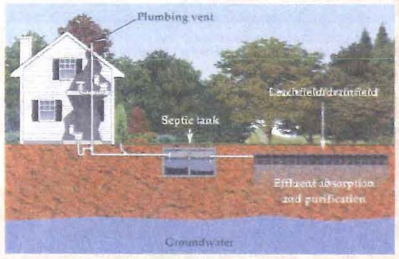
Nitrate



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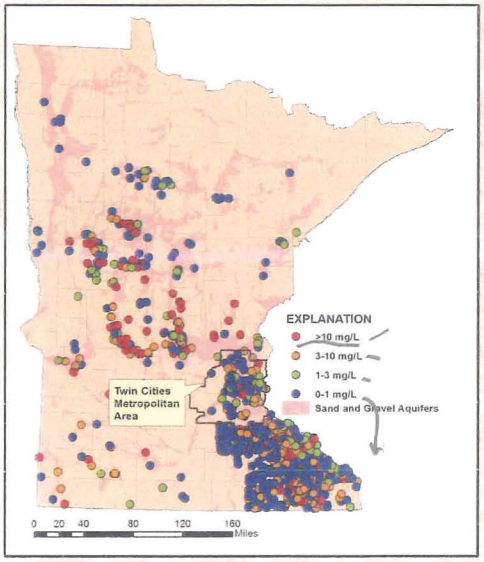
1989
MS 103H.001
Common detection for
Non degradative
gives you the tools
to go A to prevention

Nitrate Concentrations in Minnesota's GW 2007-2011



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Nitrate Concentrations by Land Use

Land use	Median nitrate concentration, in mg/L	Number of wells	Data Source
Agriculture	8.75	212	MDA
Residential SSTS	2.82	13	MPCA
Sewered Residential	2.15	36	MPCA
Commercial/ Industrial	1.96	9	MPCA
Undeveloped	0.05	18	MPCA

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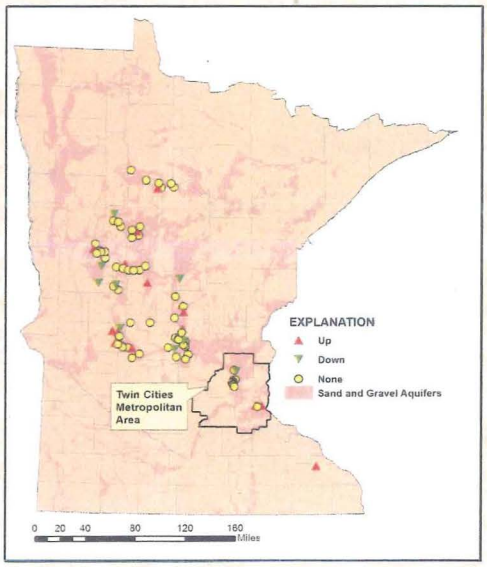
40% of wells in central MN >10 ppm
20% in SW

what is a level of concern?

Nitrate Concentration Trends in Minnesota's GW 1987-2011



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how often do you sample the wells - time of year is signif. but

CHLORIDE

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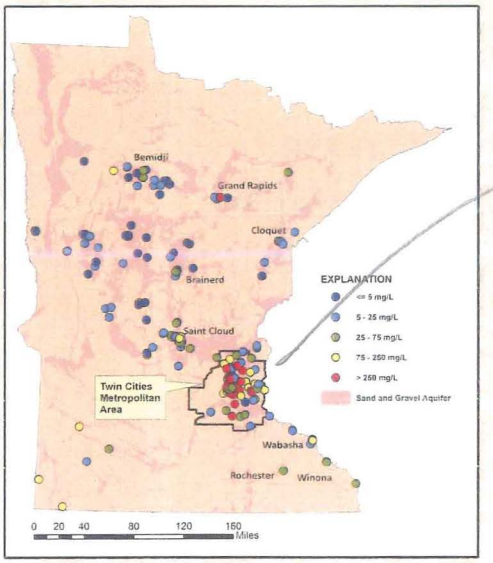
Chloride Concentrations in Minnesota's Sand and Gravel Aquifers



30% of sand & gravel aquifer in metro area > 250 mg/L

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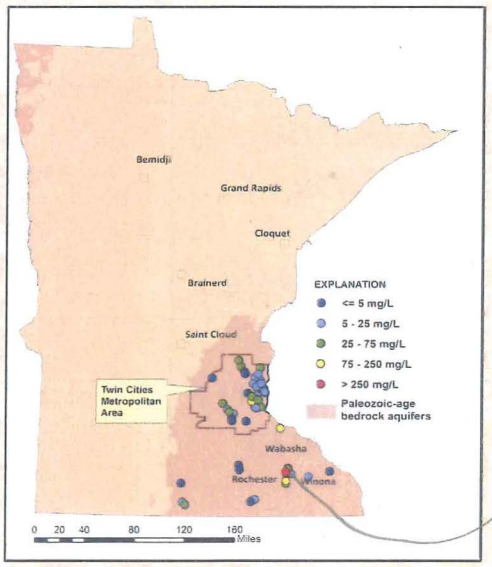
Chloride Concentrations in Minnesota's Bedrock Aquifers 2007-2011



25' to bedrock
a well is 25' deep

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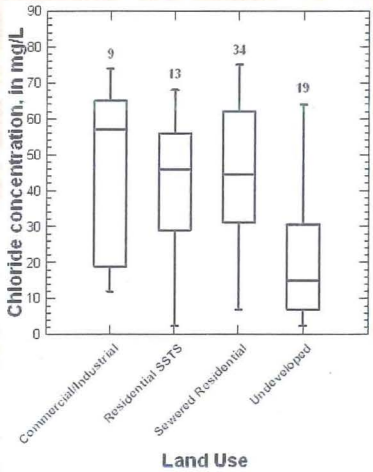
Chloride Concentrations by Land Use



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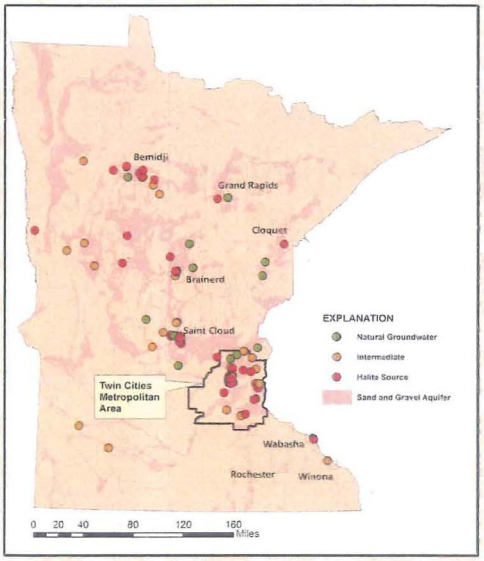
Chloride Sources in Minnesota's Sand and Gravel Aquifers 2007-2011



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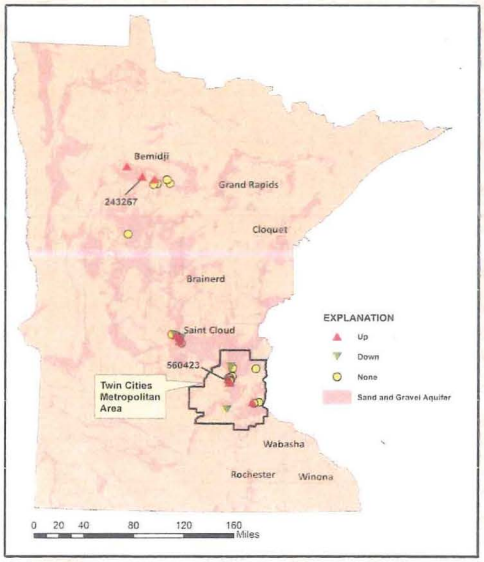
Chloride Concentration Trends in Minnesota's Groundwater 1987-2011



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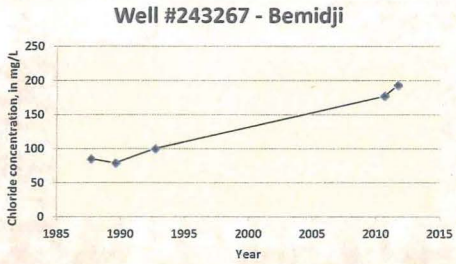
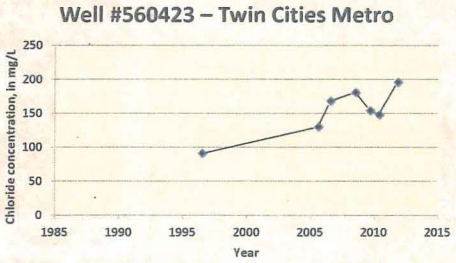
Concentrations Increased by 100 mg/L in Some Wells





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Volatile Organic Compounds

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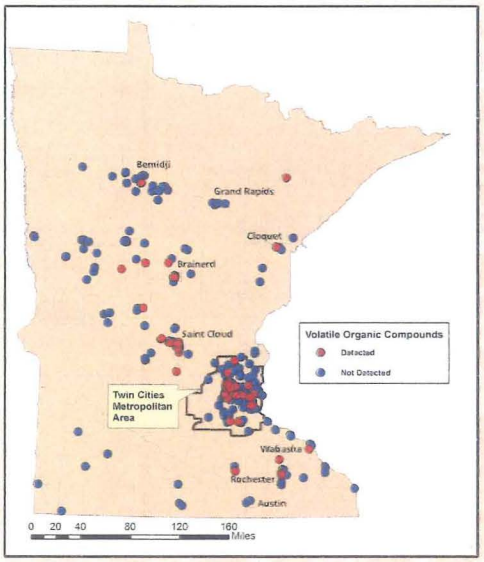
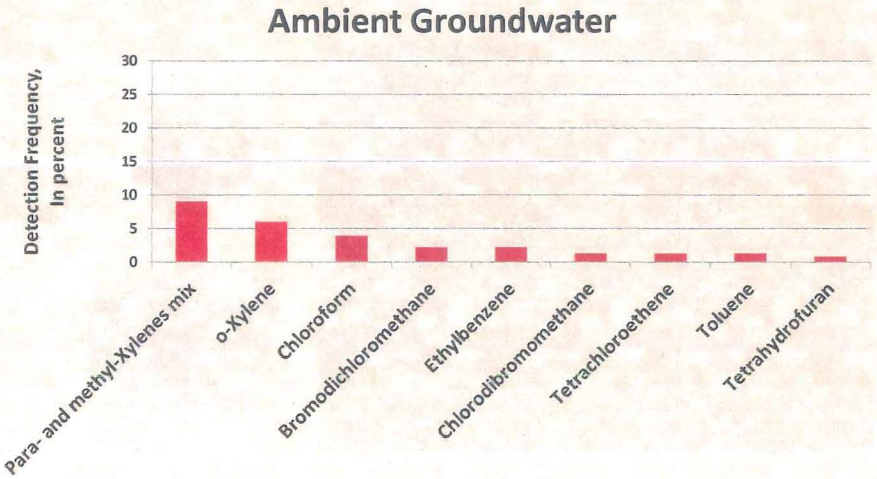
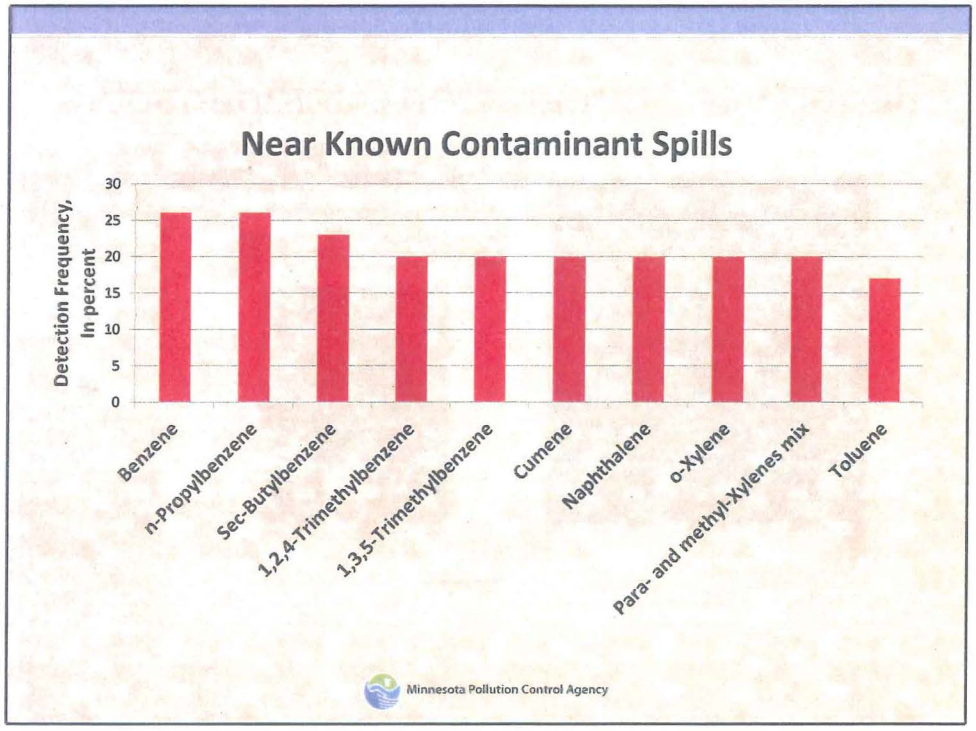
Volatile Organic Compound Detections in Minnesota's Groundwater 2007-2011

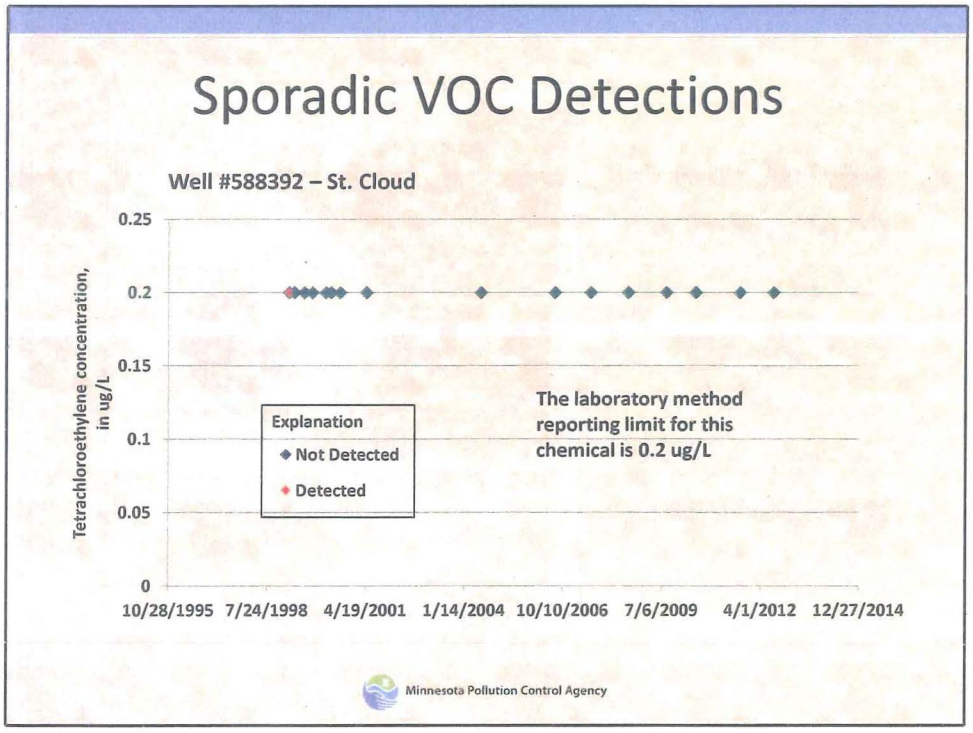


Minnesota Pollution Control Agency

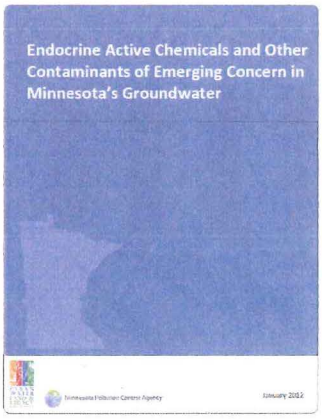


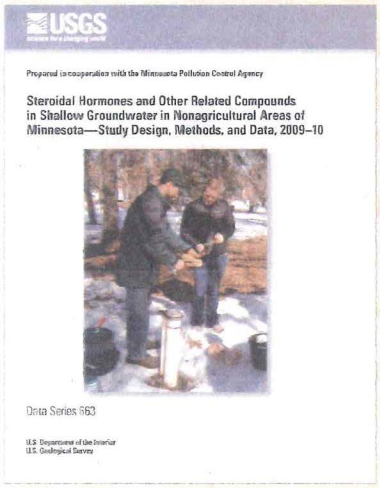
Minnesota Pollution Control Agency


Near Known Contaminant Spills
Detection Frequency, In percent
30
25
20
15
10
5
0
Benzene
n-Propylbenzene
Sec-Butylbenzene
1,2,4-Trimethylbenzene
1,3,5-Trimethylbenzene
Cumene
Naphthalene
o-Xylene
Para- and methyl-Xylenes mix
Toluene
Minnesota Pollution Control Agency


Sporadic VOC Detections
Well #588392 – St. Cloud
Tetrachloroethylene concentration, in ug/L
0.25
0.2
0.15
0.1
0.05
0
10/28/1995
7/24/1998
4/19/2001
1/14/2004
10/10/2006
7/6/2009
4/1/2012
12/27/2014
Explanation
Not Detected
Detected
The laboratory method reporting limit for this chemical is 0.2 ug/L
Minnesota Pollution Control Agency

Reports on Unregulated Contaminants





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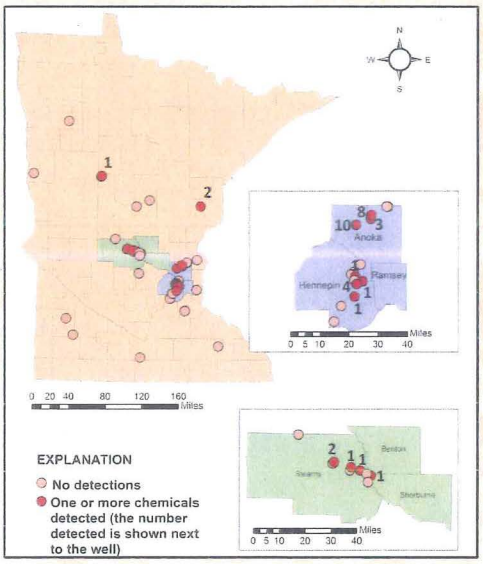
Detections of Contaminants of Emerging Concern in Minnesota's Groundwater, 2010



Minnesota Pollution Control Agency

Thank
You!

Metropolitan Council

APPENDIX 2: COMMUNITY PROFILES

A. Community Water Supply Profile Description

   i. Content

   ii. Assumptions

   iii. References

   iv. Notes

   v. Public Access

B. Summary Table of Water Supply Availability Issues by Community

C. Individual Community Water Supply Profiles

Summary of Water Supply Issues by Community

Community	Potential for well interference	Potential for significant decline in aquifer water levels	Potential for impacts on surface water features	Potential for impacts to trout habitat or calcareous fen	Significant uncertainty regarding aquifer extent and productivity	Known groundwater contamination	Significant contamination vulnerability	Total Issues in the Community
Afton	x	x	x	x				4
Andover	x		x				x	3
Anoka	x						x	2
Apple Valley	x	x					x	3
Arden Hills	x					x		2
Bayport	x		x			x	x	4
Baytown Twp.	x	x				x	x	4
Belle Plaine	x				x			2
Belle Plaine Twp.	x				x			2
Benton Twp.	x				x			2
Bethel	x		x		x			3
Birchwood Village	x							1
Blaine	x		x				x	3
Blakeley Twp.	x				x			2
Bloomington	x		x	x			x	4
Brooklyn Center	x		x				x	3
Brooklyn Park	x	x	x		x		x	5
Burnsville	x	x	x				x	4
Camden Twp.	x				x			2
Carver	x							1
Castle Rock Twp.	x		x	x				3
Cedar Lake Twp.	x				x			2
Centerville	x		x				x	3
Champlin	x		x					2
Chanhassen	x		x	x				3
Chaska	x	x	x	x				4
Circle Pines	x		x		x		x	4
Coates	x	x		x				3
Cologne	x				x			2
Columbia Heights	x					x		2
Columbus	x		x		x			3
Coon Rapids	x		x		x		x	4
Corcoran	x		x		x			3
Cottage Grove	x	x	x				x	4
Credit River Twp.	x	x					x	3
Crystal	x						x	2
Dahlgren Twp.	x				x			2
Dayton	x		x		x			3

Community	Potential for well interference	Potential for significant decline in aquifer water levels	Potential for impacts on surface water features	Potential for impacts to trout habitat or calcareous fen	Significant uncertainty regarding aquifer extent and productivity	Known groundwater contamination	Significant contamination vulnerability	Total issues in the Community
Deephaven	x							1
Dellwood	x							1
Denmark Twp.	x	x	x					3
Douglas Twp.	x			x				2
Eagan	x	x	x	x			x	5
East Bethel	x		x		x	x		4
Eden Prairie	x		x				x	3
Edina	x						x	2
Elko New Market	x							1
Empire Twp.	x	x	x				x	4
Eureka Twp.	x			x			x	3
Excelsior	x							1
Falcon Heights	x					x		2
Farmington	x		x	x			x	4
Forest Lake	x		x		x			3
Fort Snelling (unorg.)	x		x				x	3
Fridley	x		x			x	x	4
Gem Lake	x							1
Golden Valley	x						x	2
Grant	x	x					x	3
Greenfield	x				x			2
Greenvale Twp.	x		x					2
Greenwood	x							1
Grey Cloud Island Twp.	x	x	x					3
Ham Lake	x		x		x			3
Hamburg	x				x			2
Hampton	x							1
Hampton Twp.	x			x				2
Hancock Twp.	x				x			2
Hanover	x				x			2
Hassan Twp.	x		x		x			3
Hastings	x		x				x	3
Helena Twp.	x							1
Hilltop	x							1
Hollywood Twp.	x				x			2
Hopkins	x						x	2
Hugo	x		x				x	3
Independence	x		x		x			3
Inver Grove Heights	x	x	x			x	x	5
Jackson Twp.	x						x	2
Jordan	x				x			2

Community	Potential for well interference	Potential for significant decline in aquifer water levels	Potential for impacts on surface water features	Potential for impacts to trout habitat or calcareous fen	Significant uncertainty regarding aquifer extent and productivity	Known groundwater contamination	Significant contamination vulnerability	Total Issues in the Community
Lake Elmo	x	x	x			x	x	5
Lake St. Croix Beach	x			x				2
Lakeland	x			x		x	x	4
Lakeland Shores	x					x		2
Laketown Twp.	x				x			2
Lakeville	x			x			x	3
Landfall	x							1
Lauderdale	x					x		2
Lexington	x							1
Lilydale	x							1
Lino Lakes	x		x		x		x	4
Linwood Twp.	x		x		x			3
Little Canada	x							1
Long Lake	x							1
Loretto	x				x			2
Louisville Twp.	x		x					2
Mahtomedi	x							1
Maple Grove	x	x	x				x	4
Maple Plain	x		x		x			3
Maplewood	x	x	x					3
Marine on St. Croix	x							1
Marshan Twp.	x						x	2
May Twp.	x		x					2
Mayer	x				x			2
Medicine Lake	x						x	2
Medina	x			x	x			3
Mendota	x							1
Mendota Heights	x		x					2
Miesville	x							1
Minneapolis	x					x	x	3
Minnetonka	x						x	2
Minnetonka Beach	x				x			2
Minnetrista	x				x			2
Mound	x				x			2
Mounds View	x					x		2
New Brighton	x					x		2
New Germany	x				x			2
New Hope	x							1
New Market Twp.	x							1
New Prague	x							1
New Trier	x							1

Community	Potential for well interference	Potential for significant decline in aquifer water levels	Potential for impacts on surface water features	Potential for impacts to trout habitat or calcareous fen	Significant uncertainty regarding aquifer extent and productivity	Known groundwater contamination	Significant contamination vulnerability	Total Issues in the Community
Newport	x	x	x			x	x	5
Nininger Twp.	x		x		x		x	4
North Oaks	x		x					2
North St. Paul	x							1
Northfield	x							1
Norwood Young America	x				x			2
Nowthen	x				x		x	3
Oak Grove	x		x		x			3
Oak Park Heights	x	x	x				x	4
Oakdale	x	x				x	x	4
Orono	x							1
Osseo	x		x				x	3
Pine Springs	x						x	2
Plymouth	x		x				x	3
Prior Lake	x	x		x			x	4
Ramsey	x		x					2
Randolph	x							1
Randolph Twp.	x						x	2
Ravenna Twp.	x				x			2
Richfield	x		x				x	3
Robbinsdale	x						x	2
Rockford	x							1
Rogers	x		x					2
Rosemount	x	x	x				x	4
Roseville	x					x		2
San Francisco Twp.	x				x			2
Sand Creek Twp.	x		x		x			3
Savage	x		x					2
Scandia	x		x	x				3
Sciota Twp.	x							1
Shakopee	x	x	x	x			x	5
Shoreview	x					x		2
Shorewood	x							1
South St. Paul	x	x	x				x	4
Spring Lake Park	x				x			2
Spring Lake Twp.	x				x			2
Spring Park	x				x			2
St. Anthony	x					x		2
St. Bonifacius	x				x			2
St. Francis	x		x		x			3
St. Lawrence Twp.	x		x		x			3

Community	Potential for well interference	Potential for significant decline in aquifer water levels	Potential for impacts on surface water features	Potential for impacts to trout habitat or calcareous fen	Significant uncertainty regarding aquifer extent and productivity	Known groundwater contamination	Significant contamination vulnerability	Total Issues in the Community
St. Louis Park	x						x	2
St. Marys Point	x			x				2
St. Paul	x	x	x					3
St. Paul Park	x	x	x			x	x	5
Stillwater	x	x		x			x	4
Stillwater Twp.	x			x			x	3
Sunfish Lake	x			x				2
Tonka Bay	x							1
Vadnais Heights	x		x				x	3
Vermillion	x			x				2
Vermillion Twp.	x			x				2
Victoria	x							1
Waconia	x				x			2
Waconia Twp.	x				x			2
Waterford Twp.	x							1
Watertown	x							1
Watertown Twp.	x				x			2
Wayzata	x							1
West Lakeland Twp.	x	x				x		3
West St. Paul	x							1
White Bear Lake	x						x	2
White Bear Twp.	x		x					2
Willernie	x							1
Woodbury	x	x		x			x	4
Woodland	x							1
Young America Twp.	x				x			2
Total Communities	***186***	***30***	***68***	***29***	***54***	***22***	***62***	

Note:

The issues identified in the community profiles and summarized here must be addressed in such a way as to ensure that more serious limitations do not ensue. A master list of issues and corresponding response thresholds and actions may be found in Appendices 3 and 4.

Hydrogeologic Areas of Concern
Minnesota Department of Natural Resources
April 2013

		Existing or Potential Concerns						
Geographic Location	**County**	**Limited Water Supply**	**Population Growth**	**Surface Water Impacts**	**Contamination Issues Limiting Availability**	**Water Use Conflicts and Interference**	**Crop Irrigation**	**Mining**
AREAS								
Little Rock Creek	Benton/Morrison	X	X	X	X	X	X	
Chanhassen/Chaska	Carver	X	X	X				
Eden Prairie/Carver	Carver	X	X	X				
Buffalo Aquifer	Clay/Wilkin	X			X	X	X	
Red Rock Rural Water	Cottonwood	X	X	X	X			
Twin Cities (NW)	Hennepin	X	X		X			
Twin Cities (SW)	Hennepin/Carver	X	X	X	X			X
Bonanza Valley	Kandi/Pope/ Stearns	X		X		X	X	
Lincoln Pipestone Rural Water (Verdi well Field)	Lincoln	X		X		X	X	
Marshall Municipal Water (South Well Field)	Lyon	X	X	X	X	X		
Marshall Municipal Water (Dudley Well Field)	Lyon/Yellow Medicine	X	X	X	X	X		
Lincoln Pipestone Rural Water (Holland Well Field)	Pipestone	X		X	X	X	X	X
White Bear Lake	Ramsey	X		X				
Rock County Rural Water	Rock	X	X	X	X	X		
Savage/Prior Lake/Shakopee	Scott	X	X	X				X
Twin Cities (E)	Washington/ Ramsey	X	X	X	X			
Red River beach ridges	Wilkin/Clay/ Norman/Polk/ Marshall/Kittson	X		X				X
Red River Valley	Wilkin/Clay/ Norman/Polk/ Marshall/Kittson	X			X			
Albertville Infiltration (JPO)	Wright	X	X					
Lincoln Pipestone Rural Water (Burr Well Field)	Yellow Medicine	X		X		X		
Marshall Municipal Water (Wood Lake Aquifer)	Yellow Medicine	X	X	X	X	X	X	

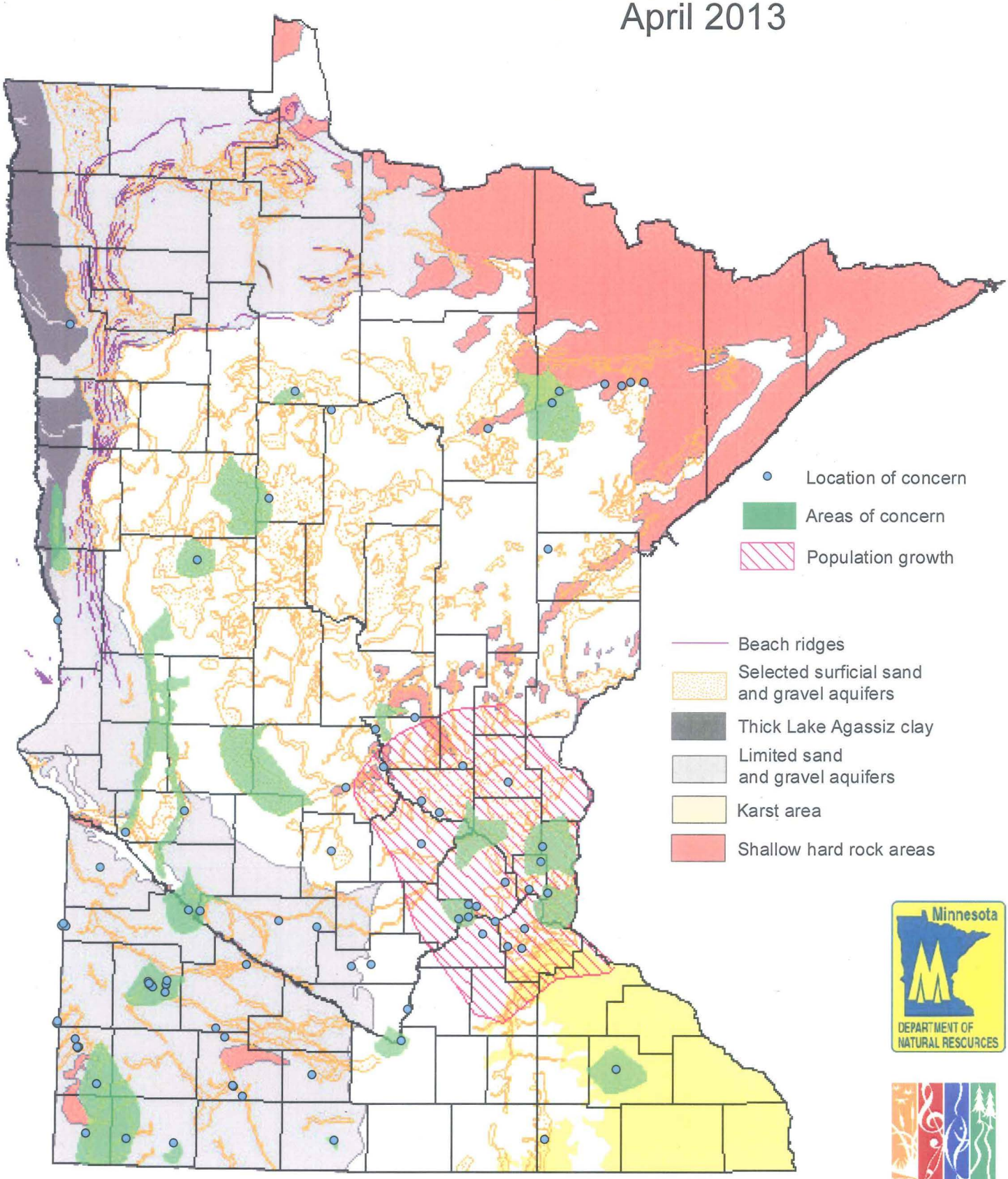
Hydrogeologic Areas of Concern
Minnesota Department of Natural Resources
April 2013

		Existing or Potential Concerns						
Geographic Location	**County**	**Limited Water Supply**	**Population Growth**	**Surface Water Impacts**	**Contamination Issues Limiting Availability**	**Water Use Conflicts and Interference**	**Crop Irrigation**	**Mining**
Communities								
Bemidji	Beltrami	X	X		X			
Rice	Benton	X		X	X	X	X	
Mankato	Blue Earth	X	X	X				X
New Ulm	Brown	X						X
Granite Falls	Chippewa	X				X		
Montevideo	Chippewa	X						
Moorhead--also see Buffalo aquifer	Clay/Wilkin	X		X		X		
Windom	Cottonwood	X		X	X			
Farmington	Dakota	X	X	X				X
Lakeville	Dakota	X	X			X		
Rosemount	Dakota	X	X			X	X	X
Elk River	Hennepin	X	X					
Park Rapids	Hubbard	X	X	X	X		X	
Isanti	Isanti	X	X					
Bovey	Itasca							X
Chisholm	Itasca	X				X		X
McKinley	Itasca	X						X
Virginia	Itasca	X						X
Madison	Lac Qui Parle	X						
Aurora	Lake	X		X	X			X
Biwabik	Lake	X		X	X			X
Fairmont	Martin	X		X	X			
Eden Valley	Meeker	X				X	X	
Litchfield	Meeker	X				X	X	
Austin	Mower	X		X	X	X		
St Peter	Nicollet	X			X			X
Adrian	Nobles	X		X	X			
Worthington	Nobles	X	X	X	X	X		
Rochester	Olmsted	X	X	X	X			
Perham	Ottertail	X		X	X	X	X	
Crookston	Polk	X				X		
White Bear Lake	Ramsey	X		X				
Bird Island	Renville	X			X	X		
Buffalo Lake	Renville	X				X		
Luverne	Rock	X	X	X	X	X		
Becker	Sherburne	X	X					
Big Lake	Sherburne	X	X					
Princeton	Sherburne	X	X	X	X			
Winthrop/Gaylord	Sibley	X				X		
Hibbing	St. Louis	X	X	X	X	X		X

Hydrogeologic Areas of Concern
Minnesota Department of Natural Resources
April 2013

		Existing or Potential Concerns						
Geographic Location	**County**	**Limited Water Supply**	**Population Growth**	**Surface Water Impacts**	**Contamination Issues Limiting Availability**	**Water Use Conflicts and Interference**	**Crop Irrigation**	**Mining**
Cold Spring	Stearns	X	X	X	X	X	X	X
St Cloud	Stearns	X				X		X
St. Joseph	Stearns	X				X	X	
Appleton	Swift	X				X	X	
Benson	Swift	X		X		X	X	
Hugo	Washington	X	X	X		X		
Woodbury	Washington	X	X	X				
St James	Watonwan	X				X	X	
Breckenridge	Wilkin	X				X		
Annandale	Wright	X				X	X	
Buffalo	Wright	X	X					
Clearwater	Wright	X	X					
Otsego	Wright	X	X					
Canby	Yellow Medicine	X				X	X	
Dakota County	Dakota	X	X		X		X	X
Highwater Ethanol	Cottonwood/ Redwood	X		X	X			
Granite Falls Energy	Renville	X				X		

Hydrologeologic Areas of Concern
April 2013



JAB April 17, 2013

Minnesota DEPARTMENT OF NATURAL RESOURCES

CLEAN WATER LAND & LEGACY AMENDMENT

Minnesota
Pollution
Control
Agency

Byron Township Stop

LCCMR Tour – July 17, 2013

Kevin Stroom, Watershed Ecologist, MPCA – Brainerd

CLEAN WATER LAND & LEGACY AMENDMENT

Reasons for concern regarding land conversion from forest to agriculture:

1) Nutrients

- Much of the nitrate that infiltrates into groundwater ends up in streams.
- Elevated nutrients (nitrogen and phosphorus) lead to eutrophication (excess plant/algae growth), which leads to lowered dissolved oxygen in the water.
- Streams in western Cass County have very low natural nitrate levels, but phosphorus is elevated due to natural landscape factors (extensive riparian peat soils). Study is occurring in the vicinity of Byron Township (Tower and Swan Creeks). Phosphorus is limiting in many of these streams, so any addition of nitrate will result in some level of eutrophication. An important protection strategy will be to prevent nitrogen inputs.

  Local example: Straight River near Park Rapids (high recreational value) – a TMDL study for dissolved oxygen is underway. Nitrate levels are much higher than typical for the Crow Wing watershed. Irrigated agriculture for potatoes and corn is prevalent in the Straight River watershed. Algal abundance appears to be above normal, and may be responsible for the oxygen levels not meeting the Minnesota standard.

  Other current examples of nitrate transport to streams via groundwater being addressed by MPCA: Little Rock Creek, Benton & Morrison Counties, numerous locations in the Whitewater River Watershed (SE MN).

2) Flow alteration

Many aspects of biological habitat can be changed when flows are altered - water velocity, water temperature, channel dimensions and physical streambed features.

Altered habitat = altered biological communities ≠ Clean Water Act goal of biological integrity

Crow Wing Watershed streams receive significant groundwater inputs due to the high water table in the area and are thus at risk if groundwater levels are altered. MPCA investigation of the Little Rock Creek situation has shown that surficial groundwater, which feeds the creek, is decreasing. Groundwater extraction for irrigation has increased rapidly in that watershed in recent years. A TMDL study was completed in 2012 for the creek.

Available soon (http://www.pca.state.mn.us/index.php/water/water-types-and-programs/watersheds/crow-wing-river.html#restoration-and-protection)

Crow Wing River Watershed Monitoring and Assessment Report - in final review

Crow Wing River Watershed Stressor ID Report - target date early fall

New Report, USGS – July 2013

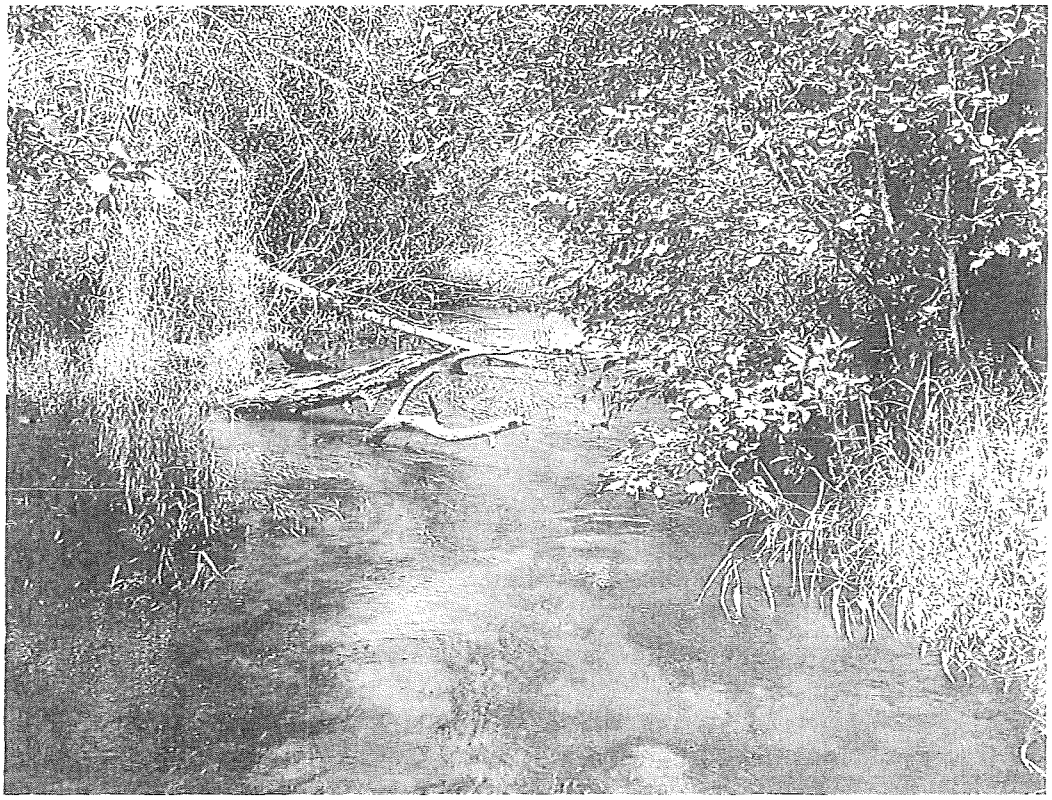
A new USGS report describes how the health of our Nation's streams is being degraded by streamflow modifications and elevated levels of nutrients and pesticides. USGS News Release, July 11, 2013.

(OVER)

Carlisle, D.M., Meador, M.R., Short, T.M., Tate, C.M., Gurtz, M.E., Bryant, W.L., Falcone, J.A., and Woodside, M.D., 2013, The quality of our Nation's waters—Ecological health in the Nation's streams, 1993–2005: U.S. Geological Survey Circular 1391, 120 p., http://pubs.usgs.gov/circ/1391/.

"Reduced stream health is associated with manmade modifications to the physical and chemical properties of streams, which are a consequence of land and water management. Maintenance of stream health requires that physical and chemical properties of streams remain within the bounds of natural variation. When manmade disturbances push these characteristics beyond natural ranges, such as might occur from increased fluctuation in streamflows or excess nutrients, vulnerable aquatic species are eliminated—ultimately reducing stream health."

USGS, 2013



Swan Creek, Byron Township, 2.25 miles southwest of where you are standing. MPCA's biological monitoring results from 2010 for both fish and invertebrate communities were excellent here. The creek is a tributary of the Crow Wing River.

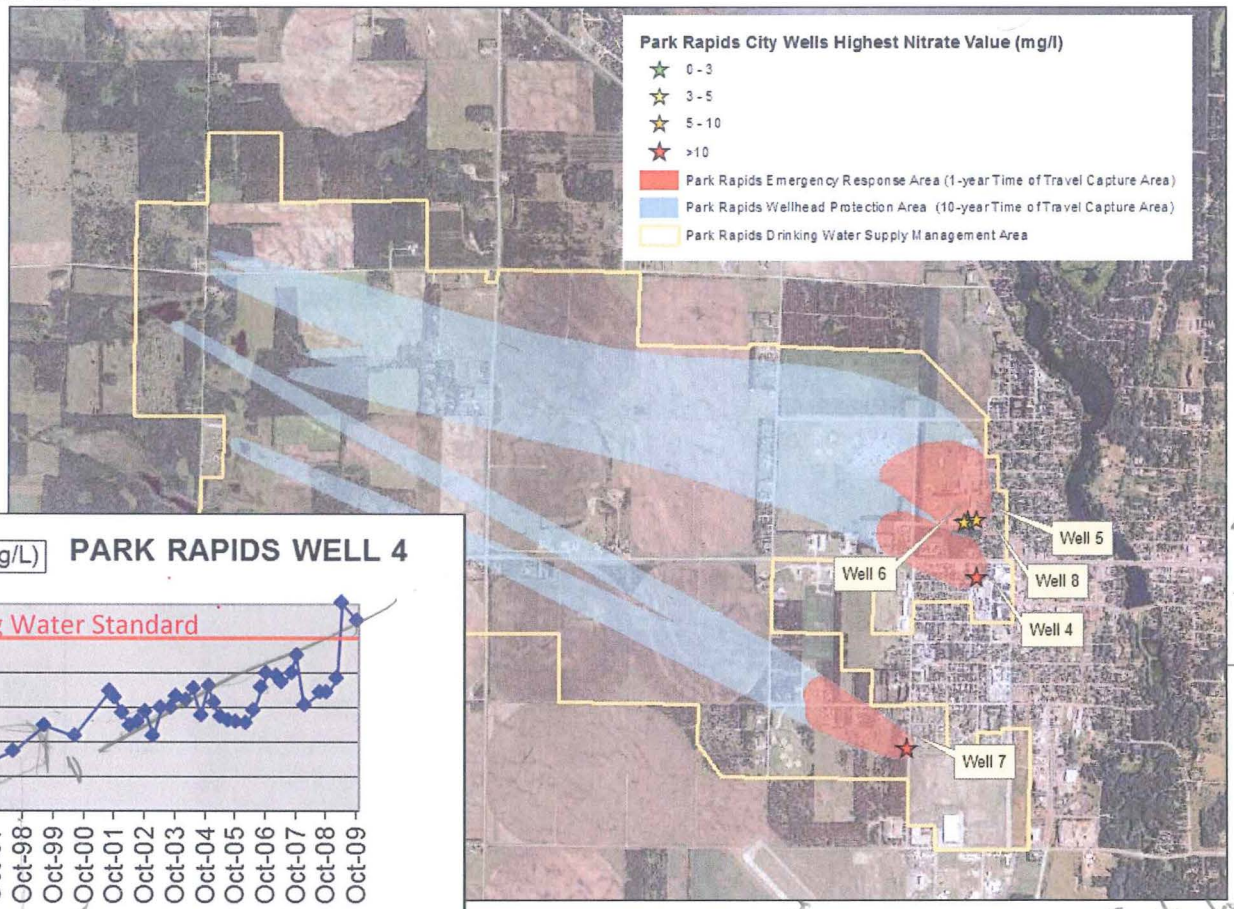
Josh Stromberg - MDA Clean Water Act Research Coordinator
can the any exception of pesticide charge in SE.

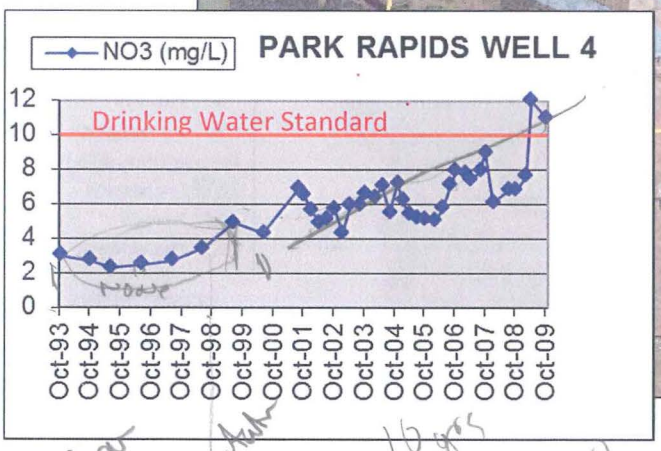
MINNESOTA MDH DEPARTMENT OF HEALTH

July 17, 2013 LCCMR field stop, Byron Twp. - Conversion of forested land to irrigated potatoes

Issue Statement - Where row-crop agriculture is practiced in sensitive geologic settings, it is common for the uppermost aquifer to become contaminated with nitrate. Once in the groundwater, nitrate is difficult and costly to remove and when present above the drinking water standard (10 milligrams per liter) poses a health threat to infants who consume that water either directly or in formula. For these reasons, it is preferable to keep nitrate contamination from occurring in the first place rather than responding to it after it has occurred. The cost of dealing with nitrate-contaminated drinking water has historically been borne by individual well owners or public water suppliers whose water supply has been impacted. These costs have ranged from drilling deeper replacement wells to installing nitrate removal systems. The following are two examples of nearby communities whose wells have been impacted by nitrate contamination and how they are dealing with this.

Park Rapids Example - For many years, the city of Park Rapids has relied on a handful of wells completed in the uppermost sand aquifer for its water supply. Nitrate levels in these wells have risen over time to the point where several of them have had to be abandoned because they couldn't meet drinking water standards (see red stars on map). Abandonment of these shallow wells has required the city to look to alternative sources to replace the lost capacity. The city is currently in the process of exploring for and installing deeper wells that will draw from an aquifer that is not contaminated with nitrate. However, the levels of naturally occurring iron and manganese in this deeper aquifer will require the installation of a treatment plant that will cost the city upwards of $2 million, excluding ongoing operation and maintenance costs.

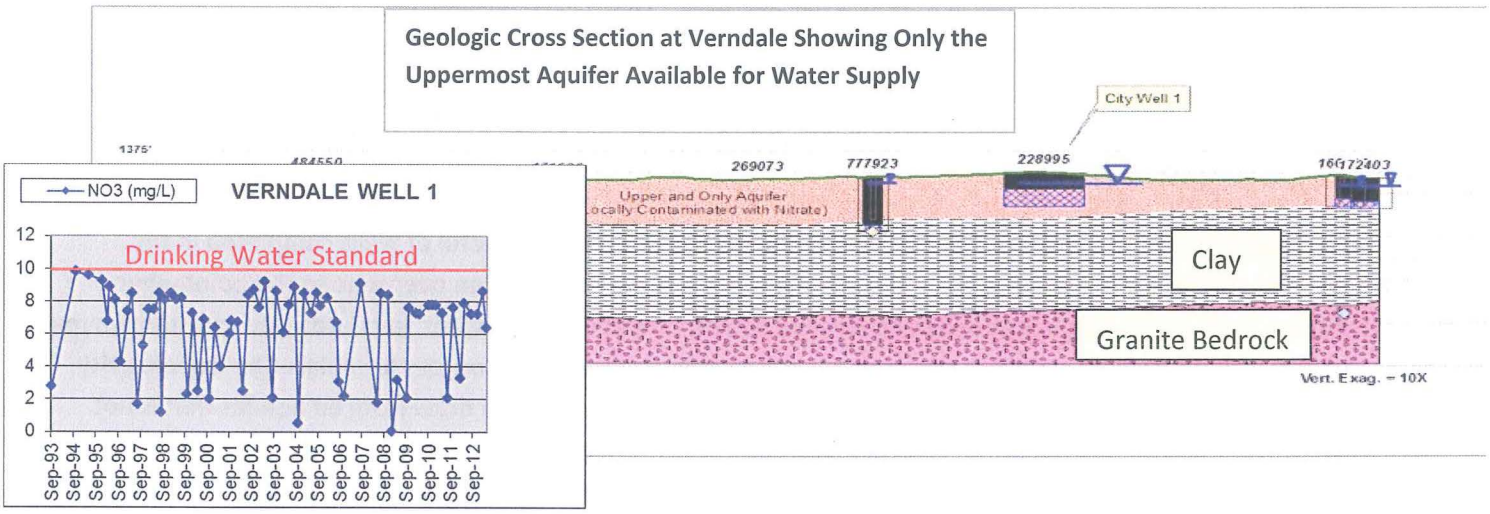




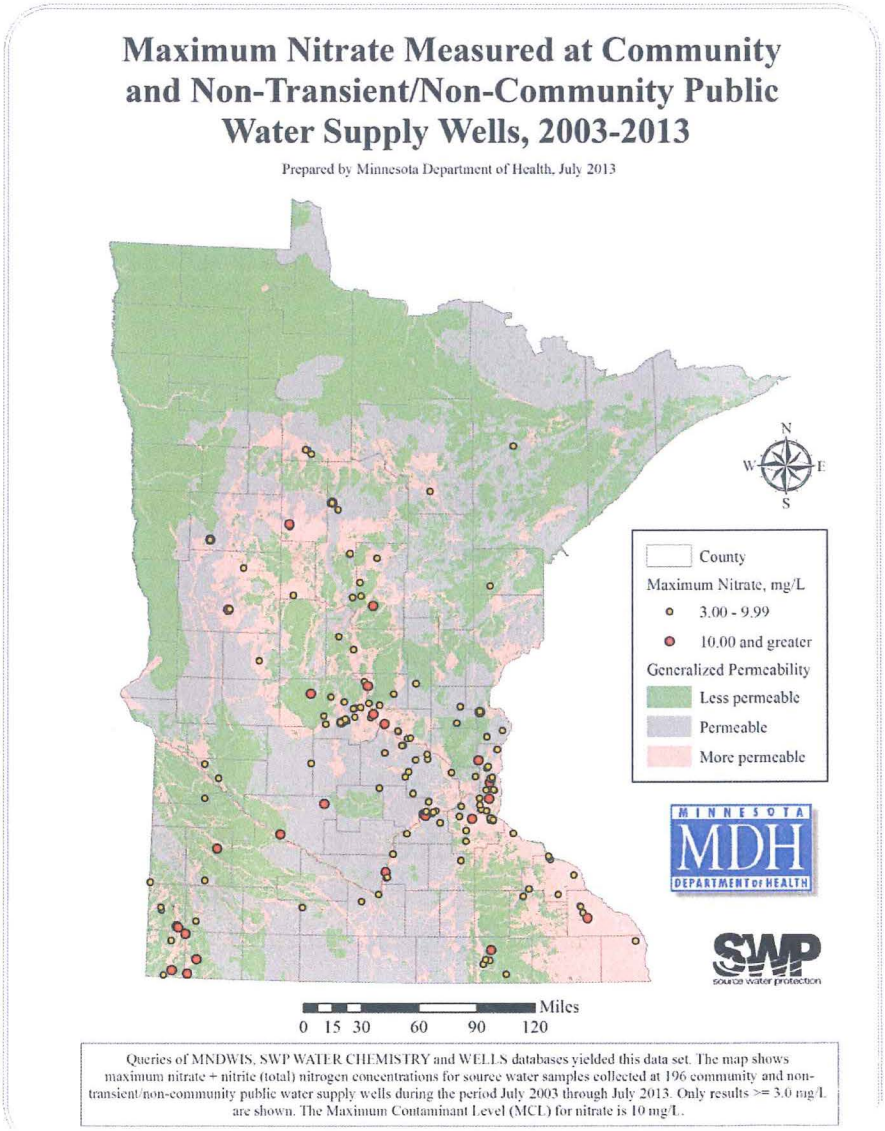
- citizen starting to detect well water pollution
high land strong is for production not conv. production
10 yrs
13 yrs
23 to 7/10
chemigation/fertigation punch
if what you see is true we have a problem
(responsibility to
regular chemical inputs
is there any correspondence with problem
with pesticides
- chemigation

Verndale Example

Located just up Highway 10 from our field stop, the city of Verndale has historically relied on 2 shallow wells for its water supply. For the past 20 years, the nitrate levels at one of these wells have fluctuated widely, often approaching the drinking water standard. Fortunately the other well is slightly lower in nitrate so the city has been able to meet drinking water standards by blending. However, any significant increase in the nitrate levels at either well would render blending useless. In addition, exploration for a deeper aquifer at Verndale has proven unsuccessful (see below). As a result, the city could be forced to turn to an expensive nitrate removal system to meet drinking water standards over the long run.



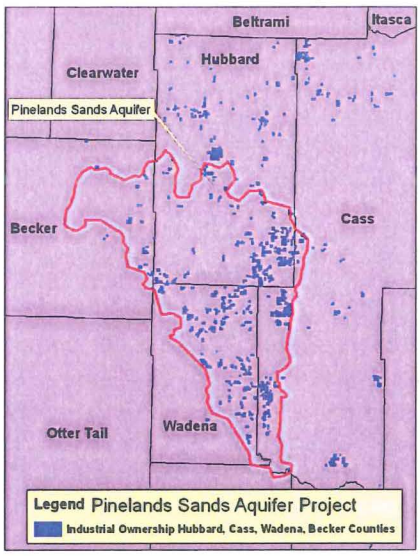
This map shows the distribution of public water wells serving large resident populations that are considered threatened by nitrate contamination.



Protecting Pinelands Sands Forest and Aquatic Habitats

1

Pinelands Sands Aquifer Assessment



Background:

- DNR has begun an effort to evaluate the state's industrial owners to determine protection priorities.
- Industrial forestlands provide a number of habitat and other ecological benefits.
- They are interspersed with public lands and also provide access and recreation benefits.
- Many of the parcels are located directly over the Pinelands Sands Aquifer – one of the most productive aquifers in the state.
- These forest lands protect both groundwater and surface water quality and are the source of water for many lakes, streams and wetlands in the area and thus directly influence fish habitat.
- These lands also provide terrestrial habitat benefits for both wildlife, non-game and rare species and plant communities.
- Several thousand acres of industrial forest lands in the Park Rapids area have been sold and converted to row crop agriculture – approximately 5,000 acres in recent years.

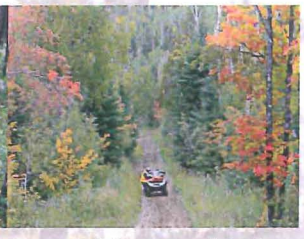
– 5-10 yr to acquire the 26,000 Ac

2

Habitat and other impacts from conversion of forestlands to irrigated agriculture:

Surface & ground water and aquatic habitats.

Loss of rare jack pine woodlands other habitats



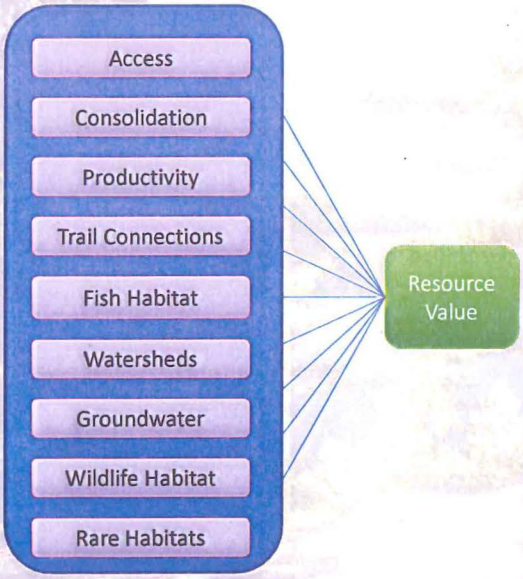
Public access & trail connectivity.

Productive forests that are a source of the regions timber supplies.

Fragmen-tation of large blocks of forest.

3

Pinelands Sands Aquifer Assessment



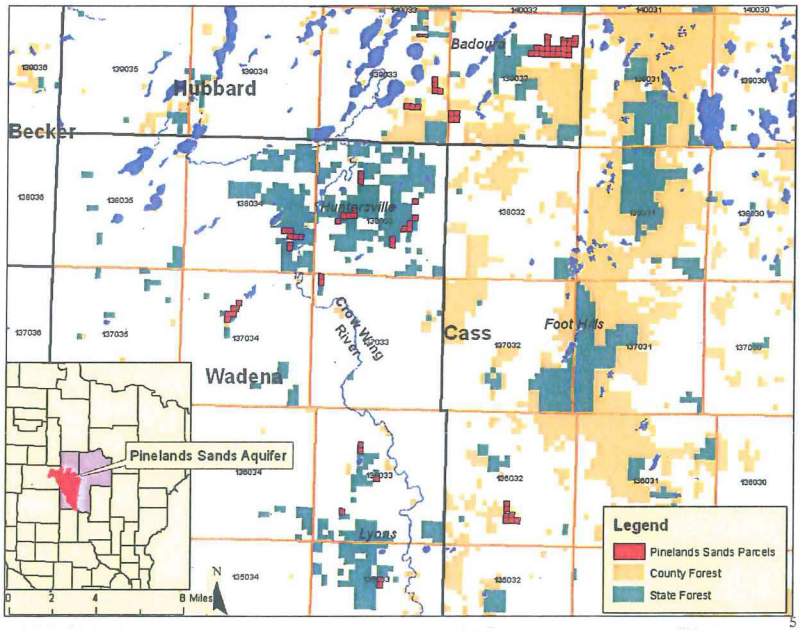
Assessment and Prioritization Process:

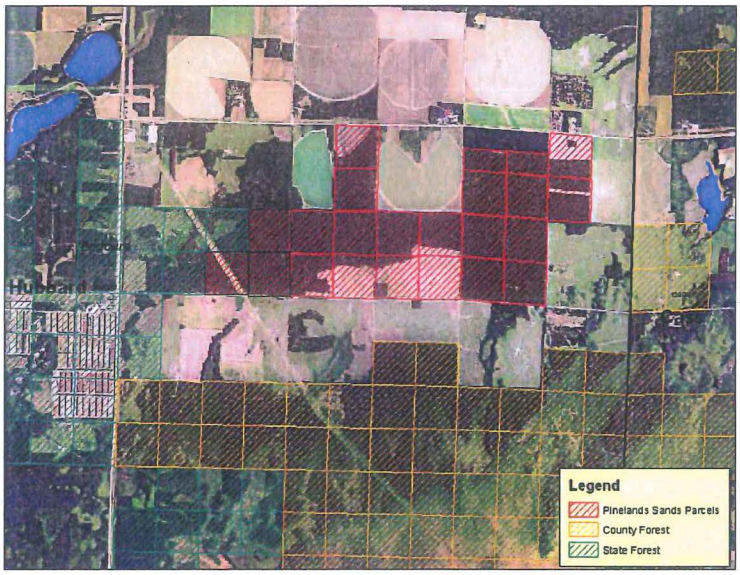
- Conversion of forest lands to agriculture uses results in many impacts to resources.
- Minnesota DNR used an interdisciplinary approach (Fish and Wildlife, Ecological and Water Resources, Parks and Trails & Forestry) to assessing the impacts of forest conversion and identified the highest priority to acquire or protect those lands most likely to be converted to agriculture and which had the highest resource values.
- Evaluation of 60,000 acres of industrial forest lands to assess resource values
- Risk assessment to determine risk of conversion to row crop agriculture.
- Our assessment resulted in the identification of about 11,000 acres of high resource value, at-risk parcels.
- The landowner identified 2,800 acres they would consider for sale at this time.
- Those 2,800 acres formed the basis of an LSOHC application.
- LSOHC has recommended $1,050,00 for fy15 (approximately 500 acres).

4

Potential 60000 ac in 4 co

Project Proposal Parcels





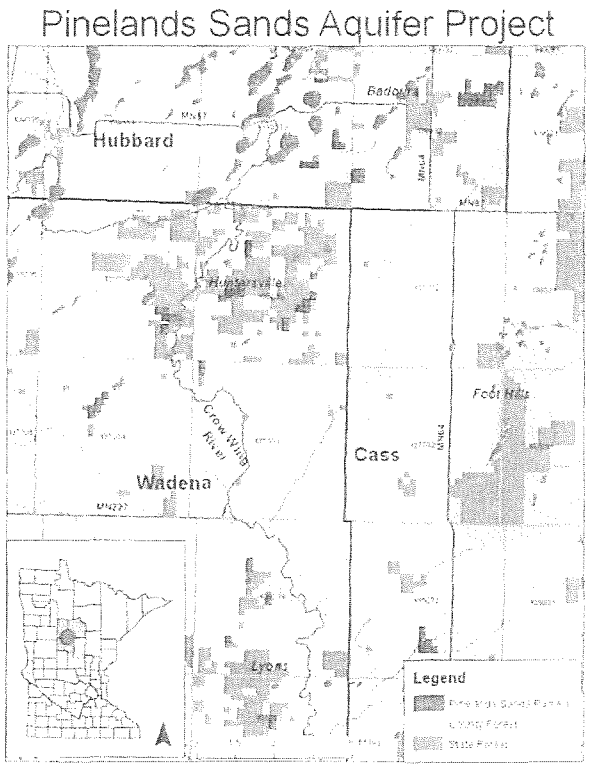
Forest conversion to agricultural lands eliminates or reduces wildlife habitat, limits access to state and county lands, reduces recreational access and trail connectivity, reduces timber supply, impacts rare plant communities and rare species, and can have a negative effect on ground water.

DNR Talking Points – Converting Forests to Annual Crops

LCCMR Tour – July 17, 2013

Conversion of forest lands to agricultural uses cause changes – above ground and below ground.

Minnesota DNR used an interdisciplinary approach to assessing impacts of forest conversion, and identified the highest priority to acquire or protect those lands most likely to be converted to agriculture where the conversion would have the greatest impact to groundwater.



This effort is a focus to retain key parcels in forest cover through acquisition that could be applied to private ownership generally. This is consistent with DNR's Strategic Land Asset Management initiative, which seeks to provide integrated planning for public lands.

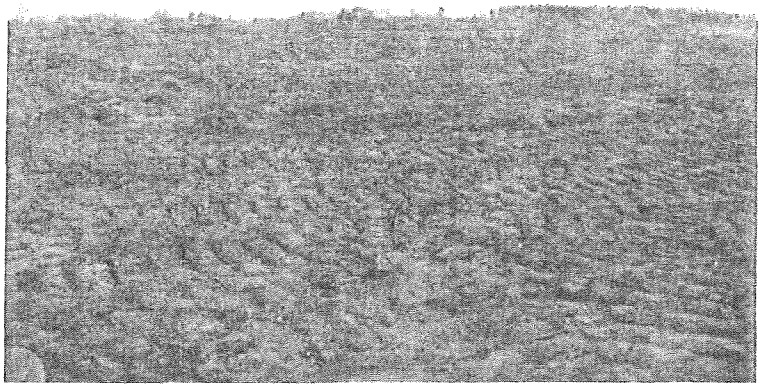
The most significant impact is below ground to ground water – both quality and quantity are affected. The evidence of the impact can be measured in stream flow and lake levels.

Above ground, forest conversion to agricultural lands limits access to state and county lands, eliminates or reduces wildlife habitat, timber supply, rare plant communities and rare species, and finally, the below ground effect on ground water can impair fish habitat. Because the conversion changes quasi-public lands to private lands, it reduces recreational opportunities. In short, protection of key industrial lands is an important strategy for protecting the benefits that nature provides people. DNR and UMN scientists want to work with stakeholders to investigate how various land management and precision conservation scenarios affect such benefits as sediment retention, water purification, groundwater protection, carbon storage and timber production over 50 years. This proposal has been submitted to LCCMR and would use state-of-the-art tools to inform precision conservation acquisitions in the region.

There are 60,000 acres of Potlatch timberland in Cass, Hubbard and Wadena counties, almost all of which is over the Pinelands Sands Aquifer. The Pineland Sands Area is a glacial outwash area characterized by fine to coarse grained sands and gravels which are well drained. The area is underlain by an extensive surficial sand and gravel aquifer (water table) along with buried sand and gravel aquifers. The water table aquifer and surface water bodies in this area are interconnected and

dependent on one another. Withdrawals in the water table aquifer can cause lower water levels in the nearby wetlands, lakes and streams. Some of the streams are designated trout streams and highly dependent on a cold groundwater supply. The deeper buried sand and gravel aquifers also have some connectivity to the shallower water table aquifer in different locations throughout this area and withdrawals from these deeper aquifers can also impact surface water bodies.

Because the soils are well drained, chemicals applied to the surface can infiltrate quickly into the soil; especially water soluble chemicals like nitrate. This can lead to groundwater contamination. This is demonstrated in the City of Park Rapids water table wells with nitrate concentrations reaching MDH Health Risk Limits; probably due to agricultural application of nitrogen fertilizers in the City well head protection area.



DNR Staff:

Mark Carlstrom, Area Forestry Supervisor, Park Rapids

Darrin Hoverson, Regional Hydrologist

Peter Jacobson, Fisheries Research Scientist

Nitrate in groundwater of the midwestern United States: a regional investigation on relations to land use and soil properties

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Abstract The intense application of nitrogen-fertilizer to cropland in the midwestern United States has created concern about nitrate contamination of the region's aquifers. Since 1991, the US Geological Survey has used a network of 303 wells to investigate the regional distribution of nitrate in near-surface aquifers of the midwestern United States. Detailed land use and soil data were compiled within a 2 km radius of 100 unconsolidated wells in the regional network to determine relations to nitrate concentrations in groundwater. For land use, the amount of irrigated land was directly related to nitrate concentrations in groundwater. For soils, the general water table depth and soil factors associated with rates of water movement were directly related to nitrate concentrations in groundwater.

INTRODUCTION

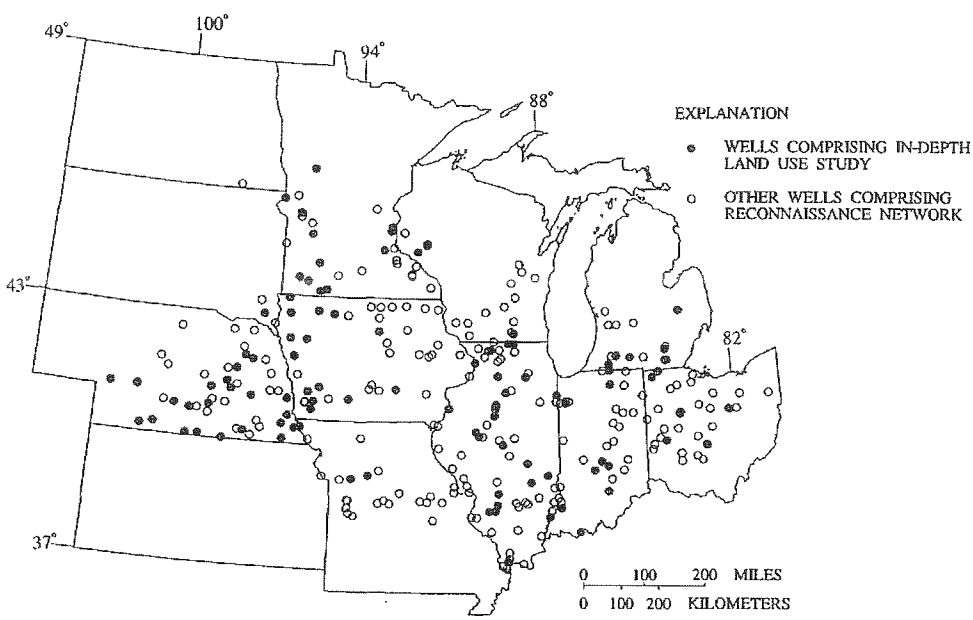
Nitrate may be the most widespread contaminant affecting the water quality of the world's aquifers (e.g. Meinardi *et al.*, 1995; Nolan *et al.*, 1997; Zhang *et al.*, 1996). Nitrate can be derived from a variety of natural and anthropogenic sources (Madison & Brunett, 1985) such as septic systems, animal manure, and atmospheric deposition. The most extensive sources of nitrate to groundwater in the United States are the transformation of soil organic matter to nitrate (Schepers & Mosier, 1991) and the application of inorganic nitrogen fertilizer to crops to increase yields (Hallberg & Keeney, 1993). Nitrate is highly soluble and can be readily transported to groundwater. If nitrogen loadings to soils repeatedly exceed what can be used in the system, nitrate concentrations in groundwater can build to problem levels (Steinheimer *et al.*, 1998). Excessive nitrate in drinking water can cause an oxygen deficient condition (methemoglobinemia) in infants (Fan & Steinberg, 1996). For this reason, the US Environmental Protection Agency has established a maximum contaminant level for nitrate at 10 mg l^{-1} nitrate as nitrogen. Ward *et al.* (1996) suggests that ingesting drinking water with nitrate concentrations of 4 mg l^{-1} or more increases the risk of non-Hodgkin's lymphoma in adults. Furthermore, nitrate has been documented to have deleterious effects on amphibians (Hecnar, 1995; Oldham *et al.*, 1997). Nitrate

concentrations in groundwater may impact aquatic ecosystems receiving groundwater discharge. It has been suggested that nitrate concentrations exceeding 2 mg l^{-1} in groundwater indicate anthropogenic sources of nitrate (Mueller & Helsel, 1996).

The midwestern United States is the largest and most intensive crop-producing region of the country. This region comprises about 21% of the Nation's land, but accounts for about 60% of the Nation's nitrogen fertilizer use. Thus, the extensive application of nitrogen fertilizer to cropland in the Midwest has created concern about nitrate contamination of the region's groundwater. In response to this concern, the US Geological Survey (USGS) designed a monitoring network in near-surface (top of aquifer material within about 15 m of land surface) aquifers in the maize- and soybean-producing regions of the midwestern United States (Kolpin *et al.*, 1994). These near-surface aquifers represent hydrogeologic settings most likely to be affected by chemical applications at the land surface. The purpose of this paper is to evaluate the statistical correlations between nitrate concentrations in groundwater and detailed land use and soil data from 100 randomly-selected unconsolidated wells from the USGS regional network.

METHODS

The original USGS network (Kolpin *et al.*, 1994) consisted of 303 randomly selected wells (from a population of existing production and monitoring wells) located in 12 midwestern states (Fig. 1). Selection criteria for these wells included having at least



Base from U.S. Geological Survey digital data, 1:2,000,000, 1972
Albers Equal-Area Conic Projection
Standard parallels 39 30 and 43 30, Central meridian -90 30

Fig. 1 Location of wells in the USGS groundwater reconnaissance network.

25% of the land use within a 3.2 km radius of the well location being in maize or soybean production during the 1990 growing season. The selection criteria, however, may have decreased the variance (increased homogeneity) in land use surrounding sampled wells. Relations to land use and soil factors may vary among fractured bedrock and unconsolidated deposits. Therefore, for this research it was decided to focus only on wells completed in aquifers that consist of unconsolidated deposits. A stratified, random process was used to select 100 wells completed in unconsolidated aquifers (Fig. 1). Stratification was by state to maintain the broad geographic distribution of wells similar to that present in the original network.

The selection strategy greatly reduced the range in well depths encountered, from 2 to 229 m in the original network to 2 to 37 m for the subset of 100 wells for this study. Thus, the selection strategy has not only limited the scope of study to unconsolidated aquifers, but also may have at least partially controlled for the effects of groundwater age (related to depth of sampled groundwater).

All water samples were collected by USGS personnel trained in a variety of water-quality sampling procedures. Representative samples were collected after an adequate volume of water was purged from each well (as determined by stable measurements of water temperature, pH, specific conductance, and dissolved-oxygen concentration). Nitrite plus nitrate as N (hereafter, referred to as nitrate) was determined with an automated colorimetric procedure (Fishman & Friedman, 1989). The analytical reporting limit for this method was 0.05 mg l^{-1}. A series of field blanks and field duplicates verified effectiveness of the sampling protocol.

Detailed land use within a 2 km radius of each of the 100 wells in this study was defined on the basis of low-altitude aerial photography. A procedure was developed (Harvey *et al.*, 1996; Kolpin, 1997) to transform the aerial photography into a GIS coverage of detailed land use.

Detailed soils data within a 2 km radius of each of the 100 wells in this study were derived from US Department of Agriculture County Soil Survey Maps. Individual map sheets (scales ranged from 1:15 840 to 1:24 000) were scanned, converted to GIS coverages, registered to geographic coordinates, and edited where necessary to match the original soil polygons from the map sheets. The various map sheets were merged to produce a 2 km buffer for each well. The soil GIS polygons were attributed with the proper map unit identifier (MUID) (US Soil Conservation Service, 1993). The MUID is used to relate to the soils attribute table containing all the available soils information for that soil.

RESULTS

Land use

The amount of irrigated land within a 2 km radius of a sampled well was directly related ($p = 0.004$; Spearman rank correlation) to nitrate concentrations in groundwater (Fig. 2). The highest nitrate concentrations generally corresponded with the greatest amounts of irrigated land. Previous research also has shown irrigation to increase nitrate transport to groundwater (Hubbard *et al.*, 1984; Timmons & Dylla, 1981).

Irrigation artificially increases recharge to shallow aquifers and thus, potentially increases nitrate transport from the unsaturated zone to the aquifer. The relation between irrigation and nitrate concentration may not be purely causative. Irrigated areas typically are characterized by soils with low water-holding capacities (Hallberg & Keeney, 1993) and higher rates of fertilizer application (Hamilton & Helsel, 1995). Thus, irrigation also could imply hydrogeologic settings with rapid groundwater flow (i.e. rapid nitrate transport) and/or high fertilizer applications (i.e. greater nitrate loadings).

Somewhat unexpected, the land-use factors thought to best reflect the amount of fertilizer use (such as amount of maize production) did not show significant relations to nitrate concentrations in groundwater. The relative homogeneity in land use (Kolpin, 1997) for these wells may have caused the lack of significant relations to nitrate.

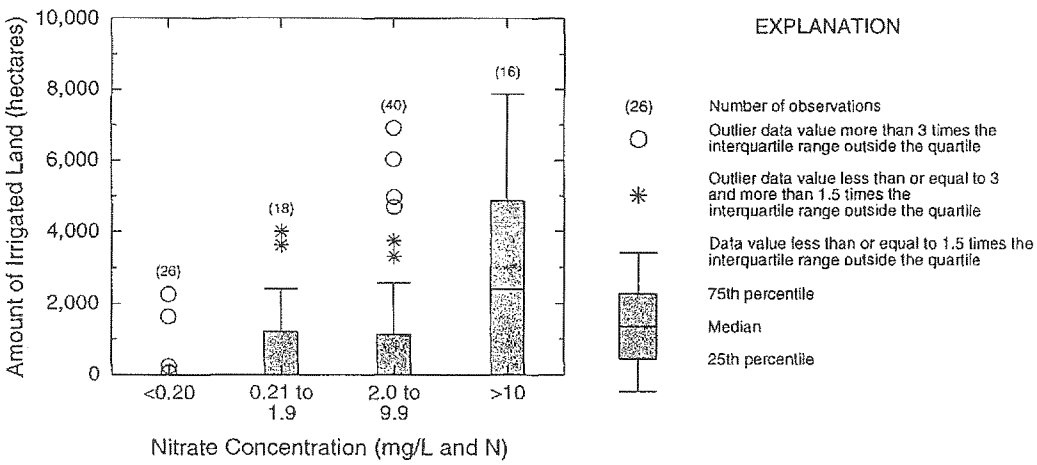


Fig. 2 Relation between nitrite plus nitrate as N (nitrate) concentration in groundwater and amount of irrigated land within a 2 km radius of sampled wells.

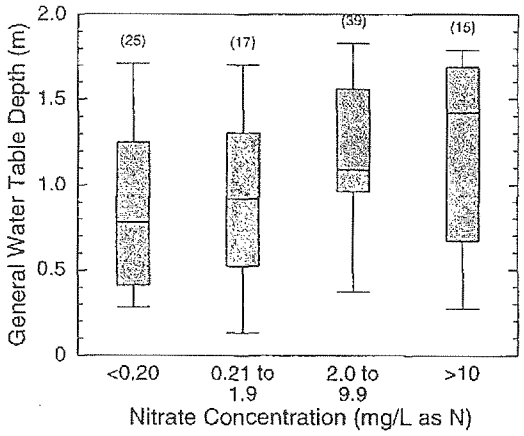


Fig. 3 Relation between nitrite plus nitrate as N (nitrate) concentrations in groundwater and general water table depth within a 2 km radius of sampled wells. Symbols as for Fig. 2.

Soils

The general water table depth was directly related ($p < 0.001$; Spearman rank correlation) to nitrate concentrations in groundwater (Fig. 3). The highest nitrate concentrations generally corresponded to areas with deeper water tables. Initially, this relation may appear opposite to expected results (decreasing nitrate with increasing general water table depth). However, shallow water tables generally reflect poorly drained soils and anaerobic conditions (Fig. 4). Under these conditions, denitrification of nitrate can occur in the presence of organic carbon and denitrifying bacteria (Korom, 1992). Similar trends between water level and nitrate concentration in groundwater have been noted in the literature (e.g. Kolpin *et al.*, 1994; Mueller *et al.*, 1995).

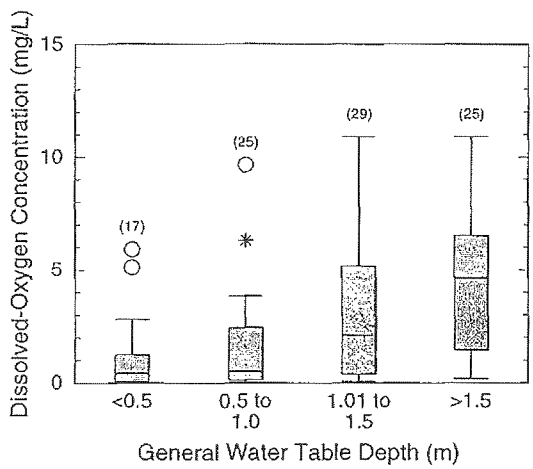


Fig. 4 Relation between dissolved-oxygen concentration in groundwater and general water table depth within a 2 km radius of sampled wells. Symbols as for Fig. 2.

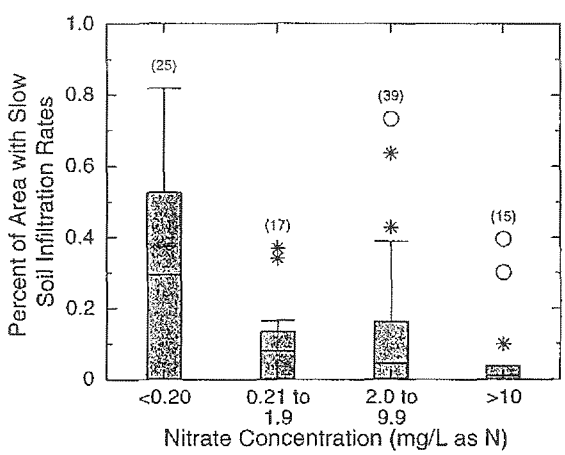


Fig. 5 Relation between nitrite plus nitrate as N (nitrate) concentrations in groundwater and amount of soils with slow infiltration rates within a 2 km radius of sampled wells. Symbols as for Fig. 2.

The remaining soil factors significantly related ($p < 0.05$; Spearman rank correlation) to nitrate concentrations in groundwater were all associated with rates of water movement. Of these, the factor with the strongest relation to nitrate ($p < 0.001$; Spearman rank correlation) was the area of soils within a 2 km radius of the sampled well with slow (US Soil Conservation Service, 1993) soil-infiltration rates (Fig. 5). These types of soils transport water (and thus, nitrate) at a slower rate than those with faster soil infiltration rates. Furthermore, poorly drained soils tend to be more oxygen deficient, potentially leading to denitrification. A further consequence of slow soil infiltration rates is that these soils are more likely to be artificially drained for improved crop production, diverting nitrate to nearby streams rather than infiltrating to groundwater.

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