A1. Purpose and Approach

Purpose

Nitrate has long been a concern for human health when elevated levels reach drinking water supplies. The 10 mg/l nitrate-N drinking water standard established for surface and groundwater drinking water sources and for cold water streams is exceeded in numerous wells and streams. In recent decades, the concern about nitrogen (N) in surface waters has grown due to nitrogen's role in causing a large oxygen-depleted hypoxic zone in the Gulf of Mexico, and an increasing body of evidence showing toxic effects of nitrate on aquatic life.

Minnesota has initiated several state-level planning efforts to address N in waters. Effective plans and strategies should be based on an understanding of the scientific data and technical body of knowledge surrounding the issues. The purpose of this study was to provide an assessment of the science concerning N in Minnesota waters so that the results could be used for current and future planning efforts, thereby resulting in meaningful goals, priorities, and solutions.

More specifically, the purpose of this project was to characterize N loading to Minnesota's surface waters, and assess conditions, trends, sources, pathways, and potential ways to achieve nitrogen reductions in our waters. The study results will be used in developing: 1) Minnesota's state-level Nutrient Reduction Strategy, 2) responses to potential river nitrate standard exceedances, and 3) other regional watershed implementation plans for addressing N in waters. Each of these three efforts is summarized below.

The state-level Nutrient Reduction Strategy is a multi-agency effort to establish paths to achieve progress toward meaningful and achievable N and phosphorus reductions. The strategy is being designed to protect and improve Minnesota's own waters, along with reducing cumulative impacts to downstream waters such as the Gulf of Mexico and Lake Winnipeg. In 2008, Minnesota committed to the U.S. Environmental Protection Agency (EPA) and the Gulf of Mexico Hypoxia Task Force to complete the first strategy by 2013. Guidance documents for state strategy development recommend that states conduct assessment work prior to establishing quantitative targets and identifying the needed management practices/strategies. The guidance suggests that each state characterize watersheds, identify sources, prioritize geographic areas, document current loads, and estimate historical trends.

River water quality nitrate standards are being developed by the Minnesota Pollution Control Agency (MPCA) in response to a 2010 Minnesota legislative directive asking the agency to establish water quality standards for nitrate-N and total nitrogen (TN) (2010 Session Laws, Chapter 361, Article 2, Section 4, Subdivision 1). The nitrate water quality standards are being developed based on aquatic life toxicity concerns. Information in this study is not intended to influence the standard, which is established based on strict independent criteria related to toxicity testing, but rather will help us understand the extent of high nitrate water, nitrate sources, and considerations for reducing nitrate in impacted watersheds.

Watershed implementation plans and protection requirements are developed at the local level where water quality standards are exceeded or have the potential to be exceeded. At the time of this writing, 15 streams, mostly in southeastern Minnesota exceed the 10 mg/l standard for nitrate-N.

While N reduction strategies are needed in many watersheds with or without new nitrate standards addressing aquatic life toxicity, the addition of such standards will likely increase Minnesota's efforts aimed at reducing nitrate concentrations. Additionally, because groundwater is a primary pathway of N movement to streams, some of the study results may also be considered for groundwater and drinking water supply protection efforts.

To aid the above efforts, the following information needs were identified and were thus addressed in this study:

1. *Watershed nitrogen conditions* – assess how N loads, yields, and concentrations in rivers and streams vary geographically across Minnesota watersheds, and estimate how much N is lost within waters before being delivered to downstream waters.
2. *Concentration trends* – evaluate how in-stream nitrate concentrations have changed since the mid-1970s and how they have changed during more recent periods.
3. *Sources* – estimate mass loadings from different point and nonpoint land uses/sources and assess which sources most influence N loading to surface waters.
4. *Hydrologic pathways* – assess the amount of N delivered to streams by groundwater baseflow, tile drainage, surface runoff, atmospheric deposition, and other hydrologic pathways.
5. *Solutions for reducing nitrogen* – evaluate different scenarios for reducing N, considering N reduction potential and costs.

The approaches used to address these areas of study are summarized below and are more specifically described within each chapter.

Approach

The general approach for this study was to:

1. Collaborate with other organizations and MPCA divisions.

   The MPCA Watershed Division and Environmental Outcomes and Analysis Division worked together with the University of Minnesota and the U.G. Geological Survey (USGS) to complete this study. The University of Minnesota's primary area of focus was determining N contributions to water from nonpoint sources. The USGS assisted with watershed modeling (SPARROW model) and N concentration mapping and trends analyses. The Minnesota Department of Agriculture (MDA) and the Metropolitan Council provided data, assistance, and review. (See acknowledgments for specific authors, co-authors and others who provided assistance.)

2. Compile existing information, data, and results, whenever possible, taking advantage of past work from multiple organizations.

   For many years prior to this study, a tremendous amount of work has been completed by several different organizations to better understand N in Minnesota's surface waters. Our approach was to build on these other efforts, pulling together information from past studies and monitoring results, and combining this information with work conducted specifically for this project. No new monitoring was conducted for this study. Instead we analyzed existing results from the MPCA, Metropolitan Council, USGS, the MDA, and other sources. While new modeling efforts were completed for this project, the models were generally built upon previous modeling efforts by the USGS, University of Minnesota, and the MPCA.

Some of the existing information used in this study includes:

- Recent water N concentration results from over 50,000 water samples collected at over 700 stream sites in Minnesota;
- Water N loads calculated from monitoring over 20 to 30 years at 9 mainstem river sites and 1-10 years near 70 watershed outlets;
- Water chemistry sampling combined with water flow monitoring for 20 to 35 years at over 50 sites around the state (used for time-trend analysis);
- Findings from over 300 published studies;
- Six previously developed computer models (and two newly developed models); and
- More than 40 existing GIS spatial data mapping efforts.

3. Use multiple methods and information sources so that the conclusions do not hinge on one data source or model.

   Rather than relying on single models, data sets, or information sources, we used multiple approaches to validate and verify results. In most cases, we had a primary approach along with one or more secondary approaches as verification of the primary approach results. Results from models were verified with recent monitoring results.

4. Focus on the 8-digit HUC (HUC8) watershed scale and larger.

   Since the results for this study are intended mostly for helping with larger scale planning efforts, the scale of project results was designed for major watersheds (HUC8s); major basins; and statewide (Figure 1).

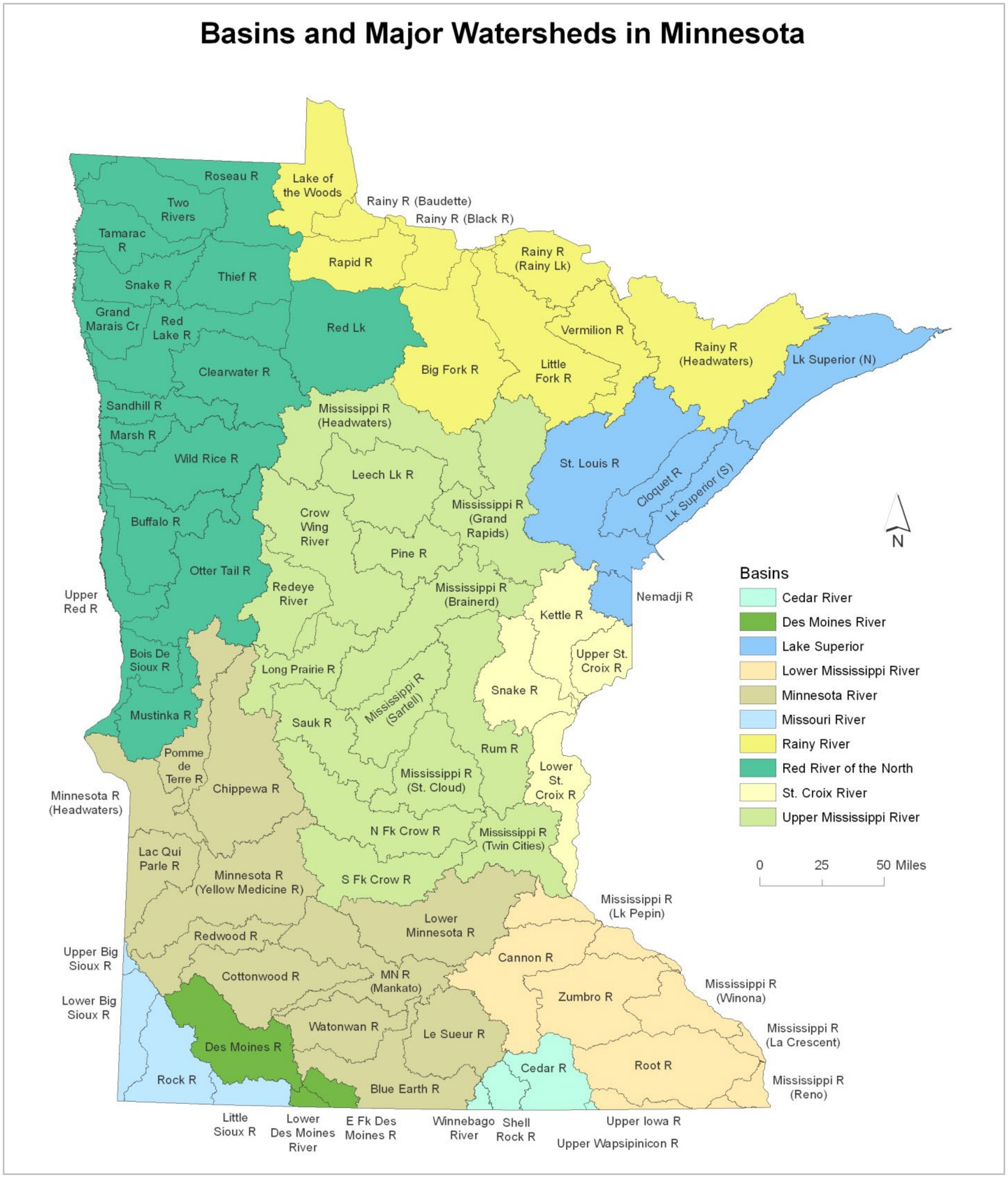

Figure 1. Major basins and HUC8 level watersheds in Minnesota.

This report focuses largely on TN since the forms of N which comprise TN can be transformed from one form into another. Since the nitrate form of N affects aquatic life toxicity and drinking water quality and is the dominant form which influences TN in high-yielding watersheds, trends analyses and certain other statistical evaluations were specifically done with the nitrite+nitrate form of N. In some analysis and discussion, we also include the ammonium and organic forms of N.

An overview of the methods used for each of the major study components is described below. More details about the methods are included in the body of the report within each chapter.

Nitrogen conditions

Nitrogen conditions across Minnesota were assessed by analyzing monitoring-based calculations of concentrations, loads, and yields, and additionally supplemented with SPARROW model results. All loads and yields in this report are annual loads and yields, unless specified otherwise.

Recent monitoring results at over 700 river and stream sampling sites were used to map and describe concentrations of different forms of N. The resulting maps show concentrations during low N periods (10th percentiles), average conditions (50th percentile) and high N periods (90th percentiles) during the past decade.

Monitoring-based watershed N annual loads were analyzed at two different levels: 1) major (mainstem) rivers, and 2) outlets of HUC8 watersheds. Annual loads were calculated by the MPCA and Metropolitan Council from continuous flow measurements and regular stream sampling. Because loads are largely influenced by the size of the watershed, the area-normalized loads (yields) and flow-weighted mean concentrations (load divided by flow) were mostly used when comparing N loads in watersheds around the state. Monthly loads were assessed at certain mainstem river monitoring points using data from the Metropolitan Council.

A spatial comparison of annual N loads and yields was also evaluated using modeling results from the SPARROW model. This model was developed and calibrated by the U.S. Geological Survey using monitoring-based results that are mostly independent of the other HUC8 watershed monitoring data described in this report. The model is specifically designed to spatially compare nutrient delivery from watersheds within a specific geographic area.

Because N forms transform within waters and are sometimes lost to the atmosphere, an extensive review of literature and data was conducted to evaluate how much N entering waters in one area is lost or transformed as it is transported to downstream waters.

Nitrate concentration trends

Stream nitrate concentration trends at 51 monitoring sites in the state were evaluated by the USGS and MPCA for nitrate concentration trends. Water quality monitoring data from the MPCA, USGS and Metropolitan Council was used, along with river flow data from the USGS. Long term trends (30 or more years) were assessed using the USGS QWTREND model. The QWTREND model allowed us to determine which specific periods of time within the entire record had increasing, decreasing, or stable trends. Trend results were mapped so that differences in trends could be observed across the state.

The statistical analyses were compared to several other previous trends studies conducted in Minnesota.

Sources and pathways

Total nitrogen inputs to waters from different sources and pathways were estimated as follows:

Point sources – MPCA NPDES permit records were used to estimate municipal and industrial point source N discharges directly into surface waters.

Atmospheric deposition – An EPA Model (CMAQ) was used to determine wet and dry atmospheric N deposition. The model is based on results from monitoring combined with N source information. Geographic Information System (GIS) data were used to determine amounts of atmospheric N falling directly onto lakes, streams, and land.

Cropland sources – The University of Minnesota estimated cropland losses for three different pathways: surface runoff, tile-line transport, and leaching to groundwater and its subsequent travel to surface waters. Different methods were used for each pathway, but all three assessments involved taking field research results and then using GIS databases to extrapolate the field-research results to the watershed and basin scales.

> For surface runoff, typical N concentrations in cropland runoff were multiplied by runoff volumes that varied for each part of the state.
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> For tile drainage, field research results from the literature were extrapolated for estimating losses to tile lines under different fertilization rates and precipitation scenarios. Fertilizer rates were estimated from recent farmer surveys.
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> For leaching to groundwater, field research results from the literature were extrapolated for estimating losses under different soils and geologic sensitivity conditions. Using GIS, the N leaching was estimated for each agro-ecoregion based on geologic sensitivity, soils, climate, fertilizer rates, etc. Recognizing that some N is lost in the groundwater via denitrification before reaching streams, denitrification loss coefficients estimated from research literature were assigned to each agroecoregion. Time lags between leaching to groundwater and delivery to surface waters were not directly accounted for.

All major cropland N inputs and outputs were evaluated in a basin-wide and state-wide N budget assessment. The budget allowed us to estimate the total fraction of cropland N inputs which is lost to waters.

Septic systems – Septic system transport was divided into direct pipe discharges and groundwater discharges. Average N generated per home was multiplied by the number of direct pipe septic systems to represent direct pipe discharges. For leachfields, N generated per home was multiplied by the number of leachfields, and then adjusted to account for denitrification losses within the soil and groundwater that would likely occur prior to N reaching surface waters.

Feedlots – Feedlot runoff N estimates were made using the Minnesota Feedlot Annualized Runoff Model (MinnFARM) and then multiplied by estimates of the size and number of non-compliant feedlots. Land application of manure was incorporated into the cropland source categories, and therefore is not included under the feedlot source category.

Forests – N loss coefficients from published studies of forest land were examined. A coefficient was selected to represent all forested land in the state. This coefficient was multiplied by the forested acreage using GIS.

Urban stormwater runoff – N loss coefficients from published studies and Twin Cities monitoring data were examined before selecting a single coefficient to represent typical urban/suburban stormwater runoff N loads. An additional amount of N was added based on a literature search, to represent urban/suburban groundwater contributions. GIS data layers were used to multiply the urban suburban lands by the loss coefficient.

Due to analysis uncertainties, the above source assessment findings were verified using five different approaches, as follows:

Monitoring results – The sum of the individual source estimates were compared with monitoring results from similar geographic areas as the source estimates. This comparison was conducted for the HUC8 and major basin scales.

Watershed land characteristics – Land characteristics in watersheds with more than one year of monitoring during normal-flow conditions were used in non-statistical and multiple regression analyses to assess relationships between the land and river N yields and concentrations. The land characteristics most associated with high and low river N levels were compared with the findings of the N source assessment.

The SPARROW model – The SPARROW model was used to estimate the relative contributions of major source categories of: agriculture, point source, and non-agricultural nonpoint sources. These statewide results were compared with similar groupings from the N source assessment.

Minnesota River Basin HSPF model – The HSPF model developed for the Minnesota River Basin was used to compare nonpoint source N delivery pathways and sources for this basin.

Literature review – Nitrogen source findings from other studies in the upper Midwest were compared to the findings from the source assessment.

Reducing nitrogen loads

The University of Minnesota and Iowa State reviewed existing literature to determine estimates of the expected N reductions which can be achieved from individual agricultural best management practices (BMPs) adopted at both the field and statewide scales. The N reduction estimates, BMP cost estimates, N loss to waters, along with limitations in the landscape for adopting each BMP, were all incorporated into a nitrogen BMP watershed planning spreadsheet (NBMP). We used the tool to estimate the N reduction effects and associated costs from different combinations of BMP adoption rates, and also compared our findings to Iowa's results.

This part of the study was intended to provide information and results that could be used for assessing large-scale potential ways to achieve N load reductions. The results are not suited for small scale analysis or individual farmer use.

Estimates of wastewater point source reductions that could be achieved with two types of technologies were developed from existing published information.