C2. Nitrogen Trend Results from Previous Studies

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Overview

Several statistical trend analyses of Minnesota's river and stream nitrogen (N) levels have been investigated during recent decades. We reviewed the results of these previous studies to: 1) compare past results to the nitrate concentration trend analyses developed for this study and reported in Chapter C1; 2) review trends of N forms not evaluated in Chapter C1, such as ammonium and total nitrogen (TN); and 3) review river N *load* trends which are not assessed in Chapter C1. Because trend results depend on the watersheds studied, the timeframe analyzed, monitoring design, parameters assessed, and statistical procedures, the studies are not directly comparable. Yet collectively, these trends analyses provide useful information for understanding possible trends in Minnesota's rivers and streams over the past several decades.

An overview of results from previous studies is shown in Table 1. The specific studies noted in Table 1 are described in more detail in the remainder of Chapter C2.

Table 1. Summary of past trend results assessed for rivers in Minnesota. "Nitrate" refers to nitrite+nitrate and "ammonium" refers to ammonia+ammonium.

Study area	Timeframe considered	Trends results summary	Organization (author)
Mississippi River			
Mississippi River in Clinton Iowa – drainage area includes much of southern MN, NE Iowa and western Wisconsin	1980 - 2008	*Nitrate concentration* - increased 76% *Nitrate load* - increased 67%	USGS (Sprague et al., 2011)
Mississippi River in Clinton Iowa – drainage area includes much of southern MN, NE Iowa and western Wisconsin	1975-2005	Total Nitrogen flow adjusted conc. increased from 1975-82, then remained stable from 1983 to 2005.	USGS (Lorenz et al., 2008)
Mississippi River – Twin Cities Area	1976 - 2005	*Total Nitrogen conc.* – no trend at all six sites *Total Nitrogen loads* – No trends at four sites; 18-24% increase at two sites; *Nitrate-N conc.* – no trend at one site; 47-59% increases at five sites; *Nitrate-N loads* – 37 to 68% increase at all six sites *Ammonium loads and conc.* – all sites decreased by 129 - 353%	Natl. Park Service, Science Museum and Met Council (Lafrancois et al., 2013)
Mississippi River at Anoka and Red Wing	1976 – 2002	*Nitrate conc.* - increased 31% at Anoka and 12% at Red Wing *Ammonium conc.* - decreased 91% and 78%	Met Council (Kloiber, 2004)

Study area	Timeframe considered	Trends results summary	Organization (author)
Minnesota River			
Minnesota River at Jordan	1976-2005	*Total Nitrogen conc*. – No Trend *Total Nitrogen load* – Increased 18% *Nitrate conc.* – No Trend *Nitrate load* – Increased 27% *Ammonium conc.* – Decrease 221% *Ammonium load* – Decrease 142%	Lafrancois et al., 2013
Minnesota River at Jordan	1976 – 2002	*Nitrate conc.* - decreased 20% *Ammonium conc.* - decreased 72%	Met Council (Kloiber, 2004)
Minnesota River and Greater Blue Earth River	Starting in Late 1970's to mid 1980s; ending 2001-2003	*Nitrate conc*. – decreasing trends in the Minnesota River Jordan and the Greater Blue Earth River; Increasing trend in the Minnesota River at Fort Snelling	U of MN (Johnson, 2006)
Minnesota River Basin – multiple locations	1999 - 2008 (some exceptions)	*Nitrate conc.* - Western end of basin (upper parts of basin) had mostly stable and increasing trends; Eastern end of basin (lower parts of basin) had mostly stable and mixed trends, with several sites showing decreasing trends.	Minnesota State Univ. at Mankato (Sanjel et al., 2009)
St. Croix River			
St. Croix River at Stillwater	1976 – 2002	*Nitrate conc.* - Increased 17% *Ammonium conc.* - Decreased 81%	Met Council (Kloiber, 2004)
Red River of the North			
Red River at Emerson (near Canadian border) and Halstad, MN	1975 - 2001	*Nitrate conc.* increased (23-27%) from 1982 to 1992 at both sites, and had no trend before 1982 and after 1992.	USGS (Vecchia, 2005)
Red River at Canadian Border	1978 - 1999	*Total nitrogen conc.* - increased 29%	Manitoba WQ Mgmt (Jones et al., 2001)
Southeastern Minnesota			
25 rivers in SE Minnesota	1984 – 1993	*Nitrate conc*. - stable, except for slight increase in St. Croix River at Prescott *Ammonium conc.* - decreased at 24/25 sites	USGS (Kroening & Andrews, 1997)
Southeastern Minnesota Springs	Early 1990's to 2010-11	*Nitrate conc.* – increased at two springs by 15% and 100%.	MPCA (Streitz, 2012)
Mississippi River Winona Watershed	Varied 16 to 35 yrs ending 2008-11	*Nitrate conc.* – All six sites had increasing trend	Olmsted Co. Env. Res., 2012 (Crawford et al)
Twin Cities area streams	Mostly 1999 to 2010; some sites 1990-2010	*Nitrate conc.* - varied trends, with 6 sites decreasing, 3 sites increasing and 9 sites having no trend or mixed trends.	Met Council (Jensen, 2013)

Mississippi River south of the Minnesota border

The U.S. Geological Survey (USGS) has been measuring flow and nutrient concentrations in the Mississippi River at Clinton Iowa since the mid-1970s. The contributing watersheds for this site include basins primarily in Minnesota, Wisconsin, and northeastern Iowa (Figure 1). Trend results were reported in two recent USGS reports.

Using the QWTREND model, Lorenz et al. (2009) found TN flow-adjusted concentrations to increase between 1975 and 1982 from 1.60 to 2.38 mg/l. Between 1983 and 2005, the concentrations remained largely stable, decreasing slightly from 2.38 to 2.30 mg/l (Figure 2). Total nitrogen *loads* also increased in the 1975 to 1982 time period, and then generally remained stable between 1983 and 2004.

Figure 1. Location of the Clinton, Iowa USGS monitoring site and the contributing drainage area (from USGS).

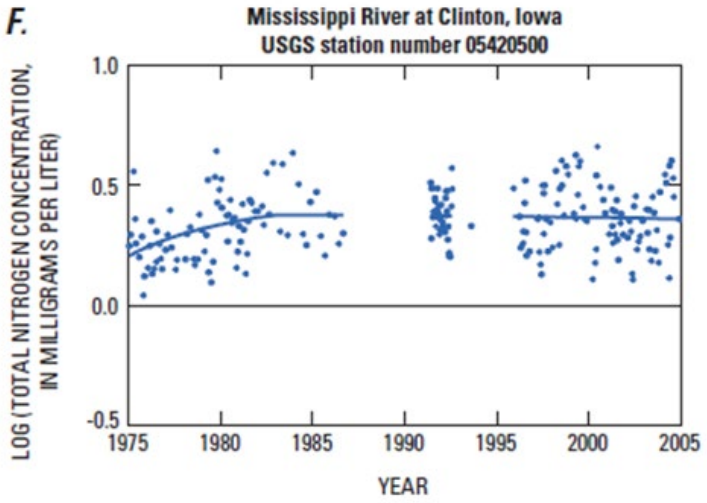

Figure 2. Flow adjusted TN concentration at the Mississippi River from 1975 to 2005. (from Lorenz et al., 2009).

Sprague et al. used the WRTDS model to evaluate nitrite+nitrate (nitrate) concentration changes at the Mississippi River Clinton, Iowa site (Sprague et al., 2011). The period of trends analysis began in 1980 and ended in 2008. Concentrations were normalized to remove variation due to random streamflow differences from one period of time to another. Results showed a nitrate increase, with the annual flow-normalized mean concentration increasing from 1.13 mg/l in 1980 to 1.99 mg/l in 2008. The increases were found at all categories of streamflow, but were largest during high and moderate streamflows at this monitoring location. Annual flow-normalized nitrate loads increased 67% during this same time period. The year-to-year load increases were found to be generally consistent, whether evaluated just for the spring months or for the entire year. One of the reasons for the difference in findings between the Lorenz et al. (2009) study and the Sprague et al. (2011) study was the assessed timeframe. Nitrate levels spiked in 2008, a year that was included in the Sprague study, but was after the Lorenz analysis period. Different statistical methods and different parameters (TN vs. nitrate) may also explain the differences in findings. Both studies showed fairly level concentrations between 1983 and 2005.

Minnesota, Mississippi, and St. Croix Rivers near the Twin Cities

Nitrogen concentration trends 1976-2005

Using data collected every other week from 1976 to 2002, the Metropolitan Council (Kloiber, 2004) assessed temporal trends at four large river monitoring sites, including the: 1) Minnesota River at Jordan; 2) St. Croix River at Stillwater; 3) Mississippi River at Anoka; and 4) Mississippi River at Red Wing (Figure 3). Using a flow-adjusted Seasonal Kendall Trend test, Kloiber found that ammonium concentrations decreased between 72 and 91% during the 1976 to 2002 timeframe at the four monitoring points. This decrease was thought to be due to improvements in point source controls which occurred during this same period. Total Kjeldahl nitrogen (TKN) decreased between 20 and 34% at the three monitored sites. Nitrate was found to have increased in the St. Croix River (+17%) and Mississippi River Anoka (+31%). Nitrate concentrations at the Minnesota River monitoring site near Jordan decreased by 20% (Table 2).

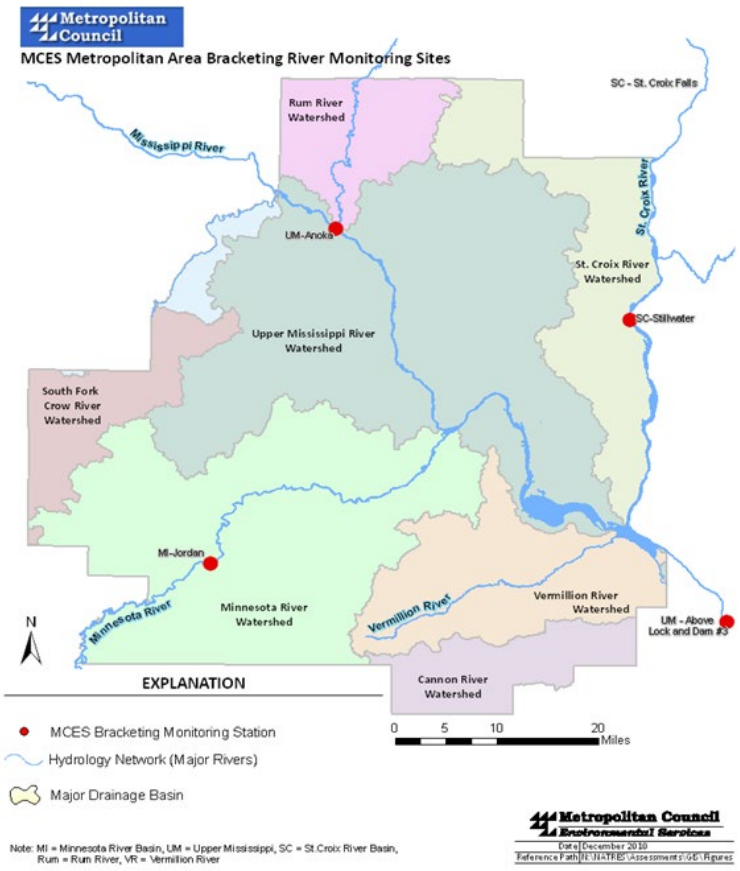

Figure 3. Location of Metropolitan Council major river load monitoring stations (from Met Council)

Table 2. Nitrogen parameter concentration medians, means and trends as determined by Metropolitan Council at their major river monitoring sites between 1976 and 2002. From Kloiber 2004.

	Median nitrate-N mg/l	Mean nitrate-N mg/l	Trend nitrate-N	Median NH4-N mg/l	Mean NH4-N mg/l	Trend NH4-N	Median TKN mg/l	Mean TKN mg/l	Trend TKN
MN River at Jordan	4.4	4.9	Decrease 20%	0.05	0.12	Decrease 72%	1.4	1.4	Decrease 20%
St. Croix River at Stillwater	0.3	0.4	Increase 17%	0.05	0.08	Decrease 81%	0.6	0.6	Decrease 33%
Mississippi River at Anoka	0.6	0.8	Increase 31%	0.05	0.11	Decrease 78%	0.9	0.9	NM
Mississippi River at Red Wing	2.2	1.4	Increase 12%	0.13	0.26	Decrease 91%	1.2	1.1	Decrease 34%

Loads and concentration trends 1976-2005

The National Park Service, working together with the Science Museum of Minnesota and Metropolitan Council Environmental Services, recently assessed flow-adjusted load and concentration trends at six Mississippi River locations between Anoka and Hastings, along with the Minnesota River near Fort Snelling. Using the Seasonal Kendall Trend test and Sen's slope estimator, long-term trends were determined for three N parameters analyzed at least twice monthly throughout each year of the 1976 to 2005 timeframe (Lafrancois et al., 2013). Percent changes over the 1976-2005 period are shown in Table 3.

Table 3. Percent increases (+) or decreases (-) in three N parameters measured at least twice monthly between 1976 and 2005. Red indicates increasing trends; blue indicates decreasing trends and white "n.s." boxes indicate no statistically significant trend. From Lafrancois et al. (2013).

Sites	TN conc.	TN load	NO2+NO3-N conc.	NO2+NO3-N load	NH3+NH4-N conc.	NH3+NH4-N load
Miss R. UM872 (Anoka)	n.s.	+22%	+49%	+62%	-214%	-129%
Miss R. UM 848 (Mpls)	n.s.	+24%	+58%	+68%	-234%	-133%
Miss R. UM839 (St. Paul)	n.s.	n.s.	n.s.	+37%	-230%	-182%
Miss R. UM831 (S. St. Paul)	n.s.	n.s.	+59%	+53%	-303%	-238%
Miss R. UM827 (Inver Grove Heights)	n.s.	n.s.	+53%	+55%	-284%	-251%
Miss R. UM816 (Hastings)	n.s.	n.s.	+47%	+51%	-353%	-271%
Minn. R. MI4 (Fort Snelling)	n.s.	+18%	n.s.	+27%	-221%	-142%

In summary, this study showed that ammonium concentrations decreased dramatically between 1976 and 2005, while nitrate concentrations increased at most Mississippi River sites. Total nitrogen concentrations did not have a statistically significant trend at any of the sites. Total nitrogen loads increased slightly (18-24%) in the north Metro part of the Mississippi River and Minnesota River Fort Snelling, and were not significant at the four Mississippi River sites downstream of Minneapolis. Nitrate loads increased by 27 to 68% at all sites.

Minnesota River Basin

Multiple sites 1998 - 2008

Nitrate concentration trends over a 10-year period (1999-2008) were evaluated in the Minnesota River Basin by Sanjel et al. (2009). For this relatively short period of time, the Seasonal Kendall test method generally showed that watersheds in the western part of the basin had either no statistically significant trend (seven sites) or an increasing trend (four sites). Watersheds in the eastern (lower) part of the

basin had sufficient data to use the more robust QWTREND model. All three tributaries in the southeast part of the Basin had decreasing trends, and the Minnesota River had a decreasing trend at Judson and no statistically significant trend at St. Peter.

Of the nine sites evaluated in the Cottonwood River and eastward, the results were mixed. With the Seasonal Kendall test, six sites showed no trend, one site showed a decreasing trend (Little Cobb River), and two sites showed increasing trends (Cottonwood River and Minnesota River at Judson). The two most downstream sites (Minnesota River at St. Peter and at Jordan) showed no statistically significant trend.

Fort Snelling, Jordan, and Greater Blue Earth - various timeframes between 1976 and 2003

Nitrate-N flow-adjusted concentration trends were evaluated by Johnson (2006) for two Minnesota River sampling locations (Fort Snelling and Jordan) and the Greater Blue Earth River, which is the largest tributary to the Minnesota River. The trend results, which extended for at least 10 years and ended between 2001 and 2003, are shown in Table 4. Both the Minnesota River Jordan and Greater Blue Earth River had decreasing trends during this timeframe. However, the Minnesota River Fort Snelling site showed an increasing trend between 1976 and 2003 with the QWTREND method. A direct comparison over this same timeframe using the Seasonal Kendall method at Fort Snelling was not performed, yet the Seasonal Kendall test showed a 63% increase in the relatively short interval from 1995 to 2003.

Table 4. Flow-adjusted nitrate concentration trends during varying time periods and statistical methods (from Johnson, 2006).

	Nitrate-N mg/l QWTREND	Nitrate-N mg/l Seasonal Kendall
MN River at Jordan		
1979-2003	-10%	-28%
MN River at Fort Snelling		
1976-2003	+89%	
Greater Blue Earth River		
1986-2001	-17%	
1990-2001		-40%

Southeastern Minnesota

Twenty-five sites in the southern half of the Mississippi River Basin, and the Cannon, Vermillion, and St. Croix River watersheds 1984 - 1993

Using data collected between 1984 and 1993, the USGS conducted an in-depth study of stream nutrients in large parts of Minnesota, including the southern half of the Mississippi River Basin, the Cannon and Vermillion River watersheds, and the St. Croix River Basin in Minnesota and Wisconsin (Kroening and Andrews, 1997).

Seasonal Kendall tests were conducted to determine temporal trends for water years 1984 to 1993. Most stream sites outside of the Twin Cities Metropolitan Area showed no increases in nitrate or TN during the 10-year period. The only site showing a slight increase in nitrate concentrations was the St. Croix River near Prescott, Wisconsin. In the Metro Area, nitrate increased, which was thought to be due to the modified wastewater treatment systems, converting ammonium into nitrate. Many upgrades

to municipal wastewater treatment facilities were made during the 10-year analysis period (131 upgrades out of 292 municipal systems). Additionally, most of the combined sanitary and storm sewers in Minneapolis and St. Paul were separated. Correspondingly, ammonium concentrations decreased at 24 of 25 stream sites, based on available data from water years 1984 to 1993.

Southeastern Minnesota springs

Nitrate trends assessed in two springs feeding fish hatcheries in southeastern Minnesota's Root River watershed both showed statistically significant (p=0.001) increasing trends over the past two decades (Streitz, 2012). The springs were monitored approximately monthly at Peterson and every other month at Lanesboro by the Minnesota Department of Natural Resources (DNR). Average annual nitrate-N concentrations in the Lanesboro spring increased from about 5.2 mg/l to 6 mg/l between 1991 and 2010 (Figure 4). Nitrate increased by a larger amount in the spring at the Peterson, Minnesota, fish hatchery, with average annual concentrations rising from less than 2 mg/l in 1989 to 4 mg/l in 2011 (Figure 5).

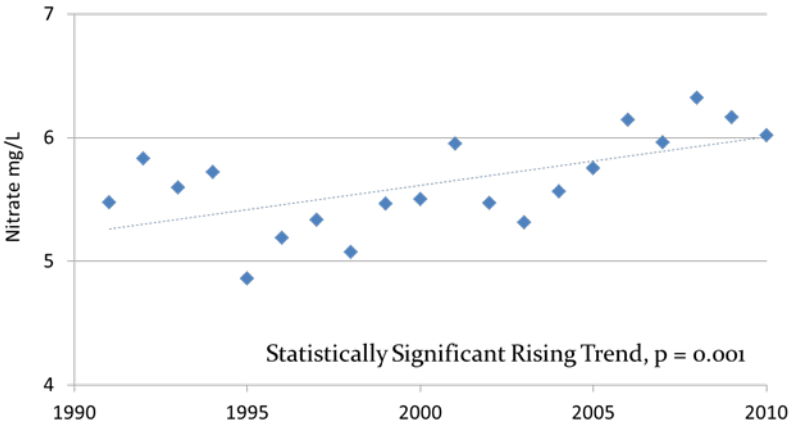

Figure 4. Lanesboro spring (DNR Fish Hatchery) average annual nitrite+nitrate-N concentrations from 1991 to 2010 (Streitz, 2012)

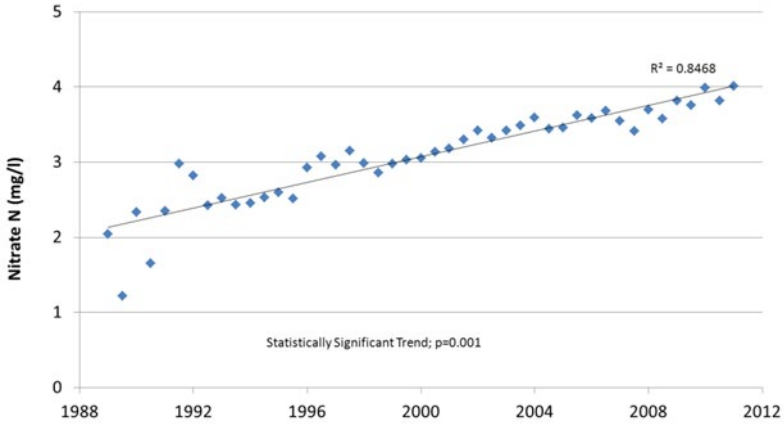

Figure 5. Peterson spring (DNR Fish Hatchery) average semi-annual nitrite+nitrate-N concentrations from 1989 to 2011 (Streitz, 2012)

Mississippi River – Winona Watershed

Nitrate concentration trends were assessed by Olmsted County Environmental Resources (2012) at six sites for periods of analysis ranging from 16 to 35 years at five sites on various branches of the Whitewater River and one site on Garvin Brook. Nitrate concentrations were not adjusted for flow; however, little relationship was found between flow and nitrate concentrations at these highly groundwater influenced streams. All six sites showed an increasing trend. The South Fork Whitewater Watershed near Utica increased from 4.2 to 11 mg/l between 1974 and 2011. The North Fork Whitewater River near Elba increased from <1 mg/l in 1967 to 6 mg/l in 2010.

Twin Cities area stream trends

The Metropolitan Council has been regularly sampling 18 stream and river sites in and around the Twin Cities Metro Area. The starting year for sampling varied between sites, ranging from 1989 to 1999. Nitrate concentration trends analyses were conducted by the Metropolitan Council from the starting year through 2010 using QWTREND (Jensen, 2013). The results provided to the MPCA showed no consistent patterns in trends. More streams showed decreases as compared to increasing trends (6 vs. 3). Four streams had no trends, and five streams had trends that were significantly increasing during certain time periods and significantly decreasing during other periods.

Summary

Nitrogen trends have varied across the state, depending on the N parameter, the location, and timeframe assessed. Ammonia+ammonium-N concentrations have consistently decreased between the mid-1970s and early 2000s, and also decreased during the shorter interval between 1984 and 1993. Improvements to both municipal wastewater treatment plants and feedlots occurred during this same time period.

Total nitrogen *concentrations* have shown few significant trends from the mid-1970s through 2005, although one study showed a few decreasing trends between 1976 and 2002. However, TN *load* trends have shown increases at some sites, with non-significant trends at other sites.

Nitrite concentrations and loads were generally increasing in the Mississippi River from the time beginning around 1976-1980 and ending 2002-2008. The St. Croix River also showed some evidence of nitrate increases. The Minnesota River showed either decreasing or non-significant nitrate concentration trends during these years at most sites, with a possible increase at Fort Snelling, as shown in one study. Nitrate *loads* in the Minnesota River at Jordan showed a slight increasing trend from 1976-2005, at the same time that nitrate concentration trends were stable or decreasing.

In the Red River, nitrate concentrations increased between 1982 and 1992, and then remained stable for the subsequent decade.

Other various rivers and stream sites sampled for nitrate showed some sites with increasing concentration trends, but several others with stable, decreasing, or mixed trends.

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