D1. Sources of Nitrogen – Results Overview

Author: Dave Wall (MPCA), incorporating results from Chapters D4 by David J. Mulla et al. (UMN), Chapter D2 by Steve Weiss (MPCA), and Chapter D3 by Dave Wall and Thomas Pearson (MPCA)

Introduction

The previous chapters focused on river monitoring results and nitrogen (N) transport within waters. In this chapter and the other chapters in Section D, we assess sources and pathways of N entering Minnesota surface waters. Section D is divided into four chapters: D1) all N source results overview, D2) wastewater point sources, D3) atmospheric deposition and D4) nonpoint sources. This chapter incorporates results from Chapters D2, D3, and D4, so that the point sources, nonpoint sources and atmospheric deposition sources can be compared together. All source estimates should be viewed as large-scale approximations of actual loadings.

In this chapter, N sources were categorized as:

1. Sources to the land
2. Sources to surface waters

The emphasis of this study was estimating N loads from specific sources to *surface waters*. Nitrogen sources to *land* are also estimated, since these sources can provide a general understanding of N potentially available for being transported to waters. A certain fraction of all N to land will enter surface waters. However, the N additions to land/soils cannot be proportionally attributed to delivery into waters, as many factors affect transport of soil N from the land into waters. These factors include: timing of the additions, form of N, climate and soils where N is introduced, potential for plant uptake and removal, potential for denitrification, along with several other variables.

Sources to the land

Statewide estimated amounts of inorganic N from primary sources added to the land and from biological processes within soils are shown below (Table 1 and Figure 1).

When considering the N additions to all soils statewide apart from mineralization, cropland commercial fertilizers account for 47% of the added N, followed by cropland legume fixation (21%), manure (16%), and wet +dry atmospheric deposition (15%). Atmospheric deposition contributes nearly the same fraction of statewide N to cropland and non-cropland soils. The combination of septic systems, lawn fertilizer, and municipal sludge account for about 1% of all N added to soils statewide.

Soil organic matter mineralization also contributes a large amount of annual inorganic N to soils, yet the precise amount is more difficult to determine than other sources. Estimates of net mineralization from Mulla et al. reported in Chapter D4 suggest that average cropland soil mineralization releases an annual amount of inorganic N that is comparable to inorganic N from fertilizer and manure additions combined. Mineralization is a complex process affected by climate, soil type and conditions, fertilization, cropping, soil tillage practices and more.

The soil N mineralization estimates were not used to calculate N transport to waters in this study. However, the N transport to waters (as discussed in the next section) accounts for differences in soil types around the state, while additionally considering fertilizer rates, precipitation, crop types, and other variables described in Chapter D4.

Table 1. Estimated annual inorganic N amounts 1) added to land (including legume N fixation), and 2) released from soil organic matter mineralization.

	Inorganic nitrogen (million pounds)	Notes and sources:
1**. Added to land**		
Commercial fertilizer to cropland	1359	From Chapter D-4 by Mulla et al. Derived from farmer surveys and GIS crop information. Average state fertilizer sales from 2005-2010 are similar (1321 million lbs), as reported by MDA.
Manure application to cropland	446	Crop available N during 1st and 2nd year after application. From Chapter D-4 by Mulla et al. Derived from MDA and MPCA data, and Midwest Plan Service and Univ. of MN N availability information.
Atmospheric deposition statewide	427	See Chapter D-3. Includes all wet and dry deposition onto all land and marshes/wetlands.
Lawn Fertilizer	12	MDA 2007 Report to the Minnesota Legislature “Effectiveness of the Minnesota Phosphorus Lawn Fertilizer Law”
Septic system drain fields	9	See Chapter D-4. Includes runoff from failing systems and leaching to groundwater from all drainfields.
Municipal sludge	2	From MPCA permit reports of acreages/crops in 2009 and 2010 cropping years, multiplied by N rates.
Cropland legume fixation	612	From Chapter D-4 by Mulla et al.
Total additions	**2867**	
2. Soil mineralization		
Cropland soil mineralization	*1728	Net mineralization from Chapter D-4 by Mulla et al. 2013
Forest soil mineralization	*830	Assumed 51 lbs/acre, based on ranges of mineralization amounts in Reich et al. (1997) and 16.3 million acres of forest.
Total mineralization	**2558**	
Total of all sources	**5425**	

*More uncertainty exists with estimates of soil mineralization N as compared to other sources to soils.

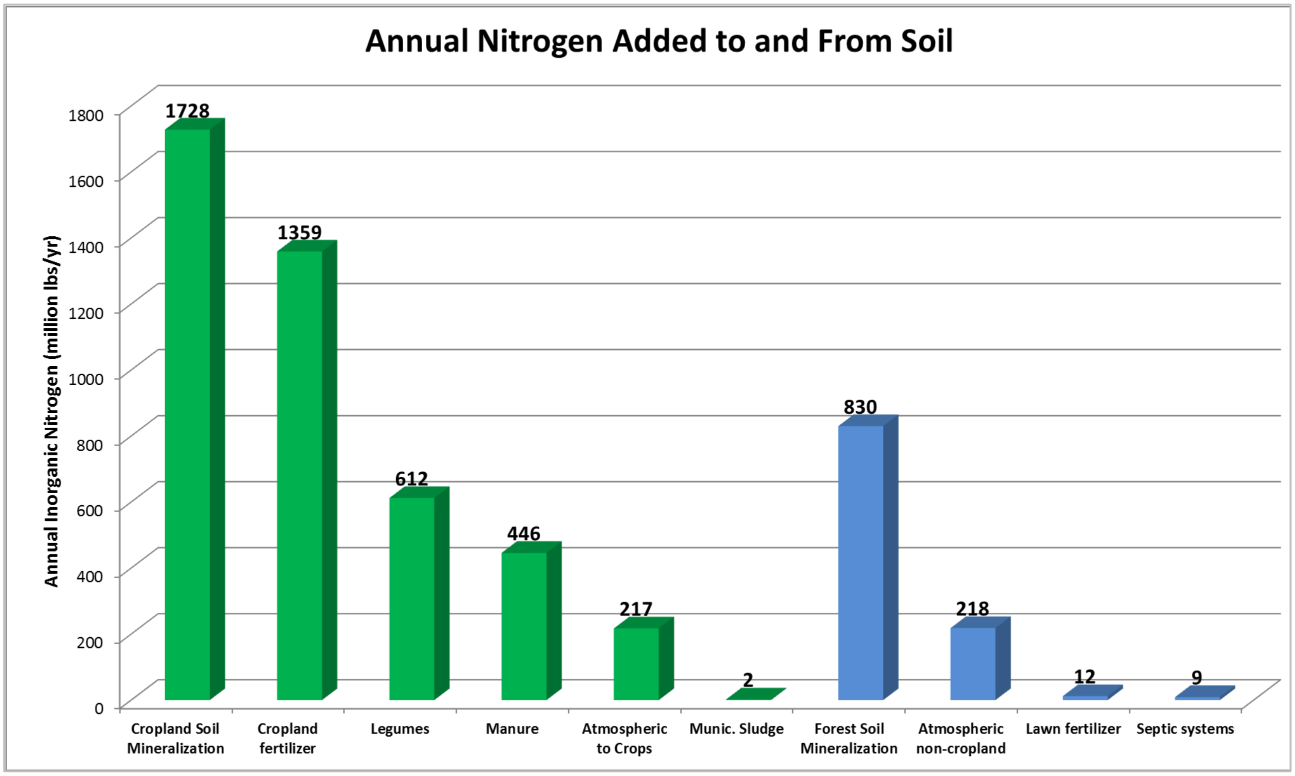

Figure 1. Estimated annual amount of inorganic N to and from cropland soils (green) and non-cropland soils (blue), in millions of pounds per year. Note: these amounts only reflect soil N and they are not proportionately delivered to surface or ground waters from each source.

Sources to surface waters: statewide

A fraction of the N added to soils reaches surface waters. Most of the soil N is either taken up by the crops or lost to the atmosphere through senescence, volatilization, or denitrification. Yet, because the N inputs and mineralization are high in many regions of the state, even a small percentage of these inputs lost to waters can cause concerns for in-state and downstream waters, as described in previous chapters.

The percentage of soil N lost to waters is expected to vary greatly from one region to another, depending on soils, climate, geology, cropping practices and other factors. In Chapter D4, Mulla et al. calculated the *statewide* fraction of cropland soil N lost to waters as a percentage of all added and mineralized N estimates. They estimated that about 6% of all cropland N additions/sources reach waters during an average precipitation year. If the N losses to surface waters are calculated as a fraction of only the added N (not including the mineralized N), then the *statewide* fraction of added cropland soil N reaching surface waters is about 8%. These estimates should not be applied at the local or regional scale, as N delivery to waters varies considerably by region.

The rest of the discussion in this chapter focuses on N source contributions to surface waters, rather than additions to soil/land. Different N source categories are used to represent contributions to *surface waters* as compared to source categories of *soil* N because: a) the pool of N sources get mixed in the soil and distinct N sources of fertilizer, manure, mineralization or atmospheric deposition to cropland were not differentiated in groundwater or tile-line drainage waters in this study , and b) some sources to waters never reach the soil but instead go directly into water (i.e. wastewater point sources and atmospheric deposition directly into lakes and streams).

The estimated annual amounts of N which reach surface waters from primary source categories are shown in Table 2 and Figure 2, and are described in more detail in chapters D2, D3, and D4 of this report. Cropland sources are estimated to contribute 72.9% of the statewide N load to streams and lakes during an average year, increasing to 78.9% during wet years when N exports to the Gulf of Mexico are highest. The cropland estimates are divided into three transport pathways: 1) surface runoff, 2) tile drainage, and 3) leaching to groundwater and subsequent travel to surface waters through groundwater baseflow. Surface runoff contributes relatively little N compared to the other pathways. Tile drainage is the largest pathway, contributing an estimated 37% of the statewide N load from all sources during an average year, and 43% during a wet year. Tile drainage contributions vary tremendously from one area of the state to another, being negligible in several basins and yet contributing about 67% of all N load in the Minnesota River Basin. Cropland leaching to groundwater and its subsequent transport to surface waters is also a major source/pathway, although it can take a long time to reach surface waters after initially entering the groundwater.

Wastewater point sources represent an estimated 9% of the N load during an average year, 6% during a wet year, and 18% of the load contribution during a dry year. Direct atmospheric deposition into lakes and streams contributes a comparable amount of statewide N load as point sources, but has a different geographic distribution compared to point sources. All forested lands together contribute an estimated 7% of the statewide N load.

Urban stormwater/groundwater, combined with septic systems and feedlot runoff contribute to less than 3% of the statewide N load to surface waters during an average precipitation year. Other sources with contributions less than an estimated 0.2% of statewide loads to surface waters are not included. An example of a very low N contributor is duck and geese excrement, which add an approximate 0.1% of the statewide N load to waters (assuming bird numbers from U.S. Fish and Wildlife Service waterfowl population reports (2012), all droppings directly enter waters, and loadings of roughly 0.4, 0.3 and 1.2 pounds N/year/bird for mallards, other ducks and geese, respectively).

Table 2. Estimated statewide annual amounts of N reaching surface waters (from chapters D2-D4). Wet years represent the 90th percentile annual precipitation years and dry years represent the 10th percentile years.

	N reaching surface waters (million pounds per year)		
	Avg. precip. year	**Wet year**	**Dry year**
1. Cropland nonpoint sources			
Leaching to groundwater*	93.3*	137.6*	49.2*
Tile drainage	113.9	199.6	31.9
Runoff from cropland	16.2	28.7	7.3
Total	223.4	365.9	88.4
	72.9%	**78.9%**	**56.5%**
2. Non-cropland nonpoint sources			
Atmospheric deposition to lakes and streams	23.8	26.2	21.4
Urban/suburban runoff and leaching**	2.8	4.3	1.4
Forests runoff/leaching	21.8	32.8	10.9
Septic system runoff/leaching	5.5	5.5	5.5
Feedlot runoff (barnyards)	0.2	0.27	0.13
Total	54.1	69.1	39.3
	17.7%	**14.9%**	**25.1%**
3. Point sources			
Municipal Point Sources	24.9	24.9	24.9
Industrial Point Sources	3.9	3.9	3.9
Total	28.8	28.8	28.8
	9.4%	**6.2%**	**18.4%**
Grand total	**306.3**	**463.8**	**156.5**
	100%	**100%**	**100%**

*This number represents the N amount which reaches surface waters from cropland ground water sources. It is substantially lower than the amount which initially reaches groundwater, since this number subtracts assumed denitrification losses which occur along the course of groundwater flow between the field and discharge into streams.

**Urban and suburban nitrogen amounts reaching waters include both stormwater and snowmelt runoff, and a relatively small amount which also leaches to groundwater and is transported to surface waters via groundwater (also accounting for denitrification losses within groundwater).

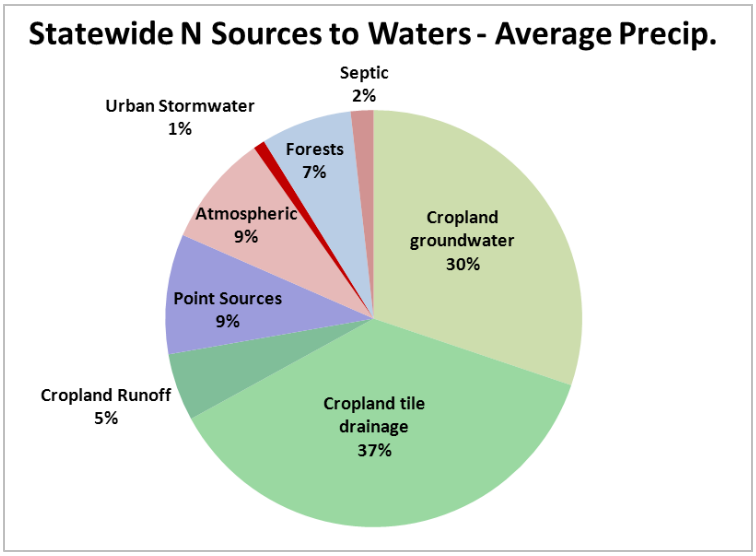

Figure 2. Estimated statewide N contributions to surface waters during an average precipitation year (rounded to the nearest percent).

Annual precipitation has a pronounced effect on N loads. During a wet year, overall estimated loads increase by 51%, as compared to an average year. During a dry year, N loads drop by 49% from average year loads. The effects of precipitation are even greater in certain basins, such as the Minnesota River Basin. In the Minnesota River Basin, wet years have 70% more N load, and dry years have 65% less N load, as compared to average years.

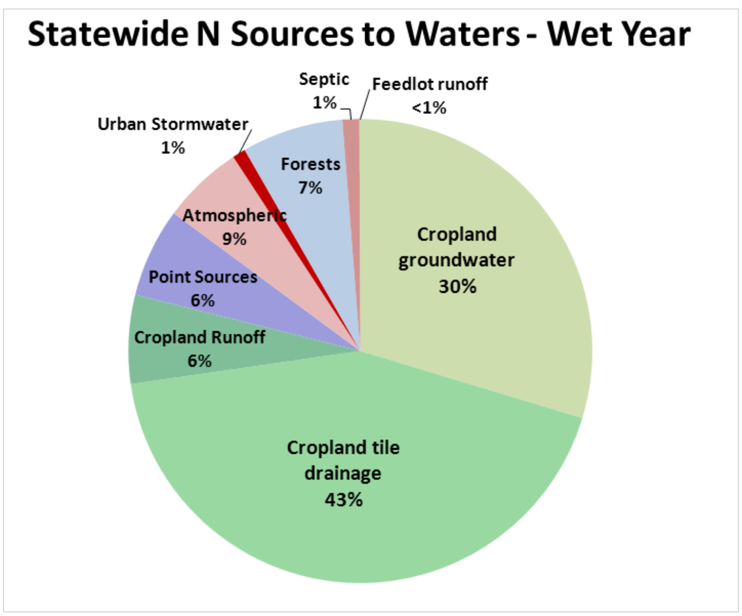

Figure 3. Estimated statewide N contributions to surface waters during a wet year.

High precipitation periods are of particular interest, since higher precipitation increases the N load transport to downstream waters such as the Gulf of Mexico. In addition to overall increasing loads, climate influences the relative source contributions from different sources and pathways. During wet years (Figure 3), the cropland sources increase to 79% of the estimated N loads to waters statewide.

Agricultural drainage increases to 43% of the loads to surface waters during wet years, cropland runoff increases to 6%, and cropland groundwater remains at 30%. The absolute loading of wastewater point source contributions remain unchanged during wet and dry years, but their relative contribution changes as the overall total annual load from all sources increases or decreases.

Sources to surface waters: by major basins

Nitrogen source contributions vary considerably from one major basin to another (Figures 5-17 and Tables 3-5). For example, during an average precipitation year, the estimated cropland sources (cropland groundwater, cropland tile drainage and cropland runoff) contribute between 89% and 95% of the load in several basins, including the Minnesota parts of the Minnesota River, Missouri River, Cedar River, and Lower Mississippi River Basins. Cropland contributes a much lower percentage of N to waters (49%) in the Upper Mississippi River Basin, and even less in the Red River (see Figure 4 for major basin locations). Point source contributions range from 1% to 30% across the different basins, generally representing a higher fraction of the load where cropland sources are relatively low and where major metropolitan areas are found (i.e. Twin Cities are largely in the Upper Minnesota River Basin). In the lower N yielding basins dominated by forests and lakes, such as in the Rainy River and Lake Superior Basins, forest and atmospheric sources contribute a higher fraction of the N.

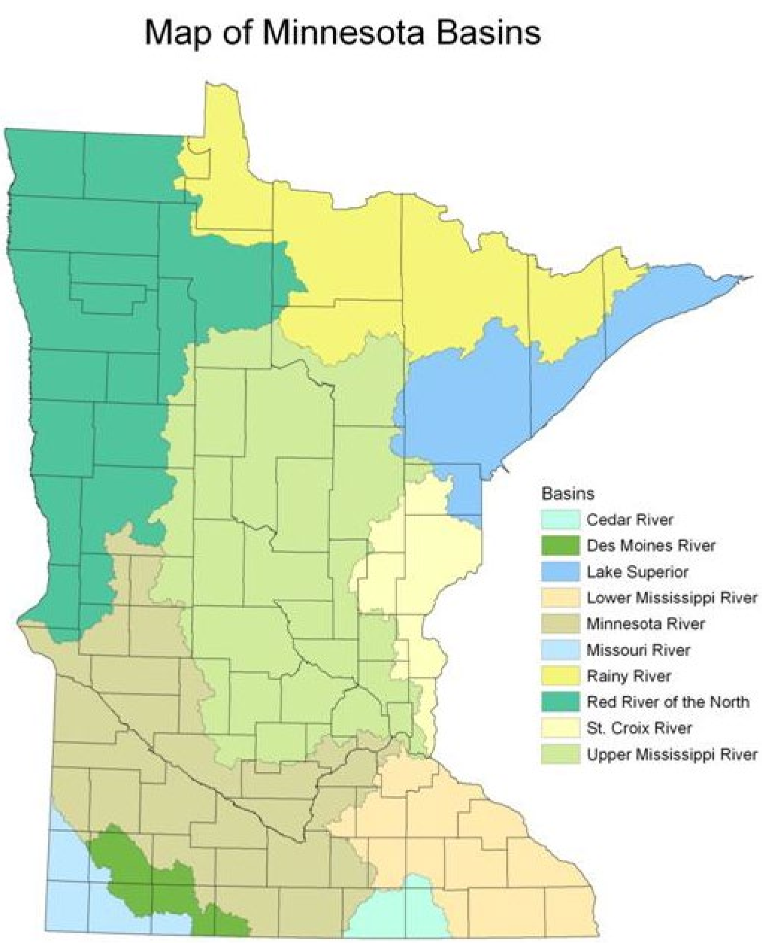

Figure 4. Location of major river basins in Minnesota.

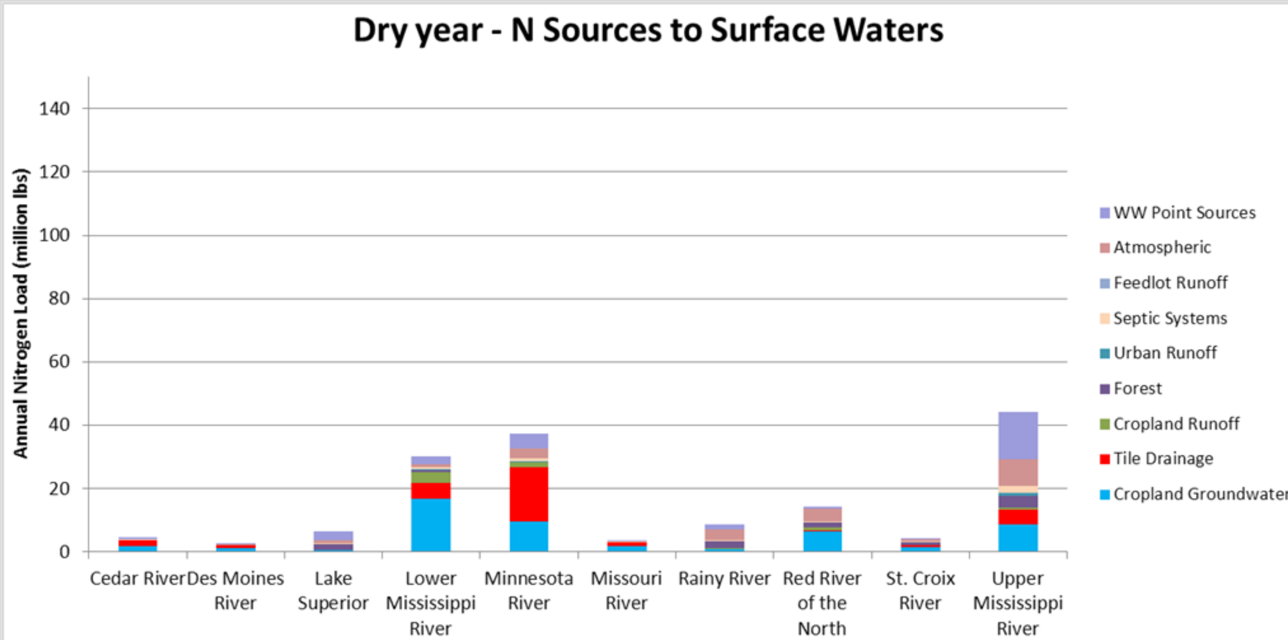

Figure 5. Estimated N loads to surface waters from different sources within the Minnesota portions of major basins during a dry year (10th percentile precipitation year).

Table 3. Estimated N loads to surface waters from different sources within the Minnesota portions of major basins during a dry year (10th percentile precipitation year).

Basin	Cropland Groundwater	Cropland Drainage	Cropland Runoff	Forest	Urban NPS	Septic	Feedlot	Atmospheric	Point Sources	Total
Cedar River	1,838,932	1,870,122	94,791	10,705	19,508	87,875	5,240	125,081	635,348	**4,687,602**
Des Moines River	1,173,366	888,502	76,405	11,038	5,971	69,203	3,368	299,546	284,353	**2,811,752**
Lake Superior	448,753	115,893	126,699	1,762,240	57,197	382,620	8	818,578	2,870,456	**6,582,444**
Lower Mississippi River	16,875,018	4,744,251	3,657,868	664,031	171,895	520,672	70,456	910,326	2,643,750	**30,258,267**
Minnesota River	9,587,169	17,172,963	1,410,743	285,815	281,171	888,027	41,709	2,874,636	4,717,144	**37,259,377**
Missouri River	1,695,077	1,387,158	62,703	8,535	9,643	84,618	6,586	175,796	98,436	**3,528,552**
Rainy River	772,685	238,187	107,451	2,346,796	13,525	141,823	58	3,447,922	1,689,520	**8,757,967**
Red River of the North	6,593,744	169,422	1,044,099	1,357,406	63,190	479,149	8,638	3,873,237	617,872	**14,206,757**
St. Croix River	1,396,201	732,743	60,944	764,478	53,368	434,357	766	499,943	441,629	**4,384,429**
Upper Mississippi River	8,795,966	4,555,276	705,877	3,711,788	744,258	2,392,008	48,354	8,420,932	14,817,420	**44,191,879**
Grand Total	**49,176,911**	**31,874,517**	**7,347,580**	**10,922,832**	**1,419,726**	**5,480,352**	**185,183**	**21,445,997**	**28,815,928**	**156,669,026**

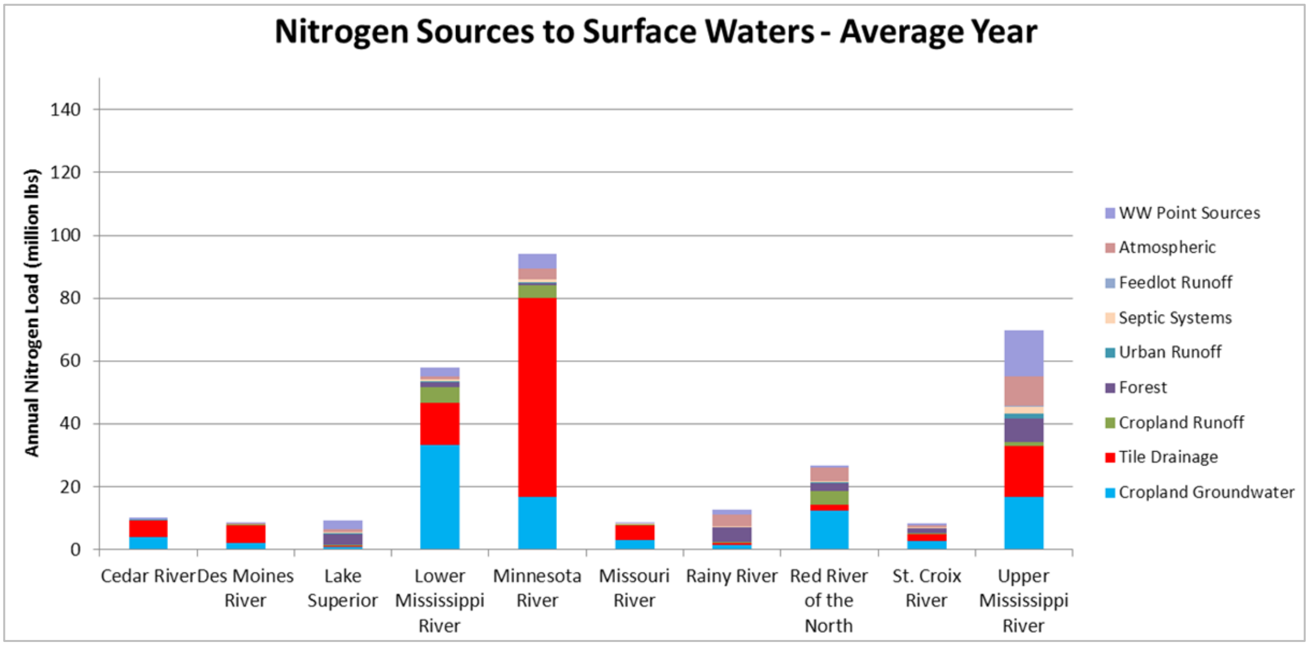

Figure 6. Estimated N loads to surface waters from different sources within the Minnesota portions of major basins during an average precipitation year.

Table 4. Estimated N loads to surface waters from different sources within the Minnesota portions of major basins during an average precipitation year.

Basin	Cropland Groundwater	Cropland Drainage	Cropland Runoff	Forest	Urban NPS	Septic	Feedlot	Atmospheric	Point Sources	Total
Cedar River	3,998,333	5,246,863	170,842	21,410	39,013	87,875	6,239	138,979	635,348	**10,344,902**
Des Moines River	2,034,489	5,672,975	355,036	22,076	11,943	69,203	4,009	332,829	284,353	**8,786,913**
Lake Superior	813,293	446,889	224,736	3,524,480	114,394	382,620	9	909,531	2,870,456	**9,286,408**
Lower Mississippi River	33,190,774	13,496,944	5,160,896	1,328,062	343,788	520,672	83,876	1,011,473	2,643,750	**57,780,235**
Minnesota River	16,875,469	63,106,270	4,034,140	571,629	562,341	888,027	49,653	3,194,040	4,717,144	**93,998,713**
Missouri River	3,095,517	4,642,270	358,054	17,068	19,285	84,618	7,840	195,329	98,436	**8,518,417**
Rainy River	1,379,430	876,724	191,282	4,693,593	27,053	141,823	69	3,831,024	1,689,520	**12,830,518**
Red River	12,427,316	1,945,435	4,156,273	2,714,812	126,383	479,149	10,285	4,303,597	617,872	**26,781,122**
St. Croix River	2,734,879	2,340,243	112,083	1,528,955	106,737	434,357	912	555,492	441,629	**8,255,287**
Upper Mississippi River	16,717,357	16,145,270	1,415,241	7,423,577	1,488,515	2,392,008	57,563	9,356,591	14,817,420	**69,813,542**
Grand Total	**93,266,857**	**113,919,883**	**16,178,583**	**21,845,662**	**2,839,452**	**5,480,352**	**220,455**	**23,828,885**	**28,815,928**	**306,396,057**

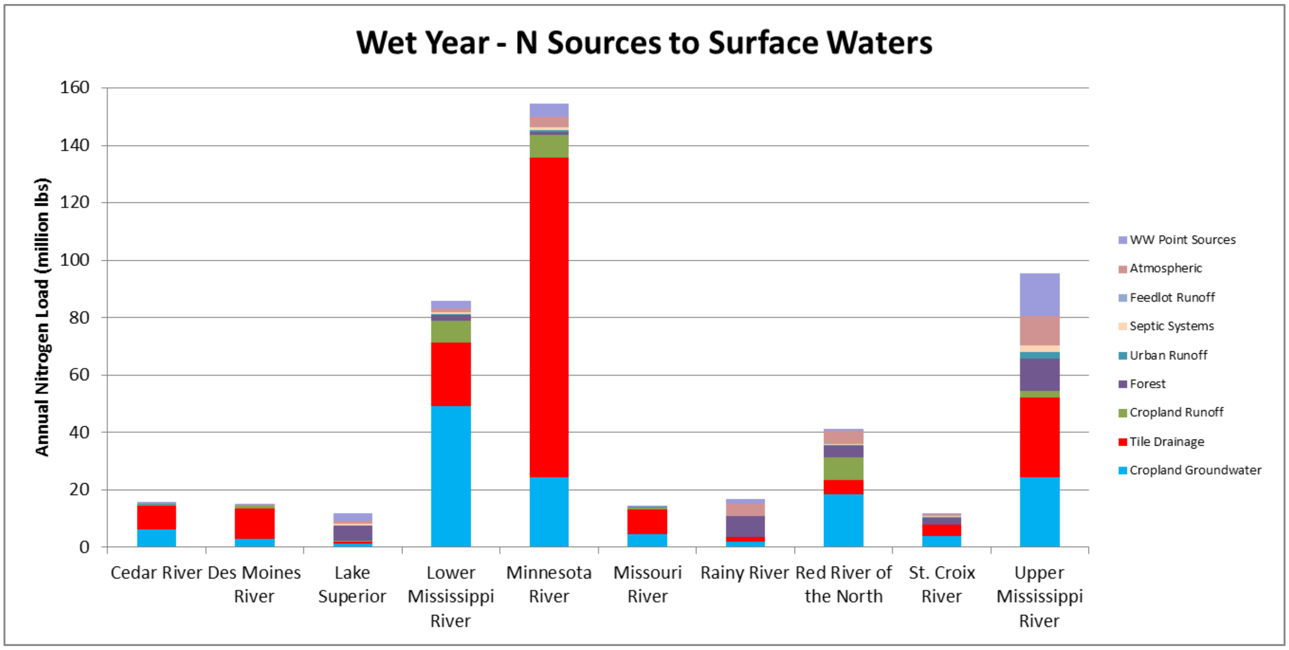

Figure 7. Estimated N loads to surface waters from different sources within the Minnesota portions of major basins during a wet year (90th percentile precipitation year).

Table 5. Estimated N loads to surface waters from different sources within the Minnesota portions of major basins during a wet year (90th percentile precipitation year).

Basin	Cropland Groundwater	Cropland Drainage	Cropland Runoff	Forest	Urban NPS	Septic	Feedlot	Atmospheric	Point Sources	Total
Cedar River	6,123,057	8,535,764	295,660	32,116	58,521	87,875	7,611	152,877	635,348	**15,928,829**
Des Moines River	2,896,958	10,657,787	828,794	33,115	17,914	69,203	4,892	366,112	284,353	**15,159,128**
Lake Superior	1,180,848	769,625	329,261	5,286,720	171,591	382,620	12	1,000,484	2,870,456	**11,991,617**
Lower Mississippi River	49,356,821	21,943,782	7,559,105	1,992,091	515,683	520,672	102,330	1,112,620	2,643,750	**85,746,854**
Minnesota River	24,393,974	111,213,311	8,199,383	857,443	843,513	888,027	60,576	3,513,444	4,717,144	**154,686,815**
Missouri River	4,497,544	8,621,258	872,115	25,604	28,928	84,618	9,565	214,862	98,436	**14,452,930**
Rainy River	1,987,456	1,496,321	282,240	7,040,390	40,580	141,823	85	4,214,126	1,689,520	**16,892,541**
Red River of the North	18,553,349	4,907,556	7,829,840	4,072,215	189,569	479,149	12,547	4,733,957	617,872	**41,396,054**
St. Croix River	4,048,735	3,787,514	168,774	2,293,431	160,106	434,357	1,112	611,041	441,629	**11,946,699**
Upper Mississippi River	24,544,775	27,685,025	2,305,990	11,135,361	2,232,772	2,392,008	70,230	10,292,250	14,817,420	**95,475,831**
Grand Total	**137,583,517**	**199,617,943**	**28,671,162**	**32,768,486**	**4,259,177**	**5,480,352**	**268,960**	**26,211,774**	**28,815,928**	**463,677,299**

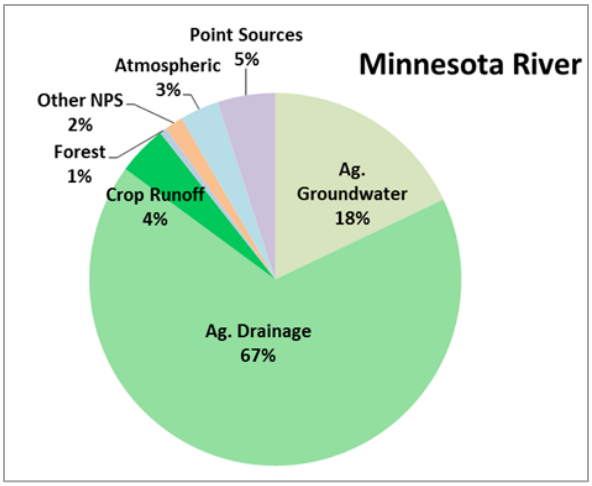

Figure 8. Estimated N sources to surface waters from the Minnesota contributing areas of the Minnesota River Basin (average precipitation year).

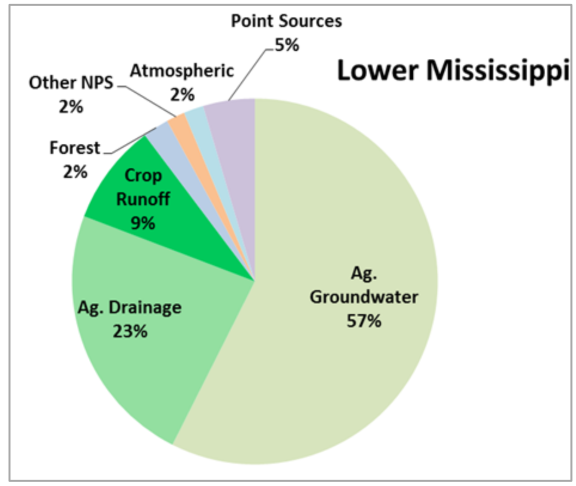

Figure 9. Estimated nitrogen sources to surface waters from the Minnesota contributing areas of the Lower Mississippi River Basin (average precipitation year).

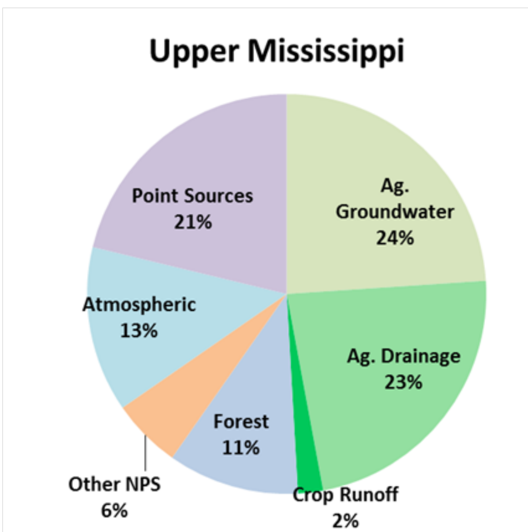

Figure 10. Estimated N sources to surface waters from the Upper Mississippi River Basin (average precipitation year).

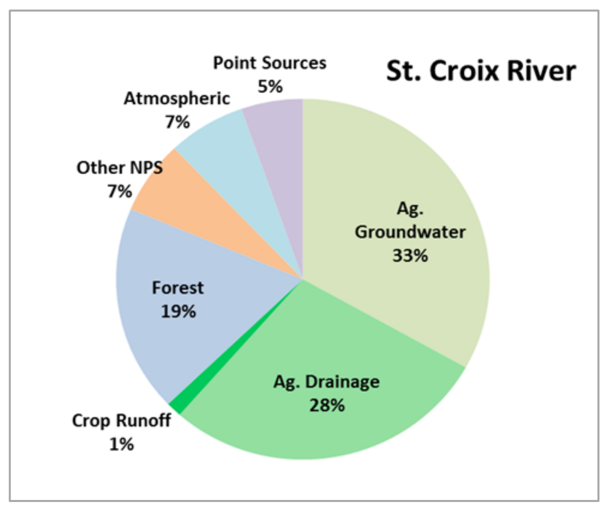

Figure 11. Estimated N sources to surface waters from the Minnesota contributing areas of the St. Croix River Basin (average precipitation year).

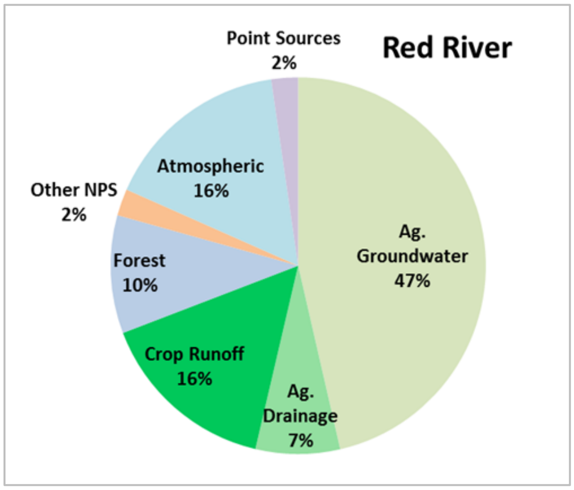

Figure 12. Estimated N sources to surface waters from the Minnesota contributing areas of the Red River Basin (average precipitation year).

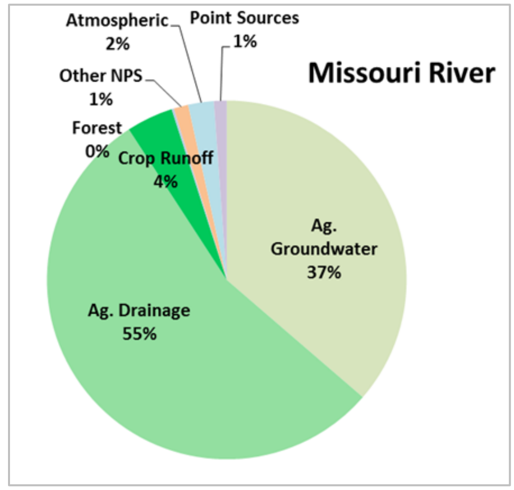

Figure 13. Estimated N sources to surface waters from the Minnesota contributing areas of the Missouri River Basin (average precipitation year).

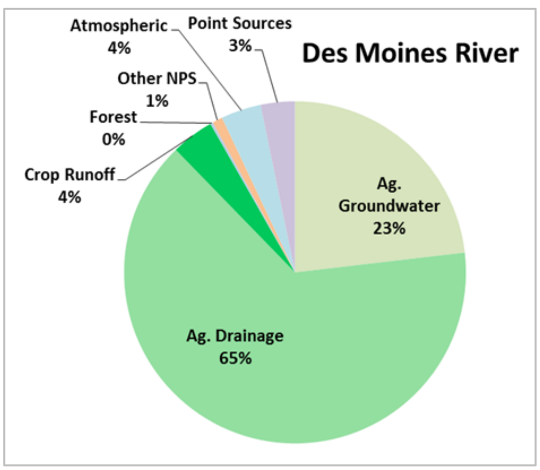

Figure 14. Estimated N sources to surface waters from the Minnesota contributing areas of the Des Moines River Basin (average precipitation year).

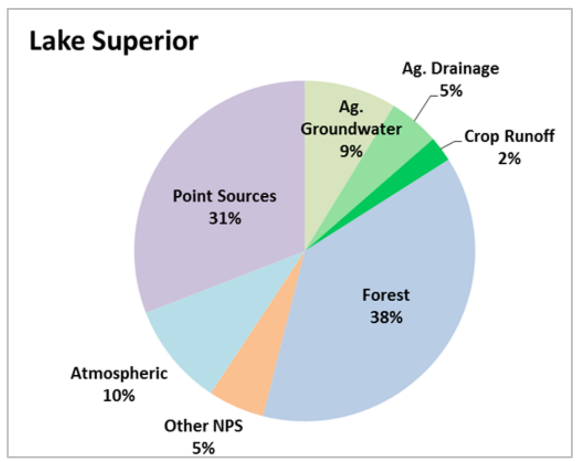

Figure 15. Estimated N sources to surface waters from the Minnesota contributing areas of the Lake Superior Basin (average precipitation year).

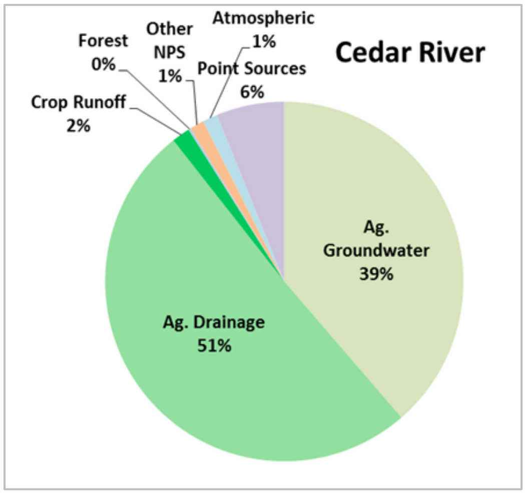

Figure 16. Estimated N sources to surface waters from the Minnesota contributing areas of the Minnesota River Basin (average precipitation year).

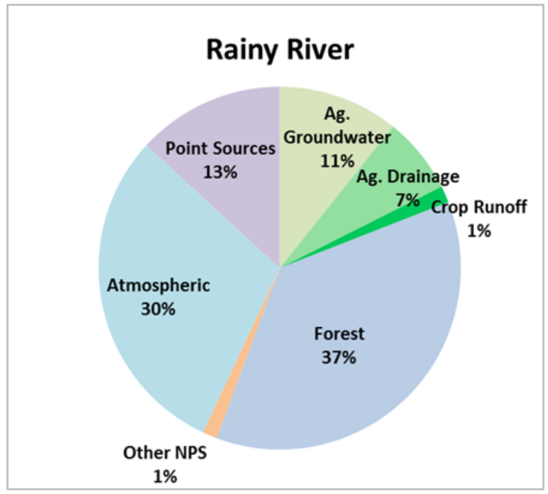

Figure 17. Estimated N sources to surface waters from the Minnesota contributing areas of the Rainy River Basin (average precipitation year).

Contributions to the Mississippi River

Because of the goal to reduce N loads going to the Gulf of Mexico in the Mississippi River, we also assessed the loads going just to the Mississippi River. About 81% of the total N load to Minnesota waters is from basins which end up flowing into the Mississippi River (including all basins except the Lake Superior, Rainy, and Red). If we look only at those Minnesota watersheds which contribute to the Mississippi River, source contributions during an average precipitation year are estimated as follows: cropland sources 78%, point sources 9%, and non-cropland nonpoint sources 13% (Figure 18). Cropland source contributions increase to 83% for these watersheds during wet (high-flow) years, while point sources decrease to 6% during wet years. During a dry year, cropland sources represent an estimated 62% of N to waters headed toward the Mississippi River and point sources contribute 19%.

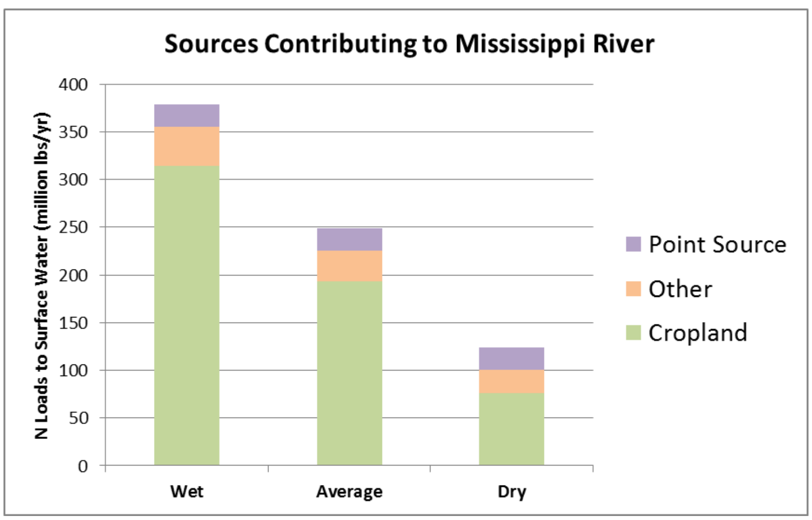

Figure 18. Sum of N source contributions in watersheds which eventually reach the Mississippi River. The "other" category includes septic systems, atmospheric deposition directly into waters, feedlots, forested land and urban/suburban nonpoint source N.

Source contributions to waters on a per-acre basis

Some sources contribute elevated N to waters on a per acre basis, but they do not represent enough cumulative acres to create an environmental threat at the statewide or regional level. Thus, sources that are relatively minor at the state-level scale can sometimes still contribute significantly to N loads at the local-level.

One way of comparing contributions from different land uses and understanding the potential for affecting local water bodies is to consider the yield, represented in pounds per acre per year delivered to surface waters. Yields from source categories are shown in Table 6 and Figure 18, for average precipitation conditions. The estimates are presented as a range, showing both the lower and higher ends of estimated yields for each source category.

Note that the yield within a single field can be larger than the yield ranges in Table 6 and Figure 18, which are based on averages across larger areas, such as subwatersheds, agroecoregions, and other monitored areas. Also, it is important to note that some source contributions to waters are not dispersed throughout the land, but enter waters at specific locations. For example, wastewater point sources from an urban area enter waters at specific points, and can therefore have a more noticeable impact in the immediate area of discharge as compared to more dispersed sources spread out over the same size area. Even though the overall loads and yields can be the same, the point source nature of discharges can affect localized water resources in different ways than more dispersed nonpoint source discharges.

The yield ranges show that N is relatively low on a per-acre basis from the following source categories: forests, urban stormwater, atmospheric deposition, and mixed crops in less geologically sensitive non-tiled regions. Row crops in sensitive areas (tile-drained, sandy, karst) have the highest yields. Point sources are a relatively small N source statewide compared to cropland sources, yet they can potentially impact localized stretches of rivers. High densities of septic systems in geologically sensitive areas can also potentially contribute moderately high N yields to surface waters, yet most areas with septic systems have yields to surface waters comparable to the lower yielding sources.

Table 6. Total nitrogen yields from various N source categories (average precipitation conditions). The estimates are presented as a range, showing both the lower and higher-end estimated yields for each source category.

Source category	Low-end lbs/ac/yr	High-end lbs/ac/yr	Assumptions and sources for yields
Row crops in sensitive areas (i.e. tiled, sandy soils, or karst regions)	20	37	Average precip cropland losses to waters based on Mulla et al. (2013) analyses presented in Chapter D4 for the following Agro-ecoregions: Rochester Plateau 37; Anoka Sand Plain 35; Level plains 33; Blufflands 20.
Mostly row crops in less sensitive areas	15	23	Average precip cropland losses to waters based on Mulla et al. (2013) analyses presented in Chapter D4 for the following Agro-ecoregions: Undulating Plains 23; Wetter clays and silts 19; Rolling moraine 15.4.
Mixed crops in less sensitive areas	5	10	Average precip cropland losses to waters based on Mulla et al. (2013) analyses presented in Chapter D4 for the following Agro-ecoregions: Cotoeu and Inner Coteau 9; Central Till 8; Steep Dryer Moraine 7; Drumlins 6
Municipal and Industrial Point Sources	8	20	From Point Source Chapter D2 by Weiss (2013). The lower density development in the Blue Lake wastewater treatment sewershed had an average of 7.8 lbs/acre/yr from both municipal and industrial wastewater, and the higher density development within the Metro sewershed had 19.7 lbs/acre/yr. Note: this N is not released in a diffuse manner – so the immediate impact to waters will be most noticeable near the points of discharge.
Urban/suburban stormwater + groundwater	2	10	Metropolitan Council monitoring of Bassett Creek and Battle Creek yielded approx. 2.5 lbs/acre/yr (from data provided by Karen Jensen); Hennepin County Three Rivers Park monitoring of subwatersheds showed industrial areas averaging 3.7 lbs/acre/yr; residential 1.9; mixed 3.9 (from data provided by Brian Vlach); Minneapolis Park Board average watershed yields in 2002-04 was 5.6 lbs/acre/yr and in different Mpls. watersheds averaged 9.7 lbs/acre/yr between 2005-2010 (data provided by Mike Perniel). All literature review results as referenced in chapter D-4 fall within these ranges, mostly averaging between 2.5 and 6 lbs/acre/yr.
Septic Systems	4	17	Low end assumes 4 person households, 7 lbs per person per year, on 3.5 acre lots, and half of N lost in groundwater through denitrification. High end assumes 4.5 person households, 8 lbs per person, on 1.5 acre lots, and 30% N lost in groundwater through denitrification.
Atmospheric	4	14	Wet plus dry deposition as shown in Chapter D-3 by Wall and Pearson (2013). Low end are estimated loads from northeastern Minnesota watershed spatial averages and High end estimates are from southeastern Minnesota watershed spatial avgs.
Forest	0.4	5	See Chapter D4. Wisconsin forested watersheds yielded 3.1 and 3.6 lbs/acre (from Clesceri, et al. (1986). USGS report showed forested watershed N yields of 0.41 lbs/acre in Namekogen and 0.25 lbs/acre in the St. Croix River (Graczyk, 1986).

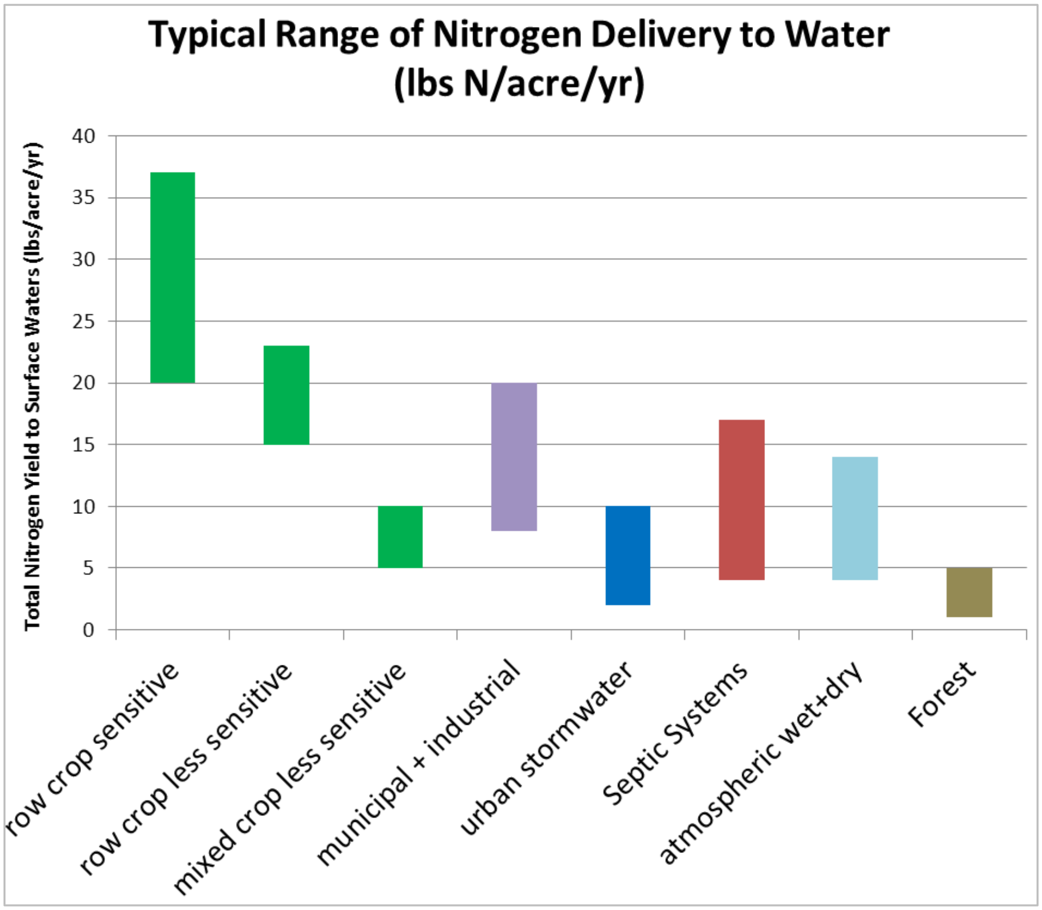

Figure 19. Graphical depiction of the source yield ranges from Table 6. Average precipitation year.

Flow pathways from all sources combined

The dominant N flow pathways between all sources and receiving surface waters vary from basin to basin and sometimes with climate. Four categories of flow pathways were estimated based on the following categorizations and assumptions:

Groundwater: The groundwater flow pathway was calculated from the source assessment information by adding 100% of the cropland groundwater that reaches surface waters, 80% of septic system N reaching surface waters, 20% of the urban/suburban nonpoint N, and 50% of forest N.

Surface runoff: The surface runoff flow pathway was calculated from the source assessment information by adding 100% of the cropland surface runoff, 20% of the septic system N reaching surface waters (direct pipe losses), 80% of the urban/suburban nonpoint N, 50% of forest N, and 100% of feedlot runoff N.

Tile line drainage: The tile drainage includes all cropland tile line drainage N.

Direct Discharge: The direct discharge pathway was calculated by adding 100% of point source discharge N and 100% of direct wet+dry atmospheric deposition into lakes and streams.

The estimated statewide N load from each N transport pathway to surface waters for average and high precipitation periods are depicted in Figures 20 and 21. Tile line and groundwater are the two dominant

N pathways to surface waters statewide. The influence of tile lines increases from 37% of the load to surface waters during and average precipitation year to 43% of the N load to surface waters during the highest loading years (wet years). The groundwater pathway is the second largest pathway in both average and wet years, representing just over one-third of the load.

The fraction of forest N delivered to surface waters via surface runoff and groundwater flow pathways was not found in the literature, and the above results assume that half is transported in surface runoff and the other half through groundwater. Because forestland only contributes an estimated 7% of the statewide N load, errors in pathway assumptions for forestland will not have an appreciable effect on the statewide pathway characterization in Figures 20 and 21.

While all the sources/pathways represent annual estimated N loads, the arrival time to surface waters varies considerably depending on the travel pathway. Much of the N from the groundwater pathway will take many years to reach surface waters. Other pathways have much shorter travel time to waters. Therefore, in areas where groundwater is an important pathway, the N concentrations in surface waters may not completely represent modern land uses and management. The N source assessment in this study attempted to account for estimated denitrification losses within the groundwater flow pathway, but did not address the time lag for groundwater flow. In other words, while the source assessment is the best estimate of source contributions to surface waters, the point in time when these sources actually reach surface waters will vary from source to source and from basin to basin, depending on how much of the N load is coming from groundwater sources and the rate at which groundwater flows.

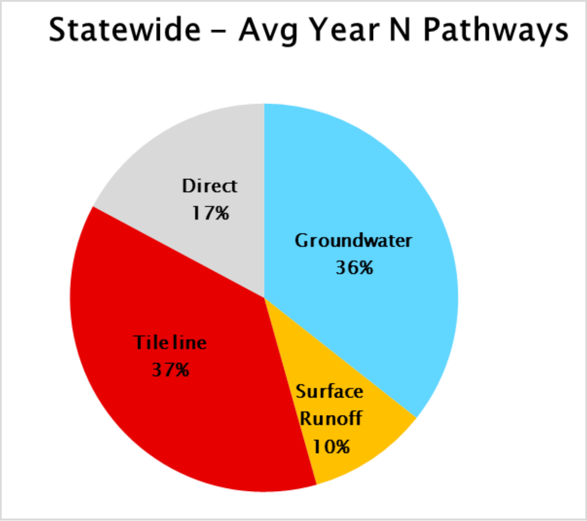

Figure 20. Statewide N pathways to surface waters during an average precipitation year, as estimated by UMN/MPCA. Direct includes both point sources and atmospheric deposition into waters.

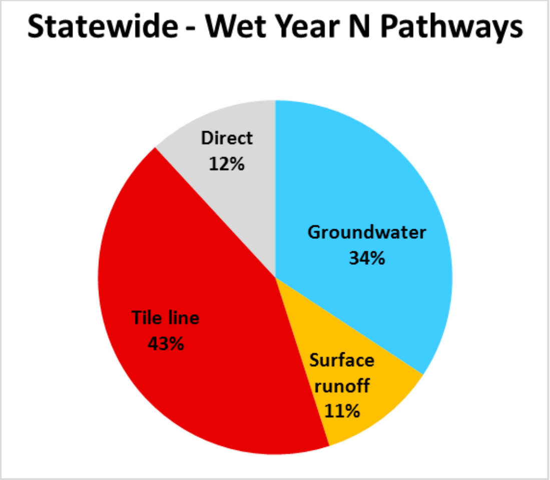

Figure 21. Statewide N pathways to surface waters during a wet year, as estimated from UMN/MPCA.

Nitrogen pathways vary by basin (Figure 22). Groundwater is a dominant pathway in the Lower Mississippi, Upper Mississippi, and St. Croix River Basins; whereas tile line flow is the dominant pathway in the Minnesota River Basin.

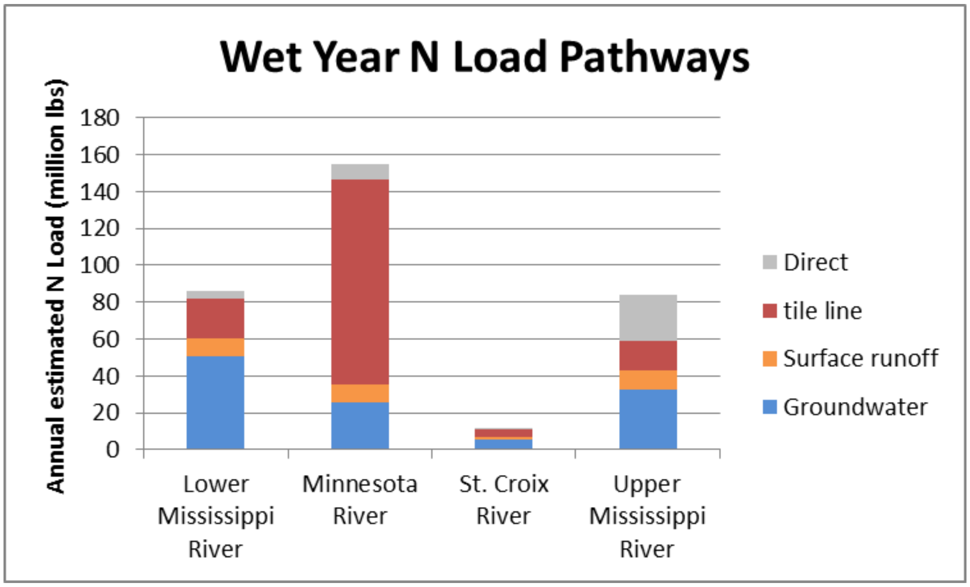

Figure 22. Basin N pathways to surface waters during a wet year for each of the four largest basins which drain into the Mississippi River system. Results are only for Minnesota land within the basins.

Uncertainty

The source contributions *to surface waters* conducted by the University of Minnesota and MPCA (UMN/MPCA) as described in Chapters D1 to D4 have areas of uncertainty. One particular area of uncertainty is the cropland groundwater component due to: a) limited studies quantifying leaching losses under different soils, climate and management, and b) high variability in denitrification losses which can occur as groundwater slowly flows toward rivers and streams.

Because of source assessment uncertainties, we compared the source assessment results with other related findings, using five different methods. These verification methods, as reported in Chapters E1 to E3, showed results which generally support the source assessment findings. However, all sources should be treated as large-scale approximations of actual loadings, and each source estimate could be refined with additional research.

Summary

Soil N comes from a variety of sources. Of the added sources, cropland fertilizer represents the largest source. Manure, legumes, and atmospheric deposition are also significant sources, and when added together provide similar N amounts as the fertilizer additions. Soil organic matter mineralization releases large quantities N annually, which were estimated to contribute about the same amount of N as cropland fertilizers and manure combined. Septic systems, lawn fertilizers and municipal sludge add comparatively small amounts of N to soils statewide (less than 1% of added N).

Cropland agricultural sources contribute an estimated 73% of the N load to Minnesota surface waters during a normal precipitation year, with the rest contributed mostly by wastewater point sources, atmospheric deposition and forestland. Feedlot runoff, urban stormwater and septic systems combined contribute less than 3% of the N load to surface waters. The sources and loads vary considerably from one major river basin to another.

The dominant pathway to surface waters is through the subsurface, with about 73% of the N load from all sources entering surface waters on an average year through groundwater pathways combined with cropland tile drainage. Surface runoff from all sources combined contributes a relatively small amount (10%) of the N loading to surface waters, and direct deposits into waters (point source discharges and atmospheric deposition) represent 17% of N to surface waters during an average year. During the highest loading years (wet weather), the tile drainage pathway contributions increase to 43% of the estimated N load, and all cropland pathways combined contribute an estimated 79% of the N load.

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