Minnesota Pollution Control Agency

Minnesota Nutrient Reduction Strategy Support

Assessment of Nutrient Source Contributions to Major River Basin Loads

December 20, 2024

Appendix 2-3 of Minnesota's 2025 NRS

TETRA TECH

wq-s1-87g

EXECUTIVE SUMMARY

In 2014, Minnesota adopted a statewide Nutrient Reduction Strategy (NRS) as a large-scale planning framework for reducing phosphorus and nitrogen in Minnesota's waterways and the loading that Minnesota waters contribute to downstream waterways. The Minnesota Pollution Control Agency (MPCA) is now working on an update to the 2014 NRS that will be published as Minnesota's 2025 NRS. To this end, MPCA has sought technical support from Tetra Tech, which provided such support to MPCA for Minnesota's 2014 NRS.

To support the development of Minnesota's 2025 NRS, MPCA contracted with Tetra Tech to:

- **#1**: Assess major river basin and state-line loads and determine the remaining nutrient load reduction needs to meet downstream goals
- **#2**: Estimate source contributions to the river nutrient loads
- **#3**: Evaluate watershed nutrient load reduction needs to achieve downstream goals

To achieve these broad objectives, MPCA has also defined specific tasks and subtasks.

This report summarizes the results of the second objective. Generally, this report presents assessments of nitrogen and phosphorus sources at the scale of major basins, including evaluation of multiple estimations of point source loads.

Point Sources

MPCA and the U.S. Geological Survey (USGS) have estimated total nitrogen (TN) and total phosphorus (TP) loads from permitted point sources. Over many years, MPCA and its contractors have estimated point source loads during the development of Hydrologic Simulation Program – FORTRAN (HSPF) watershed models for most of the watersheds across Minnesota. Recently, MPCA (2023) estimated TN and TP point source loads for all of the individual subbasins (i.e., a hydrologic unit defined by an eight-digit code [HUC8]) in Minnesota and MPCA (2024) estimated loads by major basin (Mississippi River, Lake Winnipeg, and Lake Superior). Finally, USGS (2019a,b) estimated TN and TP point source loads during the development of the SPAtially-Referenced Regression On Watershed attributes (SPARROW) model.

Three point sources datasets were compared: (1) MPCA (2023) estimated loads for individual subbasins that were summed to major basins, (2) MPCA (2023) estimated loads for major basins, and (3) loads estimated for HSPF or SPARROW model development (loads estimated for SPARROW model development were only used for watersheds where MPCA has not developed an HSPF model).

Generally, MPCA (2023, 2024) point source load estimates for individual subbasins and major basins are similar but these two datasets are considerably different than point source loads estimated for HSPF and SPARROW model development. The differences between datasets are due to the use of different averaging periods, model assumptions, and estimation techniques.

At the major basin scale, MPCA believes its point source loads estimated at the major basin scale (MPCA 2024) provides the best data for this source assessment. This dataset, updated dynamically with the latest available monitoring data and annual corrections, provides the most reliable representation of current nutrient loading conditions. When point source load estimates are needed for analyses at a finer scale, MPCA accepts the use of its point source loads estimated for individual HUC8 subbasins (MPCA 2023). Finally, MPCA considers the HSPF models' point source loads to be the least accurate for the 2020s, because these data reflect conditions at the time of model development; many models are over a decade old and may not represent recent conditions.

Local Nutrient Loads by Major Basin

Cropland is the largest contributor to nutrient loading in the *Mississippi River* (79% TN; 72% TP) and *Lake Winnipeg* (48% TN; 63% TP) major basins (Table 1), while forest/wetland is the largest contributor in the *Lake Superior* major basin (69% TN; 62% TP). Forest/wetland is the second largest contributor in the *Lake Winnipeg* major basin. Permitted wastewater is the second largest contributor of TN (18%) in the *Lake Superior* major basin. Across the major basins, atmospheric deposition (2% to 7%) and developed (urban, roads; 4% to 7%) contribute much smaller TP and TN loads than agriculture and forest/wetland.

Table 1. Simulated average annual loads by sources category and major basin

Major basin	Mississippi River		Lake Winnipeg		Lake Superior	
Source Category	**TN**	**TP**	**TN**	**TP**	**TN**	**TP**
Agriculture [a]	79%	72%	48%	63%	3%	4%
Atmospheric Deposition	3%	2%	7%	4%	2%	2%
Developed [a]	4%	7%	5%	6%	4%	4%
Forest/Wetland [a]	4%	5%	30%	20%	69%	62%
NPDES Permitted Wastewater Discharge [b]	8%	6%	5%	3%	18%	10%
Various [a]	3%	9%	8%	4%	4%	18%

Notes
Average annual loads (pounds per year) are from the HSPF or SPARROW model, except when noted otherwise. Percentages are rounded to the nearest integer and do not sum exactly to 100% due to rounding with the individual source categories.
a. Refer to Appendix A for the sources included in the aggregated source categories.
b. MPCA (2023) estimated point sources loads, originally reported by HUC8.

Several of these results vary considerably from associated source categories resented in the 2014 NRS (MPCA 2014). Directly comparing the source assessment from the 2014 NRS to this new source assessment is problematic because the individual source loads were estimated using different methods and assumptions. Thus, the differences between source loads and percentages between source assessments are likely mostly due to the differences in methods and assumptions for estimating source loads. Real-world changes in sources may also be reflected in differences between source percentages (i.e., point source phosphorus reductions), but the real-world changes are likely significantly smaller than the changes due to differences in methods and assumptions.

The differences between MPCA (2023, 2024) point source load estimates are small in the *Mississippi River* (<1% TN; 5% TP) and *Lake Winnipeg* (7% TN; 10% TP) major basins. Since the MPCA (2023, 2024) estimates are very similar, the summation of TN and TP loads across all sources is very similar, and thus, the relative distribution of loads among sources is the same. However, the differences between MPCA (2023, 2024) point source load estimates for the *Lake Superior* major basin are large (36% to 56% TN; 29% to 42% TP). While the MPCA (2023, 2024) estimates are considerably different, the summation of TN and TP loads across all sources in the *Lake Superior* major basin are similar because a majority of the loads is from forest/wetland. Due to the differences in point source load estimates, the relative distribution of loads among sources is different in the *Lake Superior* major basin.

Local Nutrient Loads by Flow Pathway in the Minnesota River and Red River of the North Basins

Detailed source assessments by flow delivery pathway were developed for select basins with available pathway modeling results, including the Minnesota River Basin (MRB) and the Red River of the North Basin (RRNB). All contributing HUC8 subbasins within these two basins have calibrated HSPF watershed models, and as such, several different source categories were evaluated comprehensively flow delivery pathway (surface flow, interflow, and groundwater flow).

The source assessment by flow delivery pathway exclude non-land-based sources that are not simulated via flow pathway in the HSPF model: atmospheric deposition, bed/bank erosion (net gain) point sources, and septic systems.

Agriculture is the largest source of TN and TP in the MRB. Agriculture is also the largest source of loads simulated as surface flow (83% TN; 85% TP), interflow (96% TN; 93% TP), and groundwater flow (92% TN; 93% TP); non-land-based sources are excluded from these calculations. Developed (i.e., urban and roads runoff and infiltration) (4% TN; 13%TP) is the second largest contributors of load. High TN and TP loads from aggregated agriculture (i.e., cropland, agricultural tile drainage, and feedlots) were simulated in interflow and groundwater flow pathways in subbasins with high levels of tiled corn-soybean production, which predominates in the subbasins in the southeast half of the MRB.

Similar to the MRB, cropland is the largest source of TN and TP in the RRNB. Cropland is also the largest source of load simulated in the surface flow (85% TN; 91% TP), interflow (85% TN; 90% TP), and groundwater flow (67% TN; 75% TP) pathways; non-land-based sources are excluded from these calculations. Developed runoff (5%) is the second highest contributor of TN and TP load in the RRNB. Evaluation of aggregated agricultural (i.e., cropland runoff, agricultural tile drainage, and feedlots) source loads was challenging because the Red River of the North is the boundary between the states of Minnesota, North Dakota, and South Dakota, and the HSPF models presented herein are limited to the Minnesota-portions of the subbasins. Generally, the largest TN loads per subbasin are simulated in interflow and groundwater flow pathways throughout the RRNB. Surface flow pathway TN loads are typically higher in the Upper RRN (HUC 090201), and surface flow pathway TN loads exceed interflow and groundwater flow pathways' TN loads in the Buffalo and Wild Rice River subbasins. Trends were not apparent with TP loads across flow delivery pathways.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ACRONYMNS AND ABBREVIATIONS

Acronym or abbreviation	Definition
HSPF	Hydrologic Simulation Program - FORTRAN
HUC	hydrologic unit code
MnDNR	Minnesota Department of Natural Resources
MPCA	Minnesota Pollution Control Agency
MRB	Minnesota River Basin
NPDES	National Pollutant Discharge Elimination System
NRS	Nutrient Reduction Strategy
RRNB	Red River of the North Basin
SPARROW	SPAtially-Referenced Regression On Watershed attributes
TN	total nitrogen
TP	total phosphorus
USGS	U.S. Geological Survey (U.S. Department of the Interior)

Unit of measure	Definition
lb.	pounds
lb./yr	pounds per year
mg/L	milligrams per liter

1 INTRODUCTION

Minnesota developed a Nutrient Reduction Strategy (NRS) in 2014 to guide the reduction of nutrient-loading to Minnesota's waters and downstream waters. This large-scale framework established milestones and final load goals at Minnesota's state boundaries. The 2014 NRS recommended reductions for agriculture, wastewater, and other sources to achieve milestones and goals. To collectively achieve these goals and milestones, reductions were estimated for each subbasin, or hydrologic unit defined by an 8-digit code (HUC8).

In 2022, the Minnesota Pollution Control Agency (MPCA) developed interim guidance to refine the necessary reductions by sector for each subbasin (MPCA 2022). The subbasin goals in the interim guidance were developed using modeling results through 2018.

In 2024, MPCA has begun developing Minnesota's 2025 NRS.

1.1 OBJECTIVES

To support the development of Minnesota's 2025 NRS, MPCA contracted with Tetra Tech for technical support to meet three objectives:

- **Objective #1**: Assess major river basin and state-line loads and determine the remaining nutrient load reduction needs to meet downstream goals
- **Objective #2**: Estimate source contributions to the river nutrient loads
- **Objective #3**: Evaluate watershed nutrient load reduction needs to achieve downstream goals

MPCA also defined specific tasks and subtasks for each objective.

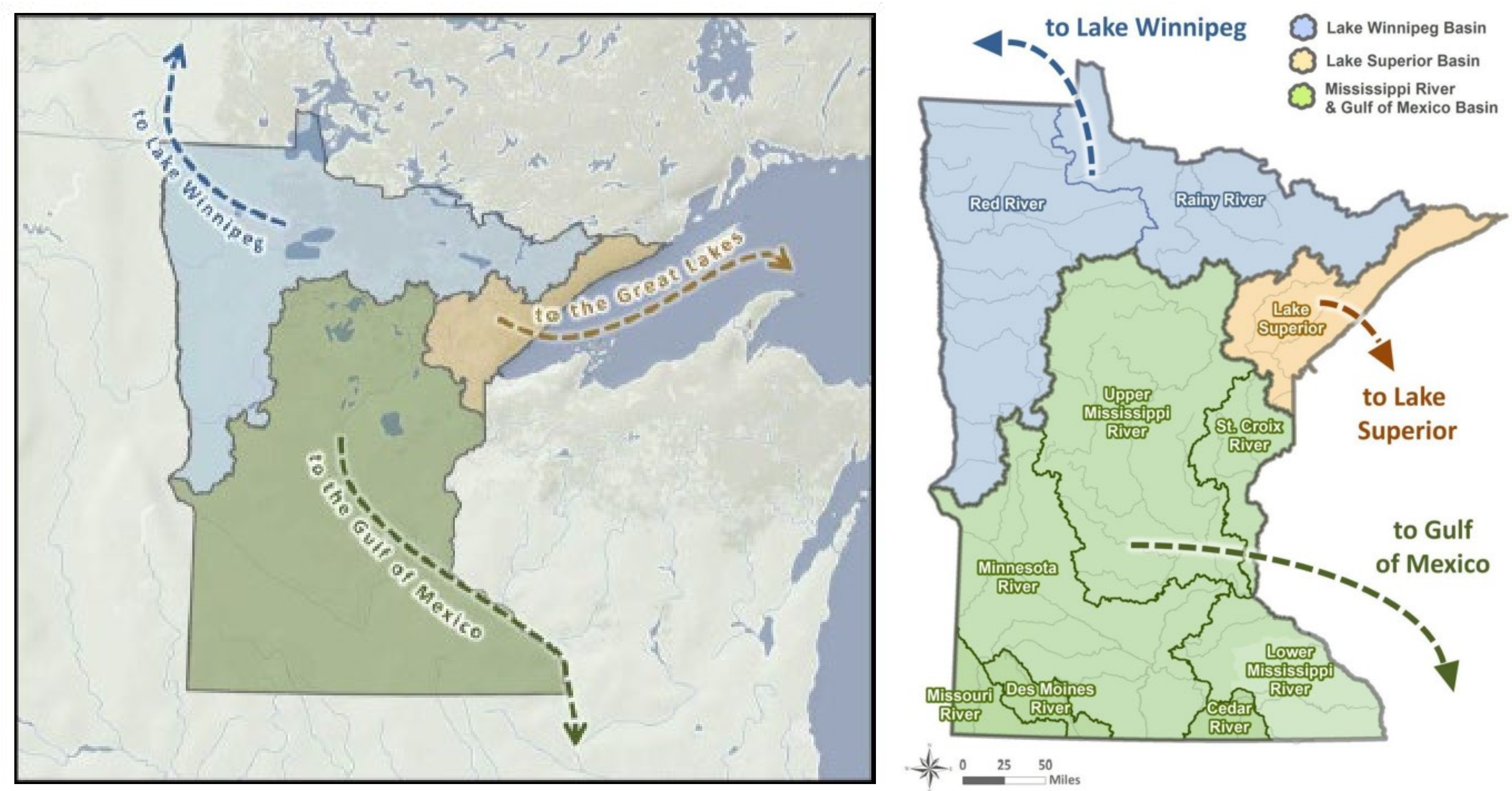
This report presents the data, analyses, and results for Objective #2. The two primary tasks for Objective #2 are:

- **Task A**: Nutrient Source Assessment
- **Task B**: Source Sector Load Reduction Targets

1.2 MAJOR BASINS

In the 2014 NRS, MPCA (2014) divided the state into three major basins: *Lake Winnipeg*, *Lake Superior*, and *Mississippi River & Gulf of Mexico* (Figure 1). MPCA (2014) established goals and milestones for these major basins.

The Minnesota Department of Natural Resources (MnDNR) developed new names for hydrologic units that were delineated and originally named by the U.S. Geological Survey (USGS). MPCA typically uses the hydrologic unit names defined by MnDNR; however, MPCA deviated from this naming scheme for the 2014 NRS and 2025 NRS. Table 2 presents the HUCs and hydrologic unit names developed by USGS, MnDNR, and MPCA (for the NRS).



Source: 2014 NRS (MPCA 2014, Figure 1 [left] and Figure 2-1 [right]).

Figure 1. Major river basins in Minnesota.

Table 2. Hydrologic unit names.

HUC	USGS	MnDNR	MPCA (for the NRS)
Mississippi River major basin			
0701	Mississippi Headwaters	Mississippi River – Headwaters	Upper Mississippi River
0702	Minnesota	Minnesota River	Minnesota River
0703	St. Crois	St. Croix River	St. Croix River
0704	Upper Mississippi – Black Root	Lower Mississippi River	Lower Mississippi River
0706	Upper Mississippi – Maquoketa – Plum	Mississippi River – Upper Iowa Rivers	
0708	Upper Mississippi – Iowa – Skunk – Wapsipinicon	Cedar River	Cedar River
0710	Des Moines	Des Moines River	Des Moines River
1017	Missouri – Big Sioux	Missouri River – Big Sioux River	Missouri River
1023	Missouri – Little Sioux	Missouri River – Little Sioux River	
Lake Winnipeg major Basin			
0902	Red River	Red River of the North	Red River of the North
0903	Rainy River	Rainy River	Rainy River
Lake Superior major basin			
0401	Western Lake Superior	Western Lake Superior	Lake Superior

Note: HUC = hydrologic unit code; MnDNR = Minnesota Department of Natural Resources; MPCA = Minnesota Pollution Control Agency; NRS = Nutrient Reduction Strategy; USGS = U.S. Geological Survey.

2 DATASETS FOR NUTRIENT SOURCE ASSESSMENT

To support the development of Minnesota's 2025 NRS, MPCA contracted with Tetra Tech to *use existing nutrient source assessments developed since 2014 to determine if any changes need to be made to the 2014 NRS source load contributions.*

To conduct the source assessment analysis, Tetra Tech used local watershed model results from Hydrologic Simulation Program – FORTRAN (HSPF) output for HUC8 subbasins within the state as the primary data source, supplementing with other available data sources when necessary. Two sets of simulated loads are available from the HSPF model: "local" loads delivered to individual reaches and "fate" loads delivered outlets of HUC8 subbasins. The fate loads account for in-stream processes along the stream network within a HUC8subbasin. This source assessment used the local loads delivered to individual reaches due to the dual nature of the NRS (i.e., the importance of nutrient reduction for both local waters and downstream waters). Additionally, implementation activities typically target upland source areas, although some best management practices target in-stream processes.

This section presents point sources datasets (Section 2.1) and nonpoint source (NPS) datasets (Section 2.2).

2.1 POINT SOURCE WASTEWATER DISCHARGE DATA SOURCES

During the initial development of Minnesota's 2025 NRS, multiple dataset sources were identified as options for obtaining annual estimates of TN and TP loads attributed to National Pollutant Discharge Elimination System (NPDES) permitted wastewater dischargers. Though HSPF model results were the primary resource used for the comparison of current nutrient source assessments to the 2014 NRS source assessment, other nutrient source load information was also evaluated, including the most updated SPAtially-Referenced Regression On Watershed attributes (SPARROW; U.S. Geological Survey [USGS] 2019a, b) model and MPCA tracking of wastewater nutrient discharges. This section provides a brief description of the various point source nutrient load data sources that were considered and the discrepancies that were found between them.

Several factors contribute to differences in point source TN and TP estimates across HUC8 subbasins. One of the primary reasons is the difference in time period over which the data is averaged. Many HSPF models used to estimate nutrient loads have not been updated since 2014; for example, the HSPF models for the Big Sioux and Little Sioux rivers were developed in 2009 and model results represent 2000-2009. In contrast, MPCA-analyzed data includes wastewater load estimates by HUC8 subbasin from 2005 through 2022. This temporal difference can cause significant discrepancies in the estimated loads. For example, the more recent MPCA data may capture changes in wastewater treatment or population growth, which the older HSPF models do not. Additionally, during HSPF model development, assumptions made during the calculation of "total" nitrogen and phosphorus varied. For instance, the processing of partitioned inorganic and organic nutrient species into a total value can differ depending on the methodologies used or even the individual performing the calculations when developing HSPF models. Finally, gap-filling procedures applied to address missing data points further contribute to variations. For the HSPF models, sporadic Discharge Monitoring Report (DMR) records may be extrapolated into daily or monthly time series to create a continuous dataset, and the gap-filling procedures that were used for each individual HUC8 model could differ from the methods employed at MPCA to gap-fill missing records. These factors could collectively explain why the point source load estimates can differ substantially across the data sources.

2.1.1 Wastewater Load Estimates from HSPF and SPARROW Modeling Data

MPCA has invested in the development of HSPF models across the state of Minnesota. Today, 68 models represent 75 subbasins, wholly or partially, within Minnesota. Since the 2014 NRS, many new models have been developed and many existing models have been updated (e.g., extended, recalibrated). RESPEC provided two sets of model results that represent the most recent 10-year (approximately) averages of flow, TP, and TN load: (1) flows and loads delivered to individual model reaches and (2) flows and loads delivered to subbasin outlets. For the nutrient source assessment update and evaluation, local TN and TP loads delivered to individual model reaches were utilized.

HSPF models are not yet available for five of Minnesota's subbasins in the *Mississippi River* major basin. Furthermore, while an HSPF model exists for the 07040001-Rush-Vermillion HUC8, it only covers part of the HUC8 extent and does not cover the Vermillion area, which is responsible for most of the flow and subsequent nutrient loading in the subbasin. The U.S. Geological Survey has developed SPARROW models to estimate long-term (2002-2014) loads, delivered loads, yields, and delivered yields. In this study, SPARROW model results delivered locally within subbasins are used to represent these six subbasins where adequate HSPF model coverage does not currently exist for a statewide nutrient source assessment (Figure 2).

It is worth noting that in general, the HSPF and SPARROW model results for point source TN and TP loads are older than the MPCA-analyzed point source load data. The most recent 10 years of summarized model output from HSPF could range from the year 2000 to 2022, depending on the HUC8 HSPF model used to gather the simulated loading summaries. As previously mentioned, SPARROW model results are already provided as long-term (2002-2014) annual averages, which is the latest simulation period for the SPARROW models for the Midwest.

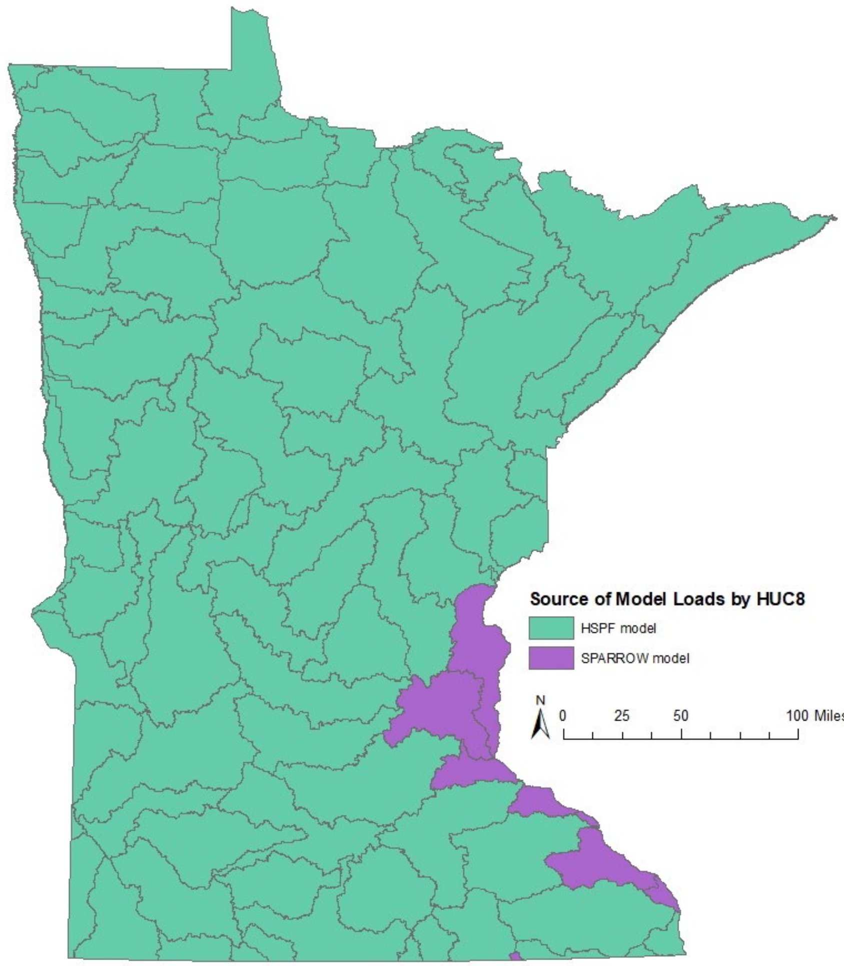


Figure 2. Source of model loads.

A summary of average annual point source TN and TP loads, in pounds per year, obtained from HSPF and SPARROW models is provided in Table 3. Note that the loads from individual HUC8s were summed to the major basin level based on HUC8 assignment to either the *Mississippi River*, *Lake Superior*, or *Lake Winnipeg* major basins. This aggregation allows for more of a direct comparison of point source loads across the other data sources provided by MPCA. The TN load from point sources across all major river basins amounts to approximately 21,082,668 pounds per year (lb./yr), with *the Mississippi River* major basin contributing the highest share (17,975,697 lb./yr or 85%). The *Lake Superior* major basin contributes around 1,294,194 lb./yr (6%), and the *Lake Winnipeg* major basin contributes 1,812,778 lb./yr (9%). In terms of TP, the total point source load obtained from HSPF and SPARROW model summaries is 4,411,144 lb./yr, with the Mississippi River contributing about 95% (4,189,781 lb./yr). The *Lake Superior* and *Lake Winnipeg* major basins contribute 1% (53,700 lb./yr) and 4% (167,663 lb./yr), respectively, showing that phosphorus loading from *Lake Superior* and *Lake Winnipeg* major basins point source dischargers is a significantly lower fraction compared to the *Mississippi River* major basin point source dischargers.

Table 3. Average Annual Point Source TN and TP Loads from HSPF and SPARROW Model Sources (Summed Across HUC8s to the Major Basin Level).

Major River Basin	Total Nitrogen (lb./yr)	Total Phosphorus (lb./yr)
Mississippi River	17,975,697	4,189,781
Lake Superior	1,294,194	53,700
Lake Winnipeg	1,812,778	167,663
Total	*21,082,668*	*4,411,144*

2.1.2 MPCA-Analyzed Wastewater Load Estimates Summarized by Major Basin

MPCA (2024) estimated average annual nutrient loads from NPDES-permitted wastewater discharges at the scale of the major basin, covering the years 2005 to 2023; Tetra Tech calculated the most recent decadal average (2014-2023; Table 4). According to this dataset, the Mississippi River major basin has significantly higher TN loading (28,305,685lb./yr) compared to the summed loads from HSPF and SPARROW models, where the load was approximately 17,975,697 lb./yr. Similarly, the Lake Superior major basin shows higher TN loads at 2,095,615 lb./yr (versus 1,294,194 from the HSPF and SPARROW models), and Lake Winnipeg shows slightly lower TN loads compared to point source loading summaries acquired from HSPF and SPARROW models (1,115,413 lb./yr versus 1,812,778 lb./yr in Table 3).

For TP, the MPCA dataset reflects lower overall loads compared to the SPARROW/HSPF data, with the Mississippi River major basin contributing 966,641 lb./yr (compared to 4,189,781 lb./yr in the Table 3 HSPF/SPARROW point source load summary). The TP load in the Lake Superior major basin is 60,335 lb./yr (compared to 53,700 lb./yr in Table 3), and in the Lake Winnipeg major basin, the TP load is 113,094 lb./yr (nearly identical to Table 3).

The MPCA data highlights a significant difference in TN loads, particularly for the Mississippi River basin, where the MPCA dataset estimates a 48% higher nitrogen load compared to the modeling data. This discrepancy can likely be attributed to differences in time periods, assumptions, and gap-filling methods used in the wastewater discharge estimates.

Table 4. Most recent 10-year period (2014-2023) Average Annual Point Source TN and TP Loads from MPCA-Provided 2005-2023 Wastewater Loads by Major Basin(MPCA 2024).

Major River Basin	Total Nitrogen (lb./yr)	Total Phosphorus (lb./yr)
Mississippi River	28,305,685	966,641
Lake Superior	2,095,615	60,335
Lake Winnipeg	1,115,413	113,094
Total	*31,516,713*	*1,140,070*

2.1.3 MPCA-Analyzed Wastewater Load Estimates Summarized by HUC8 Subbasin

MPCA (2023) also provided Tetra Tech with a dataset of MPCA-analyzed annual TN and TP loads from point sources by HUC8 subbasin, covering the years 2005-2022. The TN and TP load data, originally measured and summarized in kilograms per year (kg/yr), is averaged based on the last ten years of available NPDES data by HUC8 and then converted to pounds per year (lb./yr) to provide a representative annual loading by HUC8 subbasin. For example, if a particular HUC8 subbasin had available point source loading estimate data for each year from 2005 to 2022, the 10-year averaging period would begin in 2013 and end in 2022. Tetra Tech leveraged this averaged data for initial source assessments at the HUC8 and major river basin scales, with subbasins having less than ten years of monitoring data flagged for attention in accompanying spreadsheets.

A summary of average annual point source TN and TP loads, in pounds per year, is provided in Table 5. Similar to the HSPF/SPARROW model data sources discussed in Section 2.1.1, it is worth noting that the loads from individual HUC8s were summed to the major basin level based on HUC8 assignment to either the Mississippi River, Lake Superior, or Lake Winnipeg major basins. This aggregation allows for more of a direct comparison of point source load estimates acquired by the other MPCA dataset that was provided at the aggregated scale of the major river basins (i.e., Table 4).

The data summarized in Table 5 reveals that the Mississippi River major basin has the highest TN load at 28,500,611 lb./yr, compared to the totals reported in Table 3 and Table 4 (17,975,697 and 26,605,094 lb./yr, respectively). For TP, the aggregated data for the Mississippi River major basin, based on the MPCA-analyzed HUC8 point source loads, also shows a pronounced decrease, with the load being 1,014,052 lb./yr (compared to 4,189,781 lb./yr in Table 3 and 1,693,834 lb./yr in Table 4). For Lake Superior, the TN and TP loads are 3,273,925 lb./yr and 85,425 lb./yr, respectively. Both are higher than the point source loading estimates provided in Tables 2 and 3 for Lake Superior. In the Lake Winnipeg basin, the TN load is slightly lower than the summary value provided for Lake Winnipeg in Table 3 at 1,191,554 lb./yr, and the TP load remains relatively consistent at 123,985 lb./yr.

Table 5. Most Recent 10-Year Period Average Annual Point Source TN and TP Loads from MPCA-Provided 2005-2022 Wastewater Loads by HUC8 Subbasin (Summed Across HUC8s to the Major Basin Level; MPCA 2023).

Major River Basin	Total Nitrogen (lb./yr)	Total Phosphorus (lb./yr)
Mississippi River	28,500,611	1,014,052
Lake Superior	3,273,925	85,425
Lake Winnipeg	1,191,554	123,985
Total	*32,966,089*	*1,223,462*

2.1.4 General Comparison of the Point Source Load Data Sources

A summary evaluation highlighting the main differences observed across the three main data sources provided to Tetra Tech for point source TN and TP annual loads, to be used for the NRS update, are provided in the bullet points below.

- **HSPF and SPARROW Model Point Source Loads** (Table 3): These models provide long-term averages based on simulation outputs and often incorporate earlier datasets (e.g., 2002-2014 for SPARROW). Because the models generally simulate load estimates over an earlier time frame, they may not fully reflect more recent trends in wastewater loads of TN and TP.
- **MPCA 2005-2023 Wastewater TN and TP Loads by Major River Basin** (MPCA 2024; Table 4): This dataset is based on analyzed annual loading summaries provided by MPCA, which reflect direct monitoring and reporting of nutrient discharges from permitted wastewater facilities. Since it includes data from 2005 to 2023, it likely captures more recent point source loads, reflecting actual discharges over this period. The higher TN and TP loads for the Mississippi River basin in this dataset may suggest that recent wastewater discharges have been higher than earlier estimates or that the HSPF/SPARROW models underestimated these loads on an average annual basis.
- **MPCA 2005-2022 HUC8 Wastewater TN and TP Loads** (MPCA 2023; Table 5): This table refines the analysis by averaging individual HUC8 data over the last 10 years of available records, providing a more granular view at the HUC8 level. The differences in TN and TP loads across the major basins, especially the increase in Lake Superior loads, highlight temporal and spatial variability that the broader basin-level data (Table 4) may overlook.

The two wastewater datasets provided by MPCA (2023, 2024) are both based on the same set of assumptions and original data. The major differences are (1) the scale of the annual averages (i.e., major basins versus HUC8 subbasin) and (2) the years included in the 10-year averaging period

The load summary tables provided in Sections 2.1.1 to 2.1.3 underscore the variability in point source load estimates based on different datasets and methodologies.[1] The differences in TN and TP loads between Tables 2, 3, and 4 are significant, particularly for the *Mississippi River* major basin. The use of different averaging periods, model assumptions, and estimation techniques likely contributes to these discrepancies. For example, MPCA's 2005-2022 annual point source load summaries by HUC8 (MPCA 2023) reflect more recent estimates and may incorporate updated monitoring and discharge records that differ from the model predictions of the HSPF and SPARROW models. Table 6 displays an overall summary of the relative percent of total load, by major river basin, attributed to point source loading for each of the data sources evaluated in this section. This table further highlights the variability in point source load estimates across the three datasets and emphasizes the importance of selecting one of these data source options to proceed with finalizing the updates to the NRS source assessments by HUC8 and major river basin.

[1] The point sources datasets provided by MPCA (2023, 2024) are loads delivered to the receiving waterbodies (i.e., end-of-pipe). The HSPF point sources dataset are loads delivered to the model stream reach. These are essentially equivalent delivery locations. The HSPF point sources dataset with loads delivered to the outlets of HUC8 subbasins was not used to support this report. As such, in-stream processes and other downstream delivery assumptions are not considered herein.

Table 6. Comparison of Average Annual TN and TP Loads by Major River Basin Using Different Models and Point Source Load Analyses.

Major River Basin		Mississippi River		Lake Superior		Lake Winnipeg	
Sum of Average Annual Load		**TN (lb./yr)**	**TP (lb./yr)**	**TN (lb./yr)**	**TP (lb./yr)**	**TN (lb./yr)**	**TP (lb./yr)**
HSPF/SPARROW Model Output	PS (% of Total)	17,975,697 (5%)	4,189,781 (21%)	1,294,194 (8%)	53,700 (7%)	1,812,778 (3%)	167,663 (3%)
	Total Load	364,065,967	19,685,143	16,097,592	811,962	57,722,459	4,866,561
MPCA-Analyzed PS Loads by Major Basin (MPCA 2024) [a]	PS (% of Total)	28,305,685 (8%)	966,641 (6%)	2,095,615 (12%)	60,335 (7%)	1,115,415 (2%)	113,094 (2%)
	Total Load	374,395,955	16,462,003	16,899,014	818,597	57,025,923	4,811,993
MPCA-Analyzed PS Loads by HUC8 Subbasin (MPCA 2023) [b]	PS (% of Total)	28,500,611 (8%)	1,014,052 (6%)	3,273,925 (18%)	85,425 (10%)	1,191,554 (2%)	123,985 (3%)
	Total Load	374,590,881	16,509,415	18,077,324	843,687	57,101,235	4,822,883

Notes

lb./yr = pound per year; PS = point source; TN = total nitrogen; TP = total phosphorus.

The “Total Load” rows are computed based on the sum of average annual point source facility TN and TP loads from each respective data source added to the sum of all other TN and TP loading sources. Thus, the “Total Load” sums differ across the three main point source loading data sources.

a. The 10-year average annual loads represent 2014 through 2023.

b. The 10-year average annual loads represent the most recent 10-year period.

2.1.5 Summary of MPCA's Assessment of Point Source Load Estimates

MPCA permitting staff reviewed the three point source load estimation options presented in Subsections 2.1.1 to 2.1.3 to determine which would be most suitable for updating Minnesota's NRS: (a) HSPF data supplemented by SPARROW model outputs, (b) MPCA load estimates aggregated by major river basin (MPCA 2024), and (c) MPCA load estimates by HUC8 subbasin (MPCA 2023).

HSPF/SPARROW Model Data (Option a)

MPCA considers this dataset to be the least accurate for point source loading estimates in more recent years. A key limitation is its static nature: the HSPF data represent conditions at the time of their development but may no longer reflect current conditions due to improved data availability and understanding. Monitoring data TP were sparse in earlier periods, TN data were almost nonexistent, leading to many estimates based on assumed concentrations rather than direct measurements. Additionally, noncontact cooling water flows from facilities such as power plants were not consistently excluded, further reducing accuracy.

In their assessment, MPCA permitting staff provided an example of the Grand Rapids Wastewater Treatment Plant (WWTP), which is located in HUC8 07010103. This example highlights a specific case where assumed nitrogen concentrations were significantly higher until monitoring began, reducing reported values from 19 mg/L to under 5 mg/L in 2013. This example underscores that much of the discrepancy between datasets is due to differences in data availability and quality, particularly during and after the HSPF model periods.

MPCA Load Estimates by Major Basin (Option b)

MPCA permitting staff regarded this dataset as the most accurate. Unlike the static HSPF data, the MPCA estimates are dynamic and are continuously updated as monitoring data improve. For instance, as seen in the case of Grand Rapids WWTP, more recent monitoring data replace earlier assumptions, leading to more accurate load estimates. The major basin estimates also account for outliers by adjusting reported flows and excluding large cooling water discharges. Because this data includes the latest (June 2024) understanding of point source loads, it better reflects current conditions and the corrections made through annual compliance summaries.

MPCA Load Estimates by HUC8 Subbasin (Option c)

While more granular than the major basin estimates, this dataset is slightly less accurate due to uncertainties surrounding data corrections and the treatment of noncontact cooling water flows. However, in some major basins, such as the Mississippi River and Lake Winnipeg, the HUC8 and major basin estimates closely align. Discrepancies are larger in the Lake Superior major basin, likely due to complex industrial discharges and intermittent flows.

In conclusion, MPCA permitting staff recommended using **Option b**, the MPCA-analyzed point source load estimates by major basin (MPCA 2024), for the NRS update. This dataset, updated dynamically with the latest available monitoring data and annual corrections, provides the most reliable representation of current nutrient loading conditions. The permitting staff's discussion of increased post-HSPF data availability and monitoring improvements reinforces the importance of using these up-to-date load estimates rather than relying on the more static HSPF data.

2.2 NONPOINT SOURCE DATA SOURCES

While three point sources datasets were considered for the source assessment, only two nonpoint source (NPS) datasets were considered for the source assessment: HSPF modeling and SPARROW modeling. NPS were represented by HPSF modeling for all except six HUC8 subbasins. For the six HUC8 subbasins without HSPF modeling, NPS were represented by SPARROW modeling.

HSPF models were developed between 2000 and 2022 and were generally developed to address HUC8 subbasin-scale issues (e.g., waterbodies and pollutants on Minnesota's Section 303(d) List of Impaired Waters). As such, the HSPF models were developed differently for different HUC8subbasins. With regards to the NRS, this is important because different NPS source categories from different HPSF models need to be aggregated to allow comparison and summation across HUC8 subbasins.

The 68 HSPF models are composed of a total of 136 hydrologic response units (HRUs) that represent various sources of TP, TN, and sediment. These 136 HRUs were aggregated into 4 source categories (Table 21 in Appendix A) for the source assessment at the scale of the major drainage basin (Section 3) and were aggregated into 8 source categories (Table 22 in Appendix A) for the source assessment by flow delivery pathway for the Minnesota River and Red River of the North basins (Section 4). The aggregated source categories and HRUs are summarized in Appendix A.

The SPARROW model includes five sources for nitrogen and six sources for phosphorus. The SPARROW sources were aggregated into six source categories (Table 23 in Appendix A)) for the source assessment at the scale of the major drainage basin (Section 3). SPARROW model results were only used for six of the 80 HUC8 subbasins in Minnesota. Refer back to Figure 2 in Section 2.1.1 for a statewide map HUC8 subbasins; all six HUC8 subbasins represented by SPARROW are in the *Mississippi River* major basin.

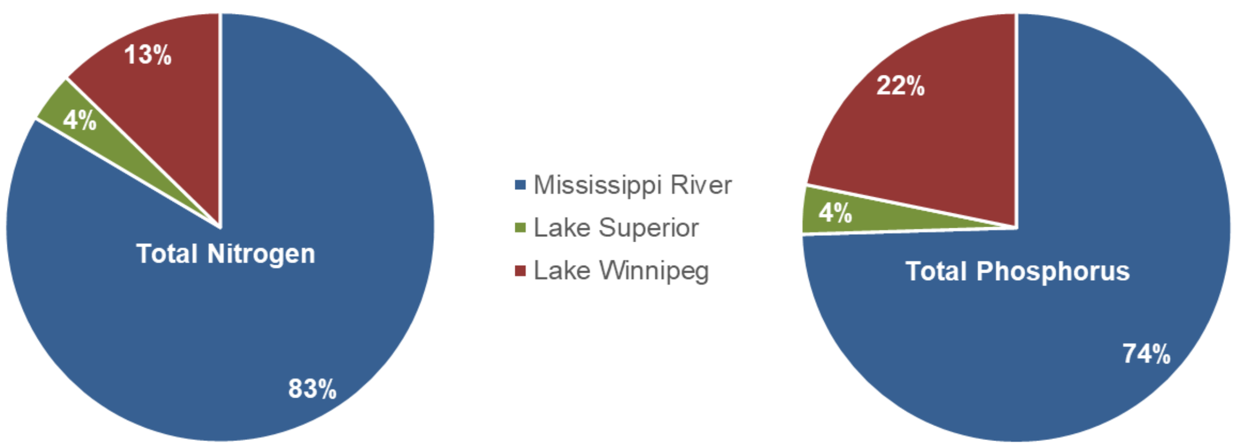
3 SOURCE ASSESSMENT IN MINNESOTA'S MAJOR DRAINAGE BASINS

Coarse-scale source assessments for TN and TP loading, on an average annual basis, are provided in the following subsections for the major drainage basins of the *Mississippi River*, *Lake Winnipeg*, and *Lake Superior*. Because the nutrient load estimates for six HUC8s within the *Mississippi River* major basin were supplied by results from the SPARROW model for the Midcontinental region of North America, which only offers five and six source categories for TN and TP, respectively, higher level aggregation of HSPF model source categories was necessary for direct incorporation with the SPARROW results.

The vast majority of TN and TP source loads across the state are from the *Mississippi River* major drainage basin. Generally, the drainage area and levels of agricultural and urban development are largest in the *Mississippi River* major drainage basin, followed by the *Lake Winnipeg* and *Lake Superior* major drainage basins. The relative TN and TP loads for the three major drainage basins are summarized in pie-charts in Figure 3.

This section begins with a discussion of TN and TP nutrient sources and presentation of charts for the three major Minnesota drainage basins (*Mississippi River* in Section 3.1, *Lake Winnipeg* in Section 3.2, and *Lake Superior* in Section 3.3). This section then concludes with a comparison of the updated source assessment findings with the 2014 NRS source assessment for TN and TP and has recommendations to address substantial differences (Section 3.4).

Figure 3. TN and TP loads across the three major basins.



3.1 *MISSISSIPPI RIVER* MAJOR BASIN

TN and TP source assessment results are presented for the *Mississippi River* major basin in two tables:

- Table 7 uses the MPCA (2023) estimated point source loads, originally estimated by HUC8 subbasin
- Table 8 uses the MPCA (2024) estimate point source loads, originally estimated by major basin

While MPCA recommended using the estimated point sources loads by major basin (MPCA 2024; Section 2.1.5), these data are too coarse for some analyses that are presented later in this report. Thus, the estimated point source loads by HUC8 subbasin (MPCA 2023) are also presented herein.

The differences between MPCA (2023, 2024) point source load estimates for the *Mississippi River* major basin are very small. TN estimates vary by 194,926 lb./yr, which is <1% of the point sources TN loads. TP estimates vary by 47,411 lb./yr, which is about 5% of the point sources TP loads. Since the MPCA (2023, 2024) estimates are very similar, the summation of TN and TP loads across all sources are very similar, and thus, the relative distribution of loads among sources is the same.

Within the *Mississippi River* major basin, cropland (overland runoff, tile drainage, leaching to groundwater, etc.)_ is the largest contributor to nutrient loading, accounting for the majority of both TN (79%) and TP (72%) load. Pie charts displaying the relative TN and TP load percentages attributed to aggregated source categories within the *Mississippi River* major basin are shown in

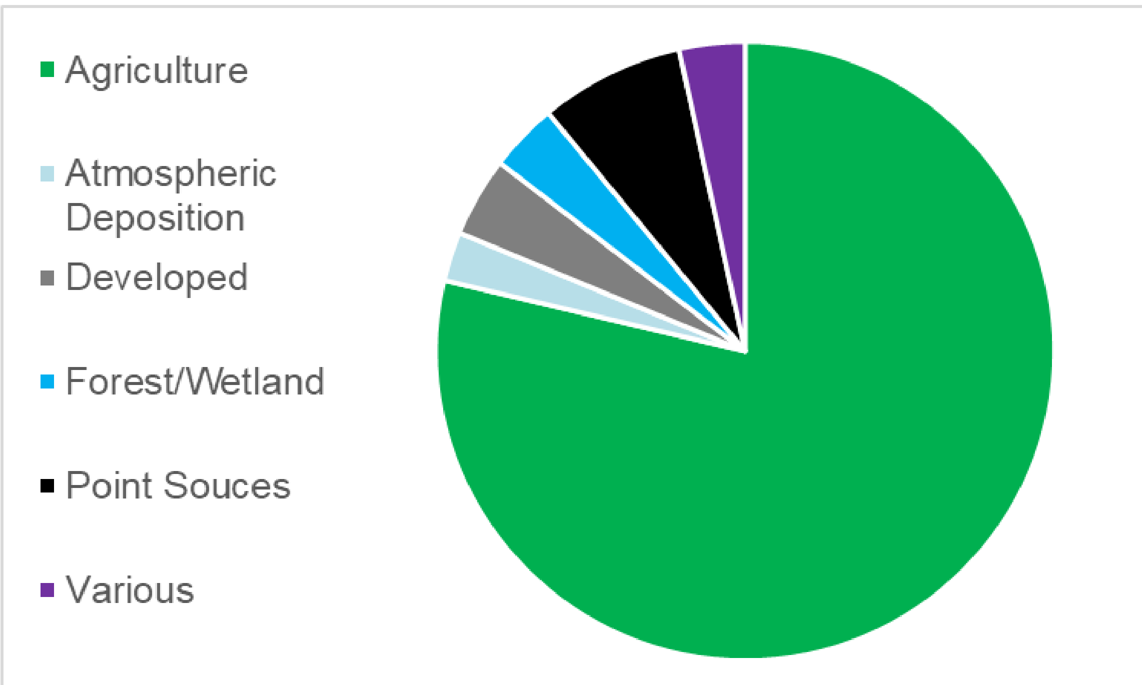


Figure 4 and Figure 5 . The relative percentages do not change for the *Mississippi River* major basin when comparing the two point source load estimates that were provided by MPCA (2023, 2024).

The total loads in Table 7 and Table 8 are loads delivered to individual streams. The NRS often reports loads delivered to HUC8 subbasin outlets or delivered to state lines. Nutrient loads decrease, due to in-stream processes, between the indivudal modeled streams and the HUC8 subbasin outlets and again between the HUC8 subbasin outlets and the state lines. For TP, loads decrease by about an eighth from the individual modeled streams to the HUC8 subbasin outlets; for TN, loads decrease about a quarter.

Table 7. *Mississippi River* Major Basin Source Assessment with MPCA (2023) Estimated Point Source Loads

Source Category	TN Load	TP Load
Agriculture [a]	294,561,372 (79%)	11,868,246 (72%)
Atmospheric Deposition	9,626,819 (3%)	272,277 (2%)
Developed [a]	15,627,663(4%)	1,084,608 (7%)
Forest/Wetland [a]	13,433,121 (4%)	790,259 (5%)
NPDES Permitted Wastewater Discharge [b]	28,500,611 (8%)	1,014,052 (6%)
Various [a]	12,841,295 (3%)	1,479,973(9%)
Total	*374,590,881 (100%)*	*16,509,415 (100%)*

Notes

Average annual loads (pounds per year) are from the HSPF or SPARROW model, except when noted otherwise. Loads and percentages are rounded to the nearest integer. The totals do not sum exactly due to rounding with the individual source categories.

a. Refer to Appendix A for the sources included in the aggregated source categories.

b. MPCA (2023) estimated point sources loads, originally reported by HUC8.

Table 8. *Mississippi River* Major Basin Source Assessment with MPCA (2024) Estimated Point Source Loads

Source Category	TN Load	TP Load
Agriculture [a]	294,561,372 (79%)	11,868,246 (72%)
Atmospheric Deposition	9,626,819 (3%)	272,277 (2%)
Developed [a]	15,627,663(4%)	1,084,608 (7%)
Forest/Wetland [a]	13,433,121 (4%)	790,259 (5%)
NPDES Permitted Wastewater Discharge [b]	28,305,685 (7%)	966,641 (6%)
Various [a]	12,841,295 (3%)	1,479,973(9%)
Total	*374,395,955 (100%)*	*16,462,003 (100%)*

Notes

Average annual loads (pounds per year) are from the HSPF or SPARROW model, except when noted otherwise. Loads and percentages are rounded to the nearest integer. The totals do not sum exactly due to rounding with the individual source categories.

a. Refer to Appendix A for the sources included in the aggregated source categories.

b. MPCA (2024) estimated point sources loads, originally reported by major basin.

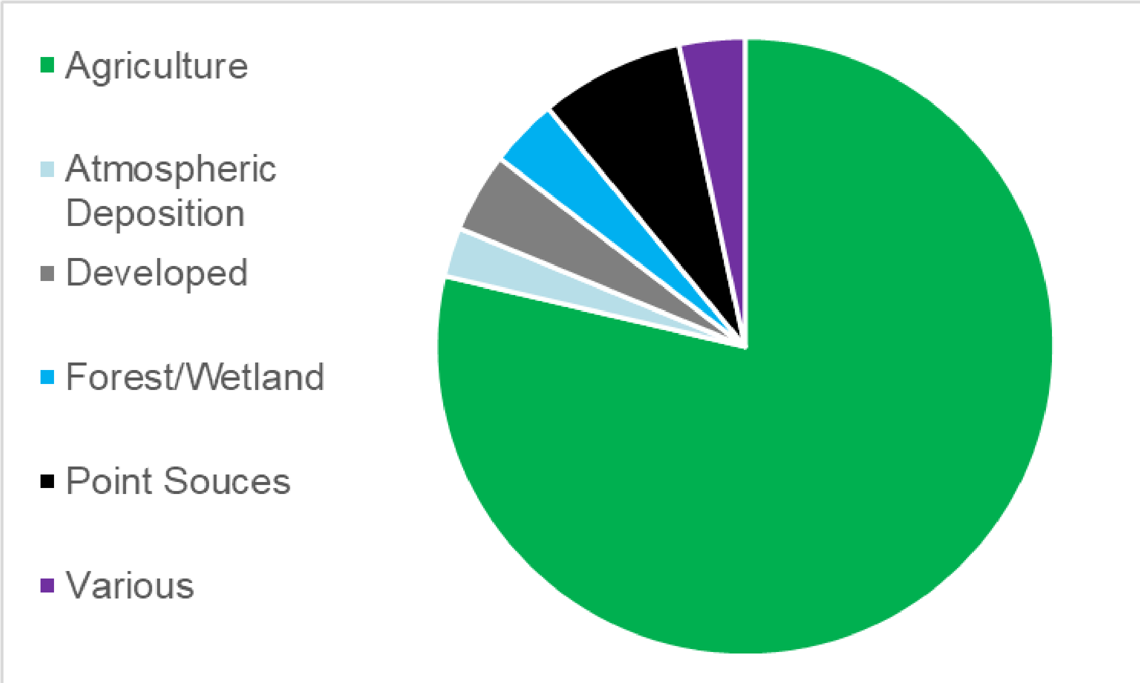


Figure 4. Pie Chart of Average Annual TN Loading within the *Mississippi River* Major Basin.

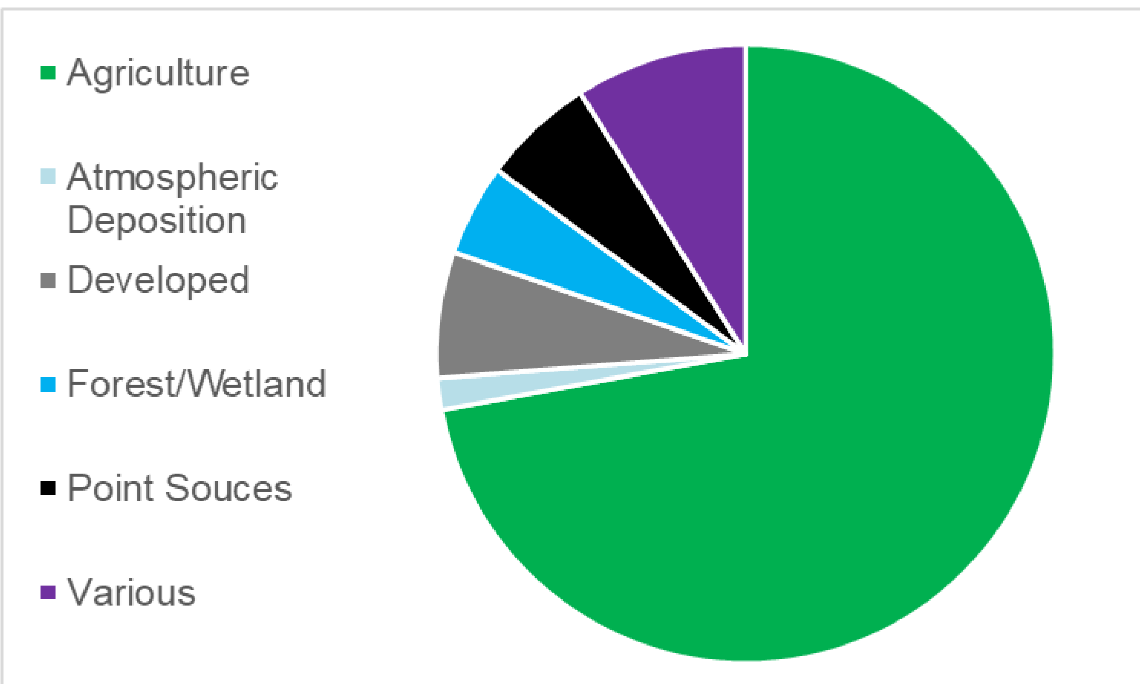


Figure 5. Pie Chart of Average Annual TP Loading within the *Mississippi River* Major Basin.

3.2 *LAKE WINNIPEG* MAJOR BASIN

TN and TP source assessment results are presented for the *Lake Winnipeg* major basin in two tables:

- Table 9 uses the MPCA (2023) estimated point source loads, originally estimated by HUC8 subbasin
- Table 10 uses the MPCA (2024) estimate point source loads, originally estimated by major basin

The differences between MPCA (2023, 2024) point source load estimates for the *Lake Winnipeg* major basin are small. TN estimates vary by 76,141 lb./yr, which is about 7% of the point sources TN loads. TP estimates vary by 10,891 lb./yr, which is about 10% of the point sources TP loads. Since the MPCA (2023, 2024) estimates are similar, the summation of TN and TP loads across all sources are similar, and thus, the relative distribution of loads among sources are the same.

Similar to the *Mississippi River* major basin, cropland is the largest source of TN (48%)and TP (63%) load in the *Lake Winnipeg* major basin. However, a higher percentage of forest/wetland contributes to nutrient loading compared to the *Mississippi River* basin: forest/wetland is 30% of TN load and 20% of TP load.

Pie charts displaying the relative TN and TP load percentages attributed to aggregated source categories within *the Lake Winnipeg* major basin are shown in Figures Figure 6 and Figure 7. The relative percentages do not change for the *Lake Winnipeg* major basin when comparing the two point source load estimates that were provided by MPCA (2023, 2024).

The total loads in Table 9 and Table 10 are loads delivered to individual streams. Loads decrease from individual modeled streams to HUC8 subbsain outlets and again from HUC8 subbasin outlets to state lines. For TP, loads decrease by about a third from the individual modeled streams to the HUC8 subbasin outlets; for TN, loads decrease about 44%.

Table 9. *Lake Winnipeg* Major Basin Source Assessment with MPCA (2023) Estimated Point Source Loads

Source Category	TN Load	TP Load
Agriculture [a]	27,643,722 (48%)	3,058,907 (63%)
Atmospheric Deposition	4,073,484 (7%)	206,700 (4%)
Developed [a]	2,697,371 (5%	265,690 (6%)
Forest/Wetland [a]	17,065,706 (30%)	957,192 (20%)
NPDES Permitted Wastewater Discharge [b]	1,191,554 (5%)	123,985 (3%)
Various [a]	4,429,398 (8%)	210,410 (4%)
Total	*57,101,235 (100%)*	*4,822,883 (100%)*

Notes

Average annual loads (pounds per year) are from the HSPF or SPARROW model, except when noted otherwise. Loads and percentages are rounded to the nearest integer. The totals do not sum exactly due to rounding with the individual source categories.

a. Refer to Appendix A for the sources included in the aggregated source categories.

b. MPCA (2023) estimated point sources loads, originally reported by HUC8.

Table 10. *Lake Winnipeg* Major Basin Source Assessment with MPCA (2024) Estimated Point Source Loads

Source Category	TN Load	TP Load
Agriculture [a]	27,643,722 (48%)	3,058,907 (64%)
Atmospheric Deposition	4,073,484 (7%)	206,700 (4%)
Developed [a]	2,697,371 (5%	265,690 (6%)
Forest/Wetland [a]	17,065,706 (30%)	957,192 (20%)
NPDES Permitted Wastewater Discharge [b]	1,115,413 (2%)	113,094 (2%)
Various [a]	4,429,398 (8%)	210,410 (4%)
Total	*57,025,093 (100%)*	*4,811,993 (100%)*

Notes

Average annual loads (pounds per year) are from the HSPF or SPARROW model, except when noted otherwise. Loads and percentages are rounded to the nearest integer. The totals do not sum exactly due to rounding with the individual source categories.

a. Refer to Appendix A for the sources included in the aggregated source categories.

b. MPCA (2024) estimated point sources loads, originally reported by major basin

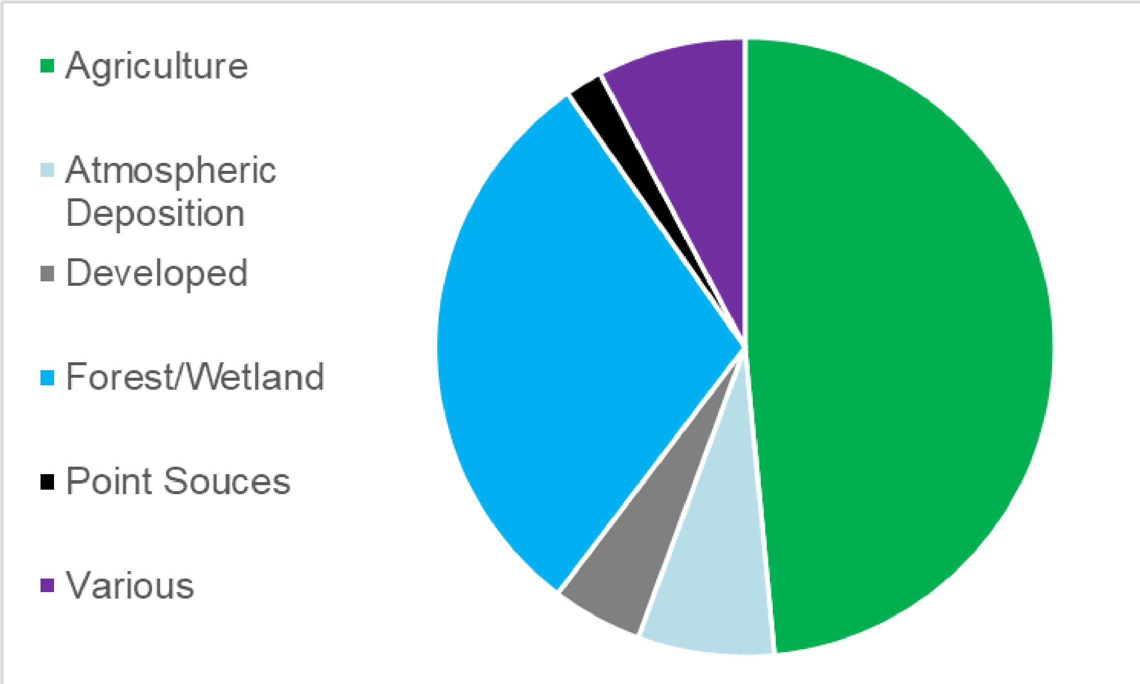


Figure 6. Pie Chart of Average Annual TN Loading within the *Lake Winnipeg* Major Basin.

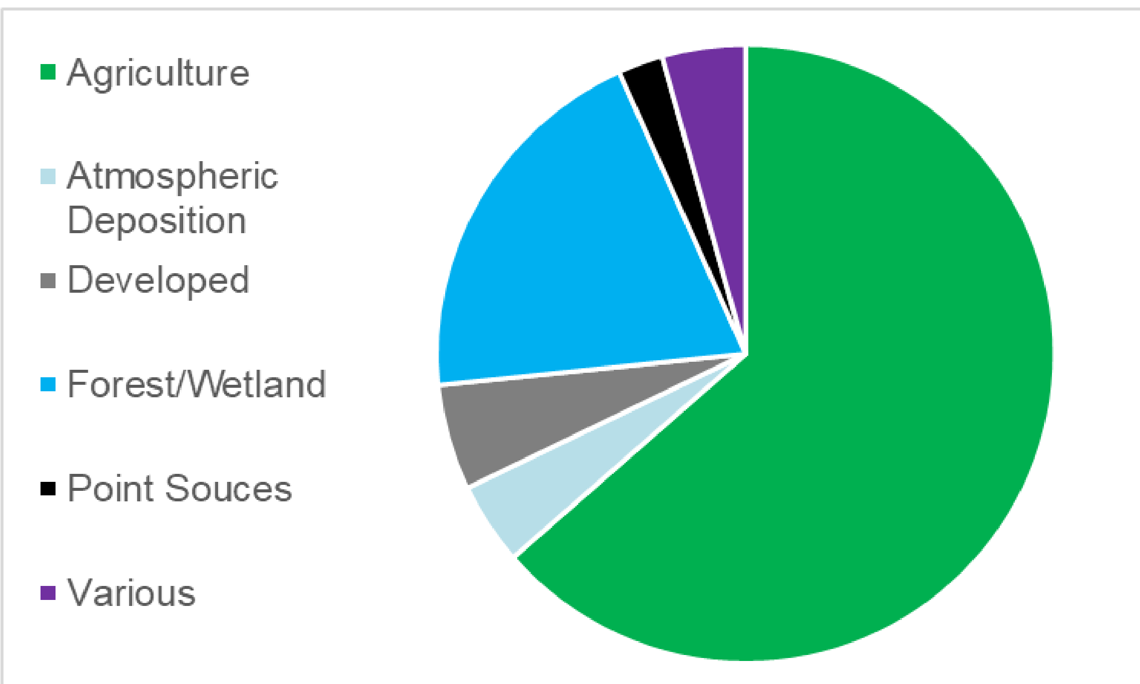


Figure 7. Pie Chart of Average Annual TP Loading within the *Lake Winnipeg* Major Basin.

3.3 *LAKE SUPERIOR* MAJOR BASIN

TN and TP source assessment results are presented for the *Lake Superior* major basin in two tables:

- Table 11 uses the MPCA (2023) estimated point source loads, originally estimated by HUC8 subbasin
- Table 12 uses the MPCA (2024) estimate point source loads, originally estimated by major basin

The differences between MPCA (2023, 2024) point source load estimates for the *Lake Superior* major basin are significant. TN estimates vary by 1,178,310 lb./yr, which is about 36% or 56% of the point sources TN loads. TP estimates vary by 25,090 lb./yr, which is about 29% or 42% of the point sources TP loads. While the MPCA (2023, 2024) estimates are considerably different, the summation of TN and TP loads across all sources are similar because a majority of the loads is from forest/wetland. Due to the differences in point source load estimates, the relative distribution of loads among sources are different.

Unlike the *Mississippi River* and *Lake Winnipeg* major basins, cropland is not a large source of TN (3%) or TP (4%) load in the *Lake Superior* major basin. Forest/wetland is the largest source of TN (69% or 74%) and TP (62% or 64%) load. Excluding the "various" source category, permitted wastewater is the second largest source of TN (12% or 18%) and TP (7% or 10%) load.

The total loads in Table 11 and Table 12 are loads delivered to individual streams. Loads decrease from individual modeled streams to HUC8 subbsain outlets and again from HUC8 subbasin outlets to state lines. For TP, loads decrease by about a 34% to 36% from the individual modeled streams to the HUC8 subbasin outlets; for TN, loads decrease about 41% to 44%.

Table 11. *Lake Superior* Major Basin Source Assessment with MPCA (2023) Estimated Point Source Loads

Source Category	TN Load	TP Load
Agriculture [a]	538,046 (3%)	32,634 (4%)
Atmospheric Deposition	354,067 (2%)	12,675 (2%)
Developed [a]	801,171 (4%)	30,858 (4%)
Forest/Wetland [a]	12,440,586 (69%)	526,016 (62%)
NPDES Permitted Wastewater Discharge [b]	3,273,925 (18%)	85,425 (10%)
Various [a]	669,528 (4%)	156,079 (18%)
Total	*18,077,324 (100%)*	*843,687 (100%)*

Notes

Average annual loads (pounds per year) are from the HSPF or SPARROW model, except when noted otherwise. Loads and percentages are rounded to the nearest integer. The totals do not sum exactly due to rounding with the individual source categories.

a. Refer to Appendix A for the sources included in the aggregated source categories.

b. MPCA (2023) estimated point sources loads, originally reported by HUC8.

Table 12. *Lake Superior* Major Basin Source Assessment with MPCA (2024) Estimated Point Source Loads

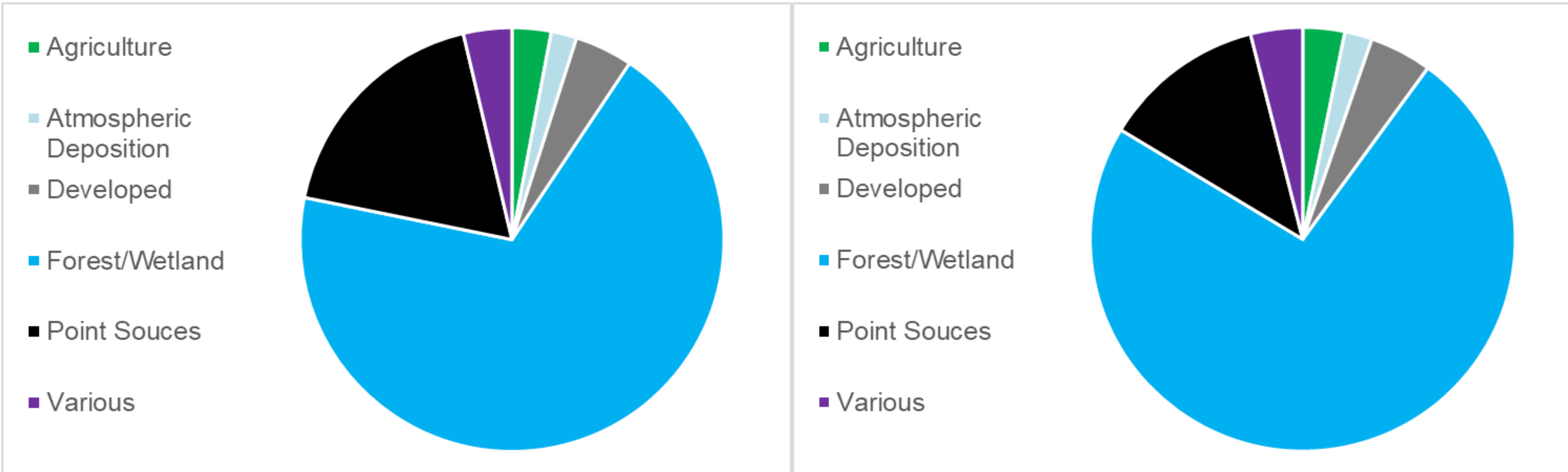
Source Category	TN Load	TP Load
Agriculture [a]	538,046 (3%)	32,634 (4%)
Atmospheric Deposition	354,067 (2%)	12,675 (2%)
Developed [a]	801,171 (5%)	30,858 (4%)
Forest/Wetland [a]	12,440,586 (74%)	526,016 (64%)
NPDES Permitted Wastewater Discharge [b]	2,095,615(12%)	60,335 (7%)
Various [a]	669,528 (4%)	156,079 (19%)
Total	*16,899,014 (100%)*	*818,597 (100%)*

Notes

Average annual loads (pounds per year) are from the HSPF or SPARROW model, except when noted otherwise. Loads and percentages are rounded to the nearest integer. The totals do not sum exactly due to rounding with the individual source categories.

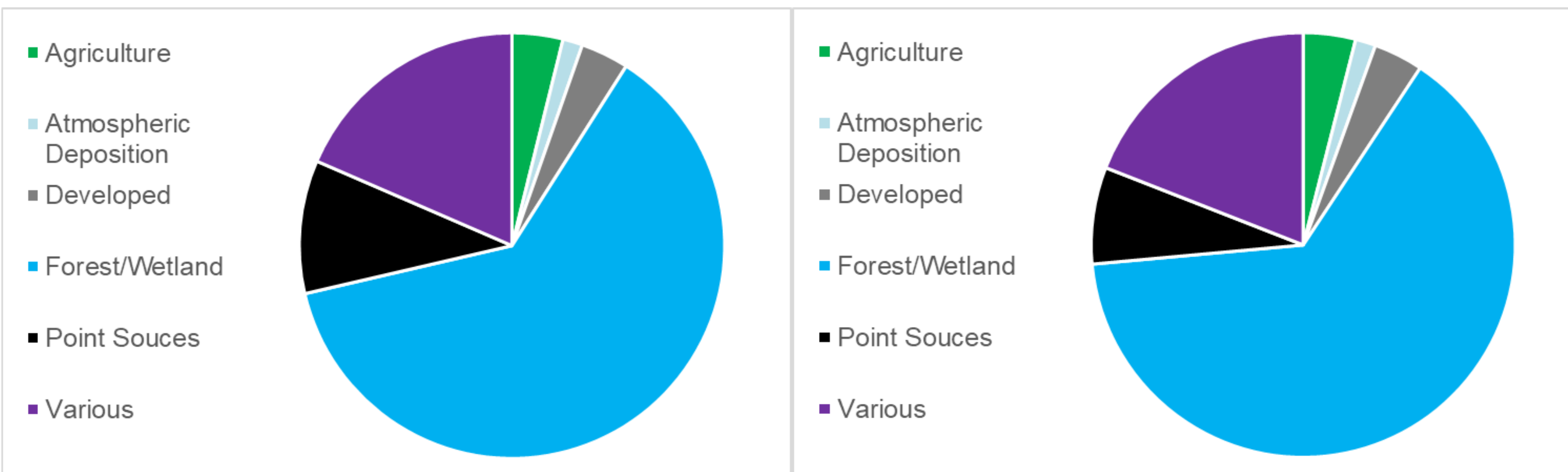
a. Refer to Appendix A for the sources included in the aggregated source categories.

b. MPCA (2024) estimated point sources loads, originally reported by major basin.



Left: MPCA (2023) point source estimates by HUC8. Right: MPCA (2024) point sources estimates by major basin.

Figure 8. Pie Charts of Average Annual TN Loading within the Lake Superior Basin.



Left: MPCA (2023) point source estimates by HUC8. Right: MPCA (2024) point sources estimates by major basin.

Figure 9. Pie Charts of Average Annual TP Loading within the Lake Superior Basin.

3.4 COMPARISON TO 2014 NRS SOURCE ASSESSMENT

The source assessment by major basin from the 2014 NRS (MPCA 2014; Table 13) was composed of 12 nutrient source categories. The source assessments provided in this section are only composed of six nutrient source categories because the SPARROW data only included six nutrient source categories. To allow for a more direct comparison, the 12 nutrient source categories from the 2014 NRS were aggregated into the seven source categories (Table 14), representing the six source categories from the source assessments presented in this section and a 7th residual category ("Other").

The source assessments presented in Sections 3.1, 3.2, and 3.3 are summarized in Table 15 and Table 16. The difference between these two tables is the estimated point sources loads: Table 15 uses loads by HUC8 subbasin (MPCA 2024) and Table 16 uses the loads by major basin the (MPCA 2023). These tables are color-coded to indicate the higher loading sources relative to other sources in the same major basin (green) and sources that contribute smaller load percentages (yellow). Key results of the comparison are summarized in the following three subsections.

Directly comparing the source assessment from the 2014 NRS (MPCA 2014) to the source assessment developed for this study is problematic because the individual source loads were estimated using different methods and assumptions. Thus, the differences between source percentages when comparing Table 14 to Table 15 or Table 16 are likely mostly due to the differences in methods and assumptions for estimating source loads. Real-world changes in sources may also be reflected in differences between source percentages (i.e., point source phosphorus reductions), but the real-world changes are likely significantly smaller than the changes due to differences in methods and assumptions.

The subsections below briefly summarize similarities and differences between the 2014 NRS source assessment and the source assessment developed for this study. Readers should not conclude that the similarities or differences are necessarily reflecting changes in land use and management. In-depth study would be necessary to determine how much the differences are due to real-world source changes since the 2014 NRS. The source assessments developed for this study, using HSPF and SPARROW modeling, are likely not predominantly representing changes since the sources assessment results presented in the 2014 NRS.

All the source categories were estimated using different methods and assumptions between the 2014 NRS and this new source assessment. The NPS for this source assessment are derived from the HSPF model that is not a groundwater model. As such, any groundwater flow pathway simulation in the HSPF models may be considerably different from the estimates for associated source categories in the 2014 NRS (i.e., *agricultural tile drainage* and *cropland groundwater*. The bed/bank erosion simulated in HSPF is presented herein as net gain in erosion; this does not represent the total sediment load that was simulated as eroding. Streambank erosion from the 2014 NRS should not be directly compared with the HSPF-derived bed/bank erosion (net gain).

Table 13. 2014 NRS Source Assessment (MPCA 2014)

Nutrient Source	Mississippi River		Lake Superior		Lake Winnipeg	
	N	P	N	P	N	P
Cropland runoff	5%	35%	2%	6%	11%	42%
Atmospheric [b]	6%	8%	10%	7%	21%	18%
NPDES permitted wastewater discharges [c]	9%	18%	31%	24%	6%	11%
Streambank erosion	--	17%	--	15%	--	6%
Urban runoff	1%	7%	1%	10%	0%	2%
Nonagricultural rural runoff [d]	--	4%	--	32%	--	15%
Individual sewage treatment systems	2%	5%	4%	3%	2%	3%
Agricultural tile drainage	43%	3%	5%	0%	7%	0%
Feedlot runoff	0%	2%	0%	0.10%	0%	0.30%
Roadway deicing	--	1%	--	2%	--	2%
Cropland groundwater [e]	31%	--	9%	--	35%	--
Forest	4%	--	38%	--	19%	--

Scale: Low → High

Notes

P = phosphorus; N = nitrogen

a. Source estimates were based on Barr Engineering (2004) with more recent MPCA updated wastewater (2011 conditions) and atmospheric deposition sources (2007). Source percentages do not represent what is delivered to the major basin outlets, but what is delivered to local waters.

b. Atmospheric deposition is to lakes and rivers (atmospheric deposition to wetlands is not reflected in this table).

c. Nutrient loads in the Lake Superior Major Basin are lower than other major basins in the state and therefore wastewater is a larger portion of the overall sources. The Western Lake Superior Sanitary District (Duluth area) accounts for more than 50%of the wastewater phosphorus load in the major basin.

d. Includes natural land cover types (forests, grasslands, and shrublands) and developed land uses that are outside the boundaries of incorporated urban areas.

e. Refers to nitrogen leaching into groundwater from cropland land uses.

Table 14. Source Assessment from 2014 NRS Aggregated to Similar Categories

Nutrient Source	Mississippi River		Lake Superior		Lake Winnipeg	
	N	P	N	P	N	P
Agriculture [a]	79%	40%	16%	6%	53%	42%
Atmospheric Deposition	6%	8%	10%	7%	21%	18%
Developed [b]	3%	13%	5%	15%	2%	7%
NPDES Permitted Wastewater Discharge	9%	18%	31%	24%	6%	11%
Other [c]	4%	21%	38%	47%	19%	21%

Scale: Low … High

Notes

Due to rounding in Table 13 and the aggregation of nutrient sources in this table, several columns sum to 99% or 101%.

a. *Agriculture* represents *Cropland runoff*, *Agricultural tile drainage*, *Feedlot runoff* and *Cropland groundwater* from Table 13.

b. *Developed* represents *Urban*, *Individual sewage treatment systems*, and *Roadway deicing* from Table 13.

c. *Other* represents *Streambank erosion*, *Nonagricultural rural runoff*, and *Forest* from Table 13.

Table 15. Source Assessment with Major Basin Scale MPCA (2024) Estimated Point Source Loads

Nutrient Source	Mississippi River		Lake Superior		Lake Winnipeg	
	N	P	N	P	N	P
Agriculture	79%	72%	3%	4%	48%	64%
Atmospheric Deposition	3%	2%	2%	2%	7%	4%
Developed	4%	7%	5%	4%	5%	6%
NPDES Permitted Wastewater Discharge	8%	6%	12%	7%	2%	2%
Other	7%	14%	78%	83%	38%	24%

Scale: Low … High

Table 16. Source Assessment with HUC8 Scale MPCA (2023) Estimated Point Source Loads

Nutrient Source	Mississippi River		Lake Superior		Lake Winnipeg	
	N	P	N	P	N	P
Agriculture	79%	72%	3%	4%	48%	63%
Atmospheric Deposition	3%	2%	2%	2%	7%	4%
Developed	4%	7%	4%	4%	5%	6%
NPDES Permitted Wastewater Discharge	8%	6%	18%	10%	5%	3%
Other	8%	14%	73%	81%	38%	24%

Scale: Low … High

3.4.1 *Mississippi River* Major Basin

Cropland is the predominant source of nitrogen in the *Mississippi River* major basin. In this new source assessment, cropland is 79% of the TN load, which is the same as the TN load in the 2014 NRS. For this analysis, *Cropland runoff*, *Agricultural tile drainage*, *Feedlot runoff*, and *Cropland groundwater* from the 2014 NRS were aggregated into the term "cropland".

Cropland runoff is also the predominant source of phosphorus in the *Mississippi River* major basin. In this new source assessment, cropland runoff is 72% of the TP load, compared with 40% in the 2014 NRS. One potential cause for this disparity is that *Streambank erosion* (17%) and *Individual sewage treatment systems* (5%) were included in the 2014 NRS but are not included in the new source assessment.

Additionally, in the new source assessment point sources loads are 6% of the TP load, as compared with 18% of the TP load in the 2014 NRS.

3.4.2 *Lake Winnipeg* Major Basin

Cropland is also the largest source of nitrogen and phosphorus in the *Lake Winnipeg* major basin. In this new source assessment, cropland is 48% of the TN load and 63% to 64% of the TP load, compared with 53% of the TN load and 42% of the TP load in the 2014 NRS. As previously discussed, four categories from the 2014 NRS were aggregated into cropland for this analysis.

Another notable difference is in the loads from atmospheric deposition. In the new source assessment, the loads are 7% for TN and 4% for TP, which are much smaller than the 21% for TN and 18% for TP in the 2014 NRS.

3.4.3 *Lake Superior* Major Basin

As was previously discussed, the point sources loads estimated by MPCA (2023, 2024) were considerably different. TN and TP loads were 12% and 7% (respectively) using the major basin estimates (MPCA 2024) and 18% and 10% (respectively) using the HUC8 estimates (MPCA 2023). Both sets of results were considerably smaller than the 2014 NRS estimates for TN (31%) and TP (24%). These new, smaller point sources loads are likely due to both (1) a different approach to estimating point sources loads and (2) load reduction at the permitted facilities.

The 2014 NRS estimated higher relative loads of atmospheric deposition (10% TN and 7% TP) compared with the new source assessment (2% TN and 2% TP).

4 SOURCE ASSESSMENT BY PATHWAY FOR TWO BASINS

This subsection provides two examples of more detailed source assessment results by flow delivery pathway for the Minnesota River Basin (MRB) and the Red River of the North Basin (RRNB). All contributing HUC8s within these two basins have calibrated HSPF watershed models, so several different source categories could be evaluated comprehensively for the basins. Furthermore, the HSPF model output allows for nutrient loads by hydrologic pathway (surface flow, interflow, and groundwater flow) to be shared.

HSPF models were not developed for one or more HUC8 subbasins in the *Upper Mississippi*, *St. Croix*, and *Lower Mississippi* basins. SPARROW modeling was used to represent the HUC8 subbasins without HSPF models for the source assessment presented in Section 3. Since SPARROW model results do not include flow delivery pathways, the SPARROW results cannot be used in the source assessment presented in this section. As such, it is not possible to evaluate the TN and TP loads by flow delivery pathways for the *Upper Mississippi*, *St. Croix*, and *Lower Mississippi* basins. Flow delivery pathway analyses could be completed for the Rainy River and Lake Superior basins because HSPF models are available for all the HUC8 subbasins in these two basins.

The following two subsections present annual average TN and TP loading in the MRB and RRNB. A key subset of analyses focus on the land-based sources for which HSPF pathway modeling is available. Atmospheric deposition, point sources, bed/bank erosion (net gain), and septic systems are identified as non-land-based sources and do not have HSPF pathway modeling results.

4.1 MINNESOTA RIVER BASIN

4.1.1 Total Nitrogen

Cropland is the largest source of TN in the MRB. Cropland is also the largest (93%) land-based source across all pathways (Table 17): surface flow (83%), interflow (96%), and groundwater (92%); the non-land-based sources are excluded from these calculations. The second largest land-based source is developed (4%), though it is a distant second: surface (13%), interflow (3%), and groundwater (4%).

Considering both land-based and non-land-based sources, the top three sources are cropland (88%), developed (4%), and point sources (4%). Grassland, pasture, and atmospheric deposition (in rank order) are the only other sources greater than or equal to 1% of the annual TN load. Source loads are summarized by category in a pie-chart presented in Figure 10.

Aggregated agricultural (i.e., cropland, agricultural tile drainage, and feedlots) source loads were evaluated by pathway. As expected, high TN loads for interflow and groundwater flow were simulated in subbasins with high levels of tiled corn-soybean production, which predominates in the subbasins in the southeast half of the MRB.

Table 17. Average Annual TN Loading by Source in the MRB

Nitrogen Source	Surface	Interflow	Groundwater	Total (% of Basin Total)
Land-based Sources [a]				
Bluff/Ravine Erosion	10,161	167	185	10,513 (0.0%)
Cropland	9,039,424	83,107,665	67,937,108	160,084,196 (88.4%)
Developed	1,430,172	2,422,055	3,202,831	7,055,059 (3.9%)
Feedlot	53,006	256,705	237,519	547,230 (0.3%)
Forest	48,301	167,057	160,395	375,753 (0.2%)
Grassland	38,815	523,450	1,033,268	1,595,532 (0.9%)
Pasture	68,654	523,689	873,505	1,465,848 (0.8%)
Wetland	204,834	6,819	525,156	736,809 (0.4%)
Non-land-based Sources				
Atmospheric Deposition				1,373,880 (0.8%)
Bed/Bank Erosion (Net Gain)				600,503 (0.3%)
NPDES Permitted Wastewater Discharge				6,433,512 (3.6%)
SSTS				799,534 (0.4%)

Notes

Average annual load (pounds per year).

a. Refer to Appendix A for the sources included in the aggregated source categories.

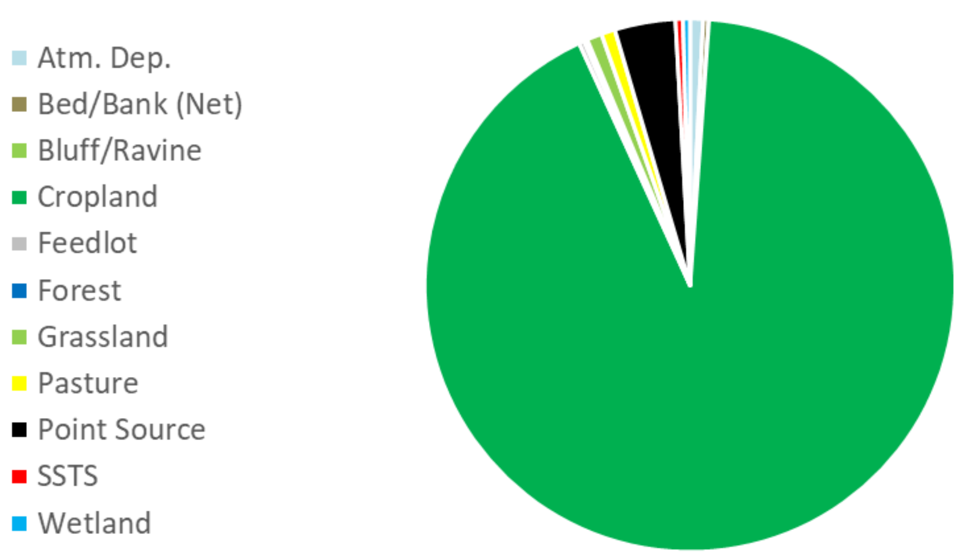


Figure 10. Pie Chart of the Average Annual TN Loading by Source within the MRB.

4.1.2 Total Phosphorus

Like with TN, cropland is the largest source of TP in the MRB. Cropland is also the largest (91%) land-based source across all pathways (Table 18): surface (85%), interflow (93%), and groundwater (93%); the non-land-based sources are excluded from these calculations. The second largest land-based source is developed (13%each): surface (5%), interflow (3%), and groundwater (6%).

Considering both land-based and non-land-based sources, the top three sources are cropland (82%), developed (5%), and bed/bank erosion (net gain; 5%). Point sources (4%) are the only other sources greater than 1% of the annual TP load. Source loads are summarized by category in a pie-chart presented in Figure 11.

The bed/bank erosion reported here in is the net gain in erosion; this does not represent the total sediment load that was simulated as eroding. Additionally, both the bed/bank erosion (net gain) and bluff/ravine erosion simulations include considerable uncertainty, due in part, to the availability of data and information to calibrate these processes in the HSPF models. Bluff/ravine erosion is only simulated in 10 of the 80 HUC8 subbasins. Since TP is bound to sediment, the uncertainties associated with bed/bank erosion (net gain) and bluff/ravine erosion also impact the simulated TP loads from these sources.

Analysis of aggregated agricultural source loads by pathway typically found higher TP loads with interflow and groundwater flow than surface flow across the MRB. The Chippewa and Cottonwood rivers were an exception. While high levels of tiled corn-soybean production likely contribute TP loads in interflow and groundwater, streambank erosion can also contribute high TP loads to groundwater. Phosphorus bound to channel-bottom sediment and streambank soils can be eroded by agricultural operations that changed the natural hydrology (e.g., pulse flows from tile outlets, channelization/straightening).

Table 18. Average Annual TP Loading by Source in the MRB

Phosphorus Source	Surface	Interflow	Groundwater	Total (% of Basin Total)
Land-based Sources [a]				
Bluff/Ravine Erosion	4,789	43	47	4,879 (0.1%)
Cropland	1,012,403	2,067,773	2,471,025	5,551,202 (81.8%)
Developed	158,037	101,442	81,759	341,239 (5.0%)
Feedlot	3,894	9,116	5,470	18,479 (0.3%)
Forest	717	6,759	6,591	14,066 (0.2%)
Grassland	6,894	22,820	33,629	63,342 (0.9%)
Pasture	6,704	23,703	33,374	63,782 (0.9%)
Wetland	199	428	25,780	26,407 (0.4%)
Non-land-based Sources				
Atmospheric Deposition				69,089 (1.0%)
Bed/Bank Erosion (Net Gain)				329,874 (4.9%)
NPDES Permitted Wastewater Discharge				244,524 (3.6%)
SSTS				60,597 (0.9%)

Notes
Average annual load (pounds per year).
a. Refer to Appendix A for the sources included in the aggregated source categories.

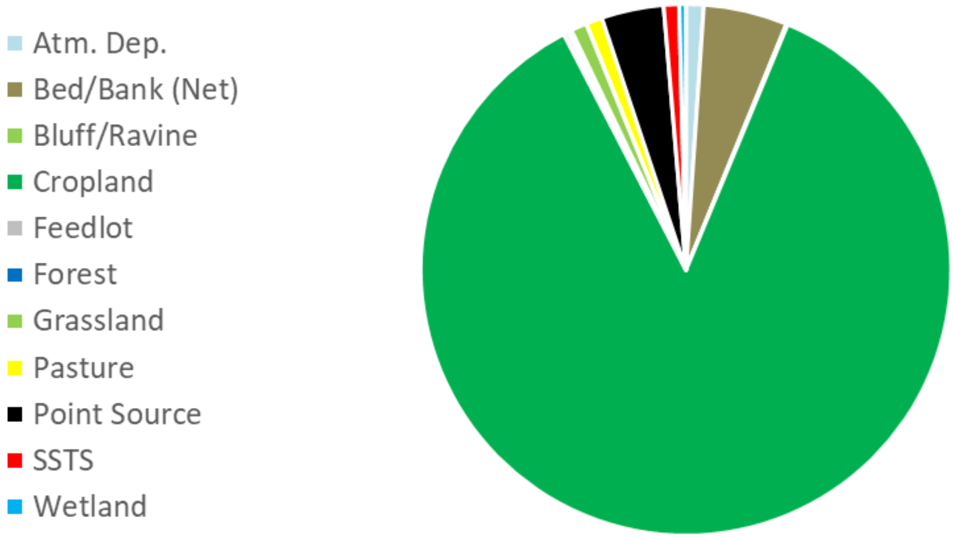


Figure 11. Pie chart of the Average Annual TP Loading by Source within the MRB.

4.2 RED RIVER OF THE NORTH BASIN

4.2.1 Total Nitrogen

Similar to the MRB, cropland is the largest source of TN in the RRNB. Cropland is also the largest (78%) land-based source across all pathways (Table 19): surface (85%), interflow (85%), and groundwater (67%); the non-land-based sources are excluded from these calculations. The second largest land-based source is developed (5%): surface (10%), interflow (4%), and groundwater (5%).

Considering both land-based and non-land-based sources, the top four sources are cropland (75%), developed (5%), atmospheric deposition (5%), and pasture (5%). Only feedlots and septic systems than 1% of the annual TP load. Source loads are summarized by category in a pie-chart presented in Figure 12.

Aggregated agricultural (i.e., cropland, agricultural tile drainage, and feedlots) source loads were evaluated by pathway (Table 19). A challenge with this evaluation is that the Red River of the North is the boundary between the states of Minnesota, North Dakota, and South Dakota, and the HSPF models presented herein are limited to the Minnesota-portions of the subbasins. Generally, the largest TN loads per subbasin are in interflow and groundwater throughout the RRNB. Surface TN loads are typically higher in the Upper RRN (HUC 090201), and surface TN loads exceed interflow and groundwater TN loads in the Buffalo and Wild Rice River subbasins.

Table 19. Average Annual TN Loading by Source in the RRNB

Nitrogen Source	Surface	Interflow	Groundwater	Total (% of Basin Total)
Land-based Sources [a]				
Cropland	4,656,037	11,284,839	9,505,542	25,446,418(71.9%)
Developed	556,486	474,107	700,467	1,731,059 (4.9%)
Feedlot	4,100	6,955	5,705	16,760 (0.0%)
Forest	62,782	293,389	1,184,676	1,540,848 (4.4%)
Grassland	46,588	104,317	384,865	535,770 (1.5%)
Pasture	125,053	469,204	1,036,801	1,631,058 (4.6%)
Wetland	14,248	200,825	1,331,082	1,546,155 (4.4%)
Non-land-based Sources				
Atmospheric Deposition				1,727,181 (4.9%)
Bed/Bank Erosion (Net Gain)				555,123 (1.6%)
NPDES Permitted Wastewater Discharge				571,783 (1.6%)
SSTS				102,844 (0.3%)

Notes

Average annual load (pounds per year).

a. Refer to Appendix A for the sources included in the aggregated source categories. No bluff/ravine erosion was simulated in the Red River of the North basin.

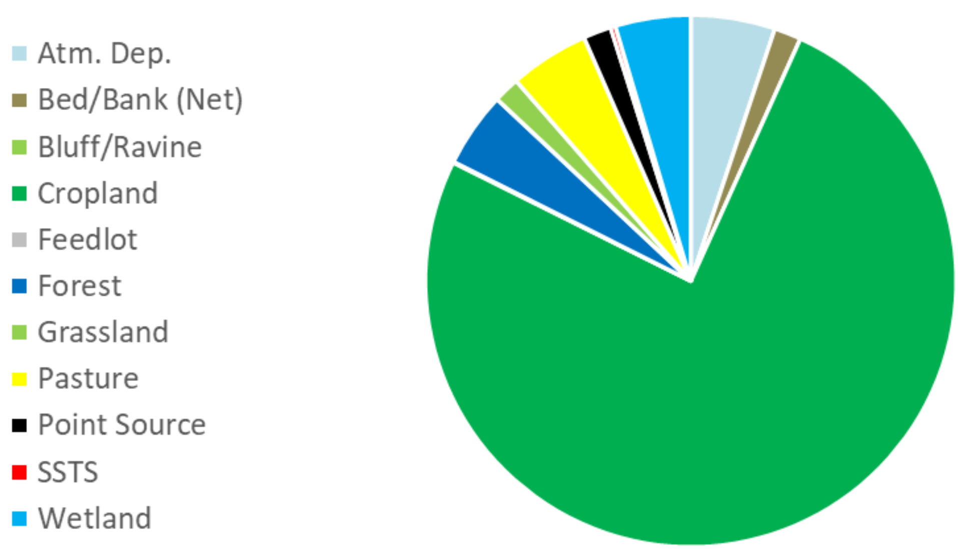


Figure 12. Pie chart of the Average Annual TN Loading by Source within the RRNB.

4.2.2 Total Phosphorus

Again, similar to the MRB, cropland is the largest source of TP in the RRNB. Cropland is also the largest (84%) land-based source across all pathways (Table 20): surface (91%), interflow (90%), and groundwater (75%); the non-land-based sources are excluded from these calculations. The second largest land-based source is developed (5%): surface (7%), interflow (4%), and groundwater (5%).

Considering both land-based and non-land-based sources, the top four sources are cropland (78%) and developed (5%). Only feedlots and septic systems than 1% of the annual TP load. Source loads are summarized by category in a pie-chart presented in Figure 13

Tetra Tech found no trends through visual analysis of aggregated agricultural source loads by pathway across the RRNB. The Upper Red River of the North subbasin had the largest surface TP loads, which were three times greater than any other subbasin. The Otter Tail River subbasin had the largest groundwater TP load, which was due to a large groundwater contribution from cropland.

Table 20. Average Annual TP Loading by Source in the RRNB

Phosphorus Source	Surface	Interflow	Groundwater	Total (% of Basin Total)
Land-based Sources [a]				
Cropland	800,590	1,138,145	965,055	2,903,790 (77.8%)
Developed	64,397	51,343	69,499	185,239 (5.0%)
Feedlot	932	1,024	440	2,396 (0.1%)
Forest	3,002	18,552	68,488	90,042 (2.4%)
Grassland	2,236	9,112	27,405	38,752 (1.0%)
Pasture	7,124	34,379	81,536	123,038 (3.3%)
Wetland	201	16,408	79,177	95,786 (2.6%)
Non-land-based Sources				
Atmospheric Deposition				130,277 (3.5%)
Bed/Bank Erosion (Net Gain)				95,160 (2.5%)
NPDES Permitted Wastewater Discharge				60,690 (1.6%)
Septic				7,083 (0.2%)

Notes

Average annual load (pounds per year).

a. Refer to Appendix A for the sources included in the aggregated source categories. No bluff/ravine erosion was simulated in the Red River of the North basin.

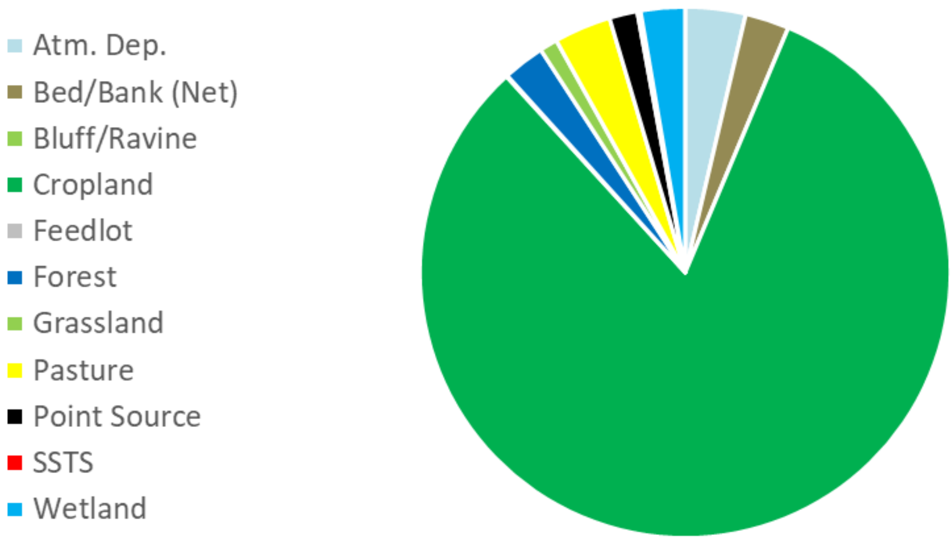


Figure 13. Pie chart of the Average Annual TP Loading from Land-Based Sources within the RRNB.

5 REFERENCES

MPCA. 2014. *The Minnesota Nutrient Reduction Strategy*. Document number wq-s1-80. St. Paul, MN. September 2014. https://www.pca.state.mn.us/sites/default/files/wq-s1-80.pdf.

MPCA. 2022. *Watershed nutrient loads to accomplish Minnesota's Nutrient Reduction Strategy Goals: Interim Guidance for Watershed Strategies and Planning*. Document number wq-s1-86. St. Paul, MN. https://www.pca.state.mn.us/sites/default/files/wq-s1-86.pdf.

MPCA. 2023. Point sources loads by point source [MN NPDES nutrients 2022.xlsx]. Provided by Dave Wall (MPCA) via electronic mail on December 20, 2023.

MPCA. 2024. Point sources loads by major basin [2005-2023 WW Loads.xlsx]. Provided by Dave Wall (MPCA) via electronic mail on June 10, 2024.

USGS. 2019a. *SPARROW modeling: Estimating nutrient, sediment, and dissolved solids transport*. U.S. Department of the Interior, USGS, Water Resources Mission Area. March 3, 2019. https://www.usgs.gov/mission-areas/water-resources/science/sparrow-modeling-estimating-nutrient-sediment-and-dissolved.

USGS. 2019b. *2002 SPARROW Model Results for the Midcontinental Region of North America: Total Phosphorus and Total Nitrogen*. U.S. Department of the Interior, USGS. https://sparrow.wim.usgs.gov/midcontinent-2002/. Downloaded December 6, 2023.

APPENDIX A. MODEL SOURCE CATEGORIES AGGREGATION

Table 21. Aggregated source categories for HSPF modeling results for the major drainage basins (Section 3)

Aggregated Source Category	HSPF Source (HRU)
Agriculture	Cropland, Cropland A Cons, Cropland A Conv, Cropland A Manure, Cropland AB, Cropland B Cons, Cropland B Conv, Cropland B Manure, Cropland CD, Cropland CD Cons, Cropland CD Conv, Cropland Drained, Cropland Drained Cons, Cropland Drained Conv, Cropland Drained Manure, Cropland HighTill, Cropland HighTill AB, Cropland HighTill ABC, Cropland HighTill C, Cropland HighTill CD, Cropland HighTill D, Cropland HighTill Drained, Cropland HighTill Manured AB, Cropland HighTill Manured Drained, Cropland LowTill, Cropland LowTill AB, Cropland LowTill ABC, Cropland LowTill C, Cropland LowTill CD, Cropland LowTill D, Cropland LowTill Drained, Cropland Manure, Cropland Manure ABC, Cropland Manure D, Cropland Manured AB, Cropland Manured CD, Cropland Riparian, Cropland Tile Drainage, Cropland/Pasture AB, Cropland/Pasture CD, Feedlot, Feedlot, Groundwater, Pasture A, Pasture AB, Pasture ABC, Pasture All, Pasture B, Pasture CD, Pasture D, Pasture High RO, Pasture Low RO, Riparian
Developed	Developed AB, Developed ABC, Developed All, Developed CD, Developed D, Developed EIA, Developed EIA Low, Developed EIA Medium, Developed EIA Open, Developed High Density, Developed High Density EIA, Developed Low, Developed Low Density, Developed Low Density EIA, Developed Low EIA, Developed Low Intensity, Developed Med-High, Developed Med-High EIA, Developed Medium, Developed Medium Density, Developed Medium Density EIA, Developed Medium Intensity, Developed Medium-High Density, Developed Medium-High Density EIA, Developed Open, Developed Open EIA, Developed Open Space, Developed Open Space EIA, Developed Road, Developed Road EIA, Developed Road Paved EIA, Developed Road Unpaved EIA
Forest/Wetland	Forest, Forest A, Forest AB, Forest ABC, Forest B, Forest C, Forest CD, Forest Conifer, Forest Conifer AB, Forest Conifer CD, Forest Conifer D, Forest D, Forest Deciduous, Forest Deciduous AB, Forest Deciduous CD, Forest Deciduous D, Forest High RO, Forest Low RO, Forest Regrowth AB, Forest Regrowth CD, Forest Young AB, Forest Young CD, Water, Wetland, Wetland Herbaceous, Wetland Woody, Wetland Woody AB, Wetland Woody CD
Various	Barren, Bluff/Ravine, Grassland A, Grassland AB, Grassland ABC, Grassland All, Grassland B, Grassland CD, Grassland D, Grassland High RO, Grassland Low RO, Grassland Riparian, Grassland/Shrubland AB, Grassland/Shrubland CD, Grassland/Shrubland D, Herbaceous, Riparian

Notes

HRU = Hydrologic Response Unit; HSPF = Hydrologic Simulation Program – FORTRAN.

Only a subset of HRUs are included in each HSPF model.

Atmospheric deposition (Atm. Dep.), permitted point sources (Point), net bank/bed erosion(Bed/Bank), subsurface sewage treatment systems (Septic)are additional sources in the HSPF models but are not land-based HRUs.

Table 22. Aggregated source categories for the source assessment by flow delivery pathway presented in Section 4

Aggregated Source Category	HSPF Source (HRU)
Bluff/ravine erosion	Bluff/Ravine
Cropland	Cropland, Cropland A Cons, Cropland A Conv, Cropland A Manure, Cropland AB, Cropland B Cons, Cropland B Conv, Cropland B Manure, Cropland CD, Cropland CD Cons, Cropland CD Conv, Cropland Drained, Cropland Drained Cons, Cropland Drained Conv, Cropland Drained Manure, Cropland HighTill, Cropland HighTill AB, Cropland HighTill ABC, Cropland HighTill C, Cropland HighTill CD, Cropland HighTill D, Cropland HighTill Drained, Cropland HighTill Manured AB, Cropland HighTill Manured Drained, Cropland LowTill, Cropland LowTill AB, Cropland LowTill ABC, Cropland LowTill C, Cropland LowTill CD, Cropland LowTill D, Cropland LowTill Drained, Cropland Manure, Cropland Manure ABC, Cropland Manure D, Cropland Manured AB, Cropland Manured CD, Cropland Riparian, Cropland Tile Drainage, Cropland/Pasture AB, Cropland/Pasture CD, Groundwater
Developed	Developed AB, Developed ABC, Developed All, Developed CD, Developed D, Developed EIA, Developed EIA Low, Developed EIA Medium, Developed EIA Open, Developed High Density, Developed High Density EIA, Developed Low, Developed Low Density, Developed Low Density EIA, Developed Low EIA, Developed Low Intensity, Developed Med-High, Developed Med-High EIA, Developed Medium, Developed Medium Density, Developed Medium Density EIA, Developed Medium Intensity, Developed Medium-High Density, Developed Medium-High Density EIA, Developed Open, Developed Open EIA, Developed Open Space, Developed Open Space EIA, Developed Road, Developed Road EIA, Developed Road Paved EIA, Developed Road Unpaved EIA
Feedlot	Feedlot, Feedlot Riparian
Forest	Forest, Forest A, Forest AB, Forest ABC, Forest B, Forest C, Forest CD, Forest Conifer, Forest Conifer AB, Forest Conifer CD, Forest Conifer D, Forest D, Forest Deciduous, Forest Deciduous AB, Forest Deciduous CD, Forest Deciduous D, Forest High RO, Forest Low RO Forest Regrowth AB, Forest Regrowth CD, Forest Young AB, Forest Young CD
Grassland	Barren, Grassland A, Grassland AB, Grassland ABC, Grassland All, Grassland B, Grassland CD, Grassland D, Grassland High RO, Grassland Low RO, Grassland Riparian, Grassland/Shrubland AB, Grassland/Shrubland CD, Grassland/Shrubland D, Herbaceous, Shrubland AB, Shrubland CD
Pasture	Pasture A, Pasture AB, Pasture ABC, Pasture All, Pasture B, Pasture CD, Pasture D, Pasture High RO, Pasture Low RO
Wetland	Riparian, Water, Wetland, Wetland Herbaceous, Wetland Woody, Wetland Woody AB, Wetland Woody CD

Notes

HRU = Hydrologic Response Unit; HSPF = Hydrologic Simulation Program – FORTRAN.

Only a subset of HRUs are included in each HSPF model.

Atmospheric deposition (Atm. Dep.), permitted point sources (Point), net bank/bed erosion(Bed/Bank), subsurface sewage treatment systems (Septic)are additional sources in the HSPF models but are not land-based HRUs.

Table 23. Aggregated source categories for SPARROW modeling results for the major drainage basins (Section 3)

Aggregated Source Category	SPARROW source
Atmospheric deposition	Atmospheric deposition [a]
Cropland	Agricultural land [b], Farm fertilizer
Developed	Urban land
Feedlot	Manure
Forest/wetland	Forest/wetland [b]
Point sources	Sewerage point sources

Notes
SPARROW = SPAtially-Referenced Regression On Watershed attributes model.
a. *Atmospheric deposition* is only a source for nitrogen.
b. *Agricultural land* and *Forest/wetland* are only sources for phosphorus.