Watershed nutrient loads

August 2022

Attachment A

Approach and Methods for the interim guidance, “Watershed Nutrient Loads to Accomplish Minnesota’s Nutrient Reduction Strategy Goals”

MINNESOTA POLLUTION CONTROL AGENCY

Contributors

Attachment A is based largely on the work and writings of Derek Schlea, Hans Holmberg and Ben Crary of LimnoTech conveyed to the MPCA in a memo entitled “Updating Nutrient Reduction Strategy to Strengthen Linkages with Watersheds and WRAPS.” Additions and edits were completed by Dave Wall (MPCA), and maps were developed by Ashley Ignatius (MPCA).

Attachment A

Approach and Methods for the interim guidance, “Watershed Nutrient Loads to Accomplish Minnesota’s Nutrient Reduction Strategy Goals”

Purpose:

This Attachment includes the detailed methods and results associated with the process of determining nutrient load targets and planning goals for the outlet of each HUC8 watershed in Minnesota, as described in “Watershed Nutrient Loads to Accomplish Minnesota’s Nutrient Reduction Strategy Goals.”

The methods and results for Minnesota’s HUC8 nutrient reduction planning targets were described in a memorandum by Derek Schlea, Hans Holmberg and Ben Crary of LimnoTech (Schlea et al. 2020). The memorandum, entitled “Updating Nutrient Reduction Strategy to Strengthen Linkages with Watersheds and WRAPS,” was completed in collaboration with the Minnesota Pollution Control Agency (MPCA). This attachment uses the work by Schlea et al. (2020), and was modified by MPCA to 1) extract the methods relevant to the interim guidance document; 2) supplement background information about baseline loads, 3) combine the Cedar, Des Moines and Missouri River Watersheds together with all other watersheds that ultimately drain to the Missississippi River, and 4) update nutrient load information from some watersheds that were recently re-modeled and correspondingly update statewide maps.

The methods described in this attachment are divided into four separate steps that led to the determination of load reduction planning targets for meeting meet downstream needs.

Step 1 - Compile and compare recent monitoring and modeling load estimates
Step 2 - Estimate natural background or nonreducible nutrient loads
Step 3 - Estimate nutrient attenuation factors
Step 4 - Update nutrient reduction goals

The methods and results for each step are described below.

Minnesota Pollution Control Agency

520 Lafayette Road North | Saint Paul, MN 55155-4194 |

651-296-6300 | 800-657-3864 | Or use your preferred relay service. | Info.pca@state.mn.us

This report is available in alternative formats upon request, and online at www.pca.state.mn.us.

Document number: wq-s1-86a

Step 1 - Compile and compare recent monitoring and modeling load estimates

Estimating load reductions needed to meet NRS goals first requires estimating “current day” TP and TN loads, often referred to as “recent” loads since they typically represent a ten-year average period that ended several years ago. Current day load estimates represent watershed conditions for the most recent years available when this task was conducted in 2019. For the purposes of this project, current day load estimates for individual HUC8 watersheds were developed to address the following constraints:

- The Minnesota-only portion of the drainage area (i.e., exclude loading from Canada and other states);
- The local HUC8 loading contribution (i.e., not cumulative for HUC8s with one or more HUC8 watersheds draining into it);
- The total HUC8 loading contribution (i.e., combine all loads for HUC8 watersheds with multiple outlets); and
- The HUC8 loading at the watershed outlet(s) or the point(s) at which rivers last leave the state (i.e., account for internal nutrient attenuation of loads to the receiving stream within a HUC8 watershed).

LimnoTech compiled TP and TN load estimates from Minnesota’s Watershed Pollutant Load Monitoring Network (WPLMN), MPCA’s HSPF models, and the USGS SPARROW model. They compared average annual load predictions for HUC8 watersheds where multiple load estimates existed. The purpose of these comparisons was to evaluate each approach for potential use in deriving statewide, current day load estimates for the updated nutrient reduction calculations. This section describes the comparison of the three load estimation approaches and the additional processing of HSPF load estimates to address the constraints listed above.

Basin and Watershed Scale Comparisons

LimnoTech compared TP and TN load estimates from WPLMN, HSPF, and SPARROW to evaluate similarities and differences between the data-based and model-based estimation approaches. The WPLMN characterizes monitoring sites along the mainstems of the Mississippi, Minnesota, Rainy, Red, Cedar, Des Moines, and St. Croix rivers as “basin” scale sites. HSPF models of the mainstem Red and St. Croix rivers were not available, so comparisons were not completed for the basin scale sites on these waterbodies. For the purposes of the basin scale load comparison analysis, the St. Louis River monitoring site at Scanlon was added as a representative location for the Lake Superior basin. The WPLMN characterizes “major watershed” scale monitoring sites as those with a drainage area of approximately 1,350 square miles. The subset of the WPLMN watershed scale sites best corresponding to HUC8 watershed outlets as represented in the HSPF models were compared below.

LimnoTech compared TP and TN load estimates from WPLMN, HSPF, and SPARROW to evaluate similarities and differences between the data-based and model-based estimation approaches. The WPLMN characterizes monitoring sites along the mainstems of the Mississippi, Minnesota, Rainy, Red, Cedar, Des Moines, and St. Croix rivers as “basin” scale sites. HSPF models of the mainstem Red and St. Croix rivers were not available, so comparisons were not completed for the basin scale sites on these waterbodies. For the purposes of the basin scale load comparison analysis, the St. Louis River monitoring site at Scanlon was added as a representative location for the Lake Superior basin. The WPLMN characterizes “major watershed” scale monitoring sites as those with a drainage area of approximately 1,350 square miles. The subset of the WPLMN watershed scale sites best corresponding to HUC8 watershed outlets as represented in the HSPF models were compared below. Results of the basin scale comparisons are shown in Tables 4 and 5. The averaging period is also presented in the tables. These were based on the maximum overlap between the WPLMN information and HSPF model results. The SPARROW model was developed with source inputs and management practices corresponding to a base year of 2012, represents long-term average loads for 1999-2014, and was calibrated with monitoring sites throughout the entire Midwest (Robertson and Saad, 2019). Therefore, output from SPARROW represents a slightly different time period than that from WPLMN and HSPF. For TP, the HSPF load estimates were closer with the WPLMN estimates for most sites as compared to SPARROW, with one notable exception for the Rainy River. The largest relative differences between HSPF and WPLMN were for the Cedar River and Des Moines River sites. Of the basin scale sites evaluated, the SPARROW TP load estimates for the Des Moines River were closer to the WPLMN estimates than the HSPF estimates. Both HSPF and SPARROW TN load estimates were in relatively good agreement with the WPLMN estimates at all basin scale sites evaluated. The largest deviations for the HSPF-based TN estimates relative to the WPLMN values were for the Rainy River (32% lower) and the Des Moines River (18% higher).

Results of the watershed scale comparisons are shown in Figures 2 and 3. Similar to the basin scale results for TP, the HSPF watershed scale load estimates were generally in good agreement for most sites with the WPLMN estimates, while the SPARROW TP load estimates tended to be higher (overall). The watershed scale comparison for TN showed good agreement across all three load estimation approaches, which was the same finding as the basin scale comparison.

Based on these comparisons, LimnoTech and MPCA determined that use of the HSPF results to characterize current day loads was most advantageous for the following reasons:

- HSPF models have been calibrated closely to the same data used in WPLMN. As a result, HSPF and WPLMN estimates of current day TP loads compare more closely than SPARROW and WPLMN;
- HSPF models predict daily values based on inputs such as precipitation, while WPLMN estimates extrapolate between observed data points;
- HSPF models have been developed and calibrated at the HUC8 scale, or finer, for time periods ranging 1996-2016. The SPARROW model was developed from statistical relationships developed over much larger areas and calibrated to the 1999-2014 period, and therefore provides different results from HSPF, particularly at the HUC8 scale; and
- HSPF models have been developed to cover a vast majority of the 81 HUC8s in Minnesota, WPLMN estimates do not cover as many HUC8s.

Table 1: Comparison of WPLMN, HSPF, and SPARROW estimated annual average TP loads for nine basin scale sites in Minnesota

WPLMN Station	Averaging Period (WPLMN and HSPF)	TP (metric tons per year)		
		WPLMN	HSPF	SPARROW
Minnesota River at St. Peter	2007-2012	1,503	1,462	2,484
Minnesota River near Jordan [1]	2007-2012	1,609	1,609	2,752
Minnesota River at Fort Snelling [1]	2007-2012	1,609	1,710	3,000
Mississippi River near Royalton	2007-2011,2014-2015	257	257	495
Mississippi River at Sauk Rapids	2007-2011,2014-2015	320	319	644
Rainy River at Manitou Rapids	2010-2014	383	290	164
St. Louis River at Scanlon	2009-2011,2014	88	80	179
Cedar River near Austin	2008-2011	115	77	233
W. Fork Des Moines River at Jackson	2007-2011,2014	150	286	235

1 – The Minnesota River near Jordan WPLMN and HSPF and Minnesota River at Fort Snelling WPLMN TP loads were all 1,609 MT for this averaging period, when rounded to the nearest whole number.

Table 2: Comparison of WPLMN, HSPF, and SPARROW estimated annual average TN loads for nine basin scale sites in Minnesota

WPLMN Station	Averaging Period (WPLMN and HSPF)	TN (metric tons per year)		
		WPLMN	HSPF	SPARROW
Minnesota River at St. Peter	2007-2012	41,543	41,339	38,477
Minnesota River near Jordan	2007-2012	51,464	45,406	42,855
Minnesota River at Fort Snelling	2007-2012	50,978	47,136	44,943
Mississippi River near Royalton	2007-2015	5,498	5,146	4,835
Mississippi River at Sauk Rapids	2007-2015	6,206	6,133	6,421
Rainy River at Manitou Rapids	2010-2014	8,513	5,778	6,436
St. Louis River at Scanlon	2009-2014	2,279	2,147	1,665
Cedar River near Austin	2008-2012	2,881	2,658	2,704
W. Fork Des Moines River at Jackson	2007-2014	3,698	4,361	3,055

Figure 1: Scatterplot comparison of HSPF and SPARROW vs. WPLMN estimated annual average TP loads for watershed scale sites in Minnesota

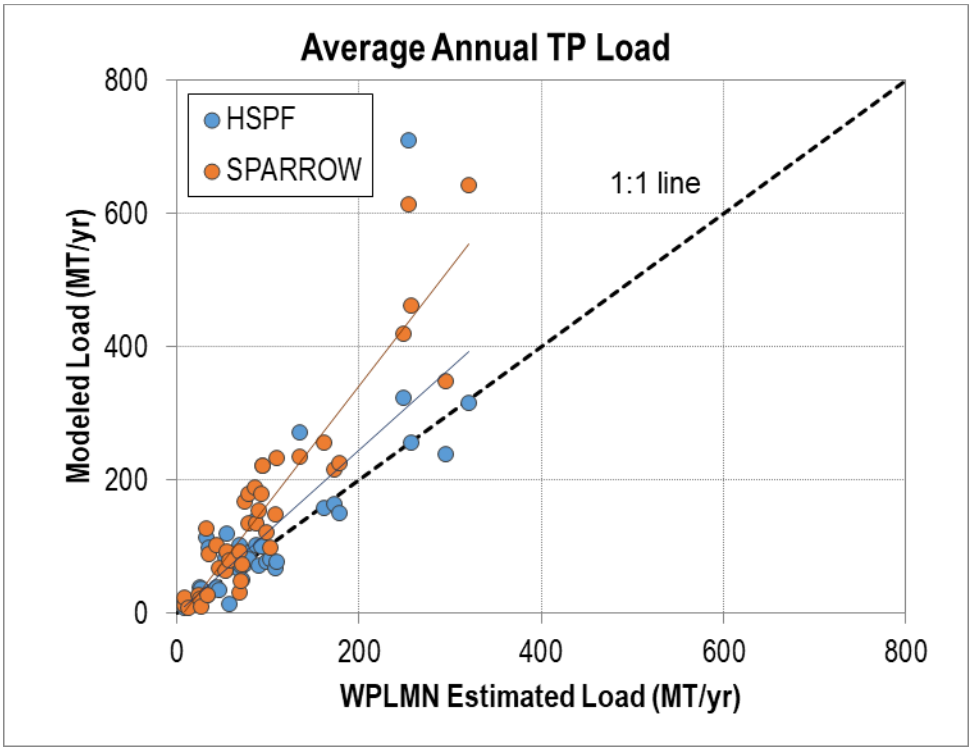
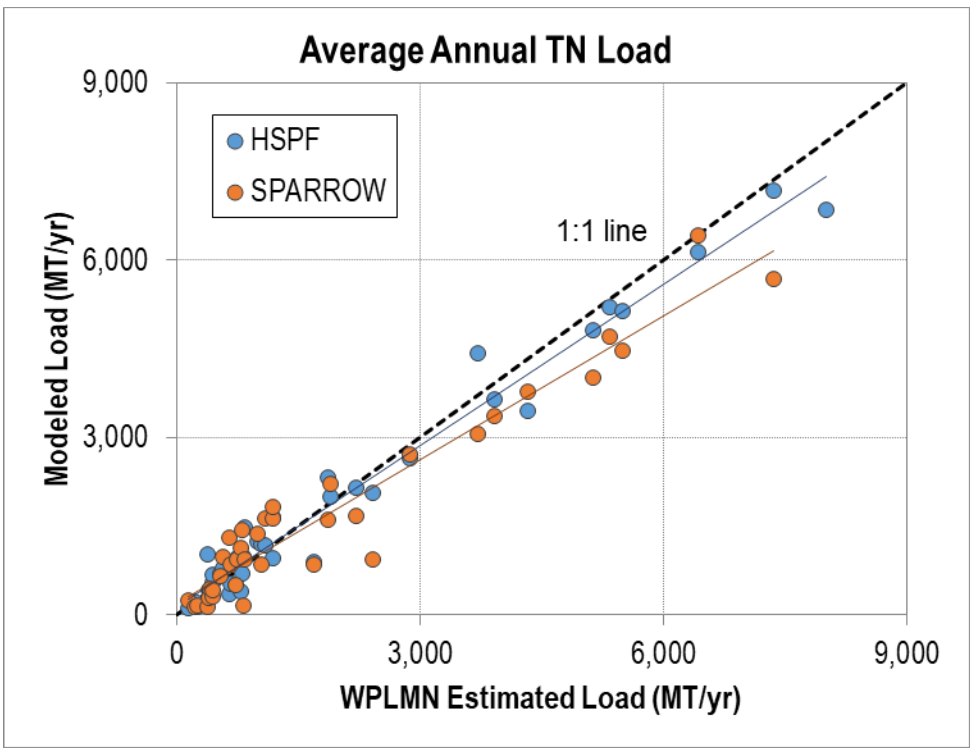


Figure 2: Scatterplot comparison of HSPF and SPARROW vs. WPLMN estimated annual average TN loads for watershed scale sites in Minnesota



HSPF Load Processing

Various processing steps were implemented to convert several of the HSPF annual load estimates provided to LimnoTech by MPCA into the current day load estimates needed for the updated nutrient reduction calculations. First, average annual loads were computed for the most recent 10-year period simulated by each model. A 10-year period was chosen to average the impact of relatively wet or dry years or periods. The last 10 years was chosen rather than the entire simulation period to account for any reductions in point sources and other loading changes that have occurred in recent years.

Meeting the requirements of the constraints previously listed required additional processing of the HSPF load estimates provided to LimnoTech, which included one or more of the complexities listed in Table 6. By addressing the complexities of the HSPF models using the solutions listed in Table 6, we were able to develop current day load estimates for each HUC8 watershed with an existing HSPF model and accommodate the constraints previously listed. Where HSPF models were not available at the time this task was completed in 2019, we filled the gaps by using WPLMN-based TP and TN yield estimates for monitoring locations within the HUC8 watershed or in neighboring watersheds.

Table 3: HSPF load estimate complexities, applied solutions, and applicable watersheds.

Complexity	Solution(s)	Applicable Watershed(s)
Loading includes non-Minnesota drainage areas	Use HSPF-SAM subbasin scale delivered loading and Minnesota-fraction of each subbasin to estimate Minnesota-only loading	Multiple watersheds in the Rainy, Red, St. Croix, Cedar, Des Moines, Iowa, Missouri, and Minnesota river basins
Multiple HUC8 watersheds represented in a single HSPF model	Use HSPF-SAM to estimate loading for outlet reaches not provided	Rainy River (Upper Rainy, Lower Rainy, and Rapid)
Watershed/model has multiple outlet points	Use HSPF-SAM to estimate loading for outlet reaches not provided	Lake Superior North, Lake Superior South, Chippewa, and Tamarac
Watershed/model has one or more HUC8 watersheds upstream	Use HSPF-SAM to estimate proportion of HUC8 outlet loading attributable to upstream boundaries	Crow Wing, North Fork Crow, Blue Earth, Red Lake River, Bois de Sioux, Lower West Fork Des Moines, Mississippi and Minnesota river mainstem HUC8s

Step 2 - Estimate natural background or nonreducible nutrient loads

In Step 1, LimnoTech developed an estimate of natural nutrient loading for each HUC8 watershed. The primary purpose of this analysis was to inform adjustments to nutrient reduction goals by distinguishing reducible and nonreducible load sources, emphasizing reduction goals based on the reducible fraction. Several approaches to quantifying natural nutrient loading were reviewed over the course of this study (Table 7). The paleolimnological studies of Engstrom et al. (2000) and Edlund et al. (2009) were limited in that they only estimated TP, not TN, and they were only representative of a portion of Minnesota. The statistical-based approach of estimating natural background nutrient yields based on major ecoregion (Smith et al., 2003) resulted in background load estimates for several HUC8 watersheds that were substantially higher than the current day load estimated by HSPF and WPLMN. The SPARROW model-based estimates were considered the best alternative methodology, but did not explicitly account for natural background sources of TN (Robertson and Saad, 2019). Therefore, LimnoTech chose to use the 10-year average HSPF model predicted TP and TN loading contributions attributable to various source categories for individual HUC8 watersheds using the approach described in the next section.

What could potentially be considered as nonreducible loads of TP and TN may result from the following (MPCA, 2018):

- Surface runoff from the natural landscape;
- Background stream channel erosion;
- Groundwater discharge from the natural landscape; and
- Atmospheric deposition, including windblown particulate matter from the natural landscape.

Internal loads of TP and TN from nutrient cycling in lakes and reservoirs can be from both natural sources and anthropogenic sources and, therefore, portions of the load considered either reducible or nonreducible.

Table 4: Potential approaches investigated for possible use in estimating natural or non-reducible nutrient loading

Approach	Description	Reference(s)
Paleolimnological / mass balance studies	Studies by the St. Croix Watershed Research Station estimating historical nutrient flux into and out of major Minnesota water bodies	Engstrom et al. (2000) Edlund et al. (2009)
Statistical	National data synthesis studies estimating TP and TN yields by ecoregion using land-based characteristics	Smith et al. (2003)
SPARROW model-based estimates	Data-driven, empirical approach for estimating TP and TN loading contributions from 5 or 6 major categories	Robertson and Saad (2019)
HSPF model-based estimates	HUC8 watershed models developed and calibrated with TP and TN load apportionment capabilities to point source and various non-point source categories	MPCA (2014)

Reducible Load Estimates – Approach

Estimating reducible and nonreducible load fractions from the HSPF models involved a number of steps. First, the HSPEXP+ software was used to export modeled TP and TN loads for various point source and nonpoint source categories for every model subbasin, averaged for the last 10 years of the model simulation period. The modeled TP and TN loads used for this subtask represent the gross nutrient loading into the receiving waters within a watershed, rather than the loads making it to the watershed outlet. A 10-year period was chosen to average the impact of relatively wet or dry years or periods. The last 10 years was chosen rather than the entire simulation period to account for any reductions in point source loading that have occurred in recent years.

Second, numerous nonpoint source categories were collapsed into a smaller group of common categories. Although all the Minnesota HSPF models were constructed in a relatively similar fashion with respect to representing landside, atmospheric, and point source loading categories, the specific naming convention used for land segments varied considerably across all models. The collapsing of original categories into common categories shown in Table 8 facilitated more uniform classification of landside loading into reducible or nonreducible sources across all models.

Third, after arriving at the common group of loading categories, an average yield for each category was calculated. Initial attempts at defining reducible fractions for each category were completed by LimnoTech, and revisions were made after consultation with MPCA. Grassland yields were ultimately selected as a baseline for characterizing a nonreducible yield, and the reducible fraction of each category was assigned based on its relative difference from the average grassland yield (Table 8). If a category's average yield was less than the average grassland yield (0.14 lbs TP/acre/year and 2.5 lbs TN/acre/year), no reductions could reasonably be expected, and the reducible fraction was assigned as zero. We recognize that although some categories were classified as >75% reducible, it may not be practical to reduce this much of the loading. An example calculation is shown for the cropland TP reducible fraction:

$$Cropland\ TP\ reducible\ fraction = \frac{Cropland\ TP\ yield - Grassland\ TP\ yield}{Cropland\ TP\ Yield}$$

$$Cropland\ TP\ reducible\ fraction = \frac{0.68\frac{lbs}{acre} - 0.14\frac{lbs}{acre}}{0.68\ \frac{lbs}{acre}} = 80\%$$

These assignments were not meant in any way to suggest that these loads can or should be reduced by that quantity. Rather, the purpose of this analysis and the reducible fraction assignments was to inform the eventual updates to the nutrient reduction targets so that watersheds with a dominance of natural landscapes and relatively low nutrient loading do not receive the exact same percentage reduction targets as highly anthropogenic-influenced watersheds with elevated nutrient loading.

The final step involved multiplying each common loading category by its reducible fraction and then summing the individual gross nutrient loads across all subbasins and loading categories for each HUC8 watershed.

Table 5: Original HSPF model loading categories, new collapsed categories, HSPF area-weighted average annual yields, and reducible fraction assignments

Collapsed Categories	Original Categories (examples, not exhaustive)	Area-weighted Average Annual Yield TP (lbs/ac)	TN (lbs/ac)	Assumed Reducible Fraction TP	TN
Grassland	Grassland-AB soils, Grassland-CD soils	0.14	2.5	0%	0%
Forest	Evergreen forest, Deciduous forest, Mixed forest	0.11	1.9	0%	0%
Wetlands	Water, Emergent Herbaceous Wetlands, Woody Wetlands	0.09	1.8	0%	0%
Rangeland	Rangeland-AB soils, Rangeland-CD soils	0.08	2.2	0%	0%
Shrub	Shrub-AB soils, Shrub-CD soils	0.09	0.9	0%	0%
Pasture	Pasture-AB soils, Pasture-CD soils, Pasture/Hay	0.18	2.9	23%	16%
Barren	Barren-AB soils, Barren-CD soils	0.23	2.9	39%	15%
Urban	Urban	0.32	5.7	56%	57%
Road	Roads, Paved Road, Unpaved Road	0.34	4.8	60%	49%
Developed	Developed Open Space, Low, Medium, High Intensity	0.40	6.3	65%	61%
Agriculture	Agriculture (unspecified)	0.54	12.1	75%	80%
Croplands	Cropland-AB soils, Cropland-CD soils, Cropland-Drained	0.68	12.4	80%	80%
Tillage	Conservation Tillage-AB soils, Conservation Tillage-CD soils	0.81	18.2	83%	87%
Manure	Manure-AB soils, Manure-CD soils	1.0	24.3	87%	90%
Bluff	Bluff	1.3	3.7	90%	34%
Feedlots	Feedlots, AFO, CAFO	1.7	31.3	92%	92%
Impervious	Impervious	2.3	12.6	94%	81%
Ravine	Ravine	4.6	10.1	97%	76%
Atmospheric Deposition	Atmospheric Deposition	n/a	n/a	0%	0%
Point Source	Municipal point source, industrial point source	n/a	n/a	80%	80%

Collapsed Categories	Original Categories (examples, not exhaustive)	Area-weighted Average Annual Yield		Assumed Reducible Fraction	
		TP (lbs/ac)	TN (lbs/ac)	TP	TN
Grassland	Grassland-AB soils, Grassland-CD soils	0.14	2.5	0%	0%
Forest	Evergreen forest, Deciduous forest, Mixed forest	0.11	1.9	0%	0%
Wetlands	Water, Emergent Herbaceous Wetlands, Woody Wetlands	0.09	1.8	0%	0%
Rangeland	Rangeland-AB soils, Rangeland-CD soils	0.08	2.2	0%	0%
Shrub	Shrub-AB soils, Shrub-CD soils	0.09	0.9	0%	0%
Pasture	Pasture-AB soils, Pasture-CD soils, Pasture/Hay	0.18	2.9	23%	16%
Barren	Barren-AB soils, Barren-CD soils	0.23	2.9	39%	15%
Urban	Urban	0.32	5.7	56%	57%
Road	Roads, Paved Road, Unpaved Road	0.34	4.8	60%	49%
Developed	Developed Open Space, Low, Medium, High Intensity	0.40	6.3	65%	61%
Agriculture	Agriculture (unspecified)	0.54	12.1	75%	80%
Croplands	Cropland-AB soils, Cropland-CD soils, Cropland-Drained	0.68	12.4	80%	80%
Tillage	Conservation Tillage-AB soils, Conservation Tillage-CD soils	0.81	18.2	83%	87%
Manure	Manure-AB soils, Manure-CD soils	1.0	24.3	87%	90%
Bluff	Bluff	1.3	3.7	90%	34%
Feedlots	Feedlots, AFO, CAFO	1.7	31.3	92%	92%
Impervious	Impervious	2.3	12.6	94%	81%
Ravine	Ravine	4.6	10.1	97%	76%
Atmospheric Deposition	Atmospheric Deposition	n/a	n/a	0%	0%
Point Source	Municipal point source, industrial point source	n/a	n/a	80%	80%

The chosen approach was slightly limited in that, at the time this task was completed in 2019, HSPF models were not available for the Lower St. Croix River and Mississippi River-Twin Cities, -Lake Pepin, -Winona, and –La Crescent HUC8 watersheds. An HSPF model has since been completed for a portion of the Mississippi River-Lake Pepin HUC8 area. To estimate natural background nutrient loading for these HUC8 watersheds, an approach was developed and implemented that involved adjusting SPARROW model estimated natural background nutrient loading based on relationships developed for watersheds with both HSPF and SPARROW model estimates (Figures 4 and 5). As noted above, the SPARROW estimates for TN did not explicitly include natural background sources. For the purposes of developing the relationships shown below, LimnoTech used the SPARROW atmospheric deposition estimates for TN as a surrogate for natural background sources, acknowledging that the source category is elevated due to anthropogenic sources. SPARROW TN atmospheric deposition estimates can be broken down based on the USEPA Community Multiscale Air Quality modeling system it uses (Robertson and Saad, 2019), but this information was not available at the time this task was completed in 2019.

Figure 3: Relationship between SPARROW model estimated and HSPF model estimated TP background fractions for Minnesota watersheds.

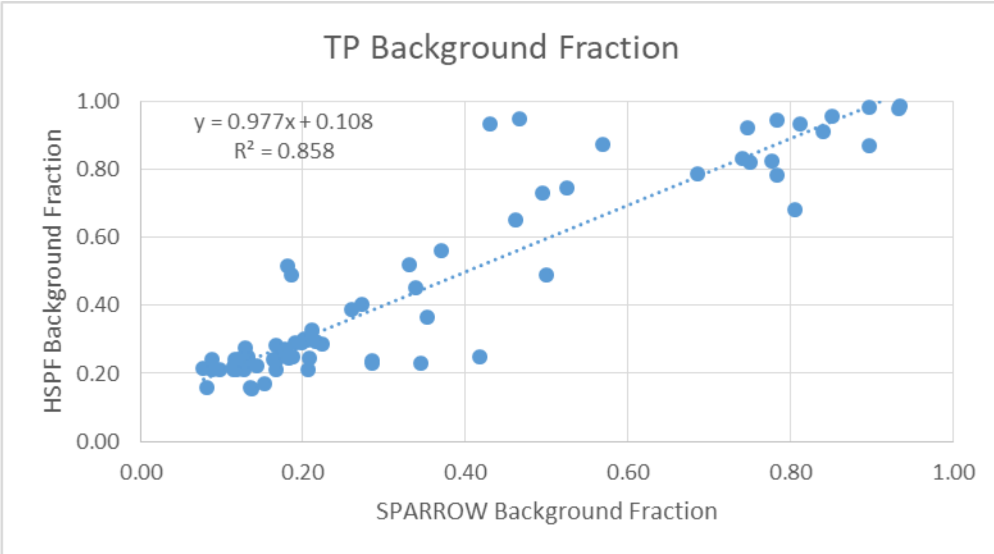
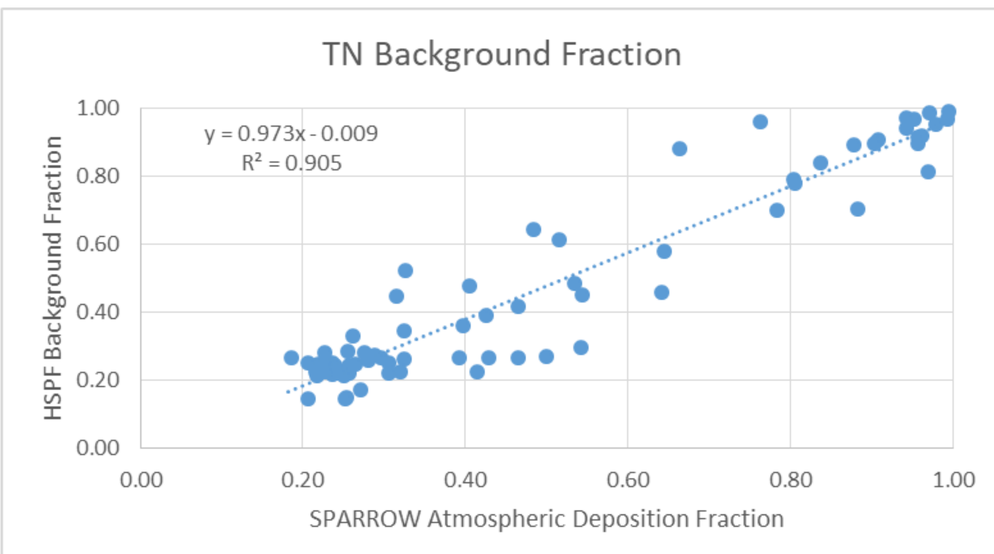


Figure 4: Relationship between SPARROW model estimated and HSPF model estimated TN background fractions for Minnesota watersheds.



Reducible Load Estimates – Results

The resulting TP and TN nonreducible load fractions for all HUC8 watersheds are shown in Figures 6 and 7, respectively. Both TP and TN nonreducible load fractions follow a spatial pattern that correlates strongly with land cover, with the highest values in the northeast quadrant of the state where forested lands and low human populations dominate. Areas with the lowest nonreducible load fractions are those with high human populations and those where agricultural land dominates the landscape.

Figure 5: Nonreducible TP load fractions for all HUC8 watersheds

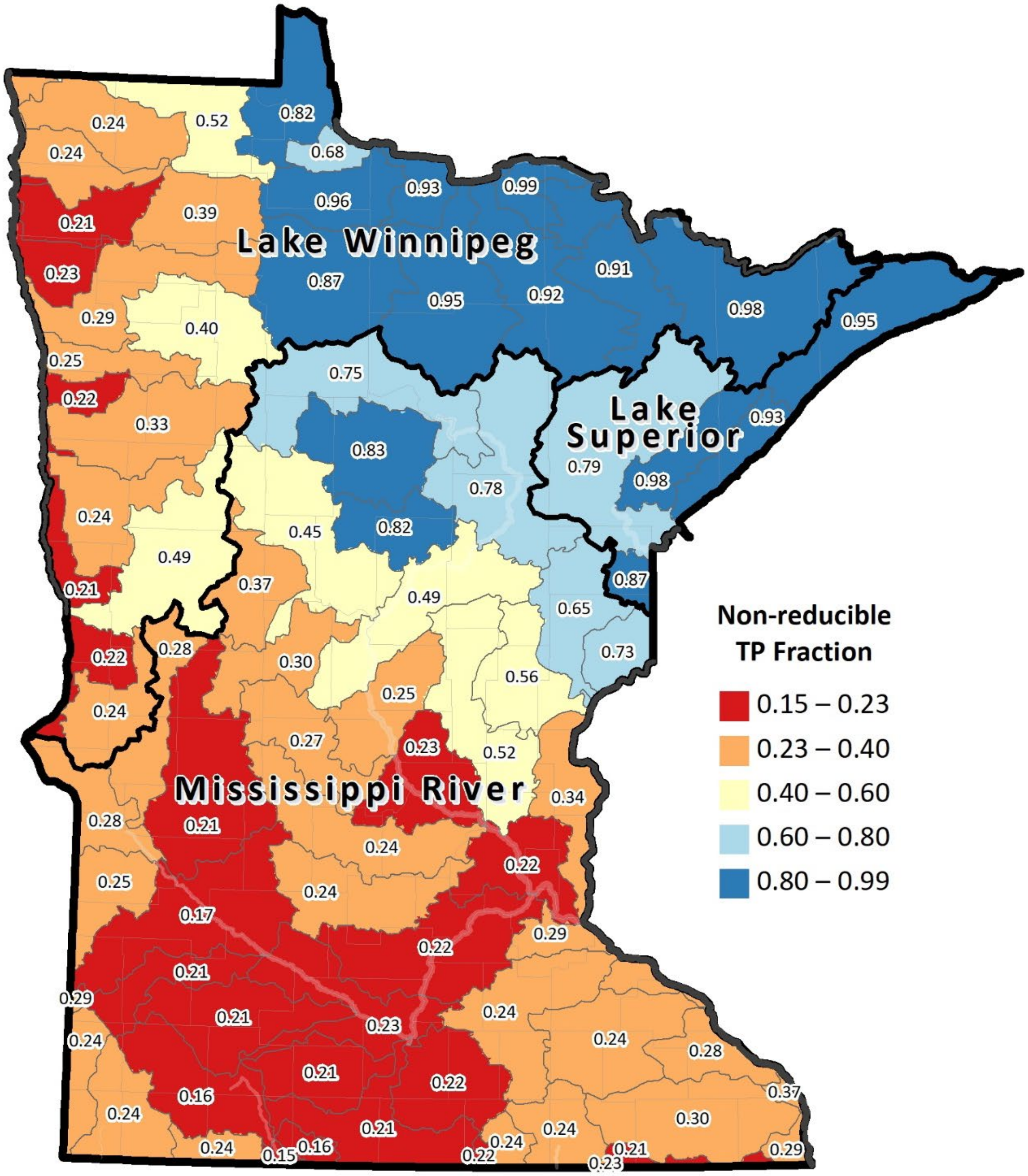
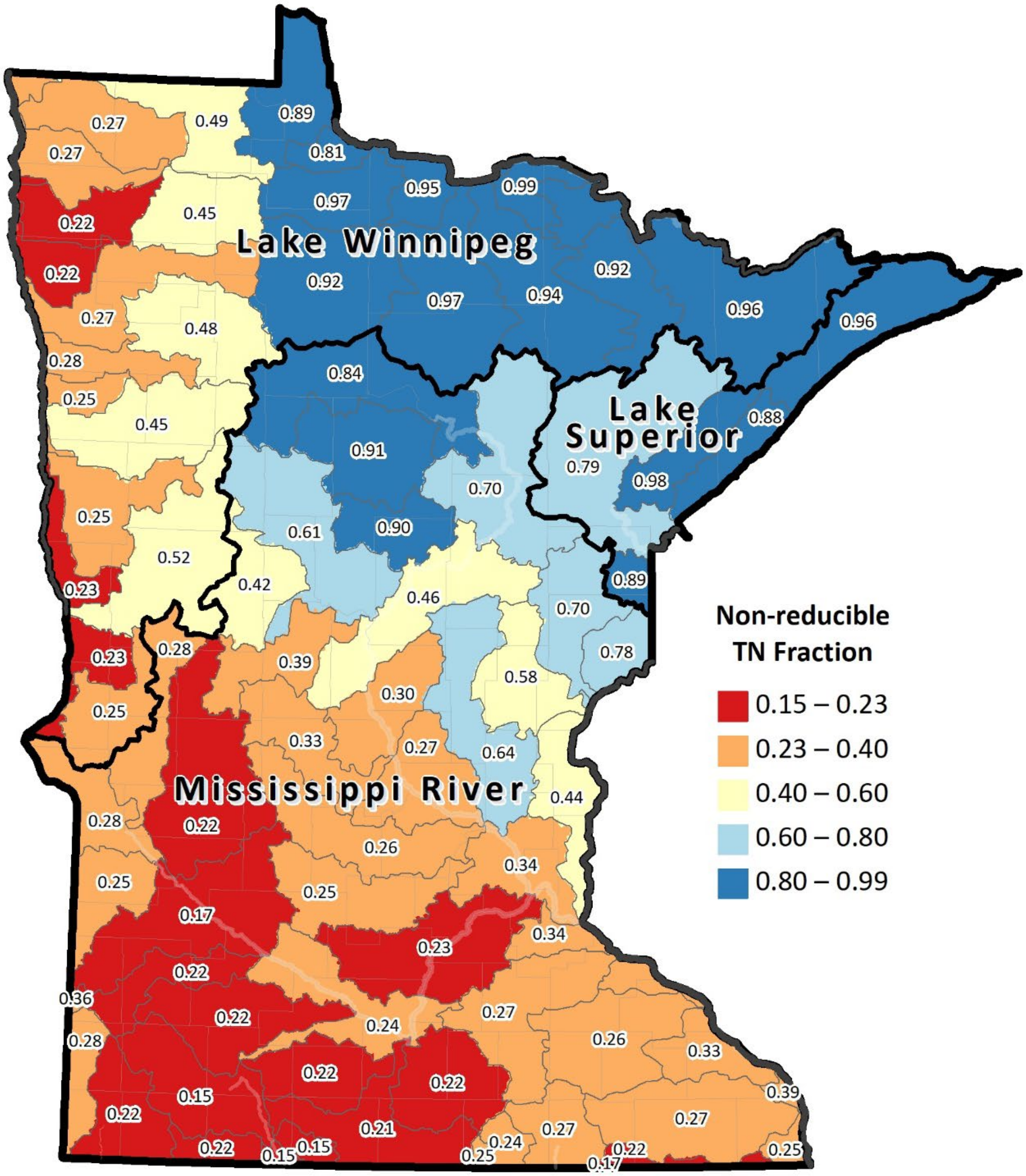


Figure 6: Nonreducible TN load fractions for all HUC8 watersheds



Step 3 - Estimate nutrient attenuation factors

Nutrients can attenuate as waters travel downstream in river networks through a combination of biotic processes such as uptake into aquatic, benthic, and riparian terrestrial biota, and through abiotic processes such as sedimentation. Most of these attenuation reactions can be considered as a form of storage, either into short-term reservoirs (e.g., short-lived plankton and riverbed sediment that gets resuspended with every storm) or long-term reservoirs (e.g., floodplain storage and reservoir sedimentation). Nutrients can either remain in storage, be reintroduced to surface waters via a variety of mechanisms, or be permanently removed from the riverine system in the case of nitrogen release to the atmosphere via denitrification. For the purposes of quantifying average annual load delivery from HUC8 watershed outlets to downstream locations, all of these nutrient attenuation processes can be wrapped into an average annual net attenuation of the given nutrient.

Various approaches to quantifying nutrient attenuation were investigated over the course of this study (Table 9). The paleolimnological studies of Engstrom et al. (2000) and Edlund et al. (2009) were limited in that they only estimated TP, not TN, and they were only representative of a portion of Minnesota. The first-order decay based approaches require reach-by-reach estimates of mean annual water velocity, showed a very wide range of coefficients, and typically not applied to systems with large reservoirs or impoundments. The nutrient spiraling approach requires reach-by-reach estimates of mean channel width and also is typically not applied to systems with large reservoirs or impoundments. The SPARROW and HSPF based approaches were therefore determined to be most appropriate for the purposes of this effort.

Table 6: Potential approaches investigated for possible use in estimating nutrient attenuation

Approach	Description	Reference(s)
Paleolimnological / mass balance studies	Local studies estimating historical nutrient flux into and out of major Minnesota water bodies	Engstrom et al. (2000); Edlund et al. (2009)
First-order decay kinetics	Regional and national data synthesis studies estimating first-order nutrient attenuation coefficients over a large range of river reaches	Smith et al. (1997); Alexander et al. (2000); Smith et al. (2003); Moore et al. (2011); Haag et al. (2019, in prep.)
Nutrient spiraling derived uptake velocity	A scale-independent approach used in stream ecology to quantify nutrient uptake rates based on the theory of nutrient spiraling	Newbold et al. (1981); Newbold et al. (1983); Hall et. al. (2013); Gibson et al. (2015)
SPARROW model-based estimates	Data-driven, empirical approach for estimating TP and TN delivery ratios for any NHDPlus segment to a downstream endpoint	Robertson and Saad (2019)
HSPF model-based estimates	HUC8 watershed models developed and calibrated under Minnesota's One Water Program with in-stream nutrient cycling and transport simulation capabilities	MPCA (2014)

For consistency of using the same modeling platform for the current day load estimates and natural background estimates, LimnoTech and MPCA chose to use the long-term average nutrient delivery predicted by various HSPF models that simulate transport from multiple HUC8 watershed outlets through major riverine systems to downstream endpoints. This approach was limited, however, in that HSPF models were not available for several major river systems including the Red River of the North, Lower St. Croix River, and Mississippi River from St. Cloud to the Iowa state line.

To estimate nutrient delivery for the river systems without an HSPF model, an approach was developed and implemented that involved adjusting SPARROW model estimated nutrient delivery where an HSPF model was not available based on relationships developed for rivers with both HSPF and SPARROW estimated nutrient delivery (Figures 8 and 9). The SPARROW estimated delivery fractions represent delivery from each catchment to the downstream endpoints of interest or "terminal" endpoints; the Gulf of Mexico, the Great Lakes, or the US/Canada border. In order to develop the relationships shown in Figures 8 and 9, we needed computed the SPARROW delivery fractions to intermediate endpoints that overlap with the HSPF riverine models. This was accomplished by dividing the SPARROW terminal delivery for the starting catchment by the SPARROW terminal delivery for the desired intermediate endpoint. Put simply, if the terminal delivery from point A to point C is 80%, and the terminal delivery from point B to point C is 90%, then the delivery from point A to point B is computed as 80%/90%, or 88.9%. Using an actual example, the SPARROW terminal TP delivery for the Watonwan River HUC8 outlet is 90.23% (to the Gulf of Mexico), and the SPARROW terminal TP delivery for the Lower Minnesota River HUC8 outlet is 90.76% (to the Gulf of Mexico), then the SPARROW TP delivery from the Watonwan HUC8 outlet to the Lower Minnesota HUC8 outlet is 99.42% (from 90.23%/90.76%). This and several other "intermediate" delivery fractions for areas of overlap between the HSPF and SPARROW models were then compared with the HSPF delivery to develop the relationships shown in Figures 8 and 9.

Table 7: Potential approaches investigated for possible use in estimating nutrient attenuation

Approach	Description	Reference(s)
Paleolimnological / mass balance studies	Local studies estimating historical nutrient flux into and out of major Minnesota water bodies	Engstrom et al. (2000); Edlund et al. (2009)
First-order decay kinetics	Regional and national data synthesis studies estimating first-order nutrient attenuation coefficients over a large range of river reaches	Smith et al. (1997); Alexander et al. (2000); Smith et al. (2003); Moore et al. (2011); Haag et al. (2019, in prep.)
Nutrient spiraling derived uptake velocity	A scale-independent approach used in stream ecology to quantify nutrient uptake rates based on the theory of nutrient spiraling	Newbold et al. (1981); Newbold et al. (1983); Hall et. al. (2013); Gibson et al. (2015)
SPARROW model-based estimates	Data-driven, empirical approach for estimating TP and TN delivery ratios for any NHDPlus segment to a downstream endpoint	Robertson and Saad (2019)
HSPF model-based estimates	HUC8 watershed models developed and calibrated under Minnesota's One Water Program with in-stream nutrient cycling and transport simulation capabilities	MPCA (2014)

Figure 7: Relationship between SPARROW model estimated and HSPF model estimated TP attenuation factors for major Minnesota rivers.

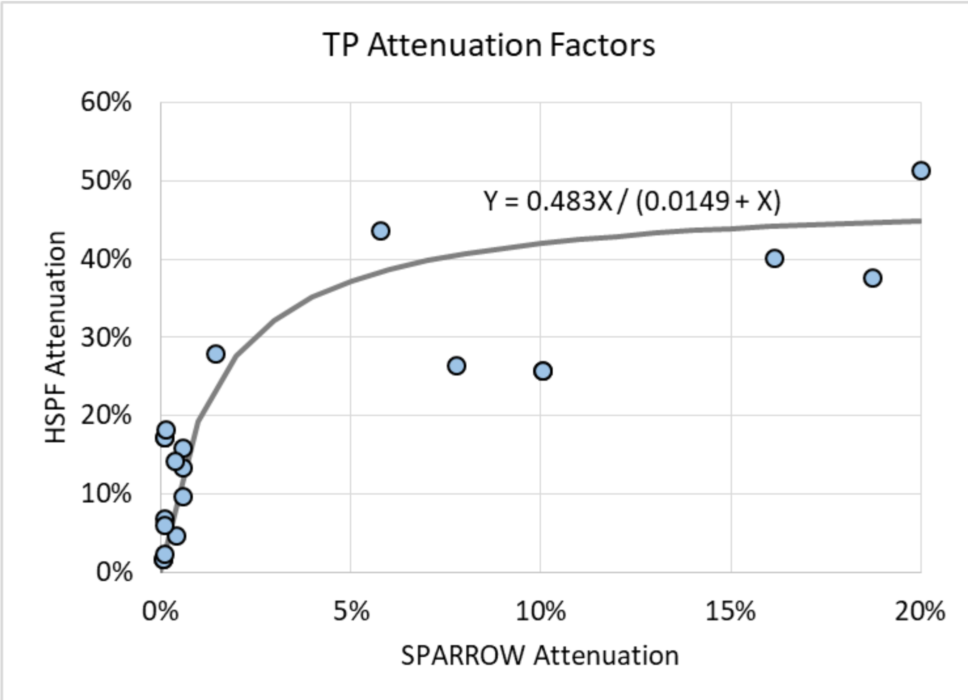
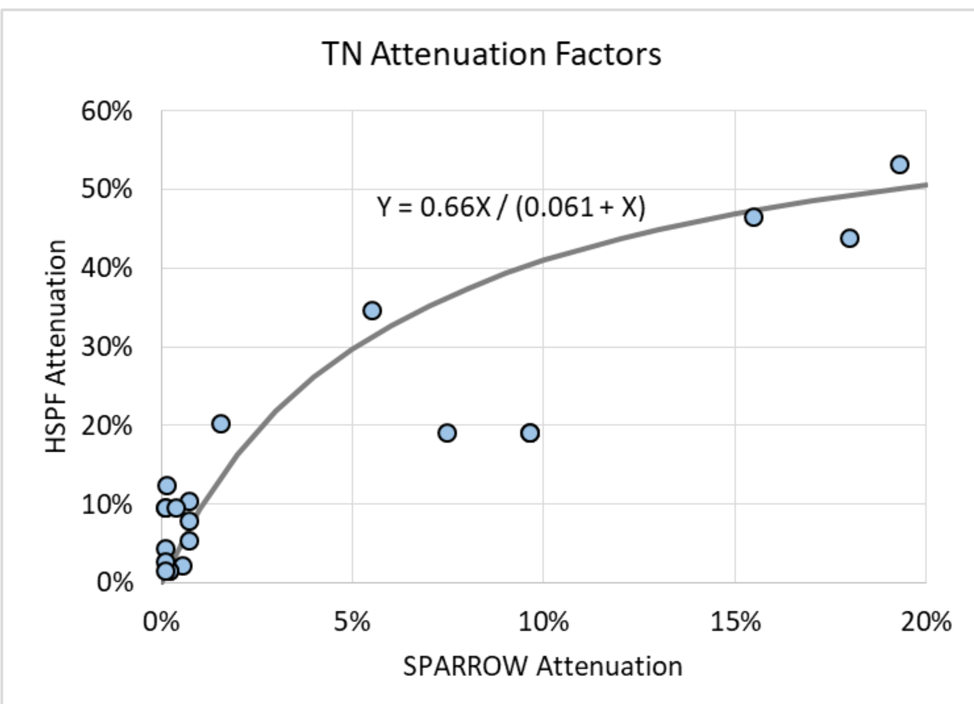


Figure 8: Relationship between SPARROW model estimated and HSPF model estimated TN attenuation factors for major Minnesota rivers.



The resulting TP and TN delivery ratios for all HUC8 watersheds to the most downstream endpoint evaluated are shown in Figures 10 and 11, respectively. The most downstream endpoints evaluated were the Red River at the US/Canada border, the Lake of the Woods inflow, Lake Superior, the Mississippi River at the Iowa border, or the Minnesota state line for the Cedar, Des Moines, and Missouri basin watersheds. HUC8 watersheds with delivery ratios of 1.00 (i.e., all TP and TN load leaving the HUC8 makes it to the downstream endpoint) include those where the HUC8 watershed intersects the downstream endpoint (i.e., the Minnesota state line) or discharges directly to the downstream endpoint. HUC8 watersheds with the lowest delivery ratios include those that have a long travel distance before reaching the downstream endpoint and/or those that discharge upstream of a major reservoir/impoundment.

Figure 9: TP delivery ratios for all HUC8 watershed outlets to the most downstream endpoint evaluated.

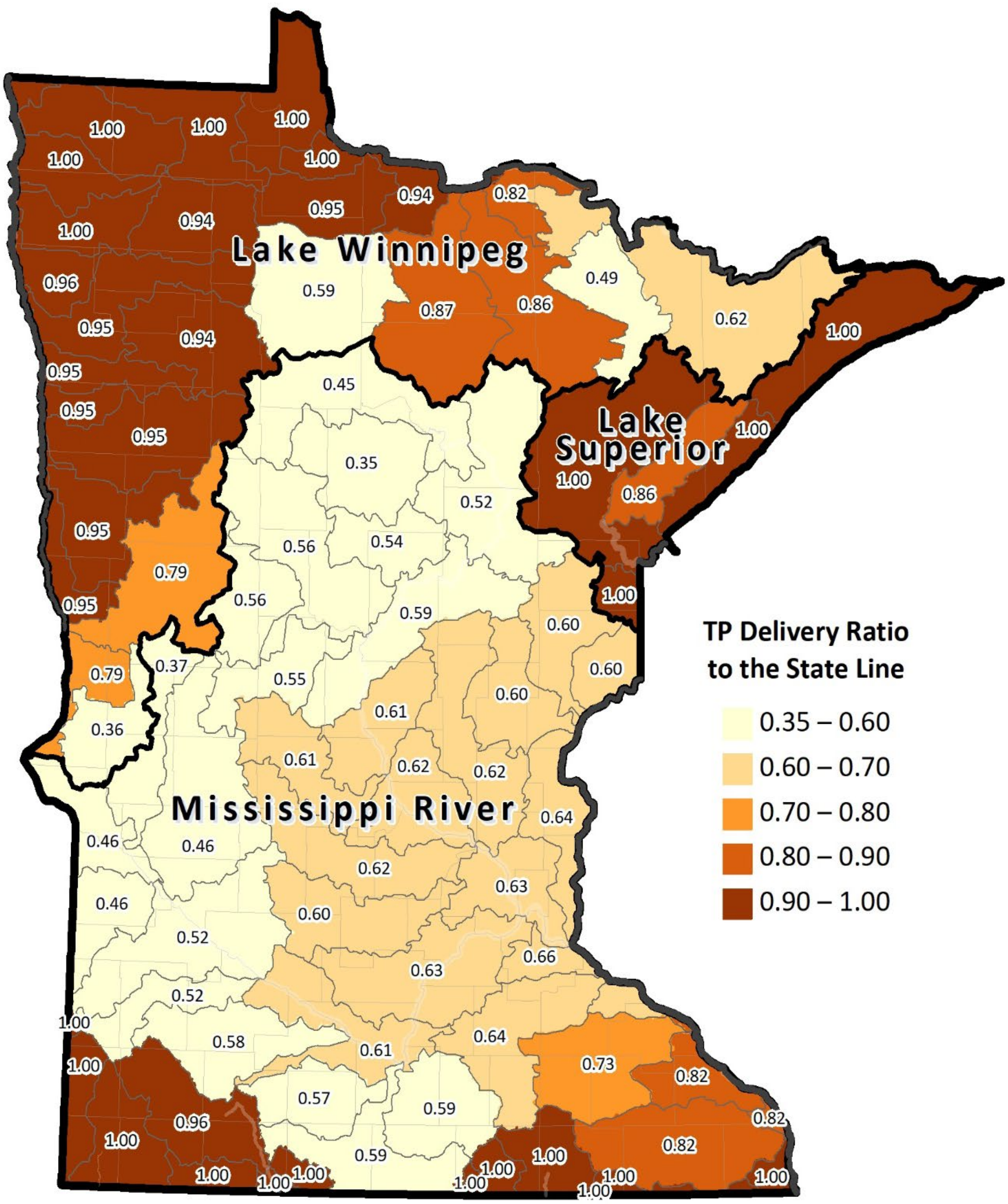
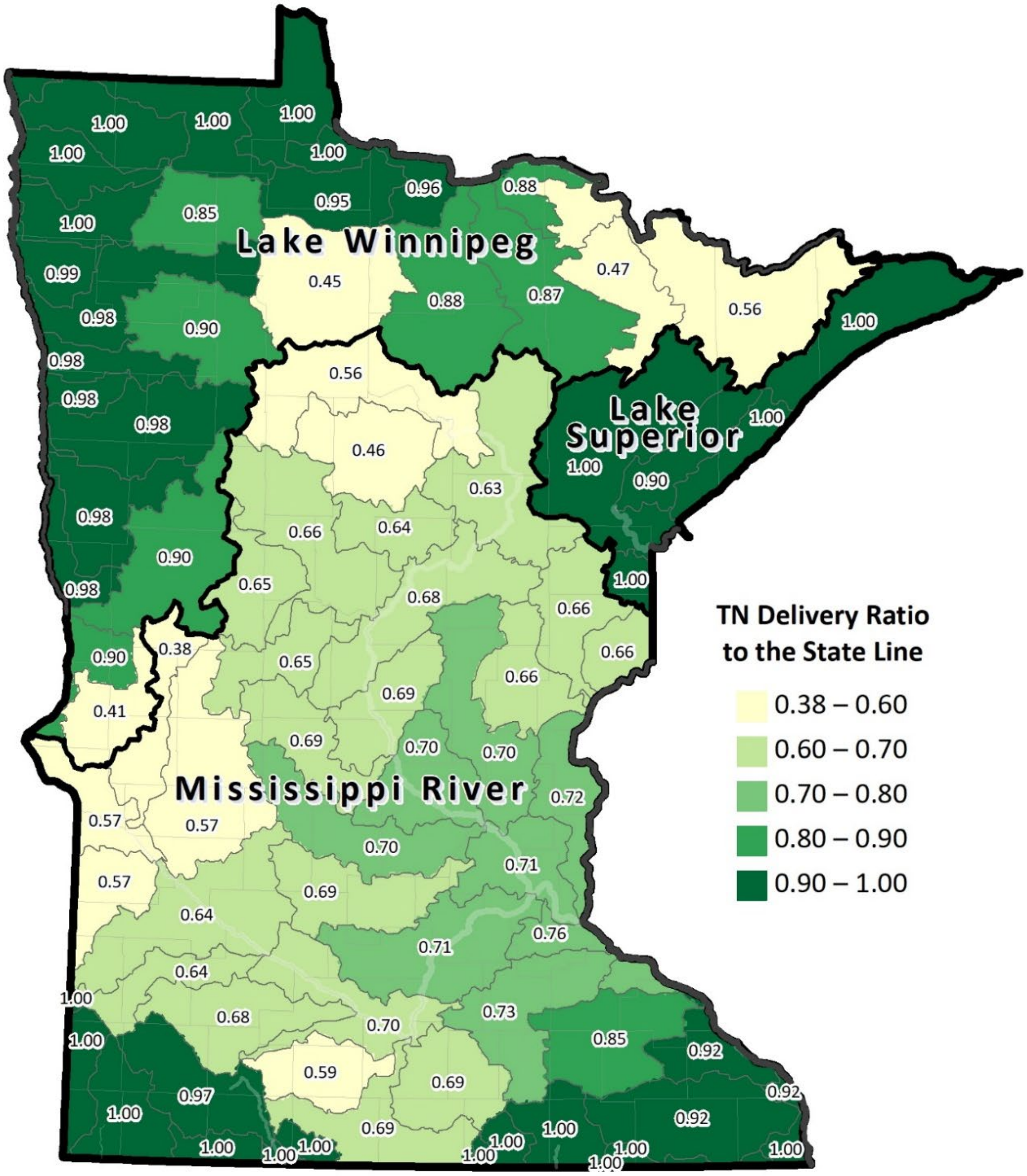


Figure 10: TN delivery ratios for all HUC8 watershed outlets to the most downstream endpoint evaluated.



Step 4 – Update nutrient reduction goals

The ultimate objective of this project was to develop equitable, or fair-share, phosphorus and nitrogen loading planning goals for each HUC8 watershed throughout the State. These planning goals were developed to update preliminary loads provided in the Minnesota NRS. The previous tasks of developing current day load estimates, identifying reducible and nonreducible loads, and estimating downstream attenuation provided the foundation for setting watershed specific goals. For each of these components of the methodology, the assessment was conducted using the best available information at the time this work was completed. The updated nutrient reduction goals described in the sections below represent an assessment of the remaining reductions needed to meet previously established downstream goals and milestones relative to current day loading conditions. Any changes in the estimated current day loading conditions relative to the 2014 NRS will have influenced the assessment of remaining reductions needed. For any given watershed, the updated estimate of current day loading conditions may be influenced by a number of factors, such as better estimates of loading due to monitoring or modeling that was previously not yet available, or relatively higher or lower precipitation over the most recent 10-year period over which annual loads were averaged.

The load reduction strategy in the 2014 NRS established percent load reduction goals equally for each HUC8 watershed within a given major basin, using an earlier version of the SPARROW model than is currently available. A long-term 45% load reduction goal relative to 1980-1996 average conditions was established for both TP and TN for all HUC8s in the Mississippi River basin. An interim 20% TN load reduction milestone was established for all HUC8s in the Mississippi River major. A 10% load reduction was identified in the NRS for TP and a 13% load reduction for TN relative to 2003 conditions for all HUCs in the Lake Winnipeg drainage basin. These goals did not take into consideration the estimated anthropogenic load contribution in each HUC8 watershed, which potentially created unrealistic load reduction targets for certain watersheds. Additionally, the previous goals did not account for in-stream attenuation occurring between the HUC8 outlets and the state line where the targets apply. This simplification may have resulted in cumulative HUC8 load reductions that, when accounting for attenuation between the HUC8 outlet and the state line, were higher or lower than the overall state line target.

The updated NRS planning goals presented here attempt to overcome those shortcomings and improve upon the 2014 NRS preliminary goals by considering the unique nutrient loading conditions and nutrient delivery of each HUC8 watershed. The planning goals were set equitably, such that each HUC8 with a major watershed has the goal of reducing an equal fraction of its reducible load. The equal fraction for all HUC8 watersheds was set to meet the overall load target at the state line, thereby accounting for attenuation that happens downstream of the HUC8 outlets.

Previously established major basin nutrient loading goals

State line targets were established based on waterbody-specific downstream goals, often in cooperation with agencies outside of the State of Minnesota such as the Gulf of Mexico Hypoxia Task Force, International Red River Board (IRRB), and International Joint Commission (IJC). The TP and TN goals and milestones for major drainage basins are listed in Table 10, along with the primary source for the mass-based goal. Nutrient load goals and milestones for the Mississippi River major basin remain the same as defined in the 2014 NRS. Although the 2014 NRS established provisional goals for HUC8 watersheds in the Red River basin based on the 2003 Lake Winnipeg Action Plan, these goals have since been updated based on recent work completed by the IRRB's Water Quality Committee (IRRB, 2019).

Table 8: Previously established TP and TN goals and milestones for five major basins, displayed for Minnesota drainage areas only. Note: For this effort, the MPCA combined all Mississippi River tributary watersheds into one drainage area, which also included the Cedar, Des Moines and Missouri Rivers.

Major Basin	TP Load Goal at State Line (MT)	TN Load Goal at State Line (MT)	Reference
Final Goals / Long-Term Goals			
Mississippi (Upper Mississippi, Minnesota, St. Croix, Cedar, Des Moines, Missouri)	2,544	50,088	Minnesota Nutrient Reduction Strategy (2014)
Lake Superior	248	-	Minnesota Nutrient Reduction Strategy (2014)
Red River	700	4,763	IRRB Water Quality Committee (2019)
Rainy River	218	-	Lake of the Woods TMDL (2018)
Milestones / Interim Goals / Provisional Goals			
Mississippi (Upper Mississippi, Minnesota, St. Croix, Cedar, Des Moines, Missouri)	-	72,856	Minnesota Nutrient Reduction Strategy (2014)
Red River	1,123	7,804	Minnesota Nutrient Reduction Strategy (2014)

Note: The following info in italics was added by the MPCA to supplement baseline load information described in Schlea et al. (2019), providing more background on both the original baseline and remaining load reduction needs at the time of NRS development. This information is also presented graphically in Appendix C to this Attachment.

Mississippi River Baseline loads – *The monitoring for the entire 1980-96 baseline period was not available for monitoring sites near the state line. The original baseline loads outlined in the NRS represented average monitored loads at the Mississippi River in LaCrosse, based on 5-year running averages centered on the year 2000. SPARROW modeling was used to estimate the fraction of loads contributed by Iowa and Wisconsin (23%), which was subtracted from the monitored loads so that the loads in the NRS reflect only Minnesota's contributions. Available monitoring and modeled loads from Minnesota's tributaries to the Cedar, Des Moines and Missouri Rivers were added to Minnesota's estimated load contributions at the Mississippi River LaCrosse site to represent the estimated Minnesota baseline load from the entire Mississippi River Basin reaching the Minnesota state line.*

> ***Nitrogen** – The original Minnesota contributions to the baseline nitrogen load was estimated at 91,096 MT/yr. To achieve the 45% load reduction goal from this baseline, the loads would need to be reduced to a long-term average load of 50,088 MT/yr (MN contributions to the Mississippi River at state line).*
>
> ***Phosphorus** – The original baseline phosphorus load was estimated to be 4627 MT/yr. To achieve the 45% load reduction goal from this baseline, the loads would need to be reduced to a long-term average load of 2544 MT/yr.*

Mississippi River Loads and Load Reductions still needed at the time of writing the NRS – *At the time of writing the NRS (2012-14), load reduction progress since the original baseline was assessed so that the strategy could be developed based on the remaining load reduction needs at that time, rather than the original load reduction needs. For nitrogen, the 2003-2013 pre-NRS period loads were believed to adequately represent the 1980-96 baseline. However, for Mississippi River phosphorus loads, the NRS found a substantial load reduction that was achieved between 2002 and 2013.*

> ***Nitrogen*** *- For nitrogen, water monitoring and BMP trends analysis did not indicate any significant progress with nitrogen in the Mississippi River since the original baseline. Long-term load monitoring averages just upstream from Lake Pepin confirmed this (Metropolitan Council data at Red Wing). Similar loads were found at this site for the 1980-96 average baseline period (75,982 MT) as the 2004-2013 pre-NRS average loads (76,245 MT). Therefore, the load reductions needed at the time of the 2014 NRS were considered to be the same as those needed from the original pre-2000 period.*
>
> *More recently, nitrogen loads calculated by the USGS from monitoring of the Mississippi River in LaCrosse, Wisconsin, showed that average nitrogen loads from 1992-2002 were similar (8% difference) compared to loads from 2003-2017 (Jankowski, 2021). Nearly one-quarter of the load at this site originates in Wisconsin. The more recent LaCrosse monitoring and analysis would also suggest that little progress was made between the original baseline period and the period leading up to the 2014 timeframe, although it is possible that a slight decrease has occurred at the LaCrosse site (which includes the Wisconsin tributary loads).*
>
> ***Phosphorus*** *– At the time of writing the NRS from 2012-14, phosphorus levels were decreasing, stemming from major reductions from municipal wastewater treatment facilities along with improvements in agricultural conservation, septic systems, feedlots, and urban stormwater. A 31-33% load reduction was estimated based on both results from river monitoring and source reduction assessments. Load monitoring averages (from Metropolitan Council Environmental Services) in the Mississippi River at Red Wing just upstream from Lake Pepin, showed that loads dropped slightly from the 1980-96 baseline average (3676 MT/yr) to the 1998-2002 period (3322 MT). When we compare the 1980-96 baseline period average loads with the 2003-2013 pre-NRS period, we calculate a 29% decrease (from 3676 down to 2628 MT/yr). This 29% decrease is reasonably consistent with the 33% decrease reported in the 2014 NRS.*

Red River baseline loads – *The original Red River baseline loads for Minnesota outlined in the NRS represented average monitored loads at the Red River in Emerson from 1999-2003, as adjusted to subtract the fraction of load contributed from North Dakota and South Dakota (ND and SD load contributions were estimated from the SPARROW model). The NRS focused on the previously documented Lake Winnipeg Action Plan reduction goals of 13 and 10% for TN and TP, respectively, while at the same time emphasizing that updated scientific findings were suggesting a final reduction need closer to 50%.*

> ***Nitrogen*** *– The original Red River baseline load for Minnesota was considered to be 8970 MT. A 50% load reduction from this estimated load would amount to a 4485 MT load reduction and 4485 MT final load goal. The International Red River Basin Water Quality Board more recently suggested a similar load goal of 4763 MT, based on the most recent monitoring and modeling information (IRRB Water Quality Board, 2019). The watershed load reduction planning goals in this document are based on the most updated load goal of 4763 MT.*

__Phosphorus__ - The original baseline load was considered to be 1248 MT. A 50% load reduction would amount to a 624 MT load reduction. The International Red River Basin Water Quality Board more recently suggested a slightly higher load goal of 700 MT, based on the most recent monitoring and modeling information (IRRB Water Quality Board, 2019), which is the goal used for calculations in this report.

Red River Loads and Load Reductions still needed when the NRS was written – At the time of writing the NRS during the 2012-14 timeframe, Minnesota determined the average loads using the 2006-10 period so that the strategy could be developed based on remaining load reduction needs, rather than the original load reduction needs.

__Nitrogen__ - For nitrogen, the 2006-10 average load was lower than the original baseline, dropping to 7500 MT. While it was uncertain whether this reduction was due to real nutrient reduction progress in the basin or other factors such as precipitation/climate, the 7500 MT average was used in the NRS to represent a more recent load at that time.

__Phosphorus__ – For phosphorus, the 2006-10 average was nearly identical to the original baseline loads (a 1% increase). Therefore, the nutrient reduction needs at the time of the NRS development were considered to be the same as original baseline period.

Lake Superior Basin original baseline loads and load goals

For the Lake Superior major basin, the 2014 NRS defined a TP goal of maintaining 1979 loading conditions and a qualitative TN goal of maintaining protection by continuing to implement nutrient management programs. Since load monitoring for the Lake Superior Basin was not consistently available for the 1979 baseline period, the NRS used the SPARROW model as a way to estimate loads with 2002 land uses, assuming that land uses had not markedly changed between 1979 and 2002 in that part of the state.

__Nitrogen__ – A baseline pollution prevention load goal for TN to maintain pre-2000 conditions was not established in the NRS for the Lake Superior Basin.

__Phosphorus__ – An approximate TP baseline of 248 MT/year was proposed in the NRS for maintaining pre-2000 conditions.

Rainy River Basin

The 2014 NRS did not establish goals for HUC8 watersheds in the Rainy River, deferring to the eventual Lake of the Woods TMDL as the ultimate approach for establishing TP load targets for these watersheds. The TP load goal of 218 MT for the Rainy River basin was computed from the Lake of the Woods TMDL (2018) by summing the allowable USA TP loads to the lake for the wastewater, tributaries, lakeshed, and septic systems categories. Allowable TP loads for Canadian sources, shoreline erosion, atmospheric deposition, and internal loading were not included as they were not considered to be part of the Minnesota HUC8 watershed loading to Lake of the Woods. Numeric TN goals have not been established for the Rainy River major basin.

Goal determination methodology

The following equations and accompanying text describe the nutrient reduction goal calculations. Sample calculations for four HUC8 watersheds are provided in Appendix B.

Load reduction planning targets for each major watershed were calculated by subtracting the loading goal for the major watershed from the total load delivered to the state line. The total delivered load was calculated as the sum of delivered loads from individual HUC8 watersheds:

$$Load\ Reduction\ Target_{mw} =$$

$$\sum(Current\ Load)_i(Delivery\ Ratio)_i - \ State\ Line\ Loading\ Goal_{mw}$$

$Where$:

$'mw'\ refers\ to\ major\ watershed$

$'i' \quad refers\ to\ individual\ HUC8\ watersheds$

This major watershed load reduction target was then expressed as a proportion of the major watershed's total reducible load delivered to the state line. This is the "Fair-Share Proportion" for each HUC8 within the major watershed.

$$Reducible\ Load\ Delivered\ to\ State\ Line_i =$$

$$(Current\ Load)_i \times (Reducible\ Fraction)_i \times (Delivery\ Ratio)_i$$

$$Fair\ Share\ Proportion_{mw} =$$

$$\frac{Load\ Reduction\ Target_{mw}}{\sum Reducible\ Load\ Delivered\ to\ State\ Line_i}$$

The HUC8 Fair-Share Load Reductions were then calculated by multiplying the Fair-Share Proportion by each HUC8 watershed's reducible load.

$$Fair\ Share\ Load\ Reduction_i =$$

$$Reducible\ Load_i \times Fair\ Share\ Proportion_{mw}$$

The Fair-Share Loads for each HUC8 were computed by subtracting the Fair-Share Load Reduction from each HUC8's Current Load.

$$Fair\ Share\ Load_i =$$

$$Current\ Load_i - Fair\ Share\ Load\ Reduction_i$$

The Fair-Share Loads for each HUC8 multiplied by the respective delivery ratio sum up to the State Line Loading Goal for each major watershed.

$$\sum(Fair\ Share\ Load)_i(Delivery\ Ratio)_i = State\ Line\ Loading\ Goal_{mw}$$

Major basin results

Current day load estimates and remaining reductions to meet the previously established milestones and goals (Table 10) for four major basins are presented in Table 11 below and are shown graphically in Appendix C. Lake Superior results are described separately, below. TP reductions of approximately 29% are needed to meet final goals for the Mississippi River and Red River basins, while the TP reduction needed for the Rainy River is about 8%. TN reductions of approximately 42% are still needed to meet final goals for the Mississippi River and Red River basins.

Table 9: Current day load estimates, final goals and milestones/interim goals, and remaining reductions for the Minnesota portion of four major basins.

Description	Mississippi River (MN watersheds) Upper Mississippi, Minnesota, St. Croix Cedar, Des Moines, Missouri		Red River		Rainy River
	TP	TN	TP	TN	TP
Current/recent load at state line (MT)	3,478	87,271	991	8,247	237
Final goal at state line (MT)	2,544	50,089	700	4,763	218
Current/recent load reduction needed to meet final goal	26.9%	42.6%	29.4%	42.3%	8.1%
Milestone / interim goal (MT)	-	72856	1,123	7,804	-
Current/recent load reduction needed to meet milestone / interim goal	-	16.5%	*none*	5.4%	-

Load goals for each HUC8 are provided in Appendix A. The current day HUC8 load estimates, mass load reduction goals, and percent load reduction goals are shown in Figures 12-14 for TP and Figures 15-19 for TN, respectively. HUC8 watersheds with relatively large reducible loads have the highest fair-share percent load reduction planning goals. These HUC8s tend to be the most human-influenced and have higher percentages of urban and agricultural land uses from which loads could be more readily reduced, as previously described.

Lake Superior results

As stated above, one task of this effort was to determine the average annual nutrient loads to Lake Superior that should be sustained to meet the goals of the NRS. Numeric TN goals were not previously established for the Lake Superior and Rainy River major basins. The TN load planning goals provided in Appendix A for HUC8 watersheds in these major basins represent the average annual loads that should be sustained to maintain loading at current conditions. These loads were computed as the sum of the current day load estimates at each HUC8 outlet times the delivery to the state line end point for that HUC8. These “hold the line” TN load planning goals were estimated as 4,658 MT/year delivered for Lake Superior HUC8 watersheds, and 4,887 MT/year delivered for Rainy River HUC8 watersheds.

The current day, delivered TP load for Lake Superior was estimated as 257 MT/year. This updated, HSPF model-based estimate compares extremely well to the 255 MT/year estimated for 2006-2010 conditions by the SPARROW model as part of the 2014 NRS. The updated current day, delivered TP load of 257 MT/year is slightly higher than the 248 MT/year proposed in the 2014 NRS for maintaining 1979 conditions, and therefore relatively small load reduction planning goals are needed for the Lake Superior HUC8 watersheds as shown in Table A-1.

Lake Pepin results

An analysis was completed to evaluate whether meeting the TP reduction needs described in the Draft Lake Pepin Watershed Phosphorus TMDL (MPCA and LimnoTech, 2019) would also meet the downstream Mississippi River/Gulf of Mexico needs. The Lake Pepin TMDL TP loading goals evaluated included the following:

- 693 MT/year delivered to Lock & Dam 1 for the Upper Mississippi basin HUC8s, Rum River HUC8, North and South Fork Crow HUC8s, and Twin Cities Metro Area HUC8 above Lock & Dam 1;
- 938 MT/year delivered to the Minnesota River mouth for the Minnesota River basin HUC8s, excluding loading from the South Dakota portion;
- 199 MT/year delivered to the HUC8 outlet for the Twin Cities Metro Area HUC8 below Lock & Dam 1; and
- 159 MT/year delivered to Lake Pepin for the Cannon River HUC8 and Mississippi River/Vermillion HUC8.

The nutrient load methodology described above was then applied to compute the individual HUC8 TP load reductions from the current day estimates needed to cumulatively achieve these Lake Pepin TMDL goals. The computed reductions accounted for the reducible load fractions and the TP delivery to the stated endpoints. The "state line" terms in the methodology were replaced with these Lake Pepin TMDL endpoints.

The summary results of this analysis are provided in Table 12. According to this analysis, the highest TP mass-based load reduction planning goals was for the Cannon River HUC8 and Mississippi River/Vermillion HUC8 at 59%. The overall load reduction planning goals for the Upper Mississippi River and Minnesota River HUC8 watersheds were 27% and 31%, respectively. Current TP loading for the Twin Cities Metro Area HUC8 below Lock & Dam 1 was estimated at 167 MT/year, below the 199 MT/year goal, and therefore a 0% reduction was computed. This finding was largely driven by the Met Council Metro WWTP discharging TP loads below the waste load allocation (WLA) stated in the TMDL. The bottom line finding from this analysis is that the TP reduction needs described in the Draft Lake Pepin Watershed Phosphorus TMDL will be sufficient to also meet the downstream Mississippi River/Gulf of Mexico TP reduction planning goals established under the NRS. The reduction needs are fairly similar for the Mississippi River and Minnesota River watersheds.

Table 10: Current day, average annual TP load estimates, Lake Pepin TMDL TP load goals, and percent reductions needed to meet Lake Pepin TMDL and NRS goals.

Major Basin	Upper Mississippi, Rum, Crow HUC8s	Minnesota River HUC8s	Twin Cities Metro below L&D1	Cannon and Mississippi/ Vermillion
Current day load at HUC8 outlets (MT)	1049	1543	167	392
Current day load at Lake Pepin TMDL endpoint (MT)	954	1358	167	392
Load goal at Lake Pepin TMDL endpoint (MT)	693	938	199	159
Proportion of current day load needing to be reduced to meet Lake Pepin TMDL goal	27%	31%	0%	59%
Proportion of current day load needing to be reduced to meet NRS goal	26%	32%	-	30%

Figure 11: Recent, average annual HUC8 watershed outlet TP load estimates in Metric Tons (See also Table A-1 in Appendix A)

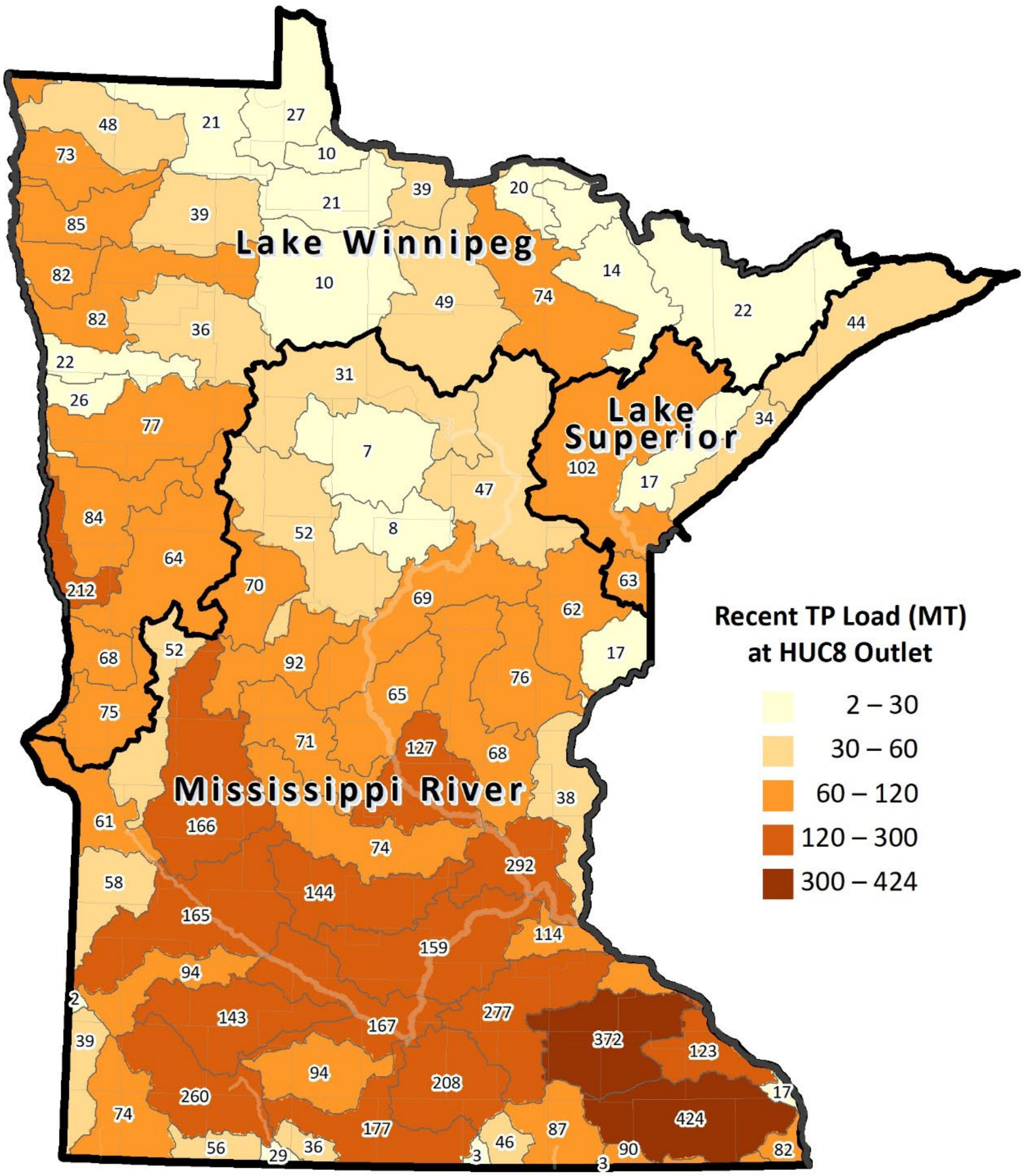


Figure 12: Average annual HUC8 watershed TP load reductions (MT) to meet the final target loads (See also Table A-1 in Appendix A)

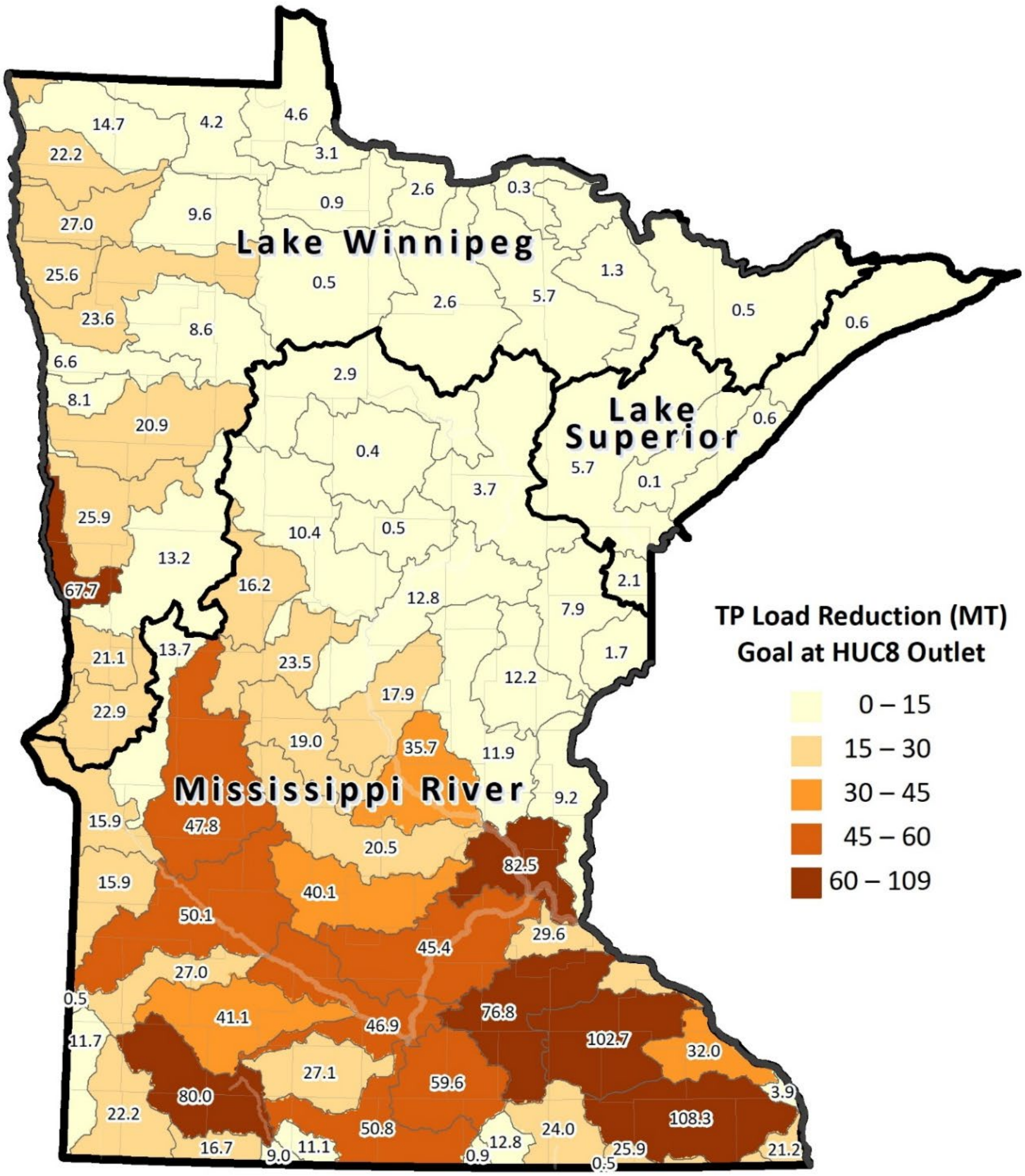


Figure 13: Percent of current day, average annual HUC8 watershed TP load to be reduced to meet the final target loads (See also Table A-1 in Appendix A)

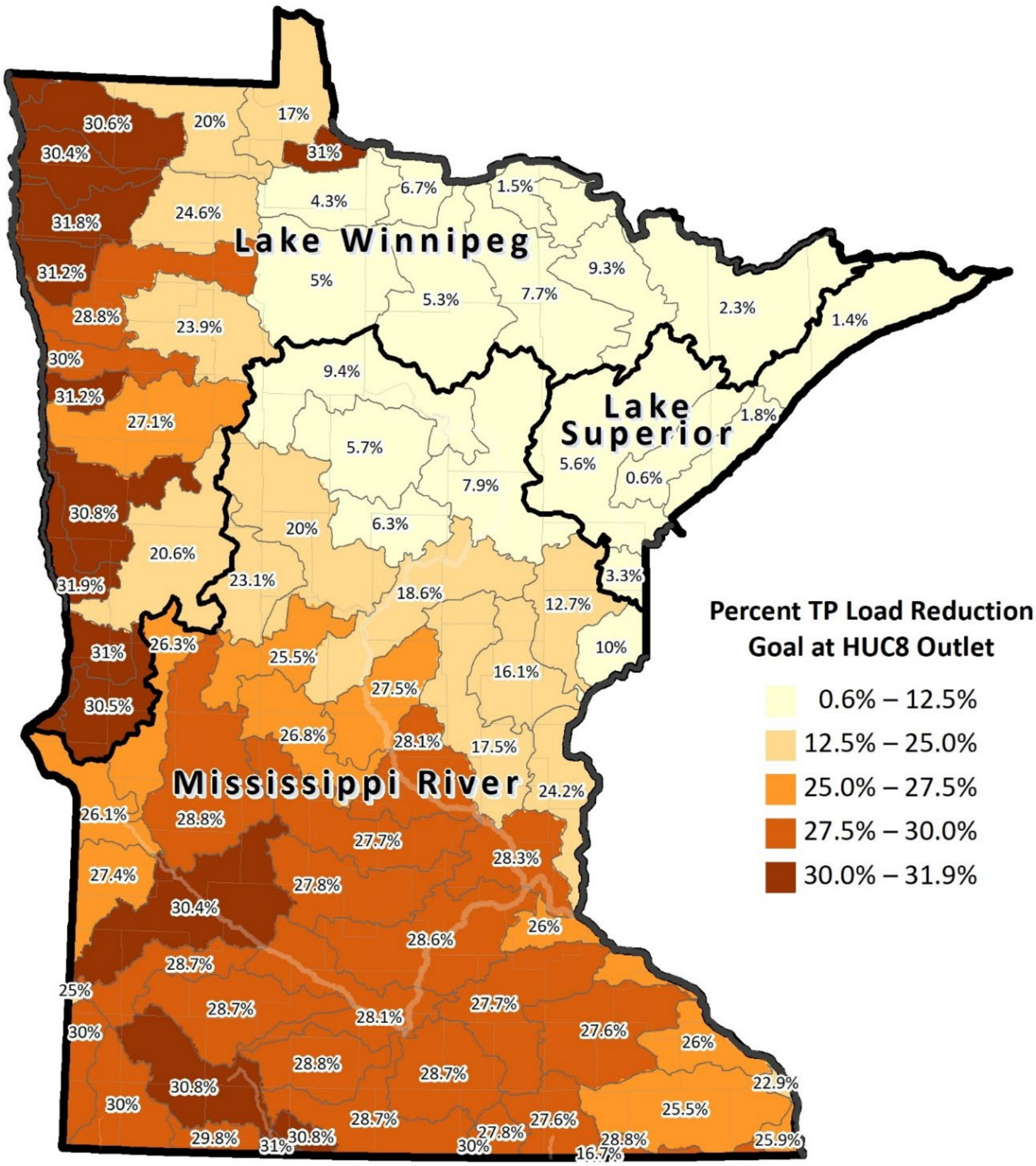


Figure 14. Recent average annual HUC8 watershed TN load estimates (See also Tables A-2 and A-3 in Appendix A)

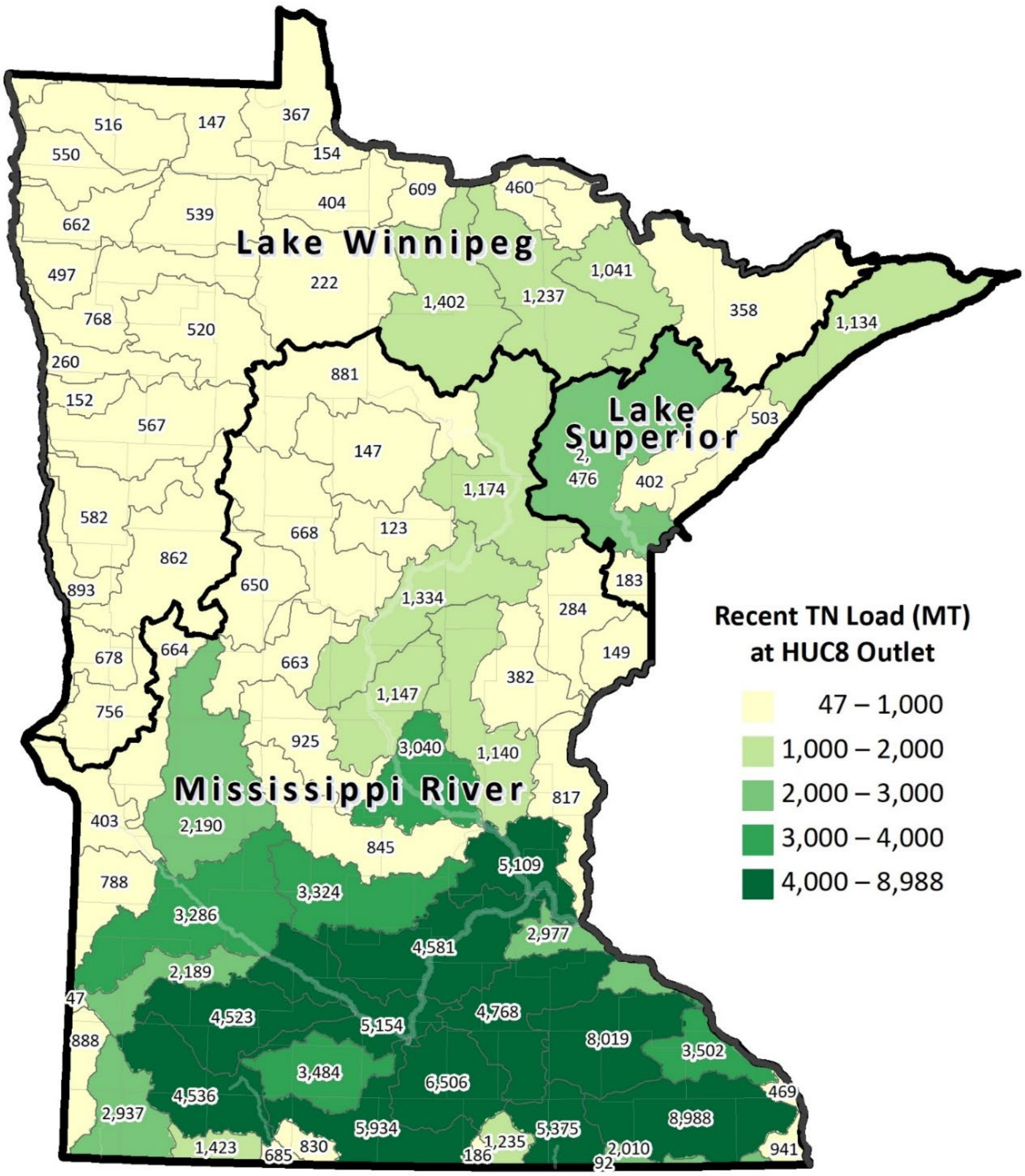


Figure 15. Average annual HUC8 watershed TN load reductions to meet the final target loads (See also Table A-2 in Appendix A)

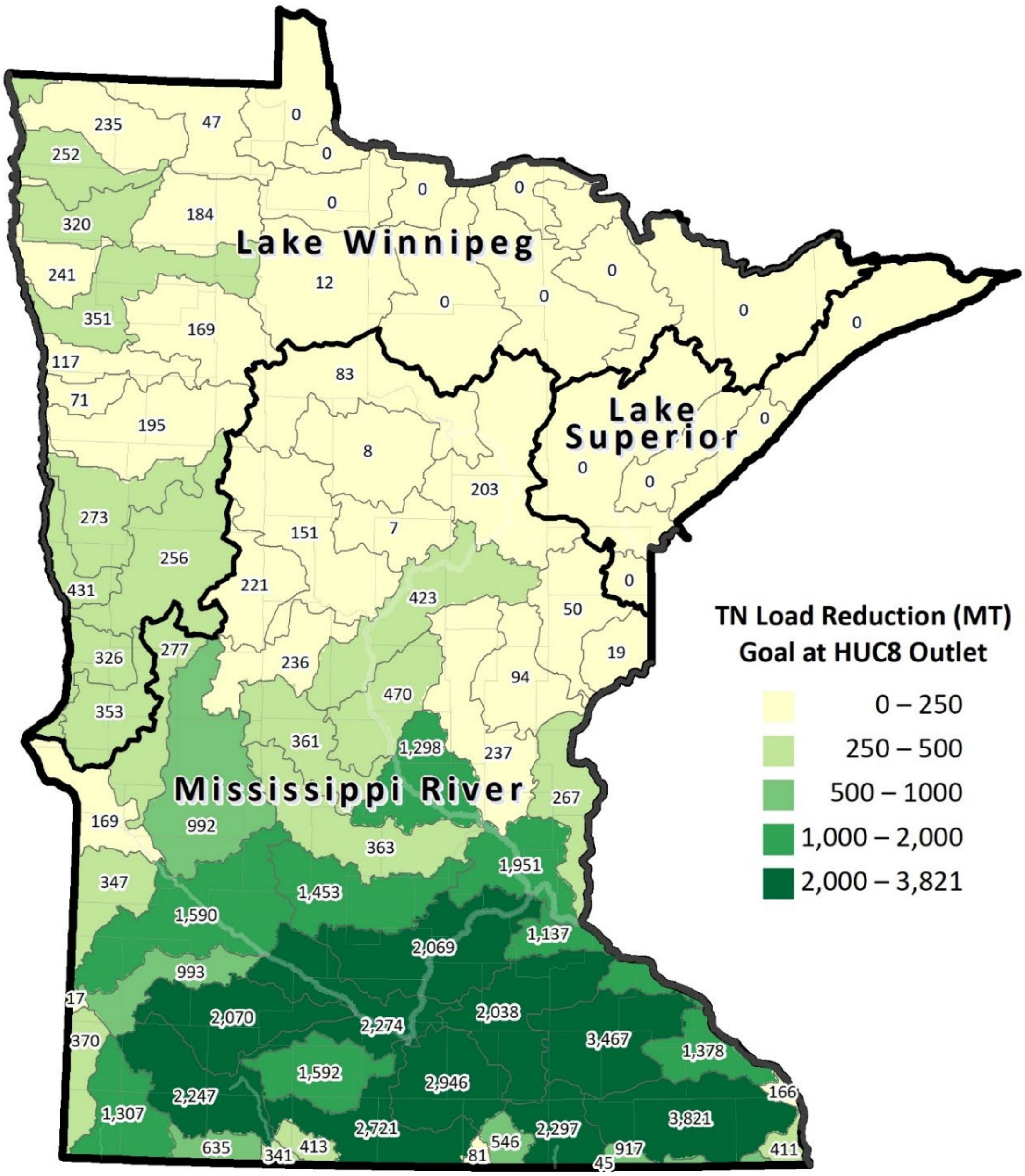
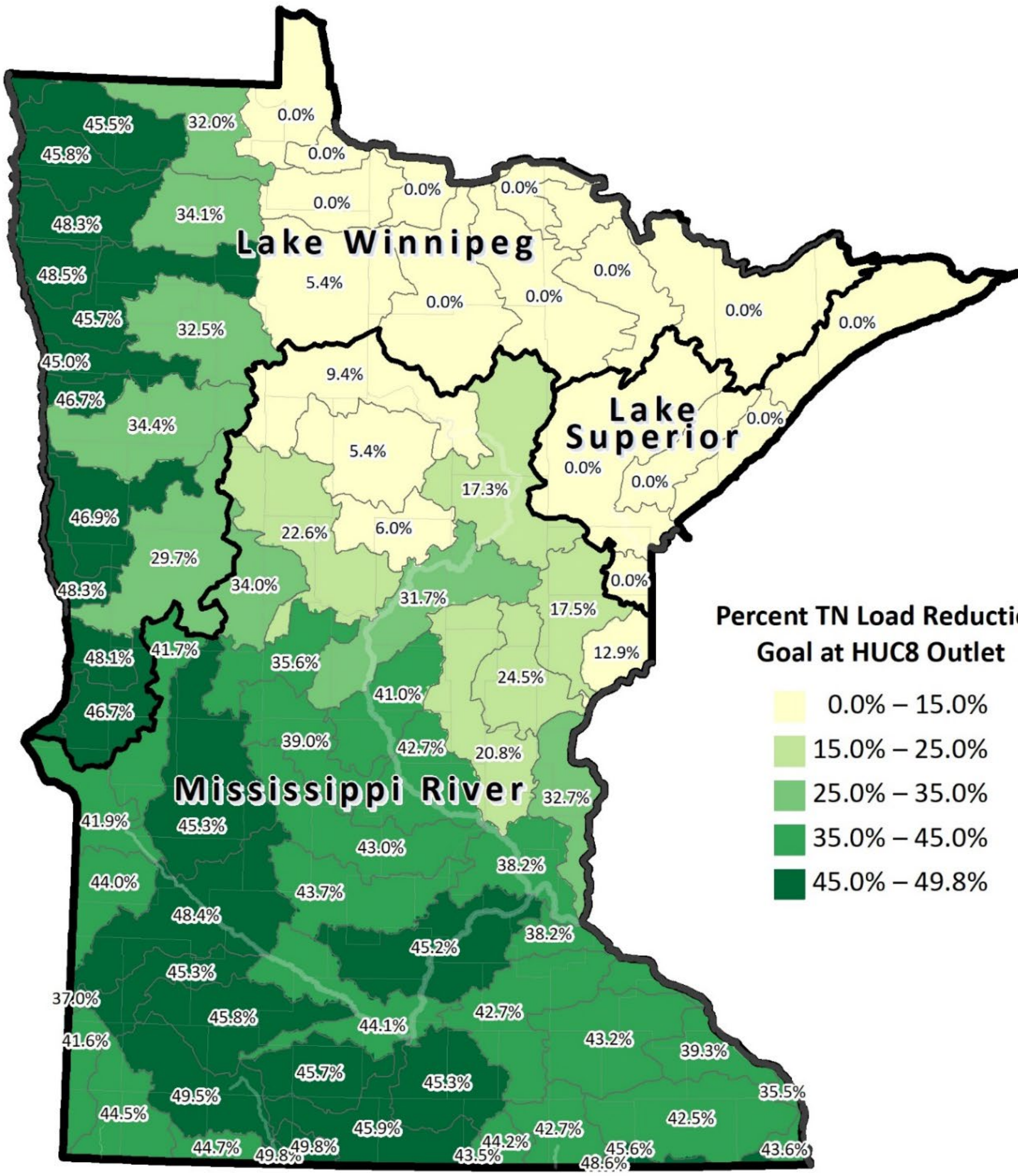


Figure 16: Percent of recent average annual HUC8 watershed TN load to be reduced to meet the final target loads (See also Table A-2 in Appendix A)



In conclusion

The performed work resulted in updated load reduction TP and TN planning goals on a HUC8 basis to achieve NRS goals. These updates to the watershed nutrient reduction needs were based on consideration of the following factors:

- Estimation of revised current day loads using WPLMN and HSPF model results;
- Estimation of load attenuation from the HUC8 outlet to the state line using HSPF and SPARROW model predictions; and
- Proportioning reductions across HUC8s based on estimates of the reducible fraction of the TP and TN loads from each HUC8. Reducible fractions of loads were estimated based on HSPF model predictions of loads across the various source categories specified in the models.

These updated reduction goals provide an improved basis to assess progress and understand the extent of additional efforts needed to achieve NRS planning goals. Continued periodic updates to recent existing loads and comparison to NRS planning goals will be essential for tracking progress, understanding the effectiveness of efforts being implemented, and informing an adaptive management approach. Continued monitoring and integration with the available modeling tools will be important for watershed planning processes.

References

Alexander, R. B., Smith, R. A., & Schwarz, G. E. (2000). Effect of stream channel size on the delivery of nitrogen to the Gulf of Mexico. *Nature*, *403*(6771), 758.

Covino, T., McGlynn, B., & McNamara, R. (2012). Land use/land cover and scale influences on in-stream nitrogen uptake kinetics. *Journal of Geophysical Research: Biogeosciences*, *117*(2), 1–13. https://doi.org/10.1029/2011JG001874

Edlund, M. B., Triplett, L. D., Tomasek, M. D., & Bartilson, K. (2009). From paleo to policy: Partitioning the historical point and nonpoint phosphorus loads to the St. Croix River, Minnesota-Wisconsin, USA. *Journal of Paleolimnology*, *41*(4), 679–689. https://doi.org/10.1007/s10933-008-9288-1

Engstrom, D. R., Almendinger, J. E., Kelley, D. W., & Nater, E. A. (2000). Historical changes in sediments and phosphorus loading of the upper Mississippi River: mass-balance reconstructions from the sediments of Lake Pepin, with a contribution on sediment apportionment.

Evans et al. (2019 in prep). MMW Model Calibration.docx

Gibson, C. A., O'Reilly, C. M., Conine, A. L., & Lipshutz, S. M. (2015). Nutrient uptake dynamics across a gradient of nutrient concentrations and ratios at the landscape scale. *Journal of Geophysical Research: Biogeosciences*, *120*(2), 326–340. https://doi.org/10.1002/2014JG002747

Haag et al. (2019 in prep). SRAT Model Calibration.pdf

Hall, R. O., Baker, M. A., Rosi-Marshall, E. J., Tank, J. L., & Newbold, J. D. (2013). Solute-specific scaling of inorganic nitrogen and phosphorus uptake in streams. *Biogeosciences*, *10*(11), 7323–7331. https://doi.org/10.5194/bg-10-7323-2013

IRRB Water Quality Committee. 2018. Proposed Nutrient Concentration Objectives and Loading Targets for the Red River at the US/Canada Boundary.

Jankowski K. 2021. Personal communication on March 3, 2021 from Kathy Jo Jankowski (USGS) to David Wall (MPCA).

MPCA. 2014. The Minnesota Nutrient Reduction Strategy. wq-s1-80. September 2014.

MPCA. 2014. Building a picture of a watershed. wq-ws1-04. July 2014. https://www.pca.state.mn.us/sites/default/files/wq-ws1-04.pdf

MPCA. 2018. Preliminary Review Draft: Lake of the Woods Excess Nutrients Total Maximum Daily Load (TMDL). wq-iw10-14b. August 2018.

MPCA and LimnoTech. 2019. Draft Lake Pepin Watershed Phosphorus Total Maximum Daily Loads. wq-iw9-22b. July 2019.

Moore, R. B., Johnston, C. M., Smith, R. A., & Milstead, B. (2011). Source and Delivery of Nutrients to Receiving Waters in the Northeastern and Mid-Atlantic Regions of the United States. *Journal of the American Water Resources Association*, *47*(5), 965–990. https://doi.org/10.1111/j.1752-1688.2011.00582.x

Newbold, J. D., Bott, T. L., Kaplan, L. A., Dow, C. L., Jackson, J. K., Aufdenkampe, A. K., … De Long, A. A. (2006). Uptake of nutrients and organic C in streams in New York City drinking-water-supply watersheds. *Journal of the North American Benthological Society*, *25*(4), 998–1017. https://doi.org/10.1899/0887-3593(2006)025[0998:UONAOC]2.0.CO;2Newbold, J. D., Elwood, J. W., O'Neill, R. V., & Sheldon, A. L. (1983). Phosphorus Dynamics in a Woodland Stream Ecosystem. *Ecology*, *64*(5), 1249–1265. https://doi.org/10.2307/1937833

Newbold, J. D., Elwood, J. W., O'Neill, R. V., & Winkle, W. Van. (1981). Measuring Nutrient Spiralling in Streams. *Canadian Journal of Fisheries and Aquatic Sciences*, *38*(7), 860–863. https://doi.org/10.1139/f81-114

Robertson, D.M., and Saad, D.A., 2019, Spatially referenced models of streamflow and nitrogen, phosphorus, and suspended-sediment loads in streams of the Midwestern United States: U.S. Geological Survey Scientific Investigations Report 2019–5114, 74 p. including 5 appendixes, https://doi.org/10.3133/sir20195114.

Schlea, D., Holmberg, H., & Crary, B. (2020). Updating Nutrient Reduction Strategy to Strengthen Linkages with Watersheds and WRAPS. Memorandum written to Minnesota Pollution Control Agency (David Wall, Justin Watkins, Charles Regan) on May 4, 2020. 53 pp.

Smith, R. A., Alexander, R. B., & Schwarz, G. E. (1997). Regional interpretation of water-quality monitoring data. *Water Resources Research*, *33*(12), 2781–2798. Retrieved from https://water.usgs.gov/nawqa/sparrow/wrr97/97WR02171.pdf%0Ahttp://doi.wiley.com/10.1029/97WR02171%5Cnpapers3://publication/doi/10.1029/97WR02171

Smith, R. A., Alexander, R. B., & Schwarz, G. E. (2003). Natural background concentrations of nutrients in streams and rivers of the conterminous United States. *Environmental Science and Technology*, *37*(14), 3039–3047. https://doi.org/10.1021/es020663b

Stream Solute Workshop. (1990). Concepts and Methods for Assessing Solute Dynamics in Stream Ecosystems. *Journal of the North American Benthological Society*, *9*(2), 95–119. https://doi.org/10.2307/1467445

Table A-1: Current day (recent) load estimates, final fair-share load goals, final load reductions, and final fair-share load goals delivered to the state line for TP for the Minnesota portion of HUC8 watersheds. *

Basin	HUC8 Name	HUC8 Number	Current load at HUC8 outlet (MT/yr)	Fair-share load goal at HUC8 outlet (MT/yr)	Load reduction goal at HUC8 outlet (MT/yr)	Percent reduction to meet target	Fair-share load goal, delivered (MT/yr)
Major drainage basin: Lake Superior							
Lake Superior	Baptism-Brule	04010101	43.9	43.3	0.6	1.4%	43.3
Lake Superior	Beaver-Lester	04010102	34.1	33.5	0.6	1.7%	33.5
Lake Superior	St. Louis	04010201	101.5	95.8	5.7	5.6%	95.8
Lake Superior	Cloquet River	04010202	16.5	16.5	0.1	0.4%	14.1
Lake Superior	Nemadji River	04010301	63.4	61.3	2.1	3.3%	61.3
Major drainage basin: Mississippi River							
Upper Mississippi	Mississippi River - Headwaters	07010101	31.4	28.5	2.9	9.3%	12.8
Upper Mississippi	Leech Lake River	07010102	6.6	6.2	0.4	6.2%	2.2
Upper Mississippi	Mississippi River - Grand Rapids	07010103	47.1	43.3	3.7	7.9%	22.7
Upper Mississippi	Mississippi River - Brainerd	07010104	68.9	56.1	12.8	18.6%	33.3
Upper Mississippi	Pine River	07010105	7.7	7.2	0.5	6.6%	3.9
Upper Mississippi	Crow Wing River	07010106	52.0	41.6	10.4	20.0%	23.4
Upper Mississippi	Redeye River	07010107	70.0	53.8	16.2	23.1%	30.0
Upper Mississippi	Long Prairie River	07010108	91.7	68.2	23.5	25.6%	37.5
Upper Mississippi	Mississippi River - Sartell	07010201	65.3	47.4	17.9	27.4%	29.1
Upper Mississippi	Sauk River	07010202	71.2	52.2	19.0	26.6%	32.0
Upper Mississippi	Mississippi River - St. Cloud	07010203	126.8	91.1	35.7	28.1%	56.8

Basin	HUC8 Name	HUC8 Number	Current load at HUC8 outlet (MT/yr)	Fair-share load goal at HUC8 outlet (MT/yr)	Load reduction goal at HUC8 outlet (MT/yr)	Percent reduction to meet target	Fair-share load goal, delivered (MT/yr)
Upper Mississippi	North Fork Crow River	07010204	73.7	53.2	20.5	27.8%	33.2
Upper Mississippi	South Fork Crow River	07010205	144.0	103.8	40.1	27.9%	62.8
Upper Mississippi	Mississippi River - Twin Cities	07010206	291.5	209.0	82.5	28.3%	130.8
Upper Mississippi	Rum River	07010207	67.8	55.9	11.9	17.5%	34.8
Minnesota	Minnesota River - Headwaters	07020001	60.5	44.7	15.9	26.2%	20.7
Minnesota	Pomme de Terre River	07020002	52.0	38.3	13.7	26.4%	14.3
Minnesota	Lac Qui Parle River	07020003	58.1	42.3	15.9	27.3%	19.6

Basin	HUC8 Name	HUC8 Number	Current load at HUC8 outlet (MT/yr)	Fair-share load goal at HUC8 outlet (MT/yr)	Load reduction goal at HUC8 outlet (MT/yr)	Percent reduction to meet target	Fair-share load goal, delivered (MT/yr)
Major drainage basin: Mississippi River							
Minnesota	Minnesota River - Yellow Medicine River	07020004	165.4	115.3	50.1	30.3%	59.7
Minnesota	Chippewa River	07020005	165.7	117.9	47.8	28.8%	54.2
Minnesota	Redwood River	07020006	93.6	66.6	27.0	28.8%	34.5
Minnesota	Minnesota River - Mankato	07020007	166.8	119.9	46.9	28.1%	73.2
Minnesota	Cottonwood River	07020008	142.8	101.7	41.1	28.8%	59.3
Minnesota	Blue Earth River	07020009	176.7	125.9	50.8	28.7%	74.1
Minnesota	Watonwan River	07020010	93.9	66.8	27.1	28.8%	38.3
Minnesota	Le Sueur River	07020011	207.7	148.2	59.6	28.7%	87.2
Minnesota	Lower Minnesota River	07020012	159.3	114.0	45.4	28.5%	71.3
St. Croix	Upper St. Croix River	07030001	17.1	15.4	1.7	9.8%	9.3
St. Croix	Kettle River	07030003	61.8	53.9	7.9	12.8%	32.4
St. Croix	Snake River	07030004	76.3	64.1	12.2	16.0%	38.5
St. Croix	Lower St. Croix River	07030005	38.0	28.8	9.2	24.1%	18.3
Lower Mississippi	Mississippi River - Lake Pepin	07040001	114.2	84.6	29.6	25.9%	55.6
Lower Mississippi	Cannon River	07040002	277.4	200.7	76.8	27.7%	128.2
Lower Mississippi	Mississippi River - Winona	07040003	122.7	90.6	32.0	26.1%	74.7
Lower Mississippi	Zumbro River	07040004	372.0	269.3	102.7	27.6%	197.6
Lower Mississippi	Mississippi River - La Crescent	07040006	17.2	13.2	3.9	23.0%	10.9
Lower Mississippi	Root River	07040008	424.0	315.7	108.3	25.5%	260.1
Lower Mississippi	Mississippi River - Reno	07060001	82.1	60.9	21.2	25.8%	60.9
Lower Mississippi	Upper Iowa River	07060002	89.9	64.0	25.9	28.8%	64.0
Missouri	Upper Big Sioux River	010170202	1.8	1.4	0.5	25.9%	1.4

Basin	HUC8 Name	HUC8 Number	Current load at HUC8 outlet (MT/yr)	Fair-share load goal at HUC8 outlet (MT/yr)	Load reduction goal at HUC8 outlet (MT/yr)	Percent reduction to meet target	Fair-share load goal, delivered (MT/yr)
Missouri	Lower Big Sioux River	010170203	39.0	28.2	10.8	27.7%	28.2
Missouri	Rock River	010170204	73.9	53.4	20.5	27.7%	53.4
Missouri	Little Sioux River	010230003	55.7	40.3	15.4	27.7%	40.3
Cedar	Upper Wapsipinicon River	07080102	3.0	2.2	0.8	28.0%	2.2

Basin	HUC8 Name	HUC8 Number	Current load at HUC8 outlet (MT/yr)	Fair-share load goal at HUC8 outlet (MT/yr)	Load reduction goal at HUC8 outlet (MT/yr)	Percent reduction to meet target	Fair-share load goal, delivered (MT/yr)
Major drainage basin: Mississippi River							
Cedar	Cedar River	07080201	86.6	62.6	24.0	27.7%	62.6
Cedar	Shell Rock River	07080202	46.2	33.4	12.8	27.6%	33.4
Cedar	Winnebago River	07080203	3.2	2.3	0.9	28.5%	2.3
Des Moines	Des Moines River - Headwaters	07100001	260.1	180.1	80.0	30.8%	172.7
Des Moines	Lower Des Moines River	07100002	29.1	20.1	9.0	30.9%	20.1
Des Moines	East Fork Des Moines River	07100003	36.3	25.2	11.1	30.7%	25.2
Major drainage basin: Lake Winnipeg							
Red	Bois de Sioux River	09020101	67.5	46.4	21.1	31.3%	36.4
Red	Mustinka River	09020102	74.6	51.7	22.9	30.6%	18.6
Red	Otter Tail River	09020103	63.7	50.5	13.2	20.7%	39.7
Red	Upper Red River of the North	09020104	212.4	144.8	67.7	31.9%	138.1
Red	Buffalo River	09020106	84.2	58.3	25.9	30.8%	55.6
Red	Marsh River	09020107	25.6	17.6	8.1	31.4%	16.8
Red	Wild Rice River	09020108	77.1	56.2	20.9	27.2%	53.6
Red	Sandhill River	09020301	21.6	15.0	6.6	30.4%	14.3
Red	Upper/Lower Red Lake	09020302	10.2	9.6	0.5	5.2%	5.7
Red	Red Lake River	09020303	82.4	58.8	23.6	28.6%	56.1
Red	Thief River	09020304	38.8	29.2	9.6	24.8%	27.5
Red	Clearwater River	09020305	35.8	27.2	8.6	24.0%	25.5
Red	Grand Marais Creek	09020306	82.2	56.6	25.6	31.1%	54.2
Red	Snake River (Red)	09020309	84.6	57.6	27.0	31.9%	57.6

Basin	HUC8 Name	HUC8 Number	Current load at HUC8 outlet (MT/yr)	Fair-share load goal at HUC8 outlet (MT/yr)	Load reduction goal at HUC8 outlet (MT/yr)	Percent reduction to meet target	Fair-share load goal, delivered (MT/yr)
Red	Tamarac River	09020311	72.7	50.5	22.2	30.6%	50.5
Red	Two Rivers	09020312	47.6	32.9	14.7	30.8%	32.9
Red	Roseau River	09020314	21.2	17.0	4.2	19.6%	17.0
Rainy	Rainy Headwaters	09030001	22.1	21.6	0.5	2.1%	13.5
Rainy	Vermilion River	09030002	14.4	13.1	1.3	8.7%	6.4

Basin	HUC8 Name	HUC8 Number	Current load at HUC8 outlet (MT/yr)	Fair-share load goal at HUC8 outlet (MT/yr)	Load reduction goal at HUC8 outlet (MT/yr)	Percent reduction to meet target	Fair-share load goal, delivered (MT/yr)
Rainy	Rainy Lake	09030003	19.7	19.4	0.3	1.4%	15.8
Rainy	Rainy River (9030004)	09030004	39.0	36.5	2.6	6.6%	34.4
Rainy	Little Fork River	09030005	73.8	68.1	5.7	7.7%	58.9
Rainy	Big Fork River	09030006	48.9	46.4	2.6	5.2%	40.5
Rainy	Rapid River	09030007	21.0	20.1	0.9	4.3%	19.1
Rainy	Rainy River	09030008	9.9	6.8	3.1	31.0%	6.8
Rainy	Lake of the Woods	09030009	26.8	22.2	4.6	17.1%	22.2

***Note: Using results from the LimnoTech Memo submitted on May 4, 2020, the MPCA subsequently combined all Mississippi River tributary watersheds into one drainage area and recalculated the load reduction needs which are shown in this table. Changes were also subsequently made by MPCA using recalibrated HSPF models for the Shell Rock and Winnebago Rivers, which extended the HSPF calibration period to also include 2013-18. Additionally, LimnoTech provided recalibrated loads (2009-18) for the Zumbro River, which was originally modeled for the 2000-2009 period. The load reduction targets in this report reflect these changes.**

Table A-2: Current load estimates, final fair-share load goals, final load reductions, and final fair-share load goals delivered to the state line for TN for the Minnesota portion of HUC8 watersheds

Basin	HUC8 Name	HUC8 Number	Current load at HUC8 outlet (MT/yr)	Fair-share load goal at HUC8 outlet (MT/yr)	Load reduction goal at HUC8 outlet (MT/yr)	Proportion of current load needing reduced	Fair-share load goal, delivered (MT/yr)
Major drainage basin: Lake Superior							
Lake Superior	Baptism-Brule	04010101	1134	1134	0	0.0%	1134
Lake Superior	Beaver-Lester	04010102	503	503	0	0.0%	503
Lake Superior	St. Louis	04010201	2476	2476	0	0.0%	2476
Lake Superior	Cloquet River	04010202	402	402	0	0.0%	363
Lake Superior	Nemadji River	04010301	183	183	0	0.0%	183
Major drainage basin: Mississippi River							
Upper Mississippi	Mississippi River - Headwaters	07010101	881	798	83	9.4%	446
Upper Mississippi	Leech Lake River	07010102	146	138	8	5.5%	63
Upper Mississippi	Mississippi River - Grand Rapids	07010103	1173	971	203	17.3%	609
Upper Mississippi	Mississippi River - Brainerd	07010104	1334	912	423	31.7%	625

Basin	HUC8 Name	HUC8 Number	Current load at HUC8 outlet (MT/yr)	Fair-share load goal at HUC8 outlet (MT/yr)	Load reduction goal at HUC8 outlet (MT/yr)	Proportion of current load needing reduced	Fair-share load goal, delivered (MT/yr)
Major drainage basin: Mississippi River							
Upper Mississippi	Mississippi River - Headwaters	07010101	881	798	83	9.4%	446
Upper Mississippi	Leech Lake River	07010102	146	138	8	5.5%	63
Upper Mississippi	Mississippi River - Grand Rapids	07010103	1173	971	203	17.3%	609
Upper Mississippi	Mississippi River - Brainerd	07010104	1334	912	423	31.7%	625
Upper Mississippi	Pine River	07010105	123	116	7	6.0%	75
Upper Mississippi	Crow Wing River	07010106	668	517	151	22.6%	343
Upper Mississippi	Redeye River	07010107	650	429	221	34.0%	278
Upper Mississippi	Long Prairie River	07010108	663	426	236	35.6%	278
Upper Mississippi	Mississippi River - Sartell	07010201	1146	676	470	41.0%	467
Upper Mississippi	Sauk River	07010202	925	564	361	39.0%	389
Upper Mississippi	Mississippi River - St. Cloud	07010203	3040	1742	1298	42.7%	1221
Upper Mississippi	North Fork Crow River	07010204	845	482	363	43.0%	338
Upper Mississippi	South Fork Crow River	07010205	3323	1870	1453	43.7%	1287
Upper Mississippi	Mississippi River - Twin Cities	07010206	5109	3157	1951	38.2%	2228

Basin	HUC8 Name	HUC8 Number	Current load at HUC8 outlet (MT/yr)	Fair-share load goal at HUC8 outlet (MT/yr)	Load reduction goal at HUC8 outlet (MT/yr)	Proportion of current load needing reduced	Fair-share load goal, delivered (MT/yr)
Upper Mississippi	Rum River	07010207	1140	903	237	20.8%	633
Minnesota	Minnesota River - Headwaters	07020001	403	234	169	41.9%	134
Minnesota	Pomme de Terre River	07020002	664	387	277	41.7%	146
Minnesota	Lac Qui Parle River	07020003	788	441	347	44.0%	252
Minnesota	Minnesota River - Yellow Medicine River	07020004	3286	1696	1590	48.4%	1081
Minnesota	Chippewa River	07020005	2190	1198	992	45.3%	684
Minnesota	Redwood River	07020006	2189	1197	993	45.3%	763
Minnesota	Minnesota River - Mankato	07020007	5154	2879	2274	44.1%	2001
Minnesota	Cottonwood River	07020008	4523	2453	2070	45.8%	1655
Minnesota	Blue Earth River	07020009	5934	3213	2721	45.9%	2203
Minnesota	Watonwan River	07020010	3484	1892	1592	45.7%	1120
Minnesota	Le Sueur River	07020011	6506	3560	2946	45.3%	2442
Minnesota	Lower Minnesota River	07020012	4581	2512	2069	45.2%	1773
St. Croix	Upper St. Croix River	07030001	149	130	19	12.9%	85
St. Croix	Kettle River	07030003	284	234	50	17.5%	153
St. Croix	Snake River	07030004	382	288	94	24.5%	189
St. Croix	Lower St. Croix River	07030005	817	550	267	32.7%	398
Lower Mississippi	Mississippi River - Lake Pepin	07040001	2977	1840	1137	38.2%	1398
Lower Mississippi	Cannon River	07040002	4768	2730	2038	42.7%	1993
Lower Mississippi	Mississippi River - Winona	07040003	3502	2124	1378	39.3%	1958
Lower Mississippi	Zumbro River	07040004	8019	4553	3466	43.2%	3882
Lower Mississippi	Mississippi River - La Crescent	07040006	469	303	166	35.4%	279
Lower Mississippi	Root River	07040008	8988	5167	3821	42.5%	4764
Lower Mississippi	Mississippi River - Reno	07060001	941	530	410	43.6%	530

Basin	HUC8 Name	HUC8 Number	Current load at HUC8 outlet (MT/yr)	Fair-share load goal at HUC8 outlet (MT/yr)	Load reduction goal at HUC8 outlet (MT/yr)	Proportion of current load needing reduced	Fair-share load goal, delivered (MT/yr)
Lower Mississippi	Upper Iowa River	07060002	2010	1094	917	45.6%	1094
Missouri	Upper Big Sioux River	010170202	47	29	18	37.5%	29
Missouri	Lower Big Sioux River	010170203	888	512	376	42.3%	512
Missouri	Rock River	010170204	2937	1608	1328	45.2%	1608
Missouri	Little Sioux River	010230003	1423	777	646	45.4%	777
Cedar	Upper Wapsipinicon River	07080102	92	48	45	48.5%	48
Cedar	Cedar River	07080201	5375	3078	2297	42.7%	3078
Cedar	Shell Rock River	07080202	1235	689	546	44.2%	689
Cedar	Winnebago River	07080203	186	105	81	43.6%	105
Des Moines	Des Moines River - Headwaters	07100001	4536	2289	2247	49.5%	2226
Des Moines	Lower Des Moines River	07100002	685	344	341	49.8%	344
Des Moines	East Fork Des Moines River	07100003	830	417	413	49.8%	417
Major drainage basin: Lake Winnipeg							
Red	Bois de Sioux River	09020101	678	353	326	48.0%	318
Red	Mustinka River	09020102	756	403	353	46.7%	165
Red	Otter Tail River	09020103	862	606	256	29.7%	545
Red	Upper Red River of the North	09020104	893	463	431	48.2%	454
Red	Buffalo River	09020106	582	309	273	46.9%	303
Red	Marsh River	09020107	152	81	71	46.8%	79
Red	Wild Rice River	09020108	567	372	195	34.4%	365
Red	Sandhill River	09020301	260	143	117	45.1%	140
Red	Upper/Lower Red Lake	09020302	222	210	12	5.3%	94
Red	Red Lake River	09020303	768	417	351	45.7%	410
Red	Thief River	09020304	539	355	184	34.2%	300
Red	Clearwater River	09020305	520	350	169	32.6%	314

Basin	HUC8 Name	HUC8 Number	Current load at HUC8 outlet (MT/yr)	Fair-share load goal at HUC8 outlet (MT/yr)	Load reduction goal at HUC8 outlet (MT/yr)	Proportion of current load needing reduced	Fair-share load goal, delivered (MT/yr)
Red	Grand Marais Creek	09020306	497	256	241	48.4%	253
Red	Snake River (Red)	09020309	662	342	320	48.4%	342
Red	Tamarac River	09020311	550	298	252	45.8%	298
Red	Two Rivers	09020312	516	282	235	45.5%	282
Red	Roseau River	09020314	147	100	47	32.0%	100
Rainy	Rainy Headwaters	09030001	358	358	0	0.0%	201
Rainy	Vermilion River	09030002	1041	1041	0	0.0%	487
Rainy	Rainy Lake	09030003	460	460	0	0.0%	402
Rainy	Rainy River (9030004)	09030004	607	607	0	0.0%	580
Rainy	Little Fork River	09030005	1237	1237	0	0.0%	1076
Rainy	Big Fork River	09030006	1402	1402	0	0.0%	1236
Rainy	Rapid River	09030007	404	404	0	0.0%	386
Rainy	Rainy River	09030008	154	154	0	0.0%	154
Rainy	Lake of the Woods	09030009	367	367	0	0.0%	367

***Note: Using results from the LimnoTech Memo submitted on May 4, 2020, the MPCA subsequently combined all Mississippi River tributary watersheds into one drainage area and recalculated the load reduction needs which are shown in this table. Changes were also subsequently made by MPCA using recalibrated HSPF models for the Shell Rock and Winnebago Rivers, which extended the HSPF calibration period to also include 2013-18. Additionally, LimnoTech provided recalibrated loads (2009-18) for the Zumbro River, which was originally modeled for the 2000-2009 period. The load reduction targets in this report reflect these changes.**

Table A-3: Current (recent) load estimates, interim fair-share load goals, interim load reductions, and interim fair-share load goals delivered to the state line for TN for the Minnesota portion of HUC8 watersheds

Basin	HUC8 Name	HUC8 Number	Current load at HUC8 outlet (MT/yr)	Fair-share load goal at HUC8 outlet (MT/yr)	Load reduction goal at HUC8 outlet (MT/yr)	Proportion of current load needing reduced	Fair-share load goal, delivered (MT/yr)
Major drainage basin: Mississippi River							
Upper Mississippi	Mississippi River - Headwaters	07010101	881	849	32	3.6%	474
Upper Mississippi	Leech Lake River	07010102	146	143	3	2.1%	66
Upper Mississippi	Mississippi River - Grand Rapids	07010103	1173	1095	79	6.7%	687
Upper Mississippi	Mississippi River - Brainerd	07010104	1334	1171	164	12.3%	802
Upper Mississippi	Pine River	07010105	123	120	3	2.3%	78
Upper Mississippi	Crow Wing River	07010106	668	609	59	8.8%	404
Upper Mississippi	Redeye River	07010107	650	564	86	13.2%	366
Upper Mississippi	Long Prairie River	07010108	663	571	92	13.8%	373
Upper Mississippi	Mississippi River - Sartell	07010201	1146	964	182	15.9%	665
Upper Mississippi	Sauk River	07010202	925	785	140	15.1%	541
Upper Mississippi	Mississippi River - St. Cloud	07010203	3040	2537	503	16.5%	1778
Upper Mississippi	North Fork Crow River	07010204	845	704	141	16.7%	494
Upper Mississippi	South Fork Crow River	07010205	3323	2760	563	17.0%	1899
Upper Mississippi	Mississippi River - Twin Cities	07010206	5109	4352	756	14.8%	3072
Upper Mississippi	Rum River	07010207	1140	1048	92	8.1%	735
Minnesota	Minnesota River - Headwaters	07020001	403	338	65	16.2%	192
Minnesota	Pomme de Terre River	07020002	664	557	107	16.2%	210
Minnesota	Lac Qui Parle River	07020003	788	653	134	17.1%	373
Minnesota	Minnesota River - Yellow Medicine River	07020004	3286	2669	616	18.8%	1701
Minnesota	Chippewa River	07020005	2190	1805	385	17.6%	1031
Minnesota	Redwood River	07020006	2189	1804	385	17.6%	1150
Minnesota	Minnesota River - Mankato	07020007	5154	4272	882	17.1%	2969
Minnesota	Cottonwood River	07020008	4523	3720	803	17.7%	2511

Basin	HUC8 Name	HUC8 Number	Current load at HUC8 outlet (MT/yr)	Fair-share load goal at HUC8 outlet (MT/yr)	Load reduction goal at HUC8 outlet (MT/yr)	Proportion of current load needing reduced	Fair-share load goal, delivered (MT/yr)
Minnesota	Blue Earth River	07020009	5934	4879	1055	17.8%	3346
Minnesota	Watonwan River	07020010	3484	2867	617	17.7%	1697
Minnesota	Le Sueur River	07020011	6506	5364	1142	17.6%	3679
Minnesota	Lower Minnesota River	07020012	4581	3779	802	17.5%	2667
St. Croix	Upper St. Croix River	07030001	149	142	7	5.0%	93
St. Croix	Kettle River	07030003	284	264	19	6.8%	173
St. Croix	Snake River	07030004	382	346	36	9.5%	226
St. Croix	Lower St. Croix River	07030005	817	714	104	12.7%	517
Lower Mississippi	Mississippi River - Lake Pepin	07040001	2977	2536	441	14.8%	1927
Lower Mississippi	Mississippi River - Winona	07040003	3502	2968	534	15.3%	2736
Lower Mississippi	Zumbro River	07040004	8019	6675	1344	16.8%	5692
Lower Mississippi	Mississippi River - La Crescent	07040006	469	405	64	13.7%	373
Lower Mississippi	Root River	07040008	8988	7507	1481	16.5%	6921
Lower Mississippi	Mississippi River - Reno	07060001	941	782	159	16.9%	782
Lower Mississippi	Upper Iowa River	07060002	2010	1655	355	17.7%	1655
Missouri	Upper Big Sioux River	010170202	47	40	7	14.5%	40
Missouri	Lower Big Sioux River	010170203	888	742	146	16.4%	742
Missouri	Rock River	010170204	2937	2422	515	17.5%	2422
Missouri	Little Sioux River	010230003	1423	1173	250	17.6%	1173
Cedar	Upper Wapsipinicon River	07080102	92	75	17	18.8%	75

Basin	HUC8 Name	HUC8 Number	Current load at HUC8 outlet (MT/yr)	Fair-share load goal at HUC8 outlet (MT/yr)	Load reduction goal at HUC8 outlet (MT/yr)	Proportion of current load needing reduced	Fair-share load goal, delivered (MT/yr)
Cedar	Shell Rock River	07080202	1235	1024	211	17.1%	1024
Cedar	Winnebago River	07080203	186	155	31	16.9%	155
Des Moines	Des Moines River - Headwaters	07100001	4536	3665	871	19.2%	3564
Des Moines	Lower Des Moines River	07100002	685	552	132	19.3%	552
Des Moines	East Fork Des Moines River	07100003	830	670	160	19.3%	670
Major drainage basin: Lake Winnipeg							
Red	Bois de Sioux River	09020101	678	637	41	6.1%	574
Red	Mustinka River	09020102	756	711	45	5.9%	291
Red	Otter Tail River	09020103	862	829	33	3.8%	747
Red	Upper Red River of the North	09020104	893	839	55	6.1%	823
Red	Buffalo River	09020106	582	547	35	6.0%	537
Red	Marsh River	09020107	152	143	9	5.9%	140
Red	Wild Rice River	09020108	567	542	25	4.4%	532
Red	Sandhill River	09020301	260	245	15	5.7%	240
Red	Upper/Lower Red Lake	09020302	222	220	1	0.7%	99
Red	Red Lake River	09020303	768	723	45	5.8%	711
Red	Thief River	09020304	539	516	23	4.3%	436
Red	Clearwater River	09020305	520	498	22	4.1%	446
Red	Grand Marais Creek	09020306	497	466	31	6.2%	461
Red	Snake River (Red)	09020309	662	622	41	6.2%	622
Red	Tamarac River	09020311	550	518	32	5.8%	518
Red	Two Rivers	09020312	516	486	30	5.8%	486
Red	Roseau River	09020314	147	141	6	4.1%	141

***Note: Using results from the LimnoTech Memo submitted on May 4, 2020, the MPCA subsequently combined all Mississippi River tributary watersheds into one drainage area and recalculated the load reduction needs which are shown in this table. Changes were also subsequently made by MPCA using recalibrated HSPF models for the Shell Rock and Winnebago Rivers, which extended the HSPF calibration period to also include 2013-18. Additionally, LimnoTech provided recalibrated loads (2009-18) for the Zumbro River, which was originally modeled for the 2000-2009 period. The load reduction targets in this report reflect these changes.**

Appendix B: Fair-Share Sample Calculations

The following table and narrative demonstrate the fair-share nutrient reduction calculations for two HUC8 watersheds in the Mississippi River major basin and two HUC8 watersheds in the Red River major basin.

Table B-1: Sample fair-share nutrient reduction calculations for final TP load goals for two watersheds each in the Mississippi River and Red River major basins

Line	Description	Mississippi River - Brainerd (07010104)	Pomme de Terre River (07020002)		Mustinka River (09020102)	Tamarac River (09020311)
	Major Basin	**Mississippi River**			**Red River**	
1	Major basin final TP planning goal (MT/yr)	2107			700	
2	Major basin current day delivered TP load *Σ Individual current day loads x individual delivery ratios*	2967			991	
3	Load reduction planning goal (MT/yr) *Line 2 minus Line 1*	860			291	
4	Reducible TP load delivered to state line (MT/yr) *Σ Individual current day loads x individual delivery ratios x individual reducible fractions*	2146			720	
5	Proportion of reducible load at HUC8 outlet to be reduced to meet planning goal (MT/yr), i.e., the ***Fair-Share Proportion*** *Line 3 divided by Line 4*	40.1%			40.4%	
6	Current day TP load at HUC8 outlet (MT/yr)	68.9	52.0		74.6	72.7
7	TP delivery ratio to state line endpoint	59.4%	37.4%		36.0%	100%
8	Reducible fraction TP	50.9%	72.3%		75.8%	75.6%
9	Current day TP load delivered to state line (MT/yr) *Line 6 times Line 7. Used in Line 2 calculation.*	40.9	19.5		26.9	72.7
10	Reducible TP load at HUC8 outlet (MT/yr) *Line 6 times Line 8*	35.1	37.6		56.6	55.0
11	Fair-Share TP load reduction goal at HUC8 outlet (MT/yr) *Line 5 times Line 10*	14.1	15.1		22.9	22.2
12	Fair-Share TP load goal at HUC8 outlet (MT/yr) *Line 6 minus Line 11*	54.8	36.9		51.7	50.5
13	Proportion of total current day load to be reduced *Line 11 divided by Line 6*	20.4%	29.0%		30.6%	30.6%
14	Proportion of reducible load to be reduced *Line 11 divided by Line 10. Matches Line 5.*	40.1%	40.1%		40.4%	40.4%
15	Fair-Share TP load goal at state line (MT/yr) *Line 12 times Line 7. The sum of all of these for HUC8s in a major basin matches Line 1.*	32.6	13.8		18.6	50.5

In the Mississippi River basin, the Mississippi-Brainerd HUC8 has a higher current day load estimate and higher delivery ratio, but a lower reducible fraction relative to the Pomme de Terre HUC8. Both HUC8 watersheds have a fair-share load reduction goal set at 40.1% of their respective reducible loads based on the fair-share proportion calculation done at the major basin level. Despite having a higher total current day load, because it has a lower reducible TP load, the Mississippi-Brainerd has a slightly lower fair-share load reduction goal of 14 MT/yr relative to the 15 MT/yr reduction goal for the Pomme de Terre. The fair-share load delivered to the state line from the Mississippi-Brainerd is over two times higher than that of the Pomme de Terre, however, because of the combination of it having a higher delivery ratio, higher current day load, and higher fair-share load at the HUC8 outlet.

In the Red River basin, the Mustinka River HUC8 and Tamarac River HUC8 have very similar current day load estimates and very similar reducible fraction estimates. This results in very similar fair-share load reduction goals for the HUC8s at the outlets and similar proportions of the current day loading needing reduced. The fair-share load delivered is quite different between the two, however, because of the different delivery ratios. The Tamarac River is relatively near the state line end point and therefore essentially all of its load reduction at the HUC8 outlet is also realized as a fair-share load reduction "delivered". The Mustinka River is relatively far from the state line end point (over half of the length of the state) and experiences attenuation in both Lake Traverse and Mud Lake before traveling the entire length of the Red River. This results in a much lower fair-share load reduction "delivered" relative to the Tamarac River HUC8.

Appendix C: Major River Basin nutrient loads to the state line, showing: original baseline loads, 2014 loads reflected in the NRS, and recent-period estimates through modeling

Figures C1-C6 were developed by the MPCA to show the comparison between the total loads (top of stacked bars) and the load upon reaching final goals (top of dark-shading). Most graphs show the loads and load goals for a) estimated original baseline conditions (left bar), b) conditions around the time the NRS was developed (middle bar), and c) sum of recent loads at the state line as modeled primarily with HSPF as described in this document (right bar). The HUC8 watershed nutrient reduction planning goals provided in Appendix A collectively add-up to the load represented by the lighter shading in the ***right-side*** bars. When the HUC8 nutrient reduction goals are achieved, the loads will be equal to the dark-blue shaded loads.

Figure C-1. Baseline, 2014 NRS, and recent modeled nitrogen loads for Minnesota contributions to the Mississippi River Basin drainage area at the state line.

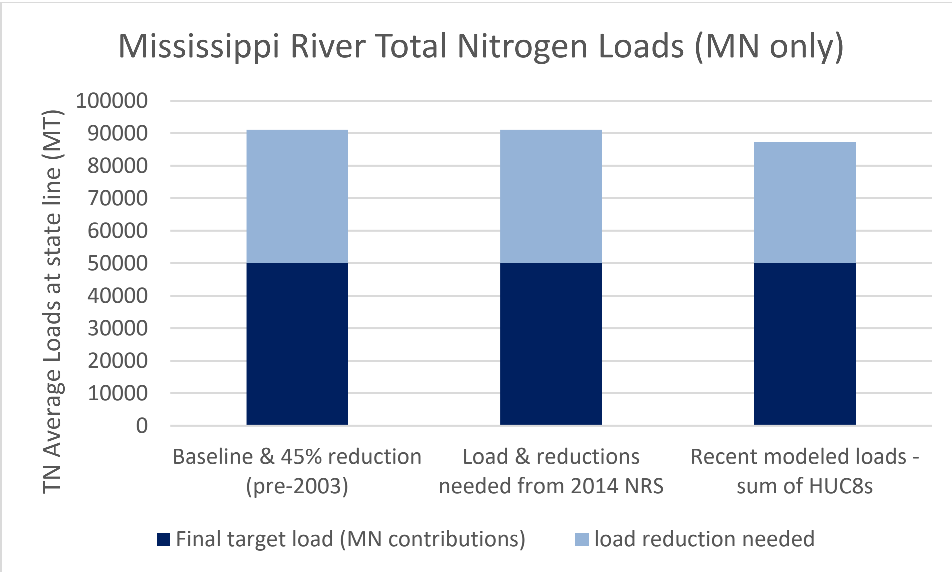


Figure C-2. Baseline, 2014 NRS and recent modeled TP loads for Minnesota contributions to the Mississippi River Basin drainage areas at the state line.

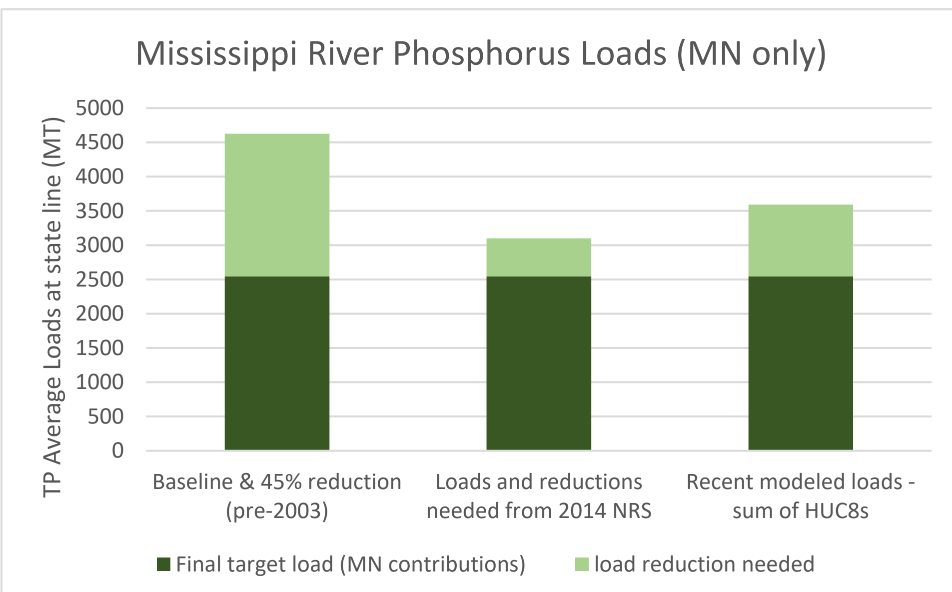


Figure C-3. Baseline and recent modeled TN loads for Minnesota contributions to the Red River Basin drainage area at the state line.

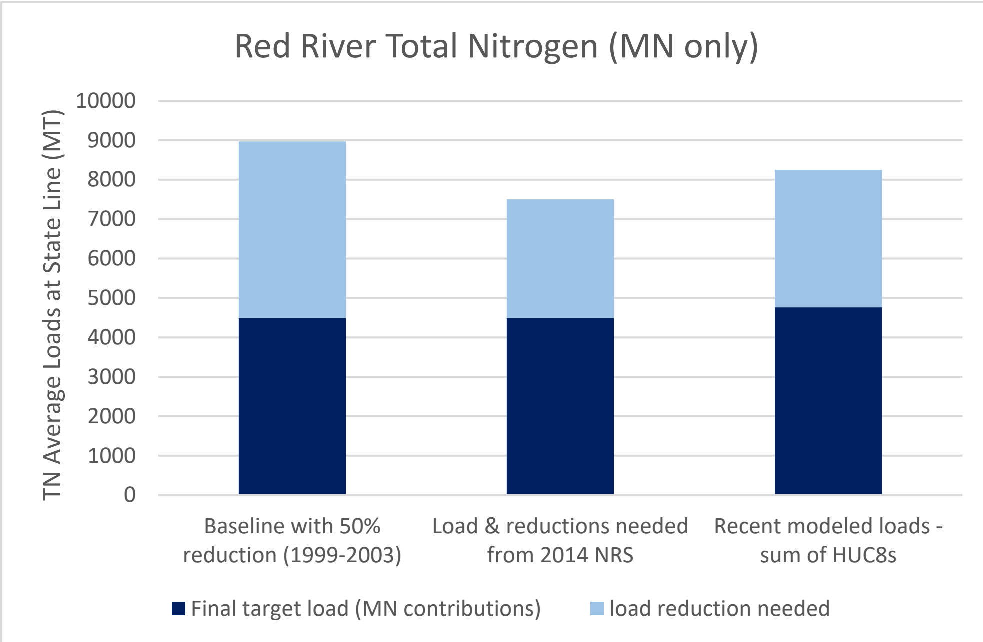


Figure C-4. Baseline and recent modeled TP loads for Minnesota contributions to the Red River Basin drainage area at the state line.

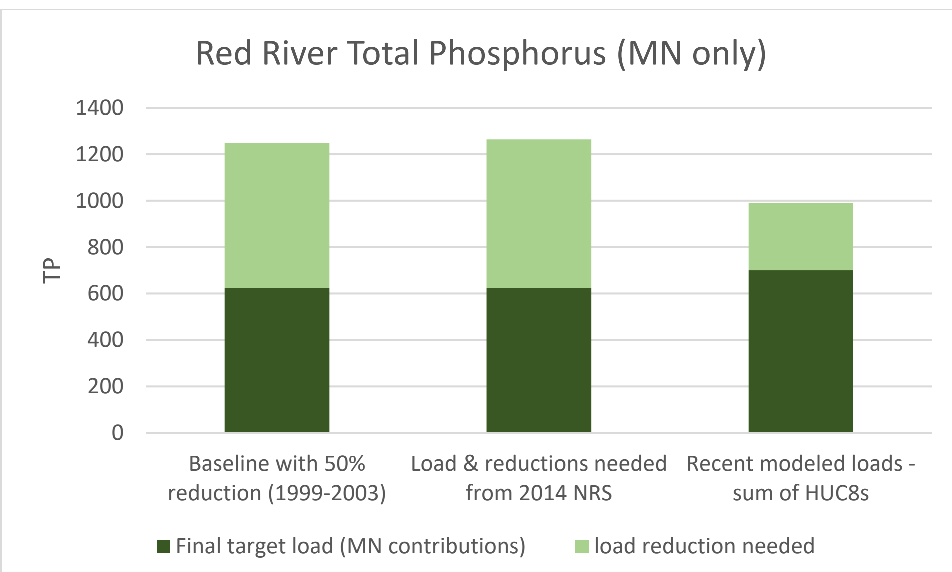


Figure C-5. Recent modeled TN loads for Minnesota contributions into Lake Superior. An original baseline was not defined in the 2014 NRS.

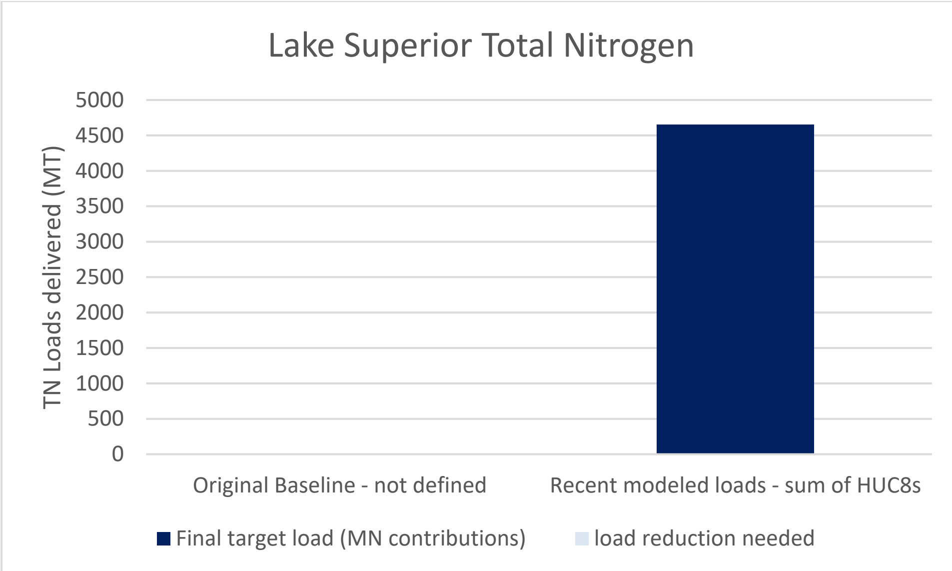


Figure C-6. Original baseline, NRS and recently modeled TP loads for the combined Minnesota watersheds flowing into Lake Superior.