Nitrogen in Northeast Lakeshore TMDL Study Area

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EXECUTIVE SUMMARY

Excess nitrogen in the environment presents risks to surface water quality, groundwater quality, human health, and aquatic health. Nitrogen is found in many different forms such as nitrate, total Kjeldahl nitrogen, and ammonia. Each of the forms present unique risks to the environment and challenges for management. Existing data and methods are available to evaluate the movement of nitrogen through the environment and identify the potential causes of excess nitrogen in the environment.

This study evaluates the sources and surface water impacts of nitrogen in the Northeast Lakeshore region of Wisconsin. The Northeast Lakeshore includes watersheds ins Ozaukee, Fond Du Lac, Manitowoc, Calumet, Sheboygan, Brown, Kewaunee, and Door counties. The study includes seven main components: evaluation of long-term trends, summary of short-term monitoring completed during the project, characterization of nitrogen added to and removed from the landscape, comparison of results to the existing SPARROW model, estimation of baseflow contributions to surface waters, exploration of nitrates in groundwater, and exploration of statistical methods to better understand nitrogen in the environment. Results from the analysis are summarized below.

Long-Term Trends

- In-stream nitrate concentrations have been increasing over time, although the upward trend has stabilized in some locations.
- In-stream total Kjeldahl nitrogen concentrations have been decreasing over time.
- In-stream nitrate concentration is highest in the Kewaunee River and lowest in the Sheboygan River.
- In-stream total Kjeldahl nitrogen concentration is highest in the Manitowoc River and lowest in the Kewaunee River.

Short-Term Monitoring

- In-stream concentrations of total nitrogen, nitrate, total Kjeldahl nitrogen, and ammonia vary by watershed.
- Total nitrogen, nitrate, TKN, and ammonia concentrations tend to be highest in the northern subbasins of the study area and lowest in the southern subbasins of the study area.

Nitrogen Mass Balance

- Nearly every subbasin in the study area has nitrogen inputs that exceed nitrogen outputs.
- The biggest contributor of nitrogen on the landscape is manure application. Commercial fertilizer is also a significant contributor of nitrogen on the landscape.
- The majority of nitrogen removal from the landscape occurs through crop harvest.

- Nitrogen inputs from manure and commercial fertilizer should be decreased if an optimal mass balance is to be achieved.

SPARROW Modeling

- The SPARROW model, which is developed by the USGS, incorporates inputs that are consistent with the inputs derived from the DNR nitrogen mass balance analysis.
- The SPARROW model inputs are an appropriate source of nitrogen input data, and the SPARROW inputs are more readily available than inputs calculated from a comprehensive mass balance analysis.
- The SPARROW model results for the study area overpredict the actual loads and concentrations in the three long-term trend site rivers.

Baseflow Separation

- Approximately 40-50 percent of flow in the three long-term trend site rivers originates from baseflow.
- Approximately 15-20 percent of flow in the three long-term trend site rivers originates from groundwater flow.
- Nitrate concentrations in the baseflow in the Kewaunee and Manitowoc Rivers are higher than the nitrate concentrations from runoff.
- Nitrate concentrations in runoff in the Sheboygan River is higher than the nitrate concentration from baseflow.
- The proportion of nitrate load from each flow source – runoff or baseflow – is important when implementing management practices to decrease nitrates in surface waters.

Groundwater Nitrates

- Groundwater susceptibility, which is a metric that considers soils and geology, is an important predictor of groundwater nitrate concentrations.
- Areas with high groundwater susceptibility have the highest nitrate concentrations.
- Excess nitrogen applications to the landscape are not as important as groundwater susceptibility in predicting groundwater nitrate concentration.

Statistical Analyses

- Simple linear regression, multiple linear regression, and random forest modeling can be used to identify which watershed characteristics are correlated with surface water nitrogen concentrations and loads.
- The impact of watershed parameters on surface water nitrogen concentrations and loads varies by season.
- The relationships between watershed parameters and surface water nitrogen concentrations can be used when planning to implement practices intended to reduce surface water nitrogen.

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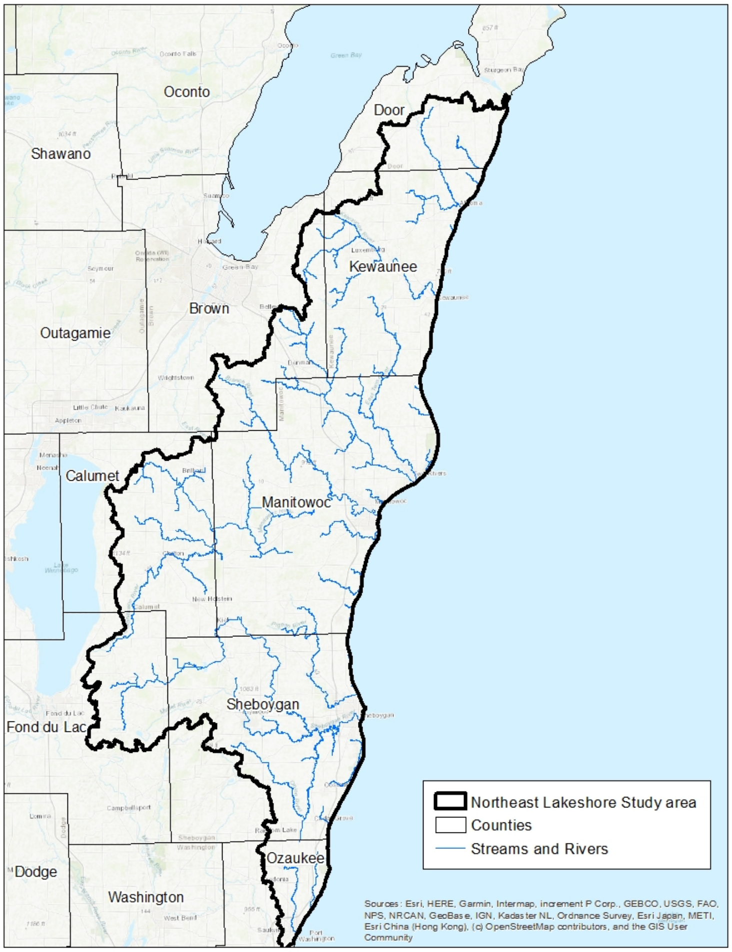
1. PROJECT BACKGROUND

In 2017 under Act 59, the Wisconsin Legislature adopted Wisconsin Statute 281.145 (WI Stat § 281.145), which outlined the requirements for river and stream monitoring and a study of nutrients from point and nonpoint sources for the study area shown in Figure 1.1. The study area spans a portion of the Lake Michigan watershed from just south of Sturgeon Bay to Port Washington and reaches west towards Lake Winnebago covering almost 2,000 square miles. The study area includes areas in Ozaukee, Fond Du Lac, Manitowoc, Calumet, Sheboygan, Brown, Kewaunee, and Door counties.

For total phosphorus (TP) the Department of Natural Resources (DNR) is developing a Total Maximum Daily Load (TMDL). Details on the TMDL found at: https://dnr.wisconsin.gov/topic/TMDLs/NELakeshore.html.

FIGURE 1.1

Northeast Lakeshore TMDL study area



Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community

A TMDL is not being developed for nitrogen because Wisconsin does not currently have water quality criteria to address nitrogen in surface water. However, this report provides a detailed analysis of the current status of nitrogen in surface waters and an exploration of factors that contribute to nitrogen in surface water. Consistent with WI Stat § 281.145, this report characterizes and quantifies the amount of nitrogen that is delivered to the waters within the study area and evaluates the loading relative to climate, land use, soil type, elevation, and drainage.

The report is separated into seven primary sections that describe specific analyses that are performed for assessing nitrogen.

1. Long Term Trend Analysis: Evaluation of the long-term trends of nitrate and total Kjeldahl nitrogen (TKN) in surface waters
2. Short-Term Monitoring Analysis: Summary of the water quality data collected during the Northeast Lakeshore TMDL study
3. Mass Balance Analysis: Quantification of the mass balance of nitrogen applied to the landscape
4. Nitrogen from SPARROW Modeling: Comparison of results to the USGS SPAtially Referenced Regression On Watershed attributes (SPARROW) model
5. Baseflow Analysis: Analysis of baseflow in streams in the study area
6. Nitrate in Groundwater: Discussion on groundwater nitrates in the study area
7. Supplemental Nitrogen Analysis: Description of additional analyses performed for nitrogen in surface waters

This report and its contents do not develop a TMDL or establish surface water standards for nitrogen. The contents only focus on the evaluation of nitrogen to identify the locations of streams with highest nitrogen loading and to identify factors that may contribute to high nitrogen loadings.

2. NITROGEN IN THE ENVIRONMENT

Nitrogen plays an important role in the environment. It is an essential nutrient for the growth of plants and crops. Nitrogen's importance for growing crops leads to the application of animal manure and nitrogen-based fertilizers to the landscape. When too much nitrogen is applied, it can be exported to surface waters or groundwater. Nitrogen in surface water and groundwater can have negative impacts on human health and aquatic health, and understanding the dynamics of how nitrogen cycles through the environment is an important step for ultimately mitigating the negative impacts.

2.1. Forms of Nitrogen

Nitrogen is an essential nutrient for plant growth. Nitrogen is present in many molecular forms, and some of these forms are commonly measured to evaluate water quality. The most important forms related to plant growth and water quality are nitrate and ammonia, which are directly available for plant uptake. Organic nitrogen is not directly available for plant uptake, but it is also important because it can be converted to ammonia. The different forms, or species, of nitrogen that are important for plant growth and water quality are summarized in Table 2.1.

TABLE 2.1

Important forms of nitrogen

Nitrogen form	Symbol	Summary	Sources
Nitrate/Nitrite	NO_3^-/NO_2^-	Available for plant uptake; high potential for leaching	Conversion from other species; fixation from plants and organisms; wastewater effluent; atmospheric deposition
Ammonia/ Ammonium	NH_3/NH_4^+	Available for plant uptake; attached to soils	Conversion of organic matter; manure; chemical fertilizers
Organic nitrogen	ON	Not directly available for plant uptake; can be converted to ammonia	Soils, plants, manure
Total Kjeldahl nitrogen	TKN	Sum of organic nitrogen and ammonia/ammonium	Organic nitrogen + ammonia/ammonium
Total nitrogen	TN	Sum of nitrogen species	Nitrate/nitrite + total Kjeldahl nitrogen

2.2. Nitrogen Cycle

Chemical and biological processes can convert nitrogen from one form to another. The collection of the processes is collectively known as the nitrogen cycle. Processes in the nitrogen cycle include fixation, mineralization, nitrification, denitrification, volatilization, immobilization leaching, and plant uptake. The nitrogen cycle is represented in Figure 2.1 (IPNI, 2013), and the processes are summarized in Table 2.2.

FIGURE 2.1
The nitrogen cycle
IPNI, 2013

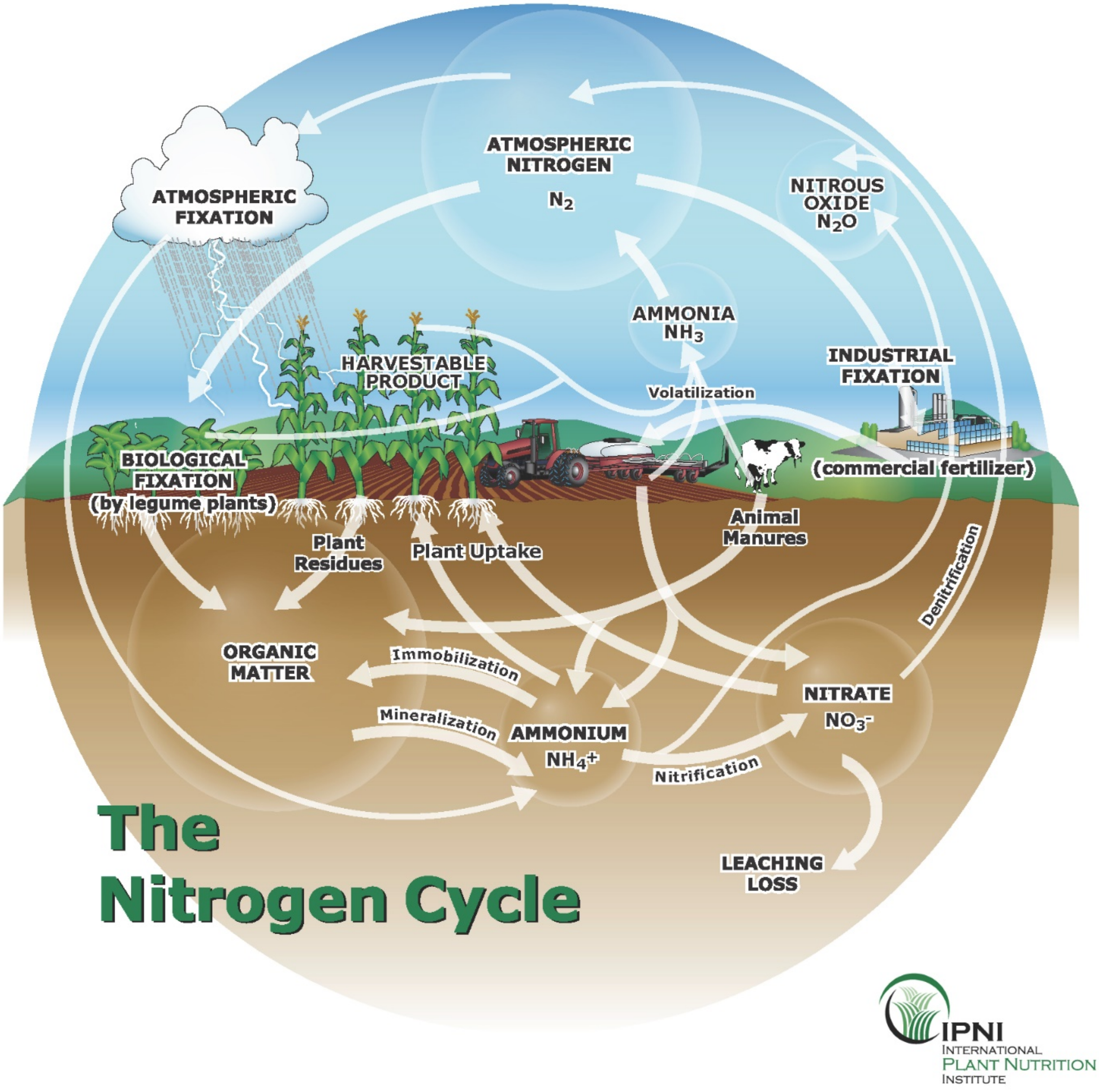


TABLE 2.2

Processes in the nitrogen cycle

Process	Summary	Mechanism
Fixation	Conversion of nitrogen gas in the atmosphere to other nitrogen compounds	Atmospheric, microbial, industrial
Mineralization	Conversion of organic nitrogen to inorganic forms that are available for plants	Microbiological
Nitrification	Conversion of ammonium to nitrate/nitrite	Microbiological
Denitrification	Conversion of nitrate to gaseous forms of nitrogen	Microbiological
Volatilization	Conversion of ammonium to ammonia gas	Chemical
Immobilization	Conversion of nitrate or ammonium to organic nitrogen	Microbiological
Leaching	Movement of dissolved nitrate to groundwater	Physical
Plant uptake	Absorption of nitrate and ammonium by plants	Biological

2.3. Impacts of Nitrogen in the Environment

Nitrogen in its various forms can be harmful to surface water quality, human health, and aquatic health. The following sections, summarized from the Minnesota Pollution Control Agency (MPCA, 2013), provide an overview of the impacts of nitrogen in the environment.

2.3.1. Surface water quality

Elevated nitrogen in surface waters contribute to excess growth of aquatic plants and organisms. When the plants and organisms die, microorganisms in the water decompose the dead biomass. The decomposition of biomass requires oxygen, so the decay of the excess biomass results in depleted oxygen within the waters. When oxygen in the water becomes to low, other aquatic organisms – such as fish – can be harmed or killed. The process of excessive plant and organism growth is known as eutrophication.

Aquatic plants and algae rely on both nitrogen and phosphorus for growth. In freshwater systems phosphorus is typically the nutrient that leads to eutrophication, so controlling phosphorus entering waterways has historically been the highest priority in Wisconsin. Surface water dynamics are complicated, however, and research is emerging that shows nitrogen can also be important for controlling algae growth in freshwater ecosystems (Dzialowski and others, 2005). Additionally, in marine ecosystems nitrogen is most important nutrient in causing eutrophication. Since waters in the western part of Wisconsin eventually discharge to the Gulf of Mexico, control of nitrogen in surface waters is important to reduce excessive eutrophication in the Gulf of Mexico.

2.3.2. Human health

High levels of nitrogen in drinking water can have negative impacts on human health. Nitrate and nitrite are the nitrogen forms that lead to the greatest risk. Drinking water standards have been developed for nitrate and nitrite to prevent infant methemoglobinemia, also known as "blue baby syndrome." Elevated levels of nitrate in drinking water have also been linked to other health impacts such as cancers, thyroid disease, and birth defects (Ward and others, 2018). Elevated nitrate levels in drinking water are most commonly found in groundwater, and methods to control of nitrogen in surface waters can also lead to the reduction of nitrates in groundwater.

Human health is also impacted by the development of harmful algae blooms (HABs) in surface waters used for recreation and drinking water. Harmful algae blooms occur when certain colonies of algae grow and produce toxins that are dangerous to humans. Recent research has indicated nitrogen in surface water can play a critical role in the growth and development of HABs (Gobler and others, 2016). A recent high-profile example of a harmful algae bloom occurred in Lake Erie near Toledo, Ohio in 2017. During the harmful algae bloom in Lake Erie, which is the source of drinking water for the city, over half a million people were unable to drink their water because excess toxins generated by the algae made it harmful to consume.

2.3.3. Aquatic life

Aquatic life can also be negatively impacted by excess nitrogen. Eutrophication caused by elevated levels of nitrogen can lead to low dissolved oxygen. When oxygen in water is depleted, fish and other aquatic animals can be harmed or killed. Specific forms of nitrogen have a more direct impact on the health of aquatic animals. Ammonia is particularly toxic to fish, and excess amounts in surface waters can harm or kill aquatic life. Nitrate and nitrite also have a negative impact on the health of fish, and elevated levels can lead to disease or death.

2.4. Discussion

Nitrogen is an essential nutrient for the growth of crops and other plants, and the cycling of nitrogen through the environment is a complex process with many unique steps. In its different forms nitrogen can harm the health of surface waters, humans, and aquatic life. Understanding the extent of nitrogen in the environment and in surface waters is essential for protecting against negative outcomes. The remainder of this report describes the extent of nitrogen in surface waters in the Northeast Lakeshore study area.

3. LONG-TERM TREND ANALYSIS

Within the NE Lakeshore study area, three monitoring sites are maintained as long-term trend (LTT) sites by the Department of Natural Resources. The sites are located near the mouths of the Kewaunee River, the Manitowoc River, and the Sheboygan River. Data from the LTT sites are used to identify changes in loads and concentrations of nitrate and total Kjeldahl nitrogen (TKN) over a period of many decades. The following section provides a summary of the analysis of long-term trends data, and a detailed explanation of the methods and results are provided in Appendix B.

3.1. Data Sources

Data for the evaluation of LTT sites are provided in the Wisconsin DNR's Long-Term Trends viewer (WDNR, 2021). The LTT viewer is an online application that allows users to visualize changes in loads and concentrations over time. The results visualized in the viewer utilize data from USGS monitoring gages and water quality data collected by the DNR. References for the data used for the LTT sites is provided in Appendix A.

3.2. Methodology

Estimates of the long-term trends in concentration and load are provided in the LTT viewer. Loads and concentrations are "flow-normalized," which means the influence of variation in river flow on water quality is removed. Evaluating flow-normalized concentration and load is beneficial because it provides a clearer understanding of meaningful changes in water quality that represent reductions in pollution rather than variability in the weather. For example, the total load in a very wet year may be higher than the historical average, but the high loads may be a result of the increases in flow. Flow-normalization smooths the high year-to-year variability of water quality observations so trends in water quality can be identified.

Concentrations and loads are normalized using the Weighted Regression on Time, Discharge, and Season (WRTDS) method (Hirsch and others, 2010). The WRTDS method uses water quality measurements to produce regression equations that incorporate a time component, a seasonal component, and a discharge component. The analysis allows for a year-to-year comparison of water quality estimates. Trends can also be established for discharge and season so differences in seasonal concentrations and loads can be compared.

3.3. Results

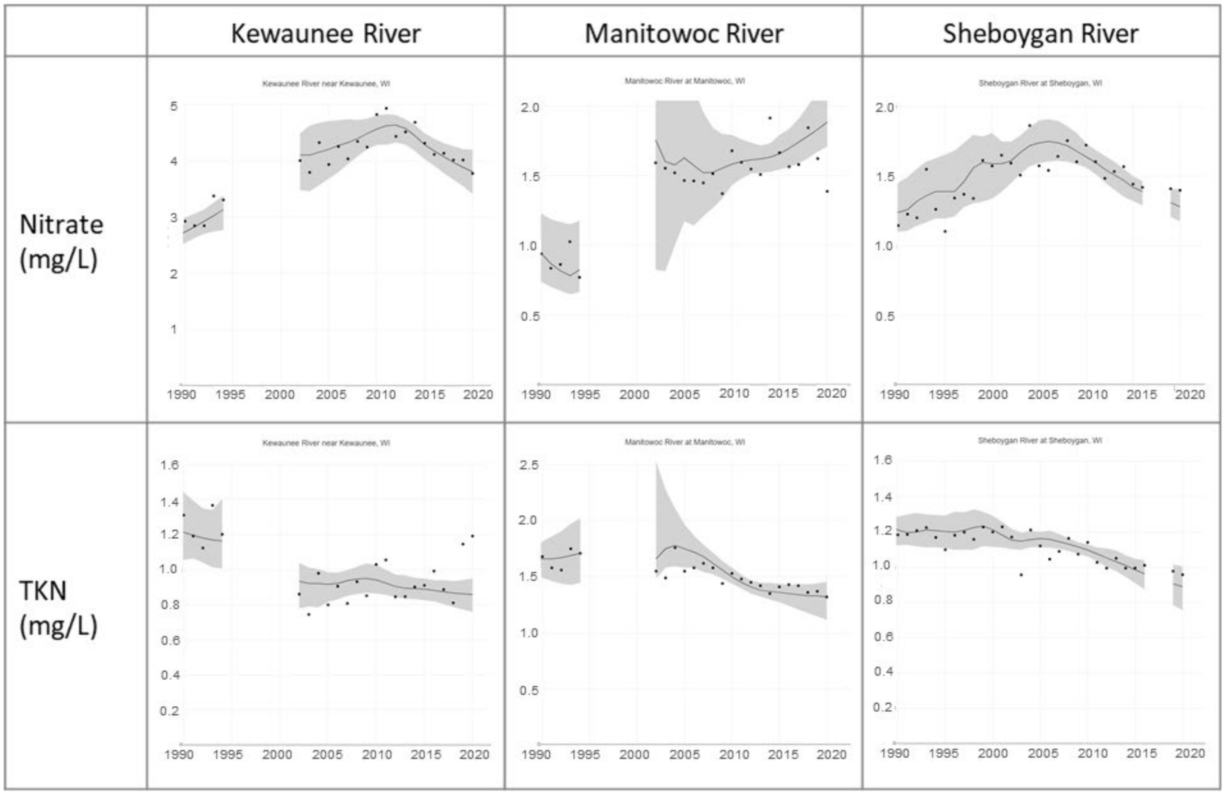
The LTT viewer provides results by nitrogen species (e.g., nitrate and TKN), water quality metric (e.g., concentration and load), and location (e.g., Kewaunee River, Manitowoc River, and Sheboygan River). For the Kewaunee River and Sheboygan River, estimated flow-normalized nitrate concentrations increased through the mid-2000s but have been steadily decreasing since that time. For the Manitowoc River, flow-normalized nitrate concentrations have steadily increased since 1990. Among the LTT sites, the Kewaunee River has the highest average flow-normalized nitrate concentrations with a range from 3.5 to 4.5 mg/L (Figure 3.1). For all three

LTT sites, estimated flow-normalized TKN concentrations have steadily decreased since 1990 (Figure 3.1). Among the three rivers, the Manitowoc River has the highest flow-normalized TKN concentrations with a range from 1.25 to 1.75 mg/L.

FIGURE 3.1

Flow-normalized nitrate and TKN concentrations

Note: Dates from 1990 to 2020; vertical axes do not have the same scale

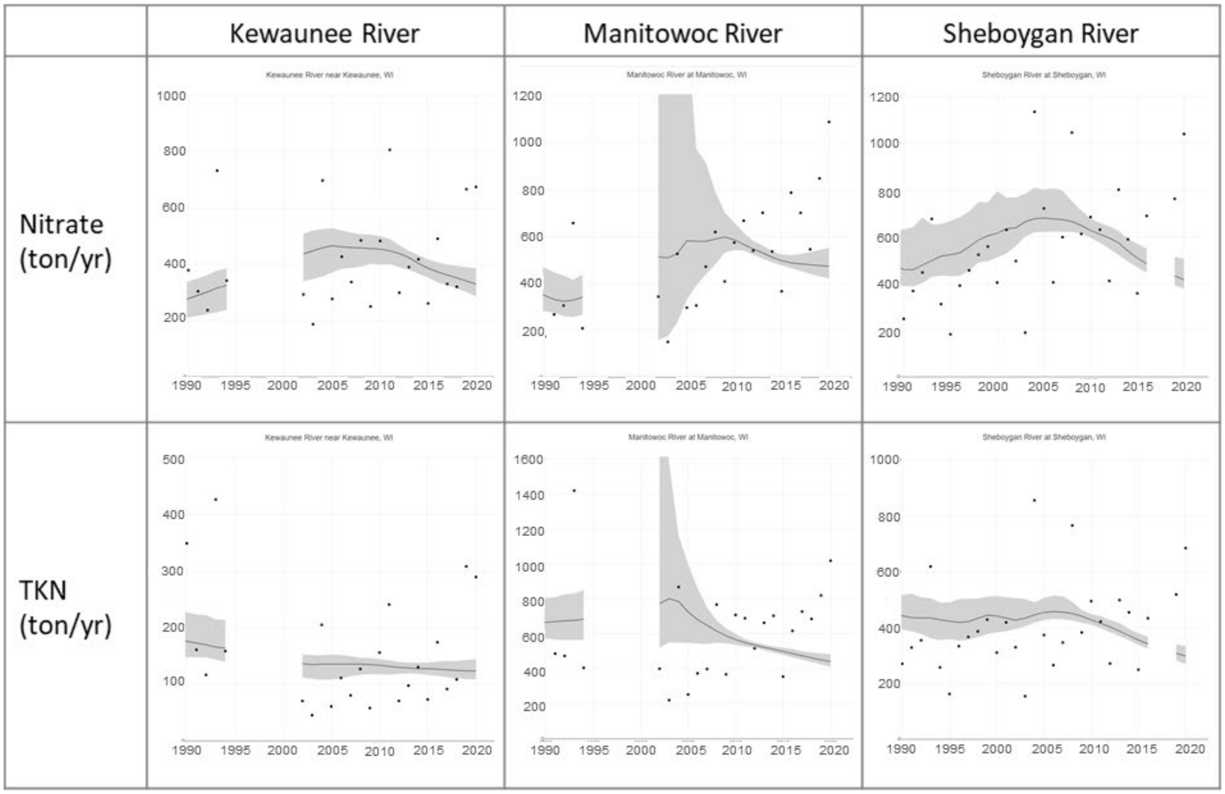


Flow-normalized nitrate loads increased until the mid-2000s but have steadily decreased since that time (Figure 3.2). The downward trends in flow-normalized nitrate load for the Kewaunee and Sheboygan Rivers are similar to the trends in flow-normalized nitrate concentrations. The trend in flow-normalized nitrate load for the Manitowoc River, however, is different than the trend for flow-normalized nitrate concentration. Flow-normalized nitrate concentration in the Manitowoc River has increased since 2008, whereas flow-normalized nitrate load has remained relatively steady. Flow-normalized TKN loads have steady decreased since 1990 (Figure 3.2). For all three sites the long-term trends for flow-normalized TKN loads are consistent with the trends for flow-normalized TKN concentration.

FIGURE 3.2

Flow-normalized nitrate and TKN loads

Note: Vertical axes do not on the same scale



3.4. Discussion

The trends for two nitrogen species measured at the long-term trend sites, nitrate and TKN, are different. Nitrate has generally been increasing or remaining steady over time, whereas TKN has been steadily decreasing. The difference in trends between the two nitrogen species has been observed in other studies (Sullivan, 2000). The decrease in TKN corresponds with an observed decrease in total phosphorus. Management practices aimed at reducing particulate phosphorus may have the added benefit of decreasing the delivery of organic nitrogen from the landscape. Additionally, improved water quality associated with reductions in phosphorus may decrease the growth of aquatic plants and algae, which would lead to a decrease the amount of organic nitrogen in surface waters. A decrease in aquatic vegetation and algae may cause an increase in nitrates in surface waters because nitrate is less likely to be converted from the dissolved inorganic form to the organic form. An increase in the application of manure and commercial fertilizer may also be contributing to the increase in nitrate in surface waters.

4. SHORT-TERM MONITORING ANALYSIS

Flow and water quality monitoring data between 2017 and 2019 were collected during the development of the Northeast Lakeshore TMDL. The monitoring efforts included measurement of nitrogen species in surface waters. Nitrogen-related data from the monitoring efforts are summarized and in the following sections, and a detailed explanation of the methods and results are provided in Appendix C.

4.1. Data Sources

All data for short-term monitoring were collected during the development of the Northeast Lakeshore TMDL. The monitoring program measured continuous water level and periodic water quality samples.

Continuous water level was collected at 18 sites throughout the study area, and periodic flow monitoring was also performed at these sites. The flow monitoring data were paired with the continuous water level data to develop a continuous record of estimated flow rates. Additionally, flow monitoring data were collected from three long-term gauges maintained by the USGS.

Water quality constituents measured for the TMDL included total phosphorus, total suspended solids, total nitrogen, nitrate, total Kjeldahl nitrogen (TKN), and ammonia. Measurements for all constituents were not collected at every site. Total nitrogen data were collected at 38 sites, nitrate and ammonia data were collected at 11 sites, and TKN data were collected at 9 sites.

4.2. Methodology

In-stream water quality standards for phosphorus are evaluated during the growing season, which includes all days between May and October. The growing season is assessed because the main concern from excess phosphorus loads is growth of aquatic plants and algae. Since nitrogen in surface waters may also impact growth of aquatic plants and algae, the analysis of the short-term monitoring data is focused on measurements during the growing season.

For all sites containing nitrogen-related monitoring data, the growing season (May through October) median (GSM) is estimated using both direct measurement of concentrations and estimates of continuous concentrations. Using estimated continuous concentrations to express the GSM has an advantage over using direct concentration measurements. Direct measurements of water quality are collected at distinct points in time. During a short monitoring period, the water quality measurements may not be truly representative of the long-term ambient water quality. The potential issue of water quality measurements not being truly representative of water quality is overcome by using the estimated continuous concentration because estimated concentrations are expressed for every day of the growing season.

The estimation of continuous water quality concentration can only be performed at sites with both water quality measurements and continuous flow data. Only 20 sites in the study area have data for both water quality and continuous flow. All sites have water quality data for total nitrogen, but not all of these sites have water quality data for nitrate, TKN, or ammonia. Additionally, the overlap of the water quality and flow data is only available for the 2018 growing season. As a result, the estimates of concentrations and loads for the 2018 growing season are evaluated in this analysis.

4.3. Results

GSM concentrations are estimated for total nitrogen, nitrate, TKN, and ammonia using concentration measurements and estimated continuous concentrations. The 2017-2020 GSM from measured total nitrogen concentrations is shown in Figure 4.1, and the 2018 GSM from estimated continuous concentrations is shown in Figure 4.2. Similar figures for nitrate, TKN, and ammonia are provided in Appendix C.

The range of measured GSM concentrations at different sites for the four constituents is 1.2 to 7.2 mg/L for total nitrogen, 0.3 to 3.6 mg/L for nitrate, 0.8 to 1.3 mg/L for TKN, and 0.021 to 0.080 for ammonia. Generally, in-stream concentrations of total nitrogen, nitrate, TKN, and ammonia are higher in the northern portion of the study area when compared to the southern portion of the study area.

FIGURE 4.1

Measured growing season median concentration (mg/L) for TN

Data available at 38 sites from 2017 through 2020

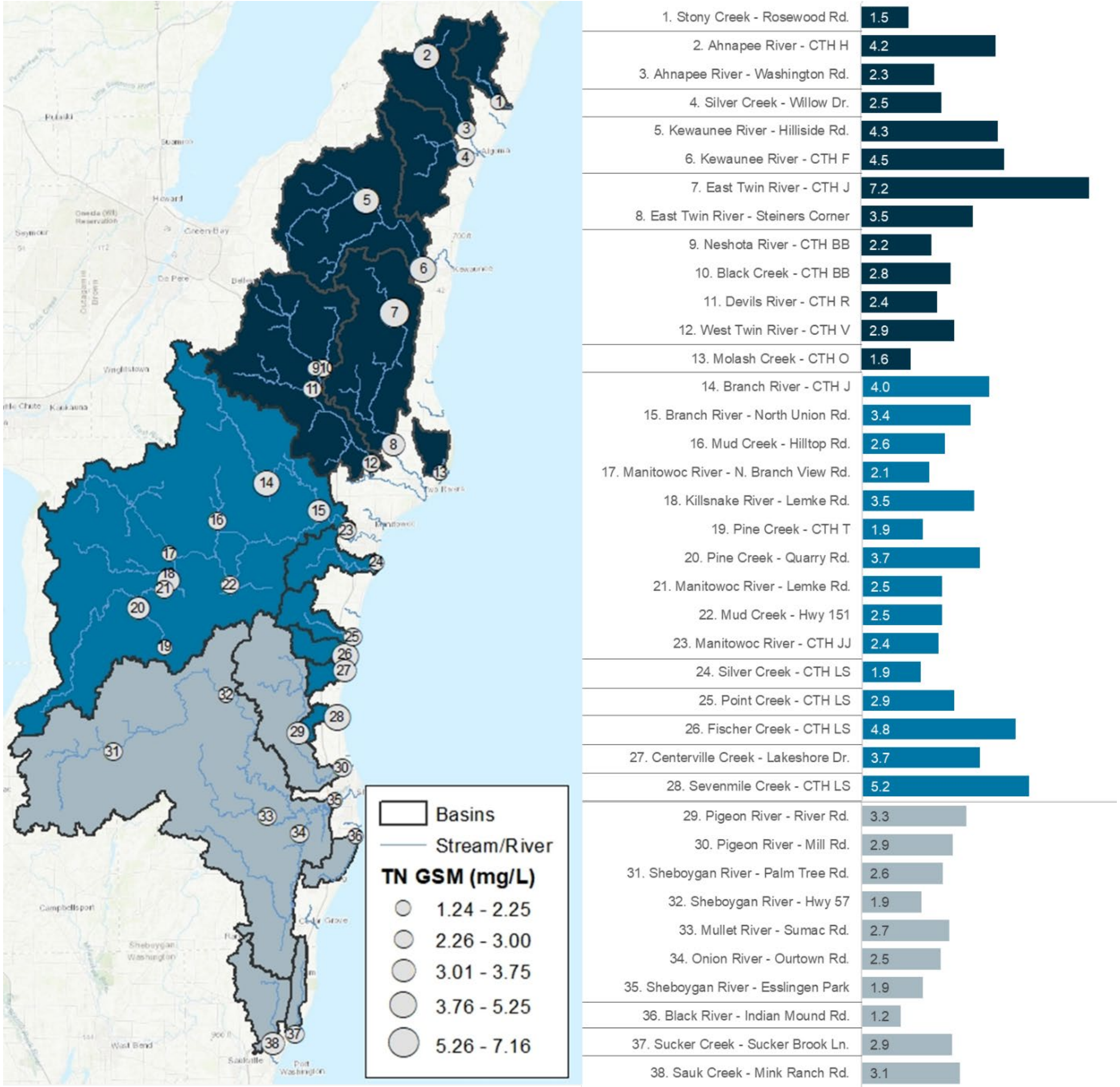
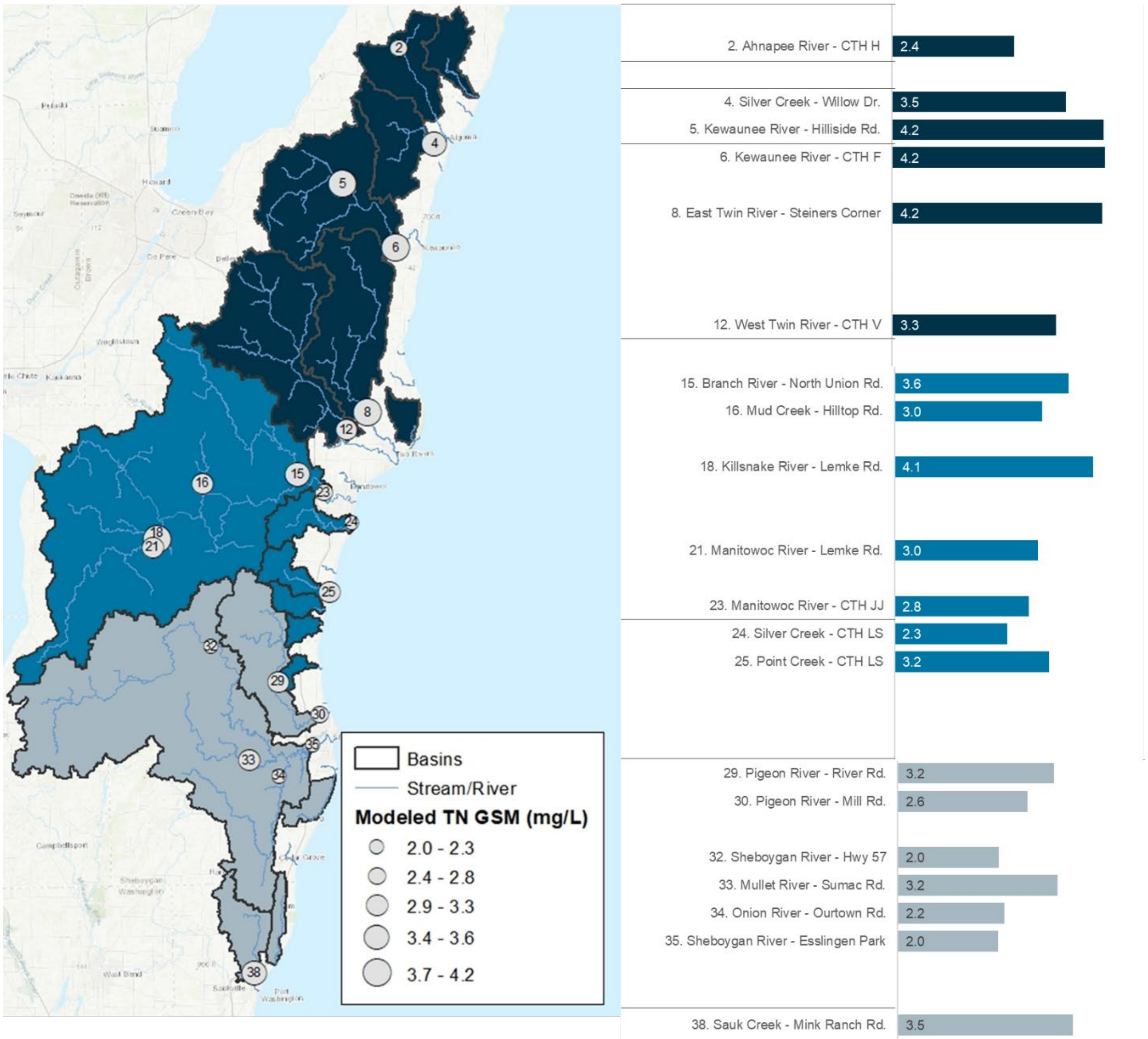


FIGURE 4.2

Modeled 2018 growing season TN concentration

Estimated concentrations only for the 2018 growing season (May – October)



4.4. Discussion

Monitoring completed for the development of the Northeast Lakeshore TMDL included measurements for total nitrogen, nitrate, TKN, and ammonia. Values for in-stream concentrations for the four constituents vary among the monitoring sites. Differences in landscape characteristics, cropping practices, and fertilizer applications may impact the in-stream concentrations of nitrogen species. Generally, surface waters in the northern portion of the study area have higher nitrogen concentrations when compared with surface waters in the southern portion of the study area. The drivers for these differences are explored in Section 9 of this report.

5. MASS BALANCE ANALYSIS

A mass balance analysis is performed for subbasins in the Northeast Lakeshore study to identify the sources and locations of nitrogen applied to the landscape. When combined with water quality data, the mass balance estimates provide insights about where excess nitrogen applications may be contributing to high concentrations of nitrogen in surface waters. The primary focus of the analysis is the evaluation of nitrogen sources from agricultural lands. A brief discussion about nitrogen from all sources, both agricultural and non-agricultural, is also provided. A detailed analysis of the methods and results for the mass balance analysis are provided in Appendix D.

5.1. Data Sources

Many agricultural nitrogen sources contribute to nitrogen loading on the landscape. These sources, also known as nitrogen inputs, include manure applied to fields, commercial fertilizers applied to fields, nitrogen generated from nitrogen fixation by microbes, and atmospheric deposition. Many data sources are available to estimate nitrogen inputs. Data sources include land use, crop rotations, crop types, crop yield, manure applications, fertilizer applications, and atmospheric deposition. Nitrogen inputs from non-agricultural sources such as natural lands, urban lands, and point sources can also be evaluated to identify the main sources of nitrogen in surface waters

Nitrogen is removed from the landscape through many processes. The nitrogen removals, also known as nitrogen outputs, include crop harvest, crop senescence, manure volatilization, fertilizer volatilization, and denitrification. Data to estimate the nitrogen outputs include land use, crop nitrogen content, and parameters to estimate loss rates from the other mechanisms. A list of the available data sources for both inputs and outputs is provided in Appendix A, and a summary of the values are provided in Appendix D.

5.2. Methodology

Nitrogen inputs and outputs are assessed for the subbasins modeled in the Northeast Lakeshore TMDL, and the mass balance is performed for 2009 through 2018. The following sections summarize the methods for estimating nitrogen inputs and outputs.

5.2.1. Agricultural nitrogen mass balance

A nitrogen mass balance for agricultural lands is calculated by subtracting nitrogen outputs from nitrogen inputs. A positive value indicates nitrogen inputs exceed nitrogen outputs, and a negative value indicates nitrogen outputs exceed nitrogen inputs. Methods for estimating agricultural nitrogen inputs and outputs are summarized below.

5.2.1.1. Agricultural nitrogen inputs

Nitrogen inputs to agricultural lands include manure application, commercial fertilizer application, nitrogen fixation, and atmospheric deposition. The sum of these four categories encompasses the majority of nitrogen sources for agricultural lands. Each of the categories are estimated using the following methods:

- Manure application: Nitrogen inputs from manure application are available from a manure analysis performed for the development of the Northeast Lakeshore TMDL (WDNR, 2020). The manure analysis estimated total volume of manure applied to fields in the study area. The volume of manure was multiplied by an estimated concentration of nitrogen in manure to obtain the total mass of nitrogen applied.
- Commercial fertilizer application: Nitrogen inputs from commercial fertilizers are estimated from data documenting the sale of fertilizer over time. Application of commercial fertilizer in the study area is averaged over all agricultural areas, and the mass of commercial fertilizer per subbasin is estimated.
- Nitrogen Fixation: Nitrogen inputs from fixation are estimated by assuming rates of fixation for different crop types. Certain crops, specifically legumes, have a symbiotic relationship with bacteria in the soil. The bacteria in the soil convert atmospheric nitrogen to nitrogen that can be used by crops. An assumed rate of nitrogen fixation by crop type is multiplied by the area of each crop in each subbasin to estimate the inputs by nitrogen fixation.
- Atmospheric deposition: Nitrogen inputs from atmospheric deposition are estimated by multiplying the average concentration of nitrogen in precipitation by the total annual precipitation and the area of agricultural areas in each subbasin.

The sum of nitrogen inputs from the four sources is calculated to provide a total mass of nitrogen applied to the subbasin. An average rate of nitrogen inputs per agricultural area is calculated by dividing the total mass by the total area of agricultural areas.

5.2.1.2. Agricultural nitrogen outputs

Nitrogen outputs from agricultural lands include crop harvest, crop senescence, manure volatilization, fertilizer volatilization, and denitrification. The sum of these five categories account for the majority of nitrogen outputs for agricultural lands. Each of the categories are estimated using the following methods:

- Crop harvest: Nitrogen removed from the landscape by crop harvest is calculated by multiplying the total yield of a crop by a literature-derived average nitrogen content of the crop.
- Crop senescence: Nitrogen removed by crop senescence, or volatilization of nitrogen from crops, is calculated by multiplying a literature-derived rate of nitrogen removal by senescence for each crop by the total land use in a subbasin.
- Manure volatilization: Nitrogen removed by manure volatilization is calculated by multiplying the mass of nitrogen applied by manure by a literature-derived rate of volatilization.

- Fertilizer volatilization: Nitrogen removed by fertilizer volatilization is calculated by multiplying the mass of commercial nitrogen fertilizer applied by a literature-derived rate of volatilization.
- Denitrification: Nitrogen removed by denitrification is calculated by multiplying the total nitrogen inputs to an area by a literature-derived rate of denitrification.

The sum of nitrogen outputs from the five sources is calculated to provide a total mass of nitrogen removed for each subbasin. An average rate of nitrogen outputs per agricultural area is calculated by dividing the total mass by the total area of agricultural areas.

5.2.2. Nitrogen mass balance and surface water concentrations

The nitrogen mass balance results are used to evaluate the impact of nitrogen mass balance on surface water nitrogen concentrations. The total upstream agricultural mass balance for each subbasin in the analysis is divided by the total agricultural area of the upstream subbasins to estimate an approximate rate nitrogen per unit area. A simple linear regression line is fit to the nitrogen mass balance and the in-stream concentrations for total nitrogen, nitrate, TKN, and ammonia. The in-stream concentrations used for the analysis are the modeled growing season median (GSM) concentrations for 2018. For consistency, the agricultural mass balance only applies to nitrogen inputs and outputs for the 2018 growing season.

5.2.3. Nitrogen mass balance from all sources at long-term trend sites

Although agriculture is the primary source of nitrogen delivered to surface waters, nitrogen from forested lands, developed areas, and point sources also contribute to nitrogen in surface waters. Nitrogen delivered to surface waters from forested lands and developed areas are expressed using export coefficients, which estimate the mass of nitrogen per area that is exported from the landscape to the receiving water. Point source discharges, on the other hand, are delivered directly into surface waters. The methods of expressing nitrogen from non-agricultural sources are different than the nitrogen mass balance described in Section 5.2.1. The nitrogen mass balance for agricultural lands represents the nitrogen applied to or removed from the landscape, and it does not represent the amount of nitrogen from agricultural areas that is delivered, or exported, to streams.

5.3. Results

Results for the agricultural nitrogen mass balance, the relationship of mass balance to surface water concentrations, and the mass balance from all sources of nitrogen are summarized in the following sections.

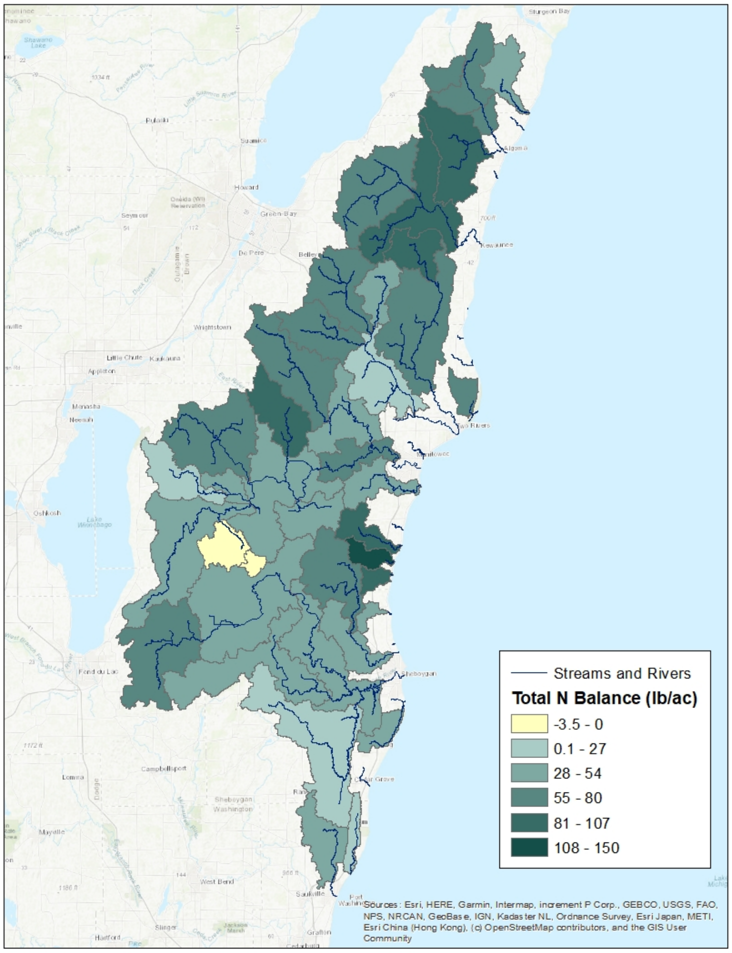
5.3.1. Agricultural mass balance

The agricultural mass balance is calculated by subtracting the agricultural nitrogen inputs by the agricultural nitrogen outputs. The result is expressed as mass per unit area. Positive values indicate more nitrogen is being applied than is being removed, and negative values indicate more nitrogen is being removed than is being applied. A summary of the nitrogen mass balance for agricultural lands is provided in Figure 5.1.

FIGURE 5.1

Average balance of nitrogen inputs and outputs in study area

Values expressed as mass divided by total agricultural area for each subbasin



Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community

Nearly all subbasins have a positive mass balance of agricultural nitrogen, which indicates more nitrogen is being applied to the landscape than is being removed. Areas with excess nitrogen application are at higher risk of nitrogen being delivered to groundwater or surface waters. In the study area the mass balance of nitrogen is generally highest in the north and lowest in the south.

The mass balance is also expressed by evaluating the proportion of nitrogen inputs and outputs from each category (Figure 5.2). The largest sources of nitrogen inputs are manure, commercial fertilizer, and nitrogen fixation. The largest source of nitrogen removal from the landscape is crop harvest (Figure 5.3).

FIGURE 5.2

Summary of nitrogen inputs for three long-term trends basins

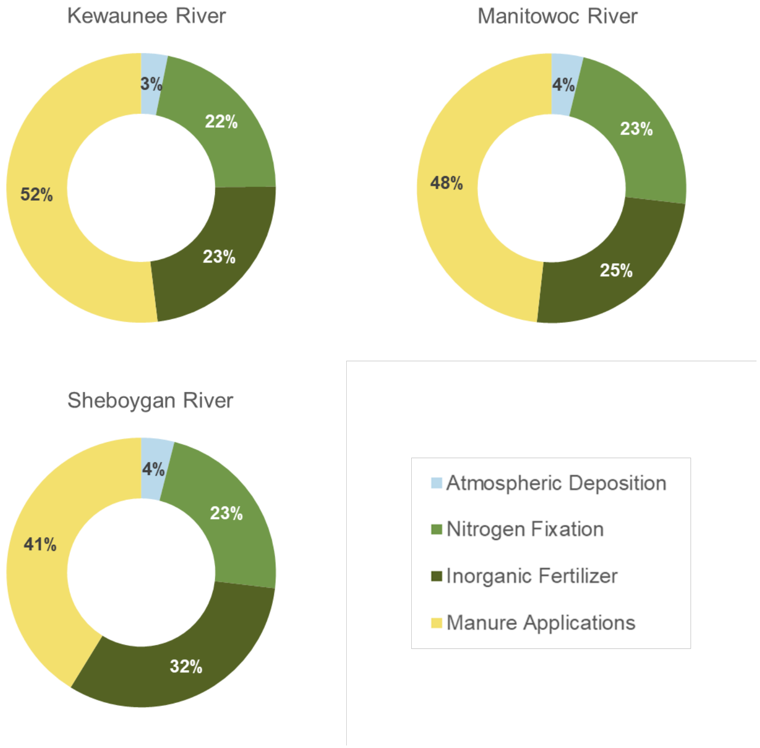
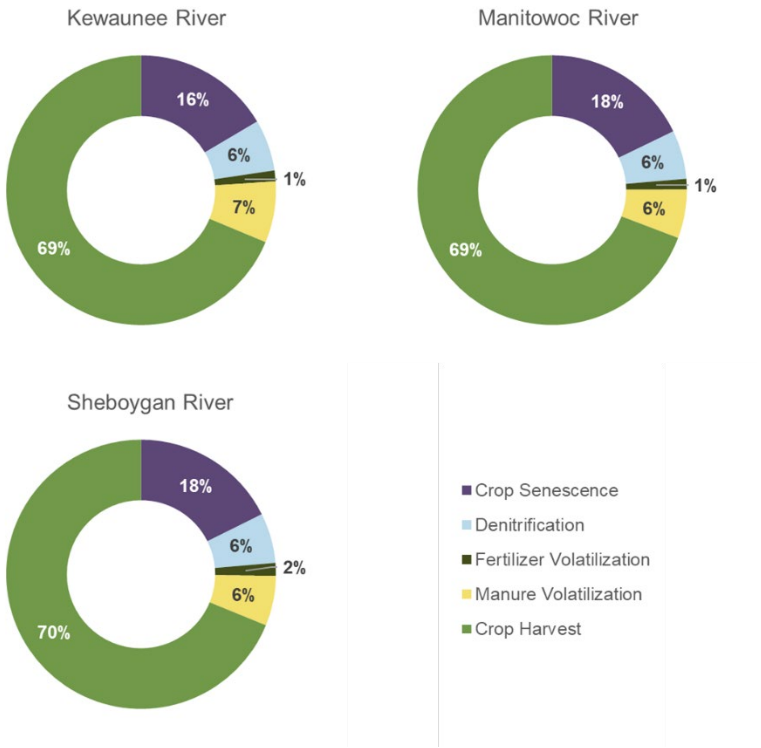


FIGURE 5.3

Summary of nitrogen outputs for three long-term trends basins



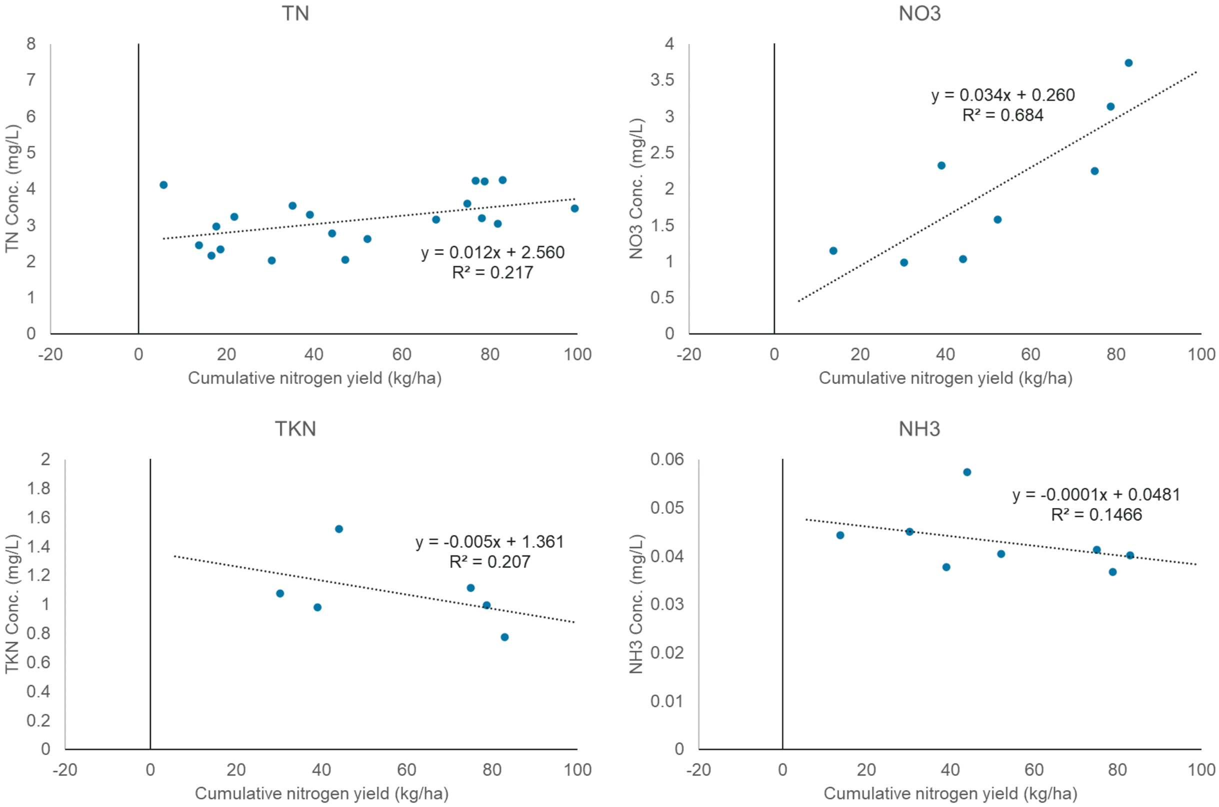
5.3.2. Nitrogen mass balance and surface water concentrations

To evaluate the impact of agricultural nitrogen inputs and outputs to surface water concentrations, the results of the mass balance are compared to the modeled growing season median concentrations. A simple linear regression is fit to evaluate a trend (Figure 5.4). The trend between in-stream concentration and upstream cumulative nitrogen mass balance is weak. In-stream nitrate concentration, however, has a moderate positive relationship between cumulative upstream mass balance, which indicates in-stream nitrates may increase when excess nitrogen is applied to the landscape.

FIGURE 5.4

Comparison of GSM concentration and nitrogen mass balance

Growing season median concentrations and mass balance results for 2018



5.3.3. Nitrogen mass balance from all sources at long-term trend sites

In-stream loads of nitrogen from forested lands, developed lands, and point sources are compared with the measured in-stream loads at the three long-term trend sites. The difference between total in-stream loads and loads three non-agricultural sources is assumed to represent the nitrogen load from agricultural areas and groundwater discharge. The results of the analysis are shown in Table 5.1. Point source, urban, and forested lands account for approximately 3 percent of total nitrogen loads in the Kewaunee River, 11 percent of total nitrogen loads in the Manitowoc River, and 17 percent of total nitrogen loads in the Sheboygan River.

Results from the in-stream mass balance can be used to estimate the percent of total nitrogen from agricultural lands that eventually is delivered to the streams (i.e., the delivery fraction). The delivery fraction ranges from 5% in the Manitowoc River to 8% in the Kewaunee River (Table 5.2). Another interpretation of these numbers is to say 8% of total nitrogen originating from agricultural areas in the Kewaunee River basin is delivered the river. Nitrogen originating from agricultural lands may be delivered to surface waters by surface runoff or discharge from groundwater.

TABLE 5.1

In-stream mass balance for the three long-term trend sites

Results are presented as annual averages between 2009 and 2018

	Kewaunee River		Manitowoc River		Sheboygan River	
	Total load (kg N)	Percent of total	Total load (kg N)	Percent of total	Total load (kg N)	Percent of total
Measured in river	477,600	100%	1,077,680	100%	905,630	100%
Point source	3,710	1%	66,390	6%	97,060	11%
Urban	6,220	1%	25,680	2%	26,440	3%
Forest	5,010	1%	25,370	2%	34,530	4%
Other (Agricultural lands)	**462,660**	**97%**	**960,240**	**89%**	**747,600**	**83%**

TABLE 5.2

Estimated delivery of nitrogen from agricultural lands

Estimates at three long-term trend sites in study area

	Kewaunee River	Manitowoc River	Sheboygan River
	Load (kg)	Load (kg)	Load (kg)
Atmospheric	188,080	718,450	495,780
Fixation	1,264,660	4,274,730	2,810,130
Fertilizer	1,362,980	4,680,420	3,982,080
Manure	3,054,570	9,068,780	5,146,110
Total on Landscape	**5,870,290**	**18,742,380**	**12,434,100**
Other Instream*	462,660	960,240	747,600
Percent Delivered**	**8%**	**5%**	**6%**

* ”Other Instream” load is equal to category named "Other" in Table 5.1. The value represents the in-stream load not attributed to point source, urban, or forest loads. The load not attributed to these sources is assumed to originate from agricultural lands.

** Percent delivered is an estimate equal to the attributable stream load divided by the landscape-level load of atmospheric, fixation, fertilizer, and manure. The value represents the amount of nitrogen from those sources that is delivered to the river.

5.4. Discussion

Throughout the study area nitrogen inputs to the landscape exceed outputs. The largest source of nitrogen applications on the landscape is manure. The proportion of nitrogen applied as manure is greatest in the northern portion of the study area and lowest in the southern portion. Another major source of nitrogen inputs to the landscape is the application of commercial fertilizers. The largest source of nitrogen output is crop harvest. Nitrogen removal from crop harvest varies based on crop type and yield, but the variability of crop removal among the subbasins is relatively small when compared to the overall nitrogen mass balance. Therefore, the most likely mechanism to address the excess nitrogen on the landscape is addressing nitrogen applications from manure and commercial fertilizer.

6. NITROGEN FROM SPARROW MODELING

Many watershed-based models have been developed to predict nutrient loading from the landscape. A commonly used model developed by USGS is the SPAtially Referenced Regression On Watershed attributes (SPARROW). SPARROW estimates flow, nutrient loads, and nutrient concentrations for streams across the United States, and a regionally specific model has been developed for streams in the Mississippi River basin and the Great Lakes (USGS, 2021). This model, known as the 2012 Midwest Sparrow Model, is evaluated in this report. Results from the DNR's water quality monitoring and the mass balance analysis are compared to the results of the SPARROW model to better understand differences in the inputs and the outputs between the different models and methods. A summary of the comparison is provided in the following sections, and a detailed analysis of the methods and data are provided in Appendix E.

6.1. Data Sources

The SPARROW model incorporates three main components when estimating loads and concentrations: sources, land-to-water delivery, and aquatic losses. The nitrogen source component includes inputs related to atmospheric deposition, municipal wastewater treatment plants, land use, fertilizers, manure, and nitrogen fixation. The nitrogen land-to-water component includes inputs related to runoff, air temperature, tile drainage, soil properties, and land management. The nitrogen aquatic loss component includes inputs related to instream decay, reservoir loss, and water withdrawals. The data sources and inputs from the SPARROW model are compared to the data sources described in Section 5 of this report.

The model inputs are used by SPARROW model to estimate loads and concentrations at the outlets of pre-defined subbasins, and the results are provided in both a database and an online viewer (USGS, 2021). The outputs of the model are used to compare the SPARROW model results to observed monitoring data and to outputs from other models.

6.2. Methodology

The evaluation of the SPARROW model and the DNR's analyses includes a comparison of the nitrogen sources used as inputs for the models and a comparison of the results of the models. Details about the methodologies are summarized below.

6.2.1. Evaluation of SPARROW inputs and mass balance inputs

Inputs from the SPARROW model are stored in a large database. The estimated nitrogen sources in the watershed area upstream of the three long-term trend sites are calculated from the SPARROW model inputs. Total nitrogen from atmospheric deposition, nitrogen fixation, fertilizers, manure, point sources, and urban areas are compared to the inputs derived in the mass balance methods described in Section 5.

6.2.2. Evaluation of SPARROW outputs and long-term trend estimates

Estimation of nitrogen sources from the landscape are only one component of the SPARROW model. Once the sources are estimated, the model applies a land-to-water delivery factors and aquatic losses to estimate in-stream nitrogen load and concentrations. Results reported in SPARROW are referenced to the year 2012. To develop a direct comparison of the outputs to the long-term trend estimates described in Section 3, the long-term trend estimates for the year 2012 is used. Annual loads, annual loading rates, and average annual concentrations from the two models are compared to evaluate potential differences.

6.3. Results

Model inputs and model results for the SPARROW model and the DNR analyses are compared. The comparison of model inputs is useful for evaluating the differences in the assumptions and data sources used to estimate nitrogen loading on the landscape, and the comparison of model outputs is useful for evaluating the accuracy of the SPARROW model.

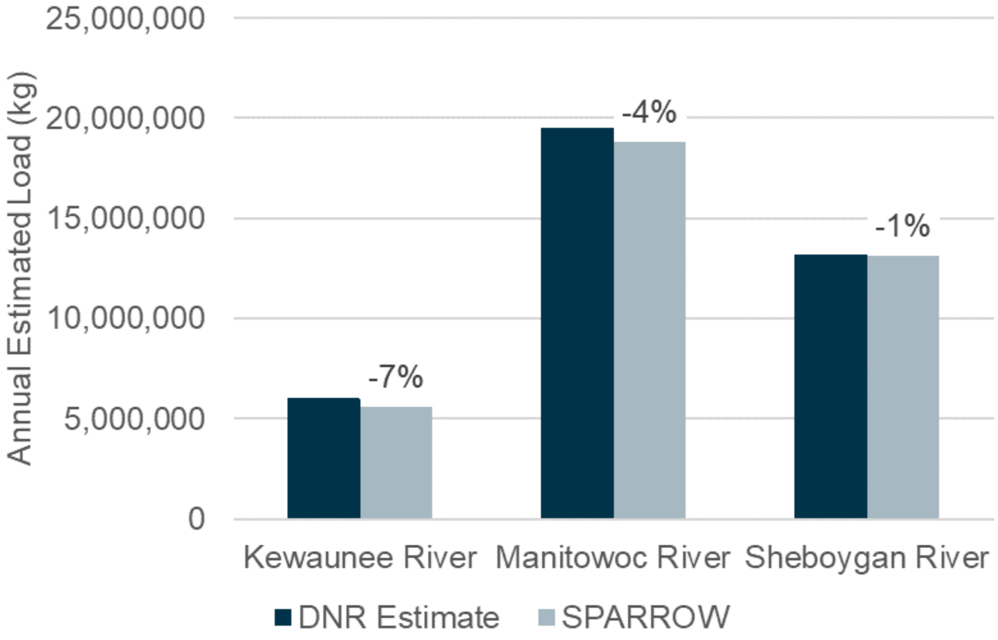
6.3.1. Comparison of SPARROW inputs to mass balance inputs

The nitrogen inputs used in the SPARROW model and the nitrogen inputs derived from the DNR mass balance (Section 5) produce similar results for estimated annual nitrogen loading to the landscape. The estimated difference in nitrogen inputs for the three long-term trend sites is shown in Figure 6.1.

FIGURE 6.1

Comparison of estimated nitrogen inputs

Estimates at three long-term trend sites for SPARROW model and WDNR method



Average nitrogen input estimates are slightly higher from the DNR method when compared to the SPARROW model estimates. The differences between the two models range from 1% to 7% among the three long-term trend sites. The highest difference occurs in the Kewaunee River basin, and the smallest difference occurs in the Sheboygan River basin.

When individual sources of nitrogen from SPARROW are compared with the landscape sources of nitrogen from the DNR mass balance method, the biggest differences occur with nitrogen fixation and manure. The comparison for the Kewaunee River basin is presented in Figure 6.2. Differences in point sources between the two methods are also large, which is demonstrated in Figure 6.3 for the Kewaunee River basin. The values expressed in Figures 6.2 and 6.3 are not directly comparable because the SPARROW database expresses loads from point sources and urban areas as loads delivered to the waterbody rather than loading on the landscape. Figures for the other long-term trend sites are provided in Appendix E.

FIGURE 6.2

Comparison of nitrogen sources for the Kewaunee River

Loads represent the amount of nitrogen applied to the landscape

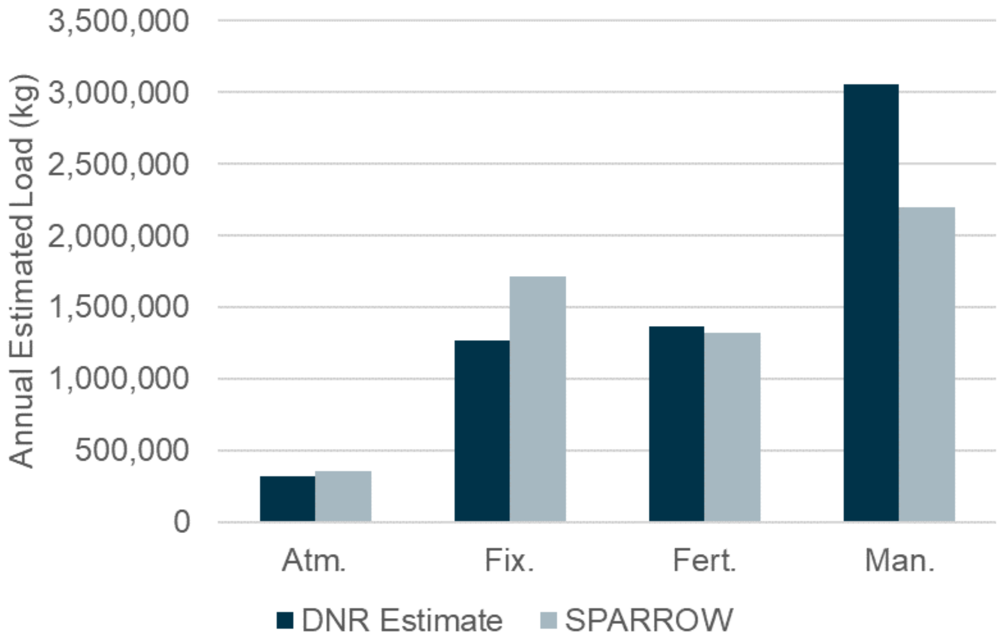
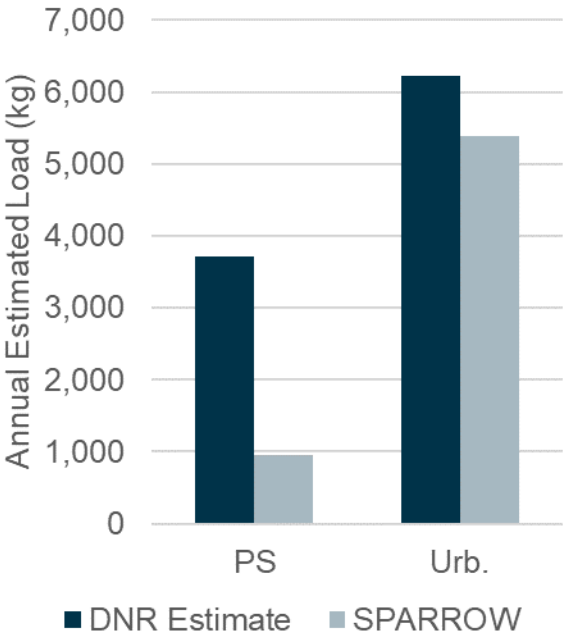


FIGURE 6.3

Comparison of non-agricultural sources for the Kewaunee River

Loads represent the amount of nitrogen delivered to the waterbody



Some noticeable difference between the DNR estimates and the SPARROW estimates exist. The differences include the following:

- Nitrogen source estimates from nitrogen fixation are higher in the SPARROW model than the DNR model. The difference is likely due to different assumptions about the nitrogen fixation rates for specific types of crops. SPARROW applies a single value for nitrogen fixation for all nitrogen fixing crops, whereas the DNR methodology estimates unique nitrogen fixation rates for specific crops.
- Manure source estimates are higher in the DNR analysis than they are in the SPARROW model inputs. The DNR analysis is more spatially refined than the SPARROW model, which may explain the difference.
- Nitrogen estimates from point sources are higher in the DNR analysis than they are in the SPARROW model. The method used by SPARROW quantifies effluent nitrogen concentrations based on the size and type of treatment facility, whereas the DNR analysis applies a single concentration for point sources. The differences in point source load estimates have only a minor impact on the overall mass balance because point sources make up only a small percentage of the total in-stream nitrogen load.

6.3.2. SPARROW outputs and long-term trend estimates

The SPARROW model uses the methods described in Section 6.2.2 to estimate nitrogen loads and concentrations at the outlet of a subbasin. The DNR inputs are not used to develop a watershed model, so the results of the SPARROW outputs are compared to the results from the long-term trends analysis (Section 3). Results from the SPARROW model and the long-term trends analysis for estimated delivered load are provided in Figure 6.4, and results for estimated in-stream concentration are provided in and Figure 6.5.

FIGURE 6.4

Estimated load (kg) delivered to LTT sites

Estimates from SPARROW and the WDNR long-term trend analysis

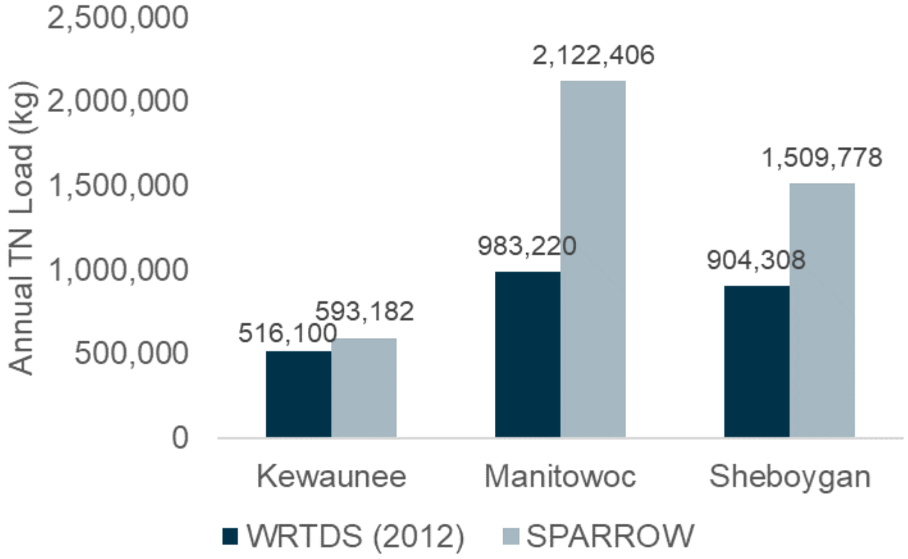
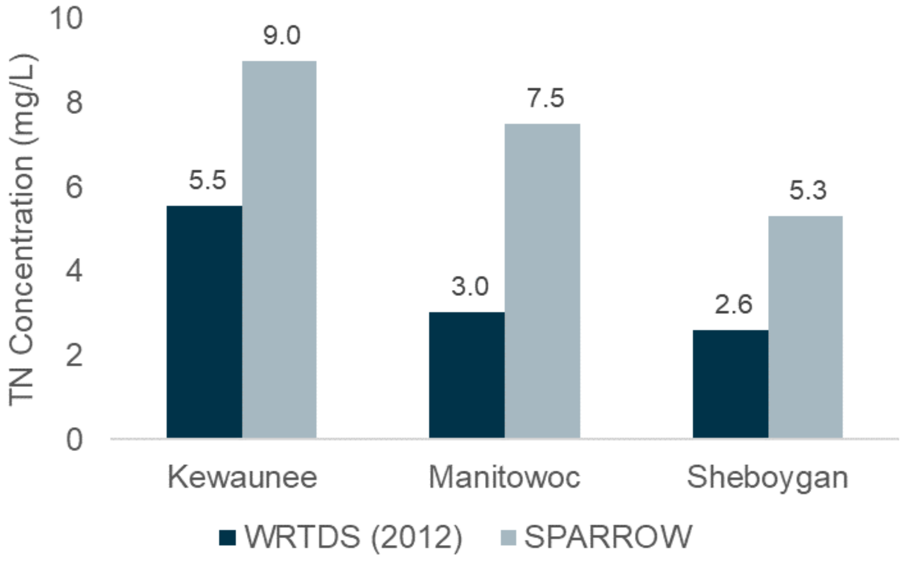


FIGURE 6.5

Estimated concentration (mg/L) at LTT sites

Estimates from SPARROW and the WDNR long-term trend analysis



The delivered in-stream load and concentration estimated by SPARROW are notably higher than the estimates derived from the DNR long-term trends analysis. The long-term trends analysis uses direct measurements for its estimates, whereas the SPARROW model only uses direct measurements for calibrating the model. The SPARROW model is calibrated for a large area over the entire Midwest. The calibration parameters for sources, land-to-water delivery, and aquatic losses are the same for the entire model domain. The estimated nitrogen sources on the landscape in SPARROW appear to be accurately reflecting the actual nitrogen sources, so the land-to-water delivery and aquatic loss parameters used in the model may not accurately representing the dynamics of nitrogen in Northeast Lakeshore study area. In surface waters outside the study area, however, SPARROW has been shown to provide accurate estimates of loads, so the discrepancies may only represent issues in this specific potion of the SPARROW model.

6.4. Discussion

Nitrogen inputs estimated from the DNR analysis and provided in the SPARROW input files are similar, which provides a level of validation for the two methods. The DNR's approach to quantifying manure within the study area is more spatially refined than the SPARROW model and is likely a more accurate representation of actual manure applications. The DNR analysis also quantifies nitrogen applications on a year-by-year basis, whereas SPARROW only represents inputs for a single point in time. Nonetheless, the DNR analysis requires extensive data collection and analysis, whereas the SPARROW data are readily available in a database. Since the results of nitrogen applications among the two methods are similar, nitrogen application estimates from SPARROW are likely an acceptable source of data in situations where less-precise data are required.

Although the projected inputs from the WDNR analysis and the SPARROW model are similar, the outputs of the SPARROW model are not accurately representing the results measured at the three long-term trend sites in the study area – SPARROW overestimates both in-stream nitrogen load and concentration. The discrepancies between the SPARROW model results and the measured results may be addressed in future iterations of the SPARROW model. Until the model is updated, SPARROW results in the study area should be used with caution.

7. BASEFLOW ANALYSIS

Streamflow is comprised of water from different sources, and nitrogen sources and concentrations among the sources can vary substantially. Generally, the sources can be summarized into three categories: surface runoff, interflow, and groundwater flow.

- Surface runoff refers to water that enters streams shortly after precipitation events. Surface runoff often contains eroded soil, manure, chemical fertilizer, and debris from streets and ditches, all of which contain nitrogen.
- Interflow refers to the water that passes through the shallow portion of the soil after precipitation events and is slowly discharged into streams. Interflow can contain dissolved forms of nitrogen from non-point sources.
- Groundwater flow refers to water that enters streams from deeper water sources that are not quickly impacted by precipitation events. Groundwater flow can contain nitrogen originating from legacy of nutrient leaching into the groundwater aquifer over a long period of time.

Characterization of the streamflow components is useful for understanding how a stream's nitrogen concentrations respond to precipitation events. The baseflow analysis is summarized in the following sections, and a detailed description of methods and results is provided in Appendix F.

7.1. Data Sources

Baseflow separation is performed by analyzing stream hydrographs, which represent flow rate over time. For this analysis flow data from USGS gages at the three long-term trend sites in the study area – the Kewaunee River, the Manitowoc River, and the Sheboygan River – are used. Previous studies have investigated baseflow index for streams in Wisconsin, including the three long-term trend sites. Results from the studies are compared to the results from the analysis described below to determine if baseflow trends have changed over time.

Once baseflow separation is completed, nitrogen concentrations collected from sampling can be applied to the calculated hydrographs. The combination of sampled nitrogen data and flow data is useful because it can be used to estimate nitrogen loads from the different streamflow components. For this analysis, short-term and long-term sampled nitrogen data at the three long-term trend sites, which are summarized in Section 3 and 4, are used.

7.2. Methodology

Stream hydrographs can be plotted to represent the flow over time in a water body. Hydrographs are commonly separated into two components: quick and slow flow. Quickflow represents runoff that enters the stream as the result of a direct runoff event, whereas slow flow represents stream flows that result from a variety of subsurface recharge mechanisms, including slow interflow and groundwater flow. This analysis evaluates both a simple method that estimates baseflow as a single category and an expanded method that separates baseflow into three categories. Nitrogen concentrations in the different components of baseflow can be useful for identifying sources of in-stream nitrogen loads.

7.2.1. Two-component baseflow separation

Baseflow analysis is performed using a method known as the automated smoothed-minima method. The method, which is developed by the UK Institute of Hydrology (1980), separates baseflow into two components: quickflow and baseflow. Once the baseflow hydrograph is determined, a parameter known as Baseflow Index (BFI) is calculated. The parameter represents the proportion of flow in a stream originates from groundwater flow. For example, a stream with a BFI of 0.3 receives 30 percent of its flow from baseflow and 70 percent of its flow from direct runoff.

7.2.2. Delayed Flow Index baseflow separation

An expanded method of baseflow separation, known as the Delayed Flow Index (Stoelzle and others, 2020), is applied to stream hydrographs to separate the flow into four components: short, intermediate, long, and baseline flows. These flows roughly represent runoff, shallow interflow, intermediate interflow, and groundwater flow, respectively. Once the four components are established, values known as the Delayed Flow Index (DFI) are calculated. The DFI represents the portion of flow in a stream that originates from each flow category.

7.2.3. Nitrate concentration and load from flow components

The baseflow separation and delayed flow separation methods provide hydrographs representing unique baseflow components. Nitrate water quality measurements can be applied to the individual hydrographs to create pairs of flow rates and water quality measurements. A model can be developed for each baseflow component to estimate the total nitrate load associated with each flow component. The model used for this analysis is a commonly used model known as LOADEST (Runkel and others, 2004).

7.3. Results

Three unique groups of results are provided in this analysis. The first group is results from the standard baseflow separation, the second is the results from the delayed flow separation, and the third is the water quality results applied to the resulting hydrographs. The results are provided in the following sections.

7.3.1. Two-component baseflow separation results

The two-component baseflow separation is performed for the three long-term trend sites. A baseflow analysis of the three long-term trend sites are also included in two previous studies conducted by the USGS: Gebert and others (2011) and Wolock (2003). The baseflow index is calculated from this analysis and is compared to the results from the two USGS studies. The comparison is shown in Table 7.1.

TABLE 7.1

Comparison of baseflow index in three major basins

Results from the current analysis and two USGS studies

Major basin	This Study	Gebert and others (2011)	Wolock (2003)
Kewaunee River	Dates: 2000-2019 BFI: 0.42	Dates: 1970-1995 BFI: 0.412	Dates: 1964-2000 BFI: 0.409
Manitowoc River	Dates: 2000-2019 BFI: 0.50	Dates: 1973-1996 BFI: 0.495	Dates: 1972-2000 BFI: 0.510
Sheboygan River	Dates: 2000-2019 BFI: 0.50	Dates: 1970-1999 BFI: 0.512	Dates: 1916-2000 BFI: 0.472

For all three basins in the study area, the baseflow index ranges from 0.4 to 0.5. These results indicate approximately 40 to 50 percent of flow in the rivers originates from delayed flow and 60 to 50 percent originates from quickflow. The results from this analysis are similar to the results derived at different times from two USGS studies, which suggests baseflow has not changed significantly over time.

7.3.2. Delayed Flow Index

The stream hydrographs for the three long-term trend basins in the study area are also evaluated using the delayed flow index. The delayed flow index method separates the hydrograph into four components: runoff, short interflow, long interflow, and groundwater flow. The delayed flow index for the three basins in shown in Table 7.2, and the percentage of total streamflow in each category is shown in Table 7.3. Values presented in Table 7.3 represent the percent of total flow in the four delayed flow categories, and they are calculated using the results in Table 7.2.

TABLE 7.2

Delayed flow index for three major basins

Results for the three long-term trend basins in the study area

Major basin	Short Interflow	Long Interflow	Groundwater Flow
Kewaunee River at Kewaunee, WI	0.47	0.28	0.18
Manitowoc River at Manitowoc, WI	0.55	0.27	0.15
Sheboygan River at Sheboygan, WI	0.55	0.32	0.21

TABLE 7.3

Percent of total flow in delayed flow categories

Results for the three long-term trend basins in study area

Major basin	Runoff	Short Interflow	Long Interflow	Groundwater Flow
Kewaunee River at Kewaunee, WI	53%	19%	10%	18%
Manitowoc River at Manitowoc, WI	45%	28%	12%	15%
Sheboygan River at Sheboygan, WI	45%	23%	11%	21%

In the long-term trend basins, groundwater flow constitutes approximately 15 to 21 percent of the total streamflow. This value compares to the 40 to 50 percent of delayed flow that is calculated using the two-component method. The two values are different because the delayed flow component also includes short and long interflow whereas the groundwater flow only estimates flows from the deeper aquifer.

7.3.3. Nitrate loading from subsurface flow

The results of the baseflow separation and water quality measurements are used to estimate the nitrogen load and concentration associated with each baseflow component. The estimated nitrate concentration for each component of the baseflow separation is shown in Table 7.4. The average baseflow concentration is higher than overall stream concentration for the Kewaunee River and Manitowoc Rivers but is lower than overall stream concentration for the Sheboygan River. Additional results are provided in Appendix F.

TABLE 7.4

Nitrate concentrations (mg/L) from baseflow separation

Results for three long-term trend basins using two-component baseflow separation

	Average Concentration (mg/L)	
Major basin	Total Streamflow	5-Day Baseflow
Kewaunee River at Kewaunee, WI	4.3	4.5
Manitowoc River at Manitowoc, WI	1.5	1.7
Sheboygan River at Sheboygan, WI	2.1	1.7

The same estimates of nitrate concentrations are calculated for the four delayed flow index components. The results from the analysis are provided in Table 7.5. In the Kewaunee River the short interflow component of streamflow has the highest nitrate concentration. In the Manitowoc River, the groundwater flow component of streamflow has the highest nitrate concentration. In the Sheboygan River, the surface runoff component of the streamflow has the highest nitrate concentration.

TABLE 7.5

Nitrate concentration (mg/L) in delayed flow categories

Estimates for three long-term trend basins using delayed flow index separation

Major basin	Runoff	Short Interflow	Long Interflow	Groundwater Flow
Kewaunee River at Kewaunee, WI	4.0	5.4	4.3	4.0
Manitowoc River at Manitowoc, WI	1.4	1.6	0.8	2.1
Sheboygan River at Sheboygan, WI	2.6	1.4	1.7	1.8

7.4. Discussion

Baseflow analysis is useful for estimating the source of flows in a stream. For the three long-term trend rivers in the study area, approximately 40-50 percent of the flow is classified as baseflow. The other 50-60 percent is classified as quickflow. The results from the analysis in this study are consistent with observations made in previous studies. The traditional baseflow analysis is expanded to further categorize streamflow into groups related to the type of baseflow. The expanded analysis indicates approximately 15-20 percent of flow in the three long-term trend sites originates from groundwater, and the remaining flow originates from short interflow, long interflow, and runoff.

The source of flow into a stream or river is important for water quality because the different flow components may have different nutrient concentrations. In the Kewaunee River and Manitowoc River, nitrate concentration in baseflow is higher than the nitrate concentration in runoff. In the Sheboygan River, nitrate concentration in runoff is higher than nitrate concentration in baseflow. The difference in concentrations by flow source is important when considering which interventions may be appropriate for reducing surface water nitrates.

8. NITRATE IN GROUNDWATER

The primary goal of the analysis for this study area is evaluation of nitrogen in surface waters in the study area, but nitrogen – particularly nitrate – in groundwater is an important topic. A brief analysis of nitrate in groundwater is performed to identify the location of groundwater sources with high nitrate concentrations and to evaluate the potential mechanisms causing elevated nitrate levels in the groundwater. Exploration of nitrate in groundwater is summarized in the following section, and a detailed description of the methods and results are provided in Appendix G.

8.1. Data Sources

The analysis of nitrogen in groundwater includes on three components: groundwater susceptibility, nitrogen applied to the landscape, and groundwater nitrate concentrations. Groundwater susceptibility is defined as "the ease with which a contaminant can be transported from the land surface to the surface of the groundwater, called the water table" (WDNR, 1989). An analysis completed by the Wisconsin DNR (WDNR, 1989) identifies characteristics that influence groundwater susceptibility and combines the characteristics to identify the overall susceptibility of groundwater. Nitrogen applied to the landscape is estimated using the mass balance approach described in Section 5. Groundwater concentration of nitrate in groundwater is collected and summarized by the Center for Watershed Science (2020), and the results are presented at a township level. These three sources of data are used to assess areas with high nitrate concentrations.

8.2. Methodology

The relationship among groundwater susceptibility, nitrogen application to the landscape, and groundwater nitrate concentration is evaluated by overlaying the results on a single map. This method does not quantify the potential causes of increased groundwater concentration, but it does provide a visual representation of areas with high groundwater nitrate concentrations. The visual representation can be utilized to identify areas that may be most at risk for increasing groundwater nitrate contamination.

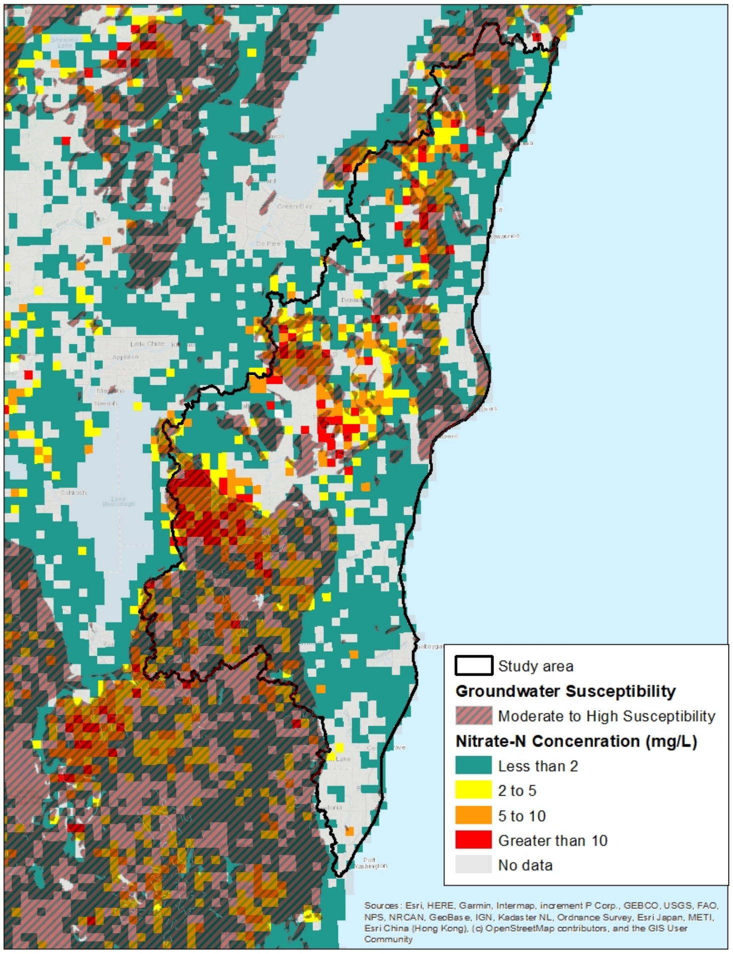
8.3. Results

Areas of high groundwater susceptibility are likely correlated with areas of high groundwater nitrate concentration (Figure 8.1). A visual inspection of the figure suggests a relationship between high groundwater susceptibility and high groundwater nitrogen. Groundwater susceptibility is a good predictor of nitrogen concentrations in groundwater, and special consideration of nitrogen application should be considered in the susceptible areas.

FIGURE 8.1

Groundwater susceptibility and groundwater nitrate

Comparison of susceptibility and nitrate concentration in groundwater



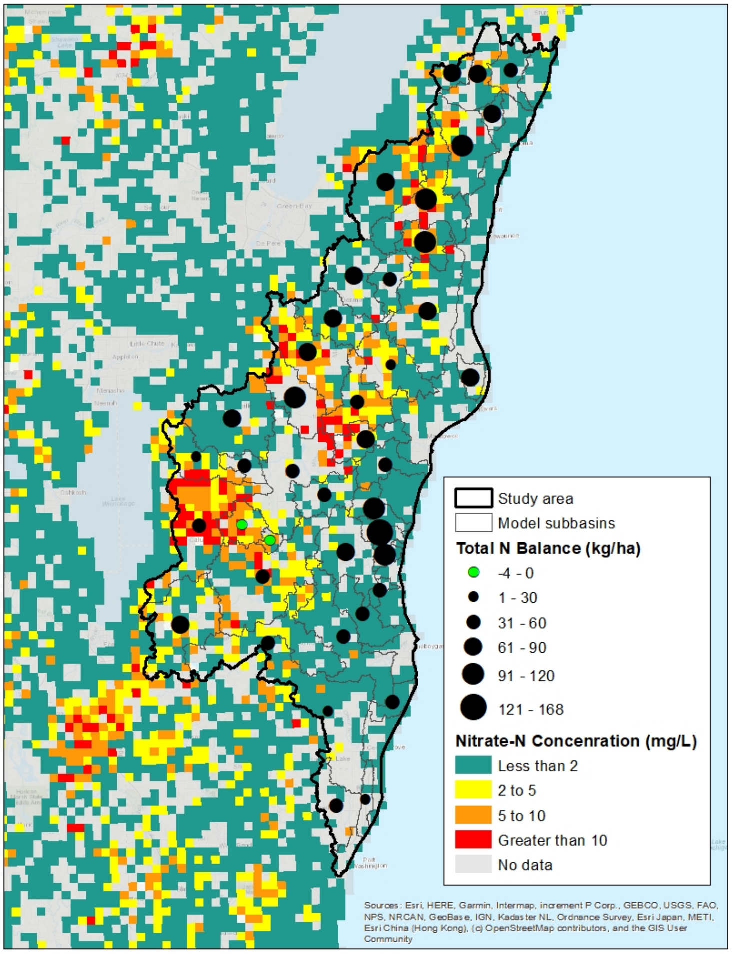
Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community

Nearly all subbasins in the study area have nitrogen inputs that exceed the nitrogen outputs. The mass balance for agricultural lands overlaid with the measured groundwater concentrations is shown in Figure 8.2. Some areas with high groundwater nitrogen concentrations are located in areas where the nitrogen inputs exceed nitrogen crop needs; however, the areas with the highest excess nitrogen inputs, particularly those along the eastern edge of the study area, do not have high groundwater nitrate concentrations. The areas with the highest groundwater nitrogen concentrations occur in areas where nitrogen is applied over areas with high groundwater susceptibility.

FIGURE 8.2

Agricultural nitrogen mass balance and groundwater nitrate

Comparison of nitrogen application and nitrate concentration in groundwater



Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community

8.4. Discussion

Groundwater susceptibility and nitrogen balances likely influence groundwater concentrations. Locations with high groundwater susceptibility are correlated with the locations with the highest groundwater nitrate concentrations. Excess nitrogen applications may play a role in causing increased groundwater nitrate concentrations, but high groundwater susceptibility appears to be more closely related to elevated nitrate concentrations.

9. SUPPLEMENTAL NITROGEN ANALYSIS

In-stream nitrogen loads and concentrations vary among the watersheds in the study area. Detailed analyses can be performed to explore which factors may be contributing to the variation of surface water nitrogen. The importance of various factors is evaluated using simple linear regression, multiple linear regression, and random forest modeling. These approaches provide insights about characteristics that affect in-stream nitrogen loading. The supplemental nitrogen analysis is summarized in the following sections, and a detailed description of the methods and results are provided in Appendix H.

9.1. Data Sources

Many data sources are available to assess the relationships between land characteristics, stream flows, and nitrogen loads. Data sources include landscape and stream details from the Wisconsin Hydrography Dataset Plus, land cover, crop types, manure spreading, fertilizer applications, artificial drainage, climate, and water quality monitoring. A list of available data sources is provided in Appendix A.

9.2. Methodology

Three methods are used to explore the impact of factors on surface water nitrogen loading and concentration. The three methods are simple linear regression, multiple linear regression, and random forest modeling, which are detailed in the following sections.

9.2.1. Simple linear regression modeling

Simple linear regression describes the relationship between in-stream nitrogen loads or concentrations and a single explanatory variable. For this analysis, a flow-weighted mean concentration during the 2018 growing season is calculated at each of the short-term monitoring sites. The 2018 growing season is used for the analysis because flow-weighted mean concentration data are only available for this timeframe. Explanatory variables for the analysis include over 850 parameters from the data sources listed above. A simple linear regression model is established for the flow-weighted mean concentrations and each of the 850 independent parameters. A Pearson’s correlation coefficient, which identifies the strength of the correlation, is calculated for each regression model.

9.2.2. Multiple linear regression modeling

The simple linear regression technique only provides information about the relationship between concentrations and a single explanatory variable. Watershed systems are complex, and a combination of watershed characteristics can influence the flows and nitrogen concentrations in a stream. To account for the influence of multiple watershed characteristics, a multiple linear regression model is developed to estimate in-stream concentrations.

Multiple linear regression models relate multiple independent variables to a single dependent variable. Independent variables in this analysis include the various watershed parameters, and the dependent variable is the nitrogen parameter of interest – either load or concentration. The short-term monitoring sites do not include enough data to perform a multiple linear regression analysis, so the multiple linear regression analysis is only performed for the three long-term trend sites.

9.2.3. Random forest modeling

Random forest modeling is a machine-learning technique that is based on decision tree analyses. Decision tree analysis is a method that relates a single dependent variable to several independent variables. The independent variables are partitioned into two groups based on the relationship between the independent variable and the dependent variable.

The random forest model develops a large number of decision trees for a large group of independent variables. Once the model is created, values of independent variables are processed through the model, and a prediction of the dependent variable is produced. Another key component of random forest modeling is the ability of the model to estimate which independent variables are most important when predicting the dependent variable.

9.3. Results

Ideally, the results from the three models can be used to predict concentrations based on independent variables, such as landscape characteristics. Results can also be used to identify which independent variables are strongly related to nitrogen-series sample concentrations.

9.3.1. Simple linear regression modeling results

Simple linear regression is useful for identifying relationships between one independent variable, such as a landscape characteristic, and in-stream nitrogen concentrations and loads. Table 9.1 lists the characteristics that are most closely related to instream total nitrogen concentrations. The column labeled “direction” in the table indicates whether the independent variable is positively or negatively correlated to total nitrogen concentration. A positive direction indicates that the total nitrogen concentration increases when the value of the independent variable increases. A negative direction indicates total nitrogen concentration decreases when the value of the independent variable increases. For example, when the percentage of excessively drained soils in a watershed increases, the total nitrogen concentration in the stream increases. The table also includes a Pearson’s r coefficient, which summarizes the strength of the relationship. Values closer to 1 or –1 indicate strong correlation. Appendix H includes results for nitrate and total Kjeldahl nitrogen at short-term and long-term sites.

TABLE 9.1

Simple linear regression results for total nitrogen concentration

Summary of the simple linear regression model based on short-term sites

Description	Direction	Pearson's *r*
Percent of soils excessively drained	+	0.79
Percent of land as developed, low intensity from NLCD	+	0.74
Percent of soils in hydrologic soil group B/D	-	-0.74
Percent of stream buffer as dairy rotation from Wiscland 2	+	0.70
Average soil organic matter	-	-0.74
Percent of soils poorly drained	-	-0.74
Annual average July temperature	-	-0.72
Percent of area as emergent wet meadow from Wiscland2	-	-0.69

9.3.2. Multiple linear regression modeling results

Multiple linear regression models are also useful for identifying relationships between independent variables and in-stream nitrogen concentrations. Table 9.2 lists the independent variables from the multiple linear regression model that have a statistically significant relationship with in-stream total nitrogen concentration. The direction of the relationship indicated in the table has the same meaning as the direction for the simple linear regression model. A positive direction indicates concentrations increase when the values of the independent variables increase, and a negative direction indicates concentrations decrease when the values of the independent variables increase, and the . The table shows relationships for six different time periods: entire year, growing season, spring, summer, fall, and winter. The difference in results among the season indicates parameters, such as landscape characteristics, may be important in influencing in-stream nitrogen concentration in one season but not another season. Results from the multiple linear regression analysis for nitrate and TKN are provided in Appendix H.

TABLE 9.2

Multiple linear regression results for total nitrogen concentration

Summary of the multiple linear regression model for six timeframes

All

Parameter	Corr.
Snow water equivalent	-
Daily rain and snowmelt	-
7-day rain and snowmelt	+
Riv. dairy rotation	+
Seasonal parameter - Sine	-
Season of sample	+
Baseflow per area	-
Runoff per area	+

Growing Season

Parameter	Corr.
Watershed slope	-
Ground-moraine (coarse)	-
Potato/vegetable (Wiscland)	-
Deciduous forest (Wiscland)	-
Woody wetlands (NLCD)	-
Developed, low intensity (Wiscland)	+
Dairy rotation (Wiscland)	+
Emergent wet meadow (Wiscland)	-
Wet meadow (Wiscland)	+
Lowland shrub (Wiscland)	+
Riv. developed (NLCD)	+
Riv. developed (Wiscland)	+
Riv. cool-season grass (Wiscland)	-
Riv. open water (Wiscland)	-
Riv. wet meadow (Wiscland)	-
Average annual July temperature	+
Soil calcium carbonate	+
Baseflow index	-

Spring

Parameter	Corr.
Solar radiation	+
Snow water equivalent	-
Woody wetlands (NLCD)	-
Riv. open water (NLCD)	-
Riv. woody wetlands (NLCD)	+
Baseflow index	-
Runoff per area	+

Summer

Parameter	Corr.
Growing degree days	-
Seasonal Parameter - Cosine	-
Baseflow index	-
Runoff per area	+
Discharge per area	-

Fall

Parameter	Corr.
Growing degree days	+
Maximum temperature	-
Ground-moraine (coarse)	-

Winter

Parameter	Corr.
Growing degree days	-
Dairy rotation (Wiscland)	-
Riv. calcium carbonate	-
Dairy rotation (Wiscland)	+

9.3.3. Random forest model results

Random forest models provide information about which parameters are important for predicting nitrogen concentrations in surface water. Unlike the multiple linear regression model, however, the results of the model do not provide information about the direction of the relationship. Figure 9.1 provides a summary of parameters that are the most important predictors of total nitrogen concentration. Figures are provided for the same six time frames presented in the multiple linear regression model: entire year, growing season, spring, summer, fall, and winter. Higher values on the plot suggests the parameter is better at predicting concentrations than the lower values. The results are color coded to group parameters into similar categories. Dark blue represents runoff and discharge parameters, light blue represents climate parameters, purple represents soil property parameters, green represents land use parameters, and black represents temporal parameters.

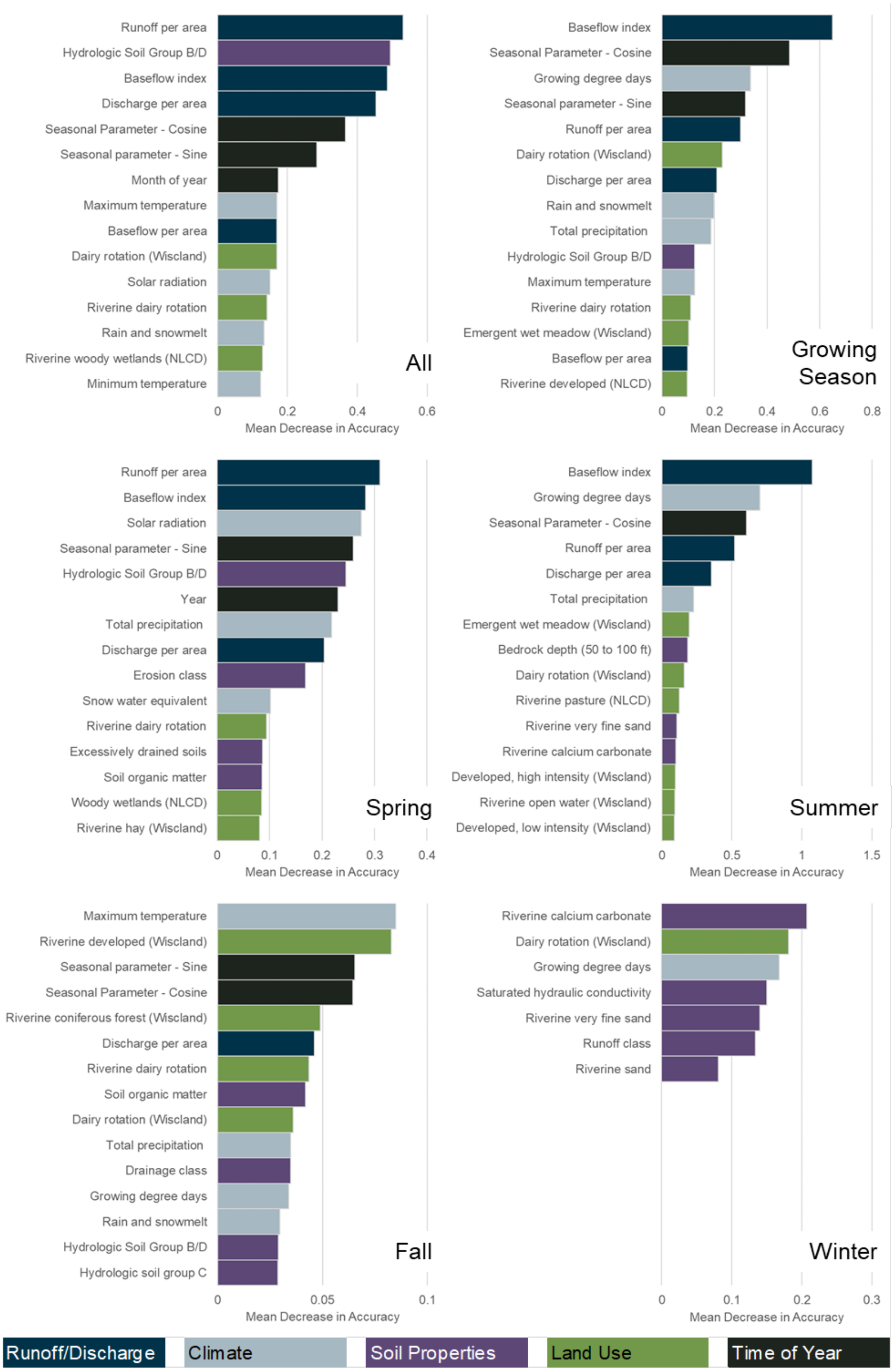
9.4. Discussion

Statistical methods can be used to estimate the influence of specific landscape and land use characteristics on surface water nitrogen loads and concentrations. For this analysis simple linear regression, multiple linear regression, and random forest modeling are used to evaluate the relationships between watershed-specific parameters and surface water concentrations of total nitrogen, nitrate, and total Kjeldahl nitrogen. The most notable result from the analysis is the influence of season on the relationships between watershed parameters and in-stream nitrogen concentrations. A watershed parameter that is a major driver in in-stream nitrogen concentration in one season may not be an important driver in another season. Results from the analyses can be used to identify which watershed parameters may be linked to an increasing concentration in in-stream nitrogen. Information about the most important parameters can be used to develop implementation plans that specifically target and address those features.

FIGURE 9.1

Important parameters influencing total nitrogen concentration

Summary of the random forest model for six timeframes



10. CONCLUSIONS

The nitrogen analysis incorporates many unique approaches to characterize nitrogen dynamics in the Northeast Lakeshore study area. Approaches include long-term monitoring data, short-term monitoring data, nitrogen balances, SPARROW modeling, baseflow, groundwater, and supplemental statistical analyses. Results from each component of the analysis provide insights that are useful when evaluating the existing situation and planning for implementation programs to reduce nitrogen in surface water. Below is a summary of the conclusions from each section:

Long-Term Trends

- In-stream nitrate concentrations have been increasing over time, although the upward trend has stabilized in some locations.
- In-stream total Kjeldahl nitrogen concentrations have been decreasing over time.
- In-stream nitrate concentration is highest in the Kewaunee River and lowest in the Sheboygan River.
- In-stream total Kjeldahl nitrogen concentration is highest in the Manitowoc River and lowest in the Kewaunee River.

Short-Term Monitoring

- In-stream concentrations of total nitrogen, nitrate, total Kjeldahl nitrogen, and ammonia vary by watershed.
- Total nitrogen, nitrate, TKN, and ammonia concentrations tend to be highest in the northern subbasins of the study area and lowest in the southern subbasins of the study area.

Nitrogen Mass Balance

- Nearly every subbasin in the study area has nitrogen inputs that exceed nitrogen outputs.
- The biggest contributor of nitrogen on the landscape is manure application. Commercial fertilizer is also a significant contributor of nitrogen on the landscape.
- The majority of nitrogen removal from the landscape occurs through crop harvest.
- Nitrogen inputs from manure and commercial fertilizer should decreased if an optimal mass balance is to be achieved.

SPARROW Modeling

- The SPARROW model, which is developed by the USGS, incorporates inputs that are consistent with the inputs derived from the WDNR nitrogen mass balance analysis.
- The SPARROW model inputs are an appropriate source of nitrogen input data, and the SPARROW inputs are more readily available than inputs calculated from a comprehensive mass balance analysis.
- The SPARROW model results for the study area overpredict the actual loads and concentrations in the three long-term trend site rivers.

Baseflow Separation

- Approximately 40-50 percent of flow in the three long-term trend site rivers originates from baseflow.
- Approximately 15-20 percent of flow in the three long-term trend site rivers originates from groundwater flow.
- Nitrate concentrations in the baseflow in the Kewaunee and Manitowoc Rivers are higher than the nitrate concentrations from runoff.
- Nitrate concentrations in runoff in the Sheboygan River are higher than the nitrate concentration from baseflow.
- The proportion of nitrate load from each flow source – runoff or baseflow – is important when implementing management practices to decrease nitrates in surface waters.

Groundwater Nitrates

- Groundwater susceptibility, which is a metric that considers soils and geology, is an important predictor of groundwater nitrate concentrations.
- Areas with high groundwater susceptibility have the highest nitrate concentrations.
- Excess nitrogen applications to the landscape are not as important as groundwater susceptibility in predicting groundwater nitrate concentration.

Statistical Analyses

- Simple linear regression, multiple linear regression, and random forest modeling can be used to identify which watershed characteristics are correlated with surface water nitrogen concentrations and loads.
- The impact of watershed parameters on surface water nitrogen concentrations and loads varies by season.
- The relationships between watershed parameters and surface water nitrogen concentrations can be used when planning to implement practices intended to reduce surface water nitrogen.

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APPENDIX A

DATA SOURCES

TABLE A

Data sources used in nitrogen analysis

Category	Data Type	Data Source	Description	Citation
Long-Term Monitoring	Flows	USGS Gages	Flow data from three USGS gages in the TMDL basin	USGS, 2021
	Concentrations	WDNR SWIMS Database	Water quality concentrations at USGS gage locations	WDNR, 2021b
	Long-Term Trends	WDNR Long-Term Trends Viewer	Estimates of long-term flow weighted mean concentrations and loads	WDNR, 2021a
Short-Term Monitoring	Water Level and Discharge	WDNR Northeast Lakeshore TMDL Monitoring	Water level and flow data collected during the monitoring performed for the Northeast Lakeshore TMDL development	WDNR, in development
	Nutrient Concentrations	WDNR Northeast Lakeshore TMDL Monitoring	Water quality data collected during the monitoring performed for the Northeast Lakeshore TMDL development	WDNR, in development
Land Use and Cropping	Land Use	Cropland Data Layer	Annual crop-specific land cover data	NASS, 2008-2019
	Land Use	Wiscland 2.0	Land cover dataset developed by University of Wisconsin-Madison and WDNR	WDNR, 2016
	Corn Ratios	NASS Crop Survey	Ratio of corn grown as grain and corn grown as silage	NASS, 2017
	Crop Yield	NASS	Estimated crop-specific yield for counties	NASS, 2017

Category	Data Type	Data Source	Description	Citation
	Tile Drainage	Valayamkunnath et al., 2020	Estimates of tile drainage extents based on land cover and soils data	Valayamkunnath et al., 2020
	Watershed parameters	Wisconsin Hydrography Dataset	Channel, riparian, and watershed level data for streams in the WDNR 24K hydrogeodatabase	WDNR, 2019
Nitrogen Sources	Manure Spreading	WDNR Northeast Lakeshore TMDL Manure Analysis	Estimated amount and extent of manure spreading on landscape in the Northeast Lakeshore TMDL study area	WDNR, 2020a
	Manure Nitrogen	Laboski and Peters, 2012	Nitrogen content of manure from dairy cattle	Laboski and Peters, 2012
	Cattle Numbers	NASS Census, 2008-2019	Annual estimate of total number of cattle by county	
	Commercial Fertilizer	Brakebill and Gronberg, 2017	Annual estimates of county-level fertilizer sales from 2007-2012	Brakebill and Gronberg, 2017
	Commercial Fertilizer	DATCP, 2019	Annual estimates of state-level fertilizer sales	Wisconsin DATCP, 2019
	Nitrogen Fixation	MPCA, 2013	Estimated rate of nitrogen fixation for different crops	MPCA, 2013
	Atmospheric Deposition	NADP, 2021	Nitrogen on the landscape from atmospheric deposition	NADP, 2021
	Crop Nitrogen Content	International Plant Nutrition Institute	Nitrogen content of different crops	IPNI, 2012
	Crop Senescence Rates	MPCA, 2013	Rate of crop senescence for different crops	MPCA, 2013

Category	Data Type	Data Source	Description	Citation
	Manure Volatilization Rate	MPCA, 2013	Rate of volatilization from land-applied manure	MPCA, 2013
	Fertilizer Volatilization Rate	MPCA, 2013	Rate of volatilization from land-applied fertilizer	MPCA, 2013
	Denitrification Rates	MPCA, 2013	Denitrification rate on the landscape	MPCA, 2013
	Deciduous Forest Export	MPCA, 2013	Export of nitrogen from deciduous forests	MPCA, 2013
	Developed Lands Export	MPCA, 2013	Export of nitrogen from developed lands	MPCA, 2013
	Nitrogen from Point Sources	WDNR SWAMP Database	Nitrogen discharges from point sources	WDNR, 2020b
Groundwater	Baseflow	Wolock, 2003	Baseflow index for watersheds in Wisconsin	Wolock, 2003
	Baseflow	Gebert et al., 2011	Baseflow index for watersheds in Wisconsin	Gebert et al., 2011
	Groundwater susceptibility	Wisconsin DNR, 1989	Groundwater susceptibility estimates for Wisconsin	WDNR, 1989
	Groundwater nitrate concentration	Center for Watershed Science and Education, 2020	Measured groundwater concentrations from private wells in Wisconsin	Center for Watershed Science and Education, 2020
Additional Data	SPARROW	USGS, 2021	Input and output data from the Spatially Referenced Regression on Watershed attributes (SPARROW)	USGS, 2021
	Climate	Daymet	Precipitation and temperature data	Thornton et al., 2020

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APPENDIX B

NITROGEN LONG-TERM TREND MONITORING RESULTS FOR THE NORTHEAST LAKESHORE STUDY AREA

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1. BACKGROUND

The Wisconsin Department of Natural Resources (DNR) maintains a water quality monitoring network. The sites within the network are known as the long-term trend (LTT) sites. At the sites basic water quality data are collected, and the data are used to establish trends in ambient water quality. The monitoring network consists of 43 sites throughout Wisconsin, and it encompass all major basins in the states.

Within the Northeast Lakeshore study area, three locations are maintained as LTT sites. The sites are located near the mouths of the Kewaunee River, the Manitowoc River, and the Sheboygan River. At each of the sites the long-term trends for different water quality parameters are estimated and can be used to track water quality changes over time.

2. DATA SOURCES

Three LTT monitoring sites in the study area are located at USGS flow monitoring stations, which provide continuous flow data. Water chemistry data are collected by the DNR once per month. Sampling includes chemistry grab samples and field measurements. Water chemistry data that are collected include dissolved oxygen, temperature, nutrients (ammonia, nitrate + nitrite, total Kjeldahl nitrogen, total phosphorus, dissolved orthophosphate), sediments, algae, E. coli, metals, and minerals. For the analysis described in this appendix, the LTT data for nitrate + nitrite – hereafter shortened to “nitrate” – and total Kjeldahl nitrogen, or TKN, are evaluated.

2.1. Flows

Daily flow data for the LTT monitoring sites are measured by USGS. The three sites within the study area are summarized in Table 2.1. Data are available for download from the USGS National Water Information System (USGS, 2021).

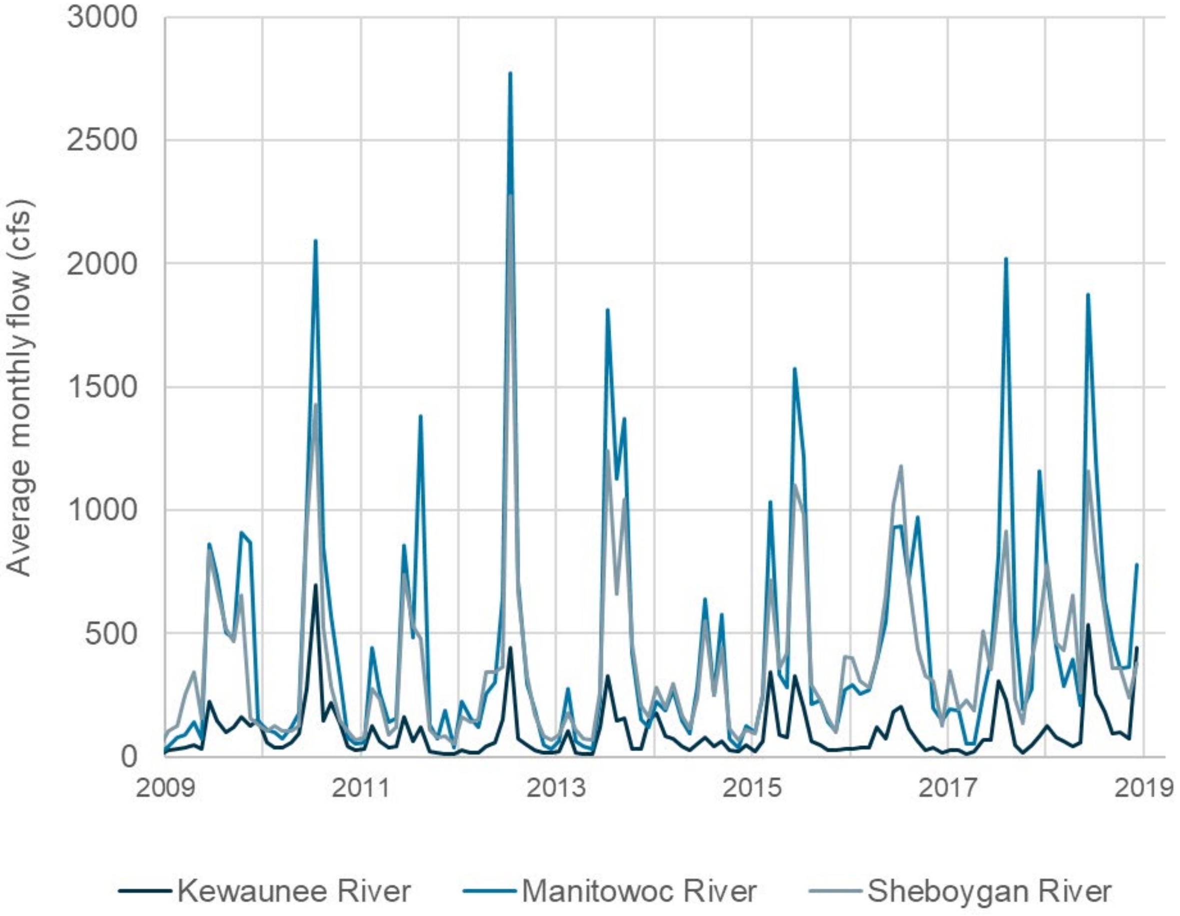
TABLE 2.1

USGS monitoring sites used in study

Station ID	Site Name	Date Range
04085200	KEWAUNEE RIVER NEAR KEWAUNEE, WI	1964 - present
04085427	MANITOWOC RIVER AT MANITOWOC, WI	1972 - present
04086000	SHEBOYGAN RIVER AT SHEBOYGAN, WI	1916 - present

Average monthly flows for water years 2000 to 2019 range from 8 to 693 cubic feet per second (cfs) for the Kewaunee River, 17 to 2,770 cfs for the Manitowoc River, and 33 to 2,275 cfs for the Sheboygan River. Flows are typically highest during March and April and are lowest during August and September. Average monthly flows from 2009 through 2019 for the three stations are summarized in Figure 2.1.

FIGURE 2.1
Average monthly flow for the Long-Term Trend sites



2.2. Concentrations

Nutrient concentrations at the LTT sites have been collected for many decades. Measurements are available in the Wisconsin DNR's Surface Water Integrated Monitoring System (SWIMS) database (WDNR, 2021b). The number of samples collected for nitrate and TKN at the LTT sites are summarized in Table 2.2. The results of the samples by month for nitrate and TKN are summarized in Figures 2.2 through 2.4. In the study area, ammonia – which is one component of TKN – ranges from 2 to 10 percent of the total of TKN. For this analysis, only TKN is evaluated in detail.

TABLE 2.2

Summary of samples at the LTT locations

Station ID	Station Location	NO3		TKN	
		# Samples	Start Date	# Samples	Start Date
313038	Kewaunee River	162	6/28/1983	157	6/28/1983
363069	Manitowoc River	307	1/16/1996	329	1/16/1996
603095	Sheboygan River	507	2/23/1977	461	3/25/1981

FIGURE 2.2

Monthly distribution of concentrations at the Kewaunee River

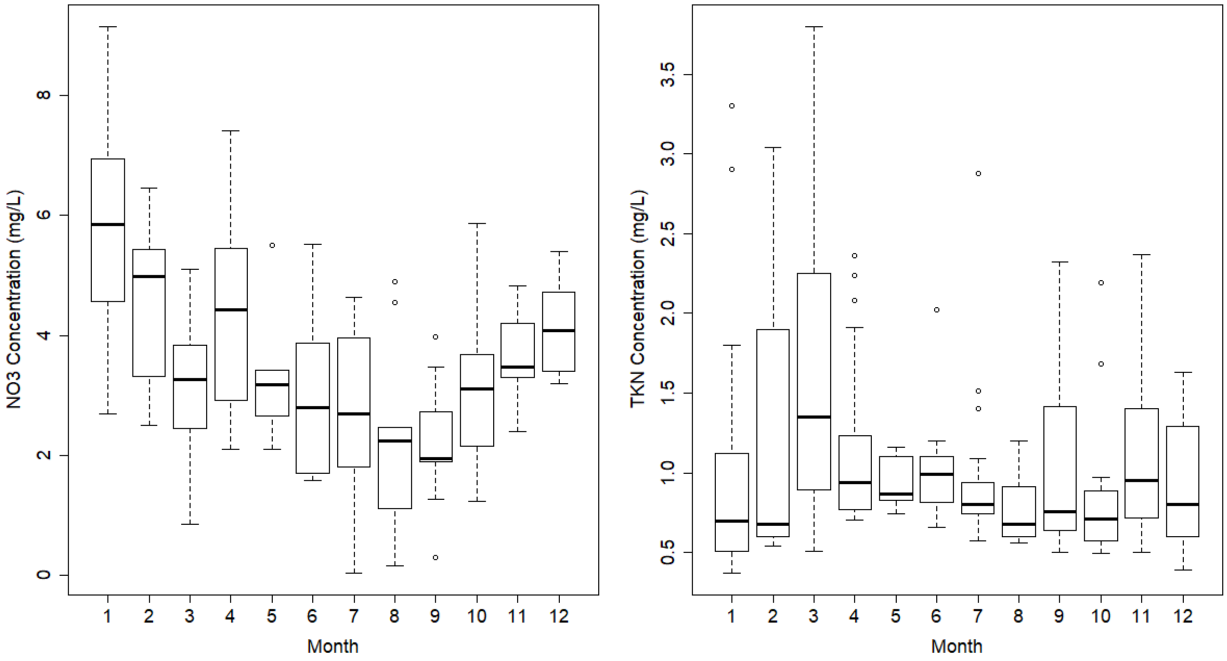


FIGURE 2.3

Monthly distribution of concentrations at the Manitowoc River

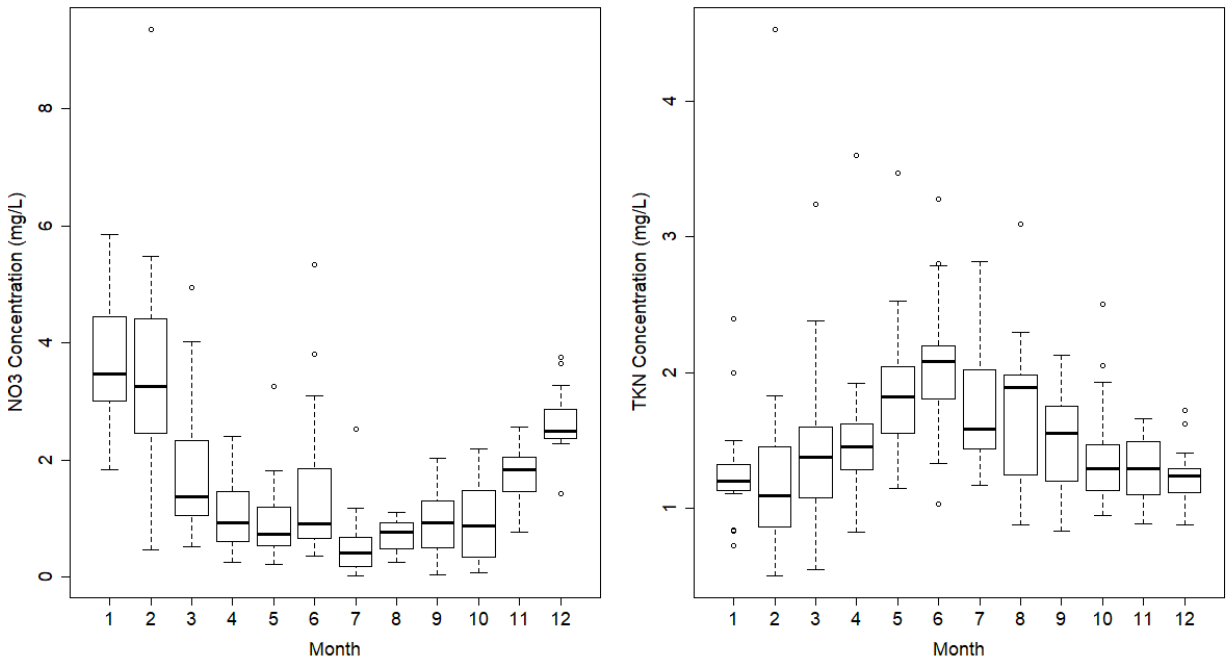
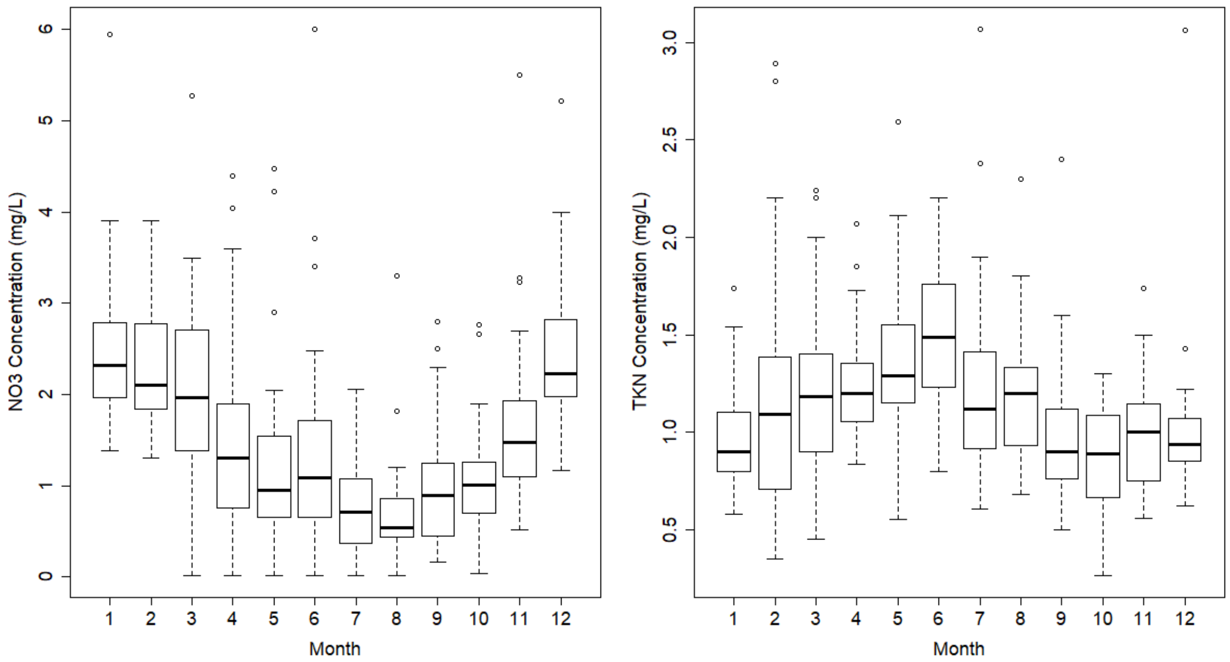


FIGURE 2.4

Monthly distribution of concentrations at the Sheboygan River



At all three sites, the average concentrations of nitrate and TKN follow a pattern. Nitrate concentration is higher in the colder months and lower in the warmer months. Conversely, TKN concentration is typically lower in the colder months and higher in the warmer months. These relationships have been observed in other studies (Lorenz and others, 2012), and the results are expected in northern climates. During the summer months the growth of algae and other aquatic vegetation increases the amount of TKN, the majority of which is organic nitrogen, in the system. The growth of aquatic vegetation involves the conversion of nitrate to organic nitrogen, which decreases the nitrate concentrations. In the winter months growth of aquatic vegetation is decreased due to the low temperatures, so organic nitrogen decreases and dissolved nitrate increases.

3. METHODOLOGY: LONG-TERM TRENDS VIEWER

Flow data and concentration data can be used to estimate average nutrient loads over time. Many methods are available for estimating the total average nutrient loads, but the general concept is similar for all methods: Total load per time, or flux, is equal to the concentration of the compound multiplied by the flow rate.

WDNR has developed an online application to visualize the changes in flow-normalized stream load over time (WDNR, 2021a). The application is commonly referred to as the Wisconsin Long-Term Trends Viewer. The basis of the application is a statistical model known as the Weighted Regressions on Time, Discharge, and Season (WRTDS). WRTDS was developed by USGS to evaluate long-term changes in river conditions while accounting for long-term changes in discharge and seasonal variation (Hirsch and others, 2010).

The analysis methods used in the Long-Term Trends Viewer are summarized on the website and are provided below (WDNR, 2021a):

> *Flow normalization: Annual and seasonal trends are flow-normalized, which means that the influence of variation in river flow on water quality has been removed. As stated by Hirsch and colleagues in the first paper on the WRTDS model, 'The resulting flow-normalized annual concentration and flux histories are very smooth temporally because they eliminate all the variation that is due to the random variation in streamflow. These results should provide a much clearer indication of true progress (or deterioration) toward (or away from) the achievement of water-quality goals. What is meant by true progress (or deterioration) is change in water-quality drivers such as land use, land-use practices, or point source loading. Because the flow-normalized records are not driven by random variations in streamflow and because they are much more stable than the actual record of water quality, they are appropriate to use when computing changes over time.'*

> *Uncertainty in trends is estimated by bootstrapping with the EGRETci R package. In this analysis, bootstrapping means taking many random samples of the water quality dataset, and for each random sample, re-estimating the WRTDS model. The distribution of trends from these models is an estimate of the uncertainty in the actual trends. 90% confidence intervals are plotted on the annual concentration and flux plots as the 5th to 95th percentiles of the bootstrap distribution.*
>
> *Season/flow-specific trends: Season/flow plots are created by plotting the model-estimated concentration for a specific day of year (the middle of each season) at three different discharges (10th percentile, mean, and 90th percentile). These plots are useful for understanding the influence of season and streamflow on concentration at a point in time. For example, total suspended solids concentrations are typically highest at high flow during the spring and summer. These plots are also useful for determining the conditions under which the greatest changes in water quality over time have occurred. For example, changes in low flow concentrations are usually caused by changes in point source inputs, while changes in high flow concentrations are usually caused by changes in non-point source inputs.*
>
> *Data gaps: Several sites have extended gaps in their water quality records due to shifts in monitoring priorities over the years. For each parameter at each site, no annual concentration or flux estimates are provided for years that had fewer than four samples.*

The Wisconsin Long-Term Trends Viewer estimates flow-normalized long-term trends for total phosphorus, orthophosphate, nitrate, total Kjeldahl nitrogen, ammonia, chlorophyll a, total suspended solids, chlorides, and silica. The viewer provides summaries of flow-normalized trends for each of the parameters, including annual concentrations and annual loads. It also provides an estimate about the long-term trend of the water quality for each parameter (i.e., whether the flow-normalized flow-weighted mean concentrations and loads are decreasing). For this analysis, the results for nitrate and Kjeldahl nitrogen are evaluated. Although growing season median concentration is not directly reported on the viewer, the inputs to the model can be used to predict flow-normalized growing season median concentrations.

4. RESULTS

The Long-Term Trends Viewer provides estimates and visualizations for the flow-normalized concentrations and loads of the water chemistry data listed in Section 3. Data from the viewer are used to understand trends in water chemistry over time for the major rivers across Wisconsin. The following sections summarize the trends in both concentrations and loads for the three rivers in the study area.

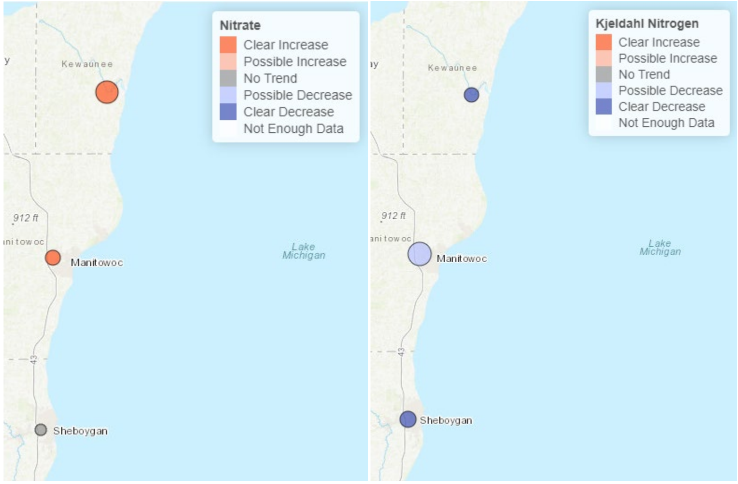
4.1. Trends in Flow-Normalized Flow-Weighted Mean Concentration

The Long-Term Trends Viewer reports the confidence that changes to flow-normalized, flow-weighted mean concentrations over time are occurring. Flow-normalized trends from 1961 through 2020 for the three rivers in the study area are provided in Figure 4.1. Since 1961, the flow-normalized total nitrate concentration has increased for the Kewaunee River and the Manitowoc River. The flow-normalized concentration during this time frame has no clear trend for the Sheboygan River. The flow-normalized TKN concentration has decreased at all three sites since 1961.

FIGURE 4.1

Long-term trend of loads for the study area

WDNR, 2021a: Trend from 1961-2020



The Long-Term Trends Viewer also provides flow-normalized annual average concentration. The annual estimate of flow-normalized concentration since 1990 for the three rivers are shown in Figures 4.2 through 4.4. For the Kewaunee and Sheboygan Rivers, flow-normalized nitrate concentrations steadily increase from 1990 to the mid-2000s but steadily decrease since the mid-2000s. For the Manitowoc River, flow-normalized nitrate concentrations have steadily increased since 1990. Flow-normalized nitrate concentrations at the Kewaunee River are the highest among the three rivers, with a range from approximately 3.5 to 4.5 mg/L. Flow-normalized nitrate concentrations at the Sheboygan River are the lowest among the three rivers, with a range from approximately 1.25 to 1.75 mg/L.

Flow-normalized TKN concentrations for all three rivers have steadily decreased since 1990. Flow-normalized TKN concentrations for the Kewaunee River and Sheboygan River range from approximately 1.0 to 1.2 mg/L. Flow-normalized TKN concentrations for the Manitowoc River are the highest among the three rivers, and the concentrations range from 1.25 to 1.75 mg/L.

FIGURE 4.2

Flow-normalized nitrate and TKN flow-weighted mean concentrations (mg/L) for the Kewaunee River

WDNR, 2021a: Annual values from 1990-2020

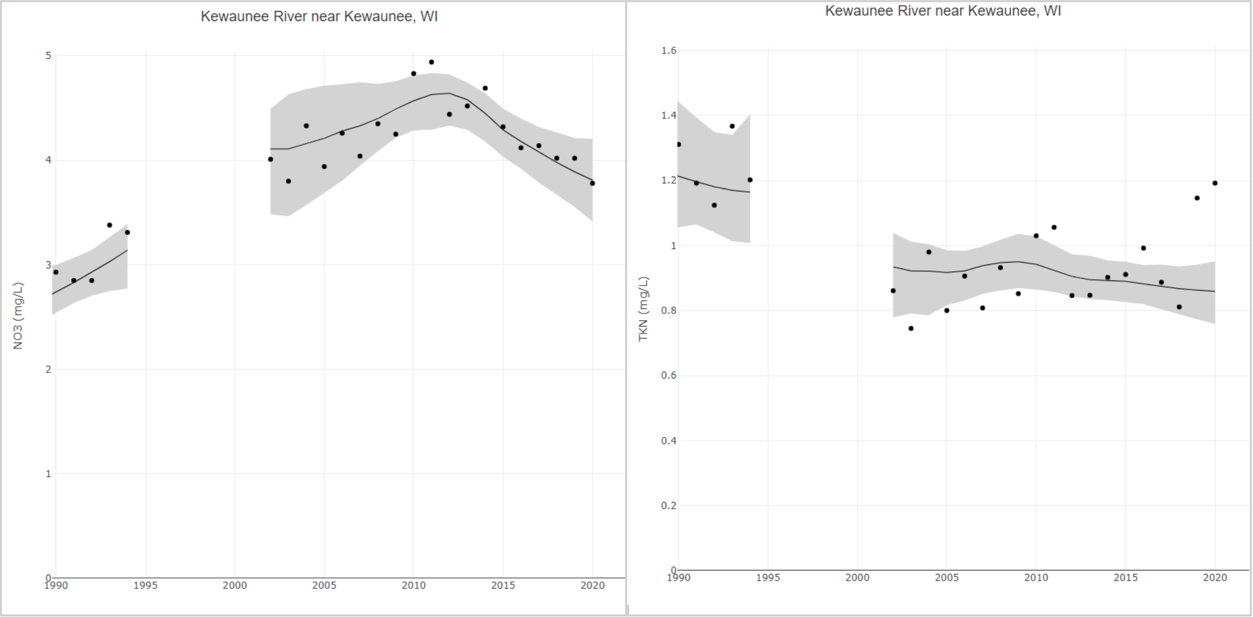


FIGURE 4.3

Flow-normalized nitrate and TKN flow-weighted mean concentrations (mg/L) for the Manitowoc River

WDNR, 2021a: Annual values from 1990-2020

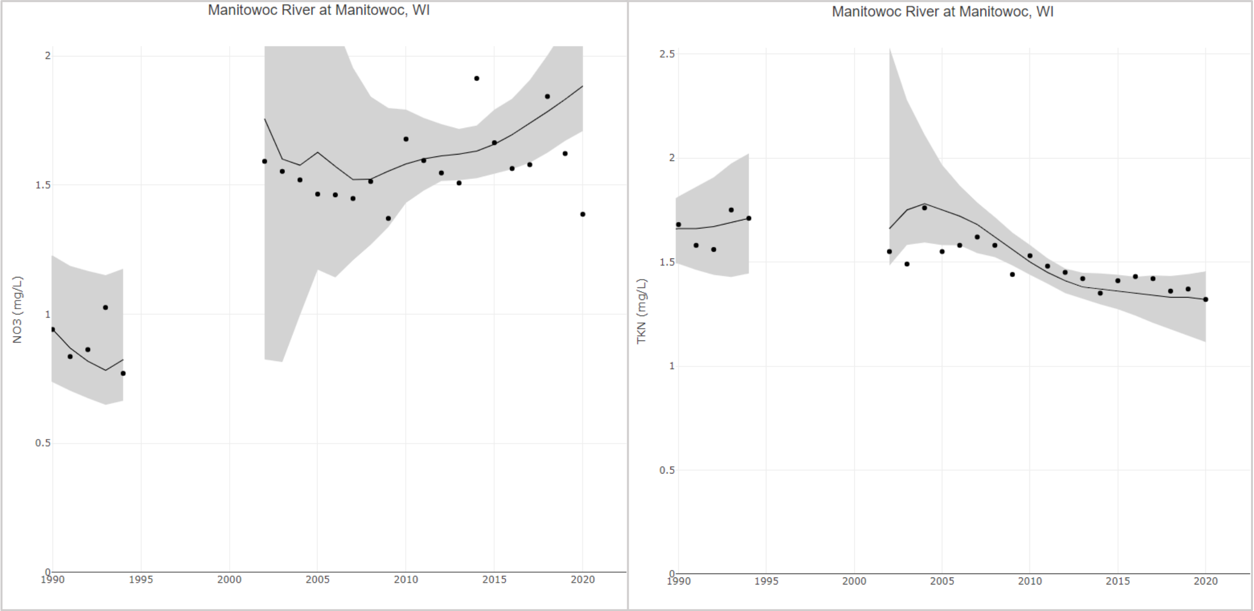
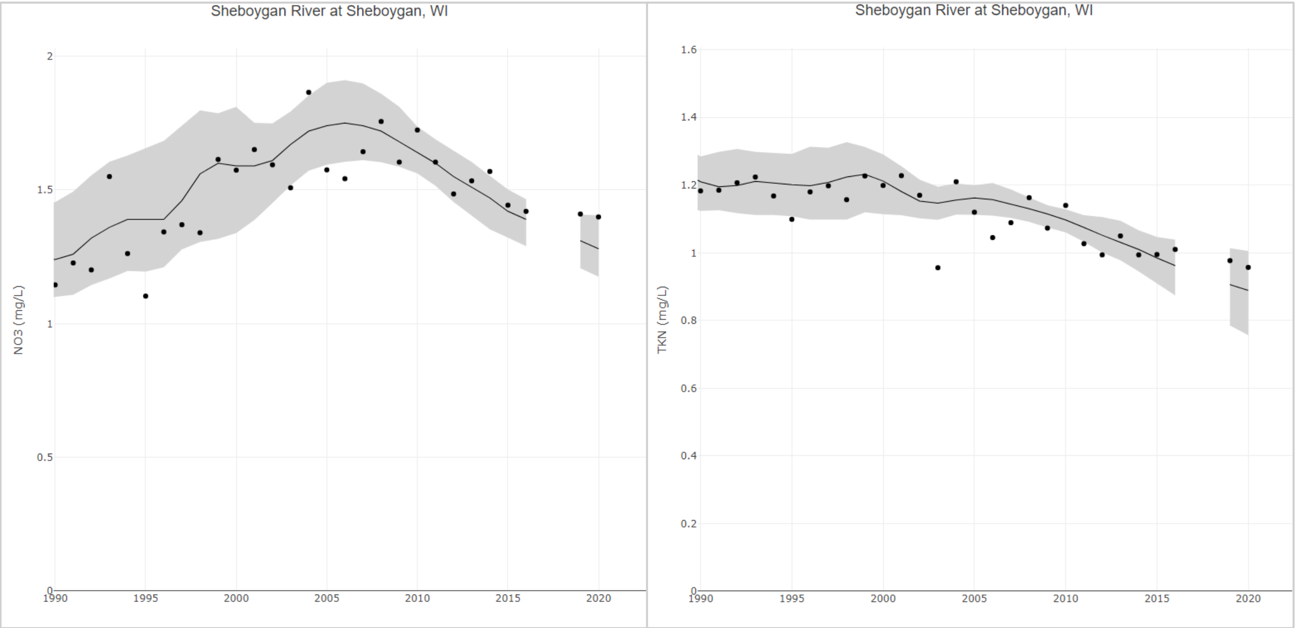


FIGURE 4.4

Flow-normalized nitrate and TKN flow-weighted mean concentrations (mg/L) for the Sheboygan River

WDNR, 2021a: Annual values from 1990-2020



4.2. Trends in Flow-Normalized Loads

The Long-Term Trends Viewer provides flow-normalized load at each site, which are calculated from WRTDS. The annual estimate of flow-normalized load since 1990 for the three rivers are provided in Figures 4.5 through 4.7. The gaps in the figures represent years where not enough flow or concentration data are available for an accurate estimation. Flow-normalized nitrate loads for the three rivers steadily increase from 1990 to the mid-2000s, but flow-normalized nitrate loads in the three rivers steadily decrease since the mid-2000s. Flow-normalized TKN loads for the three rivers are relatively stable since 1990, with a slight decrease over time.

FIGURE 4.5

Flow-normalized nitrate and TKN loads (tons) for the Kewaunee River

WDNR, 2021a: Annual values from 1990-2020

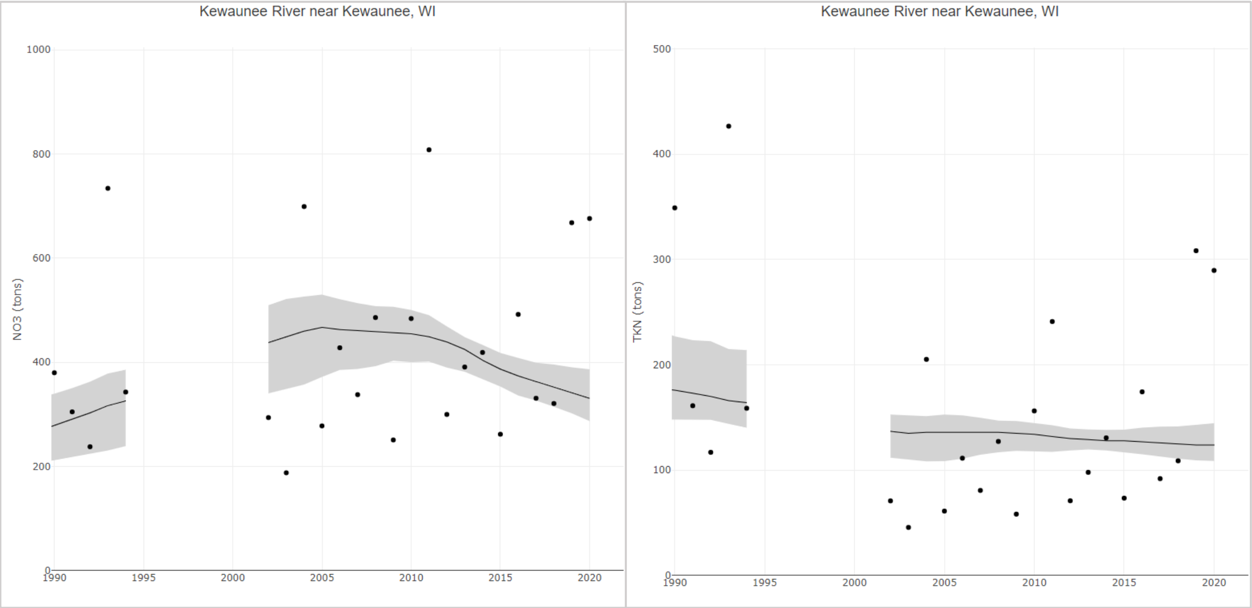


FIGURE 4.6

Flow-normalized nitrate and TKN loads (tons) for the Manitowoc River

WDNR, 2021a: Annual values from 1990-2020

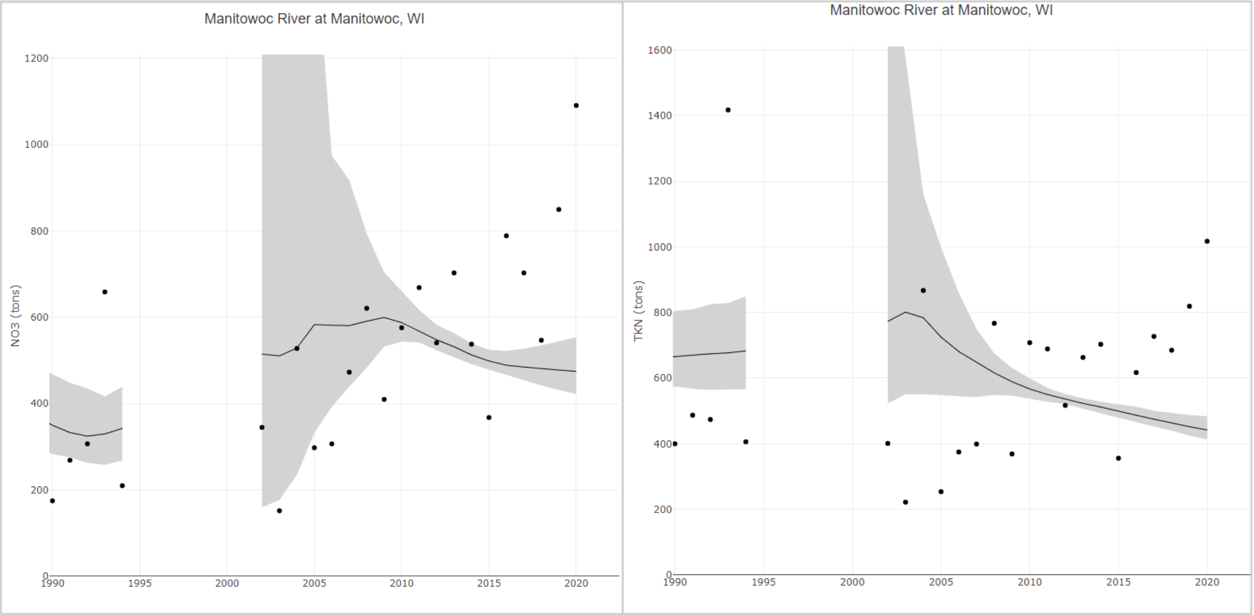
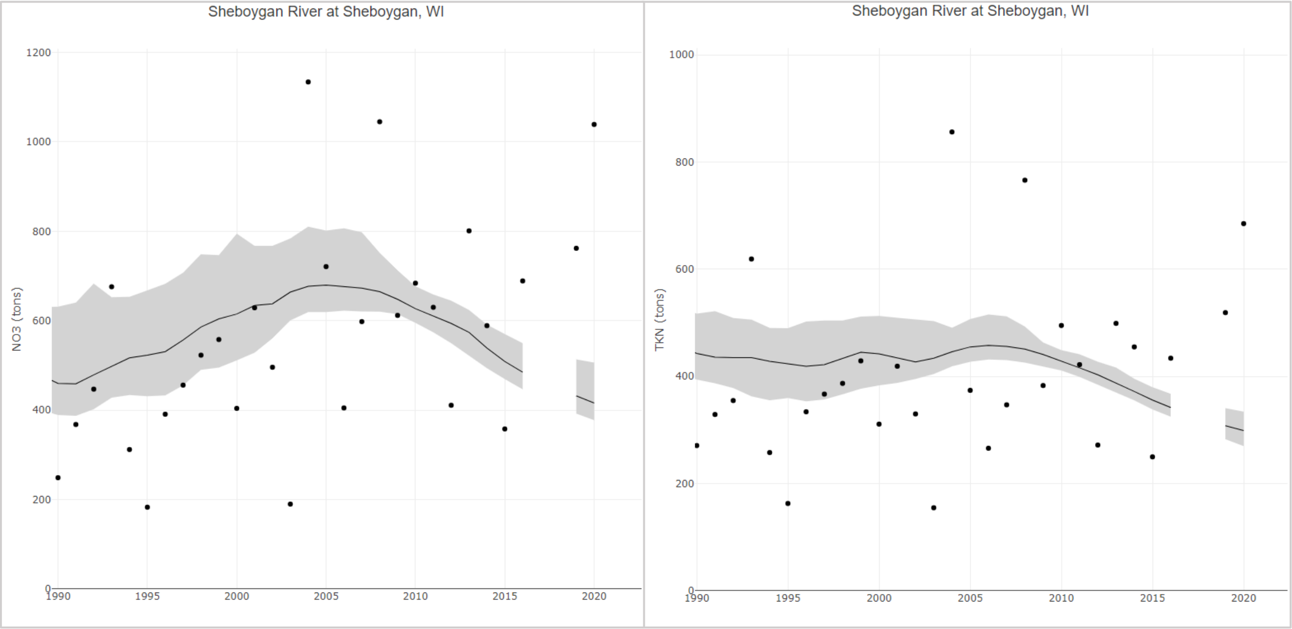


FIGURE 4.7

Flow-normalized nitrate and TKN loads (tons) for the Sheboygan River

WDNR, 2021a: Annual values from 1990-2020



4.3. Trends in Growing Season Median Concentrations

The Long-Term Trends Viewer does not directly report flow-normalized growing season median concentrations at each site, but the WRTDS model can be evaluated to estimate flow-normalized growing season median concentrations. A comparison of flow-normalized growing season median concentration and flow-weighted mean concentration is provided in Figures 4.8 through 4.13 for nitrate and TKN at the three long-term trend stations.

Trends in flow-normalized growing season median concentrations are similar for four of the six station and nitrogen species pair. For nitrates in the Kewaunee River, the growing season median concentration is relatively unchanged while the flow-weighted mean concentration increases and then decreases. The difference indicates nitrate loading during the non-growing season months (November through April) increases between 2002 and 2012 and decreases between 2012 and 2020. The trends may be explained by changes in nitrogen application during the spring and the fall, although additional investigation is required to establish that cause.

For nitrates in the Sheboygan River, flow-normalized flow-weighted mean concentration decreases between 2002 and 2010, but flow-normalized growing season median concentration increases during that timeframe. The difference in trends indicate nitrate loads outside the growing season may have been decreasing. Similar to the Kewaunee River, the difference in trends may be explained by differences in the timing of nitrogen applications or land management.

FIGURE 4.8

Flow-normalized nitrate concentrations for the Kewaunee River

Flow-normalized growing season median and flow-weighted mean

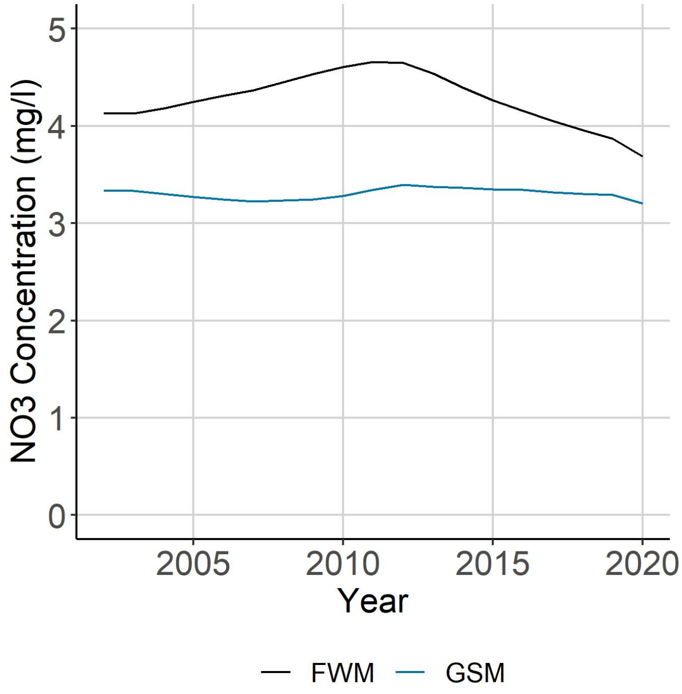


FIGURE 4.9

Flow-normalized TKN concentrations for the Kewaunee River

Flow-normalized growing season median and flow-weighted mean

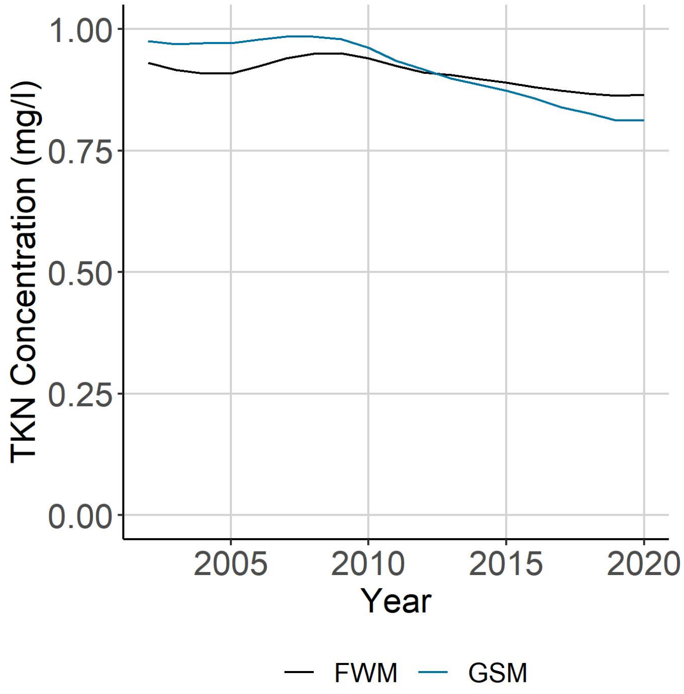


FIGURE 4.10

Flow-normalized nitrate concentrations for the Manitowoc River

Flow-normalized growing season median and flow-weighted mean

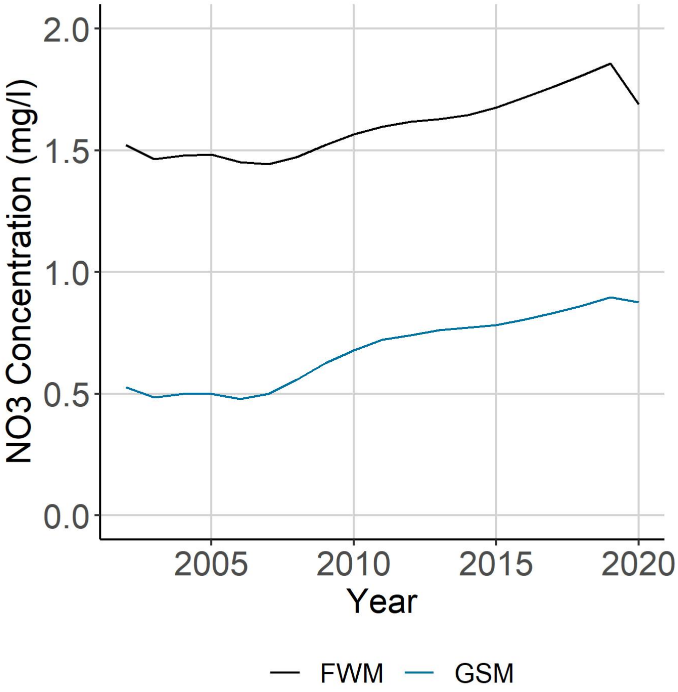


FIGURE 4.11

Flow-normalized TKN concentrations for the Manitowoc River

Flow-normalized growing season median and flow-weighted mean

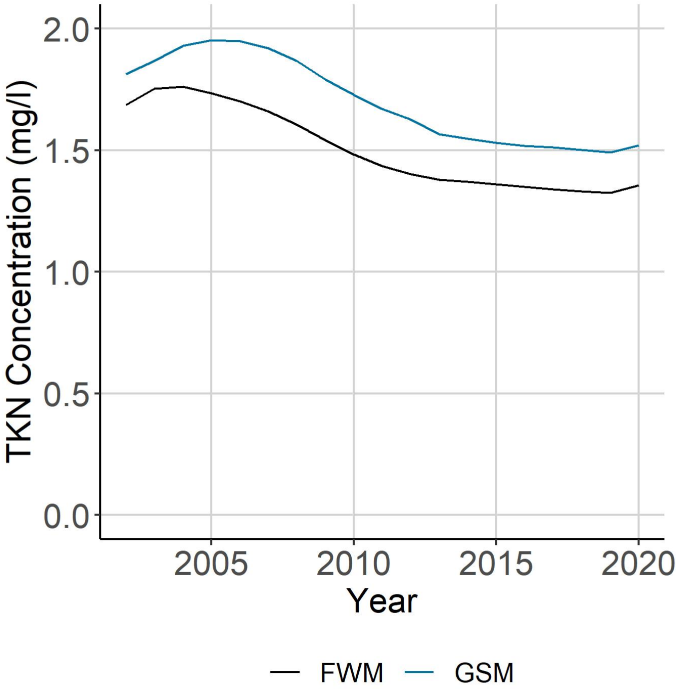


FIGURE 4.12

Flow-normalized nitrate concentrations for the Sheboygan River

Flow-normalized growing season median and flow-weighted mean

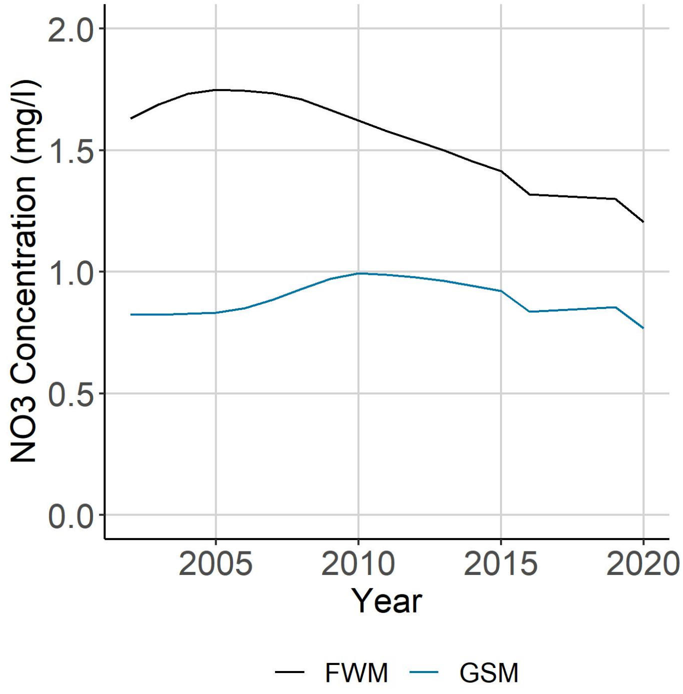
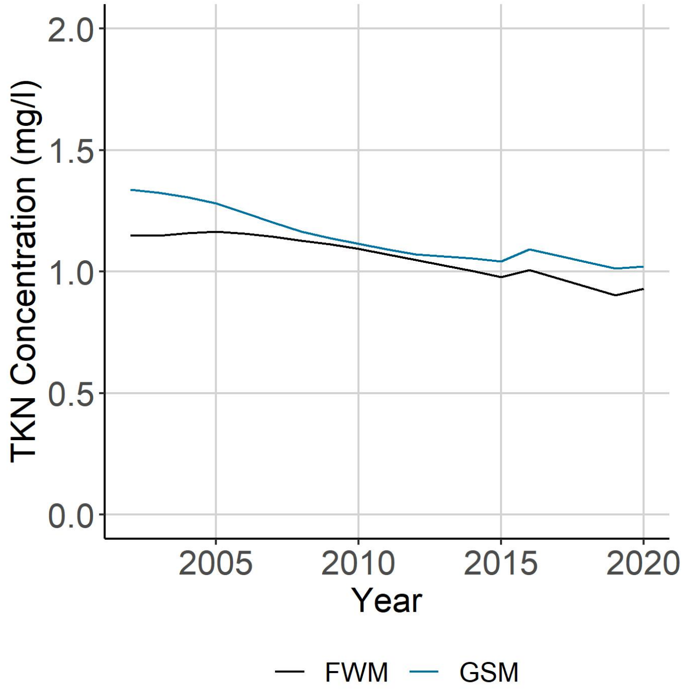


FIGURE 4.13

Flow-normalized TKN concentrations for the Sheboygan River

Flow-normalized growing season median and flow-weighted mean



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APPENDIX C

NITROGEN MONITORING RESULTS FOR THE NORTHEAST LAKESHORE STUDY AREA

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1. BACKGROUND

Stream discharge and nutrient concentration data were collected during the Wisconsin Department of Natural Resource's monitoring efforts conducted for the Northeast Lakeshore TMDL. Data are available for approximately 40 locations for the dates ranging from 2017 through 2019. Water quality data include measurements for total phosphorus (TP), total suspended solids (TSS), total nitrogen (TN), nitrate (NO_3), total Kjeldahl nitrogen (TKN), and ammonia (NH_3). The following sections summarize the data collected for the nitrogen species.

2. DATA SOURCES

Data for water quality, discharge, and depth are available from monitoring at the long-term trend sites and from monitoring conducted for the Northeast Lakeshore TMDL. Detailed information about the monitoring strategy is provided in Northeast Lakeshore TMDL report (WDNR, in development).

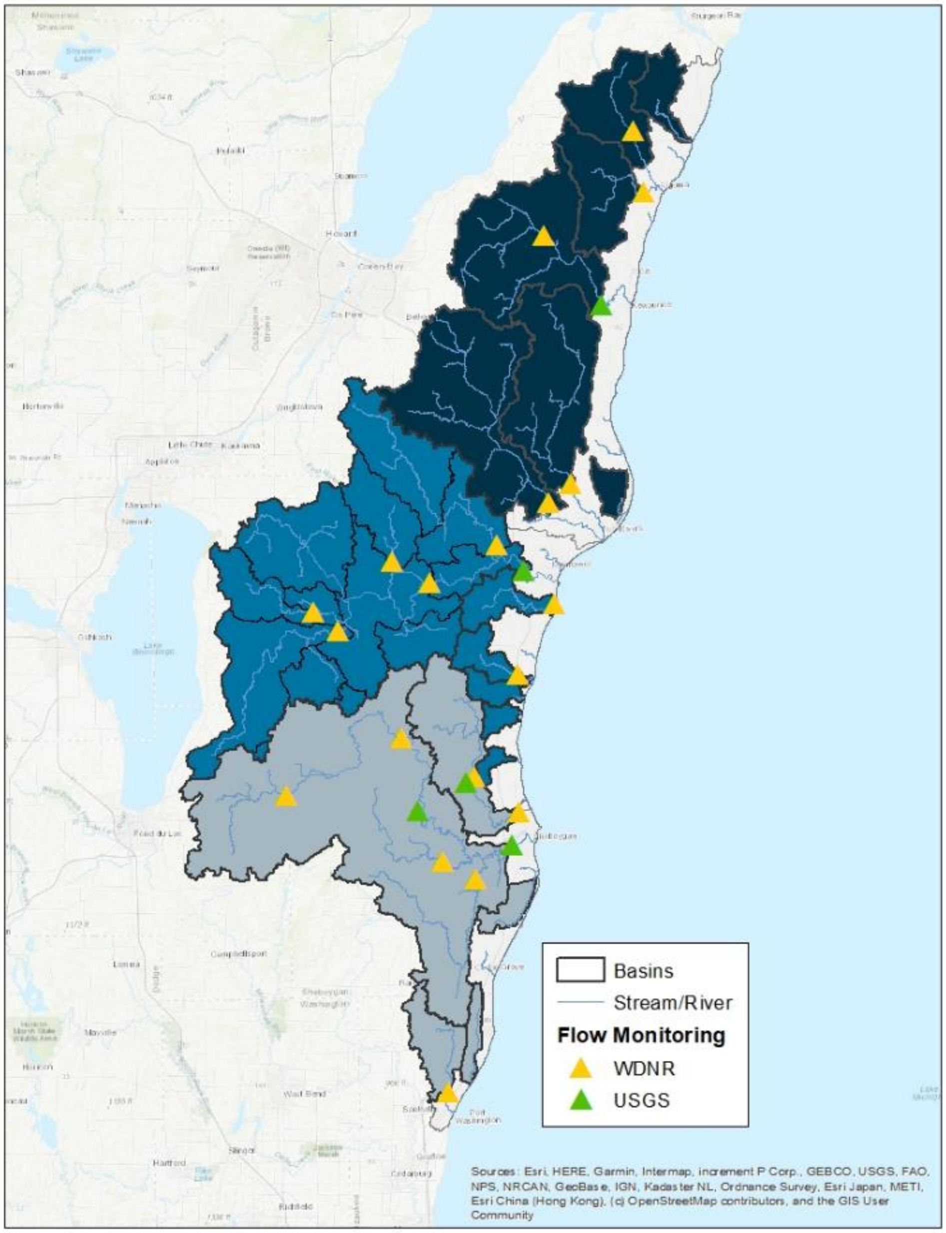
2.1. Water Level and Discharge

Continuous water level data and periodic flow rate measurements that were collected during the TMDL study period are available for 19 sites. The continuous water level data are combined with the periodic flow rate measurements to develop a stage-discharge rating curve at each location. The rating curve is used with the continuous water level data to estimate continuous flow at each site. More information about the data collection process and the development the rating curve is provided in the Northeast Lakeshore TMDL Report (WDNR, in development).

In addition to the 19 flow monitoring sites established during the study period, five USGS gages with continuous flow data are located within the study area. The location of both the DNR gages and the USGS gages are provided in Figure 2.1.

FIGURE 2.1

Northeast Lakeshore TMDL flow monitoring stations



Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community

2.2. Nutrient Concentrations

Four species of nitrogen (TN, NO_3, TKN, and NH_3) were monitored and evaluated as part of the study. The availability of data differs for the different nitrogen species. Total nitrogen data are available at 38 stations, nitrate data are available at 11 stations, total Kjeldahl nitrogen data are available at 9 stations, and ammonia data are available at 11 stations. However, one site for NO_3 and NH_3 has limited data (10 or fewer samples), and three sites for TKN have limited data (3 or fewer samples). The difference in number of samples at each station is the result of the sampling design for the TMDL study. A summary of the total number of samples collected during the entire study period and during the growing season months (May through October) are provide in Table 2.2. In the table 'All' represents all samples collected, and 'GS' represents the samples collected during the growing season. A map with locations of the monitoring sites is provided in Section 4.1.

TABLE 2.2

Number of samples collected from 2017 through 2018

TMDL Model Subbasin	Station Name	TN		NO_3		TKN		NH_3	
		All	GS	All	GS	All	GS	All	GS
Kewaunee River	Stony Creek - Rosewood Rd.	23	12						
	Ahnapee River - CTH H	13	13	24	23	13	12	18	18
	Ahnapee River - Washington Rd.	55	30	52	29			52	29
	Silver Creek - Willow Dr.	55	30						
	Kewaunee River - Hillside Rd.	56	29						
	Kewaunee River - CTH F	26	12	41	19	40	19	41	19
	East Twin River - CTH J	26	12	4	0	3	0	10	6
	East Twin River - Steiners Corner	59	32	55	31	1	1	55	31
	Neshota River - CTH BB	24	12						
	Black Creek - CTH BB	23	12						
	Devils River - CTH R	24	12						
	West Twin River - CTH V	58	32	55	31	1	1	55	31
	Molash Creek - CTH O	23	12						
Manitowoc River	Branch River - CTH J	23	11						
	Branch River - North Union Rd.	61	35	20	20	13	13	20	20
	Mud Creek - Hilltop Rd.	55	30						
	Manitowoc River - N. Branch View Rd.	22	12						
	Killsnake River - Lemke Rd.	56	31						
	Pine Creek - CTH T	7	7	13	13	12	12	13	13
	Pine Creek - Quarry Rd.	24	12						
	Manitowoc River - Lemke Rd.	58	33						
	Mud Creek - Hwy 151	23	12						
	Manitowoc River - CTH JJ	25	12	59	27	58	27	58	27
	Silver Creek - CTH LS	51	28						
	Point Creek - CTH LS	21	9						

TMDL Model Subbasin	Station Name	TN		NO_3		TKN		NH_3	
		All	GS	All	GS	All	GS	All	GS
	Fischer Creek - CTH LS	20	9						
	Centerville Creek - Lakeshore Dr.	20	9						
	Sevenmile Creek - CTH LS	18	9						
Sheboygan River	Pigeon River - River Rd.	57	29						
	Pigeon River - Mill Rd.	57	29	54	28			53	28
	Sheboygan River - Palm Tree Rd.	57	29						
	Sheboygan River - Hwy 57	57	29						
	Mullet River - Sumac Rd.	55	28						
	Onion River - Ourtown Rd.	58	30						
	Sheboygan River - Esslingen Park	47	26	45	24	41	22	46	25
	Black River - Indian Mound Rd.	29	17						
	Sucker Creek - Sucker Brook Ln.	25	12						
	Sauk Creek - Mink Ranch Rd.	57	29						

2.3. Discharge and Concentration Pairs

At locations where continuous flow data and periodic water chemistry data exist, continuous load can be estimated. Table 2.3 summarizes the monitoring sites where continuous flow data have corresponding water chemistry data between 2017 and 2020. The overlap of these datasets occurs at 21 sites for TN, 8 sites for NO_3, 4 sites for TKN, and 8 sites for NH_3. The overlapping data are used to estimate loading for each of the locations.

TABLE 2.3

Locations with overlapping flow and concentration Data

		# of Corresponding Samples (2017-2020)			
TMDL Model Subbasin	Station Name	TN	NO_3	TKN	NH_3
Kewaunee River	Ahnapee River - Washington Rd.	55	52		52
	Silver Creek - Willow Dr.	55			
	Kewaunee River - Hillside Rd.	55			
	Kewaunee River - CTH F	26	30	29	29
	East Twin River - Steiners Corner	59	55	1	55
	West Twin River - CTH V	58	55	1	55

		# of Corresponding Samples (2017-2020)			
TMDL Model Subbasin	Station Name	TN	NO_3	TKN	NH_3
Manitowoc River	Branch River - North Union Rd.	60	19	13	19
	Mud Creek - Hilltop Rd.	55			
	Killsnake River - Lemke Rd.	56			
	Manitowoc River - Lemke Rd.	57			
	Manitowoc River - CTH JJ	25	47	46	39
	Silver Creek - CTH LS	51			
	Point Creek - CTH LS	22			
Sheboygan River	Pigeon River - River Rd.	57			
	Pigeon River - Mill Rd.	57	54		53
	Sheboygan River - Palm Tree Rd.	57			
	Sheboygan River - Hwy 57	57			
	Mullet River - Sumac Rd.	55			
	Onion River - Ourtown Rd.	57			
	Sheboygan River - Esslingen Park	39	37	32	33
	Sauk Creek - Mink Ranch Rd.	57			

3. METHODOLOGY

Average annual load (pounds per year) for the nitrogen species of interest from 2017 through 2020 can be estimated using the flow and concentration pairs summarized in Section 2. The loading estimates can be used to compare the total load across the watersheds in the study area.

3.1. Discharge per Unit Area

As described in Section 2.1, continuous discharge at the monitoring sites is estimated by developing a stage-discharge rating curve. Continuous discharge data are available for 21 monitoring stations in the study area. At the monitoring stations, discharge measurements were collected at various time intervals between 2017 and 2020. Water level data and flow estimates were not collected at all sites for the entire duration of the study. Additionally, ice on the waterbodies impacted the ability to discern discharge at some sites during the winter. A detailed explanation of the development of the rating curve are estimated in the Northeast Lakeshore TMDL project (WDNR, in development).

Since availability of continuous flow data varies for each site during the monitoring period, direct comparison of the discharge among sites is limited. Flow data at all sites in the study are available for the 2018 growing season, which includes all days between May and October. Comparison of flow rates at different watersheds during this period are estimated by calculating an average discharge per day and dividing the discharge by the upstream watershed area. The resulting values, which are expressed in units of cubic feet per second per square mile, are compared across all monitoring watersheds. This information provides insights into flow behavior across the study area.

3.2. Measured Growing Season Median Concentration

Growing season median represents the median value of measured concentrations for the monitoring sites during the growing season, which runs from May through October. Water quality monitoring is available for 38 sites from 2017 through 2020. A summary of the availability of samples collected during the growing season are provided in Table 2.2. The estimated growing season median is reported for measured samples collected during the monitoring period. Samples across the different monitoring sites were collected within one or two days of each other, so the estimated growing season median concentrations provide a reasonable comparison.

3.3. Estimated Load and Concentration – Modified LOADEST Model

Continuous daily loads are estimated for TN, NO_3, TKN, and NH_3 at each site in the monitoring network where water quality and flow rate data are available. Load calculation is performed with a modified version of the methods used in U.S. Geological Survey Fluxmaster and LOADEST software programs (Schwarz, and others, 2006). The purpose of these methods is to estimate concentrations at a given site when water quality sampling frequency is insufficient for estimating continuous long-term load. The methods are most effective for water quality parameters that have a strong relationship with discharge and exhibit cyclic variation with season. Additionally, a time variable allows concentrations to vary over the sampling period. Additional information about the methodologies is provided in the Northeast Lakeshore TMDL report (WDNR, 2022).

3.3.1. Estimated Load

The average annual load for TN, NO3, TKN, and NH3 is estimated using continuous flow data and the corresponding measured concentrations. For the analysis all available concentration samples are utilized, regardless of the time of year they were collected. Some monitoring sites within the network have limited flow data during the winter months when ice was present in the water body. To compare the average load across each site, a period that includes estimated load data is selected. For the monitoring network continuous estimated load data at all sites are available for the 2018 growing season. The calculated total load is divided by the total subbasin area to get an estimate of total load per unit area, which allows for a direct comparison across sites in the watershed.

3.3.2. Modeled Growing Season Median Concentration

The modified LOADEST model provides continuous estimates of daily concentrations across all monitoring sites. The estimates of the daily concentrations are utilized to calculate growing season median. The method for estimating growing season median concentration from the modified LOADEST model is different than the method for estimating growing season median described in Section 3.2. The growing season median concentration described in the previous section represents the median of all collected samples. The distribution of concentrations from sampling do not necessarily reflect the continuous growing season median concentrations because the sampling frequency may not provide a truly representative sample. The growing season median concentration from the LOADEST model represents an estimate of growing season median when considering every day during the growing season rather than the median measured at discrete sampling events.

4. RESULTS

The data listed in Section 2 and the methodologies listed in Section 3 are used to generate estimates of discharge, concentrations, and flux. The following sections provide detailed information about the results of the analysis.

4.1. Discharge per Unit Area

The average discharge per unit area for the subbasins with continuous flow monitoring data are summarized in Table 4.1. Average flow rate per unit area ranges from 0.5 to 1.6 cubic feet per second per square mile (cfs/mi²). The table lists stations from north to south and are grouped by major basins identified in the TMDL study (WDNR, 2022). The lowest flow rates per unit area occur in the Kewaunee River basin, and the highest flow rates per unit area occur in the Manitowoc River basin.

TABLE 4.1
Average flow rates during the 2018 growing season

TMDL Model Subbasin	Station Name	Area (mi^2)	Average Flow (cfs)	Area – Weighted Flow (cfs/mi^2)
Kewaunee River	Ahnapee River - CTH H	47	23	0.5
	Silver Creek - Willow Dr.	54	34	0.6
	Kewaunee River - Hillside Rd.	69	45	0.6
	Kewaunee River - CTH F	134	92	0.7
	East Twin River - Steiners Corner	115	142	1.2
	West Twin River - CTH V	158	221	1.4
Manitowoc River	Branch River - North Union Rd.	108	125	1.2
	Mud Creek - Hilltop Rd.	39	48	1.2
	Killsnake River - Lemke Rd.	33	33	1.0
	Manitowoc River - Lemke Rd.	112	129	1.2
	Manitowoc River - CTH JJ	519	822	1.6
	Silver Creek - CTH LS	25	23	0.9
	Point Creek - CTH LS	19	16	0.9

TMDL Model Subbasin	Station Name	Area (mi^2)	Average Flow (cfs)	Area – Weighted Flow (cfs/mi^2)
Sheboygan River	Pigeon River - River Rd.	49	56	1.1
	Pigeon River - Mill Rd.	78	83	1.1
	Sheboygan River - Hwy 57	185	237	1.3
	Mullet River - Sumac Rd.	77	70	0.9
	Onion River - Ourtown Rd.	97	106	1.1
	Sheboygan River - Esslingen Park	428	504	1.2
	Sauk Creek - Mink Ranch Rd.	31	47	1.5

4.2. Measured Growing Season Median Concentrations

Growing Season Median (GSM) concentration is the median value of all concentration measurements collected between May and October. For this analysis data collected between 2017 and 2020 are evaluated. Table 4.2 summarizes the number of samples collected and the GSM for TN, NO_3, TKN, and NH_3. TN can be represented as the sum of NO_3 and TKN. In some cases, the value for TN does not equal the sum of NO_3 and TKN. The nitrogen components had different sampling frequencies, and the numbers reported in the table represent the median of all samples during the growing season. As a result, GSM for TN may be slightly different than the GSM for NO_3 plus TKN. Visual representations of the growing season median concentrations for the four nitrogen species assessed are provided in Figures 4.1 through 4.4.

TABLE 4.2

Growing season median for TN, NO_3, and NH_3 (2017-2020)

	TN		NO3		TKN		NH3	
Station Name	n	GSM (mg/L)	n	GSM (mg/L)	n	GSM (mg/L)	n	GSM (mg/L)
Stony Creek - Rosewood Rd.	12	1.5						
Ahnapee River - CTH H*	13	4.2	23	0.3	12	1.3	18	0.021
Ahnapee River - Washington Rd.	30	2.3	29	1.0			29	0.044
Silver Creek - Willow Dr.	30	2.5						
Kewaunee River - Hillside Rd.	29	4.3						
Kewaunee River - CTH F	12	4.5	19	3.6	19	0.8	19	0.038
East Twin River - CTH J	12	7.2					6	0.080
East Twin River - Steiners Corner	32	3.5	31	2.5			31	0.037
Neshota River - CTH BB	12	2.2						
Black Creek - CTH BB	12	2.8						
Devils River - CTH R	12	2.4						
West Twin River - CTH V	32	2.9	31	2.0			31	0.030
Molash Creek - CTH O	12	1.6						

	TN		NO3		TKN		NH3	
Station Name	**n**	**GSM (mg/L)**	**n**	**GSM (mg/L)**	**n**	**GSM (mg/L)**	**n**	**GSM (mg/L)**
Branch River - CTH J	11	4.0						
Branch River - North Union Rd.	35	3.4	20	2.3	13	1.1	20	0.042
Mud Creek - Hilltop Rd.	30	2.6						
Manitowoc River - N. Branch View Rd.	12	2.1						
Killsnake River - Lemke Rd.	31	3.5						
Pine Creek - CTH T	7	1.9	13	1.4	12	1.1	13	0.046
Pine Creek - Quarry Rd.	12	3.7						
Manitowoc River - Lemke Rd.	33	2.5						
Mud Creek - Hwy 151	12	2.5						
Manitowoc River - CTH JJ	12	2.4	27	1.0	27	1.5	27	0.032
Silver Creek - CTH LS	28	1.9						
Point Creek - CTH LS	9	2.9						
Fischer Creek - CTH LS	9	4.8						
Centerville Creek - Lakeshore Dr.	9	3.7						
Sevenmile Creek - CTH LS	9	5.2						
Pigeon River - River Rd.	29	3.3						
Pigeon River - Mill Rd.	29	2.9	28	1.7			28	0.027
Sheboygan River - Palm Tree Rd.	29	2.6						
Sheboygan River - Hwy 57	29	1.9						
Mullet River - Sumac Rd.	28	2.7						
Onion River - Ourtown Rd.	30	2.5						
Sheboygan River - Esslingen Park	26	1.9	24	0.9	22	1.1	25	0.025
Black River - Indian Mound Rd.	17	1.2						
Sucker Creek - Sucker Brook Ln.	12	2.9						
Sauk Creek - Mink Ranch Rd.	29	3.1						

*Note: The growing season median nitrate value Ahnapee River at CTH H is lower than one would expect if nitrate were estimated by subtracting TN by TKN. The GSM value of nitrate from 2017-2018 is 0.11 mg/L, but the GSM value of nitrate from 2019-2020 is 3.53 mg/L. The cause of the discrepancy is unknown – the variation could reflect issues with sampling and reporting or major changes in the watershed between 2018 and 2019.

FIGURE 4.1

Measured growing season median concentration (mg/L) for TN

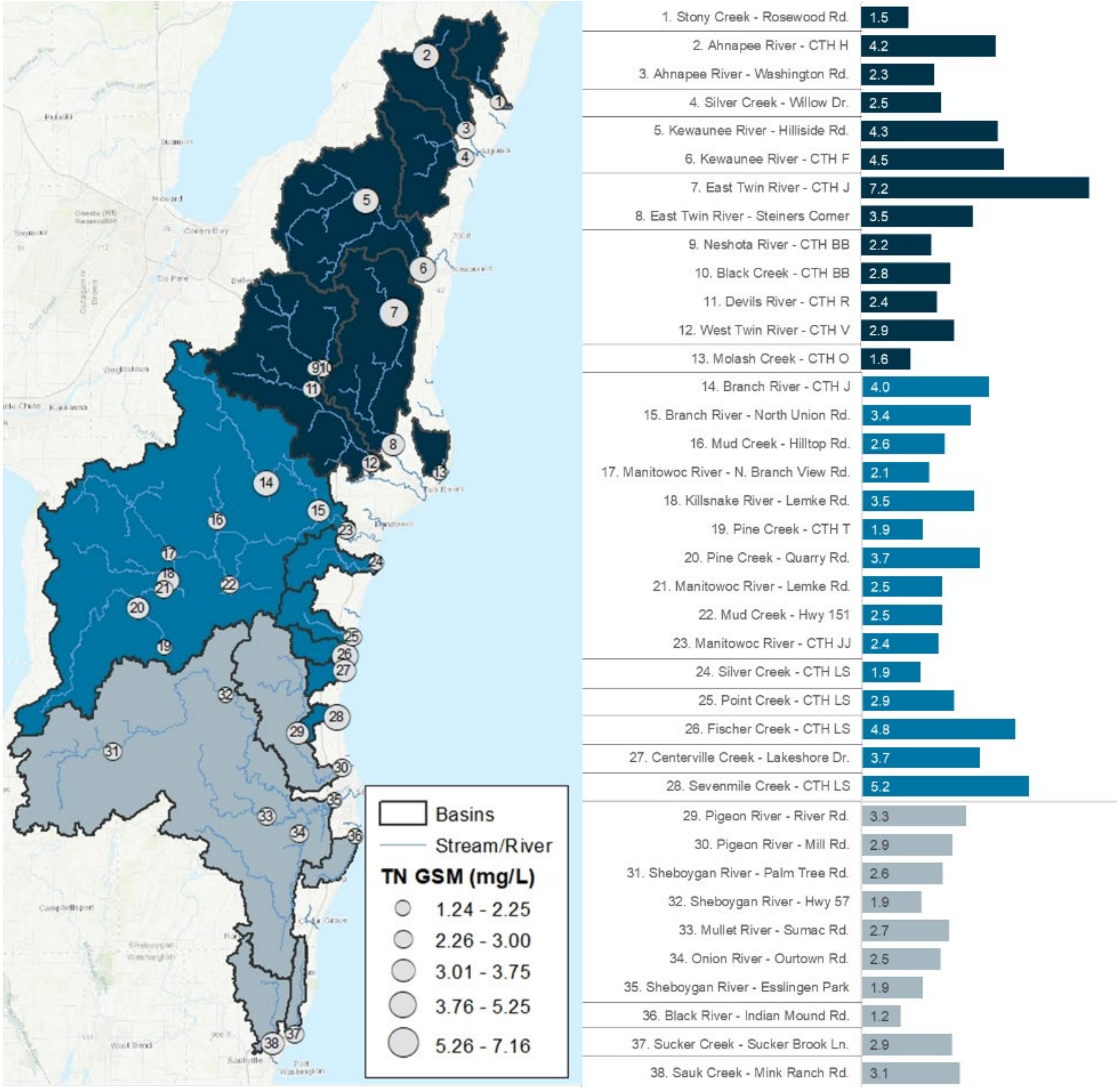


FIGURE 4.2

Measured growing season median concentration (mg/L) for NO_3

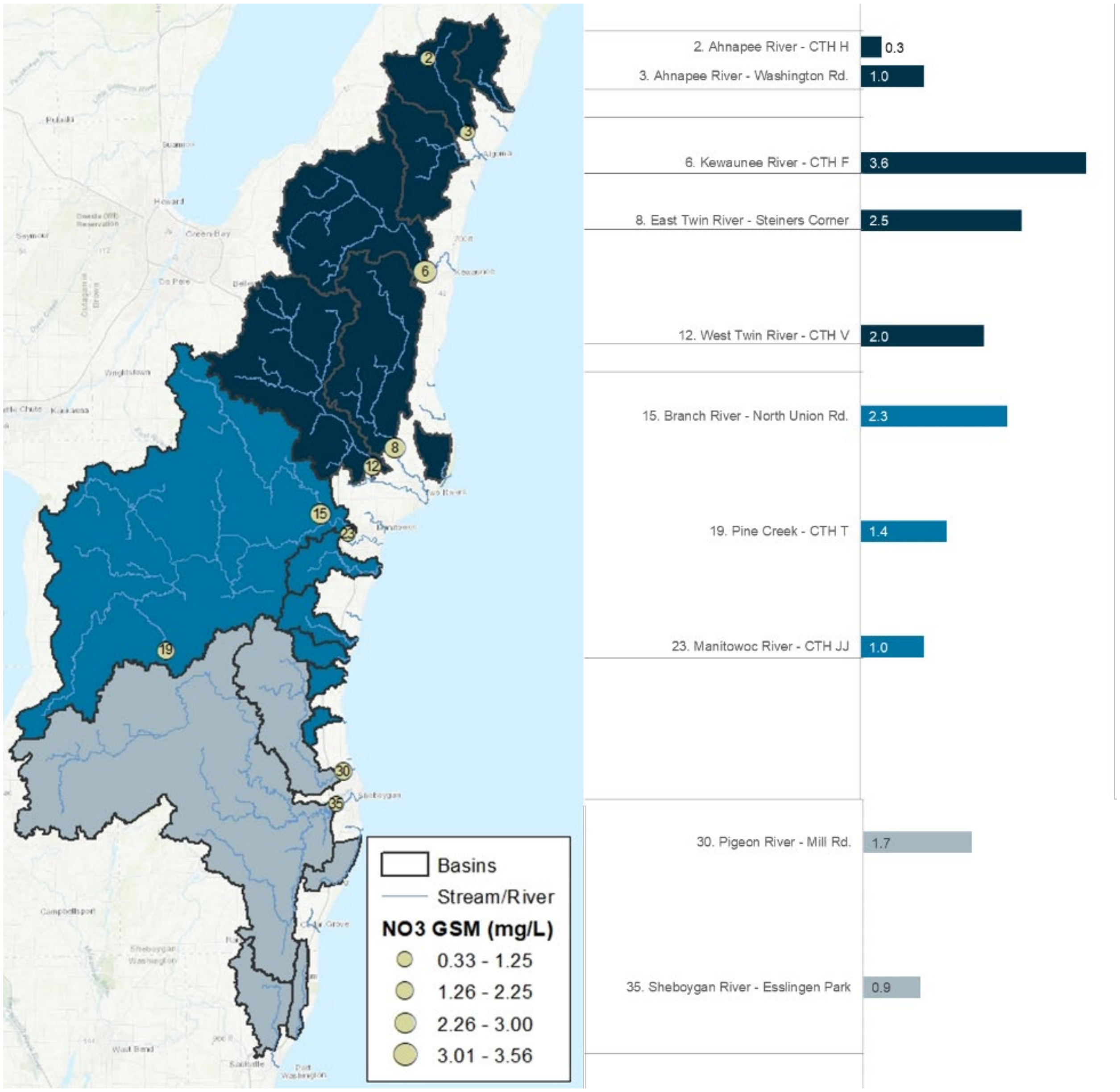


FIGURE 4.3

Measured growing season median concentration (mg/L) for TKN

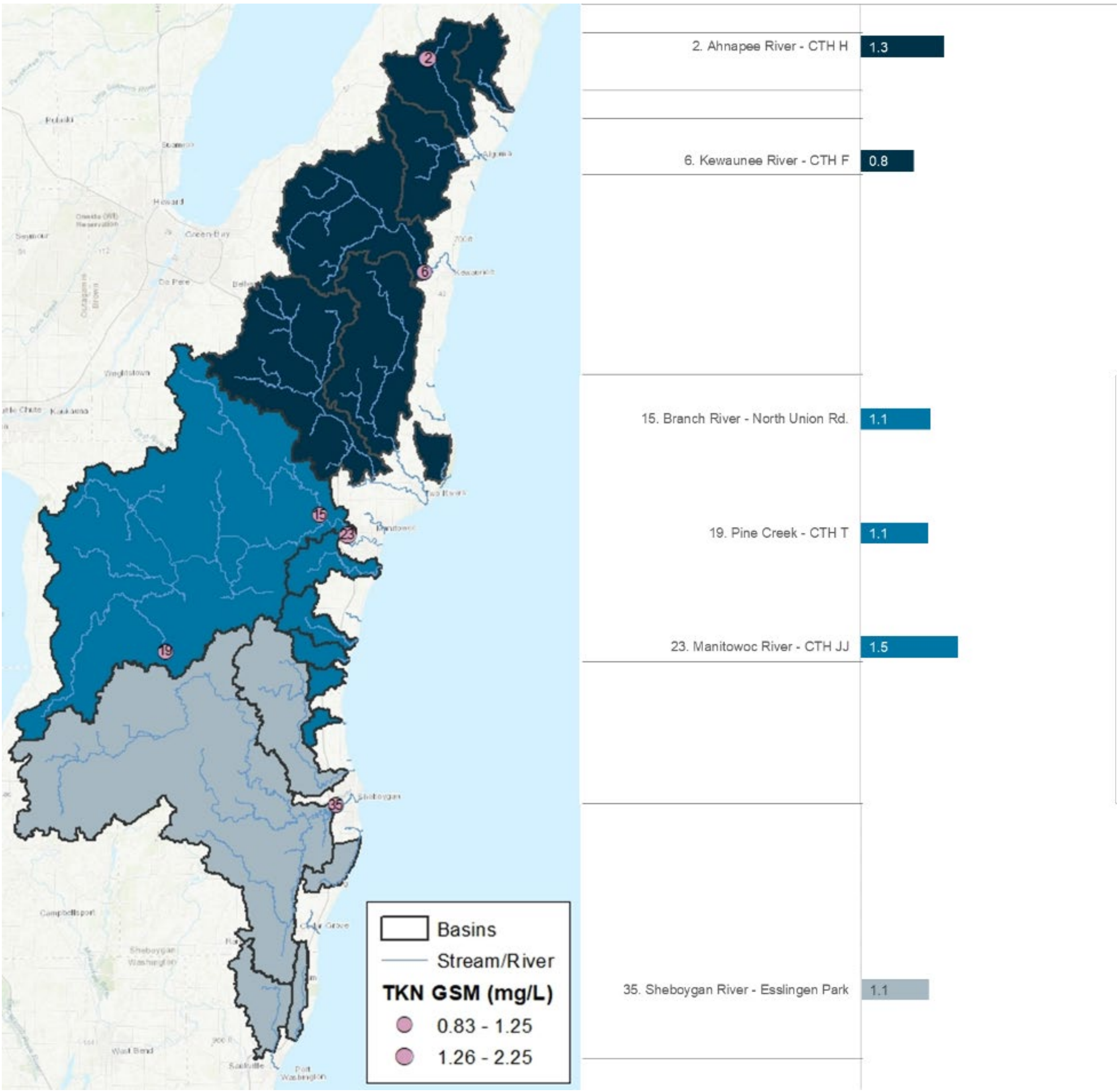
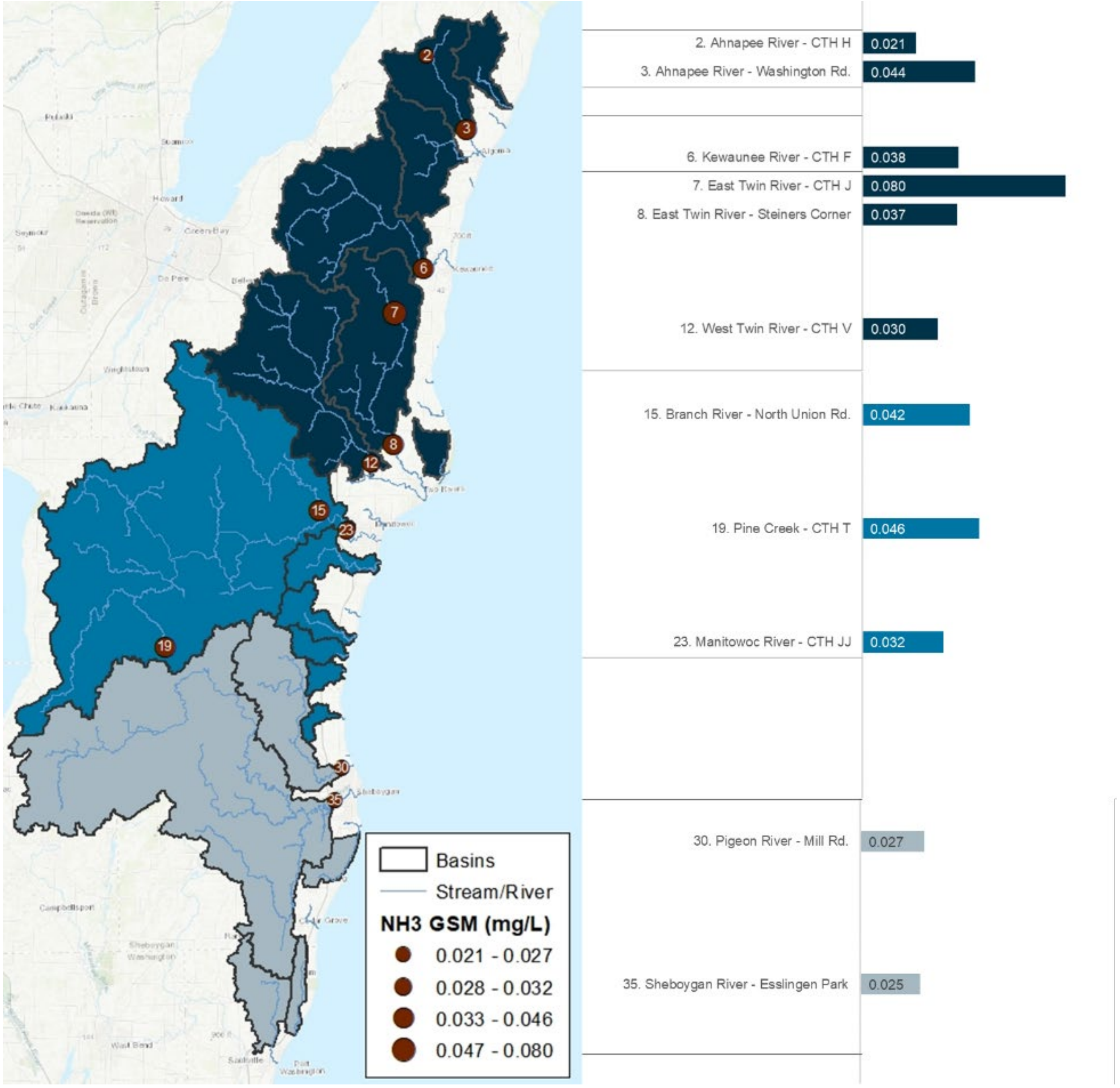


FIGURE 4.4

Measured growing season median concentration (mg/L) for NH_3



4.3. Load and Concentration – Modified LOADEST Model

The modified LOADEST model is used to estimate daily load and concentrations when water quality measurements and continuous flow data are available. All flow monitoring stations have continuous flow data for the 2018 growing season, and the load and concentrations for this growing season are estimated to compare results across monitoring sites.

4.3.1. Estimated Load

Load during the 2018 growing season is estimated for all flow monitoring stations. To compare the results of the growing season load across monitoring sites, the total estimated load is normalized by dividing by unit area of the watershed. A summary of the yield, or load per unit area, in units of kilograms per hectare (kg/ha) for the monitoring stations are provided in Table 4.3. A summary of the yield in units of pounds per acre (lb/ac) for the monitoring stations are provided in Table 4.4. A visual representation of the average load per unit area is provided in Figures 4.5 through 4.8. The figures present load as kg/ha, but the values can be converted to lb./ac by multiplying the reported values by 0.89.

Generally, smaller subbasins have higher load per unit area than the larger subbasins. For subbasins of similar size, the highest values of load per unit area occur in the Kewaunee River model area, and the lowest values of load per unit area occur in the Sheboygan River model area.

TABLE 4.3

Modeled load per unit area (kg/ha) for the 2018 growing season

	2018 Load (kg/ha)			
Station Name	**TN**	**NO3**	**TKN**	**NH3**
Ahnapee River - CTH H	2.3	1.3		0.06
Silver Creek - Willow Dr.	3.1			
Kewaunee River - Hilliside Rd.	7.6			
Kewaunee River - CTH F	5.2	4.3	1.9	0.12
East Twin River - Steiners Corner	7.5	4.9	3.8	0.11
West Twin River - CTH V	8.8	5.1	5.2	0.16
Branch River - North Union Rd.	6.0	2.7	3.6	0.09
Mud Creek - Hilltop Rd.	4.4			
Killsnake River - Lemke Rd.	5.0			
Manitowoc River - Lemke Rd.	4.8			
Manitowoc River - CTH JJ	5.7	2.8	5.0	0.17
Silver Creek - CTH LS	4.7			
Point Creek - CTH LS	5.9			
Pigeon River - River Rd.	10.2			
Sheboygan River - Hwy 57	4.0			
Mullet River - Sumac Rd.	4.0			
Onion River - Ourtown Rd.	6.7			
Sheboygan River - Esslingen Park	5.7	3.4	3.0	0.13
Sauk Creek - Mink Ranch Rd.	13.6			

TABLE 4.4

Modeled load per unit area (lb/ac) for the 2018 growing season

	2018 Yield (lb/ac)			
Station Name	**TN**	**NO3**	**TKN**	**NH3**
Ahnapee River - CTH H	2.0	1.2		0.05
Silver Creek - Willow Dr.	2.8			
Kewaunee River - Hilliside Rd.	6.8			
Kewaunee River - CTH F	4.7	3.8	1.7	0.11
East Twin River - Steiners Corner	6.7	4.4	3.4	0.10
West Twin River - CTH V	7.9	4.6	4.6	0.14
Branch River - North Union Rd.	5.4	2.4	3.2	0.08
Mud Creek - Hilltop Rd.	3.9			
Killsnake River - Lemke Rd.	4.4			
Manitowoc River - Lemke Rd.	4.3			
Manitowoc River - CTH JJ	5.1	2.5	4.4	0.15
Silver Creek - CTH LS	4.2			
Point Creek - CTH LS	5.3			
Pigeon River - River Rd.	9.1			
Sheboygan River - Hwy 57	3.5			
Mullet River - Sumac Rd.	3.6			
Onion River - Ourtown Rd.	6.0			
Sheboygan River - Esslingen Park	5.1	3.0	2.7	0.11
Sauk Creek - Mink Ranch Rd.	12.2			

FIGURE 4.5

Modeled 2018 growing season TN yield (kg/ha)

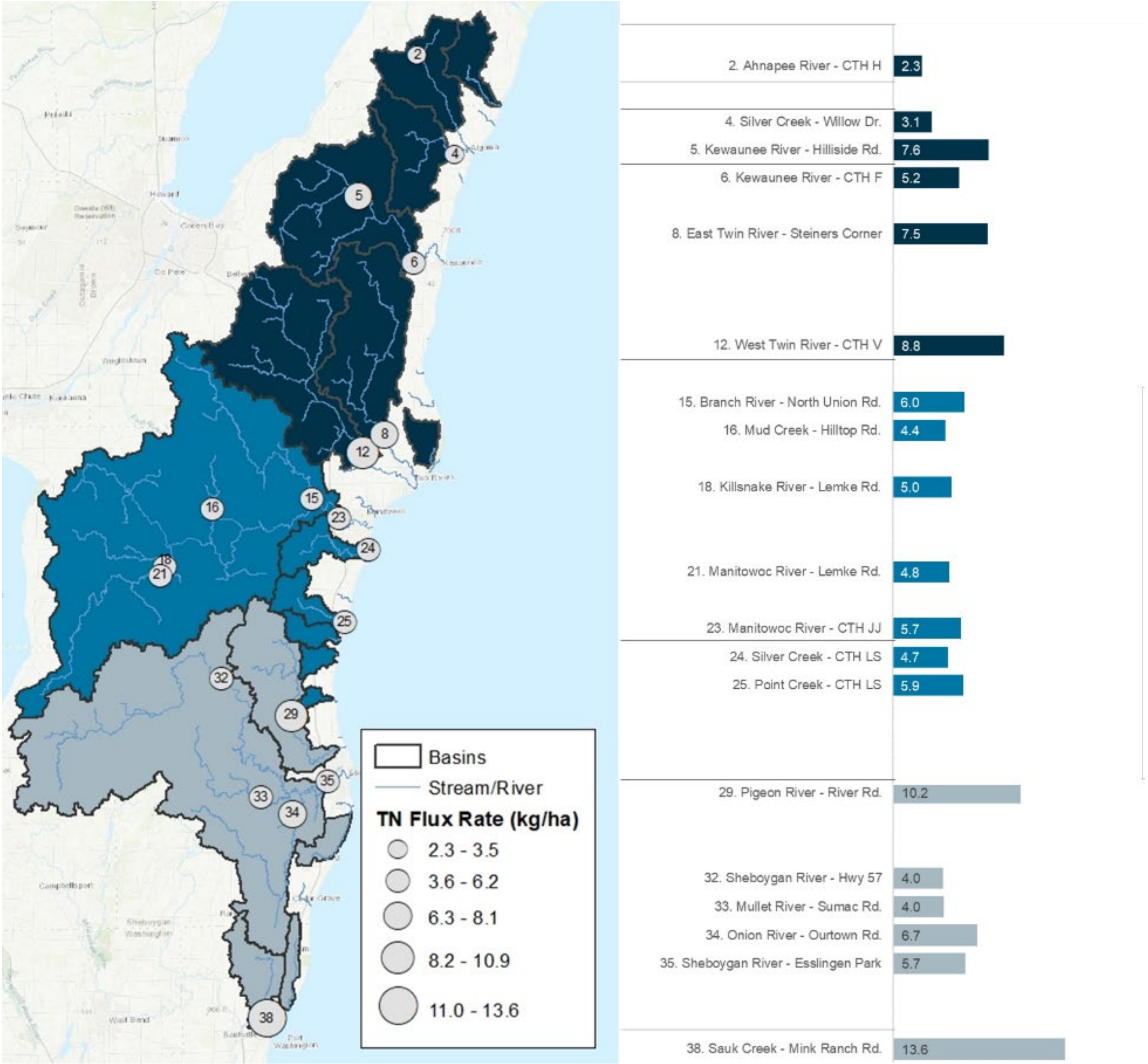


FIGURE 4.6

Modeled 2018 growing season NO_3 yield (kg/ha)

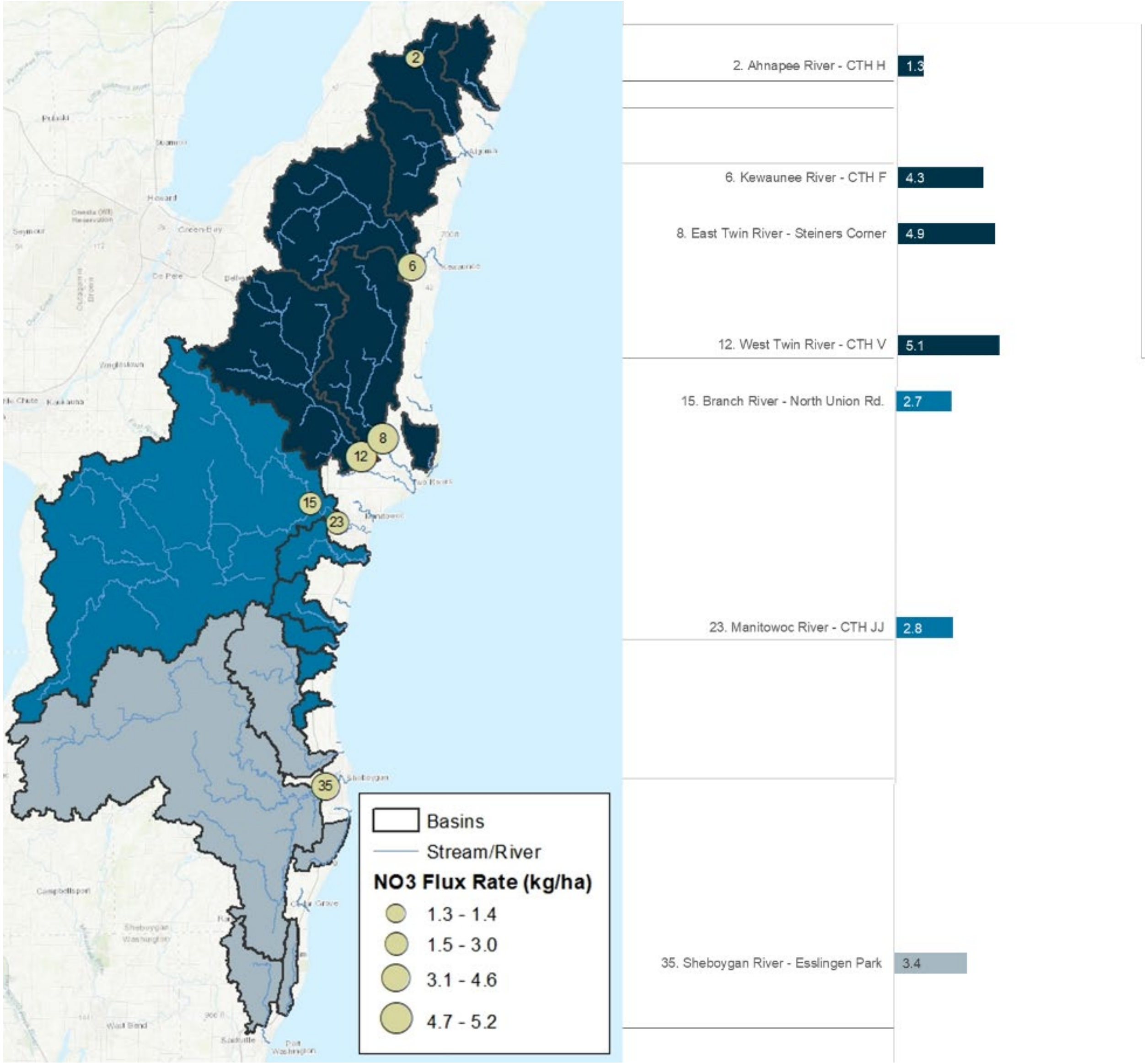


FIGURE 4.7

Modeled 2018 growing season TKN yield (kg/ha)

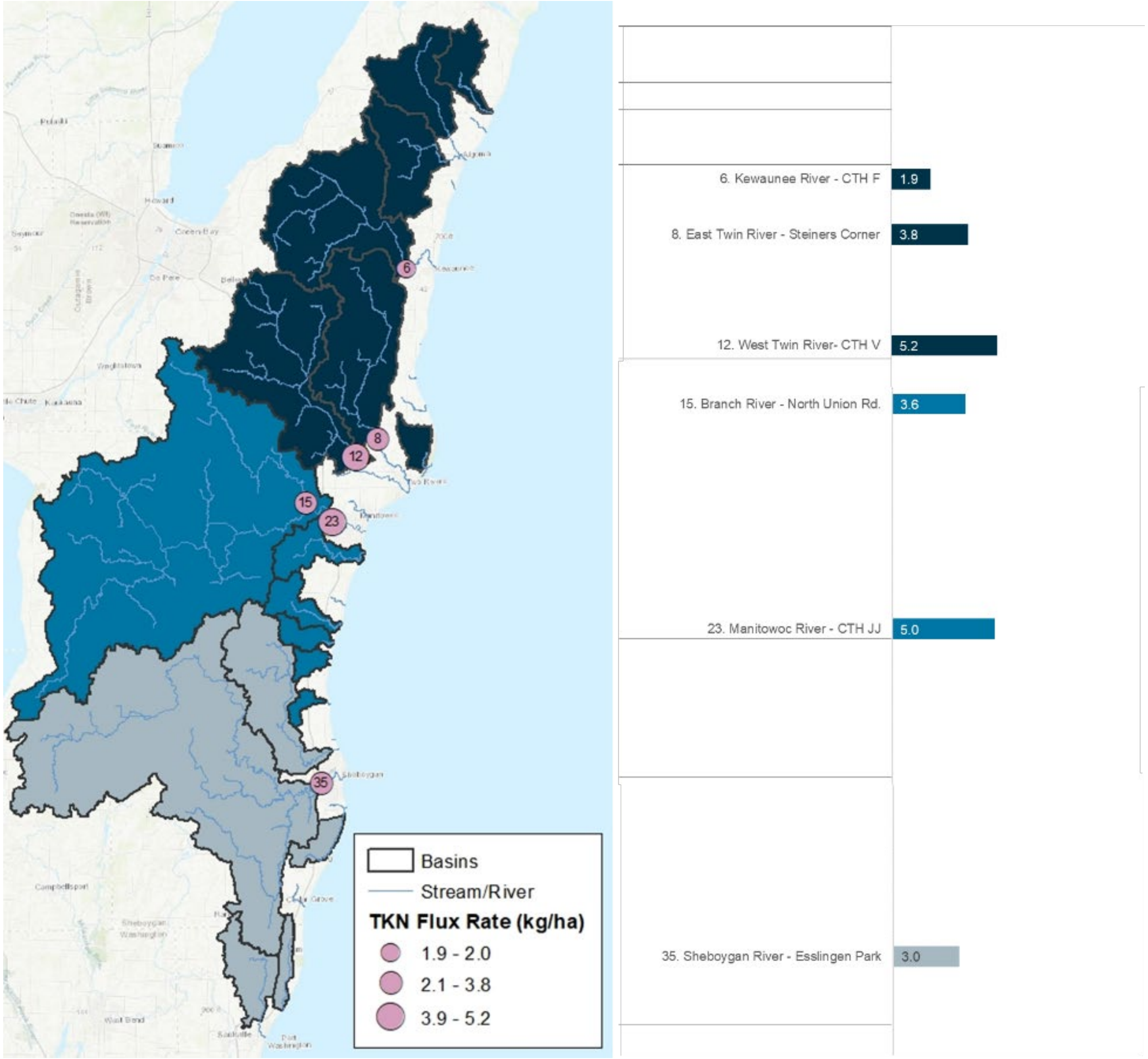
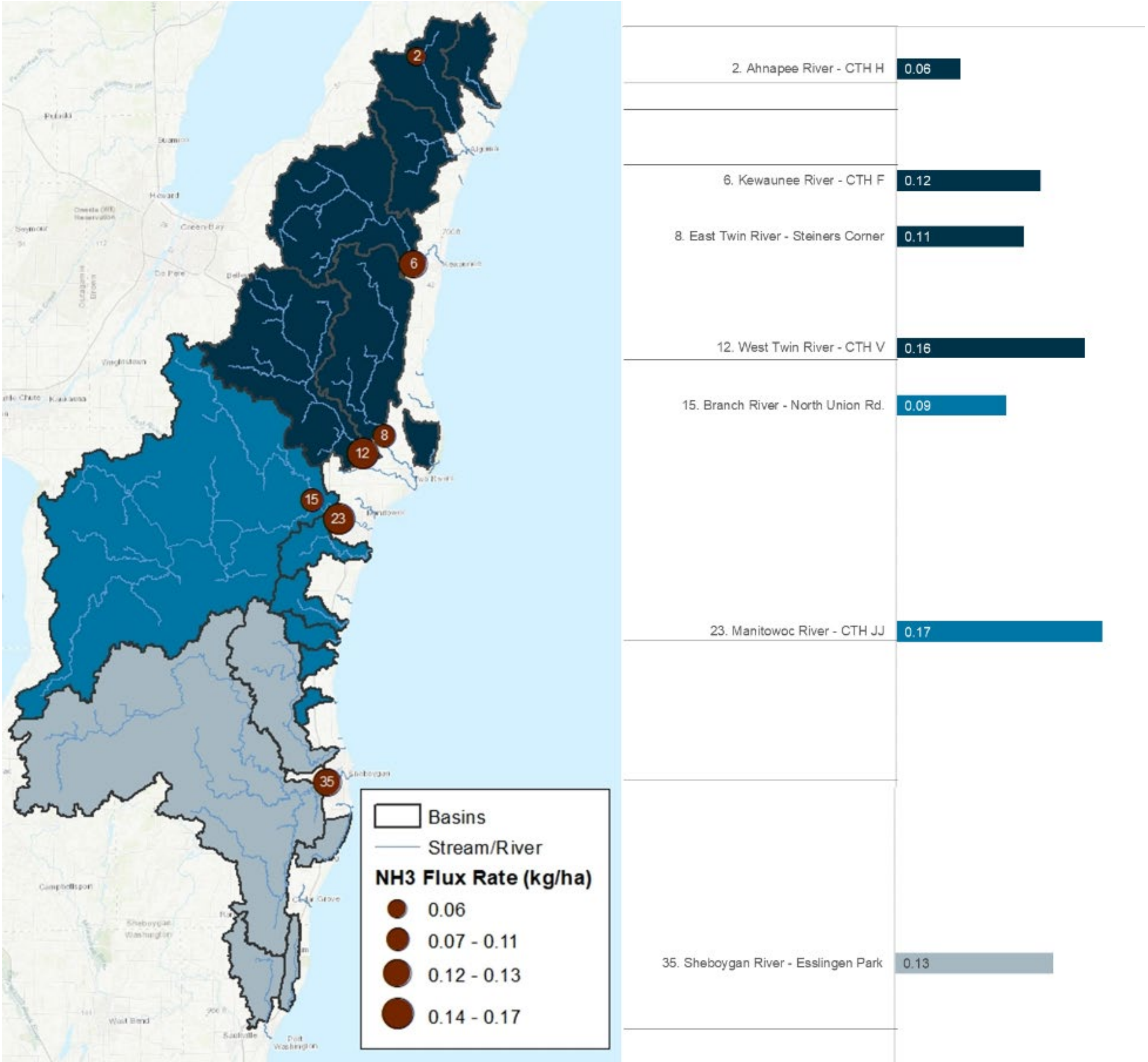


FIGURE 4.8

Modeled 2018 growing season NH_3 yield (kg/ha)



4.3.2. Modeled Growing Season Median Concentration

Average daily concentration is calculated from the modified LOADEST model. A summary of growing season median (GSM) concentration, or the median of the average daily concentrations, is provided in Table 4.5. Visual summaries of the modeled growing season median concentrations are provided in Figures 4.9 through 4.12. The values for modeled GSM concentration are different than the monitored growing season median concentration. The modeled GSM concentrations are calculated from the daily estimates derived from the modified LOADEST model for 2018, whereas the monitored GSM concentrations are calculated using directly monitored data taken at approximately two-week intervals from 2017 to 2020.

TABLE 4.5

Modeled 2018 growing season median concentration

Model Subbasin	Shorthand Name	TN GSM (mg/L)	NO3 GSM (mg/L)	TKN GSM (mg/L)	NH3 GSM (mg/L)
Kewaunee River	Ahnapee River - CTH H	2.4	1.1		0.050
	Silver Creek - Willow Dr.	3.2			
	Kewaunee River - Hilliside Rd.	4.2			
	Kewaunee River - CTH F	4.2	3.3	0.9	0.055
	East Twin River - Steiners Corner	3.9	3.1	1.0	0.038
	West Twin River - CTH V	3.0	2.2	0.9	0.036
Sheboygan River	Branch River - North Union Rd.	3.3	2.3	1.1	0.039
	Mud Creek - Hilltop Rd.	2.8			
	Killsnake River - Lemke Rd.	4.0			
	Manitowoc River - Lemke Rd.	2.9			
	Manitowoc River - CTH JJ	2.7	0.9	1.8	0.052
	Silver Creek - CTH LS	2.2			
	Point Creek - CTH LS	3.1			
Kewaunee River	Pigeon River - River Rd.	3.0			
	Sheboygan River - Hwy 57	1.9			
	Mullet River - Sumac Rd.	3.0			
	Onion River - Ourtown Rd.	2.1			
	Sheboygan River - Esslingen Park	2.1	1.1	1.2	0.045
	Sauk Creek - Mink Ranch Rd.	3.1			

FIGURE 4.9

Modeled 2018 growing season median TN concentration (mg/L)

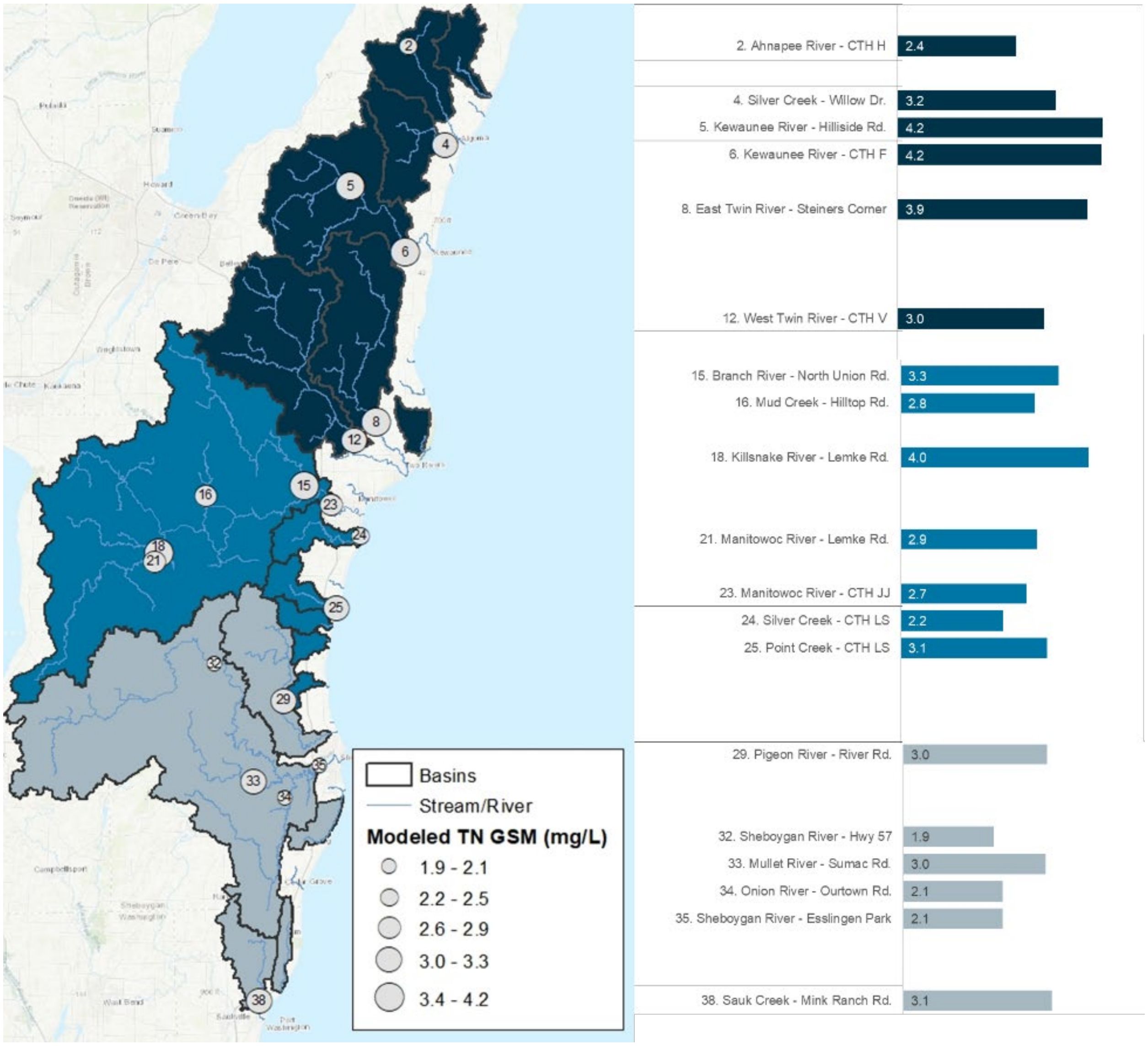


FIGURE 4.10

Modeled 2018 growing season median NO_3 concentration (mg/L)

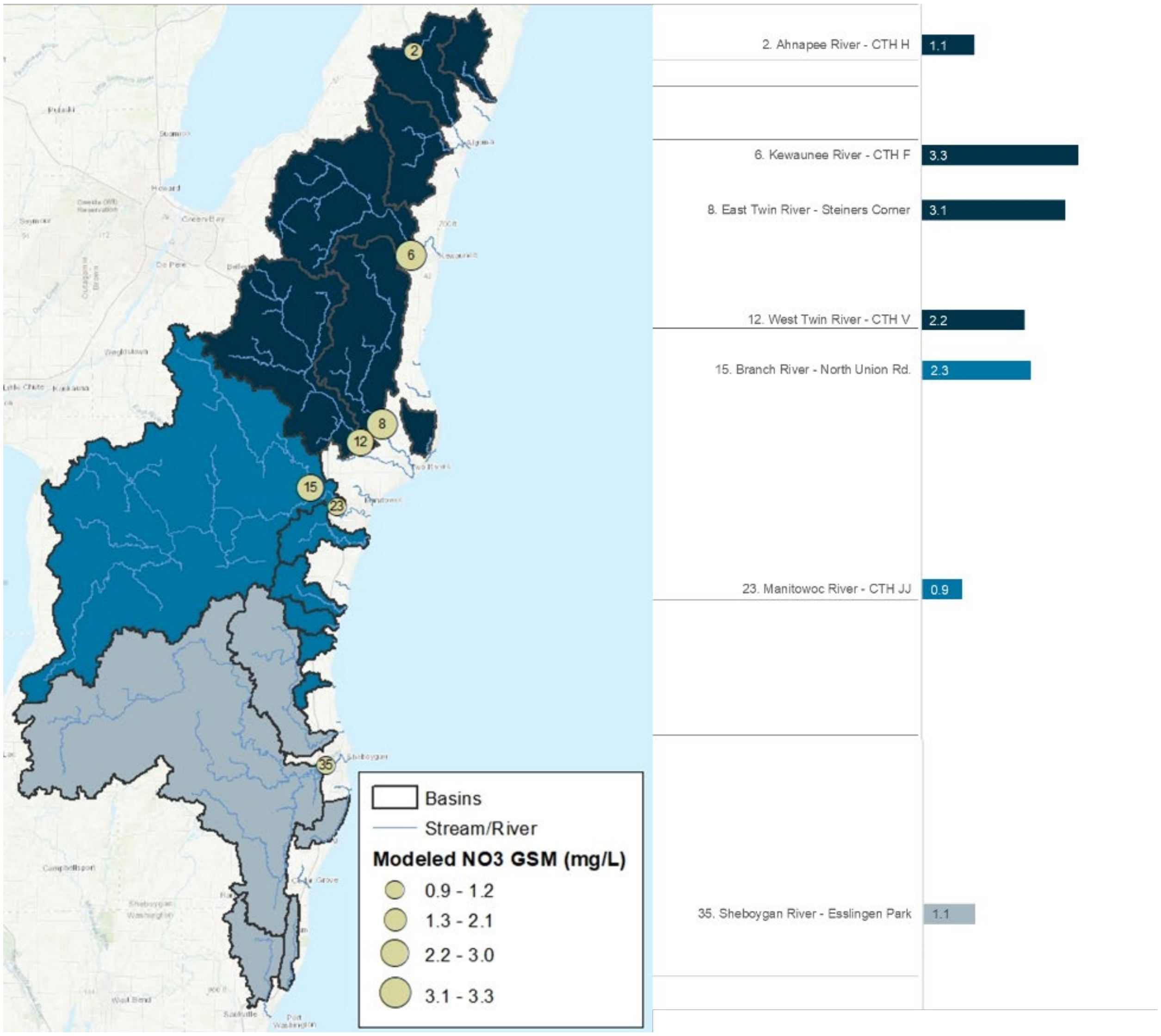


FIGURE 4.11

Modeled 2018 growing season median TKN concentration (mg/L)

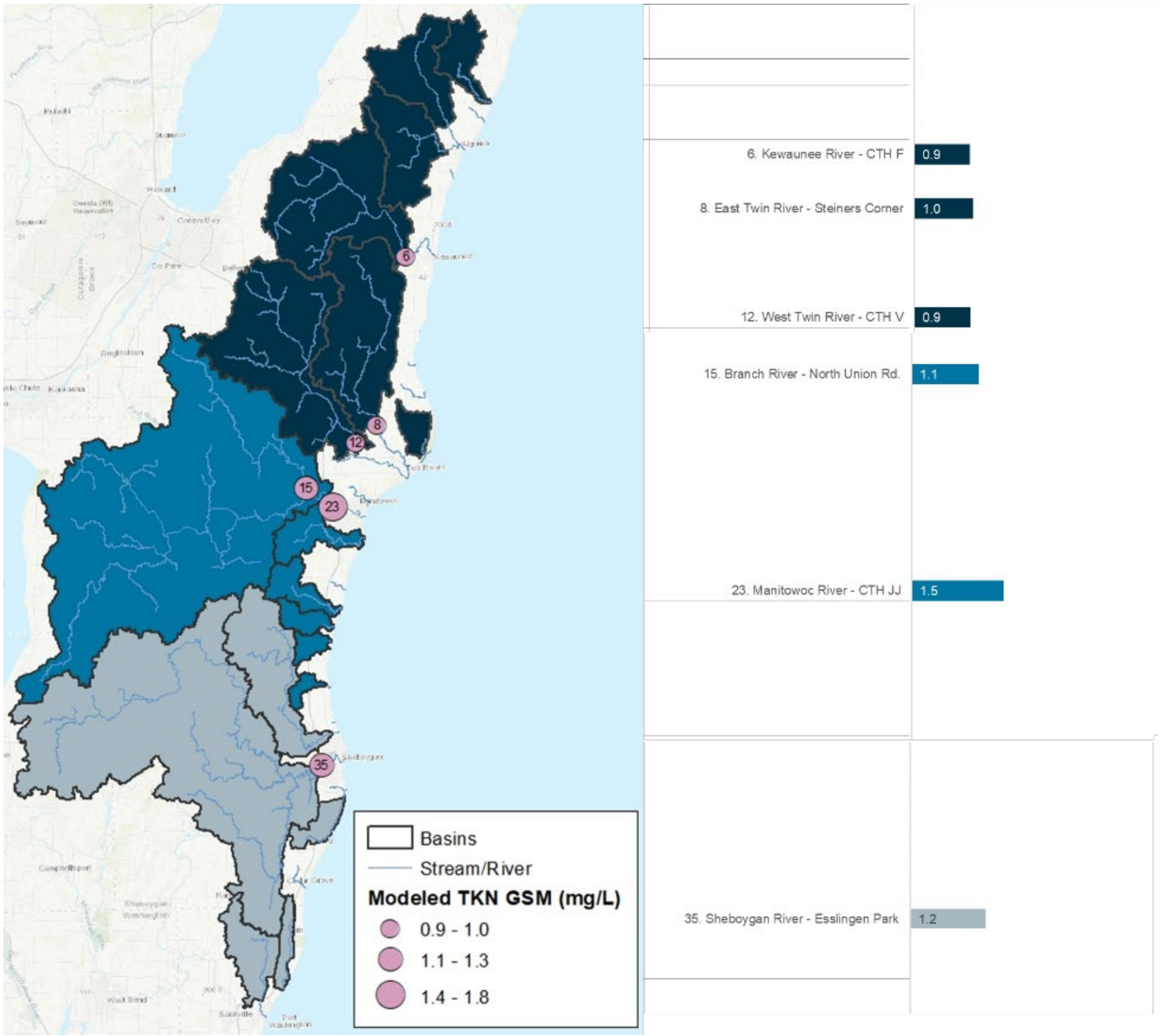
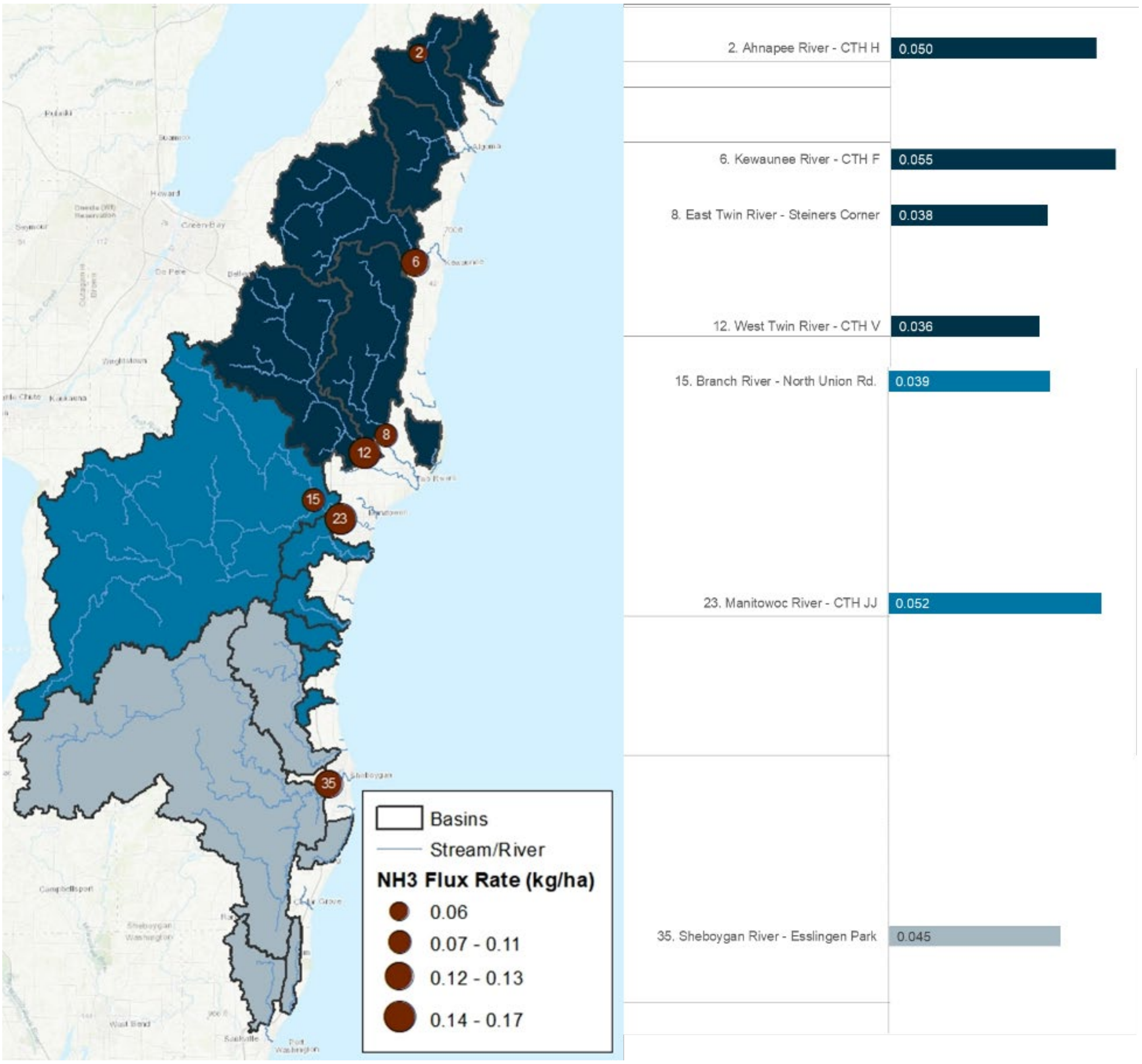


FIGURE 4.12

Modeled 2018 growing season median NH_3 concentration (mg/L)



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Wisconsin Department of Natural Resources, in development, Total maximum daily loads for total phosphorus and total suspended solids in the Northeast Lakeshore Basin: Madison, WI.

APPENDIX D

NITROGEN MASS BALANCE FOR THE NORTHEAST LAKESHORE STUDY AREA

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1. BACKGROUND

A mass balance for nitrogen provides insights into the sources of nitrogen entering surface waters. When combined with water quality data, the mass balance estimates can allow stakeholders to better target nitrogen reduction efforts. A nitrogen mass balance is performed for basins within the Northeast Lakeshore study area that have water quality monitoring data. Most of the mass balance evaluation focuses on nitrogen inputs and outputs from agricultural areas within the basin, but a brief discussion about nitrogen from all sources is also provided.

2. AGRICULTURAL NITROGEN INPUTS

When performing a mass balance of nitrogen in agricultural watersheds, the characterization of nitrogen sources from different processes is important. For this mass balance analysis, four sources of nitrogen inputs are considered. The sources include manure application, commercial fertilizer application, nitrogen fixation, and atmospheric deposition. Nitrogen extracted from the soil, known as soil mineralization, is not considered. Soil mineralization is a complex process that is difficult to estimate, so nitrogen extracted from soil mineralization is assumed to be equal to the nitrogen immobilized in the soil.

2.1. Methodology for Characterizing Agricultural Nitrogen Sources

Characterizing nitrogen sources requires data related to land use, manure spreading amounts, commercial fertilizer purchases, and atmospheric nitrogen deposition. The following sections provide a summary of the methodologies used to estimate the nitrogen sources within the monitoring basins of the Northeast Lakeshore study area.

2.1.1. Manure Spreading

The amount of manure applied to the landscape for areas within the Northeast Lakeshore study area was estimated during the development of the Northeast Lakeshore TMDL model. The full methodology for estimating manure applications is described in Northeast Lakeshore TMDL Report (WDNR, 2022), but a summary of the methodology is provided below.

The number of cattle housed in concentrated animal feeding operations (CAFOs) during 2017 was estimated from the nutrient management plans submitted by CAFO operators in the study area. Cattle in CAFOs were categorized into six distinct groups: cattle, small heifers, large heifers, dry and milking cows, steers, and bulls. The total number of cattle in a county was calculated from the National Agricultural Statistics Service cattle census (NASS, 2008-2019). The number of cattle not housed in CAFOs was estimated by subtracting the

CAFO cattle in each county from the number of cattle estimated by the county-level census data.

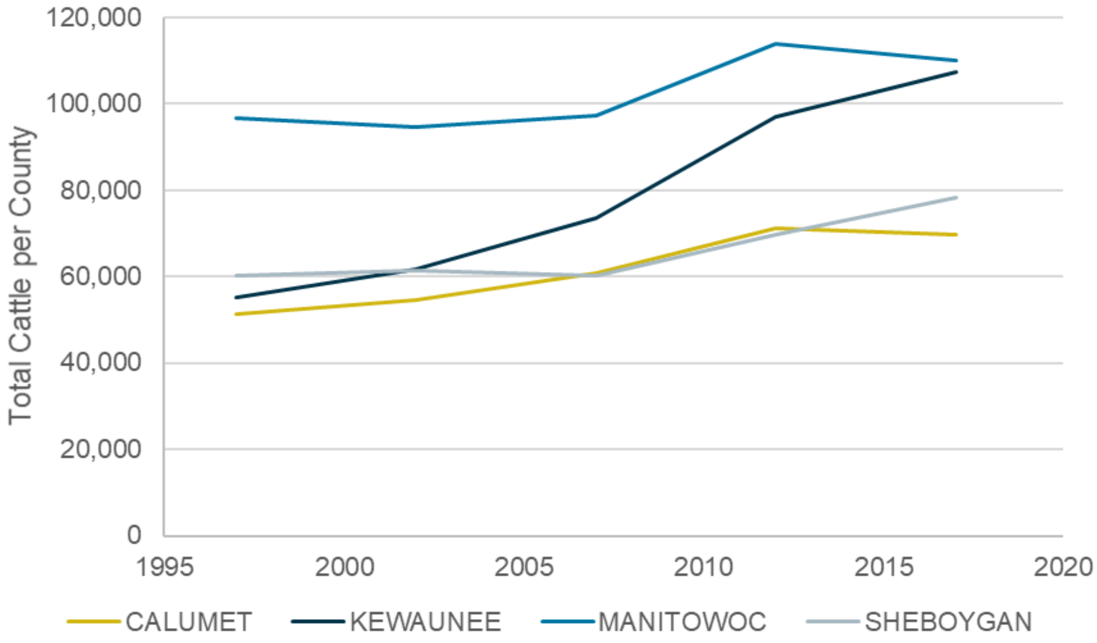
Once the number of cattle from CAFO and non-CAFO operations was determined, manure production was estimated by cattle type. The manure analysis performed by WDNR for the NE Lakeshore TMDL assumed spreadable manure fit into the “Dairy: slurry” category (4.1 – 11% dry matter), which is described in Laboski and Peters (2012). Throughout this report, the manure is referred to as “liquid manure.” The liquid manure production was reported in units of 1,000 gallons per acre per year. The liquid manure was assumed to be applied evenly across the dairy rotations reported in the Wiscland 2.0 land cover database (WDNR, 2016). The Wiscland 2.0 dataset was used in the analysis because it characterizes dairy rotations. The manure analysis provided an estimate of total volume of liquid manure spread in each of the subbasins described in the study area. The estimate is applicable for 2017.

Once the liquid manure applied during 2017 was estimated, the average annual manure applied during different years was calculated. The annual number of cattle per subbasin was estimated at the county level from 2009 to 2018 using the results of the NASS cattle survey (NASS, 2017). The change in cattle over time for the four main counties within the Northeast Lakeshore study area is provided in Figure 2.1. In Kewaunee County, Manitowoc County, and Sheboygan County, the number of cattle increased steadily since 2009. In Calumet County, the total number of cattle increased steadily from the late-1990s through approximately 2012, but the total number of cattle in the basin decreased between 2013 and 2018.

FIGURE 2.1

Change in cattle over time

Counties in the NE Lakeshore study area



The NASS cattle survey reports data on a county level, and the county-level data were translated into the number of cattle per subbasin over time using area-weighted averaging. The total manure applied during each year was calculated using the ratio of cattle each year and the number of cattle in 2017. For example, if a subbasin has 100 cattle in 2017 and 90 cattle in 2009, the total manure applied in 2009 was calculated by multiplying the total manure applied in 2017 by 0.90.

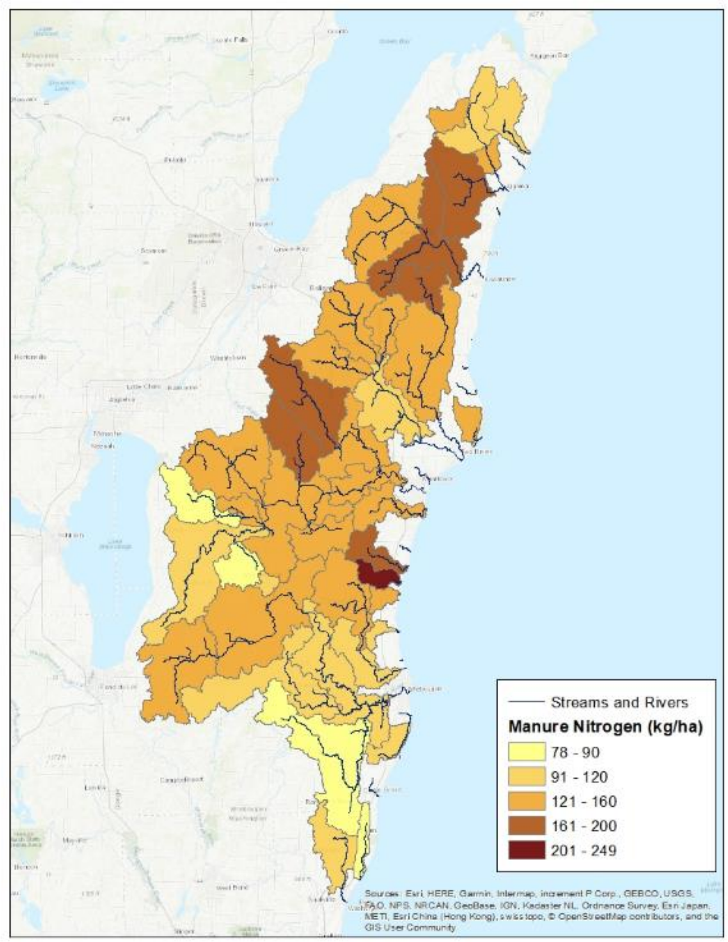
Once the total manure applied per subbasin per year was estimated, the results can be translated to the total nitrogen applied per subbasin. Total nitrogen is calculated by multiplying the volume of liquid manure by the average nitrogen content of manure. The average nitrogen content of manure is estimated using published values (Laboski and Peters, 2012, p. 75). A value of 24 pounds of total nitrogen per 1000 gallons is used in estimating the total nitrogen applied. The nitrogen content corresponds to the published value for Dairy: slurry (4.1 – 11.0% DM). Dairy slurry is used for the estimate because the methodology for estimating manure applies only to the manure generated directly from cattle – it does not include any dilution of the manure. The analysis assumes the entire 24 pounds of total nitrogen per 1000 gallons is spread on the field because the estimate provided by Laboski and Peters (2012) assumes manure is being sampled at the point of application, so it accounts for losses in storage and handling.

The spatial estimate of manure-derived nitrogen applied per agricultural acre is provided in Figure 2.2. Values in the figure can be converted to pounds per acre (lb/ac) by dividing the values in kg/ha by 1.12. The rates presented in the figure represent the total manure application in a subbasin divided by all agricultural acres in the subbasin. In practice the subbasin manure is only applied to specified fields rather than being uniformly applied to all agricultural acres. As a result, the actual rate of manure applied to specific fields in reality is higher than the overall average rate presented. Nonetheless, the results provide an overview of where the most manure-derived nitrogen is being applied among individual subbasins. Generally, the total application rate of manure-derived nitrogen increases from south to north. The highest manure application rates are within Kewaunee County, which is consistent with the high density of cattle within the county. Annual manure-derived nitrogen application ranges from approximately 80 kilograms per hectare (71 pounds per acre) in the southern basins to approximately 200 kilograms per hectare (178 pounds per acre) in the northern basins.

FIGURE 2.2

Average rate (kg/ha) of manure-derived nitrogen applied to agricultural areas

Summarized by study area subbasin



Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

The total nitrogen from manure represents the total nitrogen applied to the landscape and not the portion that is available for crops. When crop nutrient requirements are calculated, only a percentage of the nitrogen applied is available for crop uptake. The percentage available for crop uptake assumes some manure is lost to volatilization and leaching. Additionally, a portion of the nitrogen in applied manure is in an organic form that is not immediately available for crop uptake. Although the crop-available nitrogen in manure is important for determining nutrient balances for crops, it does not apply to the overall mass balance because the analysis is assessing the total amount of nitrogen that is applied to the landscape. Additionally, nitrogen lost to manure volatilization is estimated as a nitrogen output, which is described in Section 4.

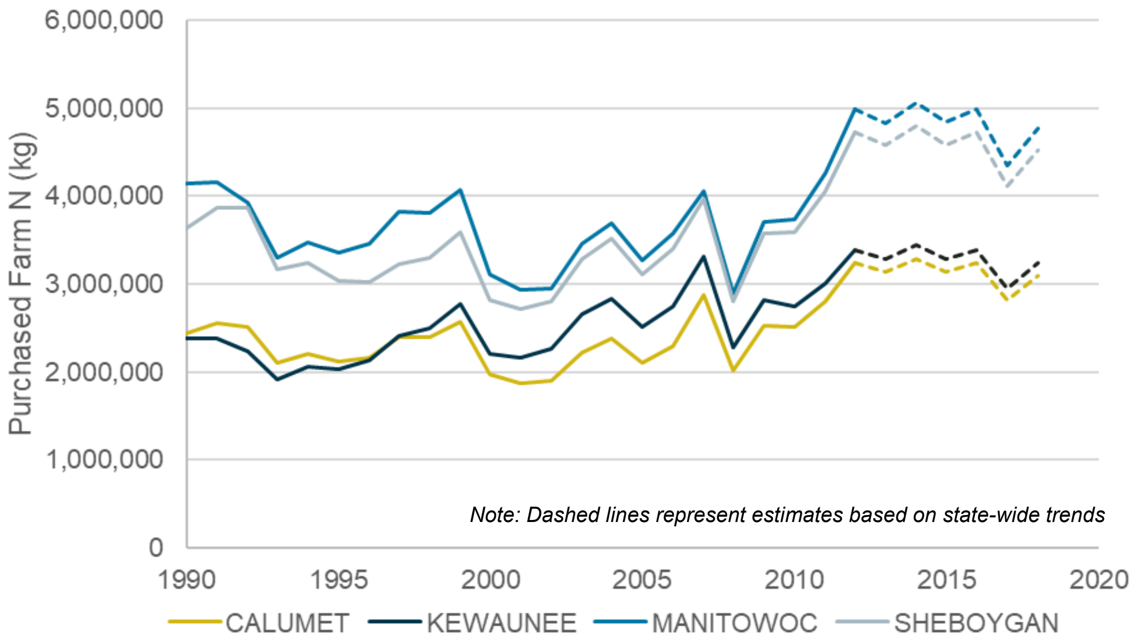
2.1.2. Commercial Fertilizer

Manure in the Northeast Lakeshore study area is readily available for spreading on crops, but the nitrogen in manure does not always meet the entire nitrogen needs for crops. Nitrogen applied through manure may be supplemented using commercial fertilizer. Additionally, some fields do not receive any manure, so commercial fertilizer is the only source of nitrogen applied.

Spatially specific data about the total inorganic fertilizer applied to the landscape is limited. The total nitrogen purchases per year in Wisconsin are only reported on a state-wide basis. However, county-level estimates for 1987 through 2012 are provided by Brakebill and Gronberg (2017). County-level data are not available for 2013 through 2018, but annual data are available for statewide commercial fertilizer sales (Wisconsin DATCP, 2021). To estimate the county-level commercial fertilizer applications for the years without county-level data (2013 to 2018), changes in fertilizer sales for the counties in the Northeast Lakeshore study area are assumed to follow the same trends as the statewide trends in fertilizer purchases. The average rate of change in state-wide fertilizer sales since 2012 is applied to the counties within the study area. The total fertilizer sales estimates for four main counties within the study area are presented in Figure 2.3. Fertilizer sales increased from 2008 through 2012, but the sales have stabilized since approximately 2012.

FIGURE 2.3

Total nitrogen fertilizer purchases by county over time



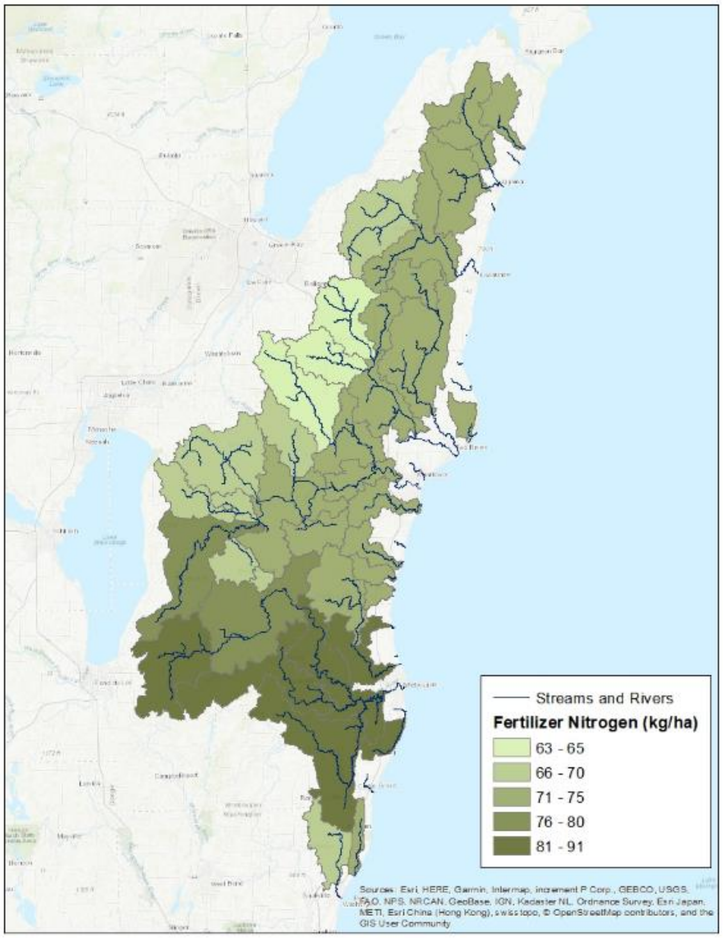
To translate the county-level data to data for each subbasin, the average commercial fertilizer rates for agricultural areas within a county is calculated by dividing the total commercial fertilizer sales by the total agricultural area within a county. The agricultural areas are estimated using the Cropland Data Layer for individual years between 2008 and 2019 (NASS, 2008-2019). The cropland data are also used to classify county-plus-agricultural-area combinations for each subbasin. The county-level average fertilizer application rates are then multiplied by the county-plus-agricultural-area combination in each subbasin to estimate the total fertilizer applied in each subbasin.

The spatial estimate of commercial nitrogen fertilizer applied per agricultural acre is provided in Figure 2.4. The rates presented in the figure only represent the subbasin-wide average applications, which assumes every acre of agricultural land receives commercial fertilizer. The commercial fertilizer is likely preferentially spread to different crops, so the actual rate of commercial fertilizer applied to specific fields in practice may be higher than the overall average rate presented. Nonetheless, the results provide an overview of the subbasins where commercial fertilizer applications are the highest. Commercial fertilizer sales are the highest in the southern basins and is lowest in the northern basins. The trends for commercial fertilizers are opposite of the trends observed with manure applications. The diverging trends are expected since the total nitrogen requirements in the basins are similar, but areas with less manure-derived nitrogen will require more commercial fertilizer to meet the nitrogen requirements of the crops. Estimated annual nitrogen fertilizer application ranges from approximately 65 kilograms per hectare (58 pounds per acre) in the northwestern basins to approximately 90 kilograms per hectare (80 pounds per acre) in the southern basins.

FIGURE 2.4

Average rate (kg/ha) of commercial fertilizer applied to agricultural areas

Summarized by study area subbasin



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The analysis for commercial nitrogen fertilizer applied to agricultural areas has limitations. First, the values for commercial nitrogen fertilizers are reported as fertilizer sales. The analysis assumes every kilogram of nitrogen fertilizer sold is applied to agricultural lands in the year it is purchased. Second, county-level data on fertilizer sales after 2012 are not currently available. The analysis assumes the changes in fertilizer sales in the counties within the study area are the same as state-wide changes.

2.1.3. Nitrogen Fixation

External sources of nitrogen, such as manure and commercial fertilizer, are important for the growth of crops. However, some crops, especially those in the legume family, can utilize nitrogen that is converted into a usable form by bacteria in the soil. These bacteria have a symbiotic relationship with the leguminous crops and convert atmospheric nitrogen to nitrogen that can be utilized by the crop.

Nitrogen fixation for each subbasin is estimated using the crops delineated from the Cropland Data Layer (CDL). Within the study area the four primary agricultural crops defined in the CDL are corn, soybeans, winter wheat, and alfalfa. Total area of each crop type between 2009 and 2018 is calculated for each subbasin, and literature-derived nitrogen fixation rates are applied to each crop type. Table 2.1 outlines the estimated symbiotic fixation rates for soybeans and alfalfa that are used in the analysis. The rates are based on estimates provided by the Minnesota Pollution Control Agency (MPCA, 2013).

TABLE 2.1

Estimated symbiotic nitrogen fixation rates for selected crops

Data Source: MPCA, 2013, p. D4-5

Crop	Symbiotic fixation rates	
Soybean	56 kg N/ha/yr	50 lb N/ac/yr
Alfalfa	22.9 kg N/ton/yr	50.4 lb N/ton/yr

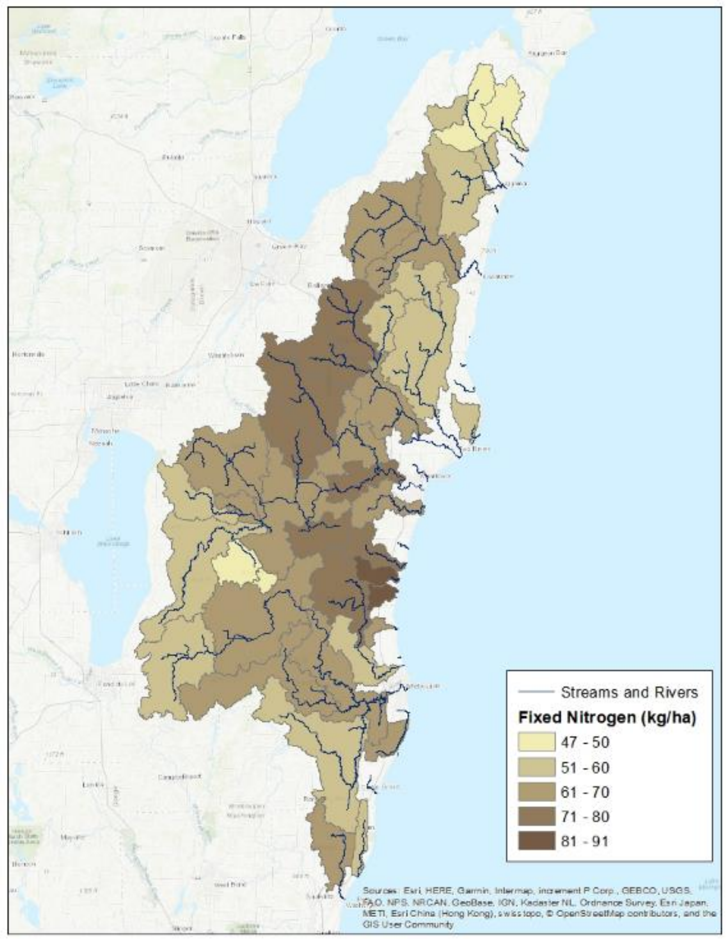
The symbiotic fixation rate for soybeans is estimated as mass per acre of soybeans. Total symbiotic fixation of nitrogen for each year between 2009 and 2018 is calculated by multiplying the fixation rate by the total area of soybeans within each subbasin. The symbiotic fixation rate for alfalfa is estimated as mass per harvested tons. The estimate of total symbiotic fixation of nitrogen from alfalfa requires both the total area of alfalfa in a basin and the average alfalfa yield per subbasin. Average alfalfa yield is calculated using data from NASS for counties within the study area. The county-average yield is translated to the average yield per subbasin by using the same methods described for commercial fertilizer. The total symbiotic nitrogen fixation from alfalfa is calculated by multiplying the total alfalfa area by the average alfalfa yield and the alfalfa fixation rate in Table 2.1. The average alfalfa yield for the years evaluated is 2.8 tons per acre (7.0 tons per hectare), which translates to a fixation rate of approximately 142 pounds per acre (159 kilograms per hectare).

Nitrogen fixation also occurs with soil bacteria that live freely and do not have a direct symbiotic relationship with crops. The non-symbiotic nitrogen fixation rate for all crops is estimated to be 2.2 kilograms per hectare per year (MPCA, 2013, p. D4-5). For the mass balance, the rate is applied to all agricultural areas within a basin. Figure 2.5 presents the average nitrogen fixation, both symbiotic and non-symbiotic, per agricultural area for the study area. Nitrogen fixation rates are higher in the southern basins when compared with the northern basins. The difference is likely driven by the proportion of soybeans and alfalfa grown in the respective areas. Annual nitrogen fixation in the study area range from approximately 50 kilograms per hectare in the northern basins to 90 kilograms per hectare in the southern basins.

FIGURE 2.5

Average rate (kg/ha) of nitrogen fixation in agricultural areas

Summarized by study area subbasin



Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

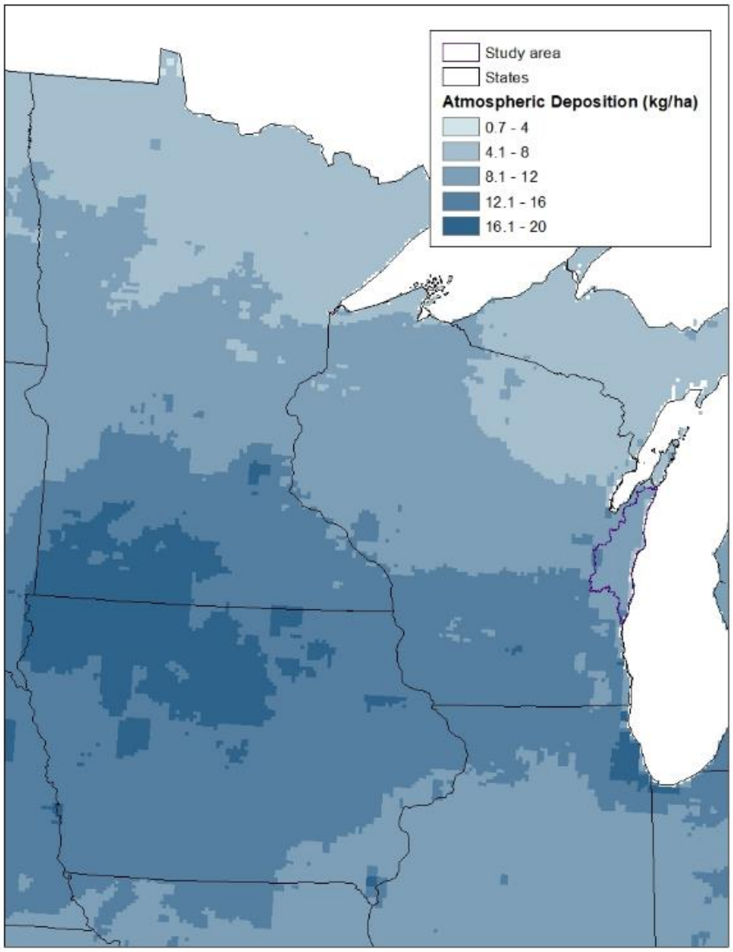
2.1.4. Atmospheric Deposition

Another source of nitrogen to agricultural lands is atmospheric deposition. Nitrogen in the atmosphere can be deposited to the landscape through wet deposition, which occurs when precipitation occurs, and dry deposition, which occurs as the nitrogen compounds settle out of the atmospher. Sources of atmospheric nitrogen compounds include lightning, vehicle emissions, industrial emissions, plant decay, and others. The concentration of atmospheric nitrogen compounds and the total deposition to the landscape varies spatially based on potential sources and annual precipitation. Urbanized areas and agricultural areas generally have the highest atmospheric concentration of nitrogen compounds.

The National Atmospheric Deposition Program (NADP) characterizes both wet and dry atmospheric deposition of nitrogen compounds. NADP provides annual estimates of atmospheric deposition on a 4 km x 4 km scale (NADP, 2021). An example of NADP's gridded data for 2018 is provided in Figure 2.6. The highest values for atmospheric deposition are found in northern Iowa and southwestern Minnesota. These areas have a very high density of corn, and the release of nitrogen compounds into the atmosphere from corn-based agriculture can be high. Atmospheric deposition is also high in the urbanized areas, such as Minneapolis, Milwaukee, and Chicago. The primary source of atmospheric nitrogen compounds in these areas is likely from vehicle emissions and industrial emissions.

FIGURE 2.6

Estimated total nitrogen deposition rates for 2018

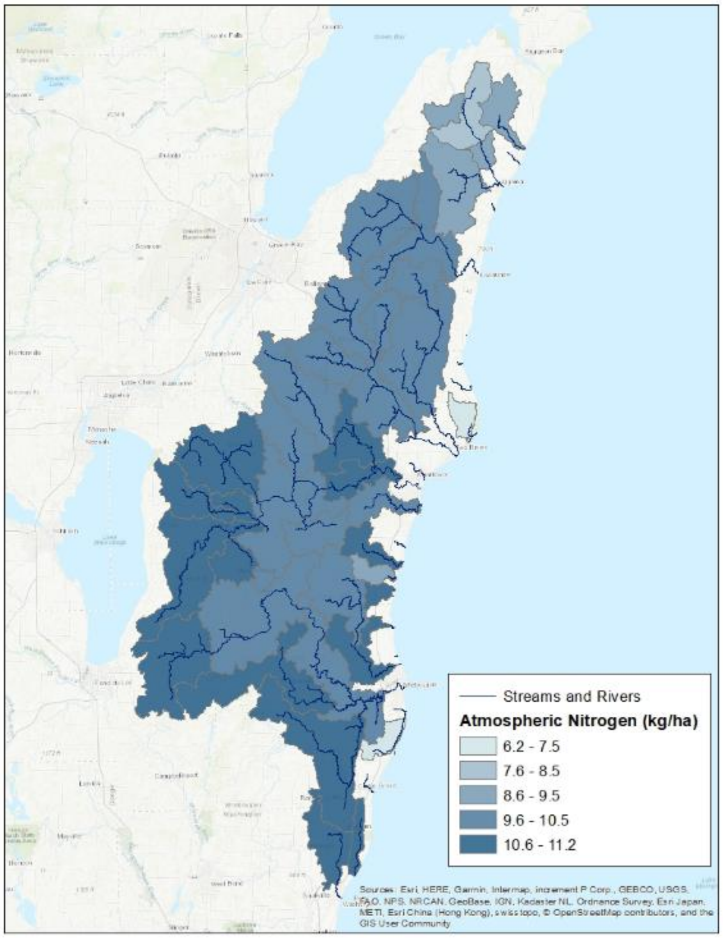


To estimate the nitrogen inputs to agricultural areas, the average atmospheric deposition rate is multiplied by the total agricultural area in each subbasin. Figure 2.7 provides a summary of average atmospheric deposition rates for the agricultural areas in the study area. Annual atmospheric nitrogen deposition in the study area ranges from approximately 7 kilograms per hectare in the north to approximately 11 kilograms for hectare in the south.

FIGURE 2.7

Average rate (kg/ha) of atmospheric deposition on agricultural areas

Summarized by study area subbasin



Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

2.2. Results of Analysis to Quantify Total Nitrogen Inputs

The four primary inputs of nitrogen to agricultural areas are manure application, commercial fertilizer application, nitrogen fixation, and atmospheric deposition. The methods to calculate the different inputs are provided in the previous section, and the results are provided in the following sections.

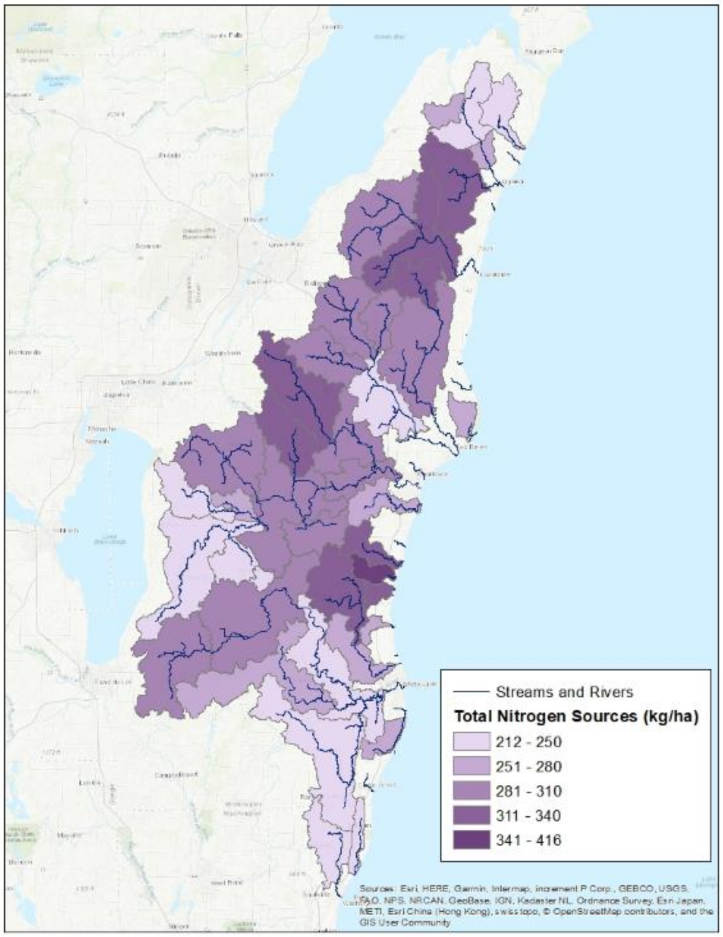
2.2.1. Nitrogen Inputs for Study Area Subbasins

The results from the nitrogen input assessment are used to provide an estimated summary of total nitrogen inputs on agricultural lands for subbasins within the study area. Total average nitrogen inputs are summarized in Figure 2.8. The total annual nitrogen inputs for basins within the study area range from approximately 210 kilograms per hectare to 400 kilograms per hectare. Total nitrogen inputs are generally highest in Kewaunee County and the southeast portion of Manitowoc County. Nitrogen inputs are lowest in Sheboygan County. The difference in nitrogen inputs among these areas is primarily driven by total nitrogen from manure applications, since manure applications tend to be higher in the north than in the south. This trend aligns with the total number of large milking operations within the study area.

FIGURE 2.8

Average rate (kg/ha) of total nitrogen inputs in agricultural areas

Summarized by study area subbasin



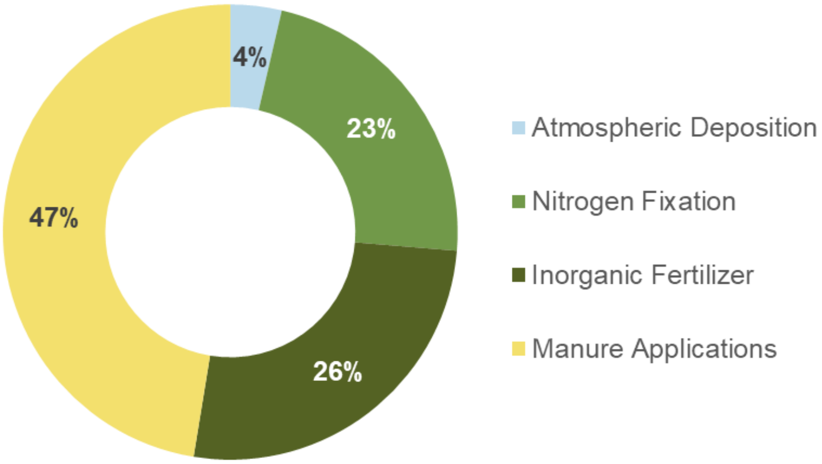
Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

Nitrogen sources can also be characterized by the proportion of total nitrogen inputs from each individual source. The percent of total nitrogen for the nitrogen input categories averaged over all subbasins within the study area are presented in Figure 2.9. The figure represents the average annual nitrogen source for agricultural areas for the years between 2009 and 2018.

FIGURE 2.9

Distribution of nitrogen sources by category for all watersheds

Average across all subbasins



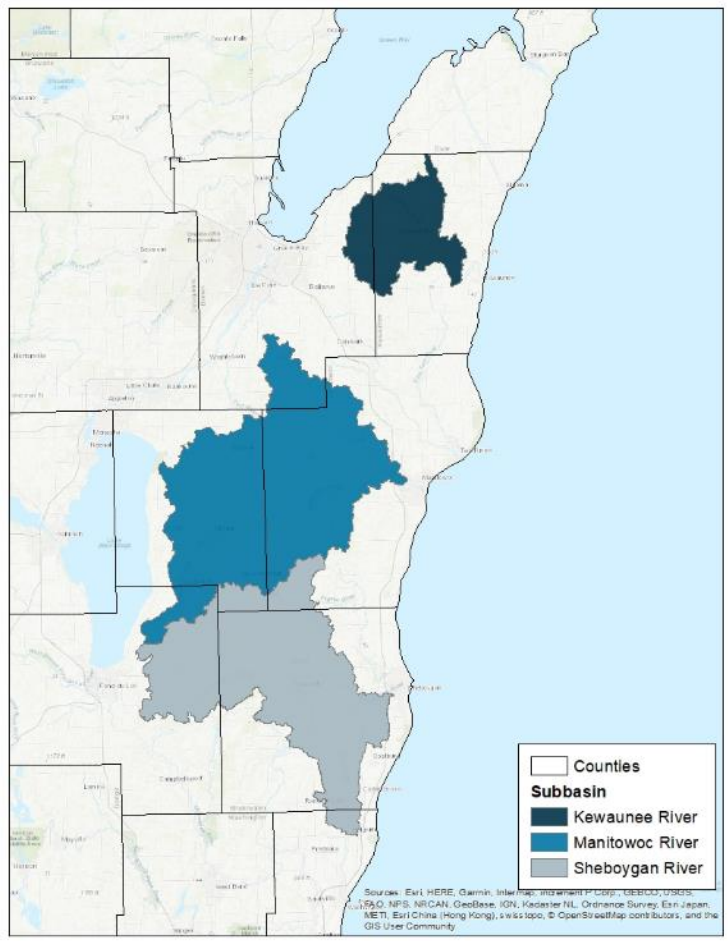
2.2.2. Nitrogen Inputs for Major River Basins in Study Area

The study area contains three large river basins: the Kewaunee River, the Manitowoc River, and the Sheboygan River. The location and extent of the basins are provided in Figure 2.10. The total nitrogen inputs from the four sources varies by subbasin and by region, and nitrogen within the three main basins of interest can be characterized as a percentage of nitrogen inputs from the individual sources. The comparison of nitrogen sources is provided in Figure 2.11. The primary source of nitrogen for the Kewaunee River watershed is manure, which makes up over 50 percent of the total nitrogen inputs. While manure is still the largest contributor of nitrogen in the Sheboygan River watershed, the proportion of total nitrogen inputs from manure in the Sheboygan River– 41 percent – is less than both the Kewaunee River and the Manitowoc River.

FIGURE 2.9

Large river basins in study area

Kewaunee River, Manitowoc River, Sheboygan River



Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

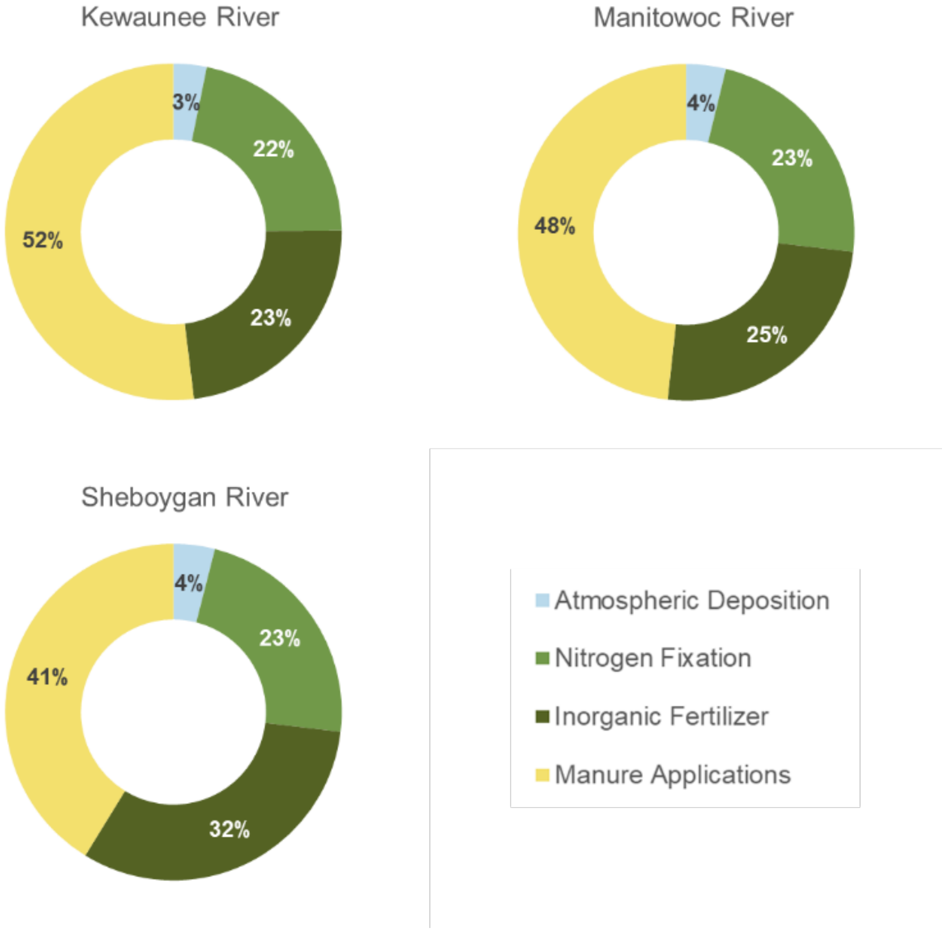


FIGURE 2.10

Summary of nitrogen sources for three primary basins

Average within each basin

3. AGRICULTURAL NITROGEN OUTPUTS

To understand the approximate agricultural mass balance for the subbasins within the study area, the outputs of nitrogen from the landscape must be characterized. The primary outputs from croplands include nitrogen lost from crop harvest, crop senescence, manure volatilization, fertilizer volatilization, and denitrification. Leaching and runoff are also important factors related to nitrogen loss, but directly estimating the amount of nitrogen lost through these pathways is difficult due to the complex and spatially variable factors that contribute to loss. A mass balance that only includes the primary inputs and primary outputs is useful because it provides a general framework for identifying the locations where leaching and runoff may be highest.

3.1. Methodology for characterizing nitrogen outputs

To characterize nitrogen outputs data related to land use, crop yields, manure spreading amounts, and commercial fertilizer purchases are required. The following sections provide a summary of the methodologies used to estimate the nitrogen sources within the monitoring basins of the Northeast Lakeshore study area.

3.1.1. Crop Harvest

When crops are harvested, the nitrogen in the crops is removed from the landscape. Crop harvest is the predominant process for nitrogen being removed from the landscape. The nitrogen removed through crop harvest depends on three main components: acres of planted crops, yield of crops, and nitrogen content within the crops.

The first component, acres of planted crops, is estimated using data from the Cropland Data Layer (NASS, 2008-2019). Crops included in the analysis include corn, soybeans, alfalfa, and winter wheat. These four crops are selected because they make up the largest proportion of agricultural land use in the subbasins. Other crops may be grown in the subbasins, but the area is minimal when compared to the four primary crops. The main output from the Cropland Data Layer is total area of the four crops within the individual subbasins.

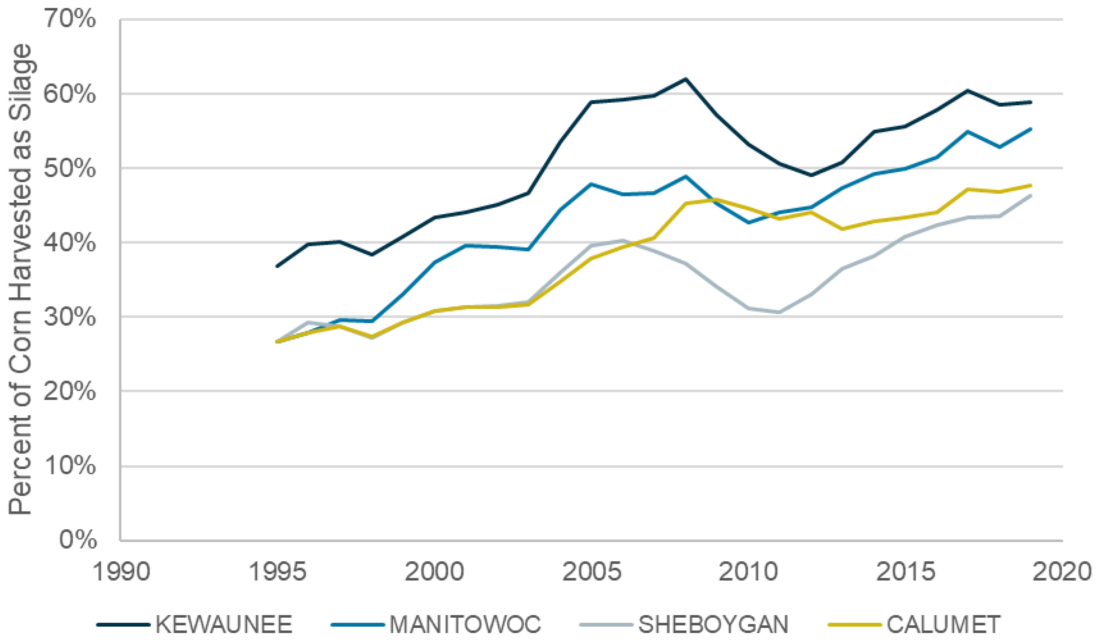
The second component, crop yield, is estimated from results from the NASS crop survey (NASS, 2017). The NASS survey data provide estimated average yields for different crop types in each county. Average crop yield for each subbasin is calculated by using the area-weighted method. The total area of each crop-and-county combination is calculated for each subbasin. Total crop yield for each crop-and-county combination is calculated by multiplying the crop area by the estimated yield. The output from the analysis is total yield – expressed in bushels or tons – for each subbasin.

An additional step is required for calculating crop yield related to corn. Corn can be grown as either corn grain or corn silage. The Cropland Data Layer only provides an estimate of corn, and it does not differentiate between the two corn types. The NASS crop survey provides county-level estimates for areas of corn grain and corn silage. These data are used to calculate the proportion of corn as grain versus corn as silage. The proportion is multiplied by the total corn area predicted by the Cropland Data Layer to estimate the area of corn grain and corn silage for each subbasin. Trends over time of the amount of corn harvested as grain versus silage are provided in Figure 3.1. The figure summarizes the 5-year average trends for the four main counties in the study area. In general, the proportion of corn harvested as silage has increased over time. The proportion of corn harvested as silage is higher in counties with a higher concentration of cattle. Since silage is generally used as feed for cattle, this trend is consistent with the trends in cattle within study area.

FIGURE 3.1

Trends in corn grain versus corn silage over time

Average by county



The third component, which is the nitrogen content of harvested crops, is estimated from literature-derived values. The estimated nitrogen content of crops is summarized in Table 3.1. The data reflect the values published by the International Plant Nutrition Institute (IPNI, 2012). The nitrogen content of crops depends on many factors, and the values presented in the table represent best estimates.

TABLE 3.1

Estimated nitrogen content of crops in the study area

Data source: IPNI, 2012, Table 4.1 and 4.5

Crop	Nitrogen Content	Unit	Nitrogen Content	Unit
Corn Grain	0.30	kg/bu	0.67	lb/bu
Corn Silage	4.9	kg/tonne	9.7	lb/ton
Soybeans	1.5	kg/bu	3.3	lb/bu
Alfalfa	26	kg/tonne	51	lb/ton
Winter Wheat	0.9	kg/bu	1.9	lb/bu

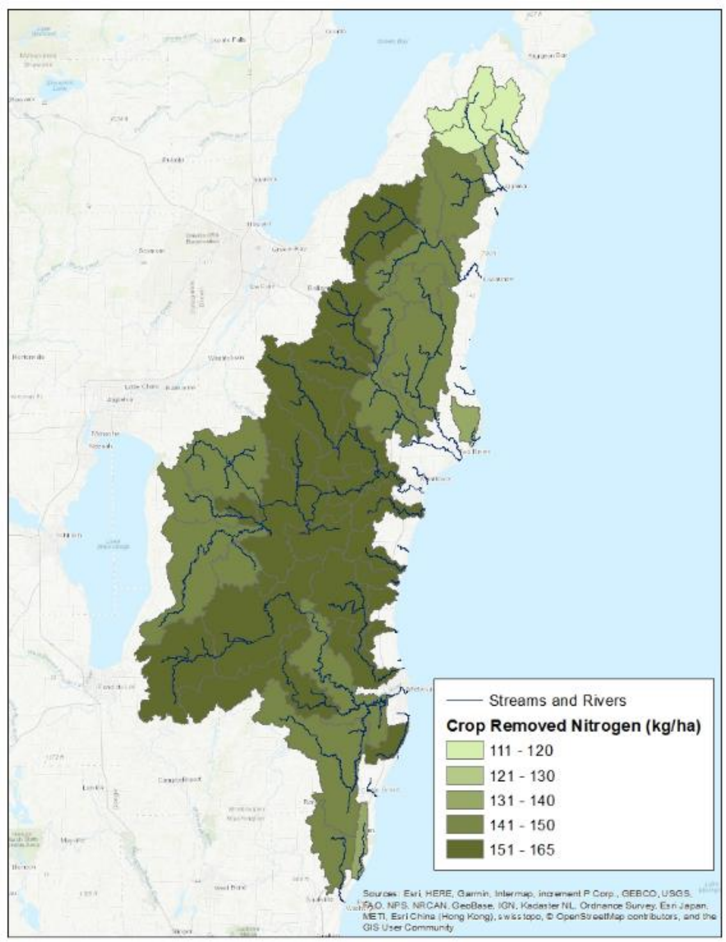
The total nitrogen removed from crops in each subbasin is presented in Figure 3.2. The differences in nitrogen removal rates in each subbasin is caused by differences in crop type and crop yield. The average nitrogen removal per agricultural hectare ranges from approximately 100 kg/ha to 160 kg/ha. The lowest average nitrogen removal per agricultural hectare is in the three northern-most subbasins. The three subbasins grow a much higher portion of winter wheat than other basins in the study area. Since winter wheat harvest removes less nitrogen per hectare than other crops, the average removal per agricultural hectare is lower.

The average nitrogen removal from crops depends on three main sources: total crop area from the cropland data layer, average crop yield from NASS, and average crop nitrogen content from published sources. Each of these assumptions have limitations, which may impact the precision of the results. Since the assumptions are the same for every subbasin, however, the general trend of nitrogen removed from crops among the subbasins is meaningful.

FIGURE 3.2

Average rate (kg/ha) of nitrogen removal from crops

Summarized by study area subbasin



3.1.2. Crop Senescence

Another major source of nitrogen loss from agricultural areas is crop senescence. Crop senescence is the process of plants volatilizing nitrogen into the atmosphere as they mature. Senescence is greatest near the end of the crop lifecycle, and it generally occurs in the late summer or early fall.

Crop senescence can represent a large loss of nitrogen from crops. Typically, it is the second largest source of nitrogen output from agricultural lands. For the calculation of nitrogen outputs, the amount of crop senescence in each subbasin is estimated by determining the total area of crops and multiplying the area by literature-derived values of crop senescence. Crop senescence varies by species, and the literature-drived values estimated for different crops is provided in Table 3.2. The values in the table are provided by MPCA (2013).

TABLE 3.2

Estimated senescence rate of crops

Data Source: MPCA, 2013, p. D4-9

Crop	Senescence Rate (kg N/ha/yr)	Senescence Rate (lb N/ac/yr)
Corn	50	45
Soybeans	45	40
Alfalfa	22	20
Small grains	35	31

The published rates in Table 3.2 are applied to the crop types estimated from the Cropland Data Layer. The senescence rate for corn is applied to the total area of corn identified in the Cropland Data Layer – it is not separated by corn grain or corn silage. Senescence rate for winter wheat is assumed to be equal to the rate for small grains. Average rate of crop senescence is similar across all subbasins within the study area. The rates vary from approximately 35 kg/ha to 40 kg/ha. The distribution of the average senescence rate corresponds with the crop types grown in each basin.

3.1.3. Manure Volatilization

Application of manure results in loss of nitrogen to the atmosphere by volatilization. Volatilized nitrogen is generally in the form of NH_3. The amount of volatilization from manure depends on the type of manure being spread. For dairy cattle, the estimated loss of nitrogen from volatilization on the landscape is estimated to be 10 percent of total manure applied (MPCA, 2013, p. D4-10). The manure applied to the landscape, which is described in Section 2.2.1, represents the nitrogen inputs from the manure spread on the field, so volatilization from manure storage is already incorporated in the analysis and not included as a distinct output. The total manure spread is summarized in Figure 2.2. Since the manure volatilization is assumed to be the same percentage for all manure applied, the relative differences of manure volatilization among subbasins is similar to the relative differences of manure applied shown in the figure. Overall, average manure volatilization outputs in the study area range from 8 kg/ha to 20 kg/ha.

3.1.4. Fertilizer Volatilization

When commercial fertilizer is applied to fields, some percentage of the fertilizer is lost to the atmosphere through volatilization. Volatilization depends on the composition of the fertilizer applied. Rates of loss tend to range from 2 percent to 5 percent (MPCA, 2013, p. D4-9). Since specifics about the type of fertilizer applied to the fields is not known, an average fertilizer volatilization rate of 4 percent is applied to all fertilizer applied. The total fertilizer applied is summarized in Figure 2.3. Since the fertilizer volatilization is assumed to be the same percentage for all fertilizer applied, the relative differences of manure volatilization among subbasin is similar to the relative differences of manure applied shown in the figure. Overall, average fertilizer volatilization outputs in the study area range from 3 kg/ha to 4 kg/ha.

3.1.5. Denitrification

Denitrification is the process of nitrogen being converted to nitrogen gas by microorganisms. Denitrification occurs on the field, in groundwater, and in surface water. For the mass balance analysis, only denitrification occurring on the field is considered.

When the nitrogen sources are incorporated into the soil, a portion is lost to the atmosphere during the denitrification process. Nitrogen available for denitrification includes all the sources listed in Section 2. The sources include manure application, commercial fertilizer application, nitrogen fixation, and atmospheric deposition.

Not all the nitrogen in manure is available for denitrification. Only the nitrogen in applied manure that is not lost through volatilization and is not immobilized as organic nitrogen is available for denitrification by microorganisms. The manure application rates are described in Section 2.1.1, and manure volatilization rates are described in Section 3.1.3. The difference between manure applied and manure volatilized in the field is multiplied by a constant to estimate the total manure nitrogen that is in an inorganic form and available for denitrification. The mass balance assumes only 40 percent of the net manure nitrogen is available for denitrification. The value is published for dairy cows in (MPCA, 2013, p. D4-6).

Similarly, not all nitrogen in commercial fertilizers is available for denitrification because some of the fertilizer is lost to volatilization and some is converted to organic forms of nitrogen that are not available for denitrification. Commercial nitrogen fertilizer application is described in Section 2.1.2, and volatilization of commercial nitrogen fertilizer is described in Section 3.1.3. The immobilization rate for nitrogen fertilizer is assumed to be 40 percent (MPCA, 2013, p. D4-6), so 60 percent of nitrogen from commercial fertilizer is available for denitrification.

To estimate the total nitrogen lost to denitrification, the total amount of inorganic nitrogen that is available for denitrification must be calculated. For the mass balance, the total inorganic nitrogen is calculated as the nitrogen available for volatilization in manure, the nitrogen available for volatilization in fertilizer, the total nitrogen from nitrogen fixation, and the total nitrogen from atmospheric deposition. Nitrogen inputs from nitrogen fixation are described in Section 2.1.4, and nitrogen inputs from atmospheric deposition are described in Section 2.1.5. The total nitrogen from these two processes are assumed to be fully available for denitrification. A summary of the assumptions for the nitrogen available for denitrification is provided in Table 3.3.

TABLE 3.3

Coefficients for nitrogen available for denitrification

Crop	Percent of Net Nitrogen[1] Available for Denitrification
Manure application	40
Fertilizer application	60
Nitrogen fixation	100
Atmospheric deposition	100

1. Net nitrogen for manure and fertilizer applications equals the total amount applied minus the total amount lost to volatilization

Once the total nitrogen available for denitrification is calculated, the total must be multiplied by an assumed rate of denitrification rate to estimate the total nitrogen lost to denitrification. The microorganisms responsible for denitrification are more prominent in moist environments, so the soil moisture and soil drainage potential are important considerations when estimating denitrification rates. The soil in the study area is primarily moderately drained or well drained. The denitrification potential for these types of soil is assumed to be 10 percent, which is consistent with published values (MPCA, 2013, p. D4-10). Overall, the average denitrification loss in the study area ranges from 10 kg/ha to 15 kg/ha.

3.2. Results

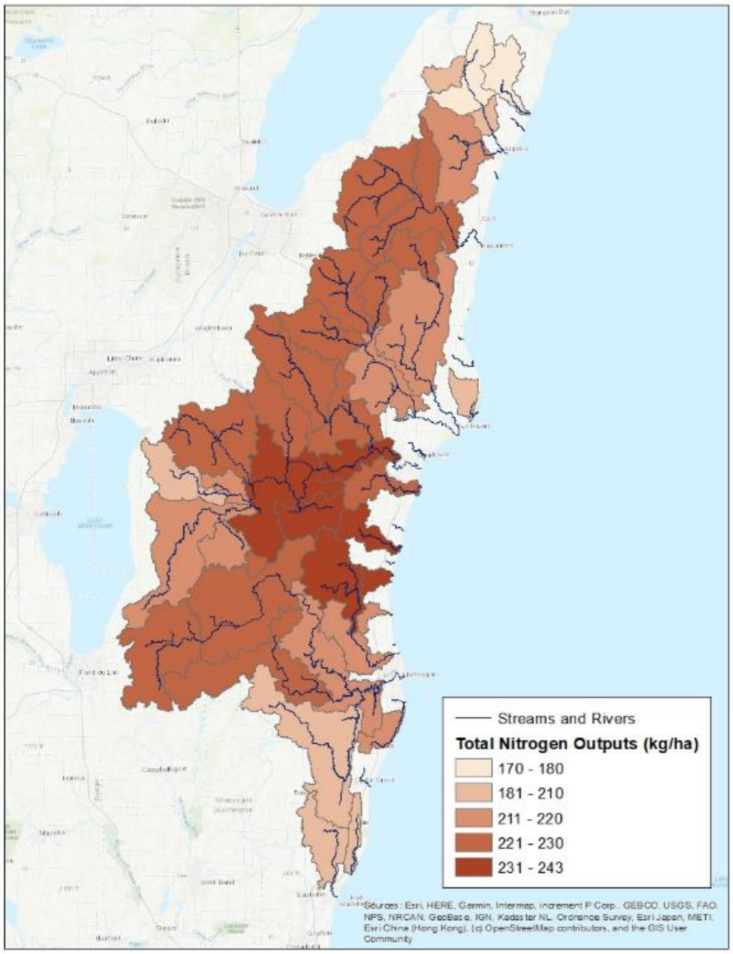
The five primary outputs of nitrogen from agricultural areas are crop harvest, crop senescence, manure volatilization, commercial fertilizer volatilization, and denitrification. The calculation for the different inputs is provided in the previous section.

The results from the individual processes are combined to estimate the total amount of nitrogen removed from agricultural lands in the study area. Figure 3.3 compares the average nitrogen outputs for the subbasins within the study area. The total annual nitrogen outputs for basins within the study area range from approximately 170 kg/ha to 240 kg/ha. Total nitrogen outputs are typically highest in Manitowoc County. The primary reason for the low nitrogen outputs in the three northern-most basins relates to the losses through crop harvest. Winter wheat is a major crop in these areas, and the amount of nitrogen removed from winter wheat is much lower than it is for other crops.

FIGURE 3.3

Average rate (kg/ha) of total nitrogen outputs in agricultural areas

Summarized by study area subbasin

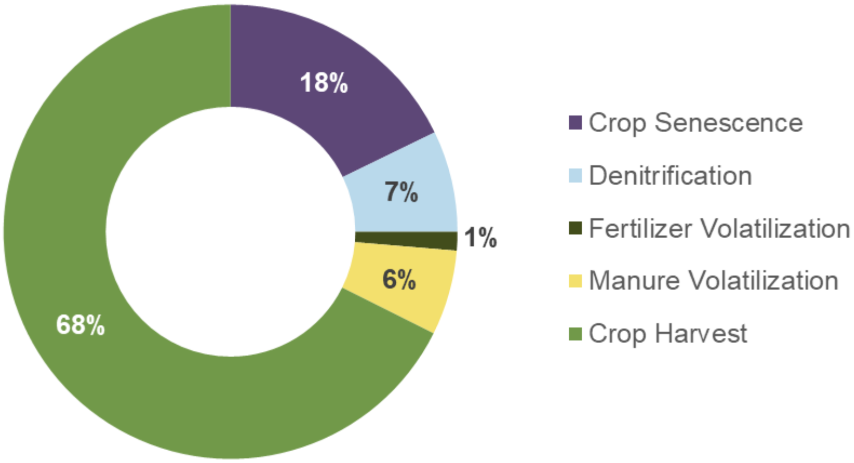


Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community

Nitrogen outputs can also be characterized by the proportion of total nitrogen removed from each individual source. Figure 3.4 presents the percent of total nitrogen outputs for the categories described above. Data are summarized as the average annual nitrogen source for agricultural areas between 2009 and 2018. Crop harvest is the main source of nitrogen loss from the landscape, but crop senescence is also a major source of nitrogen loss.

FIGURE 3.4

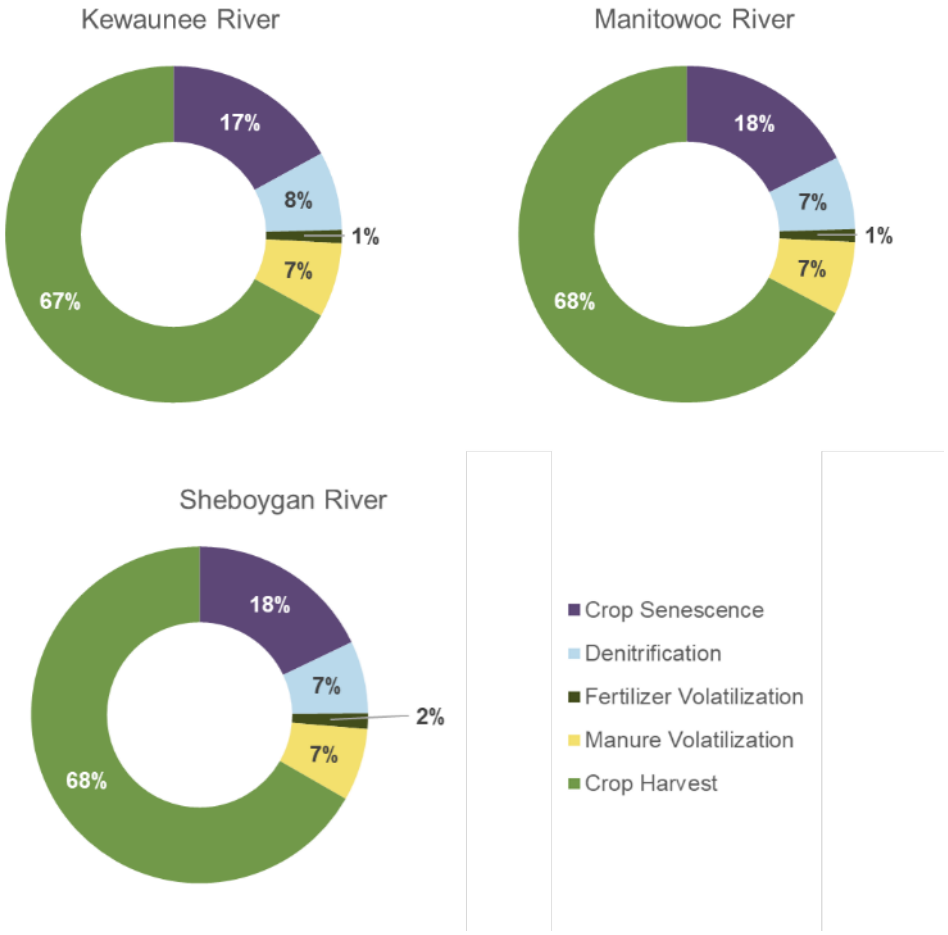
Distribution of nitrogen outputs by category



Nitrogen outputs can also be characterized by the three main river basins displayed in Figure 2.10. The comparison of nitrogen outputs is provided in Figure 3.5. The results for the three primary basins are similar to one another and to the overall estimates for the study area. For all basins, approximately 68 percent of nitrogen is lost to crop harvest, and approximately 18 percent of nitrogen is lost to crop senescence. Although the proportion of nitrogen outputs are similar for the basins, the total amount of nitrogen loss in individual basins varies, as shown in Figure 3.3.

FIGURE 3.5

Comparison of nitrogen outputs for three primary basins



4. AGRICULTURAL NITROGEN MASS BALANCE

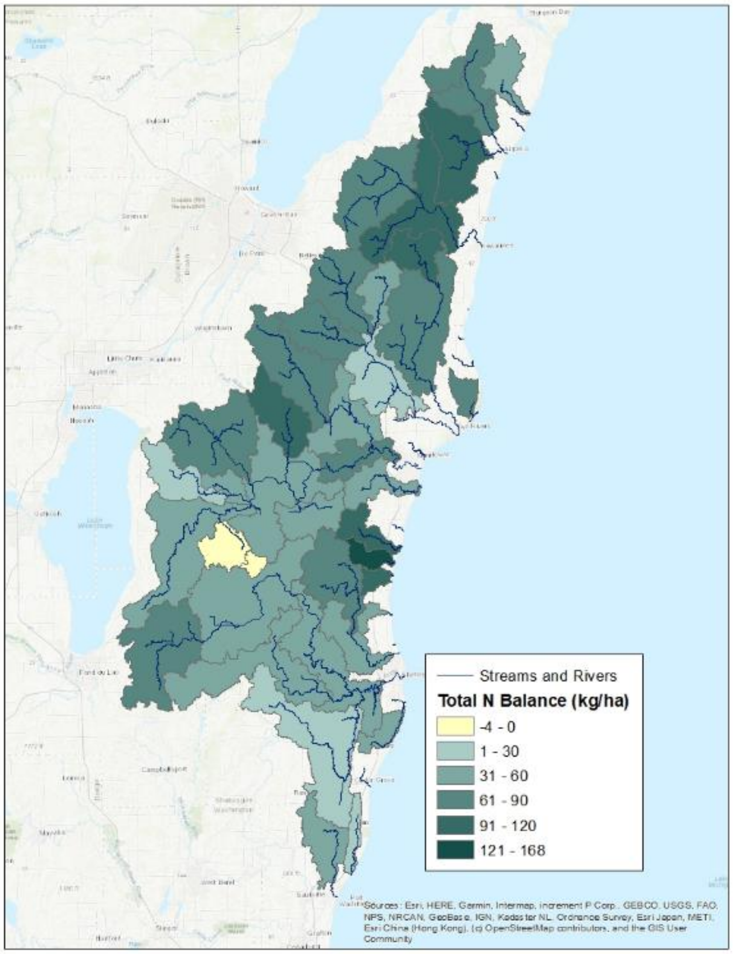
The nitrogen inputs and outputs can be compared to estimate the overall balance of nitrogen applied to agricultural lands. The results of the mass balance can be used to identify areas where excess nitrogen is being applied. The outputs calculated in Section 3 do not consider leaching or runoff outputs, so areas where excess nitrogen applications occur may also be the areas where nitrogen in groundwater and surface water are at highest risk of high nitrogen levels. The results of the mass balance can be used to better target areas for improved nitrogen management.

The balance of nitrogen in each subbasin is calculated by computing the difference between nitrogen applied to the landscape and nitrogen removed from the landscape. The results of the mass balance are shown in Figure 4.1. Positive values in the figure indicate more nitrogen is being applied than is being removed, and negative values indicate more nitrogen is being removed than is being applied.

FIGURE 4.1

Average balance of nitrogen inputs and outputs on agricultural land

Summarized by study area subbasin



Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community

5. WATERSHED NITROGEN MASS BALANCE AND SURFACE WATER CONCENTRATIONS

The mass balance of nitrogen on the landscape can be compared with water quality data to provide insight into the impact of nitrogen application on surface water concentrations. Within the Northeast Lakeshore study area, estimates of nitrogen mass balance and water quality data are available for 2018. The estimates are used to explore the impact of nitrogen on the landscape to nitrogen in surface waters.

5.1. Watershed Mass Balance and Cumulative Nitrogen Yield

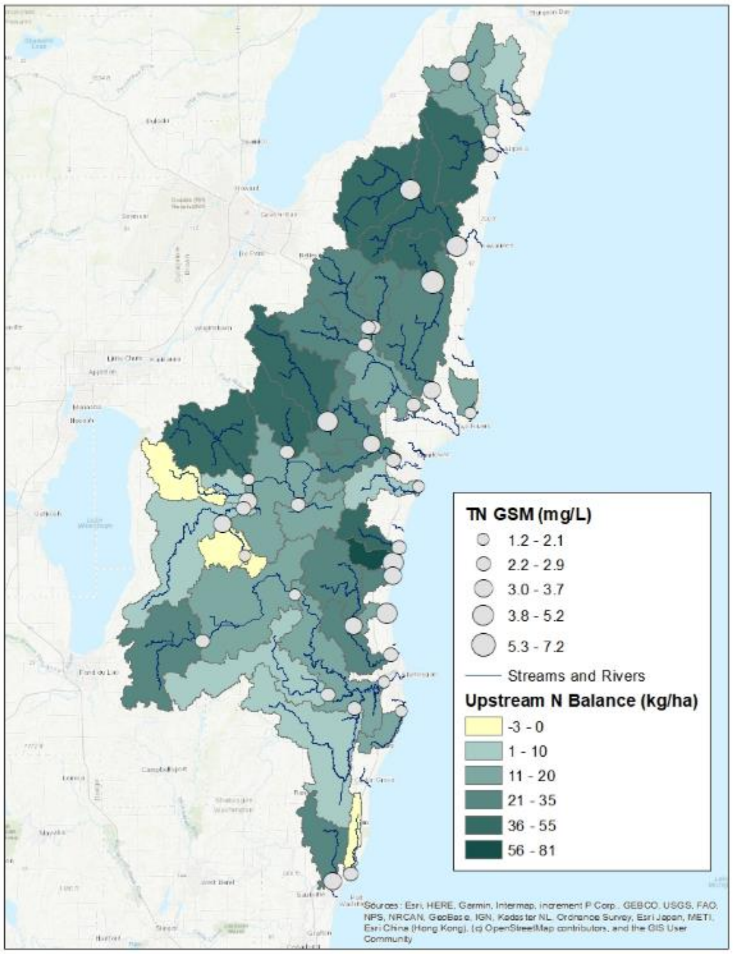
The nitrogen mass balance is expressed as the difference between nitrogen inputs and nitrogen outputs. The nitrogen yield, or mass over area, can be expressed for agricultural areas or the entire watershed area. The previous sections evaluate nitrogen inputs, outputs, and balance for agricultural areas only. When relating nitrogen application to water quality data, however, the average agricultural nitrogen mass balance expressed over the entire watershed area is useful because it allows subbasins with a small proportion of agricultural lands to be compared to subbasins with a large proportion of agricultural lands. This method assumes the nitrogen mass balance natural, non-agricultural areas is negligible and that nitrogen inputs to streams from other sources are minimal.

Cumulative nitrogen yield for a subbasin is calculated by dividing the total agricultural nitrogen balance of all upstream subbasins by the total area of all upstream subbasins. The cumulative nitrogen yield is different from the calculations in Section 4 because the mass balance in Section 4 is calculated for each independent subbasin. Additionally, the mass balance results in Section 4 are calculated using only agricultural area, whereas the cumulative nitrogen yield is calculated using entire watershed area. The cumulative nitrogen yield in units of kilograms per hectare for 2018 is shown in Figure 5.1.

FIGURE 5.1

Cumulative nitrogen yield calculated for 2018

Normalized to upstream watershed area



5.2. Mass Balance and Surface Water Concentrations

Water quality data are available at monitoring sites for the years between 2017 and 2019. The most complete datasets are available for the growing season of 2018. Details about water quality monitoring are provided in Appendix C of the nitrogen analysis report. A comparison of the *measured* growing season median (GSM) concentration from 2018 to the cumulative nitrogen yield for only 2018 is shown in Figure 5.2. A comparison of the *modeled* GSM concentration from 2018 is compared with the cumulative nitrogen yield for 2018 is shown in Figure 5.3.

FIGURE 5.2

Comparison of 2018 measured GSM concentration and 2018 cumulative nitrogen yield

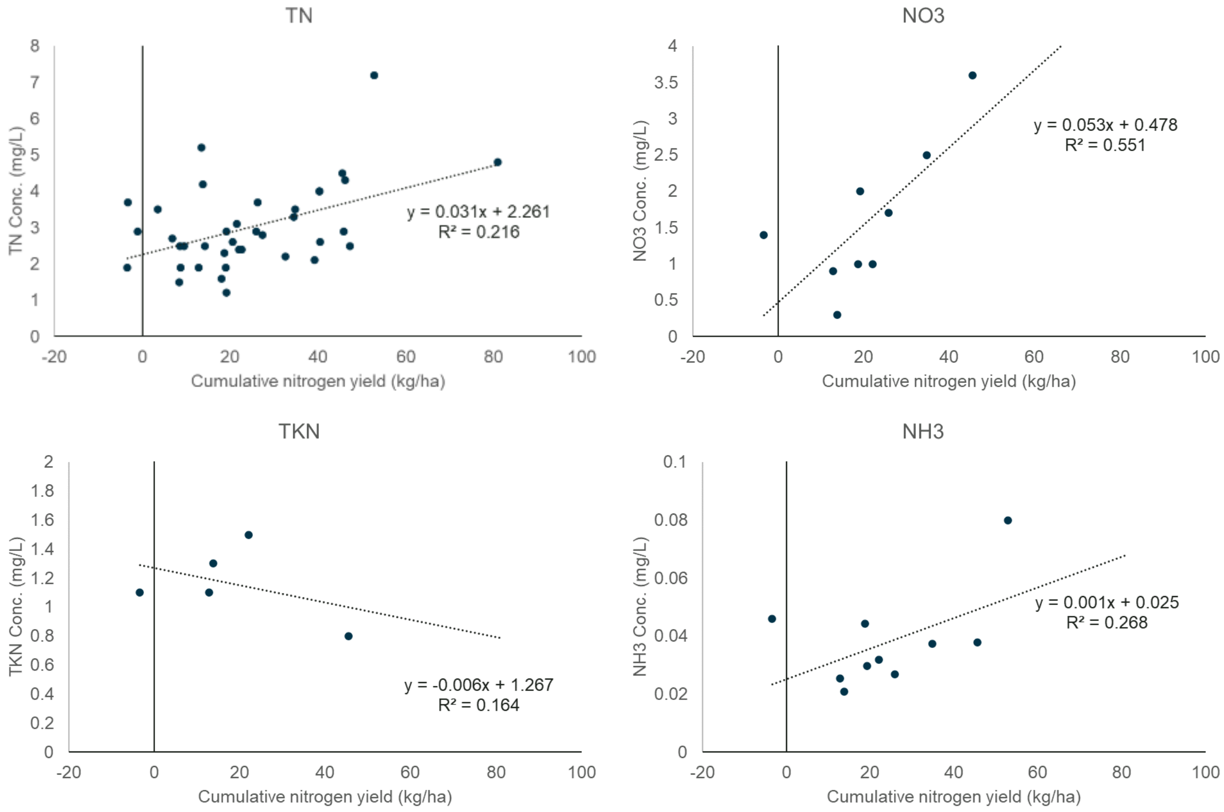
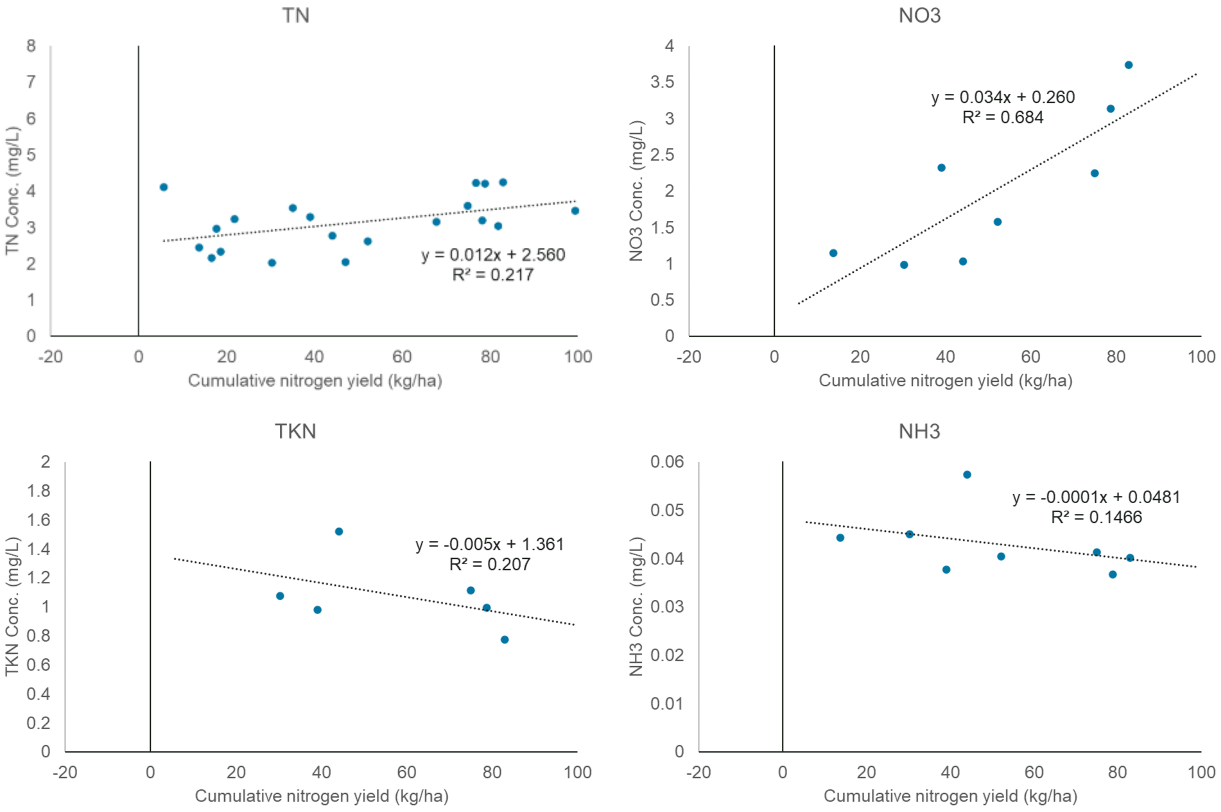


FIGURE 5.3

Comparison of 2018 modeled GSM concentration and 2018 cumulative nitrogen yield



The linear relationship between the cumulative nitrogen yield and the measured and modeled GSM concentrations for total nitrogen, total Kjeldahl nitrogen, and ammonia is weak – it is not possible to reliably estimate concentrations from cumulative nitrogen yield. The relationship between cumulative nitrogen yield and the GSM concentrations of nitrate, however, is moderately positive – GSM nitrate concentration increases as more excess nitrogen is applied to the landscape.

Although a strong linear relationship between cumulative nitrogen yield and GSM concentration is not observed, general trends can be inferred. When the cumulative nitrogen yield is higher – i.e., more nitrogen is applied to the landscape than is removed – total nitrogen and nitrate concentrations at the monitoring sites appear to increase. The opposite relationship is observed for total Kjeldahl nitrogen, which implies GSM concentration decreases as cumulative nitrogen yield increases. The relationship between cumulative nitrogen yield and ammonia concentration positive for the measured concentrations but negative for the modeled concentrations. The discrepancy likely results form inadequate data and a poor relationship between the two variables.

6. NITROGEN MASS BALANCE FROM ALL SOURCES AT LONG-TERM TREND SITES

Sections 1 through 5 focus on the nitrogen mass balance from agricultural lands because the agricultural lands are the primary source of nitrogen. However, the subbasins in the study area also contain nitrogen sources from urban lands and point sources. The study area contains three monitoring stations that are part of the Wisconsin Department of Natural Resources Long-Term Trends network (WDNR, 2015). Nitrogen mass balance in the watersheds of the three Long-Term Trends (LTT) sites is evaluated in this section.

6.1. Non-Agricultural Sources of Nitrogen in LTT Basins

In addition to agricultural nitrogen sources, sources of nitrogen within subbasins include forested lands, developed lands, and point sources. The contributions from these non-agricultural sources are small relative to the total contribution from agricultural areas, but the magnitude of their contribution is evaluated in the following sections.

6.1.1. Nitrogen Export from Deciduous Forests

While the landscape in the three LTT watersheds is heavily developed for agriculture, the watersheds contain deciduous forests that may be a source of nitrogen to the receiving waters. Deciduous forests make up approximately 5 percent of land in the Kewaunee River basin, 7 percent of land in the Manitowoc River basin, and 11 percent of land in the Sheboygan River basin (NASS, 2008-2019).

Total nitrogen export from deciduous forests is estimated based on the amount of precipitation received each year. The estimated nitrogen export from deciduous forests is presented in Table 6.1. The export coefficients are provided by the Minnesota Pollution Control Agency (MPCA, 2013). For the analysis, the following definitions of precipitation are used: Dry conditions are years in the bottom 25 percent of annual precipitation from 1989-2018, wet conditions are years in the top 25 percent of annual precipitation from 1989-2018, and average conditions are all other years. The precipitation data are downloaded from Daymet (Thornton and others, 2020), and the precipitation conditions are evaluated for each major basin.

TABLE 6.1

Estimated export coefficients for forested lands

Data Source: MPCA, 2013, p. D4-24

Conditions	N export (lb N/ac/yr)
Dry	1
Average	2
Wet	3

6.1.2. Nitrogen Originating from Developed Lands

The three LTT watersheds contain lands that are developed. Developed lands make up approximately 4 percent of land in the Kewaunee River basin, 3 percent of land in the Manitowoc River basin, and 5 percent of land in the Sheboygan River basin. The basins are delineated from the location of the USGS gages, which are located upstream of the major population centers of Kewaunee, Manitowoc, and Sheboygan.

Total nitrogen export from developed areas is based on the amount of precipitation received in a given year. The estimated export coefficients for developed areas are presented in Table 6.2 (MPCA, 2013). Definitions for the precipitation conditions are provided in Section 6.1.1.

TABLE 6.2

Estimated export coefficients for developed areas

Data Source: MPCA, 2013, p. D4-25

Conditions	N export (lb N/ac/yr)
Dry	2
Average	4
Wet	6

6.1.3. Nitrogen from Point Sources

The three major basins all contain point sources that discharge to the receiving water bodies. Table 6.3 summarizes the number of point sources located within each basin.

TABLE 6.3

Point sources located in major basins

Basin	Number of Point Sources	Number of WWTPs	Number of Industrial Point Sources
Kewaunee River	3	1	2
Manitowoc River	13	12	1
Sheboygan River	13	8	5

Flows for point sources are provided in the Wisconsin DNR's SWAMP Database (WDNR, 2020). Detailed information about the point source data are provided in the Wisconsin DNR's TMDL report for the Northeast Lakeshore (WDNR, 2022). Total nitrogen loading from each point source is calculated by multiplying the total flow by an estimated concentration for each source.

The point sources in the Great Lakes basin in Wisconsin do not routinely sample for nitrogen. Point sources in the Mississippi River basin, however, have been collecting routine nitrogen samples since 2000. Data for these point sources are available from WDNR's SWAMP database (WDNR, 2020). To estimate the concentration from point sources, the median concentrations from samples collected at 69 point sources are used. A total nitrogen concentration of 16 mg/L is estimated for the flows from each wastewater treatment plant, and a total nitrogen concentration of 11 mg/L is assumed for the flows from each industrial point source.

Point-source nitrogen loads in the three LTT watersheds do not include the major WWTPs at Kewaunee, Manitowoc, and Sheboygan because the three WWTPs discharge downstream of the USGS gages where the watershed boundaries are delineated.

6.2. Mass Balance for Major Basins for All Sources

The results from the analysis in Section 6.1 are used to estimate the total impact of forests, developed, and point sources on nitrogen export in the watershed. The following sections summarize the results.

6.2.1. Overall Mass Balance Results

The nitrogen sources described in the previous section are expressed as total nitrogen loads that are exported from the landscape and delivered to the rivers. The sum of the nitrogen loads from point source, urban, and forest lands are subtracted from the total measured instream loads to estimate the instream nitrogen loads that originate from other sources. In the analysis, other sources of nitrogen loads are assumed to be atmospheric deposition, inorganic fertilizer, manure, and nitrogen fixation on cultivated lands. Table 6.4 provides a summary of the analysis. Instream nitrogen loads attributed to cultivated lands are 97 percent for the Kewaunee River, 89 percent for the Manitowoc River, and 83 percent for the Sheboygan River.

TABLE 6.4

In-stream mass balance for the major rivers in the study area

	Kewaunee River		Manitowoc River		Sheboygan River	
	Total load (kg N)	Percent of total	Total load (kg N)	Percent of total	Total load (kg N)	Percent of total
Measured in river (2009-2018 average)	477,600	100%	1,077,680	100%	905,630	100%
Point source	3,710	1%	66,390	6%	97,060	11%
Urban	6,220	1%	25,680	2%	26,440	3%
Forest	5,010	1%	25,370	2%	34,530	4%
Other	**462,660**	**97%**	**960,240**	**89%**	**747,600**	**83%**

Results from Table 6.4 are used to estimate the percent of nitrogen applied to the landscape that is eventually delivered to the LTT sites. The percent of nitrogen delivered is estimated by dividing the total in-stream nitrogen loads from other sources, listed in Table 6.4, by the total nitrogen load applied to the landscape. Results are provided in Table 6.5. The estimated delivery rates for the three basins are 8% for the Kewaunee River, 5% for the Manitowoc River, and 6% for the Sheboygan River.

TABLE 6.5

Estimated delivery of landscape-applied nitrogen to rivers

	Kewaunee River	Manitowoc River	Sheboygan River
	Load (kg)	Load (kg)	Load (kg)
Atmospheric	188,080	718,450	495,780
Fixation	1,264,660	4,274,730	2,810,130
Fertilizer	1,362,980	4,680,420	3,982,080
Manure	3,054,570	9,068,780	5,146,110
Total on Landscape	**5,870,290**	**18,742,380**	**12,434,100**
Other Instream*	462,660	960,240	747,600
Percent Delivered**	**8%**	**5%**	**6%**

* Other instream load is equal to category named "Other" in Table 6.4. The value represents the in-stream load not attributed to point source, urban, or forest loads.

** Percent delivered is an estimate equal to the attributable streamload divided by the landscape-level load of atmospheric, fixation, fertilizer, and manure. The value represents the amount of landscape nitrogen from those sources that is delivered to the river.

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APPENDIX E

SPARROW MODEL NITROGEN COMPARISON FOR THE NORTHEAST LAKESHORE STUDY AREA

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1. BACKGROUND

Watershed-based models are available to predict sediment and nutrient loading from the landscape. Some watershed-based models automate the modeling process and allow users to generate loading estimates by selecting a specific location. Examples of these models include the USEPA's BASINS model (USEPA, 2019), Purdue University's L-THIA model (Purdue University, 2017), and USGS's SPARROW model (USGS, 2021b). SPARROW is a widely used model for estimating flows, loads, and concentrations for watersheds across the United States and is commonly used to evaluate nitrogen loading that contributes to the Gulf of Mexico Hypoxia Zone. The methods and results of the SPARROW model are compared to the methods summarized in other sections of this report.

2. SPARROW MODEL

The **SPA**tially **R**eferenced **R**egression **O**n **W**atershed Attributes (SPARROW) is a watershed model developed by United States Geological Survey (USGS) to estimate nutrient, sediment, and dissolved solids transport. The initial model was developed in 1997, and it has been updated numerous times since its inception. The most recent version of SPARROW was released in 2020. The model was developed on both a national and regional scale to support evaluation of nutrient and sediment loading in streams across the United States. For the following analysis, the model for Midwestern streams is used (Robertson and Saad, 2019). The primary output of SPARROW is an online tool that provides a user-friendly interface for watershed managers across the country (USGS, 2021a).

2.1. SPARROW Model Background

The updated SPARROW model simulates mean-annual streamflow, nutrients, and suspended sediment for the long-term period between 2000-2014. The extent of model is shown in Figure 2.1.

FIGURE 2.1

Spatial extent of the SPARROW model for Midwestern states

Figure Source: Robertson and Saad, 2019, p. 3

The SPARROW model is a hybrid mass-balance/statistical approach. USGS describes the model in the following way: "The core of the model consists of a nonlinear regression equation describing the non-conservative transport of contaminants from point and non-point (or "diffuse") sources on land to rivers and through the stream and river network." (USGS, 2021b). A detailed explanation of the model for the Midwest can be found in Robertson and Saad (2019).

The 2012 SPARROW model includes variables that evaluate sources, land-to-water delivery, and aquatic losses. Seventeen individual parameters are used in the development of the nitrogen model. The relevant parameters for the model are presented in Table 2.1.

TABLE 2.1

Calibration parameters used in SPARROW model

Variable Type	Variable
Source	Atmospheric deposition
	Wastewater treatment plants
	Urban and open areas
	Fertilizers (farms)
	Manure
	Nitrogen fixation
	Canada load
Land-to-water delivery	Runoff

Variable Type	Variable
	Detrended air temperature
	Tile drainage
	Soil clay content
	Cropland Reserve Program acres
	No-till management
Aquatic loss	Instream decay
	Reservoir loss
	Stream loss from groundwater pumping for irrigation
	Surface-water withdrawal for public supply

2.2. SPARROW Model Inputs

The SPARROW model uses four types of data in its development. The data include stream networks, annual mean loads for many calibration sites, annual source inputs, and watershed characteristics.

2.2.1. SPARROW Source Inputs

The source inputs refer to the parameters that estimate true loading from the landscape. Source inputs represent landscape characteristics and other sources that export nitrogen before it is delivered into the receiving water bodies. SPARROW uses a variety of sources for the model inputs. Table 2.2 provides a summary of the sources used. The data sources listed in the table are used directly in the development of the SPARROW, and more information about the sources are provided in the model documentation.

TABLE 2.2

Data sources for nitrogen source inputs

Variable	Source of data	Reference used in SPARROW application
Atmospheric deposition	EPA Community Multiscale Air Quality Modeling System (CMAQ)	Wieczorek and others, 2019
WWTPs	EPA Integrated Compliance Information System (ICIS) and EPA Permit Compliance System (PCS)	Skinner and Maupin, 2019
Urban and open areas	National Land Cover Database (NLCD)	Wieczorek and others, 2019
Fertilizers (farm)	Association of American Plant Control Officials (AAPFCO) commercial fertilizer sales for 2012	Stewart and others, 2019
Manure	United States Department of Agriculture 2012 Census of Agriculture.	Gronberg and Arnold, 2017
Fixation	2012 Cropland Data Layer	USDA, 2018

Variable	Source of data	Reference used in SPARROW application
Canada Load	USGS Stream Gages	-

2.2.2. SPARROW Land-to-Water Delivery Parameters

When nutrients are exported from the landscape, they are subject to processes as they flow over the landscape to the receiving water body. Six land-to-water delivery parameters are used in the SPARROW model to estimate the amount of loading that is eventually delivered in the receiving water body. A summary of the land-to-water delivery parameters and their underlying data sources is provided in Table 2.3. The data sources listed in the table are used directly in the development of the SPARROW, and more information about the sources are provided in the model documentation.

TABLE 2.3

Data sources for nitrogen land-to-water delivery inputs

Variable	Underlying data source	Reference used in SPARROW Application
Runoff	SPARROW model	Robertson and Saad, 2019
Detrended air temperature	PRISM Climate Group	Wolock and McCabe, 2018
Tile drainage	2012 Census of Agriculture, NLCD, STATSGO	Nakagaki and Wieczorek, 2016
Soil clay content	STATSGO	Wieczorek and others, 2019
Cropland Reserve Program acres	USDA, Farm Service Agency, CRP Statistics	Wieczorek and others, 2019
No-till management	National Agricultural Statistics Service (NASS)	Wieczorek and others, 2019

2.2.3. SPARROW Aquatic Loss Parameters

As nitrogen is transported downstream in rivers or streams, some of the nitrogen is lost to aquatic processes. Four nitrogen aquatic loss parameters are used in SPARROW to estimate the amount of nitrogen that is removed from the aquatic processes. A summary of the aquatic process parameters and their underlying data sources are provided in Table 2.4. The data sources listed in the table are used directly in the development of the SPARROW, and more information about the sources are provided in the model documentation.

TABLE 2.4

Data sources for nitrogen aquatic loss parameters

Variable	Underlying data source	Reference for SPARROW application
Instream decay	SPARROW calibration	Robertson and Saad, 2019
Reservoir loss	NHDPlusV2, USACE National Inventory of Dam	Robertson and Saad, 2019
Stream loss from groundwater pumping for irrigation	USGS Survey County Estimates of Water Use	Wieczorek and others, 2019
Surface-water withdrawal for public supply	USGS Survey Estimates of Population Served by Public Supply Water Use	Wieczorek and others, 2019

2.3. SPARROW Model Calibration and Outputs

The model inputs outlined in the previous section are applied to all subbasins within the Midwest SPARROW model. The model is then calibrated using the inputs and the corresponding model parameters, which are described in the following section.

2.3.1. SPARROW Model Calibration

The seventeen parameters outlined in the previous section are used in the calibration of the SPARROW model. The model is calibrated to discharges and nutrient loads measured at gages in the entire model domain. Predicted loads at each of the gages are estimated by multiplying each of the inputs by a model coefficient. The model coefficients are adjusted until the estimated loads approximately match the measured loads. The calibrated model coefficients are summarized in Table 2.5.

TABLE 2.5

Calibrated model parameters used in the SPARROW model

Variable	Variable unit	Coefficient unit	Model coefficient value
	Source		
Atmospheric deposition	kg	Fraction, dimensionless	0.163
WWTPs	kg	Fraction, dimensionless	0.495
Urban and open areas	km^2	kg/km^2/yr	122
Fertilizers (farm)	kg	Fraction, dimensionless	0.032
Manure	kg	Fraction, dimensionless	0.066
Fixation	km^2	kg/km^2/yr	667
Canada Load	kg	Fraction, dimensionless	1.0

Variable	Variable unit	Coefficient unit	Model coefficient value
Land-to-water delivery			
Ln(runoff)	Unitless	Unitless	0.673
Detrended air temperature	^{o}C	$^{o}C^{-1}$	-0.048
Ln(tile drains, % of catchment)	Unitless	Unitless	0.101
Ln(soil clay content, % of catchment)	Unitless	Unitless	0.292
CRP acres relative to total farmland	Fraction	$Fraction^{-1}$	-4.758
Ln(% of catchment in "no till")	Unitless	Unitless	0.124
Aquatic loss			
Instream decay (mean streamflow <1.4 m^3/s)	Days	$Days^{-1}$	0.375
Reservoir loss	yr/m	m/yr	3.357
Stream loss from groundwater pumping for irrigation	Unitless	Unitless	1.221
Surface water withdrawal for public supply	Unitless	Unitless	1.0

The calibration parameters are used to estimate loads derived from each source. For example, if 100 kg of atmospheric nitrogen is deposited on a landscape, 16.3% of that nitrogen is exported from the landscape. The amount exported to the landscape is then multiplied by the coefficients associated with land-to-water delivery. Finally, the amount of that loading delivered to a downstream watershed outlet is estimated by multiplying the amount of nitrogen delivered to the stream by the aquatic loss parameters for the downstream reaches.

2.3.2. SPARROW Model Outputs

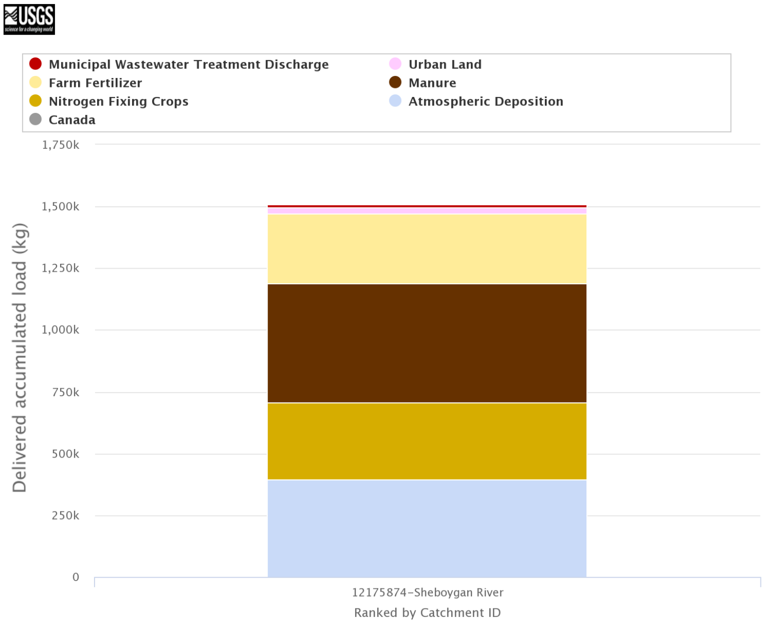
The SPARROW model has an online application that allows for easy evaluation of the results of the model (USGS, 2020). The application includes model results for total phosphorus, total nitrogen, suspended sediment, and streamflow. It provides results at different scales. From smallest to largest the scales are catchments, 8-digit hydrologic unit code watersheds, tributaries, states, and major drainage areas. The application provides results for concentration (mg/L), accumulated load (kg), incremental load (kg), accumulated yield (kg/km^2), incremental yield (kg/km^2), delivered accumulated load (kg), delivered accumulated yield (kg/km^2), delivered incremental load (kg), and delivered accumulated yield (kg/km^2). Incremental values represent the loading from individual catchments, and accumulated values represent the loading from the individual catchment and all upstream catchments.

For this evaluation the catchment-level outputs of total nitrogen from the SPARROW model are assessed. Delivered accumulated load provides an estimate of the source type (municipal wastewater treatment discharge, farm fertilizer, nitrogen fixing crops, urban load, manure, atmospheric load, and load from Canada) of nitrogen from all upstream catchments. The output of the SPARROW application for delivered accumulated load at the Sheboygan River monitoring gage near Sheboygan is provided in Figure 2.2. At the Sheboygan River gage, the largest source of in-stream nitrogen is manure.

FIGURE 2.2

Delivered accumulated load (kg) at the Sheboygan River gage

Figure source: USGS, 2020

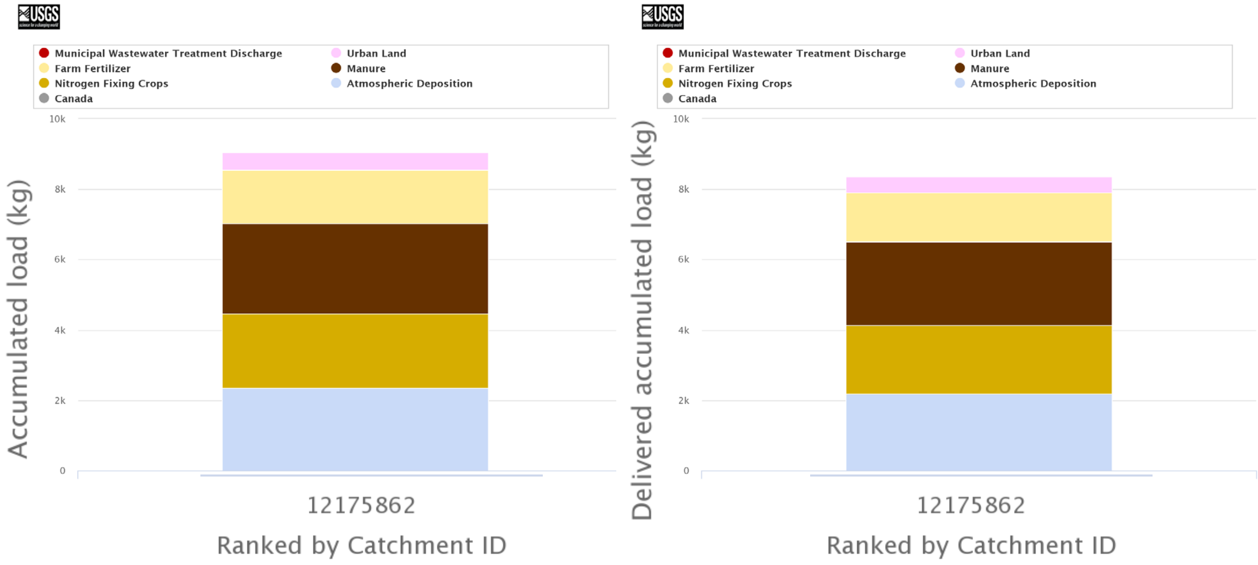


Accumulated loads for subbasins are characterized by SPARROW in two ways: accumulated load and delivered accumulated load. *Accumulated load* represents the total load entering a catchment from upstream catchments and internal loading. *Delivered accumulated load* represents the total load exiting the catchment. The two values may be different because *delivered accumulated load* incorporates aquatic losses that occur in the catchment reaches. The impact of the delivered loads for a tributary to the Mullet River is provided in Figure 2.3. For this catchment, the accumulated load delivered to the catchment is 9,052 kg. The delivered accumulated load that exits the catchment is 8,368 kg. The results show 684 kg of nitrogen is lost in the stream reach, which accounts for approximately 7.5 percent of the accumulated load. Put differently, 92.5 percent of accumulated load is delivered to the catchment outlet. This value is known as the ‘delivery factor’, which is an important concept that summarizes the aquatic losses for each catchment.

FIGURE 2.3

Accumulated load versus delivered accumulated load for catchment in the Sheboygan River basin

Figure Source: USGS, 2020 040301010903



In addition to the viewer, the SPARROW model also contains a database with all inputs and outputs for the modeled watershed. Data from the database can be extracted to estimate the inputs from sources within individual model catchments. The total source inputs are the loads that are generated in a catchment before any land-to-water delivery or aquatic loss are considered. The source inputs can be compared to mass balance approaches that estimate the sources of all nutrients in a watershed. The following section compares the results from the SPARROW model to the results from the other analyses in this report.

3. COMPARISON OF SPARROW AND MASS BALANCE CALCULATIONS

Results from the SPARROW model can be compared to the results from the mass balance analysis from Appendix D of the nitrogen analysis report. The results can also be compared to the outputs from the long-term trend sites estimated by the Wisconsin Department of Natural Resources (DNR), which is discussed in Appendix B of the nitrogen analysis report. The following sections summarize the results of the comparison.

3.1. Mass Balance Inputs

The analysis described in this report includes a mass balance performed by the DNR. The DNR mass balance summarizes nitrogen inputs from both agricultural lands in a subbasin and nitrogen inputs from all sources in the subbasin. The methodology and the results of the mass balance are provided in Appendix D of the nitrogen analysis report.

Results from the DNR analysis are compared to the SPARROW model inputs to determine how closely the two analyses match. The mass balance performed by the DNR and the input sources from the SPARROW model utilize some of the same datasets, but other datasets are different. Data sources for the DNR mass balance are summarized in Appendix D, and data sources for the SPARROW model are summarized in Table 2.2. A comparison of the sources is provided in Table 3.1. The mass balance performed by DNR only evaluates the nitrogen inputs on the landscape and at point sources, and it does not account for any delivery of the inputs to downstream waters.

TABLE 3.1

Data source used for SPARROW model and DNR analysis

Variable	Source of SPARROW data	Source of DNR Data
Atmospheric deposition	EPA Community Multiscale Air Quality Modeling System (CMAQ)	National Atmospheric Deposition Program (NADP)
WWTPs	EPA Integrated Compliance Information System (ICIS) and EPA Permit Compliance System (PCS)	DNR SWAMP Database
Urban and open areas	National Land Cover Database (NLCD)	National Land Cover Database (NLCD); Book values for urban area export
Fertilizers (farm)	Association of American Plant Control Officials (AAPFCO) commercial fertilizer sales for 2012	United States Geological Survey (USGS) County-level estimates of nitrogen and phosphorus
Manure	United States Department of Agriculture 2012 Census of Agriculture.	Wisconsin DNR Manure Analysis
Fixation	2012 Cropland Data Layer	Cropland Data Layer (CDL) 2009-2018; Book values for fixation estimates
Canada Load	USGS Stream Gages	None

To calculate the overall inputs from the SPARROW model, the database included with the SPARROW model files is required. The database, which is a .sqlite file, includes a table named ‘inputs’ that represents the raw inputs. The inputs in the database represent the estimated nitrogen loads that are used in the model before any of the model coefficients and reductions are applied.

Inputs for atmospheric deposition, wastewater treatment plants, farm fertilizers, manure, and Canada loads are all provided as a mass of nitrogen in kg. Inputs for urban areas and nitrogen fixation are provided as the area of each landscape. To estimate the load from these areas, the coefficients in Table 2.5 are utilized.

For nitrogen fixation the SPARROW model estimates 667 kg/km^2/yr is available for transport. The total load available for transport is calculated by multiplying the area of nitrogen fixation crops by the model coefficient. This value only provides an estimate of nitrogen load that is available for transport. In order to estimate the amount of nitrogen load on the landscape, an additional coefficient is required. For this analysis, nitrogen load from nitrogen fixing crops is assumed to be available at the same rate as the nitrogen fertilizer. The amount of farm fertilizer applied that is available for delivery is 0.032, meaning only 3.2% of the total nitrogen fertilizer applied to a landscape is available for delivery to the reach. Using this value, the total estimated nitrogen load on the landscape from nitrogen fixing crops is calculated by multiplying the total area of nitrogen fixing crops by 667 kg/km^2/yr and dividing by 0.032.

For urban nitrogen load the model estimates 122 kg/km^2/yr is available for transport. For this analysis, nitrogen load from urban areas is assumed to be available at the same rate as the fraction of wastewater treatment plant loads that are available for delivery to the stream. The amount of wastewater available for delivery to the streams is 0.495, meaning only 49.5% of the total nitrogen generated at a wastewater treatment plant is delivered to the reach. Using this value, the total estimated nitrogen load on the landscape from urban areas is calculated by multiplying the total urban area by 122 kg/km^2/yr and dividing by 0.495.

To compare results from the DNR analysis and the SPARROW analysis, three major river basins that are included in the DNR's Long-Term Trends monitoring program are evaluated. The three major basins, also known as LTT sites, are the Kewaunee River, Sheboygan River, and Manitowoc River. Comparisons of the results from the DNR mass balance and the SPARROW inputs are provided in Figure 3.1 through 3.6 for the three LTT sites. Point sources and urban sources are shown in a separate box in the figure because the SPARROW database expresses them as loads delivered to the waterbody, and they are not directly comparable to the agricultural loads, which are quantified as load applied to the landscape.

FIGURE 3.1

Comparison of nitrogen inputs for the Kewaunee River

Estimates for individual sources from the SPARROW model and the DNR method

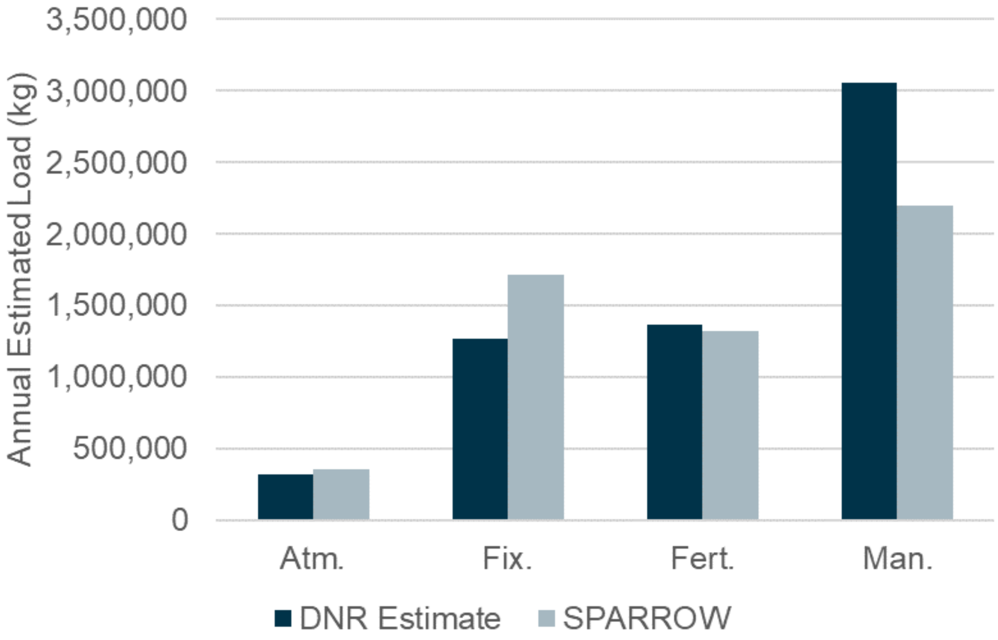


FIGURE 3.2

Comparison of non-agricultural sources for the Kewaunee River

Estimates for individual sources from the SPARROW model and the DNR method

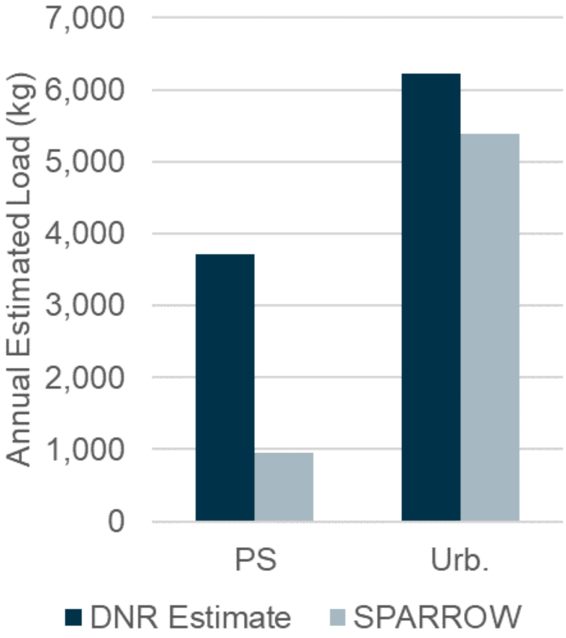


FIGURE 3.3

Comparison of nitrogen inputs for the Manitowoc River

Estimates for individual sources from the SPARROW model and the DNR method

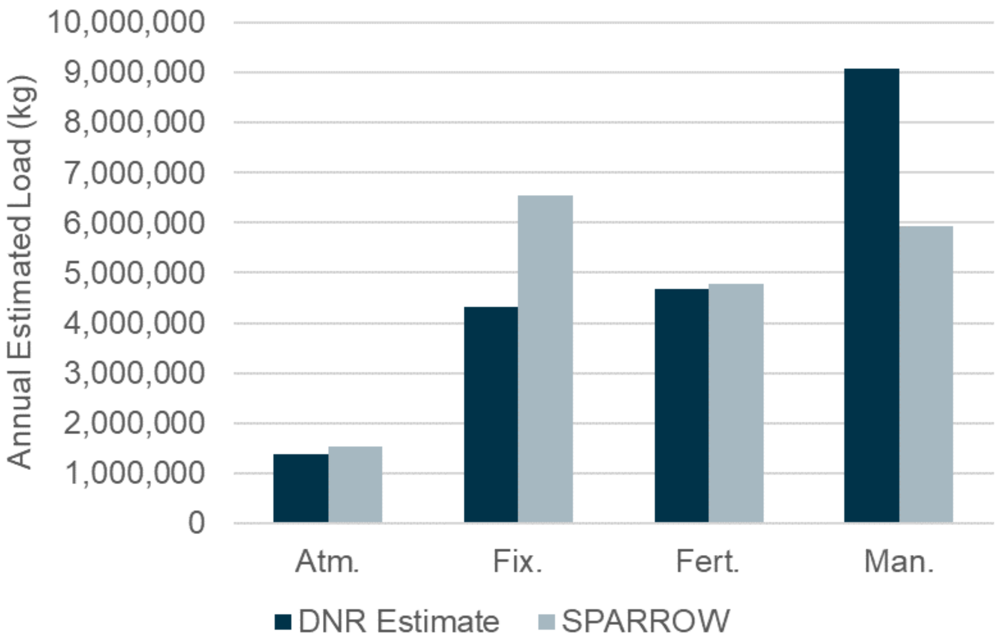


FIGURE 3.4

Comparison of non-agricultural sources for the Manitowoc River

Estimates for individual sources from the SPARROW model and the DNR method

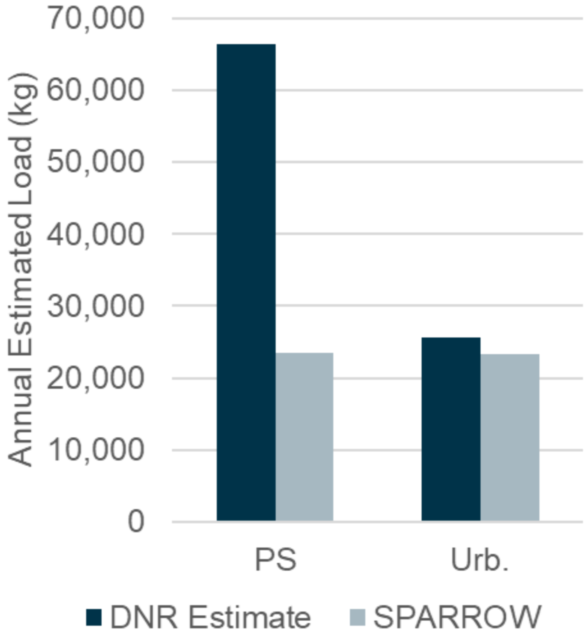


FIGURE 3.5

Comparison of nitrogen inputs for the Sheboygan River

Estimates for individual sources from the SPARROW model and the DNR method

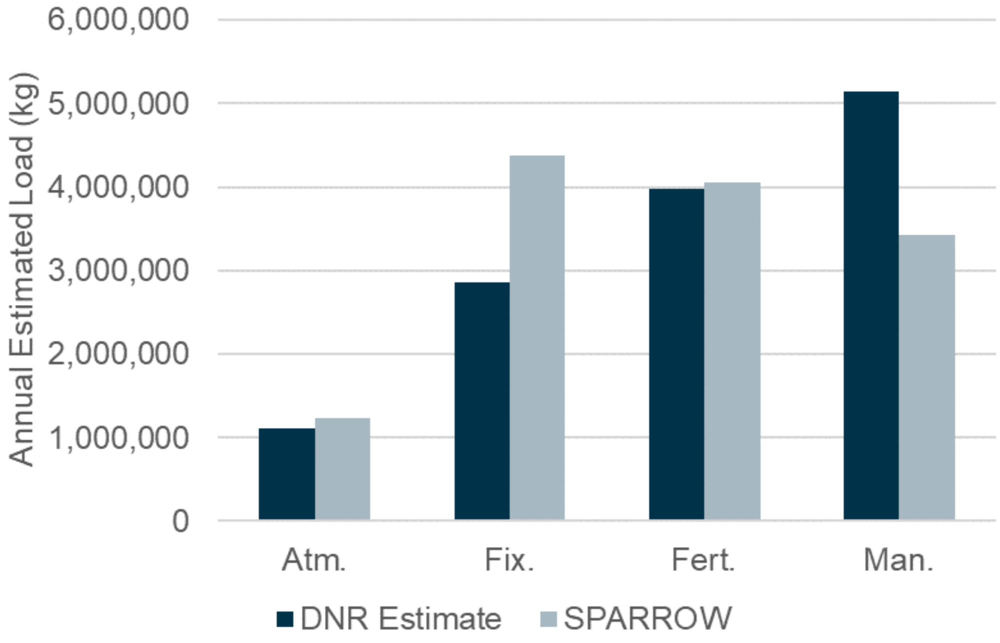
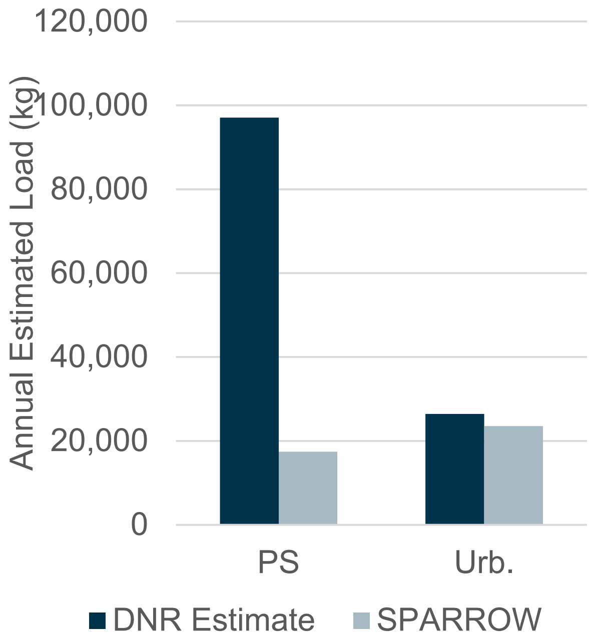


FIGURE 3.6

Comparison of non-agricultural sources for the Sheboygan River

Estimates for individual sources from the SPARROW model and the DNR method



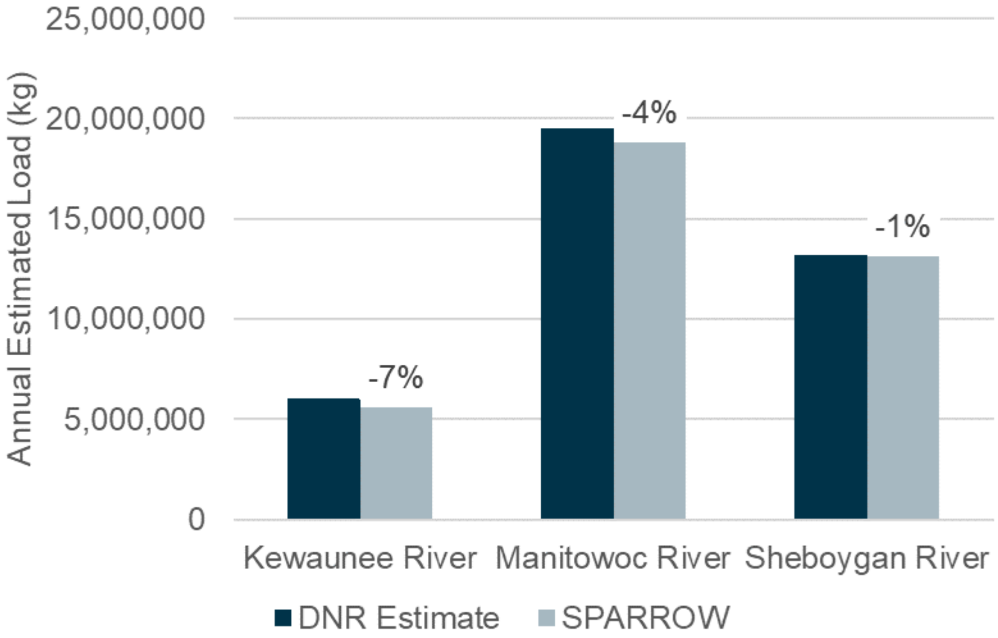
The following observations can be made from the figure:

1. Estimates for nitrogen loads from atmospheric deposition, fertilizer application, and urban areas are similar between the two mass balance methods. The similarities are expected because the inputs for both methods use similar datasets.
2. Estimated landscape load for nitrogen fixation from the SPARROW model is larger than the estimates from the DNR mass balance. The difference may be the result of uncertainty about the amount of nitrogen load generated by nitrogen fixating crops in the SPARROW model. The estimate for fixed nitrogen derived from the SPARROW model assumes the fraction of nitrogen from nitrogen-fixing crops that leaves the landscape is the same as the fraction of nitrogen that leaves the landscape from farm fertilizers.
3. Estimated nitrogen load from manure in the DNR analysis is larger than the results from the SPARROW model. The difference may be the result of methodological differences in the scale and scope of the manure estimates. The DNR manure analysis utilizes detailed data about manure spreading in the study area, while the SPARROW model uses more general, county-wide estimates of animals and manure.
4. Estimated nitrogen load from point sources from the DNR estimate are significantly larger than the nitrogen load in the SPARROW model. The difference in these values is likely caused by assumptions about the concentration of nitrogen in the outflow from point sources. The DNR analysis uses a median nitrogen concentration from measured data for point sources in the Mississippi River basin of Wisconsin. This estimated concentration is applied equally to all point sources in the three LTT basins. The input data for SPARROW model, however, utilizes more detailed data about the treatment processes at each individual facility. Facilities that use more sophisticated treatment methods are assigned a lower value for concentration, and many of the facilities in the basin use the enhanced treatment methods. More information about the point source data used in the SPARROW model can be found in Skinner and Maupin (2019).

Although some sources of nitrogen in the mass balance are different between the DNR methodology and the SPARROW inputs, the total estimated nitrogen mass for the LTT sites is similar. A comparison of the total nitrogen inputs for the DNR estimated inputs and the SPARROW estimated inputs are shown in Figure 3.7. The similarities in mass balance indicates the nitrogen inputs derived from both the DNR analysis and the SPARROW analysis may be reasonable.

FIGURE 3.7

Comparison of total nitrogen inputs for LTT sites



3.2. Long-Term Trends Outputs

As described in the previous section, the inputs for the model are only the first step in estimating downstream loads. To estimate actual outputs from each catchment, estimated inputs are multiplied by calibration parameters for source availability, land-to-water delivery, and aquatic loss.

In-stream loads from the SPARROW model can be compared to the estimated in-stream loads at the three LTT sites in the basin. Estimated loads for the SPARROW model represent delivered loads at the downstream-most catchment that corresponds with the USGS gage used in the LTT analysis. Loads for the LTT sites are extracted from the DNR Long-Term Trends Viewer (WDNR, 2021), which is described in Appendix B of the larger nitrogen analysis report. A comparison of the total load and total yield are provided in Figure 3.8 and Figure 3.9. Since SPARROW normalizes the results to 2012, the flow-normalized LTT results from the year 2012 are used for the comparison. Estimated loads from the LTT sites are represented as WRTDS loads since WRTDS is the methodology used to estimate the loads.

FIGURE 3.8

Comparison of estimated load (kg) delivered to LTT sites

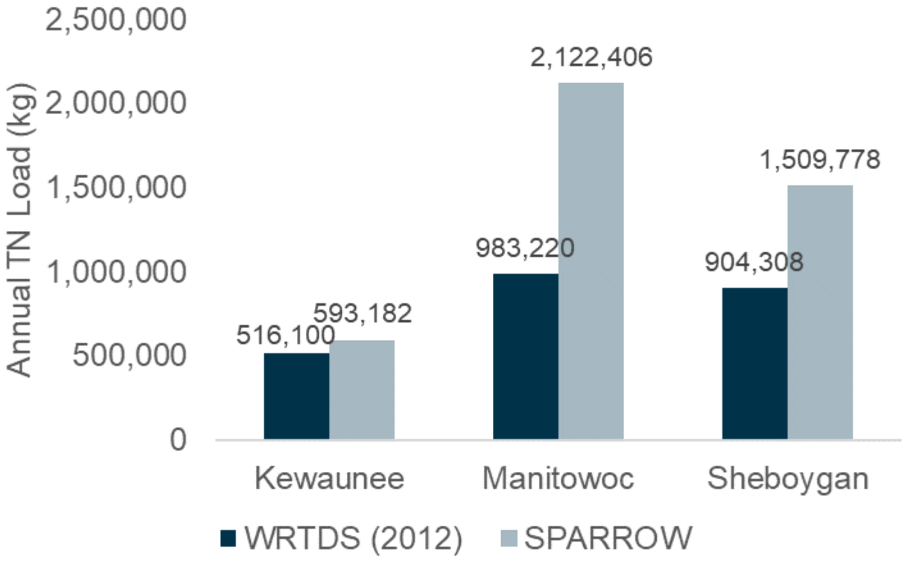
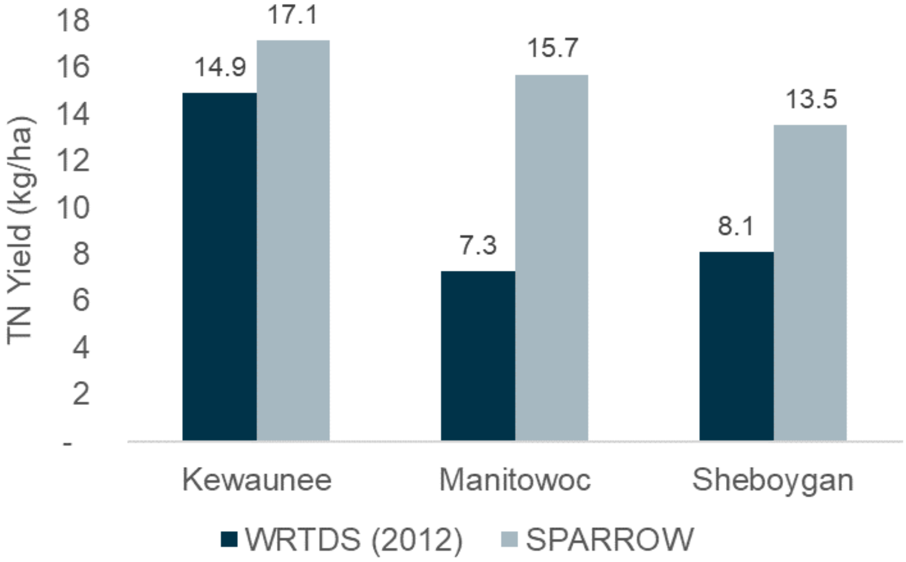


FIGURE 3.9

Comparison of estimated loading rate (kg/ha) delivered to LTT sites



Estimated loads from the SPARROW model are higher than the estimated loads from the DNR estimates. The largest difference occurs in the Manitowoc River basin, where the estimated SPARROW loads are over twice as high as the estimated DNR loads.

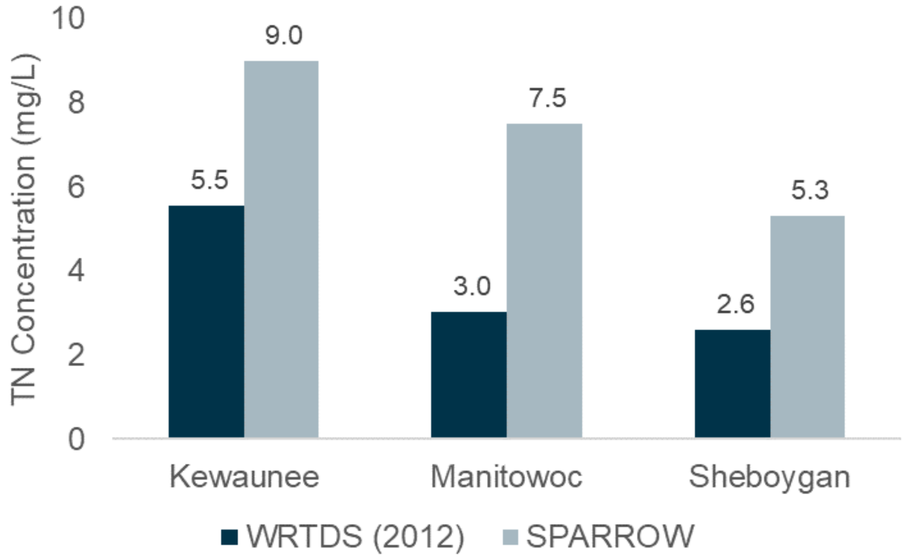
The DNR method estimates loads using flows and concentrations measured at the LTT site. The SPARROW model uses measured flows and concentrations during the calibration process, but the outputs from SPARROW are calculated using coefficients from the calibrated model. Since the DNR method uses direct measurements for its estimate, the DNR results are likely more representative of actual loading when compared to the SPARROW outputs.

The difference in the DNR results and the SPARROW results does not mean the SPARROW model is not an accurate model for other locations. The calibrated SPARROW model parameters are estimated to generate the best fit for all gages in the model domain. Landscapes, geologies, and climates are very different across the large geographic area of the model extent. It is likely the watersheds in the study area have characteristics that are not adequately captured in the generalized SPARROW model parameters. If the SPARROW model is recalibrated for a smaller spatial extent that included the study area, the updated model would likely perform better.

In addition to estimated loads, the SPARROW model provides an estimate of average concentration. A comparison of the concentrations estimated by the DNR and the concentrations estimated by SPARROW are provided in Figure 3.10.

FIGURE 3.10

Comparison of estimated concentration (mg/L) at LTT sites



As with loads, the DNR/WRTDS method estimates concentrations using measured data for concentrations and loads. When compared with measured data, the SPARROW model appears to be overrepresenting the average concentration in the three LTT reaches. The cause of the discrepancies is likely due to the limitations described for the loads. When the differences in loads and concentrations are compared, the ratio of the DNR model and the SPARROW model are not equal. The discrepancy arises because SPARROW estimates concentration by dividing the total load by the measured flows rather than the SPARROW-estimated flows.

Although the DNR analysis and the SPARROW model inputs are similar, the estimated in-stream loads at the watershed outlets for the three LTT sites differ. The discrepancy is likely due to assumptions and calibration parameters within the SPARROW model that may not be representative for the conditions in the study area. Outside the study area, SPARROW has been shown to provide accurate estimates of loads. Before the results are applied, however, local conditions and water quality measurements should be evaluated to confirm the accuracy of the model.

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APPENDIX F

BASEFLOW NITROGEN ANALYSIS FOR THE NORTHEAST LAKESHORE STUDY AREA

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1. BACKGROUND

Streamflow is composed of water from different sources. Generally, the sources can be summarized into three categories: surface runoff, interflow, and groundwater flow. Surface runoff refers to water that enters streams shortly after precipitation events. Interflow refers to the water that passes through the shallow portion of the soil after precipitation events and is slowly discharged into streams. Groundwater flow refers to water that enters streams from deeper water sources that are not quickly impacted by precipitation events. Characterization of the streamflow components is useful for understanding how the stream will respond to precipitation events.

2. BASEFLOW SEPARATION MODEL

Baseflow separation is used to separate streamflow into components that enter a receiving water body at different time intervals. This section describes the methodologies used to evaluate the baseflow in the Northeast Lakeshore TMDL study area.

2.1. Methodology

Stream hydrographs can be plotted to represent the flow over time in a water body. Hydrographs are commonly separated into two components: quick and slow flow. Quick flow represents runoff that enters the stream as the result of a direct runoff event, whereas slow flow represents stream flows that result from a variety of groundwater recharge mechanisms.

Modification of standard baseflow separation methods can be expanded to separate a flow hydrograph into additional components beyond simply quick and slow flow. The additional hydrograph components can provide insight into non-runoff flows that contribute to overall streamflow. For both the standard baseflow separation methodology and the expanded baseflow separation method, the outputs can be coupled with water quality data to estimate pollutant loads from different components of the stream hydrograph.

2.1.1. Stream Hydrographs

The Northeast Lakeshore TMDL study area contains three major basins: Kewaunee River, Manitowoc River, and Sheboygan River. These basins are referred to as Long-Term Trend (LTT) sites because they have long records for streamflow and water quality measurements. Daily hydrographs for the three long-term trend sites in the study area are provided by USGS gages at each site. Details about the long-term trend sites are described in Appendix B of the nitrogen analysis report.

2.1.2. Baseflow Index

Traditional methods of baseflow separation involve manual evaluation of hydrographs. The manual process depends on the expertise and interpretation of the evaluator and is difficult to replicate (Sloto and Crouse, 1996). To avoid the issues with manual separation of hydrographs, automated processes for estimating baseflow have been developed for baseflow separation. The automated methods have advantages over manual methods because they are replicable and fast. The methods rely on assumptions that may not be appropriate for everybody of water, however, so the methods must be used with caution (Lott and Stewart, 2016).

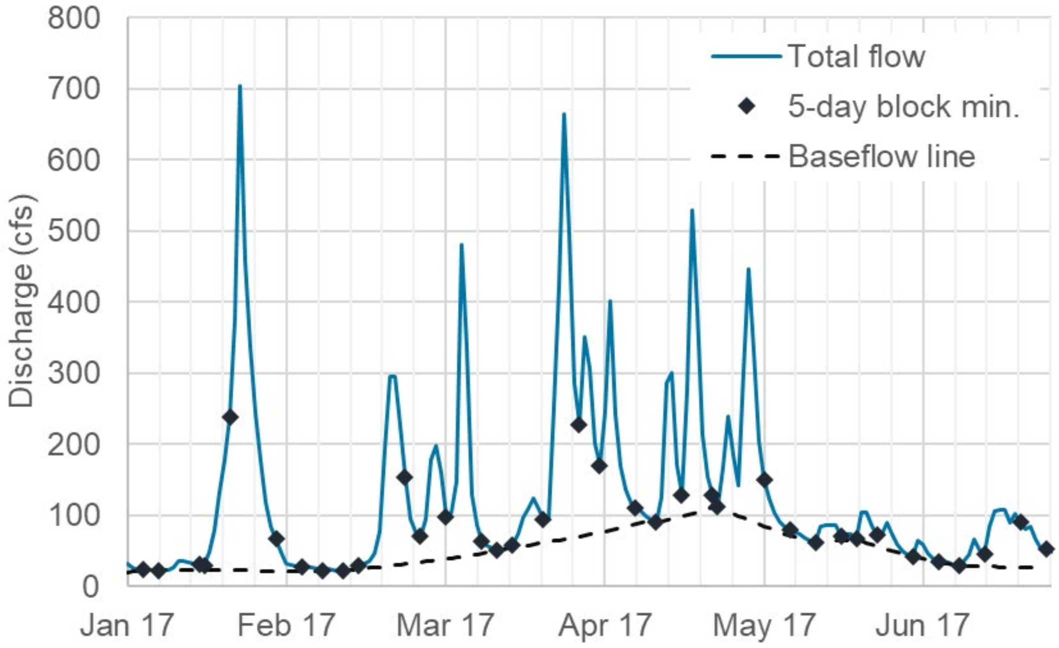
Baseflow separation for this analysis uses the automated smoothed-minima method developed by the UK Institute of Hydrology (Institute of Hydrology, 1980; World Meteorological Association, 2019). The method allows baseflow to be separated into two components: quick and delayed flow. The baseflow separation process involves the following steps (Gustard and others, 1992).

1. A hydrograph is divided into non-overlapping blocks of five days.
2. The minimum flow within each of the blocks is identified.
3. An adjusted minimum flow for each block is calculated by multiplying the minimum flow by 0.9 (also known as the turning point factor).
4. The adjusted minimum flow in each block is compared to the minimum flows from the previous block and the following block (outer values). If the adjusted minimum flow is less than the outer values, the point is identified as a turning point.
5. The turning points are connected by linear interpolation for the entire hydrograph. The resulting line represents the baseflow for the hydrograph
6. The baseflow line is adjusted. When the interpolated values of the baseflow line are greater than the actual streamflow, the baseflow is adjusted to equal the actual streamflow.

An example of the smoothed-minima baseflow separation process is shown in Figure 2.1. The values for the baseflow are calculated using the *bfi* function in the *DVstats* package (Lorenz, 2013) in R-3.6.2 (R Core Team, 2019). The blue line in the figure represents the measured flow from the USGS gage on the Kewaunee River at Kewaunee, WI (04085200). The points in the figure represent the minimum values for each of the 5-day non-overlapping blocks, the light-grey minor axes show the 5-day flow blocks, and the dashed line represents the baseflow line calculated using the smoothed-minima method.

FIGURE 2.1

Example of baseflow separation method for the Kewaunee River



Once the flows are separated, a baseflow index (BFI) can be calculated by dividing the cumulative volume of baseflow by the cumulative volume of total flow. The total flow is equal to the area under the blue line in Figure 2.1, and the baseflow is equal to the area under the dashed line in the figure. The BFI summarizes the percentage of total flow in a stream that can be attributed to baseflow. Streams with high BFIs have sustained river flows even during dry conditions, whereas streams with low BFIs are likely to have little or no flow during dry periods.

2.1.3. Delayed Flow Index

The commonly used methods for baseflow separation face a major limitation: The baseflow component includes all delayed flow components. Delayed flow components can be defined as shallow groundwater flow, intermediate groundwater flow, and deep groundwater flow. Quantifying the different categories of delayed flow is important for understanding the dynamics of the stream.

A delayed flow separation technique is applied to the three major basins in the NE Lakeshore TMDL study area. The calculations performed using the methodologies described in the following section are adapted from Stoelzle and others (2020). The methodology identifies specific breakpoints that separate the total hydrograph into four separate components: short, intermediate, long, and baseline flows.

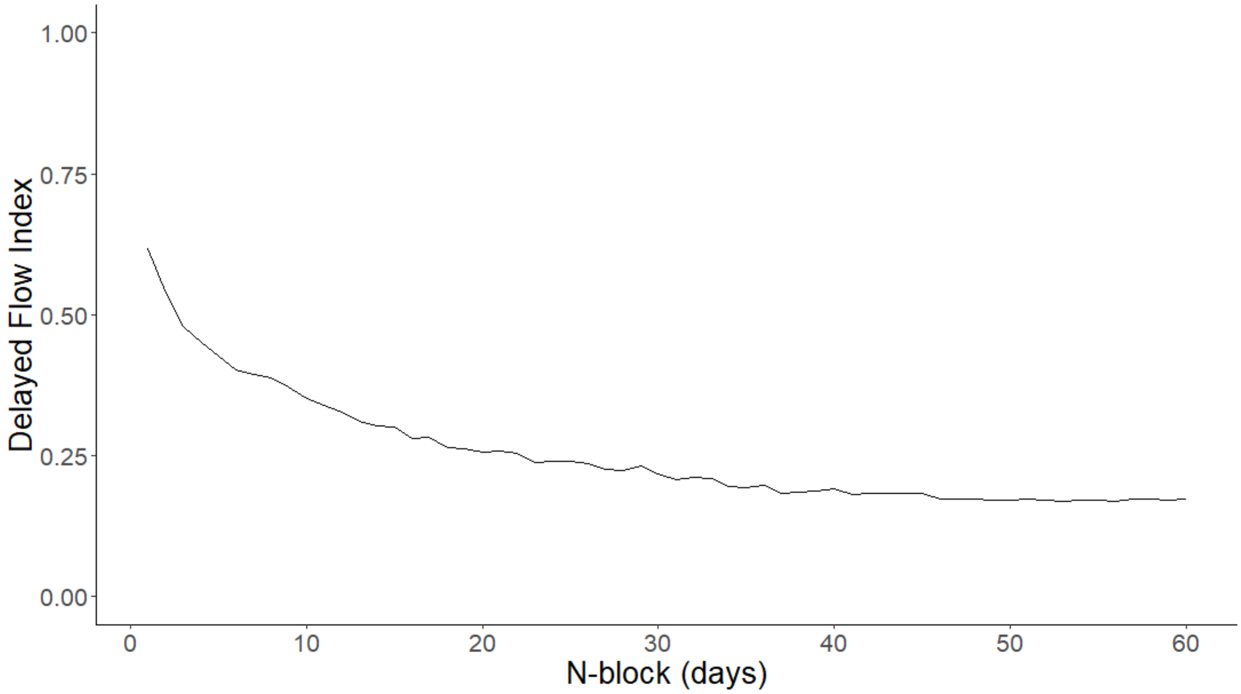
2.1.3.1. Breakpoint Identification

Hydrographs can be separated into unique delay classes that represent different types of baseflows. The delay classes can be defined by identifying breakpoints. Breakpoints delineate unique flow periods, or delay classes, where flow characteristics are similar. For this analysis, four types of delay classes are identified. The delay classes are defined as short, intermediate, long, and baseline. The short delay class is generally the same as the quick flow from the standard baseflow separation method described in the previous section. The baseline delay class represents the long-term, deep groundwater flow that would be present in the stream even during extended dry periods. The intermediate and long delay classes represent different types of shallow groundwater flow such as bank storage and interflow.

The first step to estimating breakpoint is calculating a characteristic delay curve (CDC). The CDC is a curve that represents a value for delayed flow index for a continuous series of block lengths. The delayed flow index is calculated using the same smoothed-minima methodology for baseflow index described in Section 2.1.2. The method is used to derive a delayed flow hydrograph for specified block-lengths (in days). The standard method described in Section 2.1.2 uses a standard block-length of 5 days, but the delayed flow index is calculated for block-lengths ranging from 1 to 90 days. The block length is plotted versus the delayed flow index to generate the characteristic delay curve. An example of the characteristic delay curve for the Kewaunee River is provided in Figure 2.2.

FIGURE 2.2

Characteristic delay curve for the Kewaunee River



The characteristic delay curve is evaluated to estimate four time periods with similar flow characteristics. The time periods are determined by splitting the curve into four linear segments with different slopes. The boundaries of these linear segments are classified as breakpoints. The breakpoints are then used as the block lengths to calculate a delayed flow index for each delay class. The breakpoints are calculated using the *segmented* package in R (Vito, 2021).

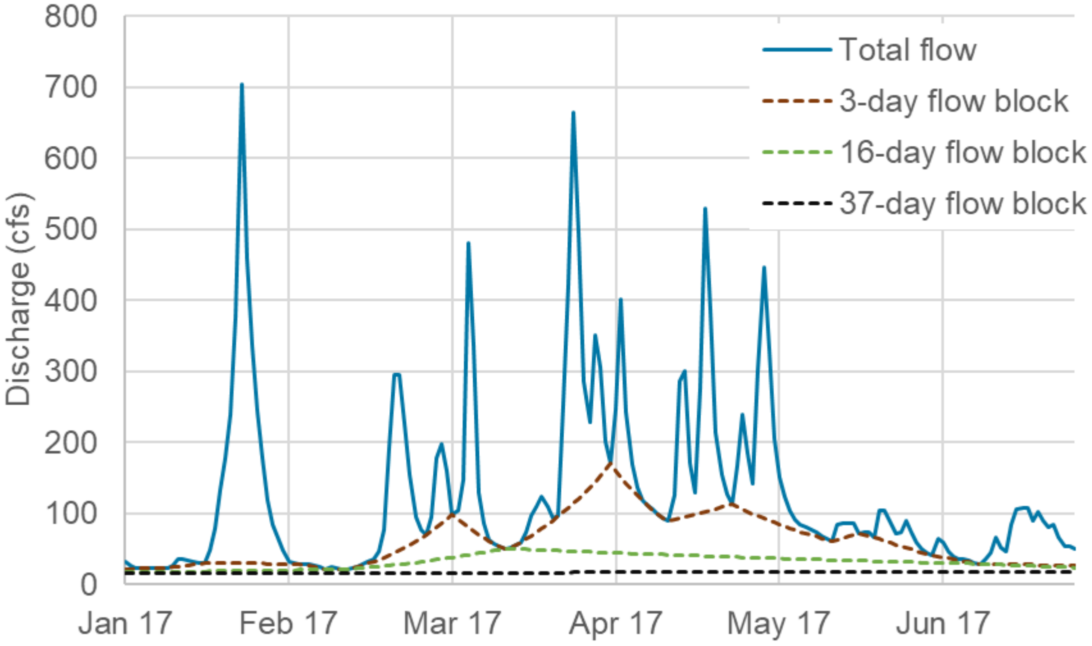
2.1.3.2. Delayed Flow Index and Flow Separation

Once the breakpoints are identified, the characteristic delay curve described in the previous section can be used to establish a delayed flow hydrograph for each delay class. The delayed flow hydrograph for each delay class can be calculated using the smoothed minima method. For the analysis the block size is set equal to the breakpoint values (Stoelzle and others, 2020).

An example of the delayed flow hydrographs for the Kewaunee River is shown in Figure 2.3. The blue line represents the total flow, and the dashed lines represent the delayed flow hydrograph for three unique block sizes. The area under each line represents the total flow volume associated with each delay class. For example, the area below the 3-day flow block represents the total volume of flow that enters the stream after a delay of approximately 3 days.

FIGURE 2.3

Delay class separation for the Kewaunee River



The delayed flow hydrographs are used to calculate the delayed flow index for each of the flow classes. The delayed flow index is equal to the total volume associated with each flow class divided by the total flow volume. For example, the delayed flow index for the short delay class, which is associated with the 3-day flow block, can be calculated by dividing the total area under the brown dashed line by the total area under the blue line.

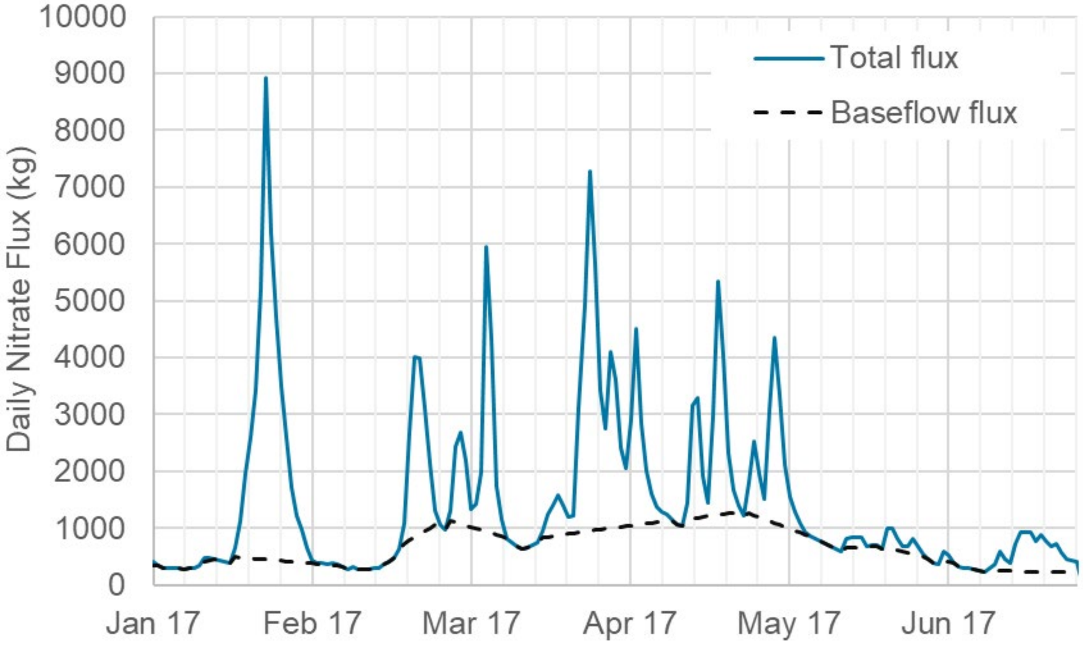
2.1.4. Nitrate Load and Concentration Estimation

The results from the delayed flow separation can be applied to estimate the nutrient loading contribution from the different delay classes. When the delayed flow hydrographs are paired with measured concentrations, loading for each class can be calculated. Details on the methodology to estimate loading contributions can be found in a USGS report (Spahr and others, 2010), and a summary of the methodology for estimating nitrate loads is provided below.

The LOADEST model (Runkel and others, 2004) can estimate total loads from continuous flows and periodic monitoring data. The three major basins in the study area have many nitrate samples that were collected on a semi-regular basis over the last many decades. Samples at the three sites are stored in the Wisconsin DNR’s SWIMS database (WDNR, 2021). For the general baseflow model, the nitrate samples are classified into two categories: baseflow samples and total flow samples. Baseflow samples are defined as samples that occurred on days when the baseflow is 77 percent or more of the total flow (Spahr and others, 2010, p.3). Loads are estimated using the LOADEST model for both total flow and baseflow. For the total flow estimate, all samples are used. For the baseflow model only the baseflow samplse are used. Calculations for the loads are performed using the *rloadest* package in R (Runkel and De Cicco, 2017). An example of the estimated daily fluxes for total flow and baseflows is shown in Figure 2.4.

FIGURE 2.4

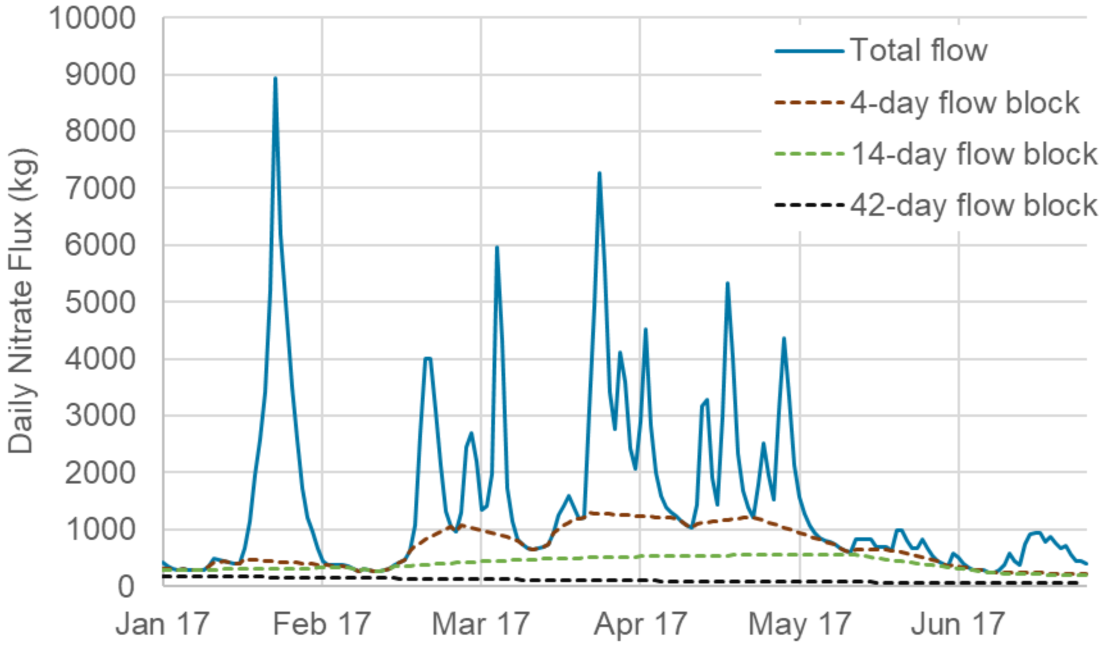
Baseflow nitrate load separation for the Kewaunee River



The same methodology can be used for characterizing loads for the four delay classes defined in the previous sections. Samples are defined for the four flow classes: short, intermediate, long, and baseline. The samples for each delay class are identified using the same process as the standard baseflow model – if the sample is collected on the day the flows from each delay flow category is 77 percent or more of the total flow, the sample is defined as a concentration for that delayed flow. The LOADEST model is run with the delayed flow hydrograph and the corresponding concentrations to estimate the total load for each flow category. An example of the daily fluxes for total flow and the delay categories is shown in Figure 2.5.

FIGURE 2.5

Delay class nitrate load separation for the Kewaunee River



A delayed load index is calculated using the same methodology as the methodology for calculating a delayed flow index. The area under the curves in Figure 2.5 represent the total load over the given period. Estimated load for each delay class is calculated, and the results are divided by the total flux to obtain the percent of total flux contributed by each flow category. The percentage represents the delayed flow load index.

3. RESULTS

Baseflows are analyzed for the three major basins in the study areas. Analysis of baseflow is performed for the water years (October through September) 2001 to 2020. The following sections detail results for the baseflow index, baseflow index, and baseflow load separation.

3.1. Baseflow and Baseflow Index

Baseflow index is a commonly calculated variable for watersheds. For this study the baseflow index is calculated at the three LTT sites using the data and methods summarized above. The calculation of a baseflow index allows for a direct comparison to other published values.

3.1.1. Baseflow index calculation summary

Baseflows are calculated using an N-block of 5 days and a turning point factor of 0.9. These values are a commonly accepted standard for the analysis of baseflow (Institute of Hydrology, 1980; Gustard and others, 1992; World Meteorological Organization, 2019)

Baseflow hydrographs for the period from water year 2010 and water year 2019 are summarized in Figures 3.1 through 3.3. For better visualizatio, the period is truncated to ten years and the baseflows are summarized by month.

FIGURE 3.1

Monthly baseflow for Kewaunee River near Kewaunee, WI

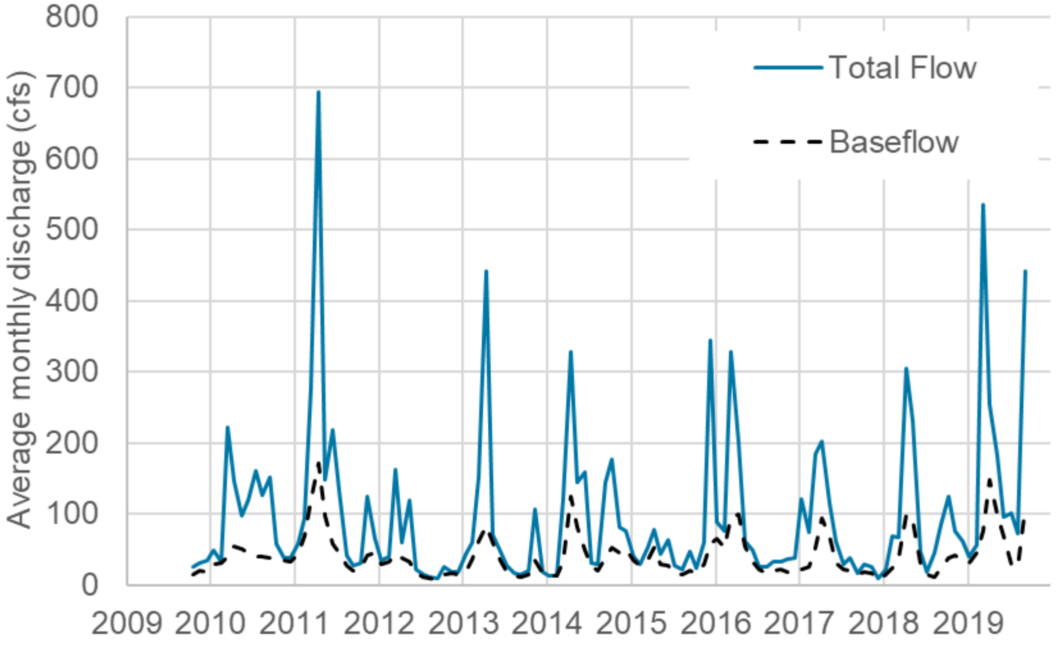


FIGURE 3.2

Monthly baseflow for Manitowoc River at Manitowoc, WI

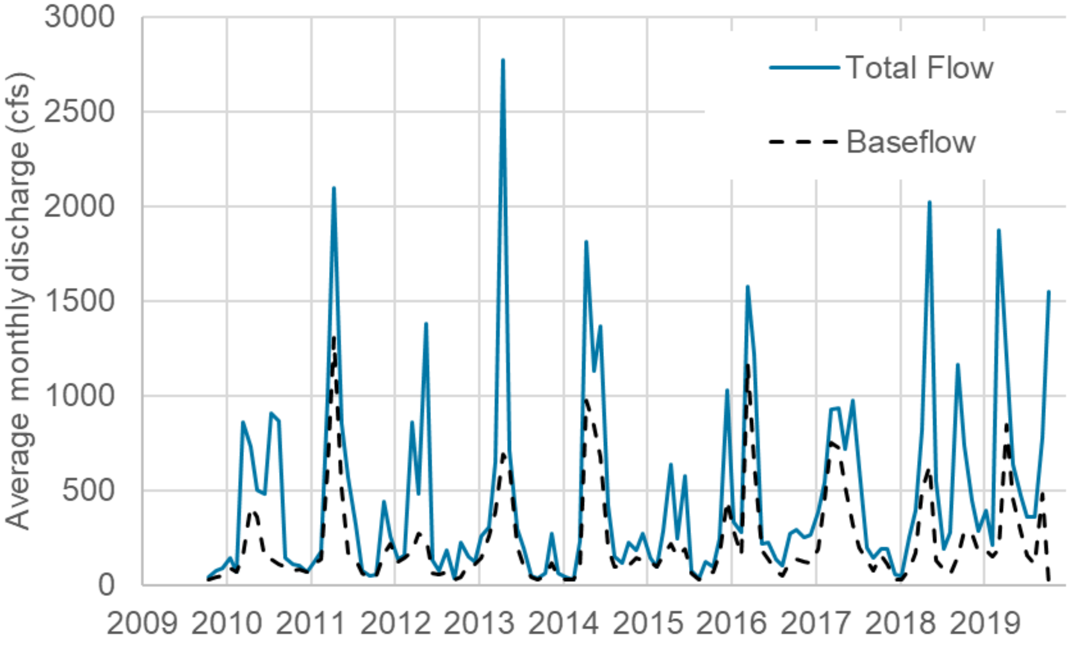
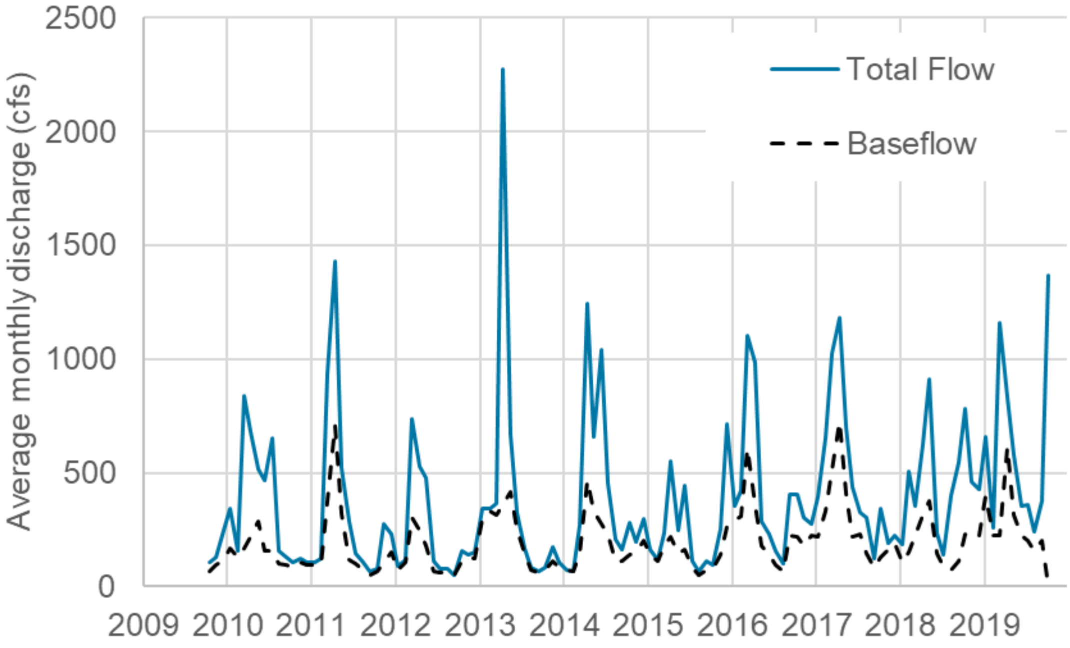


FIGURE 3.3

Monthly baseflow for Sheboygan River at Sheboygan, WI



Results from the baseflow separation are also used to calculate the baseflow index. The baseflow index for the three major basins is provided in Table 3.1. The baseflow index represents the fraction of the total flow that baseflow contributes. A higher baseflow index indicates baseflow contributes more to the total flow in the stream.

TABLE 3.1

Baseflow index for the three major basins

Major basin	Baseflow index (BFI)
Kewaunee River at Kewaunee, WI	0.42
Manitowoc River at Manitowoc, WI	0.50
Sheboygan River at Sheboygan, WI	0.50

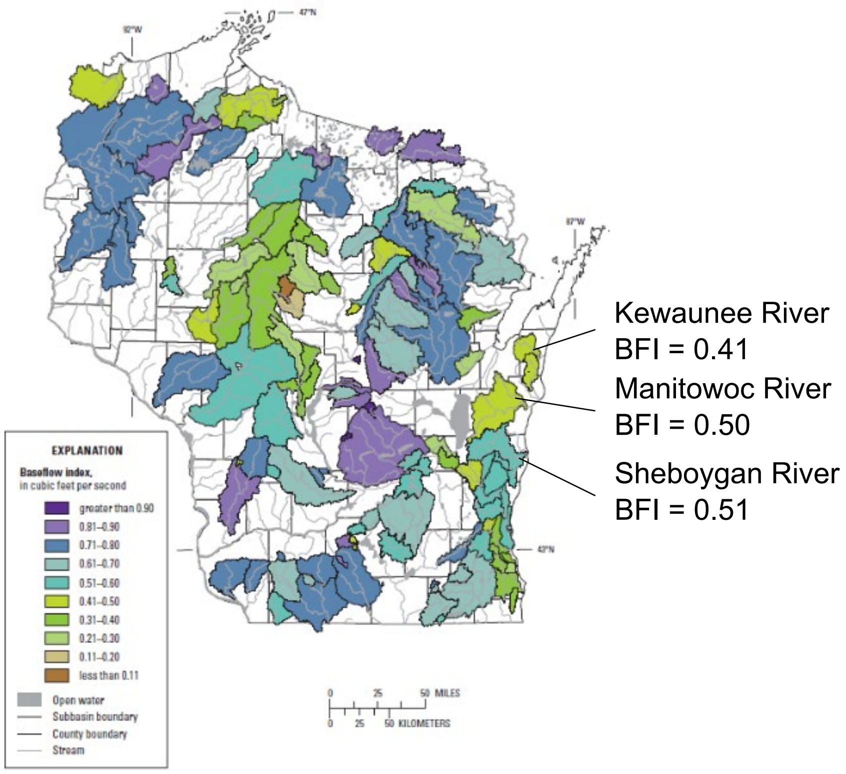
3.1.2. Baseflow index from other studies

Other studies provide estimates of baseflow indices for streams throughout the United States. The values of the baseflow index from the studies can be used to evaluate the results from this analysis.

Gebert and others (2011) used the smoothed-minima method to estimate a baseflow index for watersheds throughout the state of Wisconsin. The estimates are performed for years between 1970 through 1999. Baseflow index estimations from the report are shown in Figure 3.4. The three sites in the study area are highlighted on the figure, and the baseflow index is reported.

FIGURE 3.4
Baseflow index for Wisconsin (1970-1999)

Figure source: Gebert and others, 2009, p. 3



Kewaunee River
BFI = 0.41

Manitowoc River
BFI = 0.50

Sheboygan River
BFI = 0.51

Figure 1. Spatial distribution of base-flow index, 1970–99, at streamflow-gaging stations in Wisconsin.

TABLE 3.2
Baseflow index data for the three major basins

Data Source: Gebert and others, 2011, p. 84

Major basin	Period of Analysis	Baseflow index (BFI)
Kewaunee River at Kewaunee, WI	1970-1995	0.412
Manitowoc River at Manitowoc, WI	1973-1996	0.495
Sheboygan River at Sheboygan, WI	1970-1999	0.512

Another study estimates baseflow index for the entire continental United States. Wolock (2003) used USGS flow data and the smoothed-minima method to estimate baseflow at gages across the continental United States. The methodology for estimating baseflow index is similar to Gebert and others (2011), but different date ranges are used for the studies. The results for baseflow index from Wolock (2003) are interpolated to create a 1-kilometer grid. The results from the grid are shown in Figure 3.5, and information about the baseflow index for the three major basins are provided in Table 3.3.

FIGURE 3.5

Baseflow index grid from Wolock (2003)

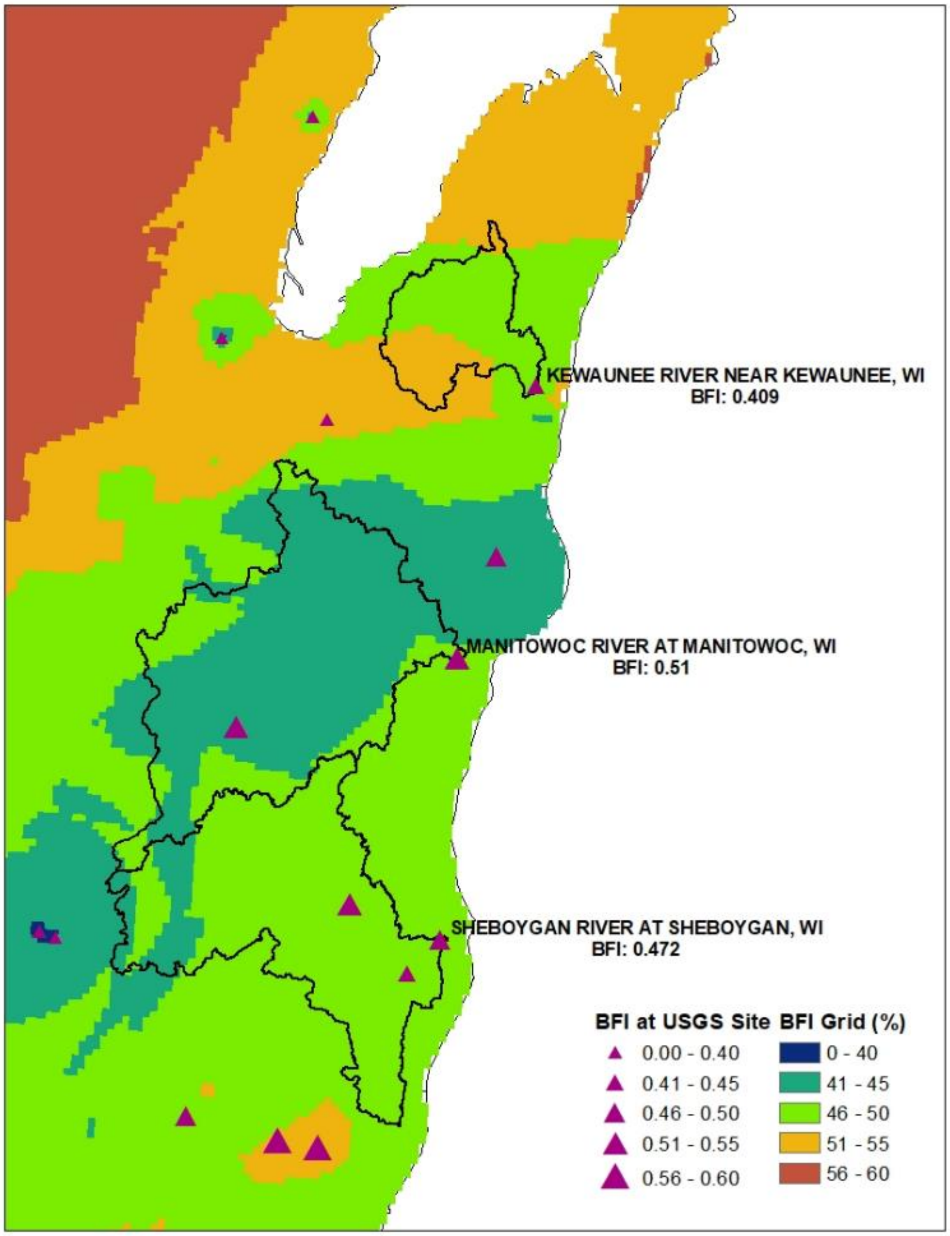


TABLE 3.3

Baseflow index data for the three major basins

Data Source: Wolock, 2003

Major basin	Period of Analysis	Baseflow index (BFI)
Kewaunee River at Kewaunee, WI	1964-2000	0.409
Manitowoc River at Manitowoc, WI	1972-2000	0.510
Sheboygan River at Sheboygan, WI	1916-2000	0.472

3.1.3. Comparison of baseflow index to published values

The values calculated for baseflow index in the two previous studies and this study can be compared for consistency and evaluation of any changes to baseflow that may occur over time. A summary of the results is provided in Table 3.4.

TABLE 3.4

Comparison of baseflow index across three major basins

Major basin	This Study	Gebert and others (2011)	Wolock (2003)
Kewaunee River at Kewaunee, WI	Dates: 2000-2019 BFI: 0.42	Dates: 1970-1995 BFI: 0.412	Dates: 1964-2000 BFI: 0.409
Manitowoc River at Manitowoc, WI	Dates: 2000-2019 BFI: 0.50	Dates: 1973-1996 BFI: 0.495	Dates: 1972-2000 BFI: 0.510
Sheboygan River at Sheboygan, WI	Dates: 2000-2019 BFI: 0.50	Dates: 1970-1999 BFI: 0.512	Dates: 1916-2000 BFI: 0.472

The estimated baseflow index for individual sites across the three studies is similar, which indicates the methodology and calculations are consistent. The Kewaunee River and Sheboygan River both demonstrate a slight trend over time. The baseflow index increases as the analysis dates increase. Changes in the landscape, including increases in urbanized area and tile drainage, can impact baseflow in streams. Urbanization can decrease baseflow because impervious areas generate more runoff and reduce infiltration. Tile drainage is more complex and can either increase or decrease baseflow. Tiled areas can reduce runoff by encouraging infiltration, which may lead to a higher baseflow. However, tiled areas decrease deep infiltration by intercepting water in the top portion of the soil and discharging it to receiving waters. The impact of tile drains depends on how long the intercepted tile flows discharge to streams. Both urbanization and tile drainage have increased over time in the three major basins. An increase in baseflow over time for the

Kewaunee River and Sheboygan River, however, indicates the impact of tile drainage that increases baseflow may be a driving factor.

3.2. Delayed Flow Index

The breakpoint analysis for the three major basins is performed using flows from 2000 through 2020. The result of the breakpoint analysis is presented in Table 3.5. Values in the table represent the cutoffs for different delay classes associated with the stream. For example, the 'short-interflow' breakpoint is three days for the Kewaunee River and four days for the Manitowoc River and Sheboygan River. This value implies that flows in the stream originating three or four days after a runoff event are characterized as short interflow.

TABLE 3.5

Delayed flow breakpoints for the three major basins

Major basin	Short Interflow	Long Interflow	Groundwater Flow
Kewaunee River at Kewaunee, WI	3 days	16 days	37 days
Manitowoc River at Manitowoc, WI	4 days	15 days	34 days
Sheboygan River at Sheboygan, WI	4 days	20 days	52 days

The breakpoints in Table 3.5 can be applied to the flows for the three major basins to estimate the total flow associated with each delay class. The proportion of flow for each delay class is calculated using the smoothed-minima method with the block size set equal to the delay flow breakpoints. Results for the delayed flow analysis are summarized in Table 3.6. The values in the table represent the proportion of the total flow associated with each block size.

TABLE 3.6

Delayed flow index for three major basins

Major basin	Short Interflow	Long Interflow	Groundwater Flow
Kewaunee River at Kewaunee, WI	0.47	0.28	0.18
Manitowoc River at Manitowoc, WI	0.55	0.27	0.15
Sheboygan River at Sheboygan, WI	0.55	0.32	0.21

Results from the delayed flow analysis can also be used to estimate the total percent of streamflow associated with each delay class. The results of this analysis are presented in Table 3.7. For example, the flows associated with short interflow contribute 15 percent of the total flow in the Kewaunee River. The values in the table represent the total area of the shaded portions of the categories in Figures 3.6 through 3.8. The figures represent monthly-average flows in each flow category for water years 2010 through 2019. In the figure, the "Short" delayed class represents runoff, the "Intermediate" represents short interflow, the "Long" delay class represents long interflow, and the "Baseline" delay class represents groundwater flow.

TABLE 3.7

Percent of total flow in delayed flow categories for the three major basins

Major basin	Runoff	Short Interflow	Long Interflow	Groundwater Flow
Kewaunee River at Kewaunee, WI	52%	20%	9%	18%
Manitowoc River at Manitowoc, WI	45%	28%	11%	15%
Sheboygan River at Sheboygan, WI	45%	23%	11%	21%

FIGURE 3.6

Delayed flow hydrographs for the Kewaunee River

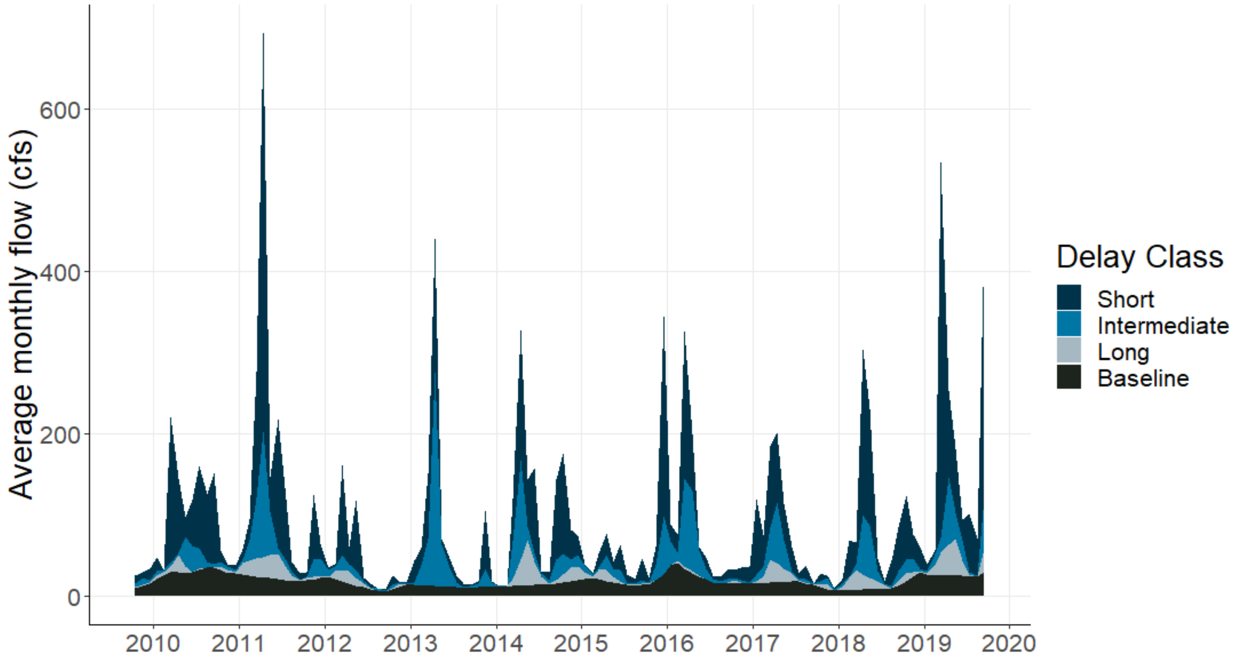


FIGURE 3.7

Delayed flow hydrographs for the Manitowoc River

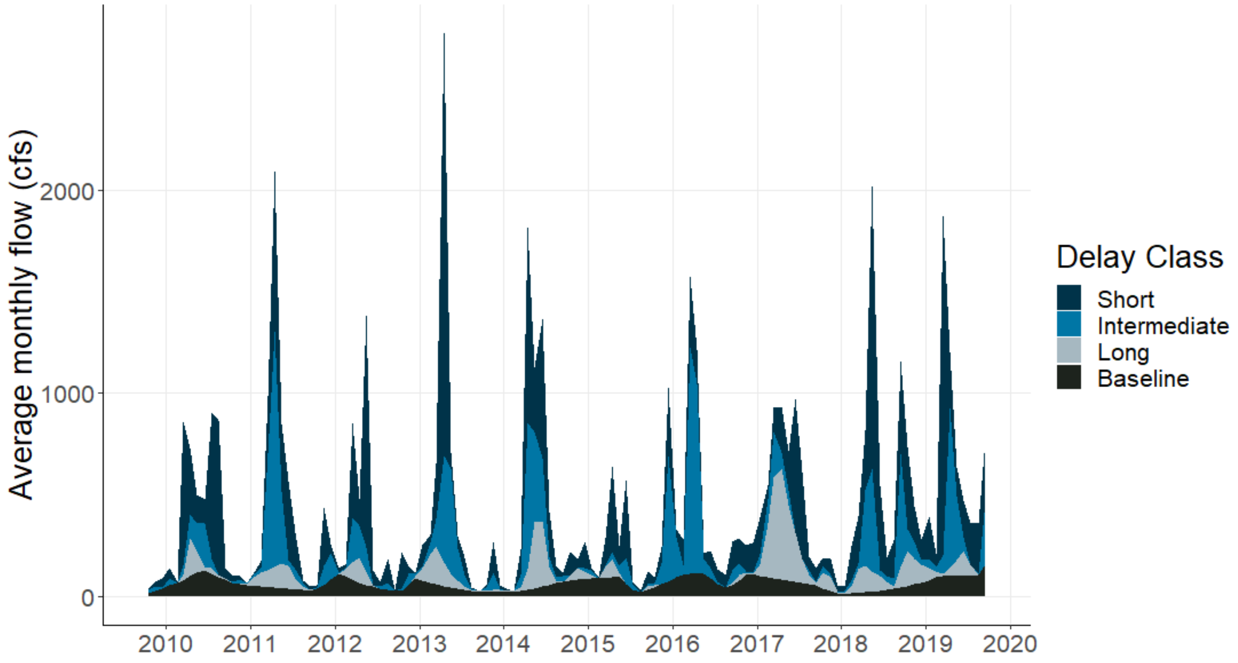
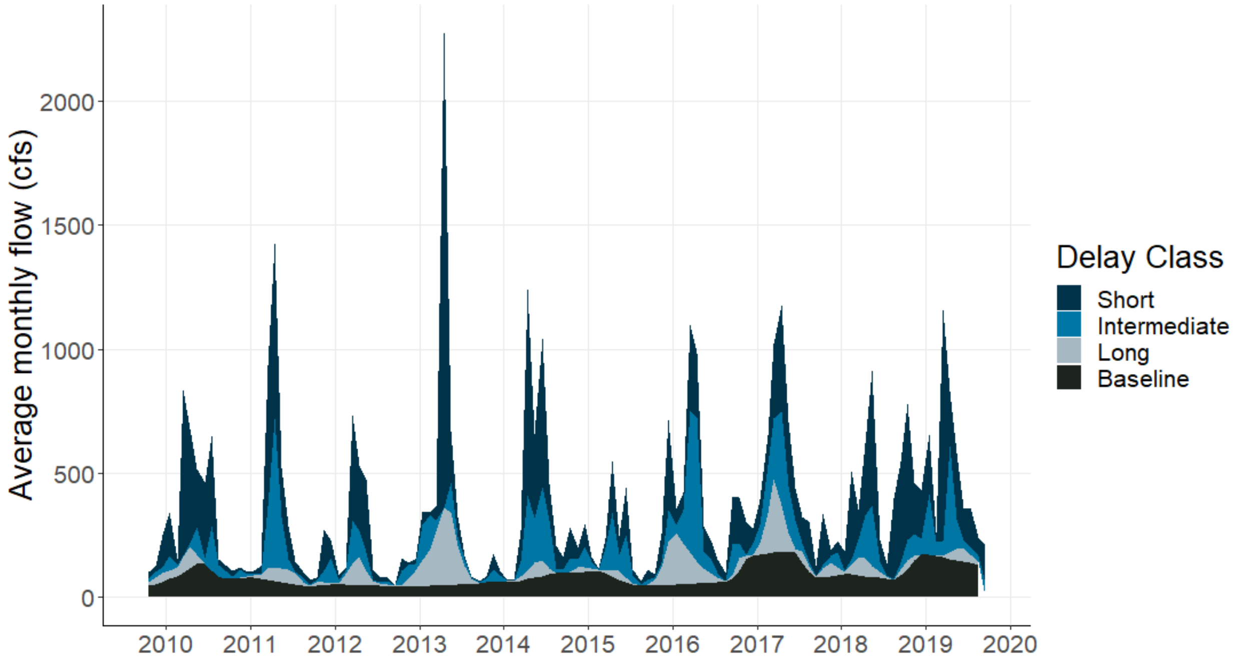


FIGURE 3.8

Delayed flow hydrographs for the Sheboygan River



3.3. Baseflow Nitrate Loading

Baseflow nitrate loading is estimated using the methodology described in Section 2.1.4. Evaluation of baseflow loads provides insight about the relative load contribution from runoff versus the 5-day baseflow. Summaries of the relative contributions at the three sites in the study area are provided in Figures 3.9 through 3.11. A summary of the average contribution of baseflow loads is provided in Table 3.8. Values in the table represent the percent of total 5-day baseflow flow and the percent of the total 5-day baseflow flux. The concentrations for the total flow and baseflow are compared in Figure 3.9.

FIGURE 3.9

5-day baseflow flux for the Kewaunee River

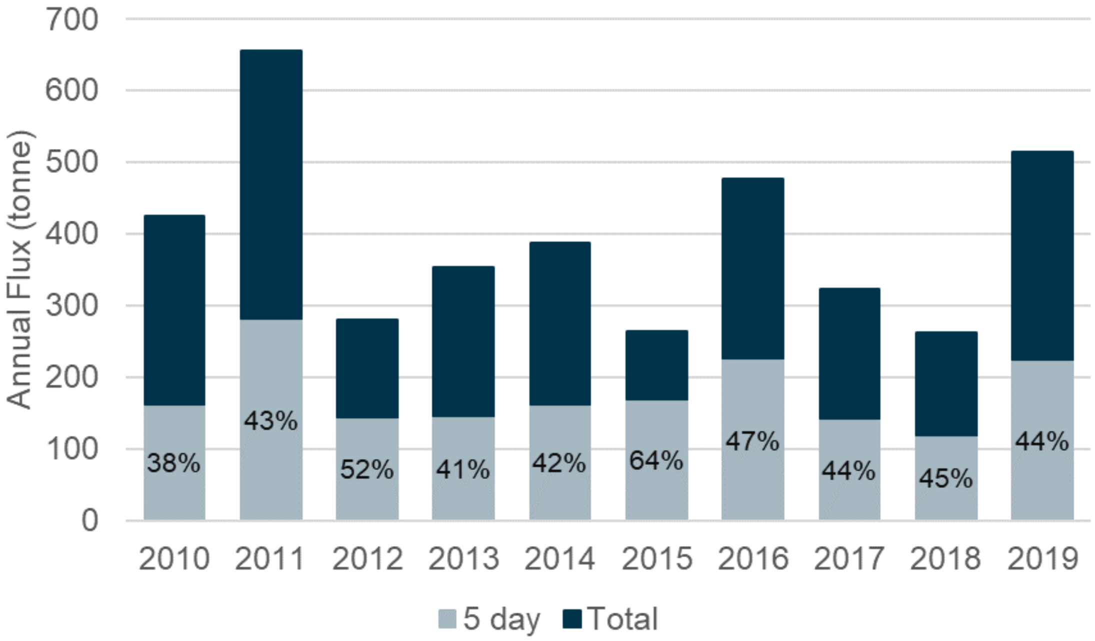


FIGURE 3.10

5-day baseflow flux for the Manitowoc River

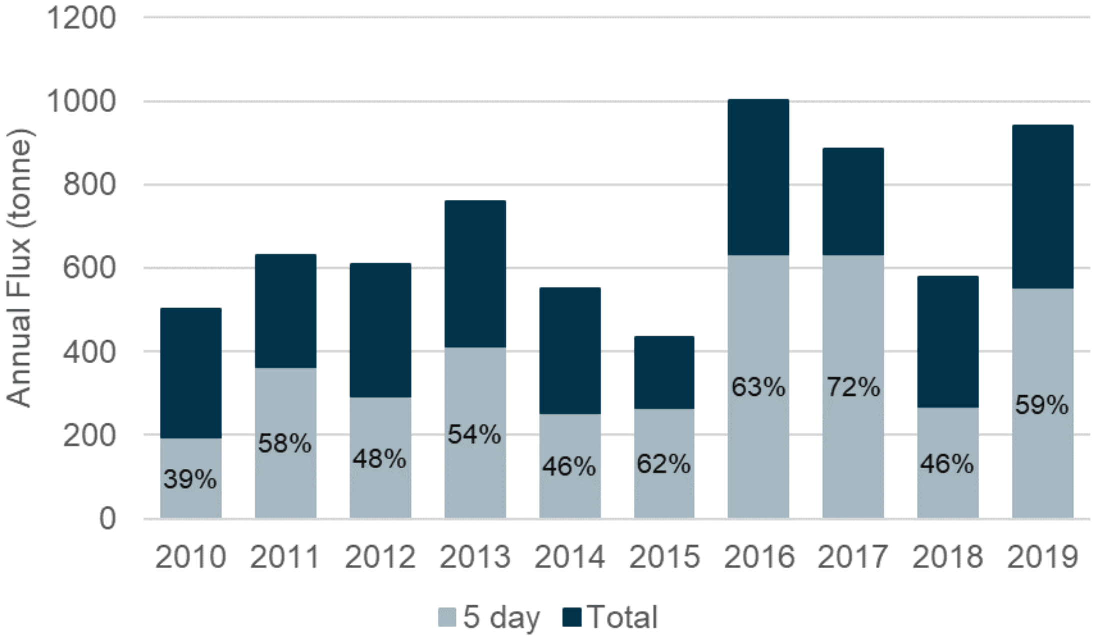


FIGURE 3.11

5-day baseflow flux for the Sheboygan River

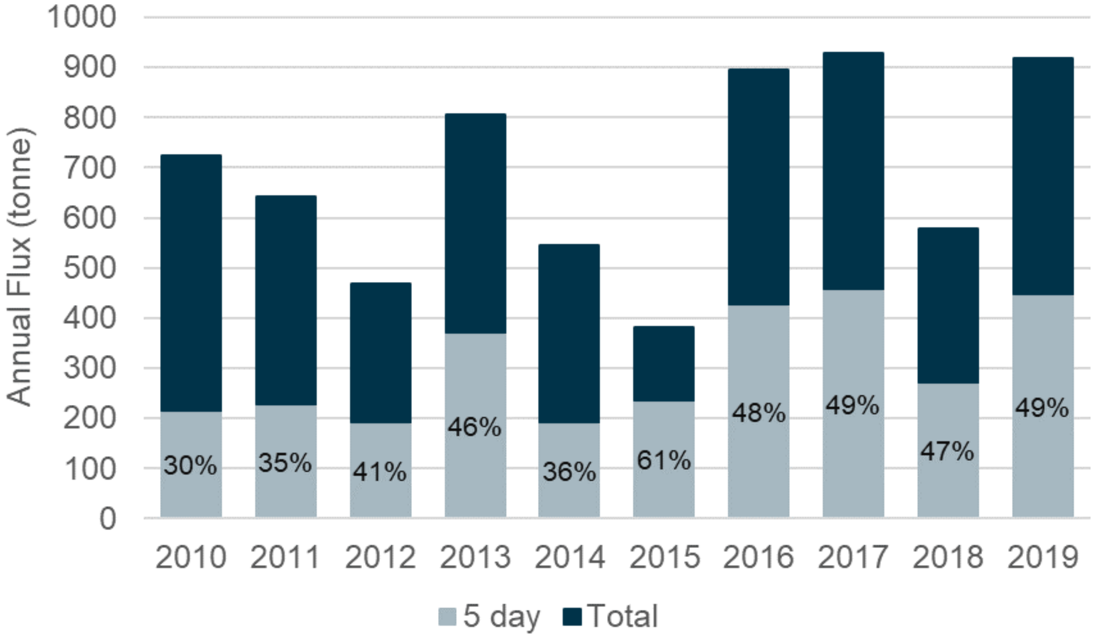


TABLE 3.8

Percentage of flows and loads in 5-day baseflow (2010-2019)

	5-day Baseflow	
Major basin	% of Total Flow	% of Total Flux
Kewaunee River at Kewaunee, WI	42	45
Manitowoc River at Manitowoc, WI	50	56
Sheboygan River at Sheboygan, WI	50	44

TABLE 3.9

Comparison of concentrations in total flow and 5-day baseflow (2010-2019)

	Average Concentration (mg/L)	
Major basin	Total Streamflow	5-Day Baseflow
Kewaunee River at Kewaunee, WI	4.5	4.9
Manitowoc River at Manitowoc, WI	1.7	1.9
Sheboygan River at Sheboygan, WI	2.0	1.7

A comparison of the results provides information about where nitrate in surface water is originating. In the Manitowoc River, the concentration of 5-day baseflow is higher than the overall concentration. The comparison indicates that concentrations from groundwater are higher than the concentrations in surface runoff. Conversely, in the Sheboygan River, the concentration of 5-day baseflow is lower than the overall concentration. The comparison indicates the concentrations from groundwater are lower than the concentrations in surface runoff.

3.4. Delayed Flow Nitrate Loading

Baseflow nitrate loading for the delayed flow classes is estimated using the methodology described in Section 2.1.4. Results from the analysis are assessed in two ways. The total flux associated with the four flow categories are calculated to understand the proportion of load originating from the categories. Summaries of these results are displayed in Figures 3.12 through 3.14. The results require context since the total flow volume in each class is not equal. In the Kewaunee River, for example, volume of the runoff class is approximately 52 percent of the total flow, and the volume of the long baseflow class is only 9 percent. As a result, the total flux in each of these categories must be evaluated relative to the total flow.

FIGURE 3.12
Delayed flow flux for the Kewaunee River

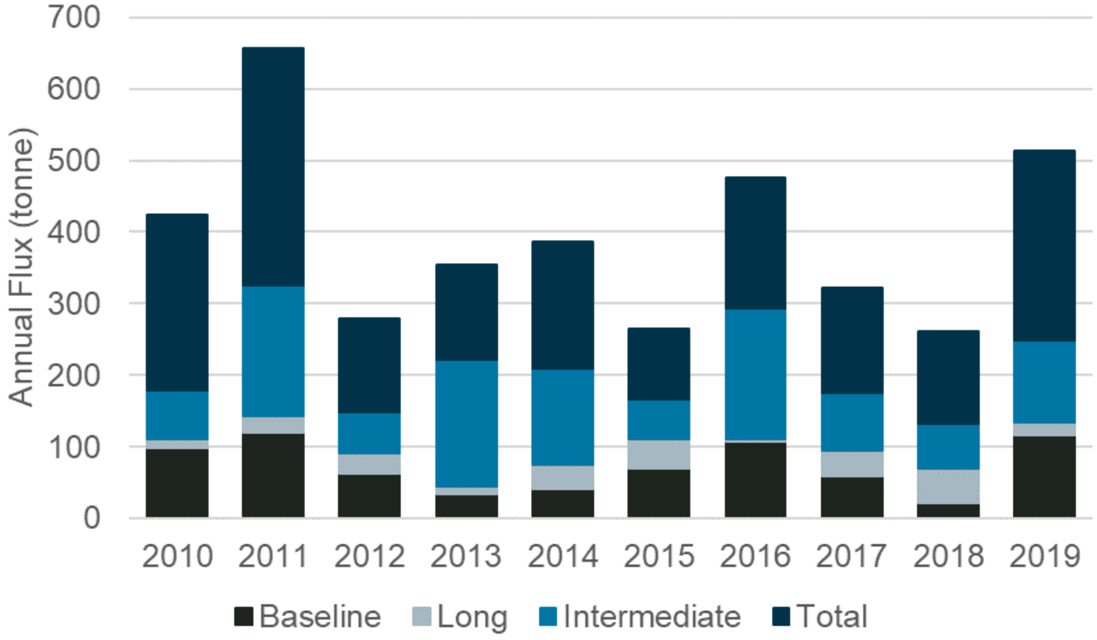


FIGURE 3.13
Delayed flow flux for the Manitowoc River

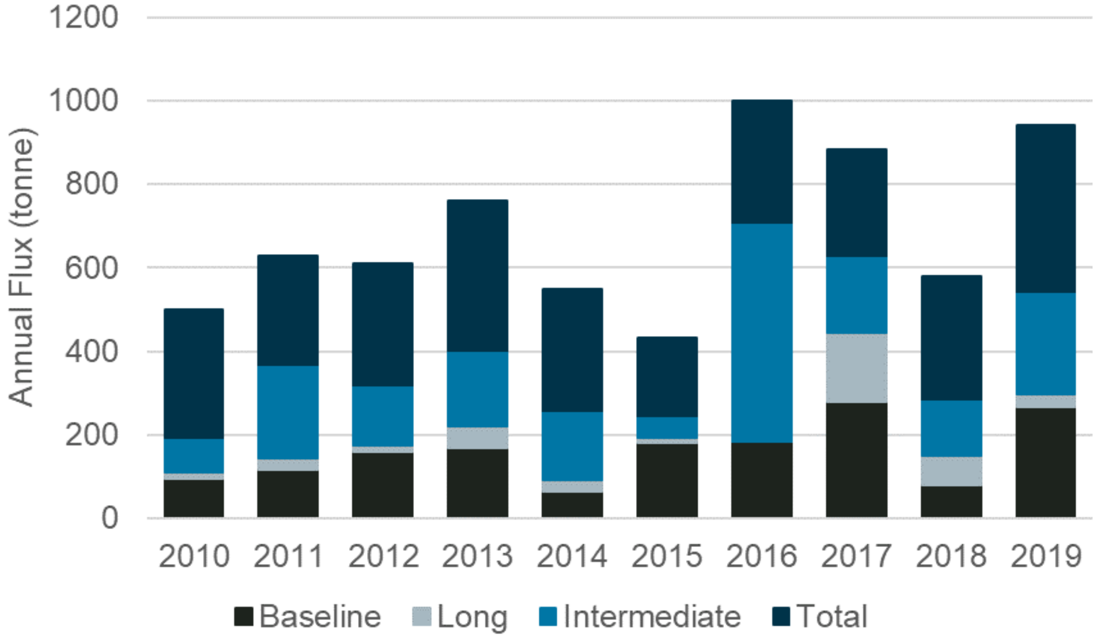
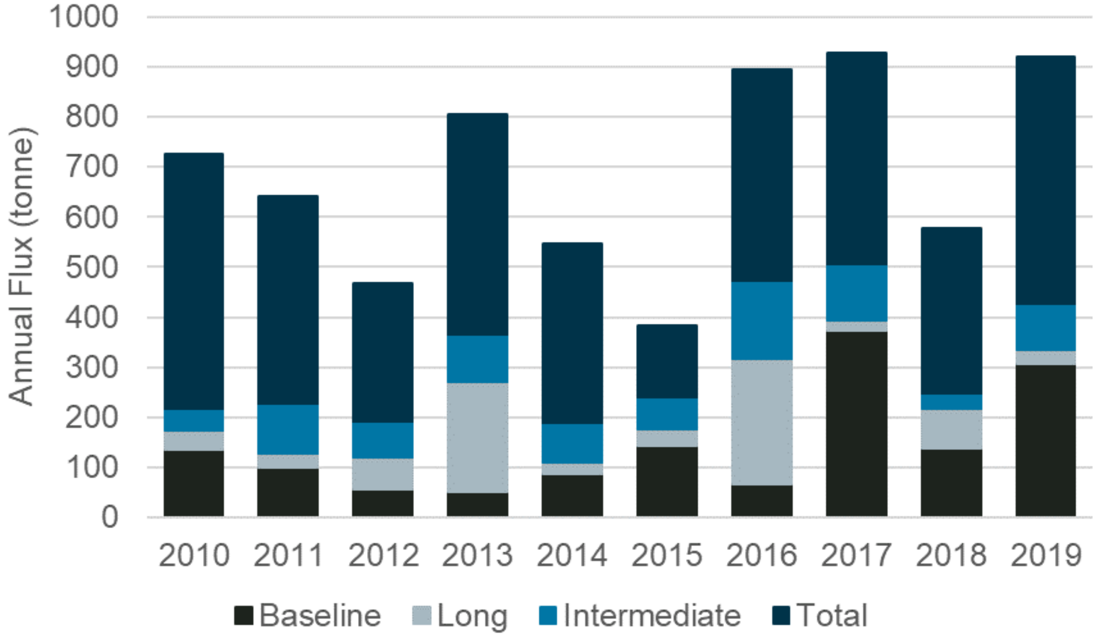


FIGURE 3.14

Delayed flow flux for the Sheboygan River



The average concentration associated with flows in each flow class between 2010 and 2019 is also calculated. This assessment provides insights into which flow class has the highest concentration. A summary of the estimated concentration associated with each flow class is provided in Table 3.9. For the Manitowoc River the average concentration of the runoff is 1.5 mg/L, and the average concentration of the baseline flows is 2.8 mg/L. This result indicates that the concentrations of groundwater are higher than the average concentrations of surface runoff. Conversely, for the Sheboygan River, the average concentration of the runoff is 2.5 mg/L, and the average concentration of the baseline flows is 1.9 mg/L. This result indicates the average concentrations of runoff are higher than the average concentrations of groundwater.

The results of the analysis, especially for the baseline flows, must be evaluated with caution. The number of concentration samples at baseline-dominated flows range from 13 to 34. LOADEST requires a minimum of 12 samples to perform the analysis (Runkel and others, 2004, p. 17). The function in the *rloadest* package prints a warning about overfitting of the model when the number of samples is less than 70, so the minimum of 12 samples may even be too small for avoiding issues with the model. Having a small number of samples can lead to autocorrelation, which means the models may be overfit. Overfitting of the model means individual correlation points at different flows can have outweighed impacts on the model. For example, if the measured data include only a single point at high flows, the concentration at that high flow may be applied to all the other high flows in the model.

If that single measurement does not represent the average concentrations at high flows, the model may not be accurate for high flows.

TABLE 3.10

Average nitrate concentration (mg/L) in delayed flow categories for the three major basins (2010-2019)

Major basin	Total Runoff	Short Interflow	Long Interflow	Groundwater Flow
Kewaunee River at Kewaunee, WI	4.0	6.1	3.7	4.4
Manitowoc River at Manitowoc, WI	1.5	1.8	0.8	2.8
Sheboygan River at Sheboygan, WI	2.5	1.1	1.9	1.9

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APPENDIX G

GROUNDWATER NITROGEN ANALYSIS FOR THE NORTHEAST LAKESHORE STUDY AREA

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1. BACKGROUND

Nitrate contamination in groundwater is a public health concern throughout Wisconsin. Wells in the Northeast Lakeshore TMDL study area are susceptible to nitrate groundwater contamination from leaching of land-applied nitrogen. Although the focus of the larger nitrogen analysis study is on nitrogen in surface waters in the study area, this section provides context about nitrates in groundwater.

2. GROUNDWATER NITRATE DATA

Nitrate in groundwater in Wisconsin is widely studied. Many wells throughout the state are contaminated with excess nitrogen. When groundwater nitrogen exceeds a certain threshold, it can no longer be used for human consumption. This analysis provides a comparison of groundwater nitrogen and the total mass of nitrogen applied to agricultural landscapes. The analysis is not meant as a comprehensive investigation into the sources of groundwater nitrates, but it provides initial context into the issue.

2.1. Groundwater Susceptibility

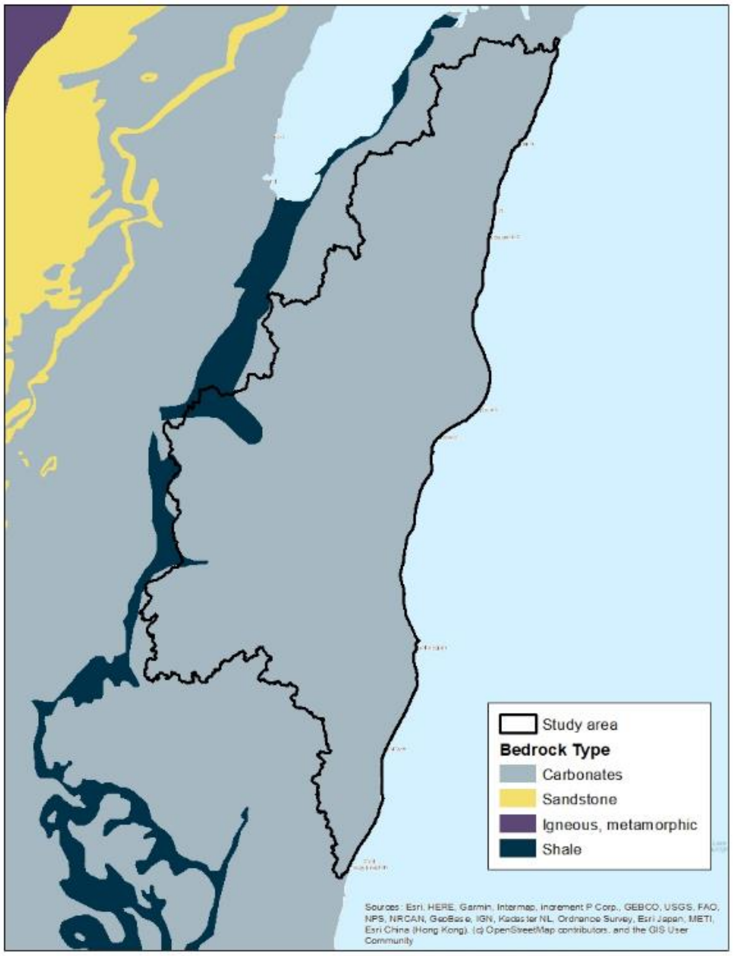
Groundwater susceptibility is defined as, "the ease with which a contaminant can be transported from the land surface to the surface of the groundwater, called the water table" (WDNR, 1989). The DNR (1989) identifies five important characteristics that can help estimate the susceptibility of groundwater. The five characteristics summarized below.

2.1.1. Type of Bedrock

Bedrock type determines the ease with which water can flow through the bedrock. Fractured limestone and dolomite bedrock allow for the rapid transport of water through preferential flow channels in the bedrock. Shale bedrock allows almost no transport of water through the bedrock. Sandstone and other bedrock materials allow for an intermediate transport of water through the bedrock. The bedrock types in the study area is shown in Figure 2.1. Nearly the entire study area is composed of carbonate bedrock.

FIGURE 2.1

Bedrock types in the study area



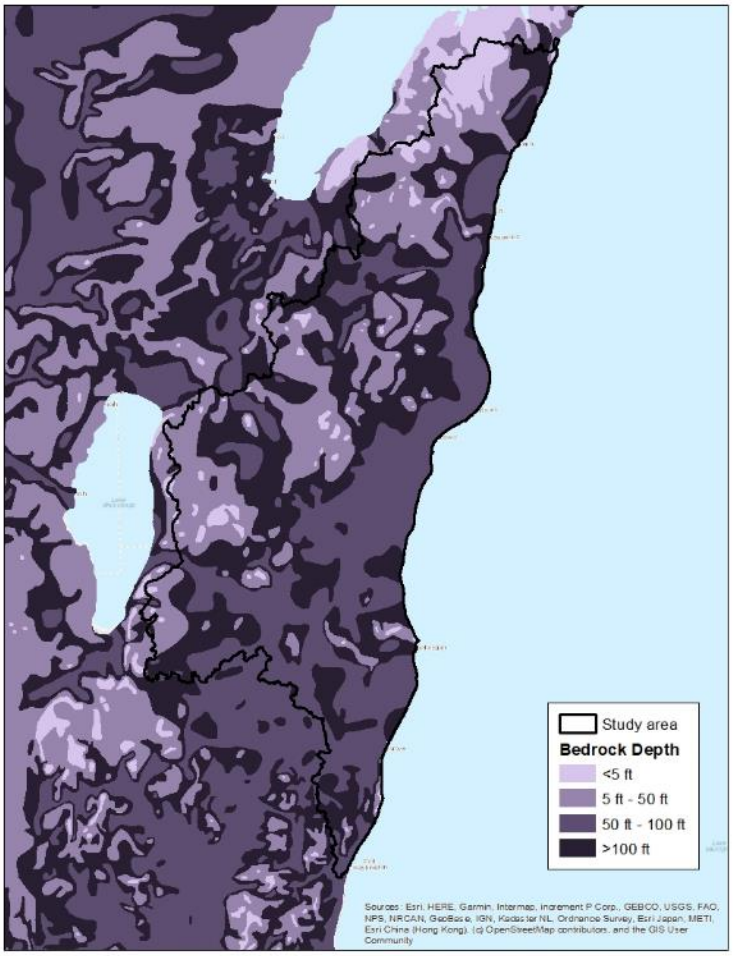
Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community

2.1.2. Depth to Bedrock

Depth to bedrock represents the thickness of material that sits above the bedrock. In locations where the depth to bedrock is large, the type of bedrock material is less important to the possible contamination of groundwater. In locations where depth to bedrock is small, however, the type of bedrock has an influence on the possible contamination of groundwater. The depth to bedrock in the study area is shown in Figure 2.2. Bedrock depth in the study area ranges from less than 5 feet to over 100 ft. Much of the northern and western portions of the subbasin have relatively shallow bedrock, while most of the eastern and southern portions of the study area have bedrock greater than 50 feet.

FIGURE 2.2

Bedrock depth in the study area

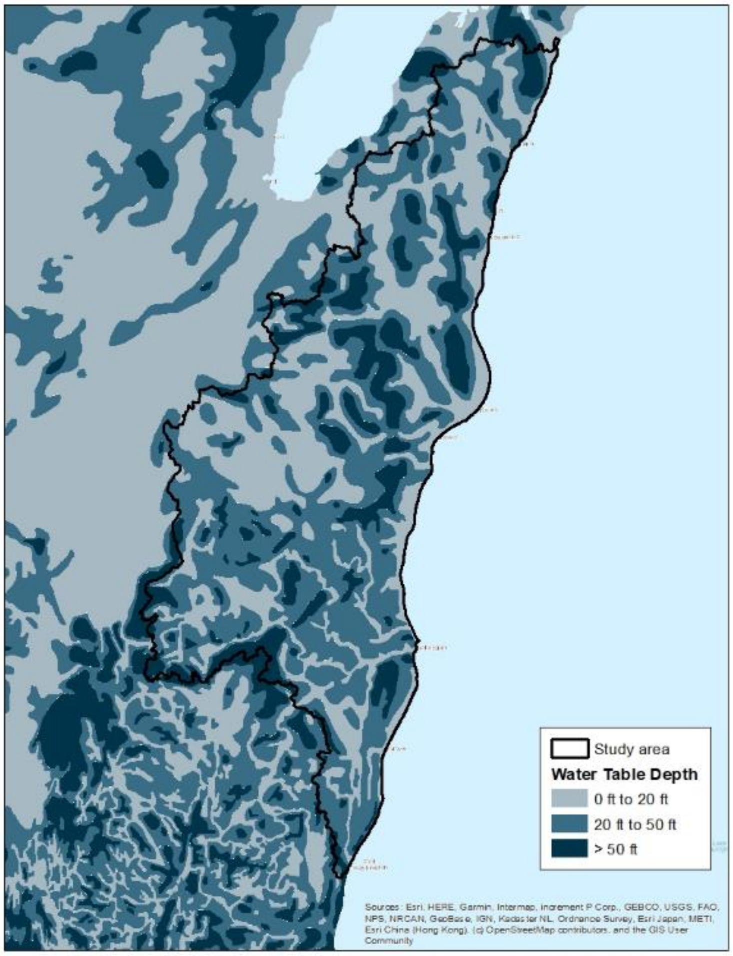


Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community

2.1.3. Depth to Water Table

Although depth to water table is difficult to map across the state, it is an important factor in determining the potential of contamination of groundwater. When the water table is very shallow – or near the surface – the contaminants can more easily enter the water table and increase the risk of contamination. The approximate depth to groundwater for the study area is presented in Figure 2.3. The depth to water table varies significantly across the study area. Some areas have water table depths between 0 and 20 feet whereas other areas have water table depths over 50 feet.

FIGURE 2.3
Water table depth in the study area



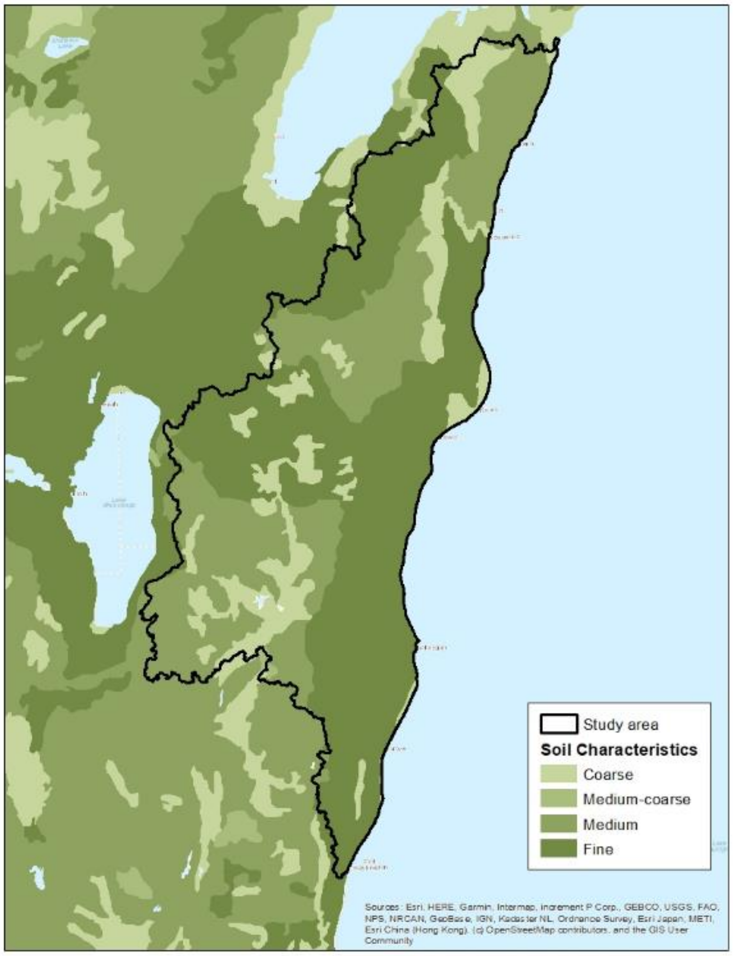
Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community

2.1.4. Characteristics of Soil

Soil characteristics are a very important factor in determining groundwater susceptibility. Soil properties such as texture, organic matter content, permeability, and water-holding capacity influence the movement of water through the soil layer. When water can move rapidly through the soil, the potential for groundwater contamination is high. Soil texture is presented in Figure 2.4. Coarse soils have a high potential for groundwater contamination, whereas fine soils have a low potential for groundwater contamination. The southwestern and northern portions of the watershed contain coarse soils and are therefore more susceptible to groundwater contamination.

FIGURE 2.4

Soil characteristics in the study area

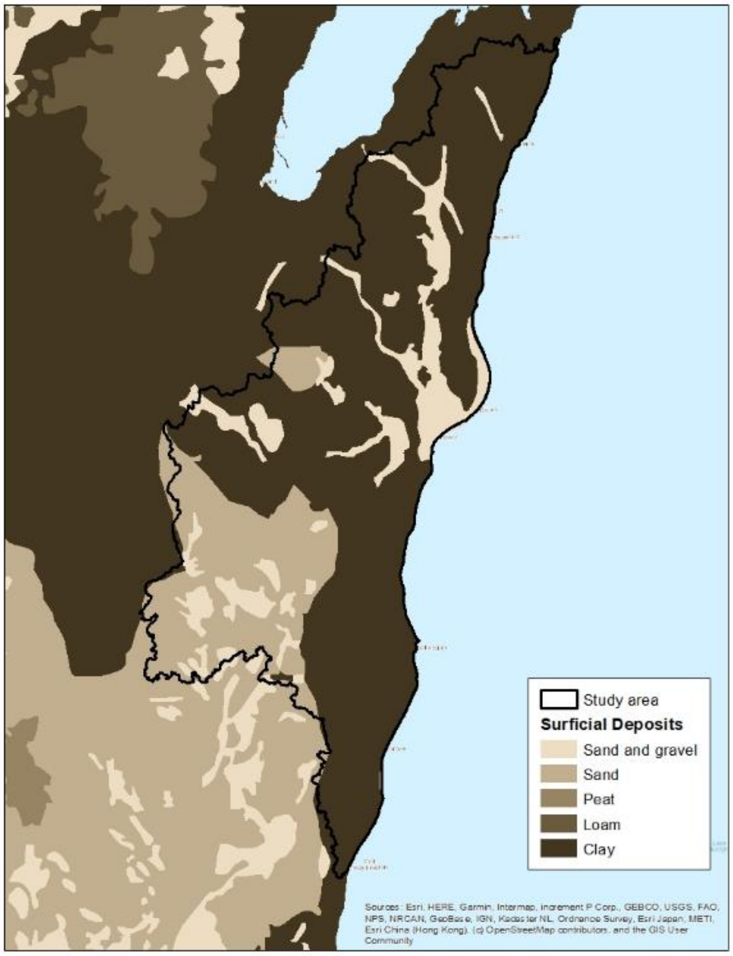


Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community

2.1.5. Characteristics of Surficial Deposits

Surficial deposits are the materials that are located below the soil but above the bedrock. The type of surficial deposits can influence the ability of water to move to groundwater. For example, surficial deposits composed primarily of sand and gravel allow for rapid transport of contaminated water to the groundwater. Surficial deposits composed primarily of clay allow for limited transport of contaminated water to groundwater. Characteristics of surficial deposits are presented in Figure 2.5. The southwestern portion of the study area is composed mainly of sand and gravel, and the rest of the study area is composed mainly of clays.

FIGURE 2.5
Surficial deposits characteristics in the study area



Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community

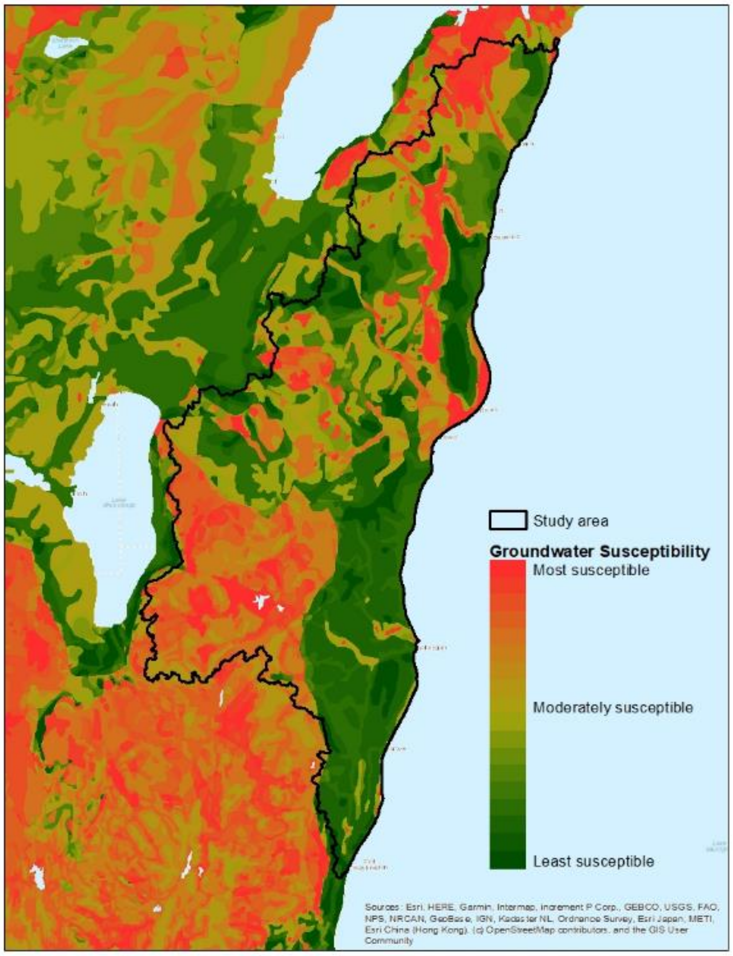
2.1.6. Groundwater Susceptibility Model

The five parameters summarized in the previous sections – bedrock type, bedrock depth, water table depth, soil characteristics, and surficial deposit characteristics – are combined to develop a composite score of groundwater susceptibility that ranges from 15 to 150. Lower values of the composite scores represent areas with higher groundwater susceptibility, and higher values represent areas with lower groundwater susceptibility. The methodology for developing the composite scores is described in a Wisconsin DNR publication (Schmidt, 1987).

The final estimated groundwater susceptibility is displayed in Figure 2.6. Areas most susceptible to groundwater contamination are located in the southwestern portion of the study area. The susceptibility in this area is strongly influenced by the coarse soils and sandy surficial deposits. The very northern portion of the study area is also highly susceptible to groundwater contamination. Although this area has clayey surficial deposits, the soils are coarse, the bedrock is very shallow, and water table is very shallow. The combination of these characteristics translates to high groundwater susceptibility.

FIGURE 2.6

Groundwater susceptibility in the study area



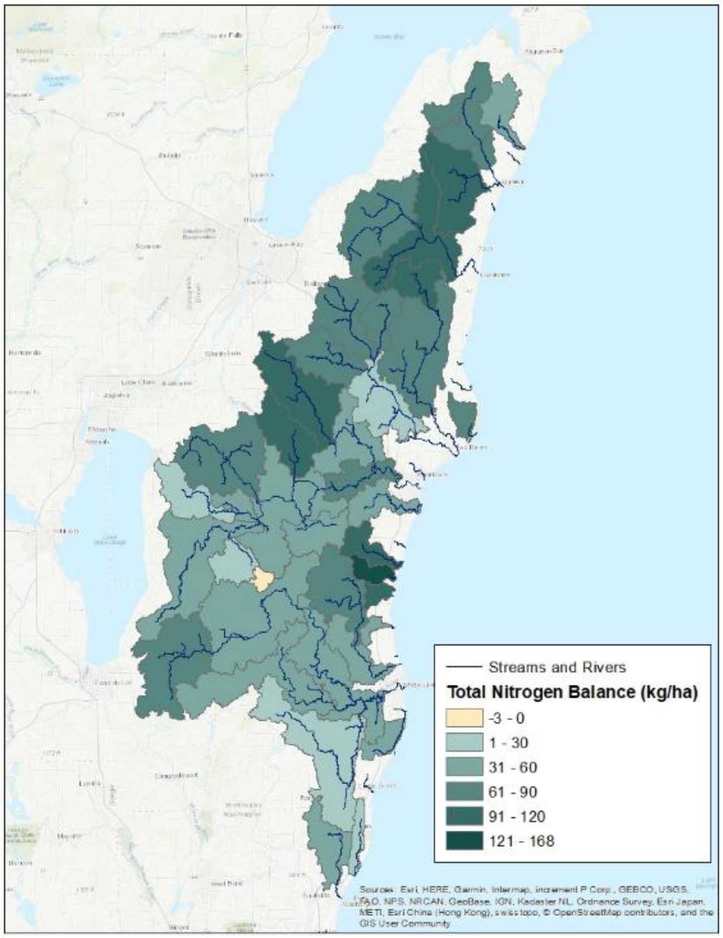
Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community

2.2. Nitrogen Application to the Landscape

Groundwater is vulnerable to nitrate contamination when areas of high nitrogen application overlap with the areas with a high groundwater susceptibility. Appendix D of the nitrogen analysis report evaluates agricultural nitrogen application to the landscape in the study area. A mass balance is performed to determine areas where nitrogen applications from fertilizer, manure, atmospheric deposition, and nitrogen fixation exceeds the nitrogen outputs from crop removal, crop senescence, denitrification, and volatilization. A summary of the mass balance is provided in Figure 2.7. Additional information can be found in Appendix D in the nitrogen analysis report.

FIGURE 2.7

Mass balance of agricultural nitrogen inputs and outputs in the study area



Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

2.3. Groundwater Nitrate Concentrations

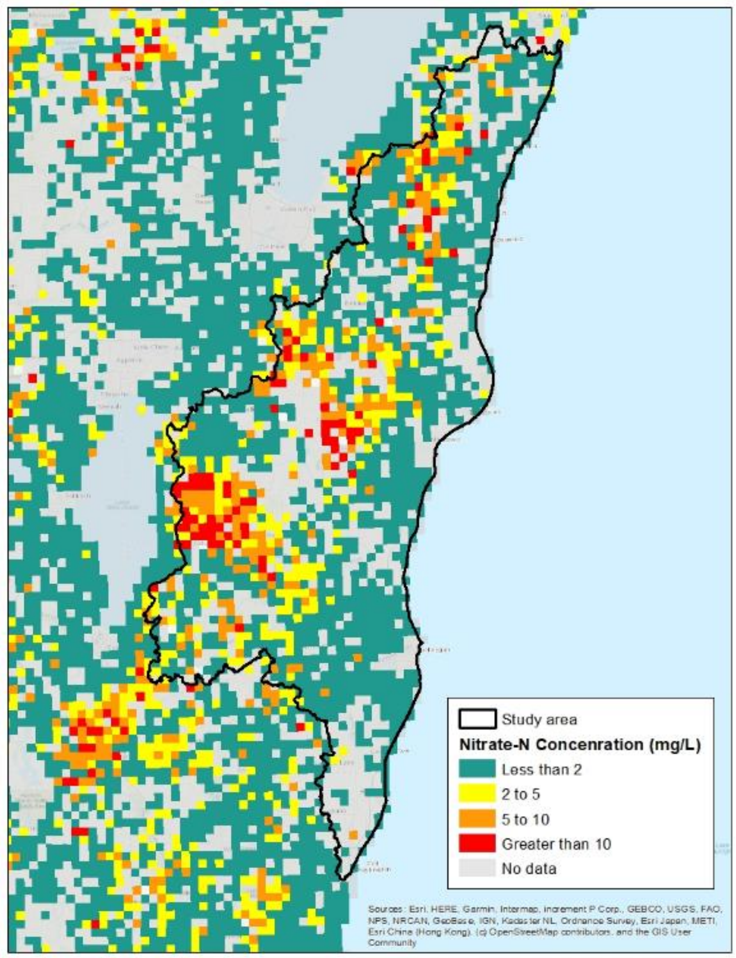
Nitrate enters groundwater when nitrogen is applied to the landscape and leaches into the soil. Excessive consumption of nitrate by humans has negative short-term and long-term impacts on human health. To protect human health Wisconsin has standards that limit the amount of nitrate in drinking water and groundwater. The maximum contaminant level (MCL) for nitrate in groundwater is 10 mg/L (Wisconsin Admin. Code § NR 140). When groundwater exceeds this MCL, it can no longer be used as a drinking water source. Additionally, Wisconsin has established a preventative action limit (PAL) of 2 mg/L for nitrate in groundwater (Wisconsin Admin. Code § NR 140). When the groundwater nitrate concentration exceeds the PAL, the Department of Natural Resources is required to "commence efforts to control the contamination and provide a basis for design and management practice criteria in administrative rule (Wisconsin State Statute, 140)".

Private and public wells throughout Wisconsin are monitored to determine concentrations of nitrate, chloride, total hardness, and other compounds. The Center for Watershed Science and Education (2020) collects these data and summarizes the average concentrations at a township level. The average nitrate concentration in individual Public Land Survey System (PLSS) Sections is presented in Figure 2.8. A PLSS Section is an area equal to one square mile, or 640 acres. The red squares in the figure indicate areas where groundwater nitrate concentration exceeds the MCL of 10 mg/L. The orange and yellow squares indicate areas where groundwater concentration exceeds the PCL of 2 mg/L but is below the MCL of 10 mg/L. The grey areas indicate areas where groundwater concentration is below the PCL of 2 mg/L.

FIGURE 2.8

Average nitrate concentration by PLSS section

Data Source: Center for Watershed Science and Education, 2020



3. EVALUATION OF GROUNDWATER NITRATE

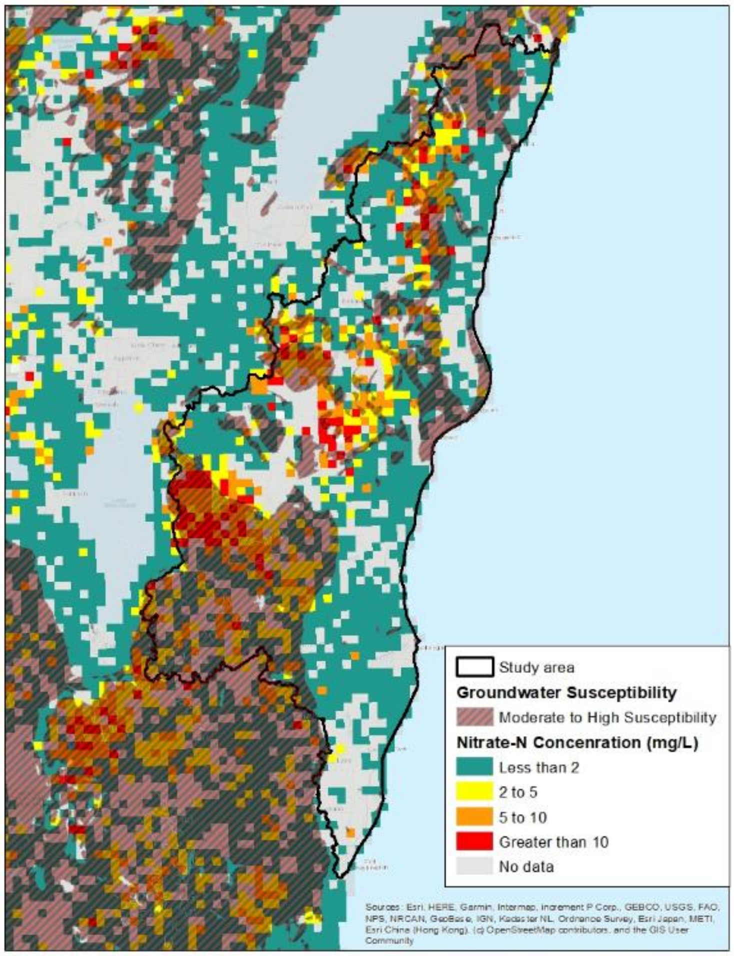
Information about groundwater susceptibility and nitrogen mass balance can be used to evaluate the relationship with groundwater nitrate concentrations. The relationships are important for identifying areas where measures can be focused to reduce groundwater nitrate contamination.

3.1. Groundwater nitrate concentrations and groundwater susceptibility

Areas of high groundwater susceptibility are correlated with areas of high groundwater nitrate concentration. A comparison of the groundwater susceptibility and the measured nitrate concentrations is provided in Figure 3.1. Areas with moderate or high groundwater susceptibility are represented by the semi-transparent black areas. The groundwater concentrations by PLSS section are represented by the grey, yellow, orange, and red squares. The relationship between high groundwater susceptibility and high groundwater nitrogen is strong. Groundwater susceptibility is a good predictor of nitrogen concentrations in groundwater, and special consideration of nitrogen application should be considered in the susceptible areas.

Figure 3.1

Groundwater susceptibility and groundwater nitrate concentrations



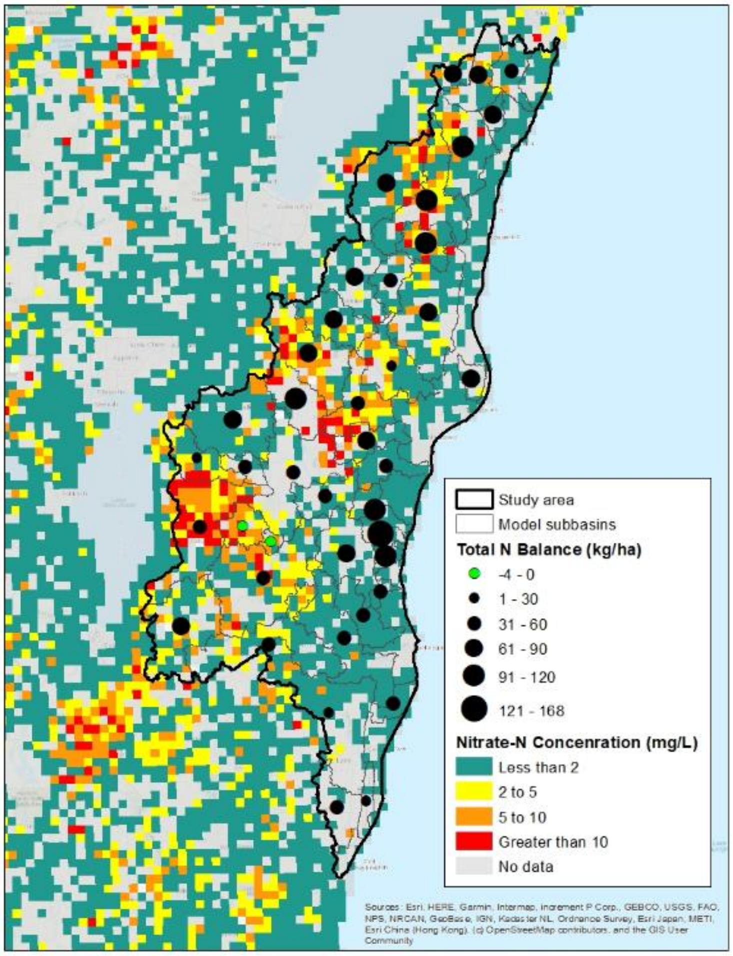
Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community

3.2. Groundwater nitrate concentrations and nitrogen mass balance

When nitrogen applications exceed crop needs, the excess nitrogen must be stored in the soils, exported to surface waters, or leached to groundwater. Nearly all subbasins in the study area received more nitrogen than the crops require. Figure 3.2 shows the mass balance for agricultural lands overlaid with the measured groundwater concentrations. Most of the areas with high groundwater nitrogen concentrations are located in areas where the nitrogen applied exceeds nitrogen crop needs by approximately 40 kilograms per hectare. However, the areas with the highest excess nitrogen applications, particularly those along the eastern edge of the study area, do not have high groundwater nitrate concentrations. While excess nitrogen application can predict high groundwater nitrate concentrations, the areas with the highest groundwater nitrogen concentrations occur in areas where nitrogen is applied over areas with high groundwater susceptibility.

FIGURE 3.2

Agricultural nitrogen mass balance and groundwater nitrate concentrations



Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community

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Schmidt, R.R, 1987, Wisconsin's Groundwater Management Plan Report No. 5 – Groundwater Contamination Susceptibility in Wisconsin: Madison, WI, Wisconsin Department of Natural Resources PUBL-WR-177-87, 27 p.

Wisconsin Admin. Code § NR 140 (2021)

Wisconsin Department of Natural Resources, 1989, Groundwater Contamination Susceptibility in Wisconsin: Madison, WI, map, available at https://dnr.wi.gov/education/documents/groundwater/susceptibilityMap.pdf

APPENDIX H

SUPPLEMENTAL NITROGEN DATA EXPLORATION AND ANALYSIS FOR THE NORTHEAST LAKESHORE STUDY AREA

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1. BACKGROUND

Nitrogen loading and concentration vary among the watersheds in the Northeast Lakeshore TMDL study area. To compare these variations a detailed analysis is performed to evaluate which factors may be contributing to the variation in the different basins. Factors potentially impacting nitrogen loading include land use, crop types, fertilizer application, geology, soils, waterbody characteristics, and others. The factors are evaluated using simple linear regression, multiple linear regression, and random forest modeling. These approaches provide insights about characteristics that affect nitrate loading.

2. DATA SOURCES

Many data sources are available to assess the relationships between land characteristics, stream flows, and nitrogen loads. Data sources include landscape and stream details from the Wisconsin Hydrography Dataset Plus (WHDPlus), land cover, crop types, manure spreading, fertilizer applications, artificial drainage, climate, and water quality monitoring.

2.1. Wisconsin Hydrography Dataset Plus (WHDPlus)

The Wisconsin Hydrography Dataset Plus – or WHDPlus – (Diebel et al., 2013) is an expanded, Wisconsin-specific version of the National Hydrography Dataset. The dataset is developed and maintained by staff at the Wisconsin Department of Natural Resources (DNR). It is based on the Wisconsin 24K hydrogeodatabase and includes a variety of geologic, land cover, and other base data. The WHDPlus dataset serves two purposes: mapping lakes, rivers, and their contributing watersheds and providing value-added attributes associated with each waterbody and its watershed. The dataset includes over 800 value-added attributes related to stream channel and landscape-level characteristics. A summary of the types of data included in the datasets is provided in Table 2.1. An example of the spatial resolution of the dataset for the Kewaunee River is provided in Figure 2.1. The dataset is available for download by through the DNR (WDNR, 2019).

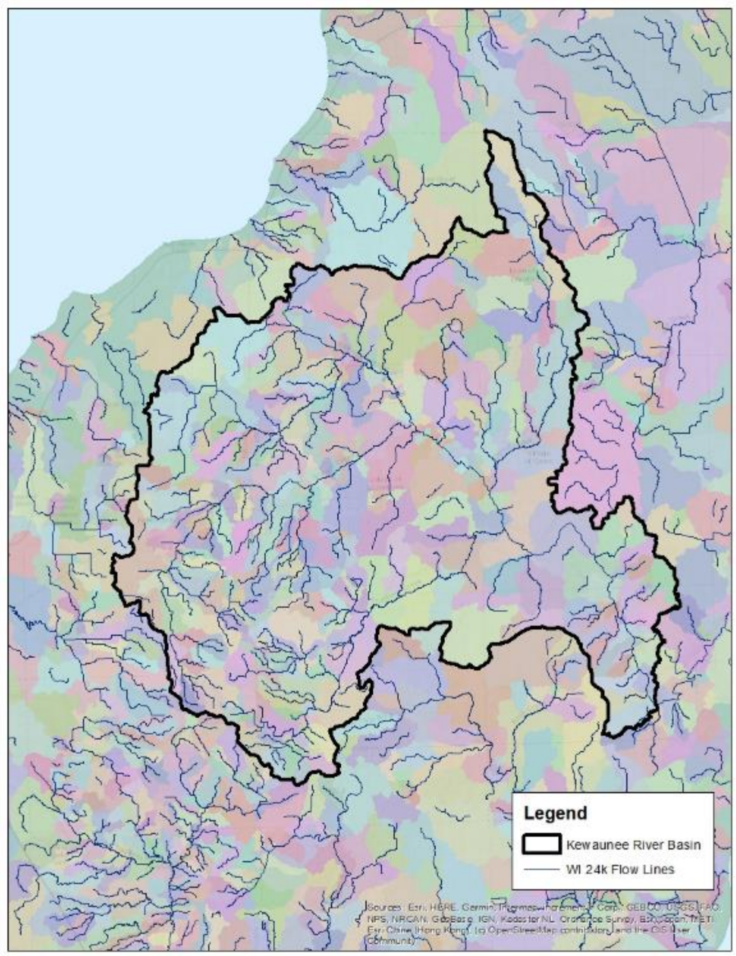
TABLE 2.1
Summary of WHDPlus data types

Data groups	
Land cover (1992-2012)	Soil characteristics
Pre-settlement land cover	Watershed and stream slopes
Modeled land cover	Stream and lake characteristics
Surficial geology	Artificial drainage
Bedrock geology	High capacity wells

FIGURE 2.1

Spatial extent of WHDPlus dataset for the Kewaunee River Basin

Note: Shaded polygons in the figure represent WHDPlus 24K Hydro Basins



Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community

2.2. Land cover

Land cover data for the analysis are provided from two sources: the National Agricultural Statistics Service Cropland Data Layer (NASS, 2008-2019) and the Wisconsin Department of Natural Resources Wiscland 2.0 Land Cover data (WDNR, 2016). Cropland data from each source are summarized for the watersheds upstream of the monitoring sites used in the study.

Land cover data from the Cropland Data Layer are downloaded for each year between 2008 and 2019. The twelve most common land cover types, which are listed in Table 2.2, are included in the analysis. A map of the distribution of land use for the Northeast Lakeshore study area is provided in Figure 2.2.

The Wiscland 2.0 land cover dataset is a collaborative effort between the Wisconsin Department of Natural Resources, the University of Wisconsin, and the Wisconsin State

Cartographer's Office. The analysis covers the period between 2013 and 2016. The dataset provides detailed land cover information for Wisconsin. The data are classified into four levels: Level 1 through Level 4. Level 1 is the most generalized data, and each successive level provides more details about specific land use categories. A figure of the Level 2 data for the study area is provided in Figure 2.3.

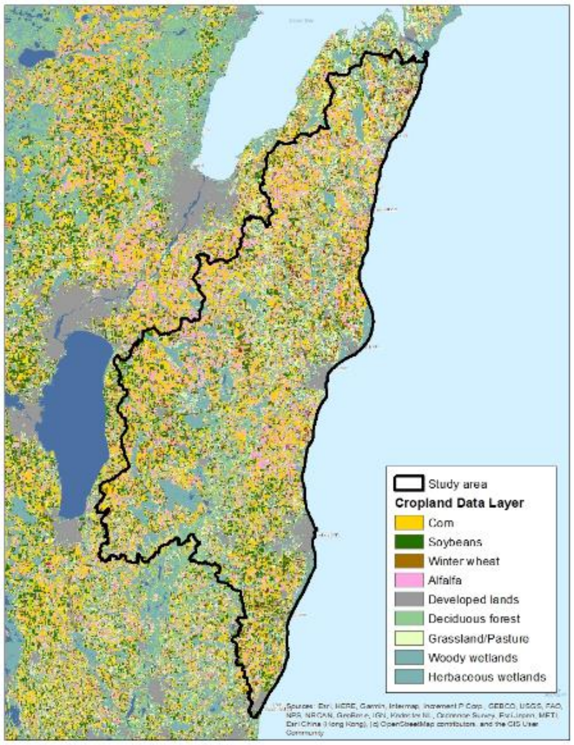
TABLE 2.2

Summary of predominant Cropland Data Layer categories

CDL land use code	Land use description
1	Corn
5	Soybeans
24	Winter wheat
36	Alfalfa
121	Developed/Open Space
122	Developed/Low-intensity
123	Developed/Med-intensity
124	Developed/High-intensity
141	Deciduous forest
176	Grassland/Pasture
190	Woody wetlands
195	Herbaceous wetlands

FIGURE 2.2

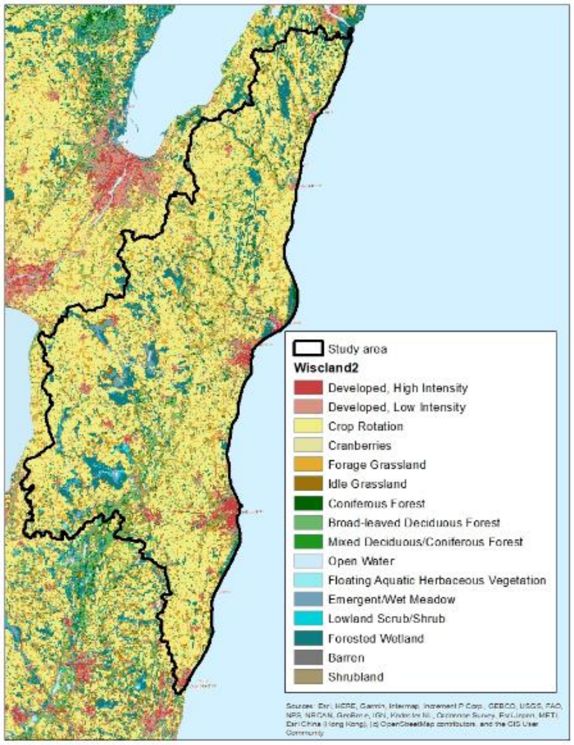
NASS Cropland Data Layer land cover for study area



Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community

FIGURE 2.3

Wiscland 2 land cover for study area



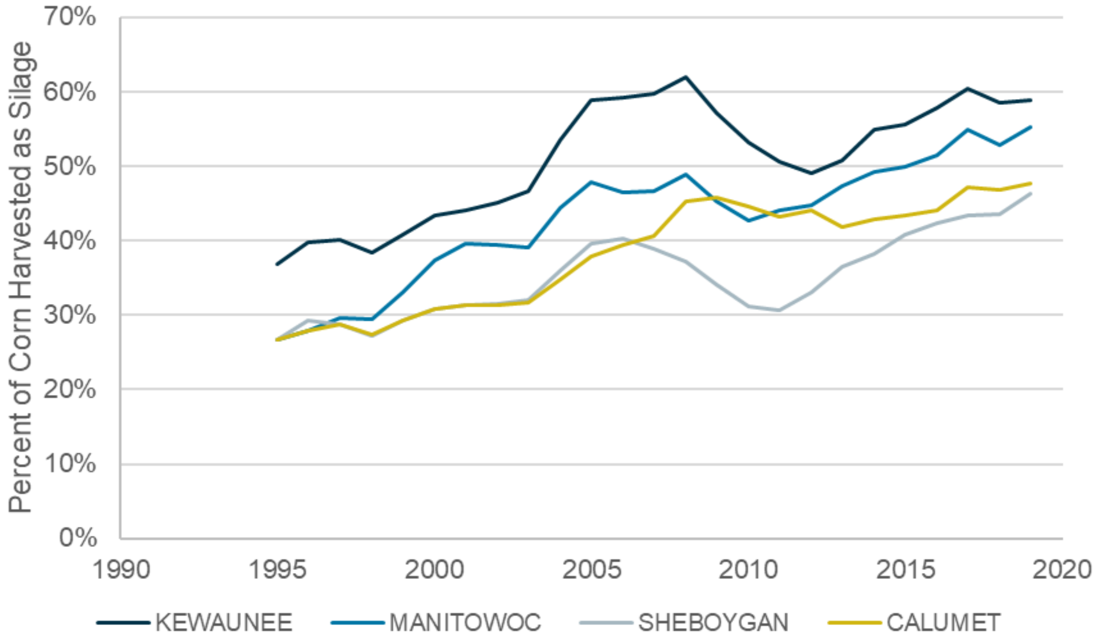
Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community

2.3. Corn Grain and Corn Silage

Corn can be grown as either corn grain or corn silage. The Cropland Data Layer does not differentiate between the two corn types. The NASS crop survey (NASS, 2017), however, provides county-level estimates for areas of corn grain and corn silage. These data are used to calculate the proportion of corn as grain versus corn as silage. The proportion of each type is multiplied by the total corn area predicted by the Cropland Data Layer to estimate the area of corn grain and corn silage for each subbasin. Trends over time of the amount of corn harvested as grain versus silage are provided in Figure 2.4. The figure presents the 5-year average trends for the four main counties in the study area. In general, the proportion of corn harvested as silage has increased over time. The proportion of corn harvested as silage is higher in counties with a higher concentration of cattle. Since silage is generally used as feed for cattle, this trend is consistent with the trends in cattle within study area.

FIGURE 2.4

Trends in corn grain versus corn silage over time



2.4. Manure Spreading and Cattle Density

Annual manure estimates for areas within the Northeast Lakeshore study area were derived by the Wisconsin Department of Natural Resources during the development of the TMDL model. The full methodology is described in a manure analysis report (DNR, 2020), which is a supplement to the Northeast Lakeshore TMDL. A summary of the methodology is provided below.

The number of cattle housed in CAFO operations during 2017 were estimated from the nutrient management plans submitted by CAFO operators. The number of cattle was categorized into five cattle types: small heifers, large heifers, dry and milking cows, steers, and bulls. The number of cattle housed outside of CAFO operations were estimated at a county level using the National Agricultural Statistics Service 2017 cattle census (NASS, 2008-2019). CAFO cattle in each county were subtracted from the county-level census data to determine the number of cattle not housed in CAFO operations.

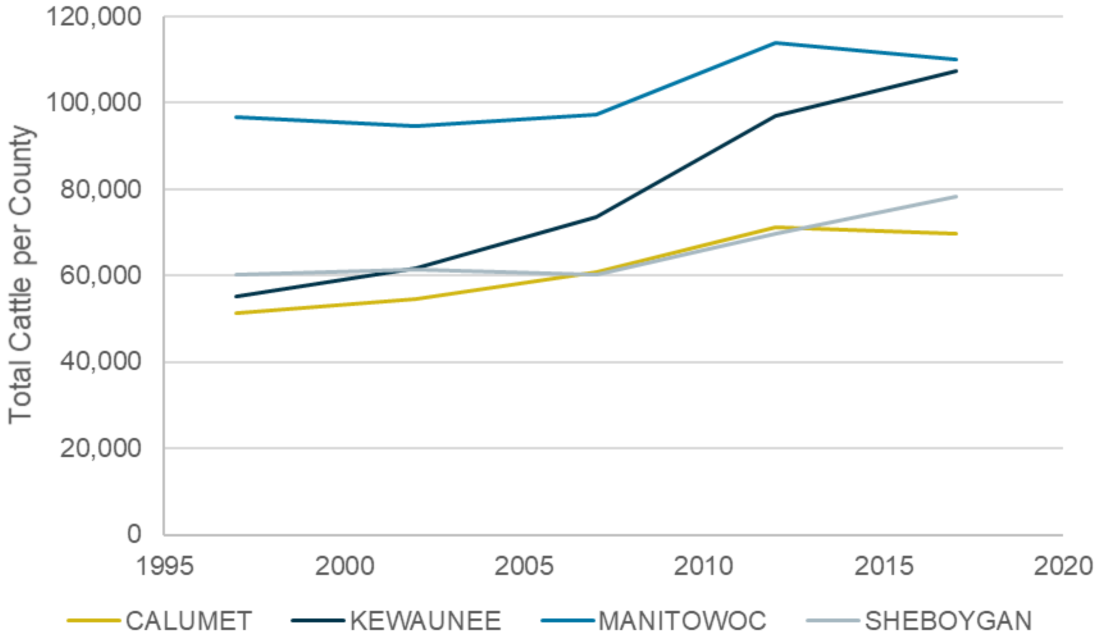
Once the number of cattle from CAFO and non-CAFO operations was determined, the liquid manure production was estimated by cattle type. The liquid manure production is reported in units of 1,000 gallons per area per year. The analysis assumed liquid manure is spread evenly across the dairy rotations reported in the Wiscland 2.0 land cover database (WDNR, 2016). The Wiscland 2.0 dataset was used in the analysis because it characterizes dairy rotations. The manure analysis provides an estimate of total volume of liquid manure spread in each of the subbasins described in the study area. The estimate is applicable for 2017.

Once the liquid manure applied during 2017 was estimated, the average annual manure applied during different years was calculated. The number of cattle per subbasin was estimated at the county level from 2009 to 2018 using the results of the NASS cattle survey (NASS, 2017). The change in cattle over time for the four main counties within the Northeast Lakeshore study area is provided in Figure 2.5. In Kewaunee County, Manitowoc County, and Sheboygan County, the number of cattle has increased steadily since approximately 2009. In Calumet County, the total number of cattle increased steadily from the late-1990s through approximately 2012, but the total number of cattle in the basin decreased between 2013 and 2018.

FIGURE 2.5

Change in cattle over time

Counties in the NE Lakeshore study area



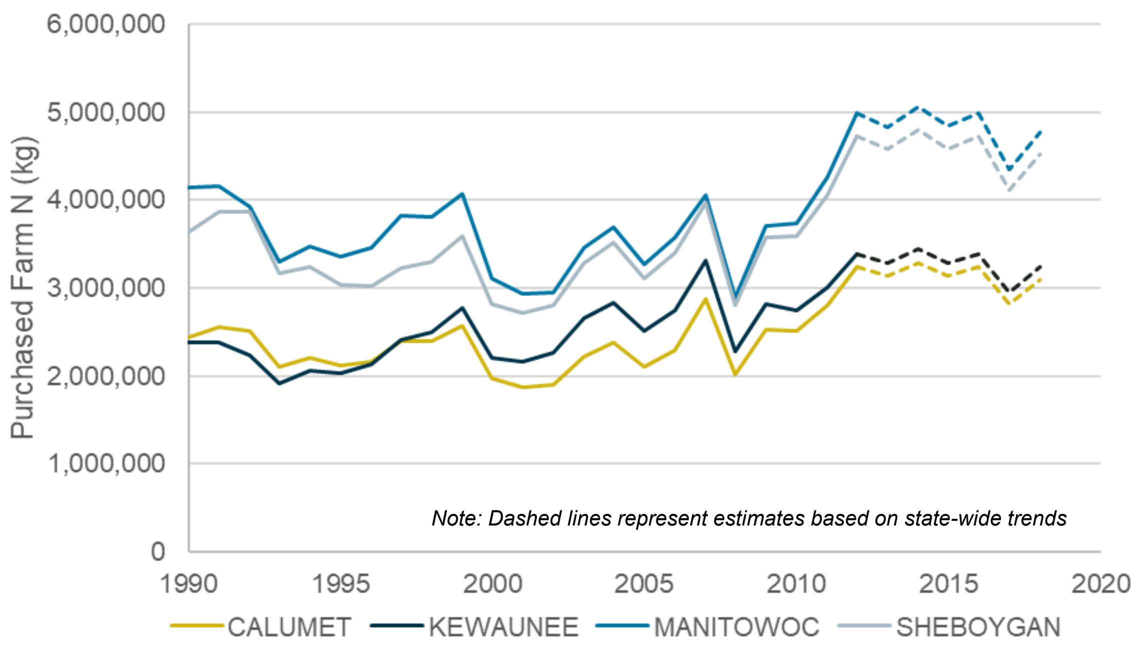
The NASS cattle survey reports data on a county level, and the county-level data were translated into the number of cattle per subbasin over time. The total manure applied during each year was calculated using the ratio of cattle each year and the number of cattle in 2017. For example, if a subbasin has 100 cattle in 2017 and 90 cattle in 2009, the total manure applied in 2009 is calculated by multiplying the total manure applied in 2017 by 0.90.

2.5. Commercial Fertilizer

Detailed spatial data about the total commercial fertilizer applied to the landscape is limited. Generally, the total nitrogen purchases per year are only reported on a state-wide basis. However, county-level estimates for 1987 through 2012 are provided by Brakebill and Gronberg (2017). County-level data are not available for 2013 through 2018. To estimate the total commercial fertilizer for the years without county-level data, the average change in fertilizer sales at the state-wide level since 2012 is used. Changes in fertilizer sales for the counties in the Northeast Lakeshore study area are assumed to follow the same trends as the statewide trends in fertilizer purchases. Estimates of the total fertilizer sales for four main counties within the study area are presented in Figure 2.6. Fertilizer sales increased between 2008 through 2012, but the sales have stabilized since approximately 2012.

FIGURE 2.6

Total nitrogen fertilizer purchases by county over time



Note: Dashed lines represent estimates based on state-wide trends

2.6. Tile Drainage

Tile drains are installed in fields to alleviate issues associated with standing water on the fields. The drains are installed below the crops and transmit water from the field to ditches. The presence of tile drains can impact both water quality and flow characteristics within a receiving water body.

The Northeast Lakeshore study area contains more tile drainage than any other part of the state. The exact location of tile drains is difficult to determine, but county-level estimates are available. Valayamkunnath and others (2020) developed a methodology to predict the location of tile drainage locations based on soils, croplands, slopes, and county-wide tile drainage estimates. A summary of the methodology from their work is provided in Figure 2.7. Output from the analysis is combined with estimates of county-wide agricultural area to estimate the percentage of agricultural lands with tile drainage. A summary of the county-level tile drain estimates is shown in Figure 2.8. Tile drain estimate within the study area is provided in Figure 2.9, and the estimated percent of agricultural lands with tile drainage within the study area subbasins is provided in Figure 2.10.

FIGURE 2.7

Methodology for predicting locations of tile drainage

Figure source: Valayamkunnath et al., 2020, Figure 2, p. 4

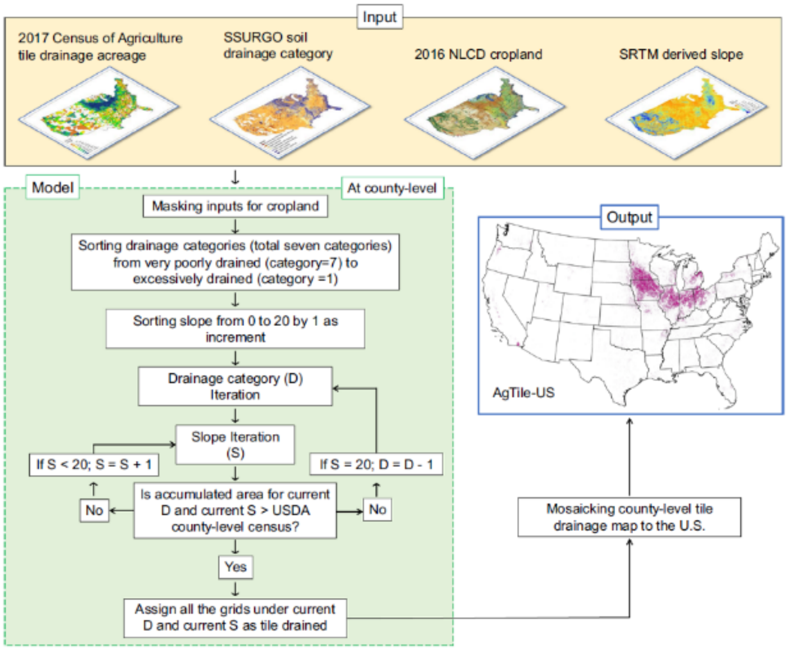


FIGURE 2.8

Statewide estimate of agricultural tile drainage

Percent of agricultural lands with tile drainage

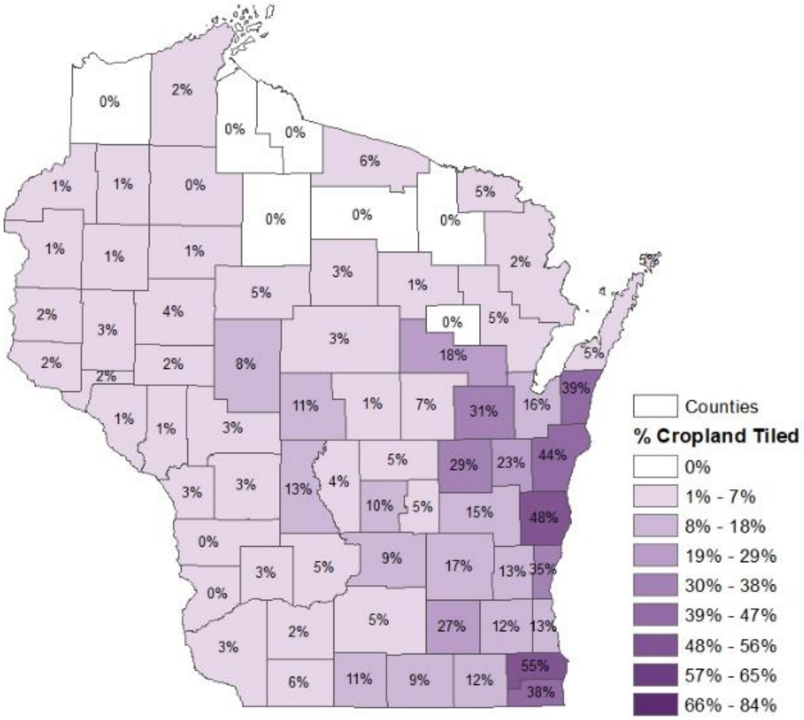


FIGURE 2.9

Predicted location of lands with tile drainage

Northeast Lakeshore TMDL study area

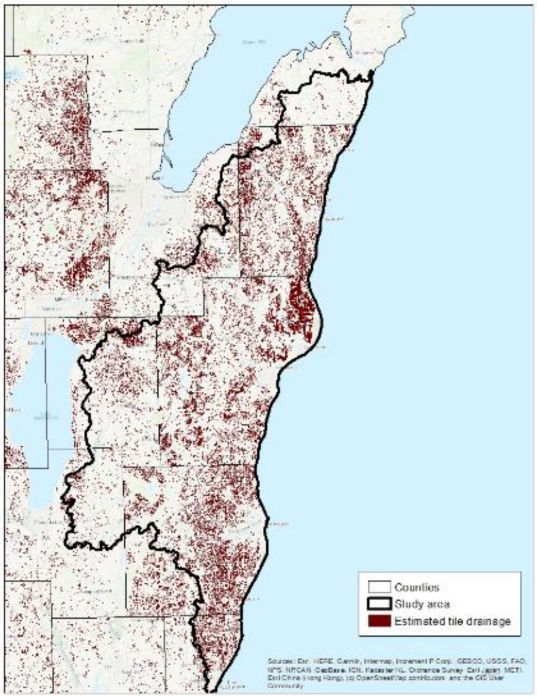


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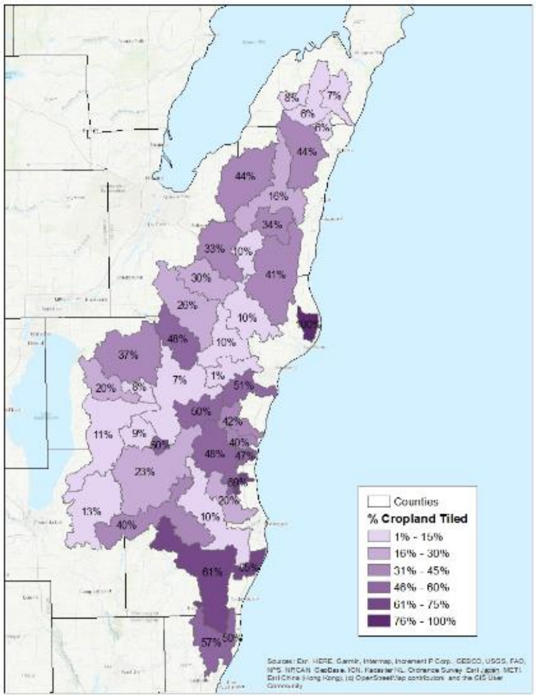
FIGURE 2.10

Study area agricultural lands with tile drainage

Percent of agricultural lands with tile drainage



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2.7. Climate data

Climate data for the study area are available from Daymet (Thornton and others, 2020). Daymet is a data product that interpolates and extrapolates data from observed meteorological data to create a gridded dataset at a 1 km x 1 km scale. Data downloaded from Daymet include day length, precipitation, shortwave radiation, snow water equivalent, maximum air temperature, minimum air temperature, and water vapor pressure. Daymet data are processed to provide estimates of lagged precipitation, snowmelt, lagged temperature, and growing degree days (A. Fisch, written commun., 2020).

For this analysis, data are downloaded at the location the monitoring stations used in the Northeast Lakeshore TMDL. Climate data for three basins with long-term trend data – the Kewaunee River, the Manitowoc River, and the Sheboygan River – are downloaded from the midpoint of each basin. Precipitation trends over time for the three long-term trend stations are provided in Figure 2.9. Between 1990 and 2018, the average annual precipitation across the three long-term trend basins increased. Average annual precipitation in the Sheboygan and Manitowoc River basins is greater than the average annual precipitation in the Kewaunee River basin. Average annual temperature trends are presented in Figure 2.10. Between 1990 and 2018, average annual temperature remained steady. The average annual temperature for the three basins is similar, although the Sheboygan and Manitowoc River basins have a slightly higher than the average annual temperature the Kewaunee River.

FIGURE 2.9

Precipitation trends over time for long-term trend basins

Daymet data

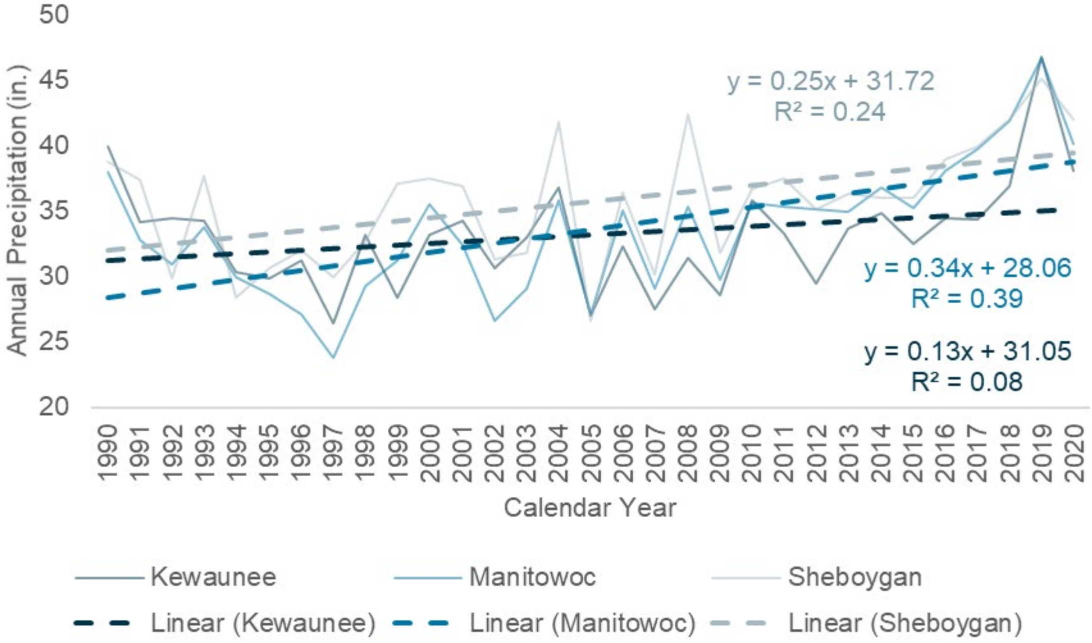
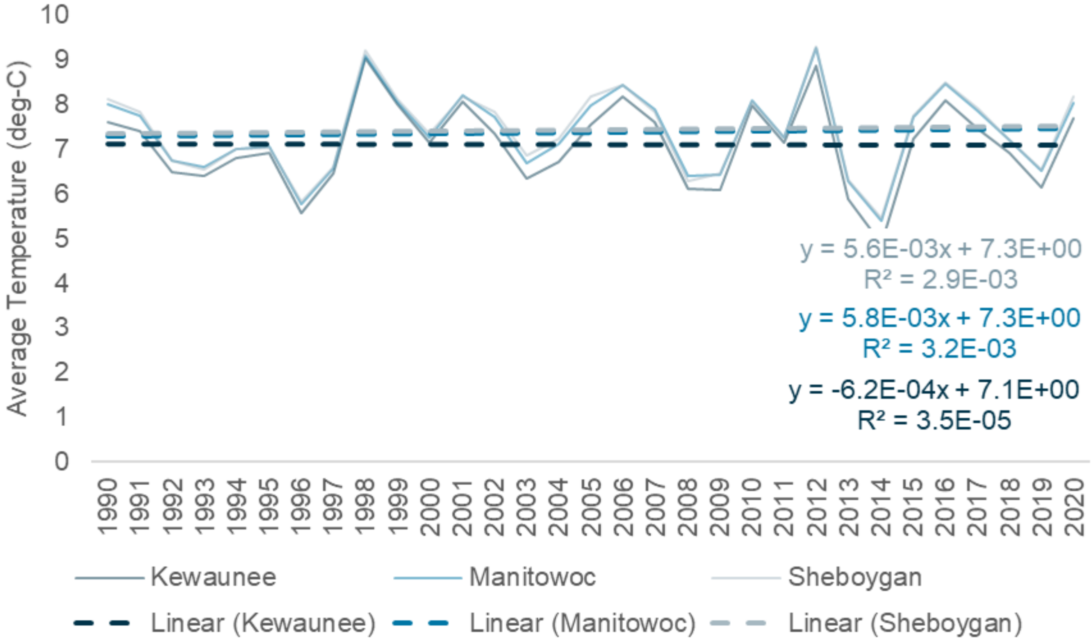


FIGURE 2.10

Temperature trends over time for long-term trend basins

Daymet data



Average precipitation for each month is summarized in Figure 2.11. Generally, the highest precipitation occurs in July and the lowest precipitation occurs in February. For most months of the year, precipitation in the Sheboygan and Manitowoc River is greater than the Kewaunee River precipitation. Between September and December, however, the Kewaunee River basin receives approximately the same amount or greater amount of precipitation. Average temperature for each month is summarized in Figure 2.12. The highest average monthly temperature occurs in July, and the lowest average monthly temperature occurs in January.

FIGURE 2.11

Average monthly precipitation for long-term trend basins

Daymet data

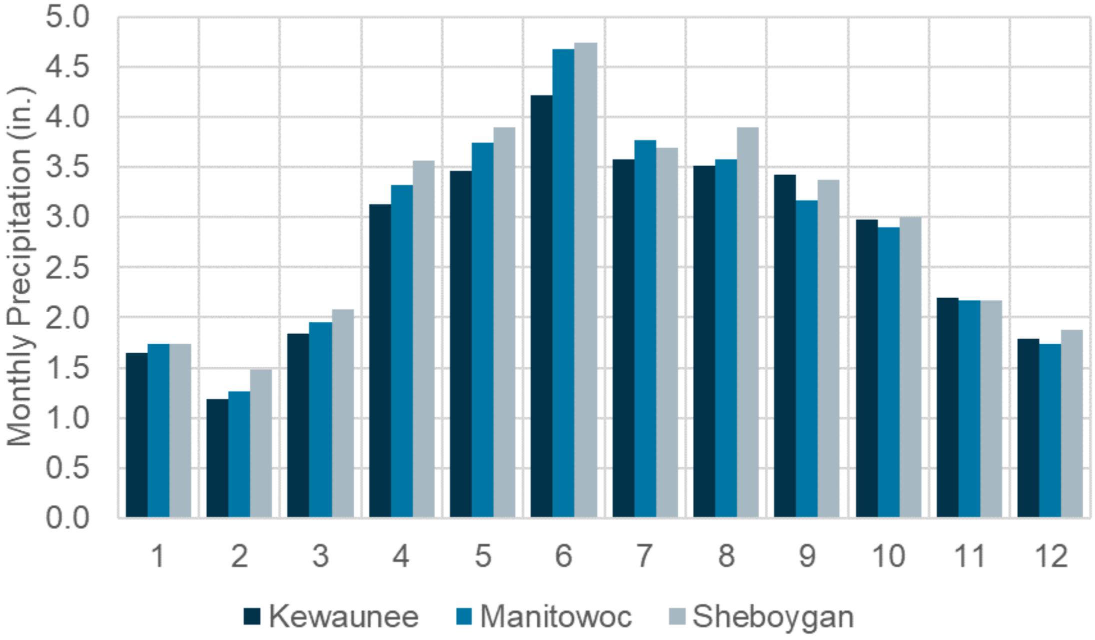
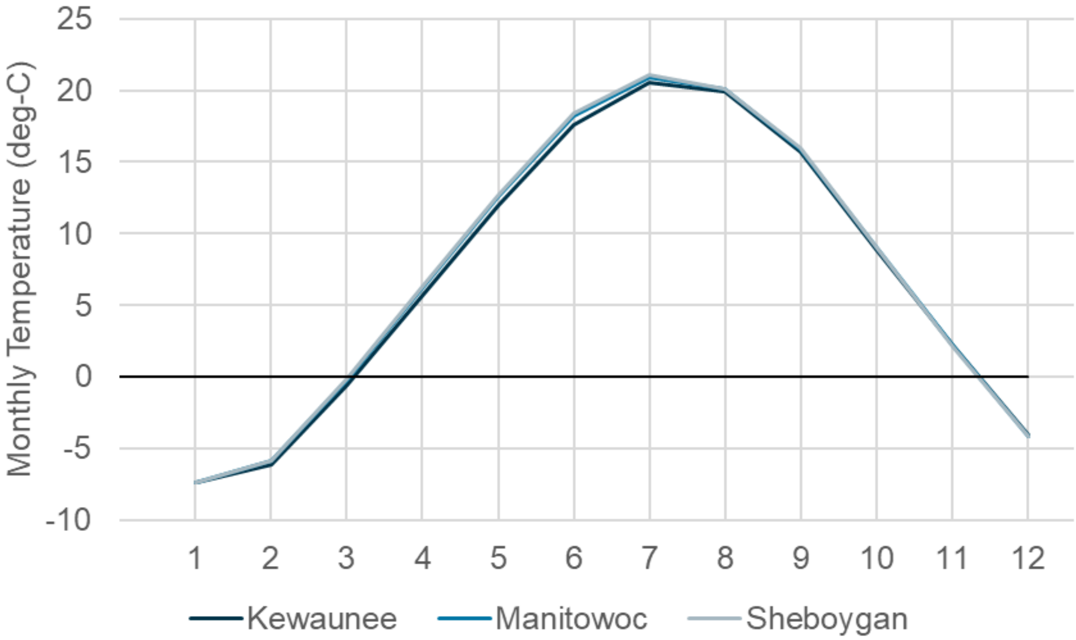


FIGURE 2.12

Average monthly temperature for long-term trend basins

Daymet data



2.8. Long-term monitoring data

Within the NE Lakeshore study area, three monitoring sites are maintained as long-term trend (LTT) sites by the Wisconsin Department of Natural Resources (DNR). The sites are located near the mouths of the Kewaunee River, the Manitowoc River, and the Sheboygan River. The LTT monitoring program tracks and analyzes water quality trends over time throughout Wisconsin's rivers. The monitoring network consists of 43 sites, and it encompass all major basins in Wisconsin. Water quality data for the sites are collected and are used to establish trends in ambient water quality throughout the state. More information about the program can be found in the DNR's Water Monitoring Strategy (WDNR, 2015).

The three LTT monitoring sites in the study area are located at USGS gages, which provide continuous flow data. Water chemistry data are collected by the DNR once per month. Sampling includes chemistry grab samples and field measurements. Chemistry collected includes nutrients such as nitrogen and phosphorus. Details about the long-term trends data are provided in Appendix A of the larger Northeast Lakeshore Nitrogen Analysis report.

An example of average monthly flows for the Kewaunee River is provided in Figure 2.13. For the Kewaunee River and the other two long-term trend sites, flow is typically highest in March and April and lowest in August and September. An example of average monthly concentration data for nitrate and total Kjeldahl nitrogen in the Kewaunee River is provided in Figure 2.14. The trend of concentration data over time is similar for all three long-term trend basins: Nitrate concentration is highest in the winter months and lowest in the summer months, and the opposite relationship occurs for TKN. The relationships have been observed in other studies (Lorenz and others, 2012), and the results are common in northern climates.

FIGURE 2.13

Average monthly flow for the Kewaunee River (USGS 04085200)

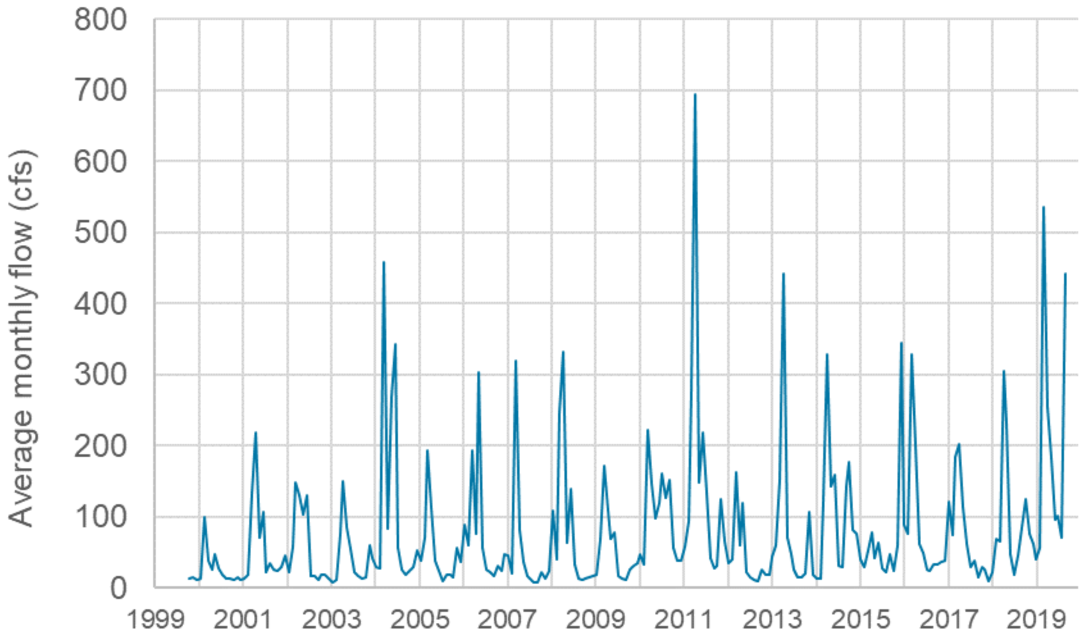
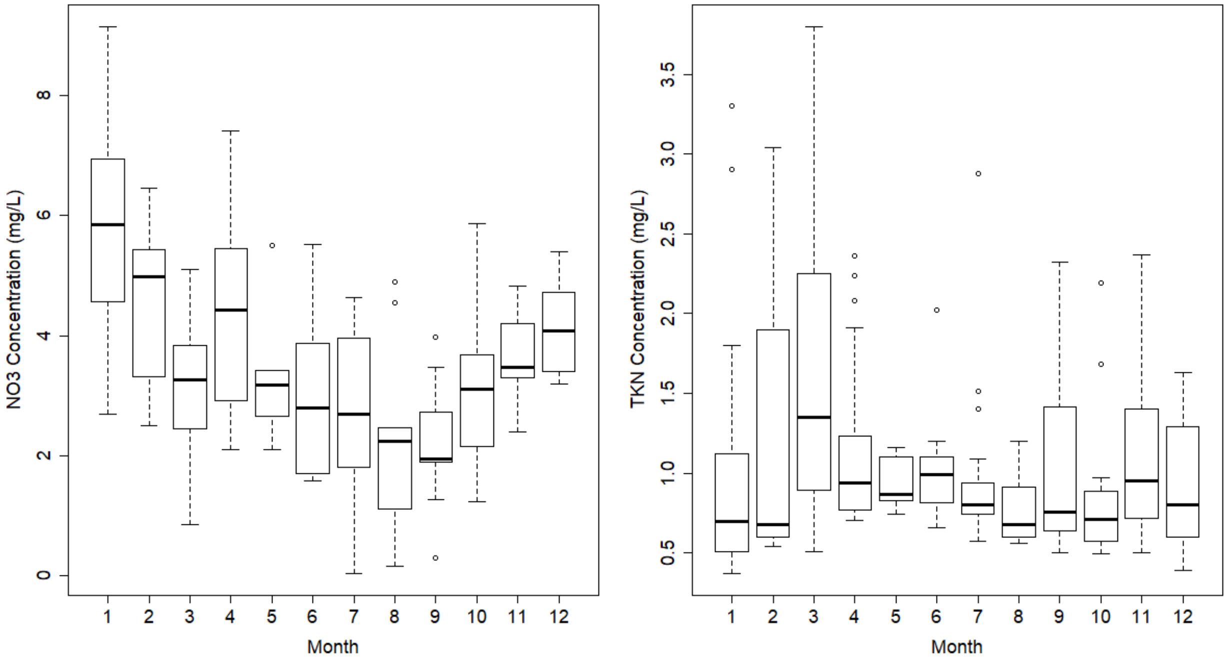


FIGURE 2.14

Monthly distribution of concentrations at the Kewaunee River



2.9. Short-term monitoring data

In addition to the data at the long-term trends site, stream discharge and nutrient concentration data are available from the monitoring efforts conducted for the Northeast Lakeshore TMDL, which was performed by the DNR. Data are available for approximately 40 locations during the study period. Water quality data include measurements for total phosphorus (TP), total suspended solids (TSS), total nitrogen (TN), nitrate (NO3), total Kjeldahl nitrogen (TKN), and ammonia (NH3). Data are available between 2017 and 2018 from the entire year and the growing season, which occurs from May through October. Additional information about the short-term monitoring data is available in Appendix C of the nitrogen analysis report.

Maps of the results for total nitrogen at the short-term monitoring sites are provided in Figure 2.15 and Figure 2.16. Average total nitrogen concentrations are displayed in the first figure, and average total nitrogen fluxes are displayed in the second figure. Similar results are available for NO3, TKN, and NH3. The results for all constituents and all sites are further summarized in Appendix C of the nitrogen analysis report.

FIGURE 2.15

Growing season median concentration (mg/L) for TN

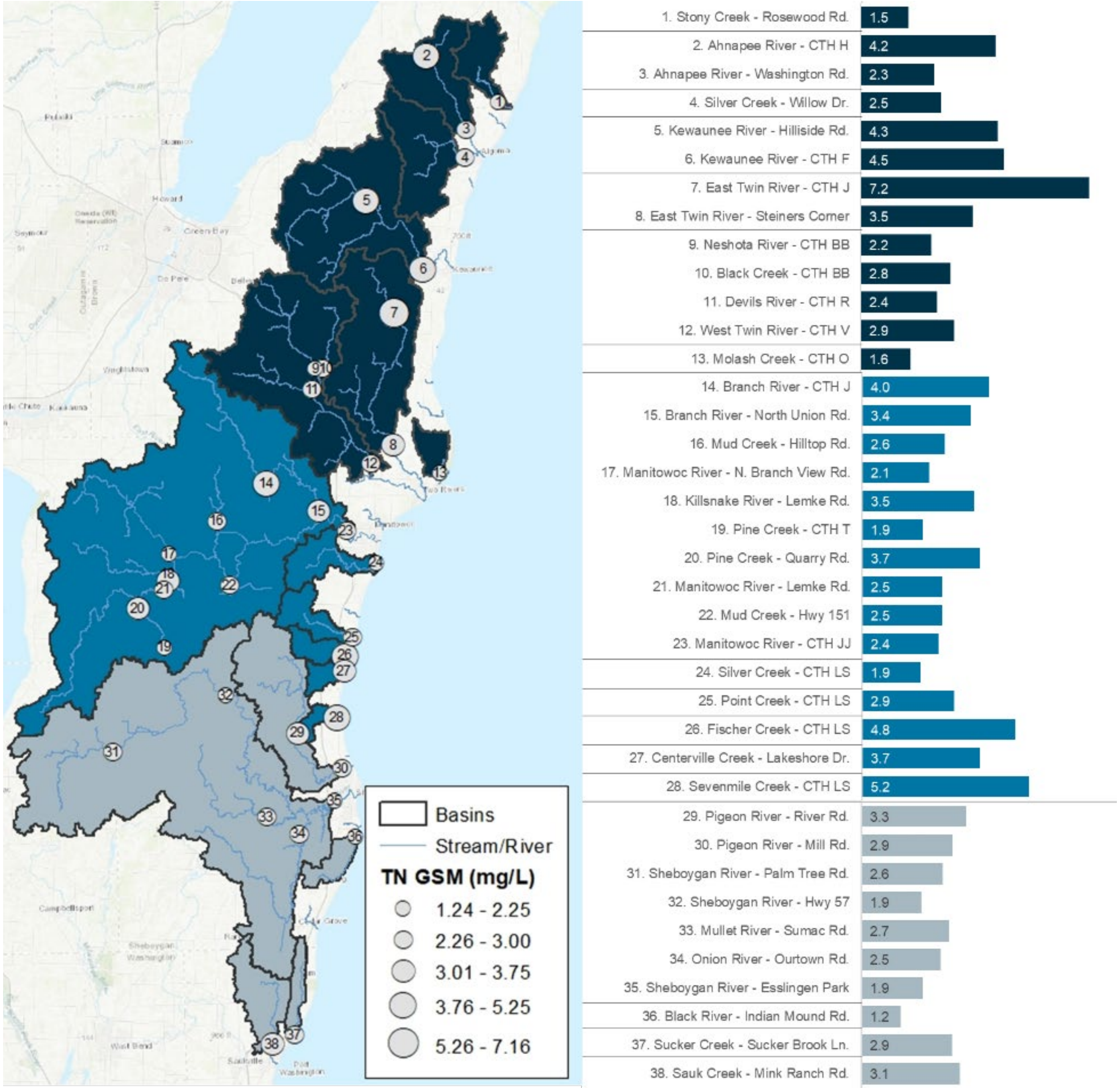
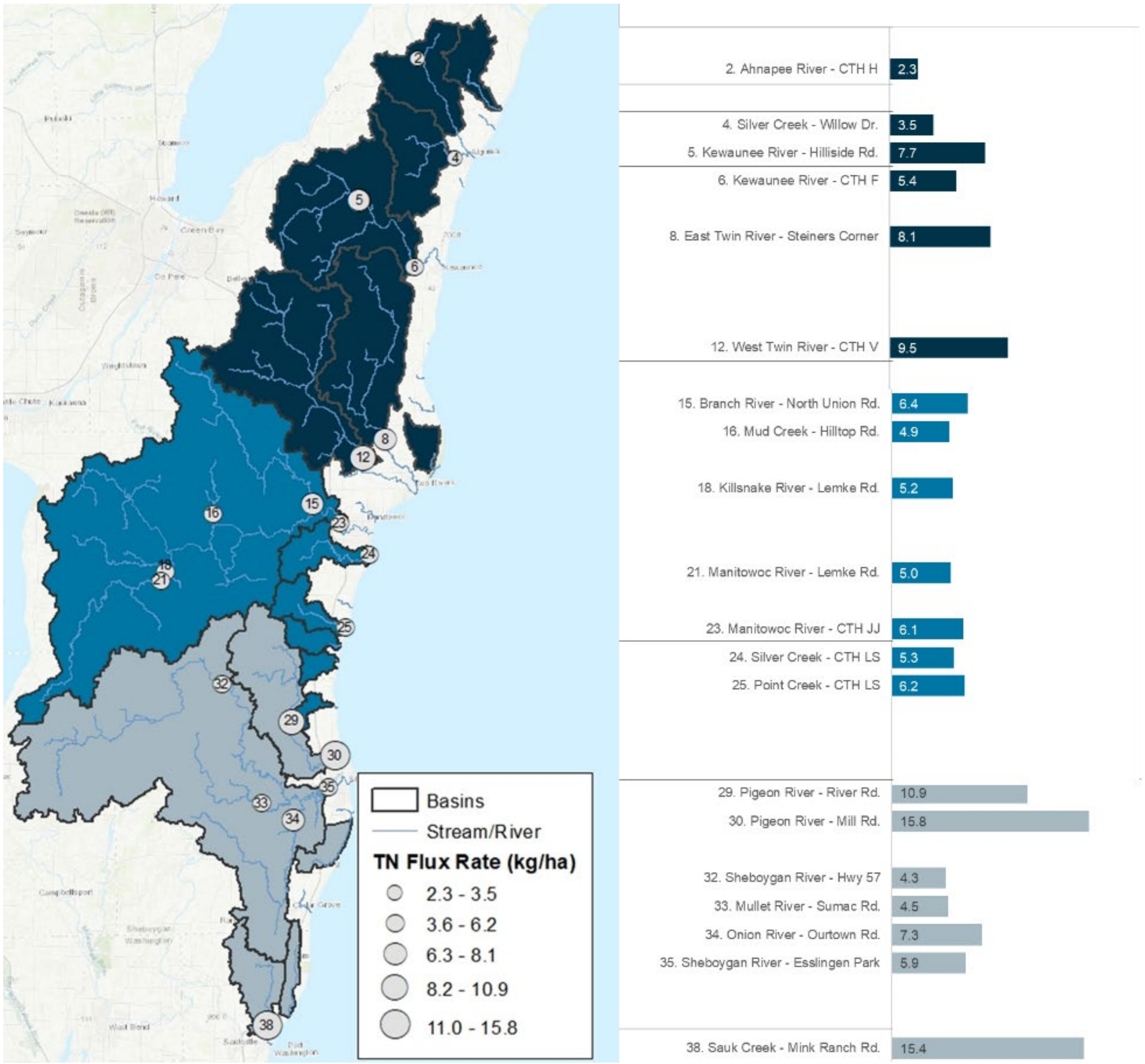


FIGURE 2.16
Modeled 2018 growing season TN flux (kg/ha)



2.10. Baseflow

Baseflow is incorporated in the analysis to evaluate the impact of runoff, interflow, and baseflow on concentrations and loading. An assessment of baseflow conditions for the three long-term trend sites is provided in Appendix F of the larger nitrogen analysis report. The baseflow for the sites are evaluated using a traditional baseflow separation approach and a delayed flow index approach.

Typical baseflow separation splits stream hydrographs into two components: quickflow and baseflow. Quickflow is loosely defined as the flow that originates from overland flow, and baseflow is defined as the flow that originates from the groundwater. Many methods exist for evaluating baseflow (Lott and Stewart, 2016). For this analysis, an automated smoothed-minima method developed by the UK Institute of Hydrology (Institute of Hydrology, 1980; World Meteorological Association, 2019) is used. The method requires a 'flow block' to be defined, and the commonly accepted flow block of 5 days is used. The 5-day flow block essentially assumes streamflow contributions that occur within five days of a precipitation event are associated with quickflow, and streamflow contributions that occur after five days of a precipitation event are associated with baseflow.

Baseflow is evaluated for the three long-term trend sites discussed in Section 2.8. A summary of the results from the baseflow separation for the three sites are summarized in Table 2.3. The baseflow index is equal to the sum of baseflow divided by the sum of all streamflow. For example, the baseflow index of 0.42 for the Kewaunee River indicates 42 percent of all flow in the river is associated with baseflow. Baseflow is also expressed using hydrographs, and the hydrograph for the Kewaunee River is provided in Figure 2.17. Baseflow index can be calculated from this graph by dividing the area under the dashed line by the total area under the blue line.

TABLE 2.3

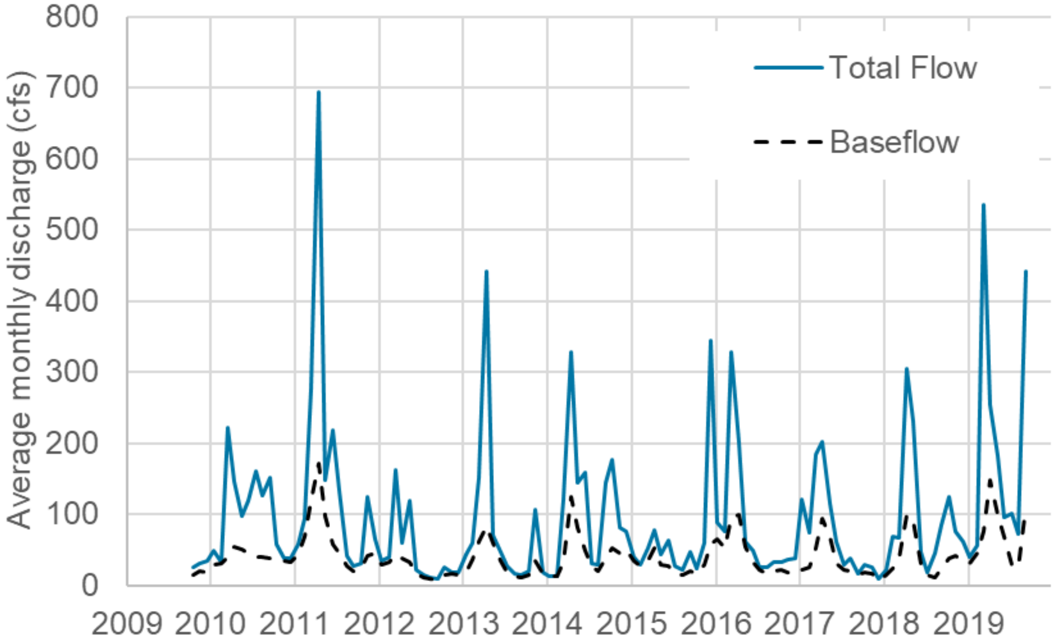
Baseflow index for the three major basins

Major basin	Baseflow index (BFI)
Kewaunee River at Kewaunee, WI	0.42
Manitowoc River at Manitowoc, WI	0.50
Sheboygan River at Sheboygan, WI	0.50

FIGURE 2.17

Average monthly temperature for long-term trend basins

Daymet data



Baseflow can be separated into additional categories using an approach known as the delayed flow index. A detailed description of the delayed flow index is provided in Stoelzle and others (2020). Calculation of the delayed flow index for a stream is similar to the approach used for the traditional baseflow separation described above. Rather than being separated into only two components, however, the hydrograph is separated into four components: quickflow, short interflow, long interflow, and groundwater flow. The distinction is important because chemical and nutrient characteristics of short interflow, long interflow, and groundwater flow may be different.

For the three long-term trend basins, the percent of total flow in each flow category is summarized in Table 2.4. The results indicate the runoff for the three basins accounts for 45 percent of flow in the Manitowoc River and Sheboygan River and 43 percent for the Kewaunee River. Groundwater flow accounts for 15 percent of total flow for the Manitowoc River, 18 percent of the total flow for the Kewaunee River, and 21 percent of the total flow for the Sheboygan River. A hydrograph for the Kewaunee River demonstrating the four flow categories is provided in Figure 2.18. The percentages in Table 2.4 represent the total area for each of the solid colors in the figure.

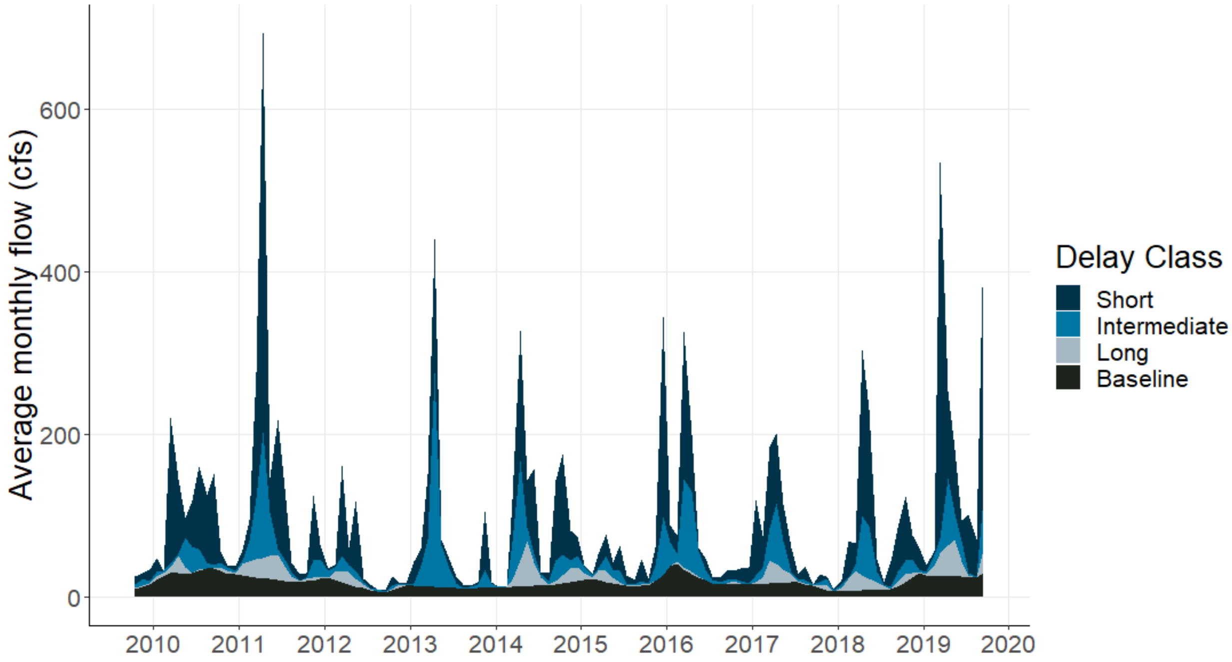
TABLE 2.4

Percent of total flow in delayed flow categories for the three major basins

Major basin	Runoff	Short Interflow	Long Interflow	Groundwater Flow
Kewaunee River at Kewaunee, WI	52%	20%	9%	18%
Manitowoc River at Manitowoc, WI	45%	28%	11%	15%
Sheboygan River at Sheboygan, WI	45%	23%	11%	21%

FIGURE 2.18

Delayed flow hydrographs for the Kewaunee River



3. METHODS

Data summarized in Section 2 can be used to evaluate the relationships between water quality and environmental characteristics. For this analysis the methods include regression tree analysis, simple linear regression, multiple linear regression, and random forest modeling. The following sections describe each of the methods in detail.

3.1. Forward Stepwise Regression and Regression Tree Analysis

Robertson and Saad (2003) explored the relationship between water quality constituents and environmental characteristics. The relationships were established by compiling water quality data and environmental characteristics from a large number of sites in the north-central and central regions of the continental United States. Environmental characteristics in the analysis included a portion of the characteristics described in Section 2. The authors explored data using three methods: Pearson correlation coefficients, stepwise linear regression, and decision-tree analysis.

In the first part of the analysis, Pearson correlation coefficients were calculated for water-quality concentrations and individual environmental variables. Factors describing land use and soils in the watershed were most highly correlated with water quality concentrations. Several environmental variables were highly correlated with other environmental variables, however, so the most important factors causing the variation were difficult to ascertain.

In the second part of the analysis performed by Robertson and Saad (2003), a forward stepwise regression was conducted with all environmental characteristics. The forward stepwise regression analysis was used to determine which three environmental characteristics best predicted water quality characteristics. The regression was also performed excluding land use characteristics to determine which three natural characteristics best predict water quality. The number of characteristics selected was limited to three because the addition of additional parameters did not significantly increase the accuracy of the results. A summary of the selected parameters for different water quality constituents is provided in Table 3.1 and Table 3.2. The variables in the table help discern which constituents may be having the largest impact on water quality.

TABLE 3.1

Results of forward stepwise regression with land-use characteristics included

Robertson and Saad (2003)

Dependent variable	First variable	Second variable	Third variable
Total phosphorus	Forest	Soil permeability	Runoff
Total nitrogen	Agriculture	Urban	No aquifer
Nitrate nitrogen	Agriculture	Urban	Soil slope
Kjeldahl nitrogen	Soil slope	Barren	Till
Sediment/solids	Forest	Clay content	Runoff

TABLE 3.2

Results of forward stepwise regression with land-use characteristics excluded

Robertson and Saad (2003)

Dependent variable	First variable	Second variable	Third variable
Total phosphorus	Till	Clay content	Runoff
Total nitrogen	Till	No aquifer	Soil slope
Nitrate nitrogen	Erodibility	No aquifer	Soil slope
Kjeldahl nitrogen	Soil slope	Till	Carbonate
Sediment/solids	Clay content	Runoff	Air temperature

In the third part of the Robertson and Saad (2003) analysis, a regression-tree analysis was performed to divide locations into four distinct groups. A regression-tree analysis (Breiman and others, 1984) is a statistical technique that explores the relationships between a single dependent variable and several independent variables. Data are partitioned into subgroups based on regression between the dependent variable and the independent variable.

An example of a regression-tree analysis is the SPAtial Regression-Tree Analysis (SPARTA) developed by Robertson and Saad (2003). SPARTA uses a regression tree analysis to define "environmental-water quality zones" that are zones with similar existing or potential water quality. A regression-tree analysis was used define four groups based on the relationships between water quality constituents and environmental variables. The results of the analysis for total nitrogen are provided in Figure 3.1 for the evaluation with land use characteristics included and Figure 3.2 for the evaluation with land use characteristics excluded. A summary for the other water quality constituents is provided in Robertson and Saad (2003, Table 5, p. 593).

FIGURE 3.1

Results of total nitrogen regression-tree analysis with land-use characteristics included

Adapted from Robertson and Saad (2003)

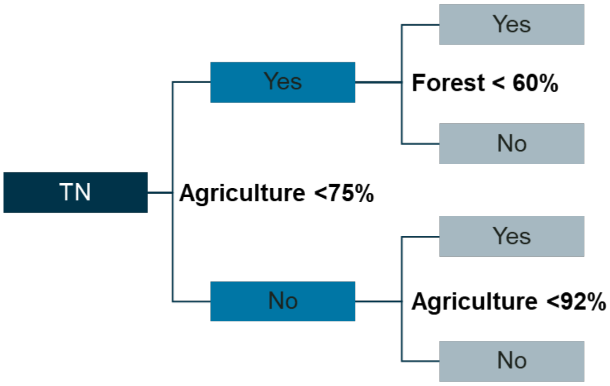
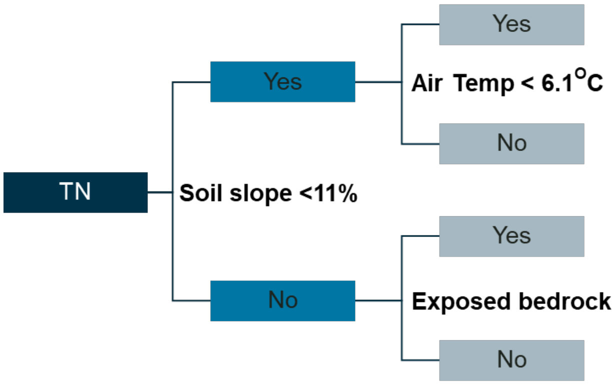


FIGURE 3.2

Results of total nitrogen regression-tree analysis with land-use characteristics excluded

Adapted from Robertson and Saad (2003)

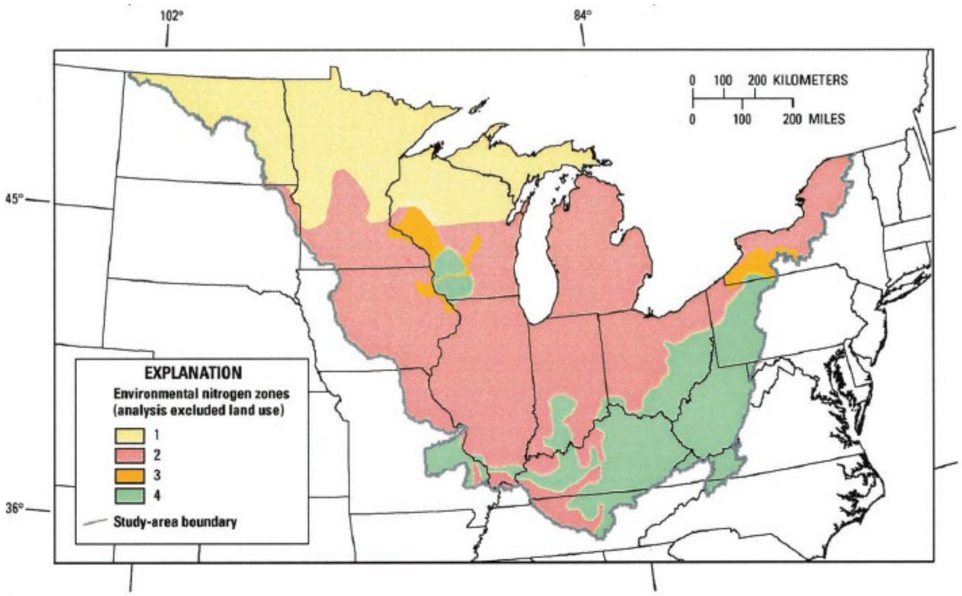


The results of the regression-tree analysis identified characteristics that impact nutrient concentrations in streams. When land use characteristics were included, the amount of agricultural and land forest land were predictive of the total nitrogen concentrations. When land use characteristics were excluded, the soil slope, the air temperature, and the percentage of exposed bedrock were predictive of the total nitrogen concentrations. The results from the regression-tree analysis were applied to geographic data to establish different water-quality zones. Figure 3.3 shows the geographic distribution of the four zones from the SPARTA analysis. The colors on the figure provide information about the qualitative concentration range. Green zones have the lowest stream nitrogen concentrations followed by yellow, orange, and red, which has the highest concentrations.

FIGURE 3.3

Environmental nitrogen zones derived from regression-tree analysis

Robertson and Saad (2003, Figure 5B, p. 597)



3.2. Simple Linear Regression Modeling

A simple linear regression analysis for sites in the Northeast Lakeshore TMDL study area is used to evaluate the relationship between the watershed characteristics and the water quality results described in Section 2. The method is similar to the approach described by Robertson and Saad (2003).

At the short term monitoring sites, each of the 850 characteristics is compared with the average flow-weighted mean concentration calculated from April to September of 2018. The timeframe is selected based on the availability of monitoring data and continuous flow data. More information about the short-term monitoring is described in Section 2.9 and Appendix C of the nitrogen analysis report.

The availability of monitoring and continuous flow data varies across the different parameters in the study area. The data are available at 20 sites for total nitrogen, 8 sites for nitrate, and 5 sites for total Kjeldahl nitrogen. Since the number of sites is small, only a simple linear regression can be performed to establish the presence of a correlation between the watershed characteristics and the concentration estimates.

The linear regression is performed by assigning the flow-weighted mean concentration, growing season median concentration, or flux as the dependent variable and the watershed characteristics as the independent variable. The regression is performed for each of the 850 watershed characteristics that are described in Section 2. The calculated Pearson’s correlation coefficient is examined to determine how well the water quality data are described by each watershed parameter.

Given the large number of watershed characteristics, a relationship between two individual characteristics is likely. To determine if any of the watershed characteristics are related, a Pearson's correlation coefficient is calculated to compare each of the parameters to one another. For example, agricultural land use upstream of the monitoring sites is compared with urban land use upstream of the monitoring sites. If the correlation coefficient is sufficiently high, the amount of agriculture in a watershed and the amount of urban area in a watershed are likely related. Knowledge about the relationships among watershed characteristics is important when characteristics are combined in further analysis.

For this analysis, all calculations are performed using the base packages in the R language for statistical computing (R Core Team, 2019).

3.3. Multiple Linear Regression Modeling

The simple linear regression technique only provides information about the relationship between concentrations and a single explanatory variable. Given the complexity of watershed systems, many watershed characteristics can influence the flows and water quality in a stream. To account for the influence of multiple watershed characteristics, a multiple linear regression approach is used to estimate in-stream concentrations.

Multiple linear regression relates more than one independent variable to a single dependent variable. In this analysis the dependent variable is concentration and independent variables are watershed characteristics. Multiple linear regression analysis can be performed on the long-term trend sites because a large dataset of water quality measurements is available. The analysis is run using multiple years of data. Multiple linear regression cannot be performed on data from the short-term monitoring programs, however, because the sites do not contain enough water quality measurements for a meaningful relationship to be discerned.

The multiple linear regression is performed using the following methodology:

1. All available watershed characteristics and climate observations for each long-term trend site is consolidated into a single database.
2. All available water quality data since 2008 are cross-referenced with the watershed characteristics and climate observations so each individual water quality measurement is assigned a single set of parameters.
3. The distribution of water quality data is evaluated to determine if the data follow a normal distribution. Measured concentrations are often right-skewed, which means the average concentration is higher than the median concentration. In other words, the distribution has more high-concentration samples than one would expect with a

standard normal distribution. If the distribution is right-skewed, the measured data are log-transformed, and the linear regression is performed on the log-transformed data.

4. The compiled database for the long-term trend sites is checked to determine which are most appropriate for inclusion in the analysis. For example, each monitoring station only contains a single value from WHDplus. Since only three monitoring stations are used in the analysis, only three unique values of watershed characteristics are available for all water quality measurements. As a result, WHDPlus parameters are excluded from the analysis. Once the exclusion exercise is completed, approximately 50 watershed characteristics remain.
5. A multiple linear regression model is initially fit using all remaining watershed characteristics and climate observations. The multiple linear regression is performed using the base packages in R (R Core Team, 2019). Watershed characteristics and climate observations that may have a relationship with the observed water quality data are identified, and all other parameters are removed from the analysis.
6. The remaining parameters are checked for collinearity using the steps described in Section 3.2. When parameters have a strong correlation, best judgement is used to select one of the parameters.
7. An additional multiple linear regression model is fit for the remaining parameters from Step 5. The results of the analysis are evaluated to screen out parameters that do not have a noticeable correlation. For the purpose of this analysis, noticeable correlation is defined as any parameter that has a p-value of less than 0.10.
8. A final multiple linear regression model is fit for the remaining parameters from Step 6. This multiple linear regression model is used as the final predictor equation that relates watershed characteristics and climate parameters to measured concentrations.
9. If the concentration data are log-transformed in step 3, the predicted concentrations are converted to concentrations using a bias correction factor.

The multiple linear regression model can be run for an individual long-term trend site, a combination of all long-term trend sites, the entire year, the growing season, or an individual season (spring, summer, fall, and winter). The final output of the analysis allows for the determination of parameters that have the biggest influence on water quality concentration. The model can also be used to predict water quality concentration when the independent variables in the analysis are known.

3.4. Random Forest Modeling

A final method for analyzing measured water quality data and watershed characteristics is a random forest model. Random forest analysis is a machine-learning technique that expands on the basic decision tree analysis and allows for a more robust prediction of a dependent variable and multiple independent variables.

While decision trees are useful analysis tool, they are prone to overfitting models to the data set used for training the model (Ho, 1995). Additionally, decisions made to remove parameters from the decision tree analysis may result in the loss of accuracy and optimization of the model.

The basis of random forests is provided in Brieman (2001). Random forest models evaluate multiple decision trees. For this analysis and the corresponding datasets, water quality data are assigned as the dependent variable, and the watershed characteristics and climate observations are assigned as the independent variables. The random forest method is summarized by the following steps:

1. The dataset is trimmed by randomly selecting a group of dependent variables that are used for building a decision tree.
2. A new training dataset is created. A training dataset is a collection of individual observations that are randomly selected from the original dataset. The selection of the training dataset is performed with replacement, meaning the same observation may be used in the training dataset more than once. Only a percentage of all observations are used to develop the training dataset – the observations collected within the training dataset are known as in-bag data. The remaining observations that are not used to build the decision tree are known as out-of-bag data, and these data are used to validate the model.
3. A decision tree is built using the randomly selected group of dependent variables and the training dataset. The decision tree is validated using the out-of-bag data.
4. Steps 1 through 3 are repeated to build the random forest model, which is a combination of a pre-determined number of individual decision trees.

An example of the development of the random forest model is provided in Figure 3.4. The final random forest model is a 'black-box' model. A 'black-box' model means the inputs and outputs of the model can be observed, but the inner-workings of the model are not knowable. The random forest models built for this analysis use the watershed characteristics and climate observations as the inputs. Estimates of water quality results can be obtained by entering input data for a particular space and time into the random forest model. The procedure for using the random forest model for estimates is provided in Figure 3.5.

FIGURE 3.4

Development of a random forest model

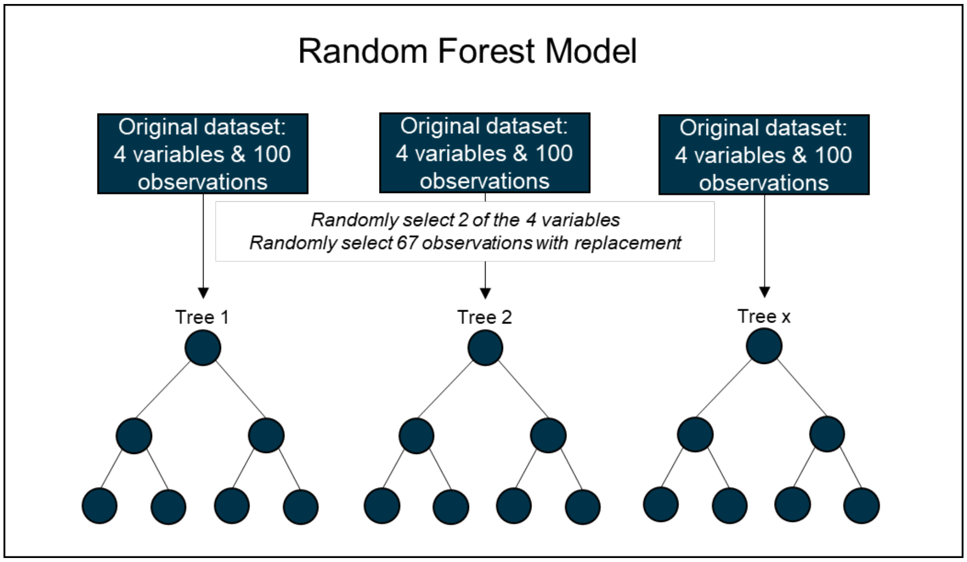
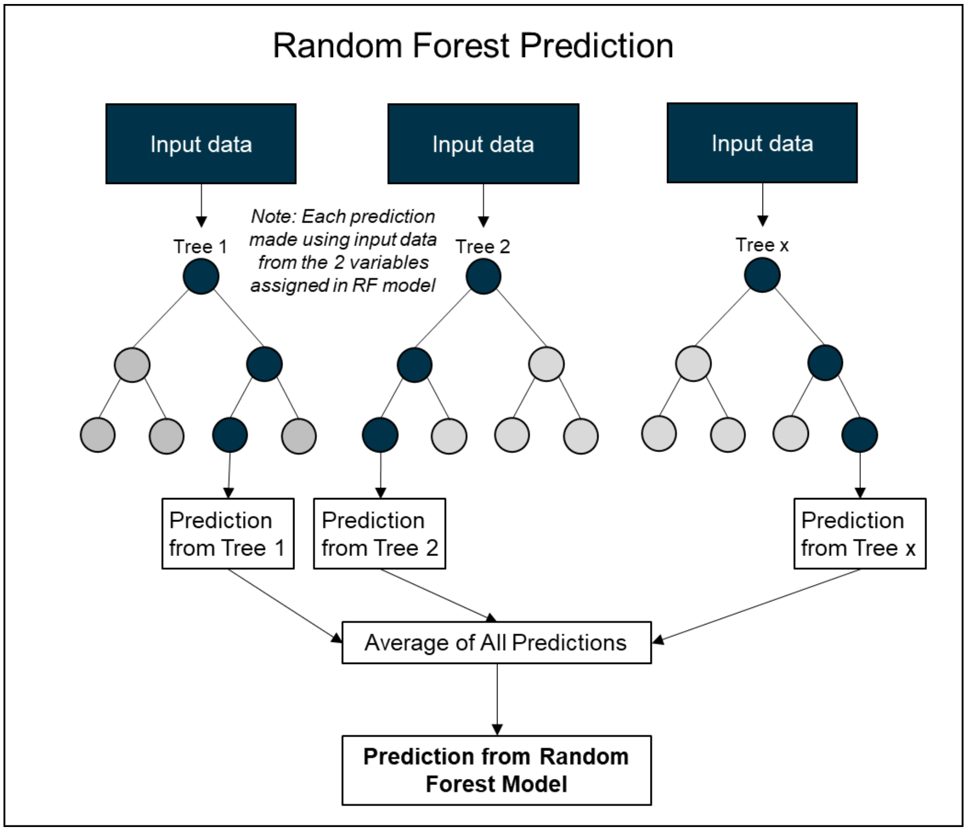


FIGURE 3.5

Prediction using random forest model

Adapted from Chakure, 2019



The random forest analysis is performed in R (R Core Team, 2019) using the *Boruta* package (Kursa and Rudnicki, 2010) and the *randomForest* package (Liaw and Wiener, 2002). The *Boruta* package uses a variable selection algorithm to determine which independent variables are related to the dependent variable. The algorithm assigns each independent variable one of three classifications: confirmed, tentative, or rejected. The algorithm is based around the random forest methods. The *randomForest* package is used to develop the random forest models for this analysis. The package uses the methods that are described in the preceding paragraphs.

The methods for developing random forests for this analysis are described below:

1. All available watershed characteristics and climate observations for each long-term trend site is consolidated into a single database.
2. All available water quality data since 2008 are cross-referenced with the watershed characteristics and climate observations so each individual water quality measurement is assigned a single set of watershed parameters.
3. The entire dataset is evaluated using the *Boruta* package. All variables that are classified as "rejected" are removed from the dataset.
4. The remaining variables from the *Boruta* package analysis are assessed for collinearity using the findCorrelation function in the *caret* package (Kuhn, 2001). When two dependent variables that are highly correlated, one of the parameters is selected and the other is removed from the dataset.
5. A random forest model is constructed using the *randomForest* package. The primary inputs for the randomForest function in the *randomForest* package are input data, number of trees, and the number of variables randomly sampled as candidates for building the individual decision trees. The value for the number of trees is selected to ensure the analysis is optimized to ensure the input data are adequately incorporated into the model. The number of variables randomly selected for creating the individual decision trees is typically set as the total number of variables in the original dataset divided by three.
6. The importance of variables in the initial random forest is evaluated. The importance of variables is classified in the output of the random forest analysis. The *randomForest* package creates a bar-chart that illustrates the relative importance of each variable. Best judgement is used to select parameters that are most important.
7. A random forest model is created with a new dataset that only includes the most important variables identified in Step 6.

The random forest model can be run for an individual long-term trend site, a combination of all long-term trend sites, the entire year, an individual season (Spring, Summer, Fall, Winter), or only the growing season. The final output of the analysis provides information about the parameters that have the biggest influence on water quality concentration. The model can also be used to predict water quality concentration when the independent variables in the analysis are known.

4. RESULTS

Data available for the Northeast Lakeshore TMDL study area are evaluated using the methods described in Section 3. The methods used are linear regression for concentrations for short-term and long-term trend sites, multiple linear regression for all sites, and random forest modeling for all sites.

4.1. Simple Regression Modeling for Monitored Sites

To develop a simple linear regression model for all monitored sites, the flow-weighted mean concentration, total export, and growing season median concentration are calculated calculated from the mixed-effects model, which is described in Appendix C of the report. Results from the model are calculated for the growing season, which is defined as May through October. The timeframe is selected based on the availability of the water quality data and continuous flow monitoring data.

4.1.1. Simple Linear Regression Results for Total Nitrogen

Tables 4.1 through 4.3 summarize results from the simple linear regression modeling for flow-weighted concentration, total export, and growing season median concentration of total nitrogen. The direction of the relationship, the Pearson's correlation coefficient (Pearson's r), and the probability of the correlation being non-random (p-value) is presented in the tables. Only relationships with a p-value less than 0.05 are presented. No significant relationships between total nitrogen growing season median concentration and watershed parameters are identified in the analysis, which is reflected in Table 4.3.

Information about how the watershed characteristic influences the concentration is provided by the direction of the relationship: A positive relationship indicates that concentration increases when the value of the watershed characteristic increases, and a negative relationship indicates that concentration decreases when the value of the watershed characteristic increases. Figures 4.1 through 4.2 provide a graphical representation of the relationships for the parameters most strongly correlated with total nitrogen flow-weighted mean concentration and total export.

Since data about the flow-weighted mean concentration is limited to only a small number of sites and a single growing season, the correlations must be carefully evaluated to verify the reasonableness of the relationship – some correlations may be coincidental and may not represent a true cause-and-effect relationship. Additionally, in-stream concentrations and loads of total nitrogen are related to many interacting watershed parameters. A single watershed parameter is not likely sufficient to provide an accurate prediction of in-stream concentration or loads at other sites, so the results should be used primarily as a basis for providing a starting point for further watershed evaluation.

TABLE 4.1

Parameters with a significant relationship to flow-weighted mean total nitrogen concentration (2018 growing season)

Description	Direction	Pearson's *r*	p-value	Min. Value	Max. Value	Units
Dairy rotation in riparian zone	+	0.82	1.4E-05	11.6	47.1	% of total area
Excessively drained soils in watershed	+	0.82	1.9E-05	42.5	65.2	% of total area
Average soil organic matter of soils in watershed	-	-0.78	7.6E-05	1.5	10.7	Average %
Poorly drained soils in watershed	-	-0.78	7.9E-05	2.6	20.8	% of total area
Dairy rotation in watershed	+	0.76	1.5E-04	22.6	49.4	% of total area
Emergent/wet meadow wetland in watershed	-	-0.73	3.8E-04	0.2	5.0	% of total area
Erosion Class V soils	-	-0.71	6.3E-04	4.4	45.5	% of total area
Hydrologic soils group B/D in watershed	-	-0.71	6.8E-04	3.9	23.5	% of total area
Hydrologic soil group A/D in watershed	-	-0.69	1.2E-03	0.7	16.0	% of total area

TABLE 4.2

Parameters with a significant relationship to total export (kg/ac/yr) of total nitrogen (2018 growing season)

Description	Direction	Pearson's *r*	p-value	Min. Value	Max. Value	Units
Average oven dry bulk density of soils in watershed	+	0.73	3.7E-04	1.25	1.72	g/cm^3
Percent of silt in watershed soils	+	0.82	1.9E-05	42.5	65.2	% of total area
Percent of basin with tile drainage	+	0.68	1.4E-03	2.9	34.9	% of total area
Excessively drained soils in watershed	+	0.68	1.4E-03	42.5	65.2	% of total area

TABLE 4.3

Parameters with a significant relationship to growing season median total nitrogen concentration (2018 growing season)

<table>
<tr><th>Description</th><th>Direction</th><th>Pearson's *r*</th><th>p-value</th><th>Min. Value</th><th>Max. Value</th><th>Units</th></tr>
<tr><td colspan="7">None identified</td></tr>
</table>

FIGURE 4.1

Regression between flow-weighted mean total nitrogen concentration and landscape variables (2018 growing season)

(a) % of riparian zone in dairy rotation, (b) % of basin with excessively drained soils, (c) average organic matter of soils in basin, (d) % of basin with poorly drained soils

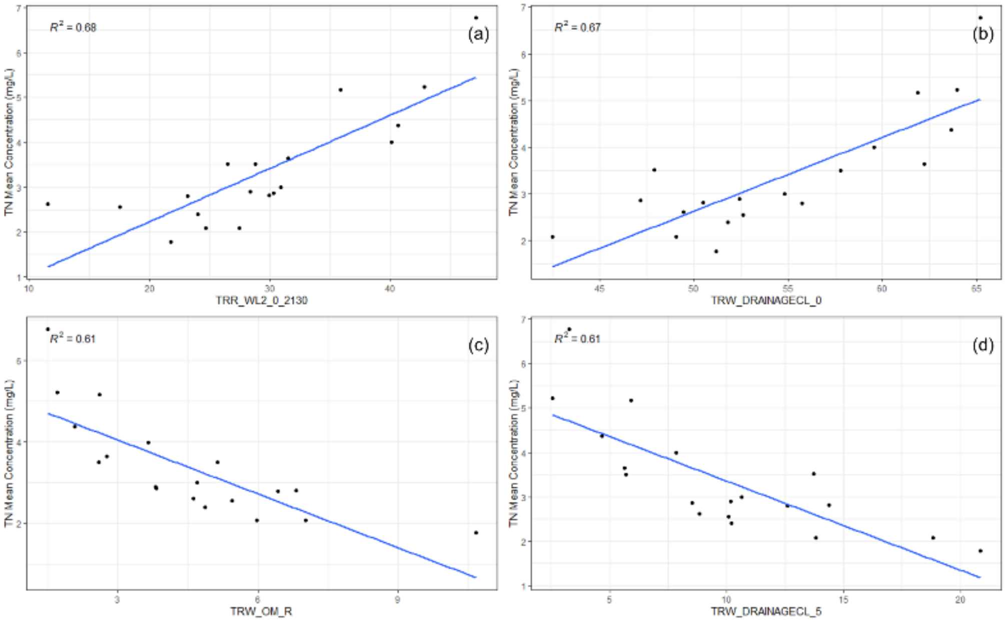
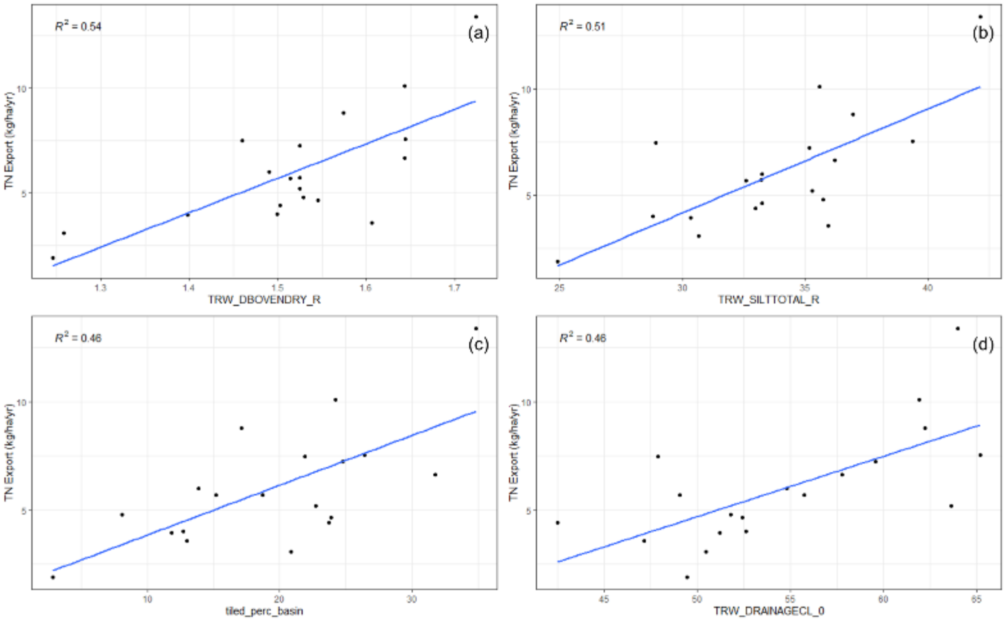


FIGURE 4.2

Regression between export (kg/ha/yr) of total nitrogen and landscape variables (2018 growing season)

(a) average bulk density of soils in watershed, (b) % of silt in basin, (c) % of basin with tile drainage, (d) % of basin with excessively drained soils



4.1.2. Simple Linear Regression Results for Nitrate

Tables 4.4 through 4.6 summarize results from the simple linear regression modeling for flow-weighted concentration, total export, and growing season median concentration of nitrate. The direction of the relationship, the Pearson's correlation coefficient (Pearson's r), and the probability of the correlation being non-random (p-value) is presented in the tables. Only relationships with a p-value less than 0.05 are presented.

Information about how the watershed characteristic influences the concentration is provided by the direction of the relationship: A positive relationship indicates that concentration increases when the value of the watershed characteristic increases, and a negative relationship indicates that concentration decreases when the value of the watershed characteristic increases. Figures 4.3 through 4.5 provide a graphical representation of the relationships for the parameters most strongly correlated with flow-weighted mean concentration, total export, and growing season median concentration. Limitations of the simple linear regression analysis for nitrate are similar to the limitations described for total nitrogen, which are discussed in Section 4.1.1.

TABLE 4.4

Parameters with a significant relationship to flow-weighted mean nitrate concentration (2018 growing season)

Description	Direction	Pearson's *r*	p-value	Min. Value	Max. Value	Units
Emergent/wet meadow wetland in watershed	-	-0.83	2.2E-02	0.51	1.67	% of total area
Somewhat excessively drained soils in watershed	+	0.78	3.9E-02	0.1	64.4	% of total area

TABLE 4.5

Parameters with a significant relationship to total export (kg/ha/yr) of nitrate (2018 growing season)

Description	Direction	Pearson's *r*	p-value	Min. Value	Max. Value	Units
Mean slope in riparian zone	+	0.94	1.7E-03	1.37	3.01	% slope
Emergent/wet meadow wetland in riparian zone	-	-0.90	5.9E-03	1.3	6.4	% of total area
Soils with runoff class 0 (negligible) in watershed	-	-0.89	8.0E-03	14.7	55.8	% of total area
Percent of basin with tile drainage	+	0.86	1.3E-02	2.9	22.7	% of total area
End-moraine (fine) surficial geology in riparian zone	+	0.86	1.4E-02	0.1	58.3	% of total area
Bedrock with 50 to 100 ft depth in watershed	+	0.81	2.8E-02	0.0	70.4	% of total area
Potato/vegetable in watershed	-	-0.76	4.8E-02	0.06	11.95	% of total area

TABLE 4.6

Parameters with a significant relationship to growing season median nitrate concentration (2018 growing season)

Description	Direction	Pearson's *r*	p-value	Min. Value	Max. Value	Units
Continuous corn in watershed	+	0.93	2.3E-03	1.4	4.3	% of total area
Emergent/wet meadow wetland in watershed	-	-0.92	3.4E-03	0.5	1.7	% of total area
Average nitrogen mass balance on agricultural lands in watershed	+	0.88	9.5E-03	30.3	82.9	kg/ha/yr
Liquid manure spread on agricultural lands in watershed	+	0.86	1.3E-02	3.0	5.2	1000 gallons/ac/yr
End-moraine (fine) surficial geology in riparian zone	+	0.85	1.5E-02	0.1	58.3	% of total area
Emergent/wet meadow wetland in riparian zone	-	-0.84	1.8E-02	1.3	6.4	% of total area
Dairy rotation in watershed	+	0.83	2.1E-02	25.6	46.1	% of total area
Hydrologic soil group C/D in watershed	+	0.83	2.2E-02	0.0	24.3	% of total area

FIGURE 4.3

Regression between flow-weighted mean nitrate concentration and landscape variables (2018 growing season)

(a) % of basin with emergent/wet meadow wetlands, (b), % of basin with somewhat excessively drained soils

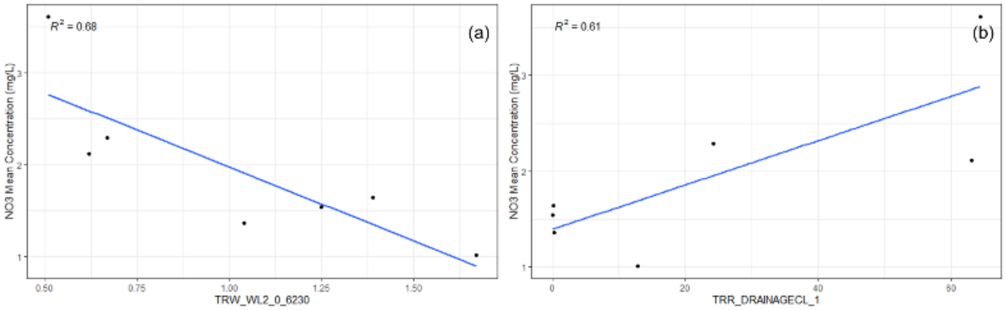


FIGURE 4.4

Regression between export (kg/ha/yr) of nitrate and landscape variables (2018 growing season)

(a) Mean slope in riparian zone, (b), % of riparian zone with emergent/wet meadow wetland, (c) % of basin with negligible-runoff soils, (d) % of basin with tile drainage

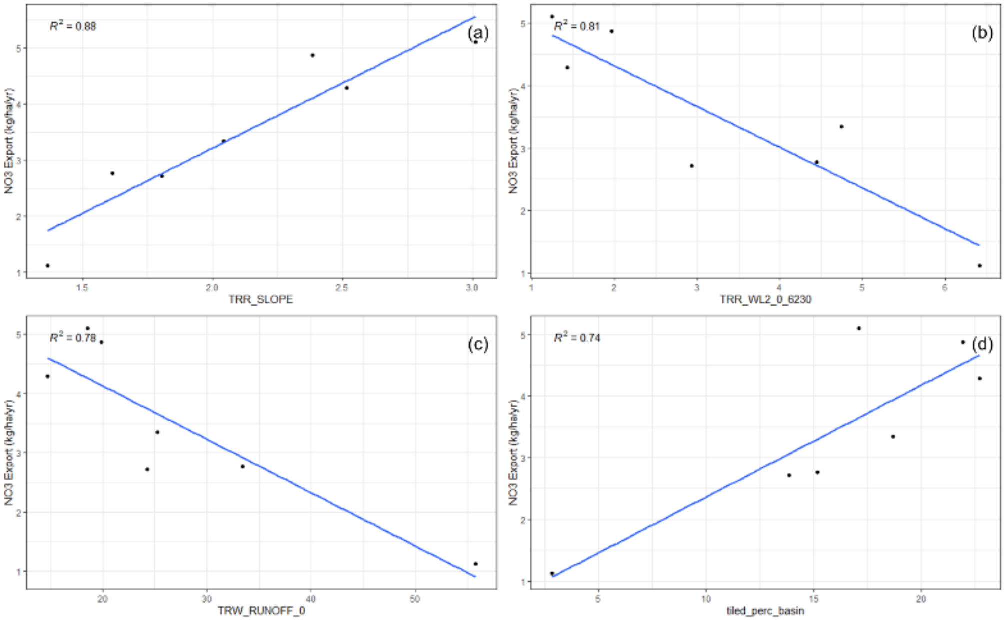
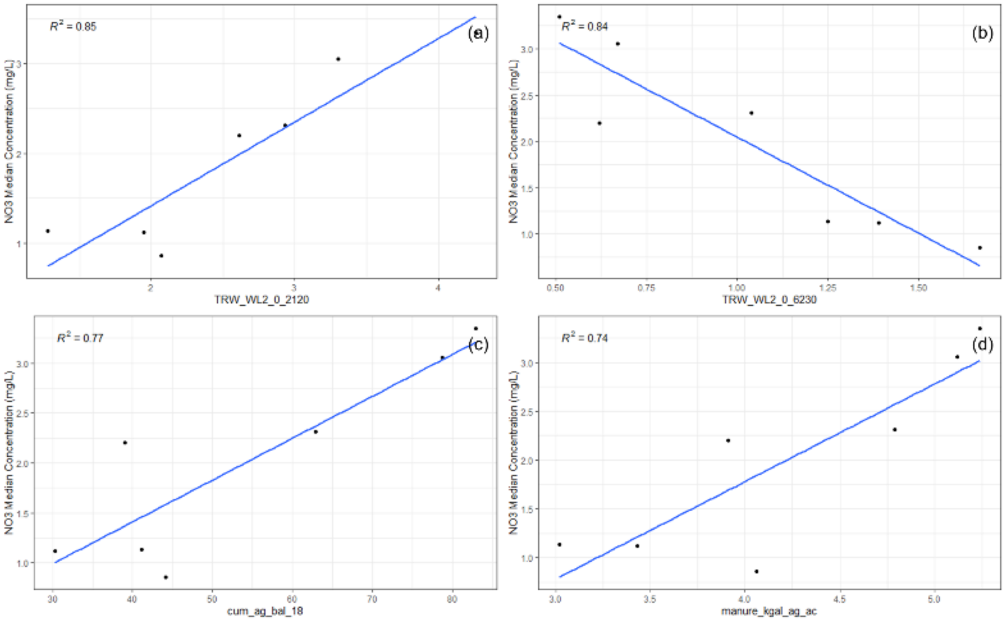


FIGURE 4.5

Regression between growing season median nitrate concentration and landscape variables (2018 growing season)

(a) % of basin with continuous corn, (b), % of basin with emergent/wet meadow wetland, (c) average nitrogen mass balance in basin, (d) liquid manure application in basin



4.1.3. Simple Linear Regression Results for Total Kjeldahl Nitrogen

Tables 4.7 through 4.9 summarize results from the simple linear regression modeling for flow-weighted concentration, total export, and growing season median concentration of total Kjeldahl nitrogen. The direction of the relationship, the Pearson's correlation coefficient (Pearson's r), and the probability of the correlation being non-random (p-value) is presented in the tables. Only relationships with a p-value less than 0.05 are presented. No significant relationships between total Kjeldahl nitrogen flow-weighted mean concentration and watershed parameters are identified in the analysis, which is reflected in Table 4.7. No significant relationships between total Kjeldahl nitrogen flow-weighted mean concentration and watershed parameters are identified in the analysis, which is reflected in Table 4.9.

Information about how the watershed characteristic influences the concentration is provided by the direction of the relationship: A positive relationship indicates that concentration increases when the value of the watershed characteristic increases, and a negative relationship indicates that concentration decreases when the value of the watershed characteristic increases. Figures 4.6 provides a graphical representation of the relationships for the three parameters most strongly correlated with total export of total Kjeldahl nitrogen.

TABLE 4.7

Parameters with a significant relationship to flow-weighted mean total Kjeldahl nitrogen concentration

Description	Direction	Pearson's *r*	p-value	Min. Value	Max. Value	Units
None identified						

TABLE 4.8

Parameters with a significant relationship to total export (kg/ha/yr) of total Kjeldahl nitrogen concentration

Description	Direction	Pearson's *r*	p-value	Min. Value	Max. Value	Units
Percent of silt in riparian zone	+	0.86	2.9E-02	6.35	19.89	% of total area
Average saturated hydraulic conductivity of soils in riparian zone	+	0.85	3.2E-02	23.2	62.7	um/s
Hydrologic soil group C in watershed	-	-0.82	4.6E-02	12.32	58.91	% of total area

TABLE 4.9

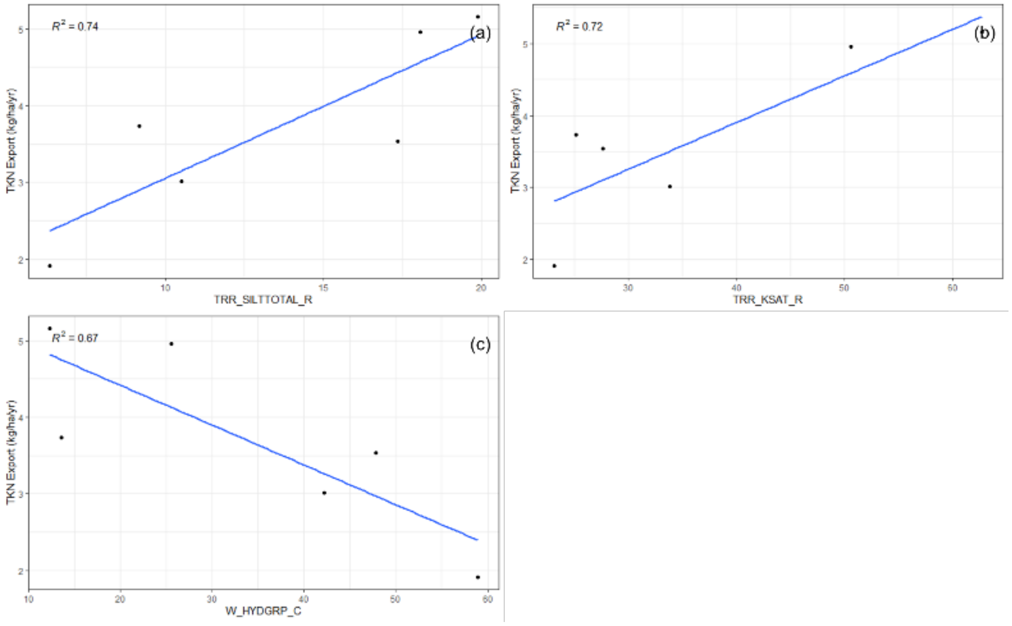
Parameters with a significant relationship to growing season median total Kjeldahl nitrogen concentration

Description	Direction	Pearson's *r*	p-value	Min. Value	Max. Value	Units
None identified						

FIGURE 4.6

Regression between export (kg/ha/yr) of total Kjeldahl nitrogen and landscape variables (2018 growing season)

(a) average bulk density of soils in watershed, (b) % of silt in basin, (c) % of basin with tile drainage, (d) % of basin with excessively drained soils



4.1.4. Limitations of Simple Linear Regression Results at Monitored Sites

Since only a small number of sites are available for the analyses, the correlations must be carefully evaluated to determine the reasonableness of the correlations. The correlations may provide insights about which watershed characteristics may be predictive of higher annual concentrations and yields, but they do have limitations in their application. Concentrations of nitrogen species are related to many different interacting watershed parameters. Using a single parameter to predict nitrogen concentrations and yields in other years is likely to produce unreasonable results, so the results should be used primarily as a basis for providing a starting point for further watershed evaluation.

4.2. Simple Linear Regression Modeling of Annual Load at LTT Sites

Annual estimates for flow-normalized flow-weighted mean concentration, total flux, and growing season median concentration at the three long-term trend sites – Kewaunee River, Manitowoc River, and Sheboygan River – are available from the Long-term Trends Viewer, which is described in Appendix B of the nitrogen analysis report. Flow-normalized values are used to remove the year-to-year variability in precipitation and flows. Only data for nitrate and TKN are assessed because long-term trends data for total nitrogen are not available.

The flow-normalized water quality data are compared to annual watershed characteristics in each of the basins to determine if relationships exist. Data for annual watershed characteristics are available from 2008 through 2018 and include land use, estimated fertilizer application, manure application, and crop yields. The relationships between these data and the water quality data are evaluated using the same simple linear regression methods described in the previous section.

4.2.1. Simple Linear Regression Results for Nitrate at LTT Sites

Results of the correlation between watershed characteristics and nitrate water quality data at each of the three long-term trend basins are summarized in Tables 4.10 through 4.12. Interpretation of the results is the same as the previous section: A positive direction indicates that concentration or yield increases as the value for the parameter increases. Visual representation of the relationships between nitrate and watershed characteristics are provided in Figures 4.7 through 4.9 for the Kewaunee River, Figures 4.10 through 4.12 for the Manitowoc River, and Figures 4.13 and 4.15 for the Sheboygan River.

TABLE 4.10

Parameters with a significant relationship to flow-normalized flow-weighted mean nitrate concentration at LTT sites

LTT Site	Description	Direction	Pearson's *r*	p-value	Min. Value	Max. Value	Units
Kewaunee	Year	-	-0.92	1.83E-04	2008	2017	-
	Percent of basin as soybeans	-	-0.84	2.36E-03	3.6	7.4	% of area
	Percent of basin as grassland/pasture	+	0.83	2.73E-03	17.4	26.2	% of area
	Annual grain yield	-	-0.76	1.09E-02	116.6	171.6	bu/ac/yr
	Percent of basin as woody wetlands	-	-0.73	1.70E-02	6.4	7.7	% of area
Manitowoc	Year	+	0.92	1.83E-04	2008	2017	-
	Percent of basin as winter wheat	-	-0.78	8.15E-03	2.8	6.1	% of area
	Nitrogen outputs from landscape	+	0.77	1.60E-02	197.3	235.9	kg/ha
	Atm. deposition to landscape	+	0.74	2.21E-02	8.7	11.8	kg/ha
	Annual grain yield	+	0.72	1.83E-02	134.3	180.0	bu/ac
Sheboygan	Year	-	-0.99	1.11E-07	2008	2016	-
	Nitrogen outputs from landscape	-	-0.82	1.34E-02	187.8	230.3	kg/ha
	Denitrification from landscape	-	-0.76	2.92E-02	13.6	17.4	kg/ha
	Annual grain yield	-	-0.71	3.28E-02	133.1	175.4	bu/ac
	Nitrogen inputs to landscape	-	-0.70	5.13E-02	234.4	290.3	kg/ha

TABLE 4.11

Parameters with a significant relationship to flow-normalized mean nitrate flux (ton/yr) at LTT sites

LTT Site	Description	Direction	Pearson's *r*	p-value	Min. Value	Max. Value	Units
Kewaunee	Year	-	-0.98	1.47E-06	2008	2017	-
	Percent of basin as soybeans	-	-0.82	3.79E-03	3.6	7.4	% of area
	Annual grain yield	-	-0.81	4.25E-03	116.6	171.6	bu/ac
	Percent of basin as grassland/pasture	+	0.77	9.45E-03	17.4	26.2	% of area
	Manure applied to landscape	-	-0.70	3.43E-02	144.3	167.1	kg/ha
	Percent of basin as woody wetlands	-	-0.69	2.83E-02	6.4	7.7	% of area
Manitowoc	Year	-	-0.98	3.40E-07	2008	2017	-
	Percent of basin as woody wetlands	-	-0.86	1.37E-03	8.8	11.4	% of area
	Percent of basin as winter wheat	+	0.72	1.81E-02	2.8	6.1	% of area
	Nitrogen outputs from landscape	-	-0.70	3.45E-02	197.3	235.9	kg/ha
	Annual grain yield	-	-0.65	4.09E-02	134.3	180.0	bu/ac
Sheboygan	Year	-	-0.93	2.66E-04	2008	2016	-
	Annual grain yield	-	-0.76	1.63E-02	133.1	175.4	bu/ac
	Nitrogen outputs from landscape	-	-0.75	3.29E-02	187.8	230.3	kg/ha
	Percent of basin as grassland/pasture	+	0.71	3.35E-02	12.0	23.0	% of area

TABLE 4.12

Parameters with a significant relationship to flow-normalized growing season median nitrate concentration at LTT sites

LTT Site	Description	Direction	Pearson's *r*	p-value	Min. Value	Max. Value	Units
Kewaunee	Nitrogen inputs to landscape	+	0.89	1.17E-03	274.2	331.2	kg/ha
	Percent of basin as corn	+	0.88	8.44E-04	24.4	29.7	% of area
	Manure applied to landscape	+	0.84	4.96E-03	144.3	167.1	kg/ha
	Commercial fertilizer applied to landscape	+	0.76	1.85E-02	63.8	78.9	kg/ha
	Atmospheric deposition to landscape	+	0.75	2.04E-02	8.4	10.6	kg/ha
	Nitrogen outputs from landscape	+	0.71	3.12E-02	187.5	233.5	kg/ha
Manitowoc	Year	+	0.95	1.86E-05	2008	2017	-
	Nitrogen outputs from landscape	+	0.77	1.57E-02	197.3	235.9	kg/ha
	Percent of basin as winter wheat	-	-0.76	1.03E-02	2.8	6.1	% of area
	Atmospheric deposition to landscape	+	0.75	1.95E-02	8.7	11.8	kg/ha
	Percent of basin as woody wetlands	+	0.70	2.46E-02	8.8	11.4	% of area
	Annual grain yield	+	0.70	2.52E-02	134.3	180.0	bu/ac
Sheboygan	Percent of basin as grassland/pasture	+	0.83	5.87E-03	12.0	23.0	-
	Percent of basin as alfalfa	-	-0.68	4.44E-02	9.5	14.9	bu/ac

FIGURE 4.7

Regression between flow-weighted mean concentration of nitrate and landscape variables at the Kewaunee River LTT site

(a) Year, (b) % of basin as soybeans, (c) % of basin as grassland/pasture, (d) Annual grain yield

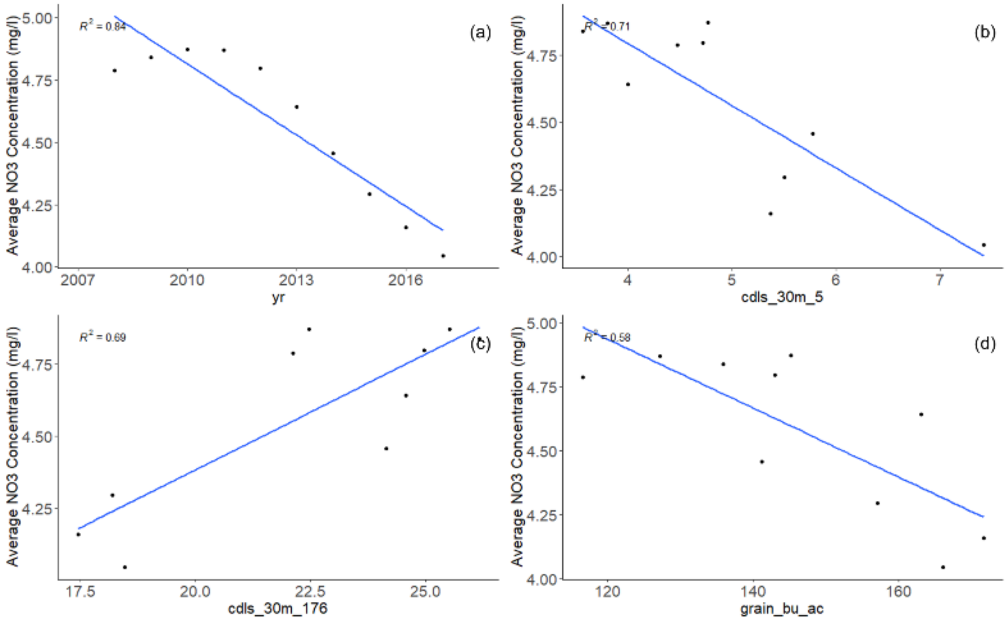


FIGURE 4.8

Regression between flow-normalized annual flux of nitrate and landscape variables at the Kewaunee River LTT site

(a) Year, (b) % of basin as soybeans, (c) Annual grain yield, (d) % of basin as grassland/pasture

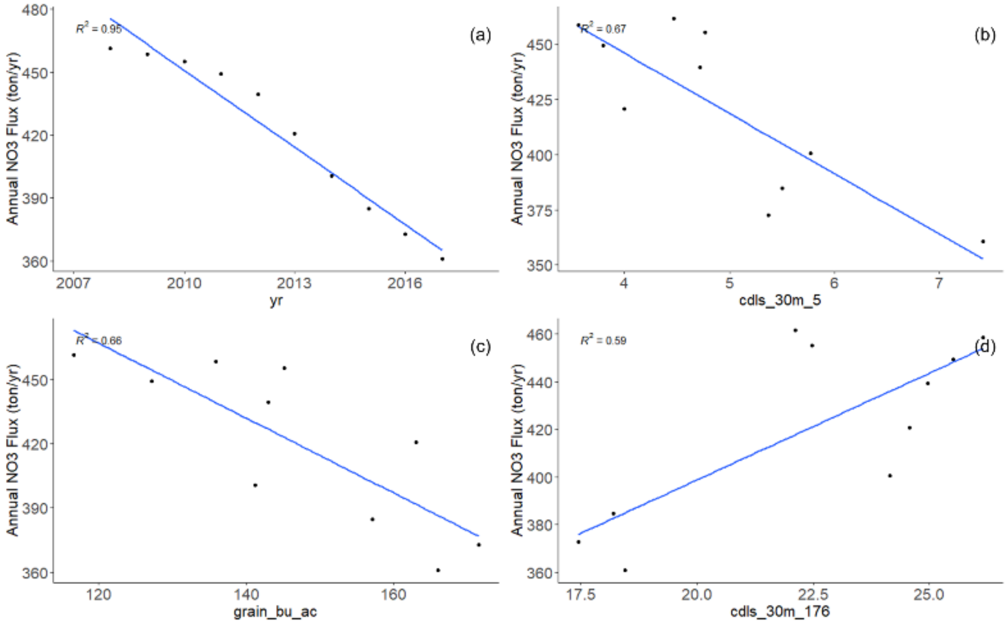


FIGURE 4.9

Regression between flow-normalized GSM concentration of nitrate and landscape variables at the Kewaunee River LTT site

(a) Nitrogen inputs to landscape, (b) fraction of basin as corn, (c) Manure inputs to landscape, (d) Fertilizer inputs to landscape

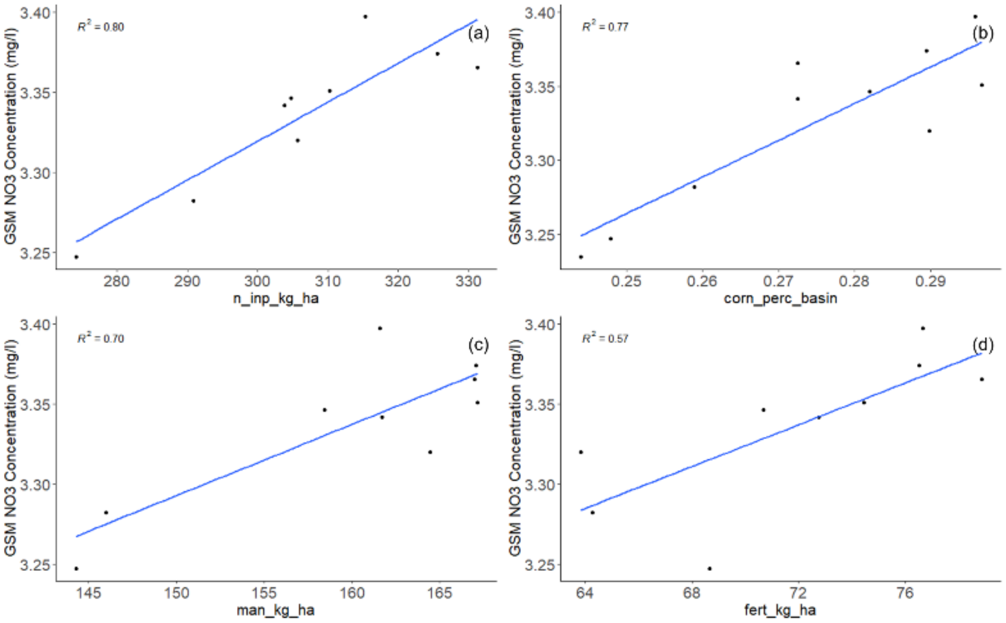


FIGURE 4.10

Regression between flow-weighted mean concentration of nitrate and landscape variables at the Manitowoc River LTT site

(a) Year, (b) % of basin as winter wheat, (c) Nitrogen outputs from landscape, (d) Atmospheric deposition to landscape

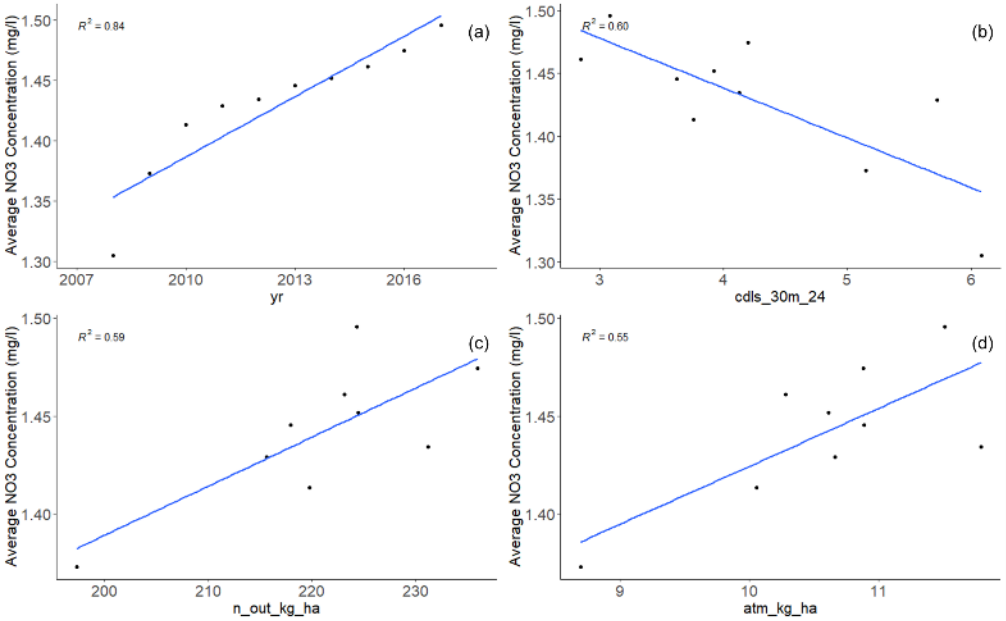


FIGURE 4.11

Regression between flow-normalized annual flux of nitrate and landscape variables at the Manitowoc River LTT site

(a) Year, (b) % of basin as woody wetlands, (c) % of basin as winter wheat, (d) Nitrogen outputs from landscape

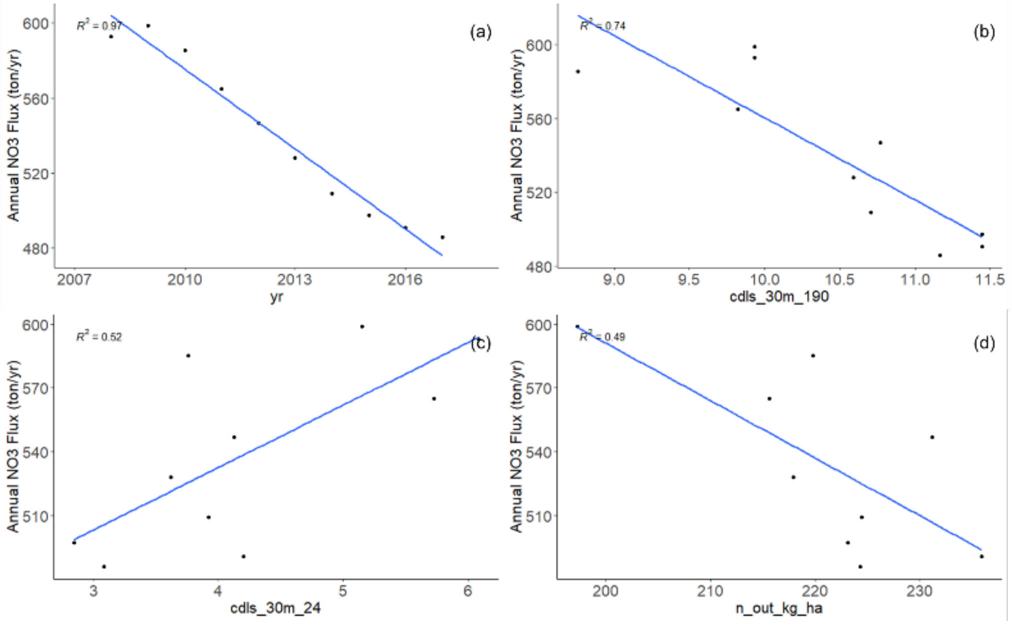


FIGURE 4.12

Regression between flow-normalized GSM concentration of nitrate and landscape variables at the Manitowoc River LTT site

(a) Year, (b) Nitrogen outputs from landscape, (c) % of basin as winter wheat, (d) Atmospheric deposition to landscape

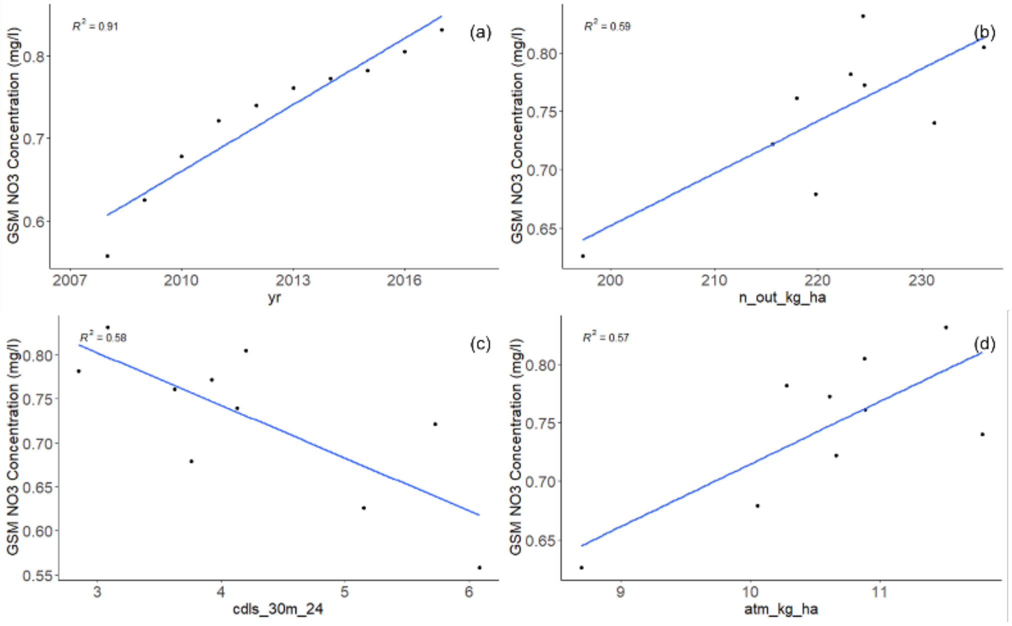


FIGURE 4.13

Regression between flow-weighted mean concentration of nitrate and landscape variables at the Sheboygan River LTT site

(a) Year, (b) Nitrogen output from landscape, (c) Denitrification from landscape, (d) Annual grain yield

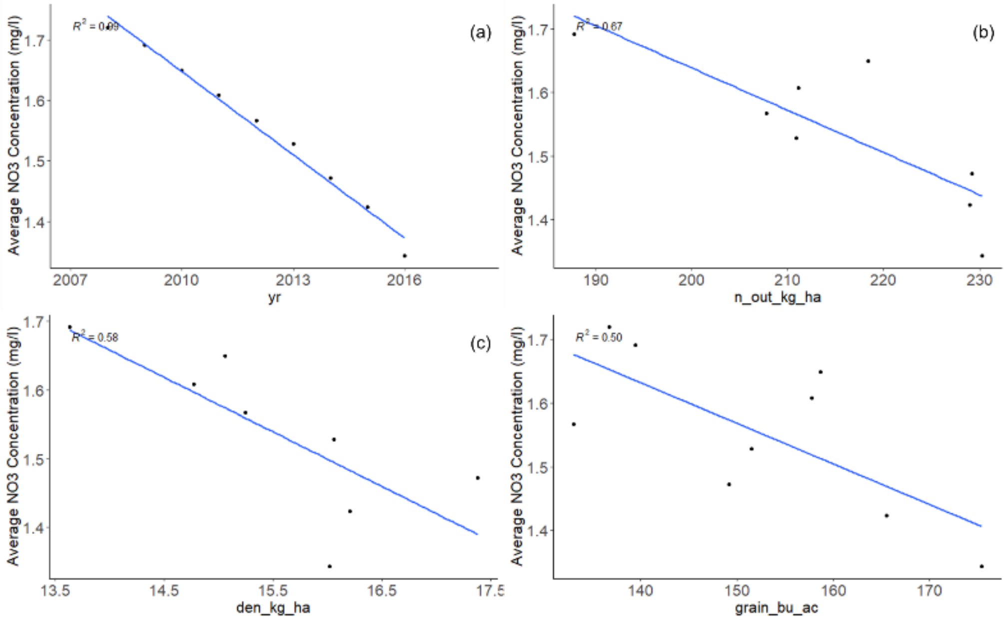


FIGURE 4.14

Regression between flow-normalized annual flux of nitrate and landscape variables at the Sheboygan River LTT site

(a) Year, (b) Annual grain yield, (c) Nitrogen output from landscape, (d) % of basin as grassland/pasture

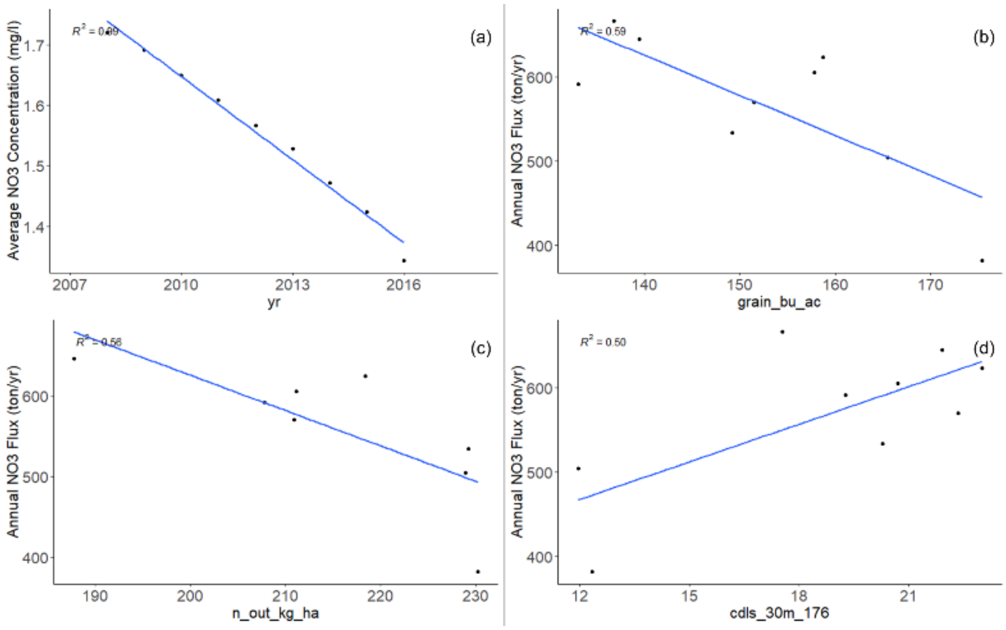
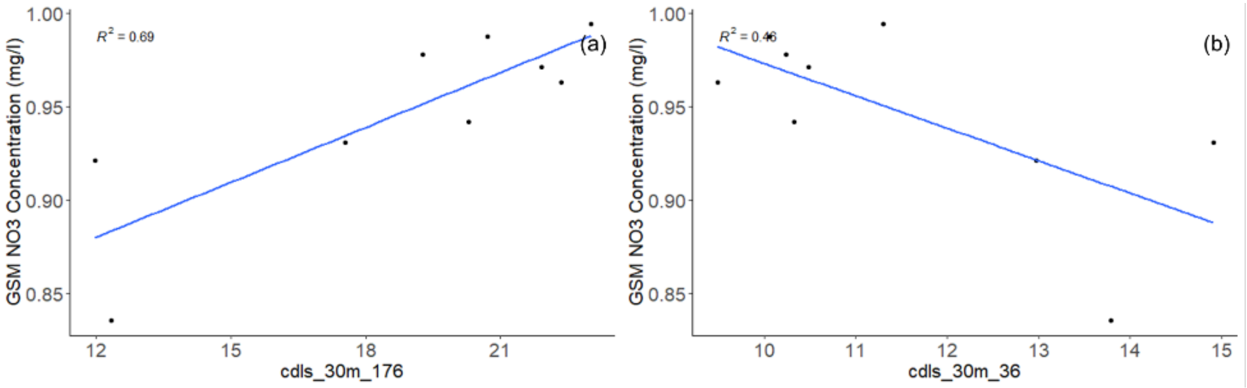


FIGURE 4.15

Regression between flow-normalized GSM concentration of nitrate and landscape variables at the Sheboygan River LTT site

(a) % of basin as grassland/pasture, (b) % of basin as alfalfa



4.2.2. Simple Linear Regression Results for TKN at LTT Sites

Results of the correlation between watershed characteristics and total Kjeldahl nitrogen water quality data at each of the three long-term trend basins are summarized in Tables 4.13 through 4.15. Interpretation of the results is the same as the previous section: A positive direction indicates that concentration or yield increases as the value for the parameter increases. Visual representation of the relationships between total Kjeldahl nitrogen and watershed characteristics are provided in Figures 4.16 through 4.18 for the Kewaunee River, Figures 4.19 through 4.21 for the Manitowoc River, and Figures 4.22 and 4.24 for the Sheboygan River.

TABLE 4.13

Parameters with a significant relationship to flow-normalized flow-weighted mean TKN concentration at LTT sites

LTT Site	Description	Direction	Pearson's *r*	p-value	Min. Value	Max. Value	Units
Kewaunee	Year	-	-0.99	2.86E-08	2008	2017	-
	Manure applied to landscape	-	-0.82	6.70E-03	144.3	167.1	kg/ha
	Annual grain yield	-	-0.81	4.23E-03	116.6	171.6	bu/ac
	Percent of basin as soybeans	-	-0.77	8.72E-03	3.6	7.4	% of area
	Nitrogen outputs from landscape	-	-0.76	1.73E-02	187.5	233.5	kg/ha
	Percent of basin as grassland/pasture	+	0.69	2.72E-02	17.4	26.2	% of area
	Percent of basin as corn	-	-0.69	2.80E-02	24.4	29.7	% of area
Manitowoc	Year	-	-0.96	1.29E-05	2008	2017	-
	Percent of basin as winter wheat	+	0.78	8.30E-03	2.8	6.1	% of area
	Percent of basin as woody wetlands	-	-0.76	1.10E-02	8.8	11.4	% of area
	Nitrogen outputs from landscape	-	-0.74	2.18E-02	197.3	235.9	kg/ha
	Atmospheric deposition to landscape	-	-0.68	4.44E-02	8.7	11.8	kg/ha
Sheboygan	Year	-	-0.98	3.32E-06	2008	2016	-
	Denitrification from landscape	-	-0.86	6.04E-03	13.6	17.4	kg/ha
	Nitrogen inputs to landscape	-	-0.84	9.35E-03	234.4	290.3	kg/ha
	Nitrogen outputs from landscape	-	-0.81	1.50E-02	187.8	230.3	kg/ha
	Percent of corn as silage	-	-0.77	1.60E-02	29.1	44.2	% of corn
	Fertilizer inputs to landscape	-	-0.76	2.84E-02	73.4	96.8	kg/ha

TABLE 4.14

Parameters with a significant relationship to flow-normalized TKN flux at LTT sites

LTT Site	Description	Direction	Pearson's *r*	p-value	Min. Value	Max. Value	Units
Kewaunee	Year	-	-0.99	3.99E-08	2008	2017	-
	Manure applied to landscape	-	-0.86	2.91E-03	144.3	167.1	kg/ha
	Annual grain yield	-	-0.83	3.01E-03	116.6	171.6	bu/ac
	Nitrogen outputs from landscape	-	-0.82	7.42E-03	187.5	233.5	kg/ha
	Percent of basin as corn	-	-0.78	8.35E-03	24.4	29.7	% of area
	Percent of basin as soybeans	-	-0.73	1.72E-02	3.6	7.4	% of area
	Percent of basin as deciduous forest	-	-0.64	4.72E-02	4.4	6.4	% of area
Manitowoc	Year	-	-0.99	2.79E-08	2008	2017	-
	Percent of basin as winter wheat	+	0.78	8.18E-03	2.8	6.1	% of area
	Percent of basin as woody wetlands	-	-0.77	8.57E-03	8.8	11.4	% of area
	Annual grain yield	-	-0.73	1.67E-02	134.3	180.0	bu/ac
	Nitrogen outputs from landscape	-	-0.72	3.04E-02	197.3	235.9	kg/ha
Sheboygan	Year	-	-0.95	6.70E-05	2008	2016	-
	Nitrogen outputs from landscape	-	-0.76	2.92E-02	187.8	230.3	kg/ha
	Annual grain yield	-	-0.74	2.17E-02	133.1	175.4	bu/ac

TABLE 4.15

Parameters with a significant relationship to flow-normalized TKN growing season median at LTT sites

LTT Site	Description	Direction	Pearson's *r*	p-value	Min. Value	Max. Value	Units
Kewaunee	Year	-	-1.00	1.89E-09	2008	2017	-
	Manure applied to landscape	-	-0.84	4.97E-03	144.3	167.1	kg/ha
	Annual grain yield	-	-0.82	3.56E-03	116.6	171.6	bu/ac
	Nitrogen outputs from landscape	-	-0.78	1.41E-02	187.5	233.5	kg/ha
	Percent of basin as soybeans	-	-0.76	1.13E-02	3.6	7.4	% of area
	Percent of basin as corn	-	-0.74	1.48E-02	24.4	29.7	% of area
	Percent of basin as grassland/pasture	+	0.64	4.52E-02	17.4	26.2	% of area
Manitowoc	Year	-	-0.96	1.29E-05	2008	2017	-
	Percent of basin as winter wheat	+	0.78	8.30E-03	2.8	6.1	% of area
	Percent of basin as woody wetlands	-	-0.76	1.10E-02	8.8	11.4	% of area
	Nitrogen outputs from landscape	-	-0.74	2.18E-02	197.3	235.9	kg/ha
Sheboygan	Nitrogen inputs to landscape	-	-0.87	4.96E-03	234	290	kg/ha
	Precent of corn as silage	-	-0.87	2.34E-03	29.1	44.2	% of corn
	Fertilizer inputs to landscape	-	-0.85	6.93E-03	73.4	96.8	kg/ha
	Denitrification from landscape	-	-0.82	1.19E-02	13.6	17.4	kg/ha
	Year	-	-0.82	6.91E-03	2008	2016	-

FIGURE 4.16

Regression between flow-weighted mean concentration of TKN and landscape variables at the Kewaunee River LTT site

(a) Year, (b) Manure inputs to landscape, (c) Annual grain yield, (d) % of basin as soybeans

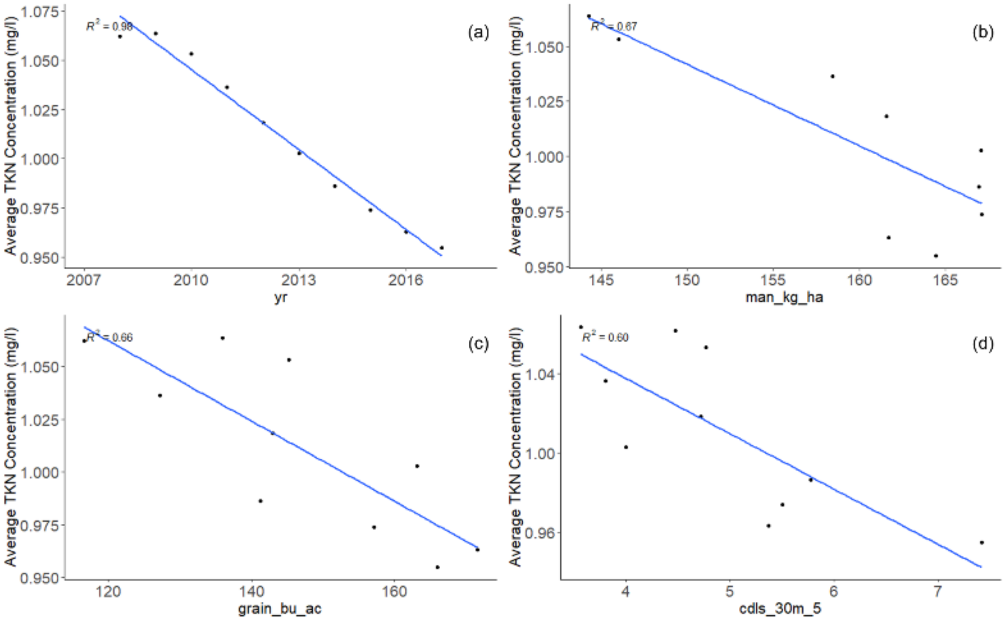


FIGURE 4.17

Regression between flow-normalized annual flux of TKN and landscape variables at the Kewaunee River LTT site

(a) Year, (b) Manure inputs to landscape, (c) Annual grain yield, (d) Nitrogen output from landscape

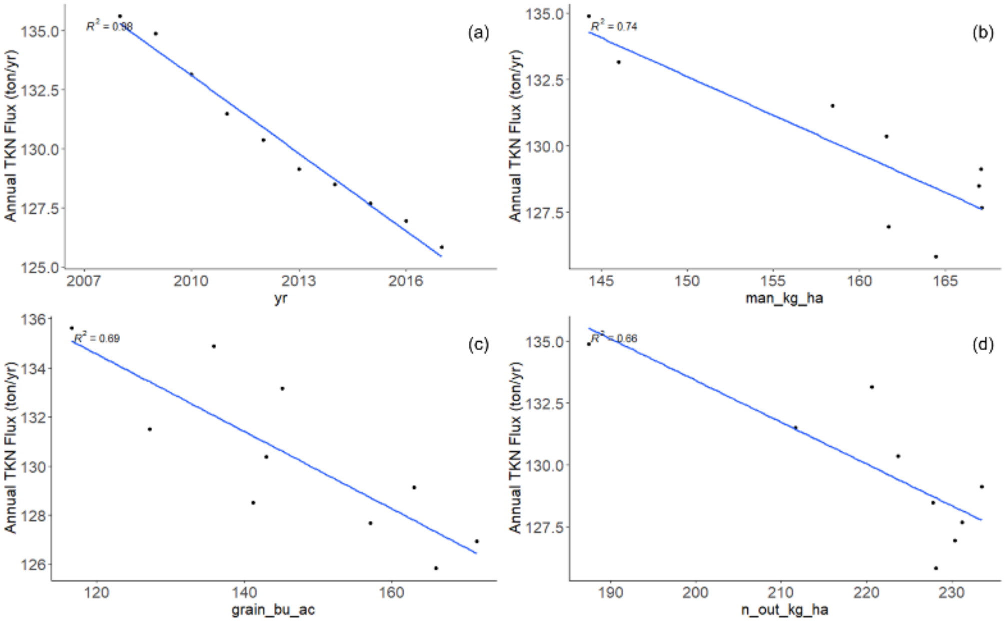


FIGURE 4.18

Regression between flow-normalized GSM concentration of TKN and landscape variables at the Kewaunee River LTT site

(a) Year, (b) Manure inputs to landscape, (c) Annual grain yield, (d) Nitrogen output from landscape

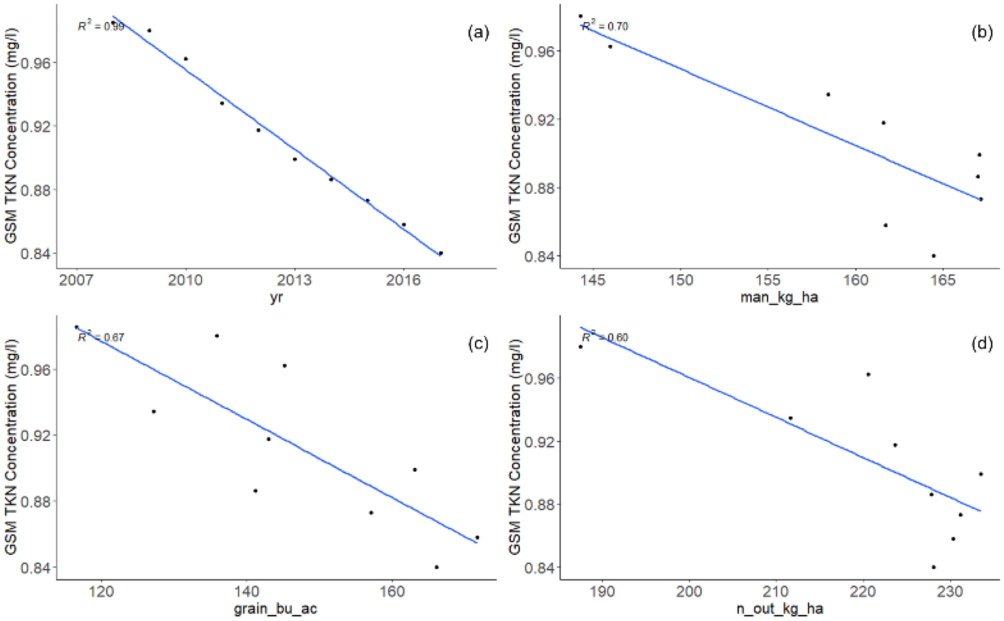


FIGURE 4.19

Regression between flow-weighted mean concentration of TKN and landscape variables at the Manitowoc River LTT site

(a) Year, (b) % of basin as winter wheat, (c) % of basin as woody wetlands, (d) Nitrogen output from landscape

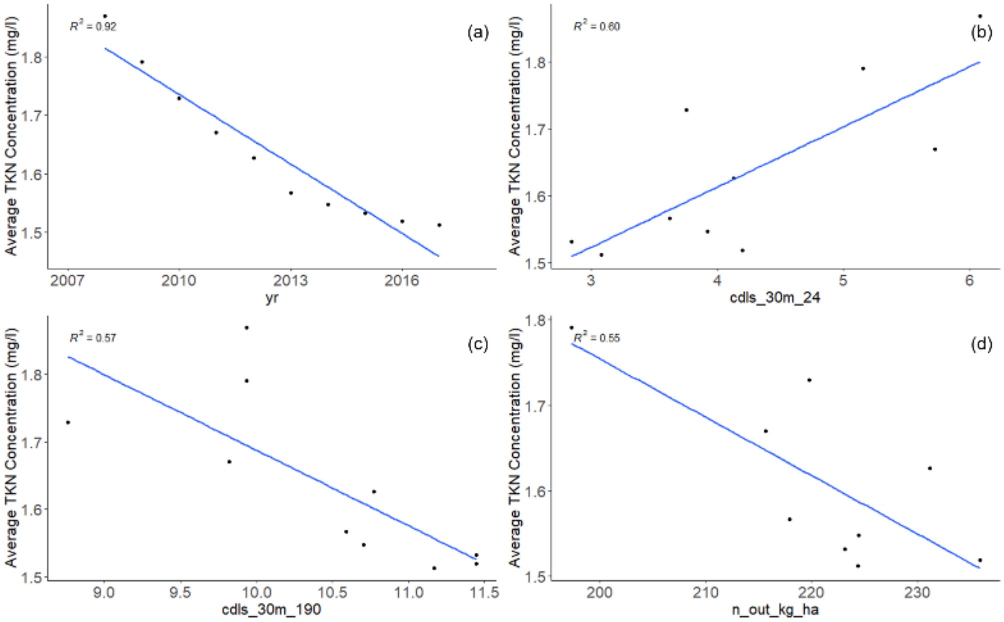


FIGURE 4.20

Regression between flow-normalized annual flux of TKN and landscape variables at the Manitowoc River LTT site

(a) Year, (b) % of basin as winter wheat, (c) % of basin as woody wetlands, (d) Annual grain yield

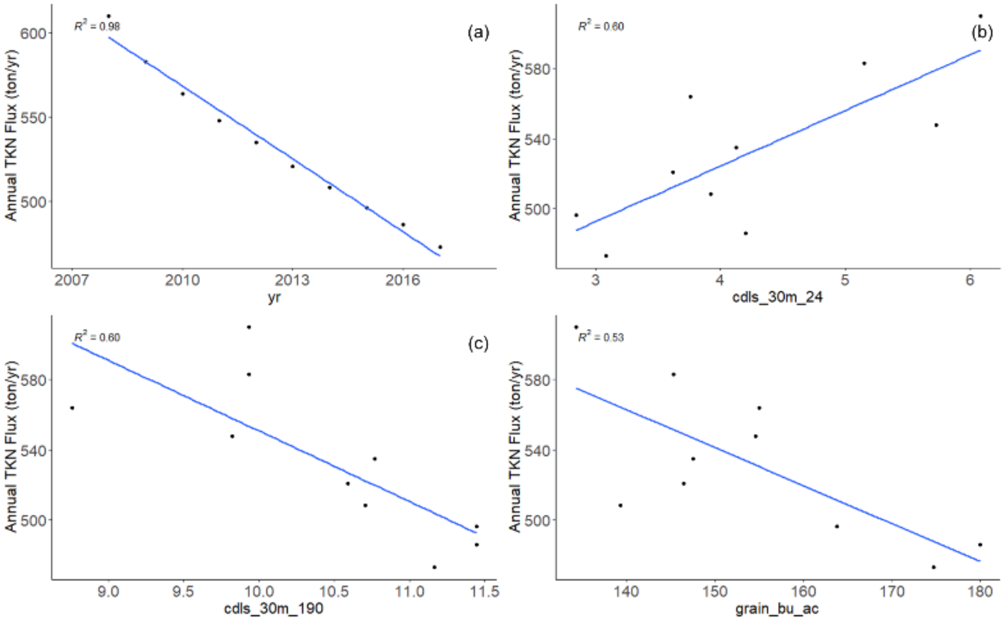


FIGURE 4.21

Regression between flow-normalized GSM concentration of TKN and landscape variables at the Manitowoc River LTT site

(a) Year, (b) % of basin as winter wheat, (c) % of basin as woody wetlands, (d) Nitrogen output from landscape

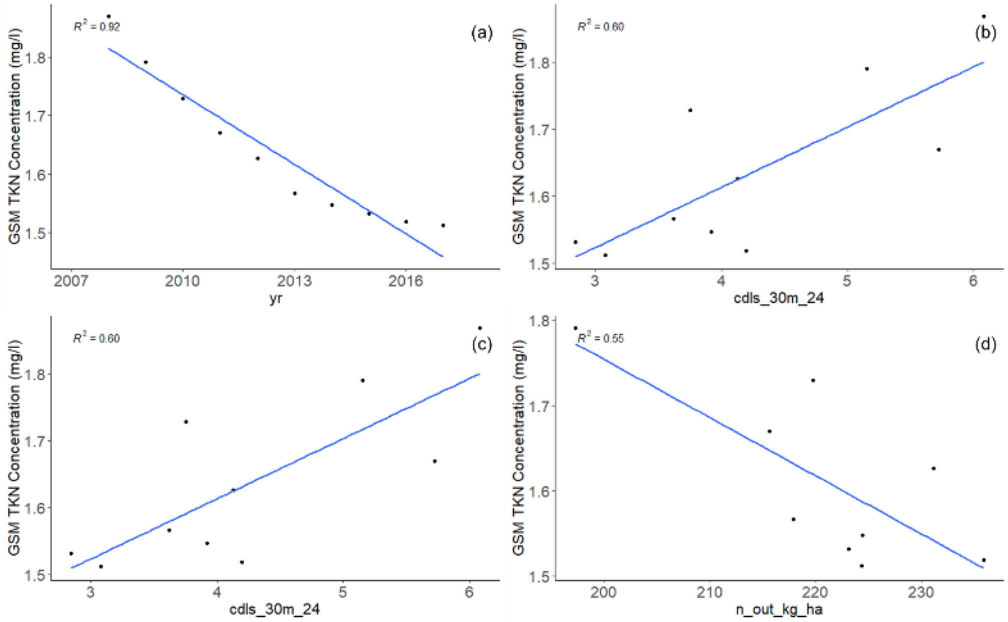


FIGURE 4.22

Regression between flow-weighted mean concentration of TKN and landscape variables at the Sheboygan River LTT site

(a) Year, (b) Denitrification from landscape, (c) Nitrogen inputs to landscape, (d) Nitrogen output from landscape

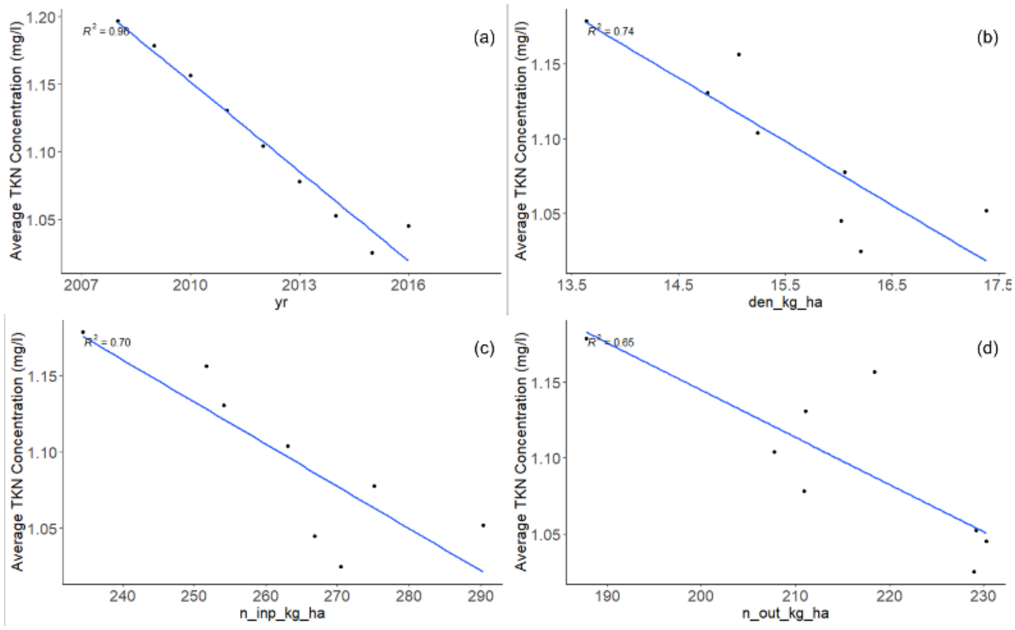


FIGURE 4.23

Regression between flow-normalized annual flux of TKN and landscape variables at the Sheboygan River LTT site

(a) Year, (b) Nitrogen output from landscape, (c) Annual grain yield

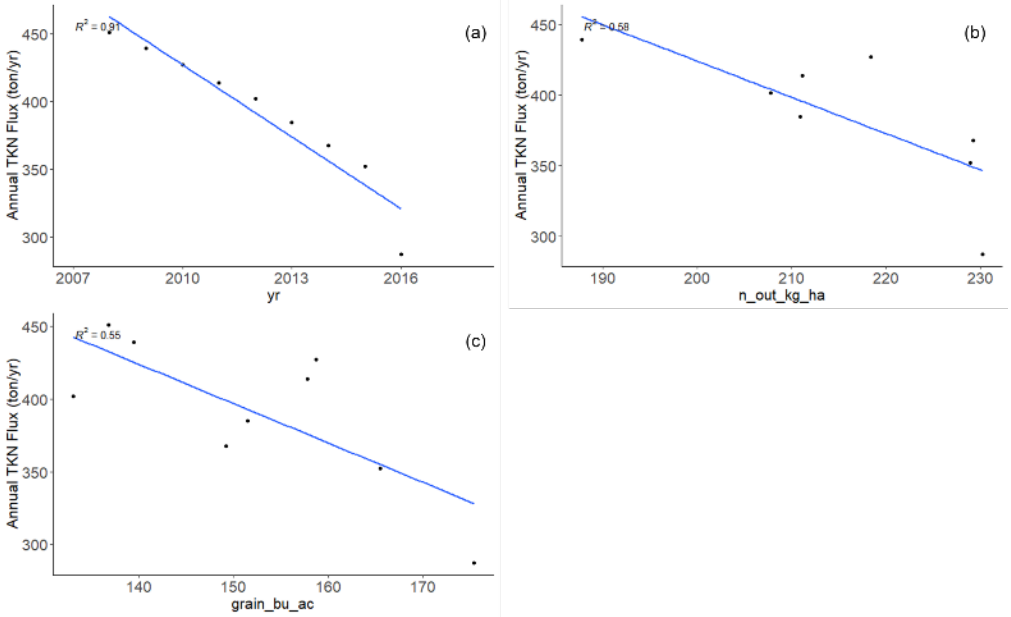
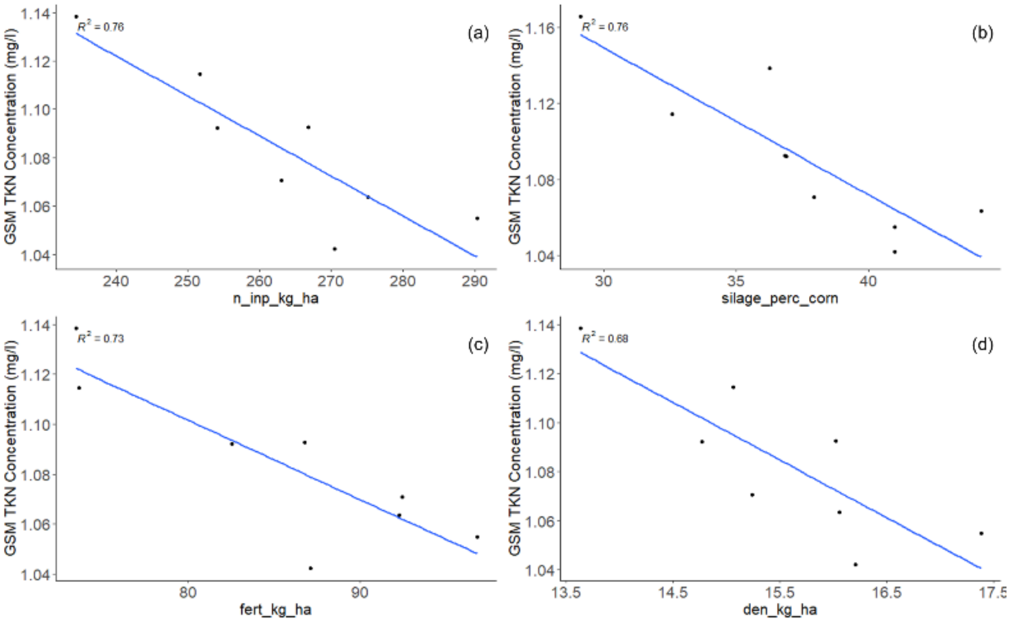


FIGURE 4.24

Regression between flow-normalized GSM of TKN and landscape variables at the Sheboygan River LTT site

(a) Nitrogen input to landscape, (b) Percent of corn as silage, (c) Fertilizer inputs to landscape, (d) Denitrification from landscape



4.2.3. Limitations of Simple Linear Regression Results at LTT Sites

Since data about the concentrations and flux are limited to only ten years for each site, the correlations must be carefully evaluated to determine the reasonableness of the correlations. For example, the correlation between cattle numbers and nitrate concentration in the Sheboygan River is negative, meaning nitrate concentration is lower when the number of cattle in the basin is higher. One may expect an opposite response since years with more cattle would likely have higher manure applications and potentially higher in-stream nitrate concentrations. Other factors in the watershed may be contributing to the decrease in nitrate concentrations, and the negative correlation between cattle and nitrates may just be coincidental.

The correlations may provide insights about which watershed characteristics may be predictive of higher annual concentrations and yields, but they do have limitations in their application. Concentrations of nitrogen species are related to many different interacting watershed parameters. Using a single parameter to predict nitrogen concentrations and yields in other years is likely to produce unreasonable results, so the results should be used primarily as a basis for providing a starting point for further watershed evaluation.

4.3. Multiple Linear Regression Modeling

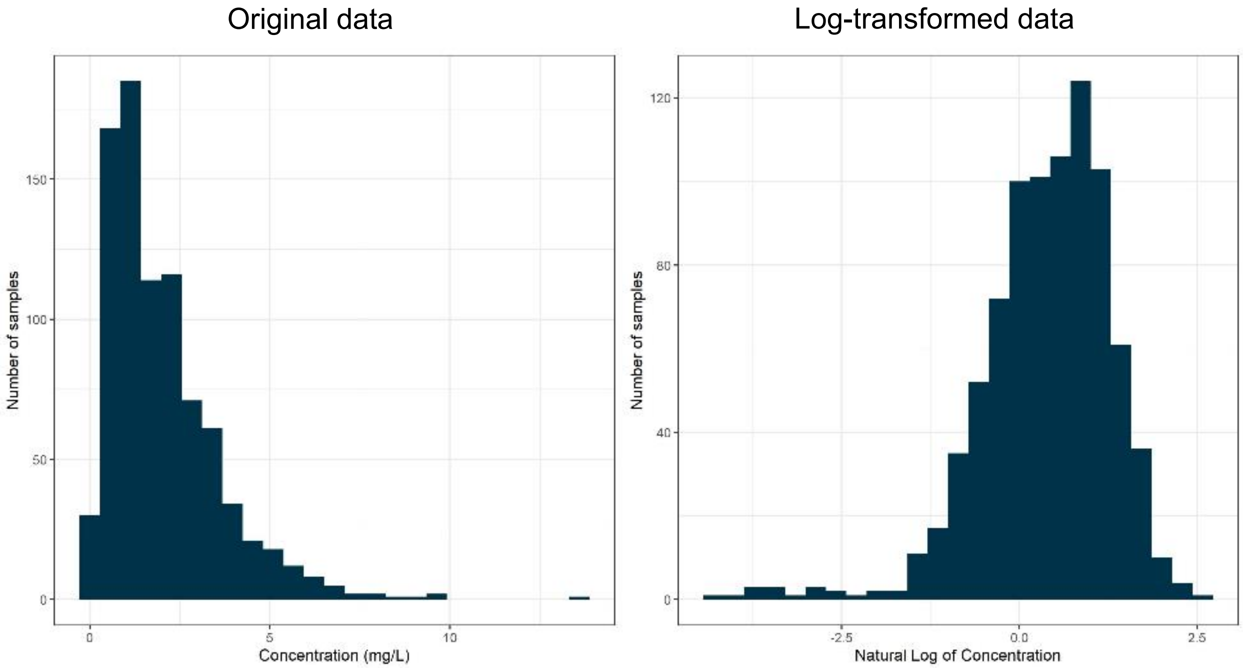
Multiple linear regression model has two main benefits. First, the results of the model can indicate which landscape parameters may be predictive of in-stream concentrations. Second, if the model fits well, it may be useful for predicting in-stream concentrations at sites in both the study area and other basins around the state. If the multiple linear regression model does a good job of predicting in-stream concentrations, it could be used to enhance or replace complex hydrologic and hydraulic models.

4.3.1. Application of Multiple Linear Regression Modeling

Before a multiple linear regression model is fit to the data, the distribution of the concentration data is evaluated by viewing a histogram of all water quality data. For the three parameters of interest – nitrate, total nitrogen, and TKN – the distributions are right-skewed. A histogram of non-transformed concentrations and the log-transformed concentrations for nitrate are shown in Figure 4.25. The log-transformed data have values in the left-tail of the distribution, but the overall distribution is closer to a normal distribution. For the analysis log-transformed data are used to fit the multiple linear regression model.

FIGURE 4.25

Histogram of water quality data for nitrate


Original data

Log-transformed data

The multiple linear regression models are evaluated using six different groups of water quality data: data from all samples, data from samples collected during the growing season, and data collected during each of the four seasons (spring, summer, fall, and winter). After the multiple linear regression models for all six groups of log-transformed water quality data are established, the goodness-of-fit is evaluated using the adjusted R-squared value. The adjusted R-squared value represents the explanatory power of the linear regression, and it is adjusted based on the number of predictors. Another interpretation of the adjusted R-squared value is the percent of variation explained by the multiple linear regression model. The results for the goodness of fit parameters are provided in Table 4.16. For this evaluation, an adjusted R-squared value greater than 0.50 is considered acceptable.

TABLE 4.16

Goodness of fit for multiple linear regression models

	R-squared: Variation explained by multiple linear regression model					
Parameter	All	Growing Season	Spring	Summer	Fall	Winter
TN	0.25	0.28	0.46	0.11	0.32	0.40
NO3	0.54	0.40	0.55	0.06	0.59	0.26
TKN	0.54	0.63	0.19	0.37	0.53	0.25

While the R-squared value is a useful screening tool to quickly estimate how well the model estimates observed data, it can be impacted by a small number of values that are have a very poor prediction. The appropriateness of the model fit can be qualitatively evaluated by plotting the measured versus the predicted concentrations and plotting a 1:1 line. If the model is accurately predicting the concentrations, the distribution of measured versus predicted points should generally fall close to a 1:1 line on the plot. Scatterplots for each of the water quality constituents are provided in Figures 4.26 through 4.28.

Similar to the simple linear regression models, the direction of relationships between independent and dependent variables can provide useful information. A positive relationship between a predictor variable and the predicted concentration indicates that an increase in the value of the predicted concertation occurs with an increase in the predictor variable. The inverse is true for negative values. Tables 4.17 through 4.19 summarize the relationships between the predictor variables and the predicted concentrations. The predictor variables listed in the table are variables that are included in the analysis. They are used in the multiple linear regression model because the probability of the relationship is significant to a level of significance of 0.10.

TABLE 4.17

Parameters having significant relationships with concentration for TN multiple regression model

All

Parameter	Corr.
Snow water equivalent	-
Daily rain and snowmelt	-
7-day rain and snowmelt	+
Riv. dairy rotation	+
Seasonal parameter - Sine	-
Season of sample	+
Baseflow per area	-
Runoff per area	+

Growing Season

Parameter	Corr.
Watershed slope	-
Ground-moraine (coarse)	-
Potato/vegetable (Wiscland)	-
Deciduous forest (Wiscland)	-
Woody wetlands (NLCD)	-
Developed, low intensity (Wiscland)	+
Dairy rotation (Wiscland)	+
Emergent wet meadow (Wiscland)	-
Wet meadow (Wiscland)	+
Lowland shrub (Wiscland)	+
Riv. developed (NLCD)	+
Riv. developed (Wiscland)	+
Riv. cool-season grass (Wiscland)	-
Riv. open water (Wiscland)	-
Riv. wet meadow (Wiscland)	-
Average annual July temperature	+
Soil calcium carbonate	+
Baseflow index	-

Spring

Parameter	Corr.
Solar radiation	+
Snow water equivalent	-
Woody wetlands (NLCD)	-
Riv. open water (NLCD)	-
Riv. woody wetlands (NLCD)	+
Baseflow index	-
Runoff per area	+

Summer

Parameter	Corr.
Growing degree days	-
Seasonal Parameter - Cosine	-
Baseflow index	-
Runoff per area	+
Discharge per area	-

Fall

Parameter	Corr.
Growing degree days	+
Maximum temperature	-
Ground-moraine (coarse)	-

Winter

Parameter	Corr.
Growing degree days	-
Dairy rotation (Wiscland)	-
Riv. calcium carbonate	-
Dairy rotation (Wiscland)	+

FIGURE 4.26

Modeled versus predicted concentrations for TN multiple linear regression model

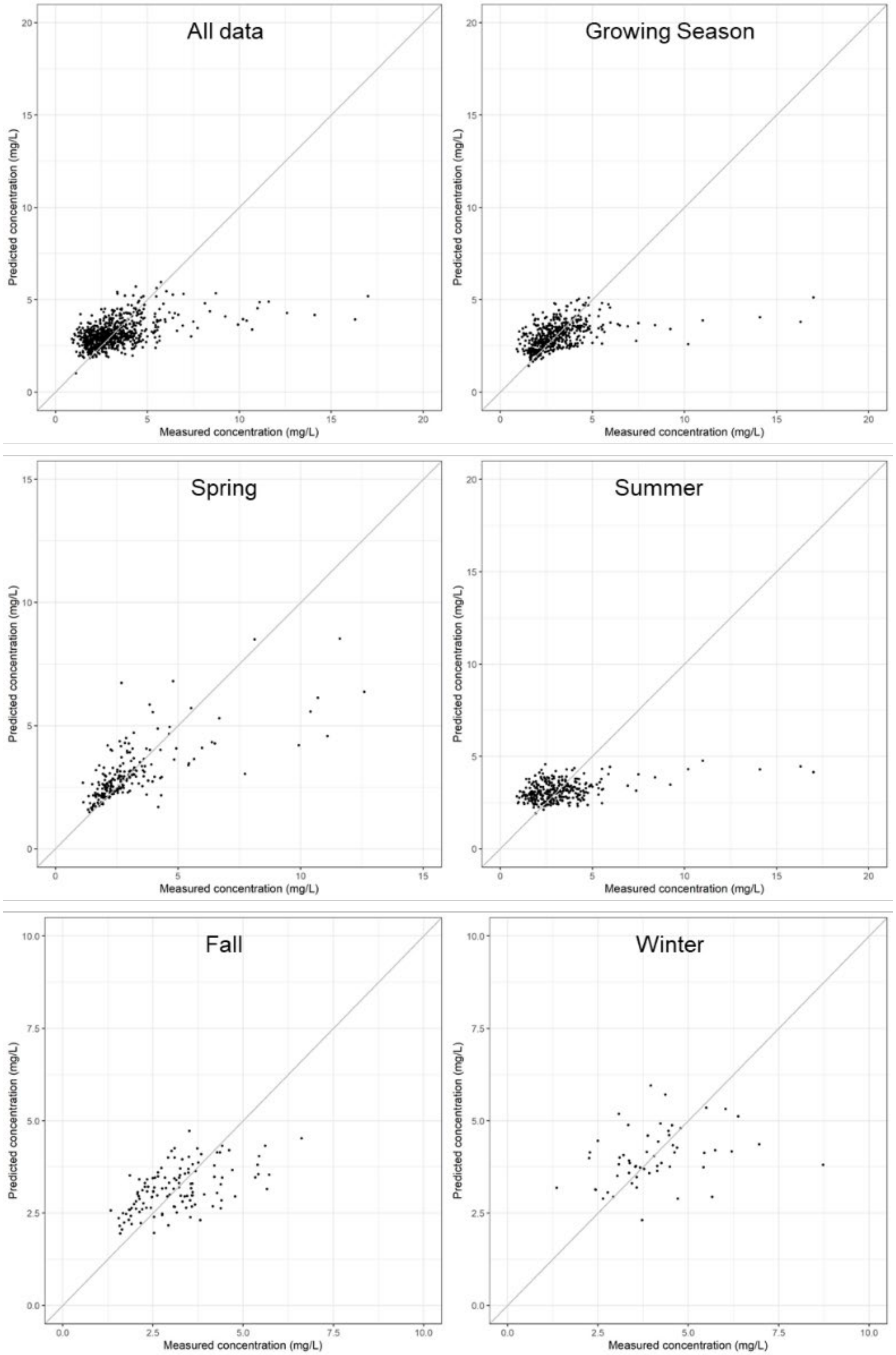


TABLE 4.18

Parameters having significant relationships with concentration for nitrate multiple regression model

All

Parameter	Corr.
Year	+
Solar radiation	+
Minimum temperature	+
Maximum temperature	-
Snowmelt	-
Rain and snowmelt	+
Soil permeability	+
Ground moraine	+
Developed, med. intensity (NLCD)	-
Deciduous forest (NLCD)	+
Seasonal parameter - Sine	-
Seasonal Parameter - Cosine	-
Season of sample	+
Baseflow per area	-

Growing Season

Parameter	Corr.
Daily precipitation	-
Total 7-day precipitation	+
Maximum temperature	-
Riv. herbaceous wetland (Wiscland)	-
Baseflow index	-

Spring

Parameter	Corr.
Total 7-day precipitation	+
Maximum temperature	-
Riv. lacustrine clay and silt	-
Deciduous forest (Wiscland)	-
Emergent wet meadow (Wiscland)	-
Seasonal parameter - Sine	+
Seasonal Parameter - Cosine	-
Baseflow index	-
Baseflow per area	-

Summer

Parameter	Corr.
Total 7-day precipitation	+

Fall

Parameter	Corr.
Year	+
Rain and snowmelt	+
Emerg. herbaceous wetlands (NLCD)	+
Pasture/hay (NLCD)	+
Seasonal Parameter - Cosine	-

Winter

Parameter	Corr.
Maximum temperature	-
Baseflow per area	-
Discharge per area	+

FIGURE 4.27

Modeled versus predicted concentrations for nitrate multiple linear regression models

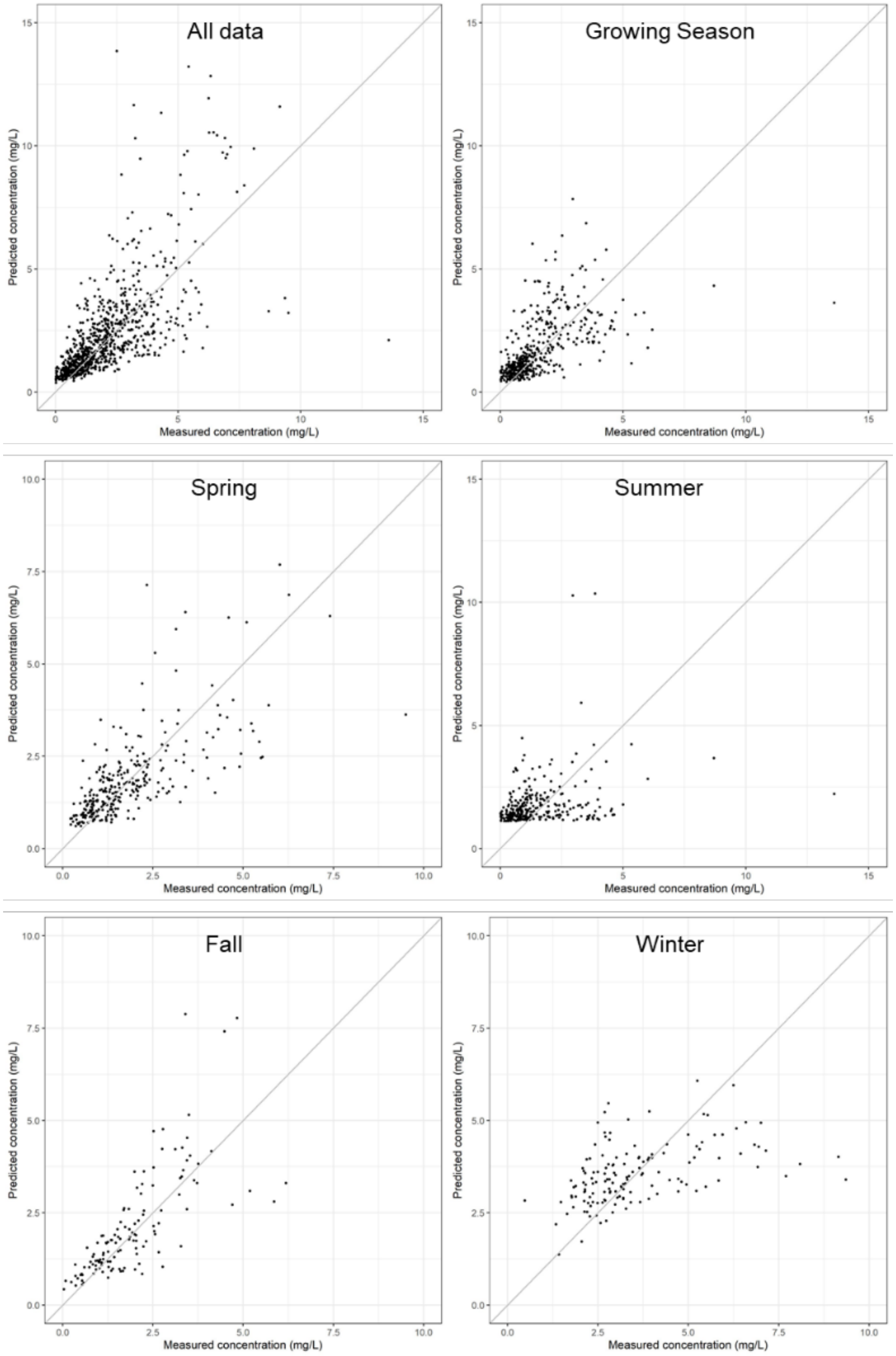


TABLE 4.19

Parameters having significant relationships with concentration for TKN multiple regression model

All

Parameter	Corr.
Year	-
Bedrock depth (50 to 100 ft)	-
Ground moraine (fine)	+
Outwash (coarse)	-
Ground-moraine (medium)	-
Water	+
Seasonal parameter - Sine	-
Seasonal Parameter - Cosine	+
Baseflow index	-
Season of sample	+
Baseflow per area	-
Runoff per area	-

Growing Season

Parameter	Corr.
Year	-
Maximum temperature	+
Shale bedrock	+
Baseflow index	-
Season of sample	-
Runoff per area	-

Spring

Parameter	Corr.
Year	-
Baseflow index	-

Summer

Parameter	Corr.
Baseflow index	-
Baseflow per area	+
Runoff per area	-

Fall

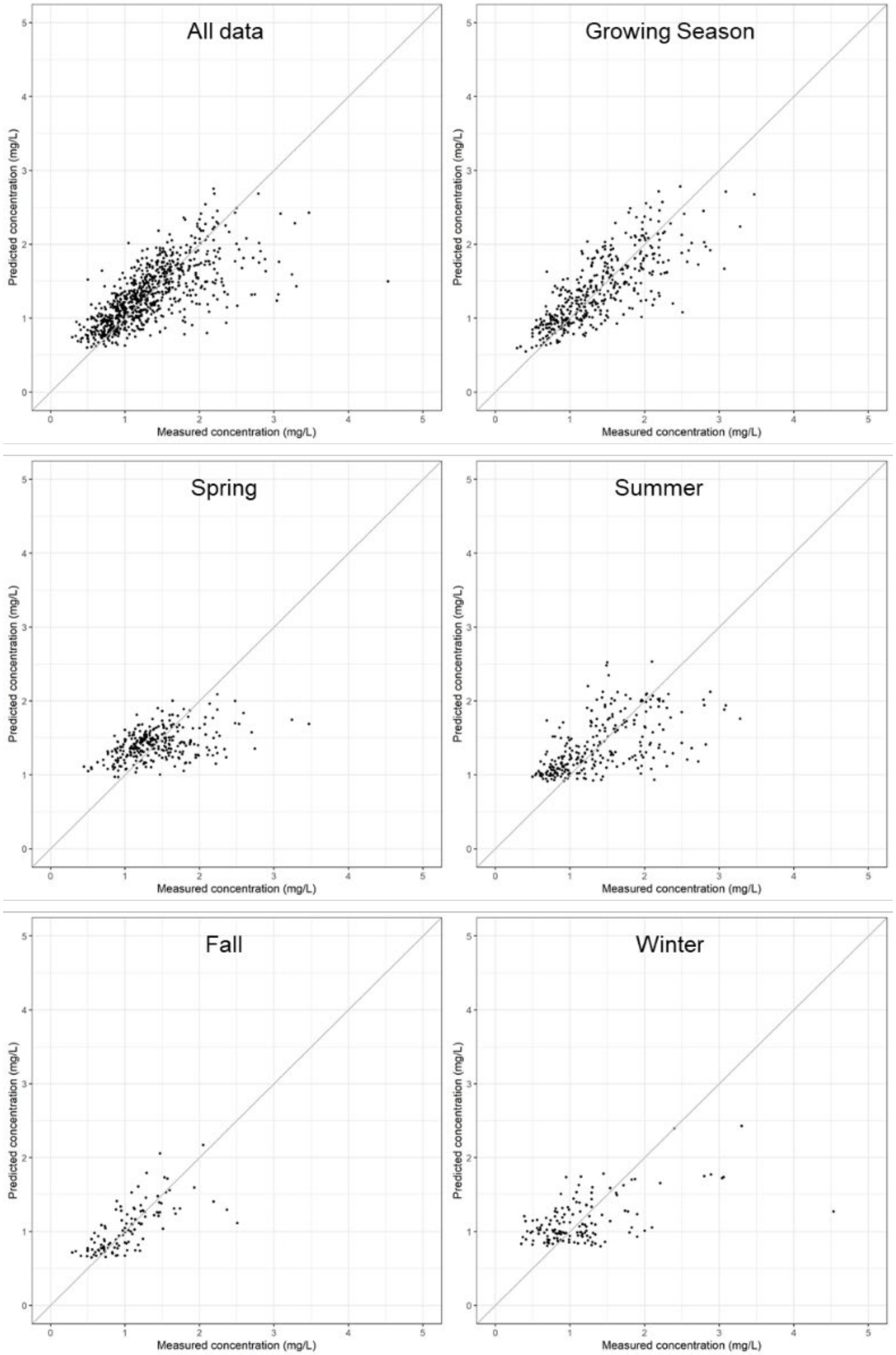
Parameter	Corr.
Watershed slope	+
Riv. soil permeability	-
Baseflow index	-

Winter

Parameter	Corr.
Snow water equivalent	+
Baseflow index	-

FIGURE 4.28

Modeled versus predicted concentrations for TKN multiple linear regression model



4.3.2. Discussion of Multiple Linear Regression Modeling

The multiple linear regression models provide some insight into which parameters may be important in predicting in-stream concentrations of total nitrogen, nitrate, and TKN. Overall, however, the multiple linear regression models do a poor job of predicting in-stream concentrations for the evaluated nitrogen species and seasons. The model is particularly problematic for predicting in-stream concentrations in the summer and winter. Data from additional sites may improve the fit of the model, but generally the model does not appear to be an adequate replacement for mechanistic hydrologic and hydraulic models.

4.4. Random Forest Modeling

Similar to multiple linear regression model, random forest modeling has two main benefits. First, the results of the model can indicate which landscape parameters may be predictive of in-stream concentrations. Second, if the model fits well, it may be useful for predicting in-stream concentrations at sites in both the study area and other basins around the state. If the multiple linear regression model does a good job of predicting in-stream concentrations, it could be used to enhance or replace complex hydrologic and hydraulic models.

4.4.1. Application of Random Forest Modeling

The random forest model uses the framework of a described in Section 3. A unique random forest model is created for six groups of water quality data: all data collected, data collected during the growing season, and data collected during the four unique seasons. The ability of the model to predict measured data for each of the three parameters of interest – nitrate, total nitrogen, and TKN – is evaluated using the R-squared value, which describes the variation explained by the model. A summary of the results from the random forest models are provided in Table 4.20. For this analysis, models with an R-squared value greater than 0.50 are considered to be moderately predictive.

TABLE 4.20

Goodness of fit for random forest models

	R-squared: Variation explained by random forest model					
Parameter	**All**	**Growing Season**	**Spring**	**Summer**	**Fall**	**Winter**
TN	0.49	0.45	0.50	0.43	0.55	0.03
NO_3	0.61	0.47	0.50	0.46	0.64	0.32
TKN	0.55	0.65	0.48	0.63	0.52	0.27

The ability of the model to predict measured concentrations can also be qualitatively evaluated by plotting measured concentrations versus predicted concentrations. If the plotted points approximately fit a 1:1 line on the plot, the model is likely performing appropriately. Scatterplots comparing the measured concentrations versus the predicted concentrations are provided in Figure 4.29, Figure 4.31, and Figure 4.33.

The random forest model can also be used to evaluate which watershed characteristics are most important when predicting concentrations. Figure 4.30, Figure 4.32, and Figure 4.34 show plots of the results of an importance analysis. The higher values on the plot have a higher predictive power than the lower values on the plot. In each of the figures the variables are color-coded based on the type of variable. While the figures provide information about how important each parameter is when developing the random forest model, they do not provide any information about the direction of the relationship. For example, discharge may be established as the most important parameter in the model, but the model does not indicate whether concentrations increase or decrease with an increase in discharge.

FIGURE 4.29

Important parameters for TN RF models

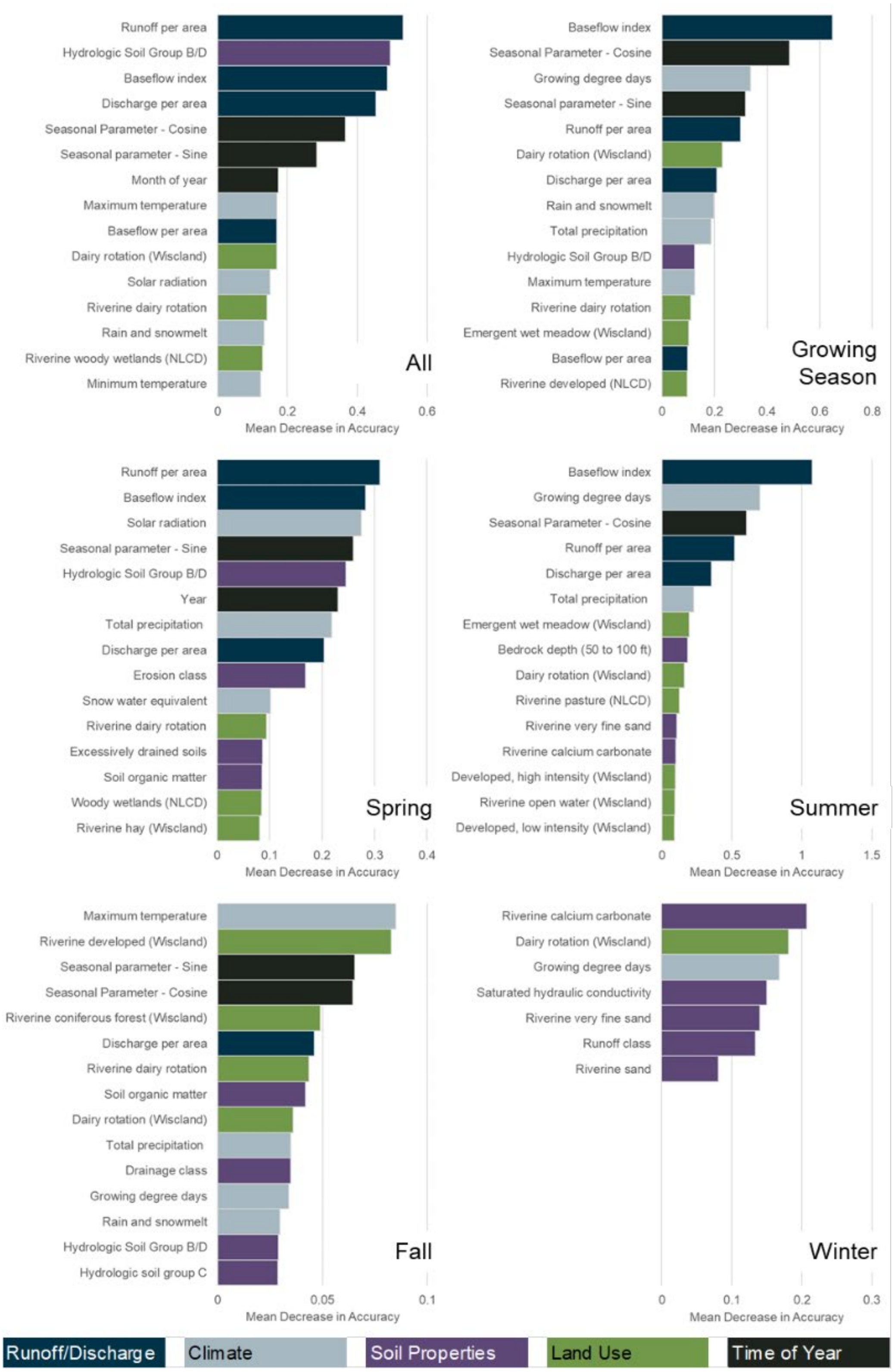


FIGURE 4.30

Modeled versus predicted concentrations for TN RF models

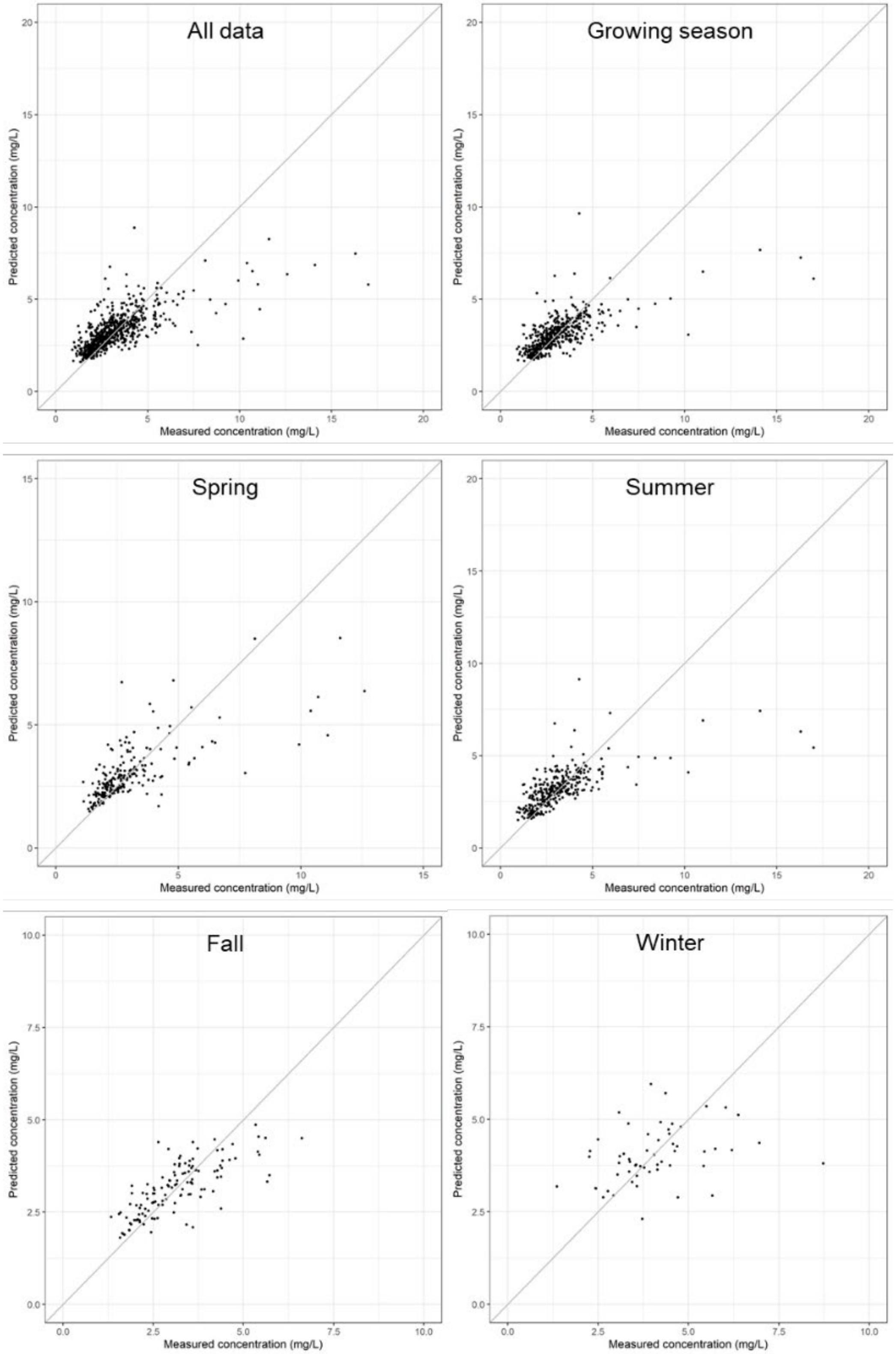


FIGURE 4.31

Important parameters for nitrate RF models

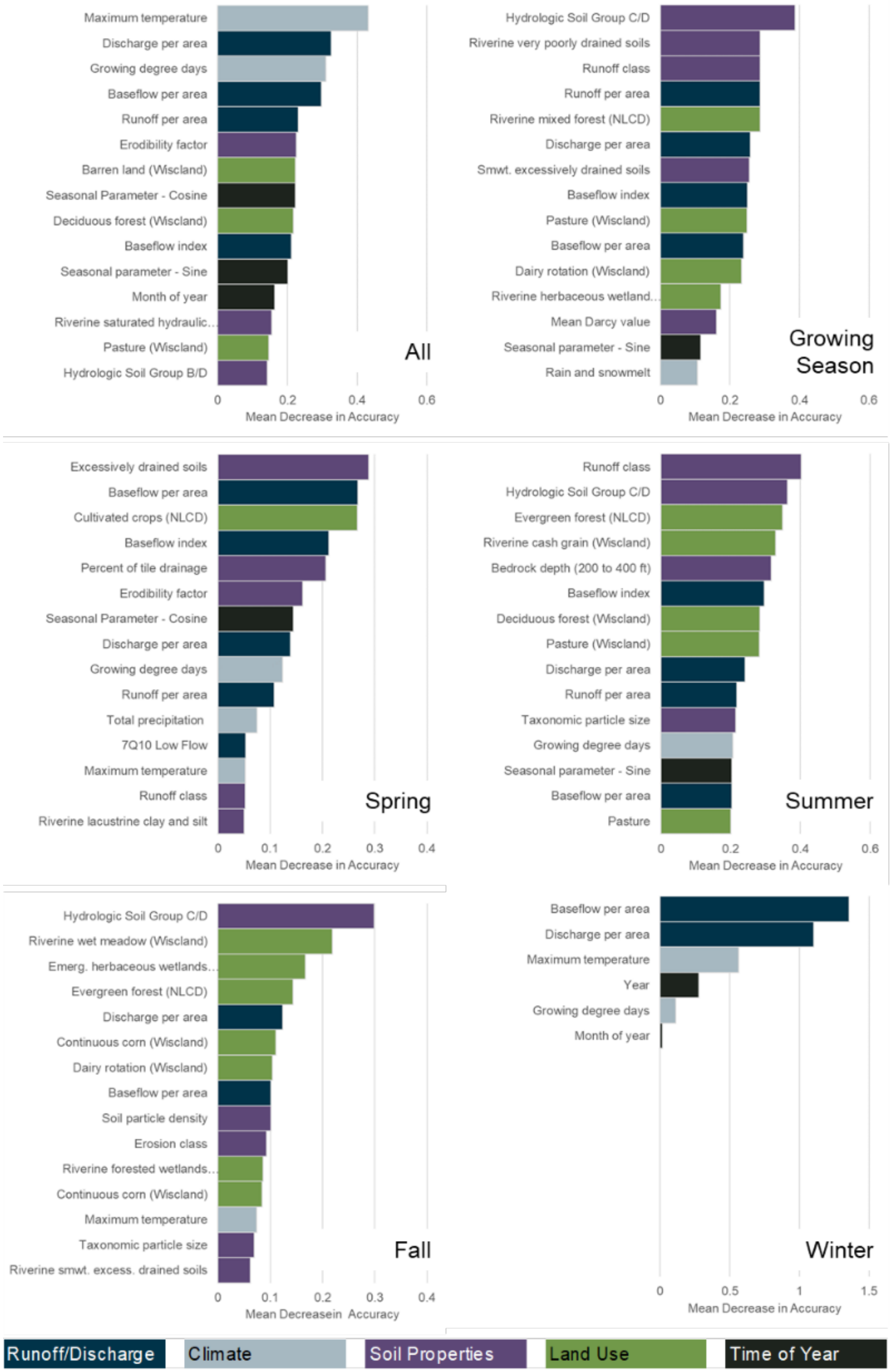


FIGURE 4.32

Modeled versus predicted concentrations for nitrate RF models

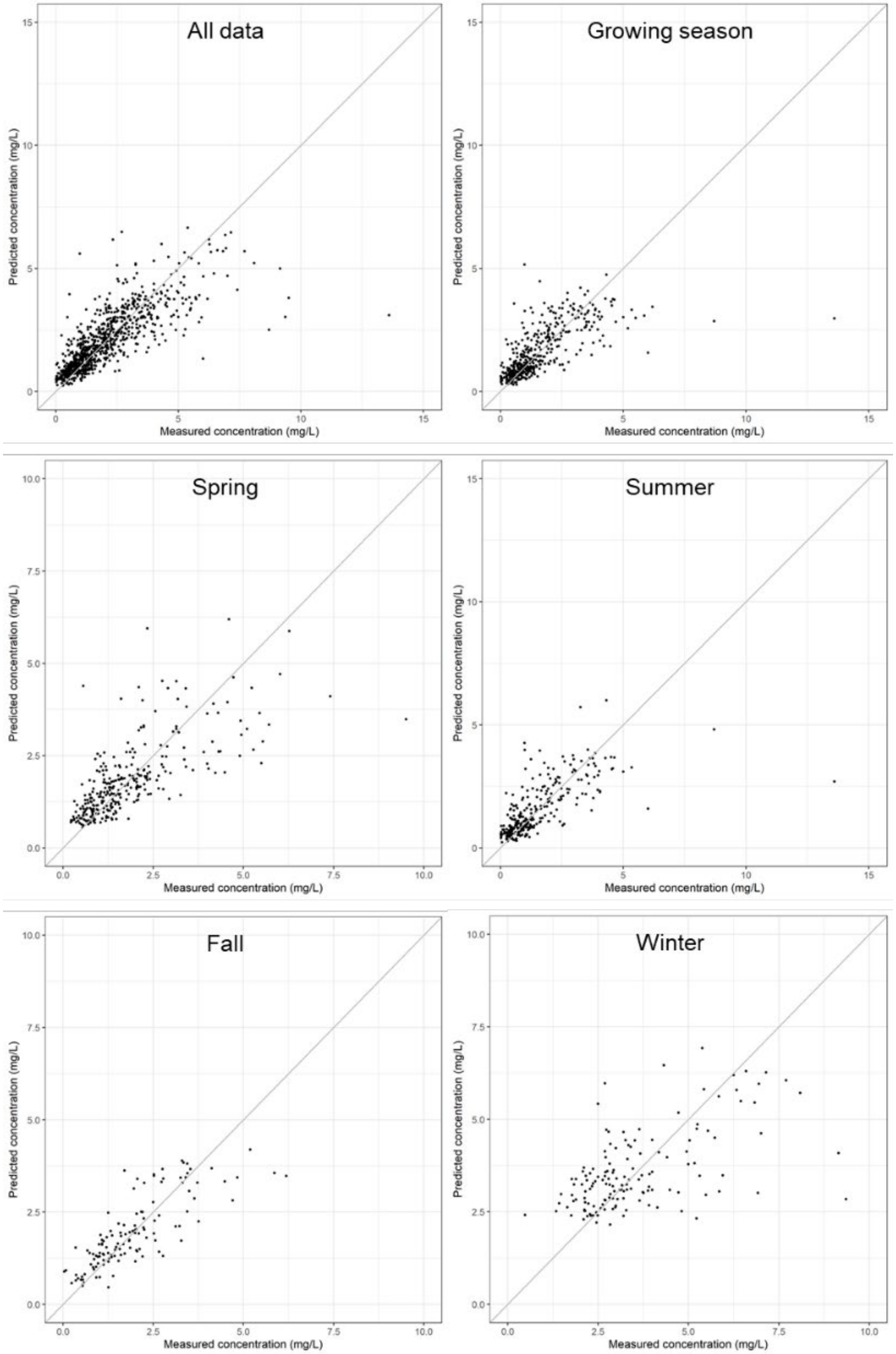


FIGURE 4.33

Important parameters for TKN RF models

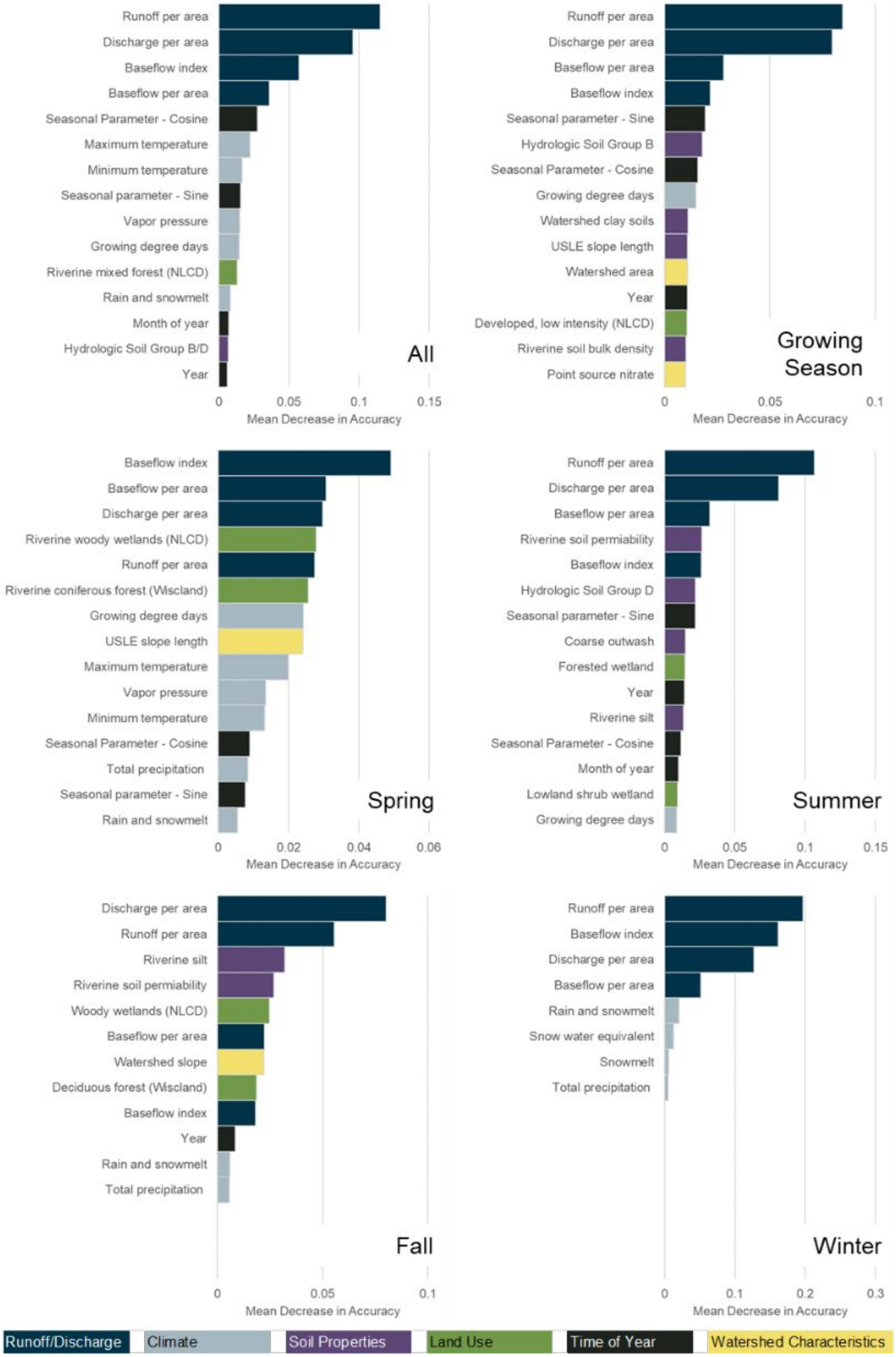
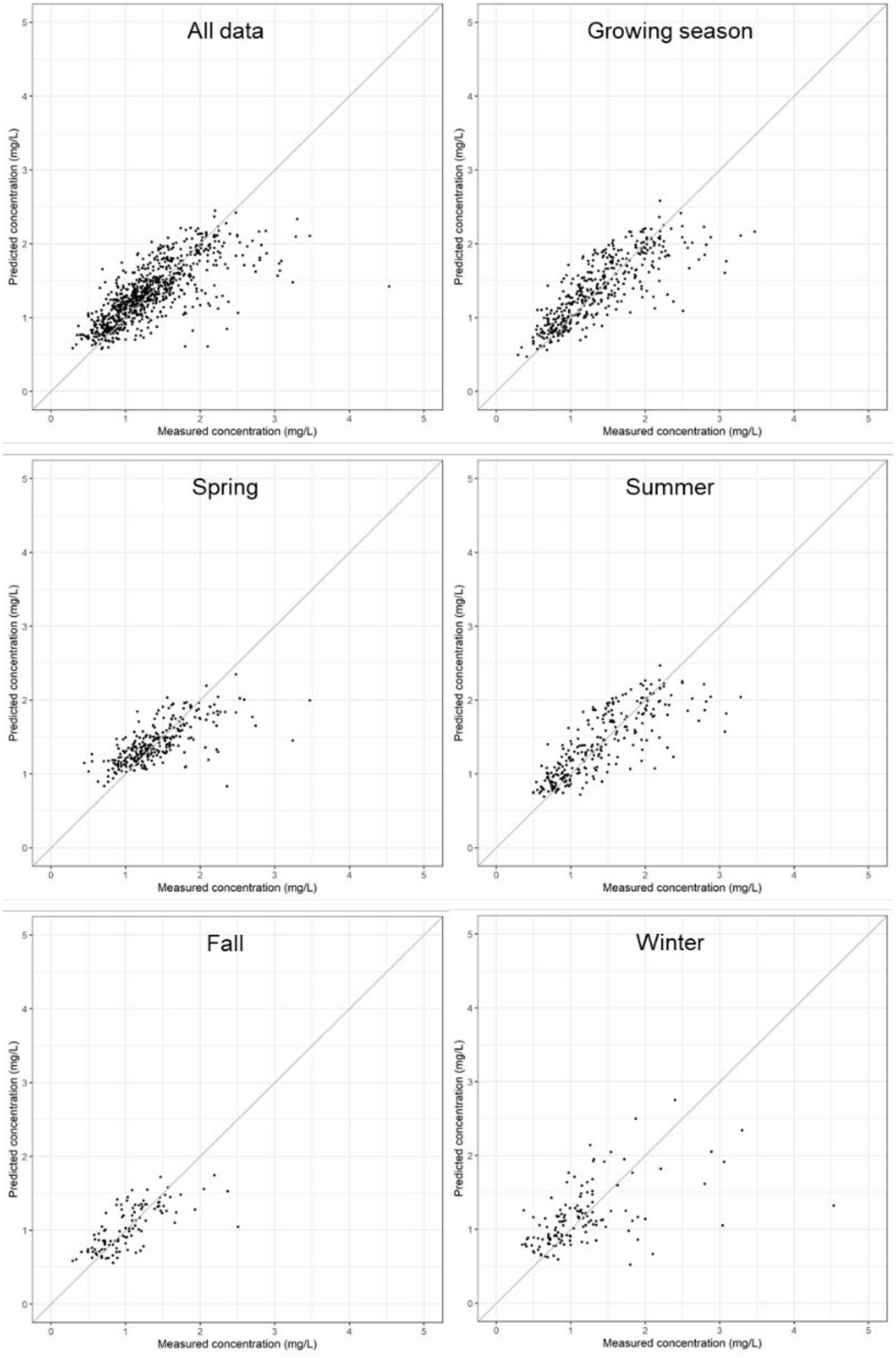


FIGURE 4.34

Modeled versus predicted concentrations for TKN RF models



4.4.2. Discussion of Random Forest Modeling

The random forest models provide some insight into which parameters may be important in predicting in-stream concentrations of total nitrogen, nitrate, and TKN. Predictions from the random forest models are slightly better than the multiple linear regression model, although the results indicate the models are still not adequate for accurately predicting in-stream concentrations. The models are particularly problematic for predicting in-stream concentrations in the winter. Nonetheless, data from additional sites may improve the fit of the model. If the models could be improved, they may be useful for predicting in-stream concentrations. Until the model is improved, it is not likely a useful replacement for mechanistic hydrologic and hydraulic models.

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