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Watershed

Straight River (Hubbard County, Minnesota) Nutrient Study

MINNESOTA POLLUTION CONTROL AGENCY

CLEAN WATER LAND & LEGACY AMENDMENT

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Cover photo: The Straight River on the downstream side of the US Highway 71 culverts.

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Contents

List of Tables

List of Figures

Executive Summary

The Straight River is a coldwater stream with excellent water clarity, including a mid-section lake (Straight Lake), located just west of Park Rapids, in Hubbard County, Minnesota. It flows in a landscape of deep, sandy surficial soils which contribute to the formation of the Pineland Sands Aquifer, a large regional groundwater feature. The aquifer supplies significant flow to the Straight River via springs and seeps. Groundwater input makes up a substantial amount of the flow of the Straight River (Stark et al., 1994). This groundwater input creates cold water habitat conditions that are sufficient to make the Straight River a designated trout stream. Additionally, the Minnesota Department of Natural Resources (DNR) has purchased angler easements along a significant portion of the stream corridor downstream of Straight Lake, which form the Straight River Aquatic Management Area. It also lies in a part of the state that has few other trout streams. The DNR has done much work to enhance or restore fish habitat in the Straight River (DNR website, search "Straight River"). As such, it is a recreationally important stream for anglers interested in pursuing a trout fishing experience, while the flow-through lake has many shoreland cabins/homes.

The Straight River, despite its clear waters, has been listed on Minnesota's 303(d) impaired waters list as not meeting the Class 2A (coldwater) standard for dissolved oxygen (DO). A total maximum daily load (TMDL) report was written in 2014 to achieve the DO standard via stream water temperature reduction (MPCA, 2014a, Section 2.3.1.2). Subsequently, more monitoring was done on nutrients and DO percent saturation. Nutrient enrichment is likely playing a strong role in this impairment through a process called eutrophication. Large mats of filamentous (surface-attached) algae are observed in the river. Midday DO levels are above natural saturation limits, evidence of large amounts of oxygen production by algae. At night, these same algae respire, drawing oxygen from the water column and decreasing DO levels. Eventual decay of algae also decreases oxygen levels as bacteria break it down.

The Straight River has a mixed land cover of forest and agricultural fields. The sandy soil here quickly dries out and makes growing crops difficult. Many of the historical fields were no longer planted and/or were cut for hay. Over the years, farmers have moved to utilize the easy-accessed surficial aquifer and irrigation was begun in order to grow row crops. The move to irrigation and row-cropping has grown in the last 30 years in the Straight River's drainage area, close to doubling acre-wise since 1992. Nitrogen fertilization accompanies the conversion to the row crops.

The sandy soils of these cropped fields allow leaching of nitrate from fertilized acres. Nitrate is a soluble molecule and easily moves with water. Nitrate levels in the surficial groundwater aquifer surrounding the Straight River are elevated and in some places exceed the Minnesota drinking water nitrate standard of 10 mg/L. The City of Park Rapids recently had to drill a deeper well for its municipal water needs due to exceedances of the nitrate standard.

The springs that supply flow to the Straight River also transport their elevated nitrate concentrations to the river. Nitrate levels in much of the Straight River are anomalously high, based on comparisons of nitrate data from many streams in the surrounding area. Straight River nitrate concentrations are much, much higher than the regional norm. Nitrate concentrations in the river at US Highway 71, where the data record is longest, have statistically-significantly increased since the 2004 through 2010 period, leveling off recently as the pace of new row crop acre additions in the Straight River drainage have slowed. Nitrate concentrations in the river are highest just upstream of Straight Lake and in the area of the Highway 71 crossing. Nitrate levels in the reaches downstream of Straight Lake start out fairly low and increase in the downstream direction as more groundwater is added to the flow via springs.

Nitrate concentrations in the Straight River vary substantially by season, with the summer period having the lowest concentration. The concentration peaks from late fall through early spring. At that time of year, concentrations are approaching a level that recent nitrate aquatic toxicity study show to be harmful to aquatic macroinvertebrates, which are an important component of the river's ecological health. Decreasing the levels of nitrate in the river would contribute to improving the DO levels that are the cause of the river's listing as impaired and improve the ecological health of the river.

Explanation of terms

Cycle 1 IWM

Intensive Watershed Monitoring (IWM)-1 -The first rotation of chemical and biological monitoring through Minnesota's HUC-8 watersheds (see "IWM" and "HUC-8" below) using Clean Water Legacy Act monies, started in 2007. The first monitoring effort of all HUC-8 Minnesota watersheds was completed in 2016. A second cycle effort (IWM-2) is underway throughout the state and has been accomplished for the Crow Wing River Watershed.

Detection limit - The lowest concentration of a chemistry parameter, such as phosphorus or iron, etc., that a given analysis can measure.

Eutrophication - A condition where excess plant nutrients, particularly nitrogen and/or phosphorus, enter surface waters and stimulate algal growth, resulting in low DO and/or large daily fluctuations of DO. These altered oxygen levels can be harmful to aquatic organisms.

GIS -Geographic Information System: a computer software that allows for analysis of landscape features, including quantification of landscape elements such as land cover types.

HUC-8 watershed - One of the United States Geological Survey hierarchy levels of drainage area scale of streams and rivers. Example - the Crow Wing River drainage area is a HUC-8 scale watershed.

IWM - A statewide stream and lake monitoring program conducted by the Minnesota Pollution Control Agency and Department of Natural Resources, sampling within state HUC-8 watersheds on a rotating basis (i.e., revisiting each HUC-8 watershed every 10 years).

Nitrate - Nitrate is the molecular ion NO_3^-. At some concentrations, this nitrogen-containing molecule can be toxic to biological organisms. Measurements referred to as "nitrate-N" in this report are actually measures of the amount of elemental nitrogen from the inorganic nitrogen molecules (nitrate and nitrite, not including ammonia or ammonium). In the environment, a very high percentage of these two nitrogen molecules will be nitrate. The report will refer to this nitrogen data from inorganic nitrogen molecules as nitrate-N for simplicity. The Minnesota state drinking water standard is 10 mg/L of nitrate N + nitrite N (commonly referred to as just "nitrate"). An aquatic life standard has not yet been enacted. Many nontechnical documents refer to "nitrate-N + nitrite-N" as "nitrate".

Polynomial regression line - A statistical tool that draws an unbiased trend line through a set of data using a polynomial line function, similar to a simple linear regression.

Straight River Subwatershed - The drainage area that contributes to the Straight River.

Subwatershed - The drainage area contributing to stream flow at a specific point on a stream/river. Example - The Straight River Highway 71 Subwatershed.

TMDL - Total maximum daily load. The amount of a pollutant that can be allowed into a water body per day while still meeting state water quality standards.

Watershed - The drainage area contributing to flow at a specific point on a stream/river, often used for the point of the river mouth. For this report, it will refer to HUC-8 scale watersheds. Watersheds of a smaller scale will be referred to as subwatersheds.

10X site - An IWM site that has 10 chemistry parameter sampling visits.

Background on the Straight River

The Straight River is one of the top stream trout fisheries in Minnesota and located in a part of the state that has few trout streams. The stream lies in an area with very high sand content soils, which continue to be sand and gravel commonly to depths of 20 to 40 feet, with some areas going to depths of greater than 100 feet below the ground surface (DNR 2024). Such soils allow for the formation of substantial surficial aquifers. The Straight River Watershed lies atop part of the Pineland Sands Aquifer (Figure 1). The Aquifer's sandy composition makes it strongly hydrologically connected to the Straight River, creating springs at many points along the channel. The Aquifer's characteristics have been described in detail in a USGS study, which highlighted the substantial role of groundwater inputs to the flow of the Straight River (Stark et al., 1994). The DNR has recently completed several years of additional study of the aquifer to collect additional information about its characteristics and has issued a report on their findings (DNR, 2024). The report states that monitoring will continue.

The upper part of the river is a spring-fed coldwater (trout) stream that flows into Straight Lake. The lower part of the river is fed by Straight Lake as well as additional groundwater via many springs along its course (Figure 2). This reach is also a designated trout stream. Land and water use developments over the last couple decades in the Straight River's Watershed, perceived as threats to the Straight River's quality, have received significant citizen and media attention. The Straight River was featured in a prominent article in the Minneapolis Star-Tribune (Marcotty, 2016) on December 31, 2016, titled *A great river, at risk*, about water quality of the upper Mississippi River Basin in north central Minnesota. Articles about the Straight's unique fishing opportunities and environmental challenges have been written in other prominent Minnesota media outlets (Gunderson, 2002; InForum, 2014; Kallok 2010; Johnson, 2020). Most recently, the Park Rapids Enterprise published a story on the Straight River and various monitoring going on within the Straight River Groundwater Management Area (GWMA; Geisen, 2021). Nitrate pollution is showing up in problematic levels in several agricultural landscapes with geological groundwater sensitivity in Minnesota, with a couple newspaper case studies highlighting Little Rock Creek in central Minnesota (Bjorhus and Stanley, 2021) and the southeastern Karst (limestone geology) region of Minnesota (Hargarten and Bjorhus, 2023).

The water of the Straight River eventually enters the Mississippi River after first becoming part of the Fishhook and then Crow Wing Rivers.

Figure 1: The Pineland Sands aquifer (gray area), with the Straight River highlighted (USGS, 2023).

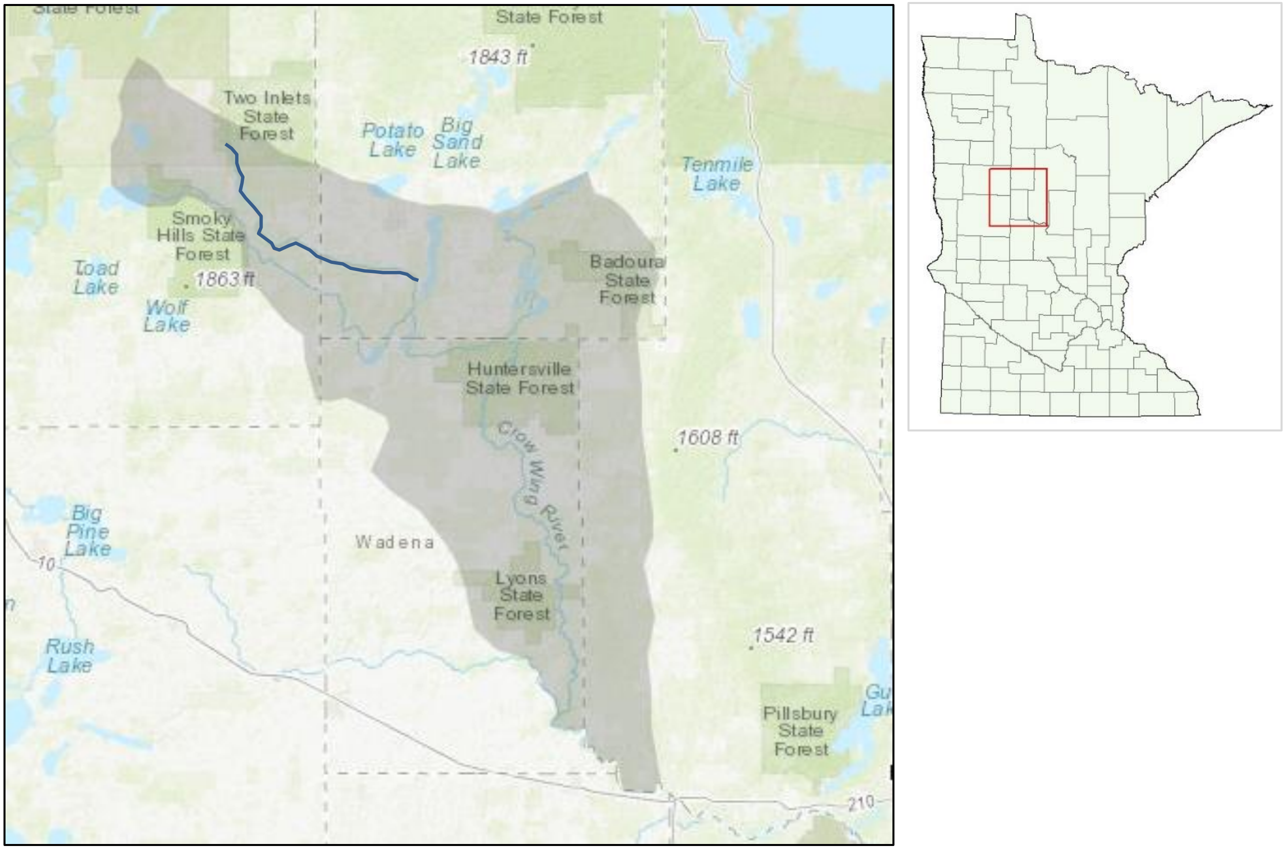
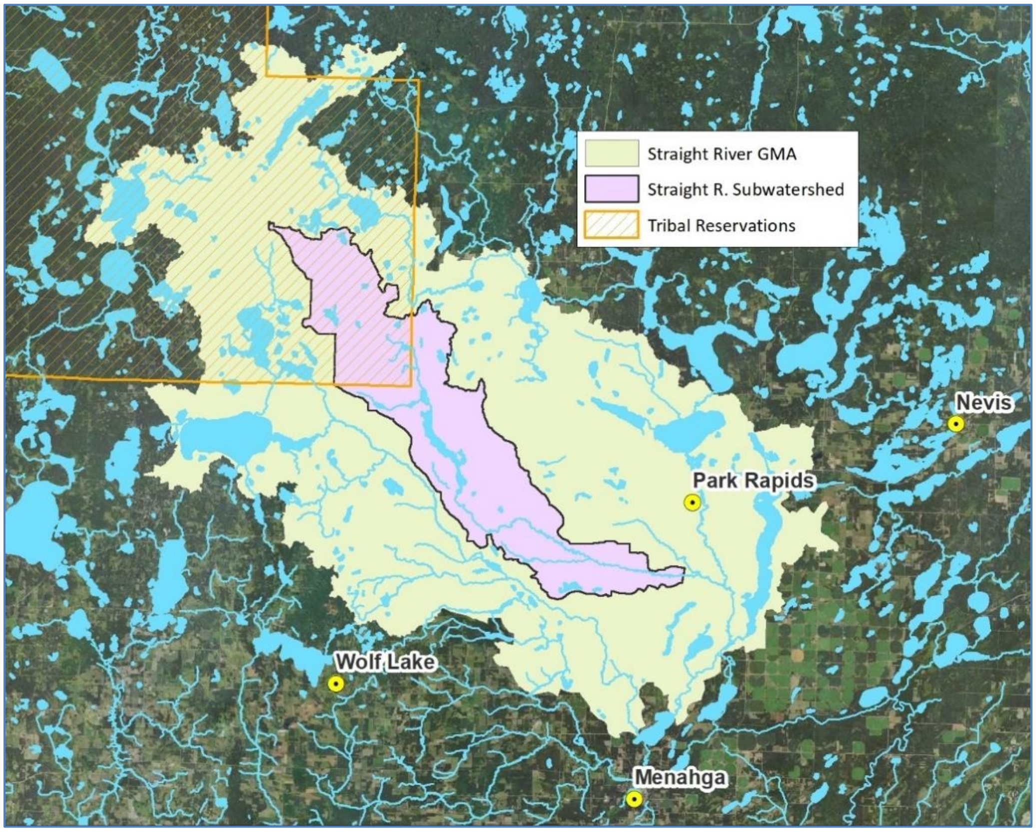


Figure 2: A large spring-water channel as it enters the Straight River downstream of CR-123.

In 2012, the Minnesota Legislature created a law allowing for the designation by DNR of GWMAs in response to concerns about groundwater withdrawals in various parts of Minnesota having issues involving sustainability of aquifer resources. The DNR provides a discussion that defines their aquifer sustainability goals (DNR, 2013; also search “Groundwater Management Areas” on DNR’s website). The

DNR has created three pilot GWMAs in the state, one of which is the Straight River GWMA (Figure 3; internet search "Minnesota Groundwater Management Areas"). Much study has occurred recently in this GMA, led by DNR. An additional study is underway by a Tribal-University of Minnesota team focusing on the broader Pineland Sands aquifer area and land use influences on area resources (Marohn, 2023).

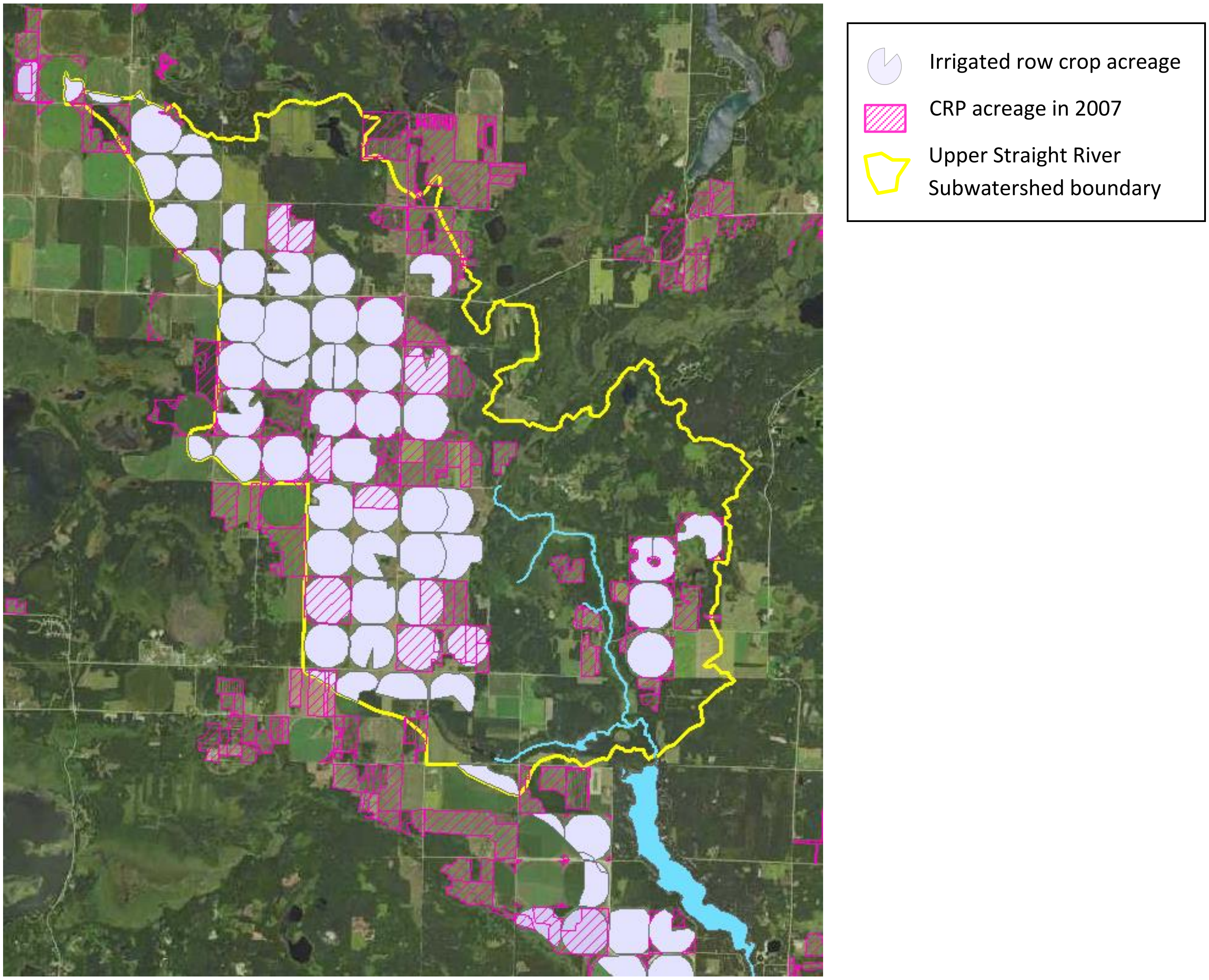
Figure 3. Map of the boundary of the Straight River Groundwater Management Area and the Straight River Subwatershed for the sample site at Highway 71.



The surrounding landscape and changes in recent years

The landscape surrounding the Straight River is a mix of forest and agricultural land. The growing of row crops is extremely difficult in these sandy soils, which quickly dry out following precipitation events unless augmented via irrigation. Many of the historical agricultural fields had been placed into the Conservation Reserve Program (CRP) in the last 20 to 30 years due to the difficulty in growing crops in these quick-drying soils and the susceptibility of these sandy soils to wind erosion. Irrigation of fields in the Straight River Watershed began more than thirty years ago. In recent years, there has been a steady conversion of these set-aside and/or nonrow-crop fields to center-pivot irrigated row cropping (Figure 3, Figure 4, and Figure 5; Table 1.). The more recent irrigation expansion first occurred mostly in the watershed upstream of Straight Lake, in the period between 1992 through 2009. Expansion has also happened in the lower part of the subwatershed, downstream of Straight Lake, especially between 2007 through 2016.

Figure 4. The upper portion of the Straight River Subwatershed (above Straight Lake). Irrigated fields in this subwatershed are current as of 2013 aerials. Areas where cross-hatching overlies the irrigated fields depicts land that was in the CRP program as perennial grasses in 2007 which now is an irrigated row crop.



The changes in acreage of irrigated row cropped fields shown visually in Figure 4 were quantified using GIS tools. Shapes of the circular or semi-circular areas were digitized by hand from aerial photography to create a shapefile in ArcMap, from which areas were calculated (Table 1 and Figure 4 and Figure 5).

Figure 5. Change in irrigated acreage over time from that present in 1992 to 2021 in the full Straight River Subwatershed. These changes are cumulative, so in 2021, all colors denoting irrigated cropland were operating as irrigated row crops. The municipal and industrial wastewater irrigation fields were present in 1992.

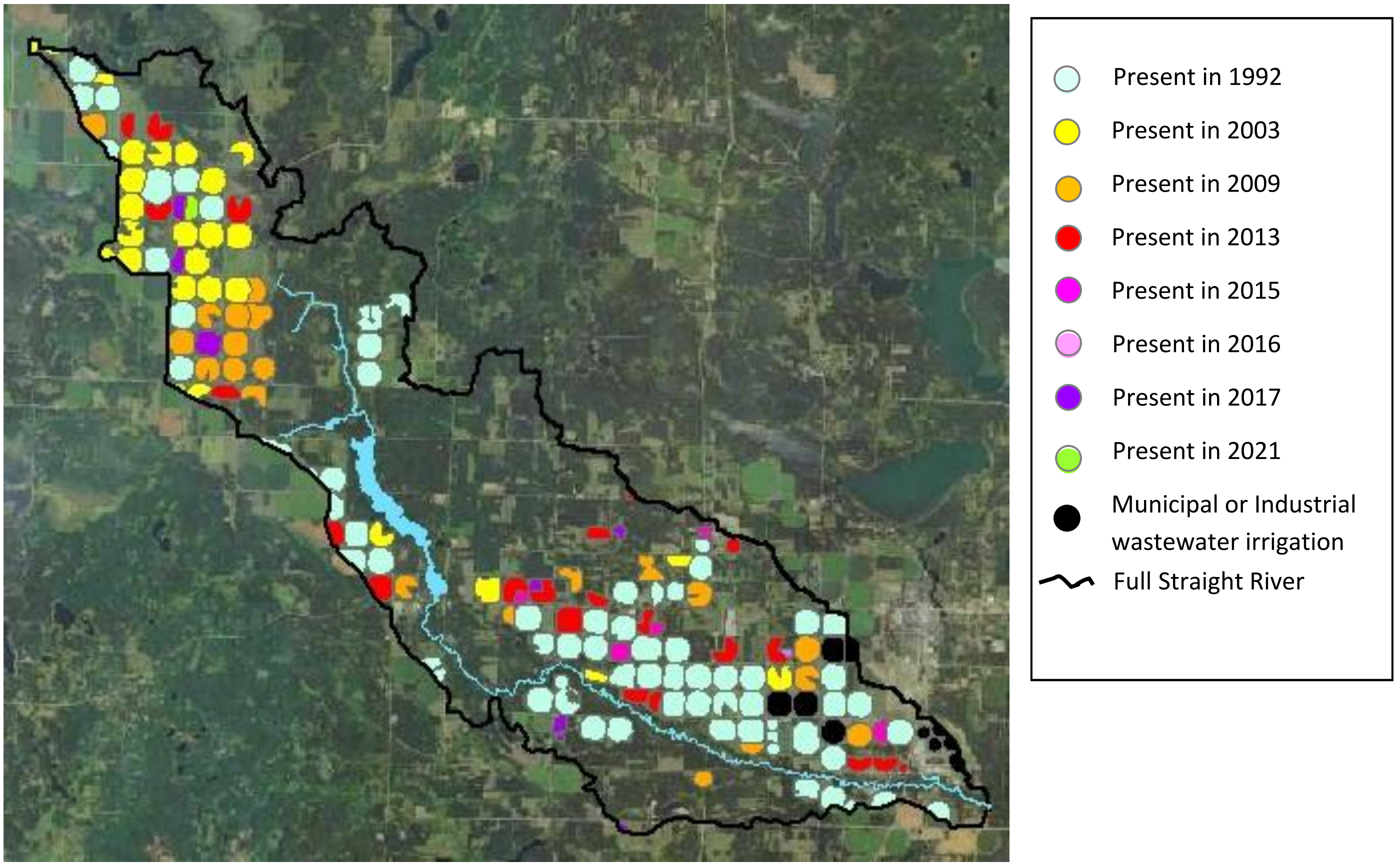


Figure 6. Graph of the changes in acreage of irrigated row cropped fields in the Straight River Subwatershed shown in Figure 4 and Table 1.

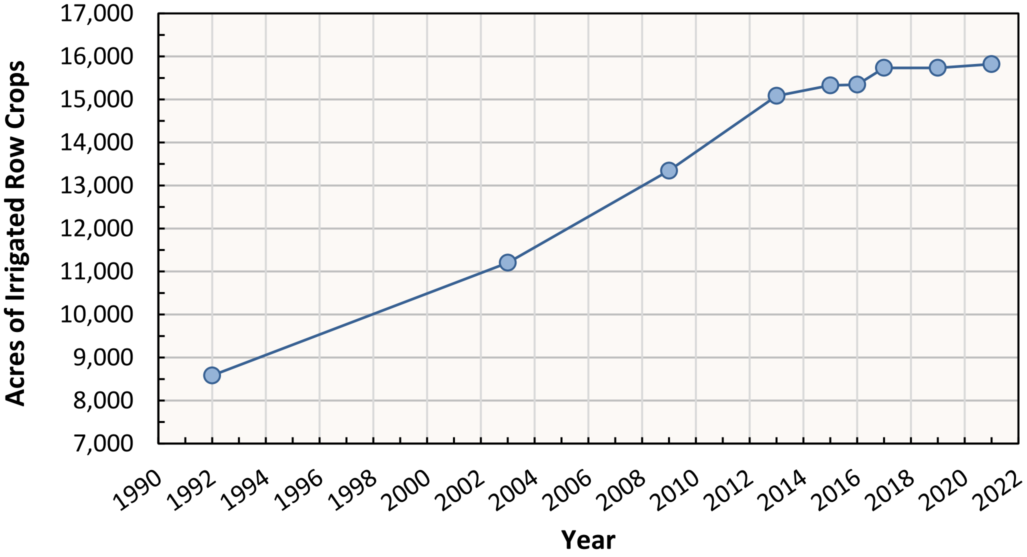


Table 1. Acreages of irrigated fields in the Straight River Subwatershed beginning in 1992 through 2021 (from available aerial photo sets). These acreage numbers are close approximations.

As of the Year	Added Acres	Total Acres
1992	--	8,582
2003	2,621	11,203
2009	2,142	13,345
2013	1,739	15,084
2015	244	15,328
2016	16	15,343
2017	391	15,734
2019	0	15,734
2021	87	15,821

In some cases, these conversions also resulted in forest patches being converted to row crop agriculture (Figure 7), as removing these wooded plots results in achieving the most cropland under the footprint of the reach of the irrigation equipment. Many irrigated fields are quite closely adjacent to the river. In the lower Straight River landscape, six fields are within ~ 375 feet of the river, based on measurements from aerial photos (Figure 8). The distances of these six fields were 373, 340, 305, 202, 182, and 151 feet at their nearest field edge to the riverbank. Most of the fields in the Straight River Watershed; however, are relatively close to the river. The nearness of fields to the river mean that nitrate-containing groundwater has little distance to travel before it emerges in the river channel to become part of the Straight River's flow. Rates of flow within the aquifer may be available with data collected in the Straight River Groundwater Management Zone study project, headed by DNR.

Figure 7. Example of a land cover conversion to irrigated agriculture that straddles the Shell River - Straight River Subwatershed boundary. Note that forest area was also lost in this conversion to maximize irrigated field area, in addition to the perennial grassland.

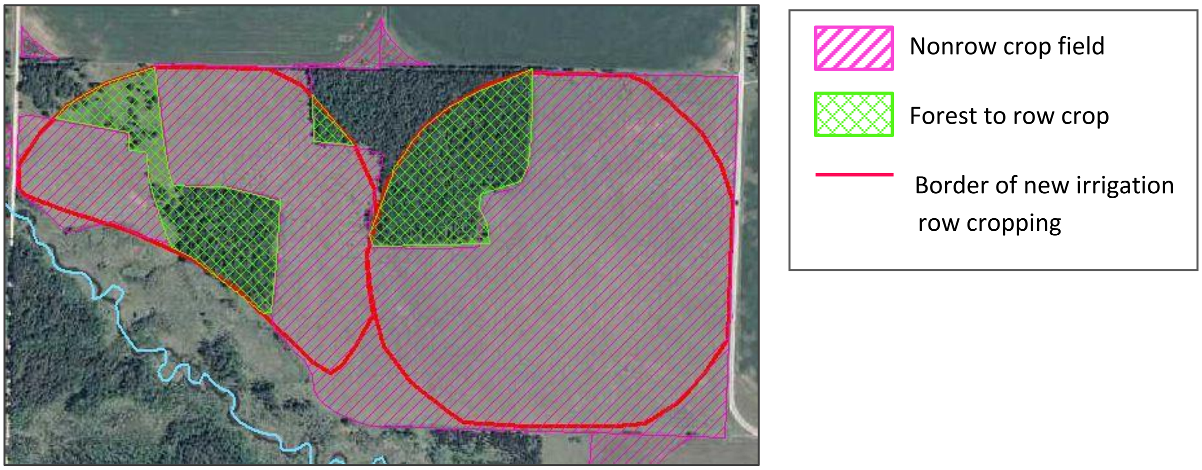
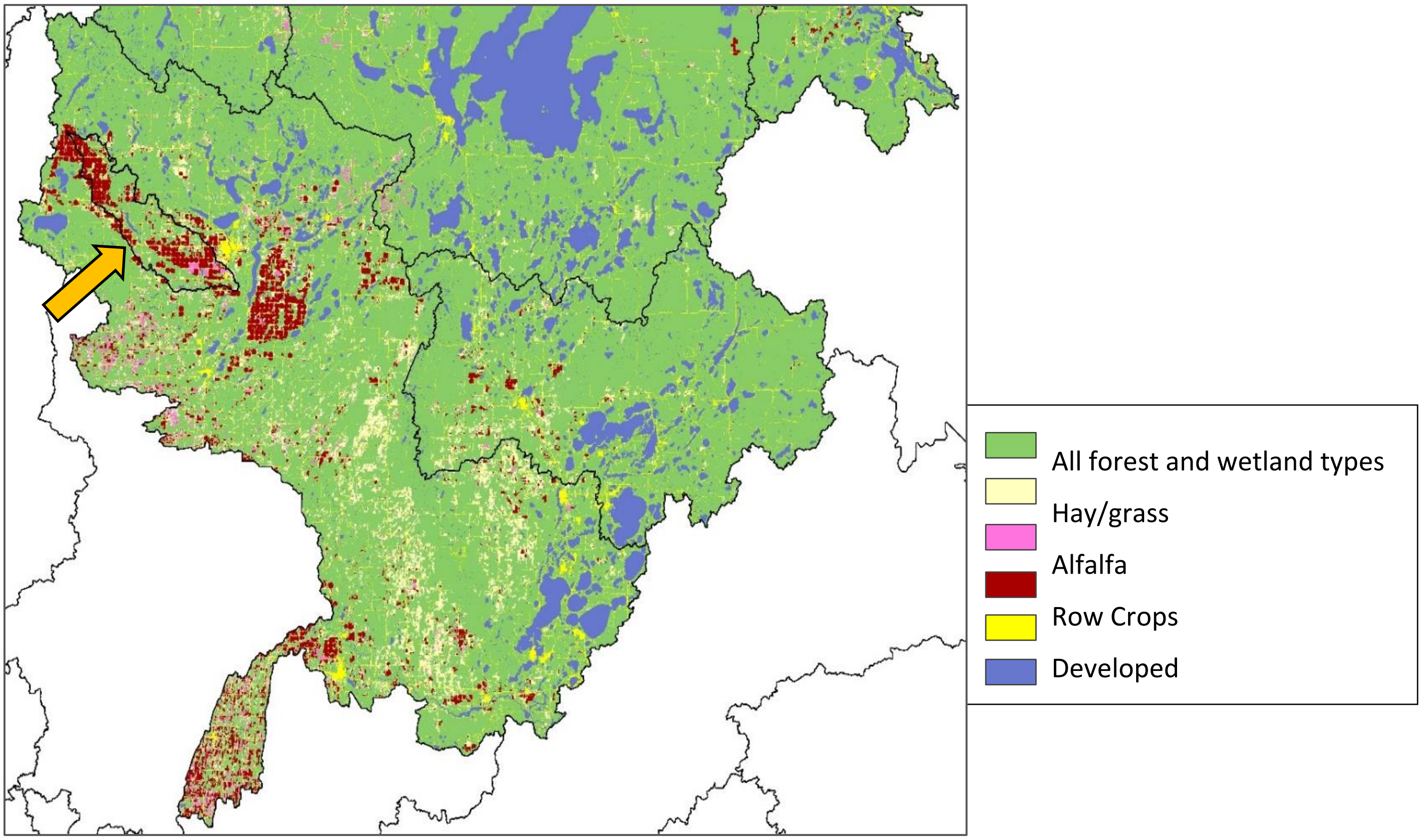


Figure 8. Measured distances (in feet) from field edge to nearest riverbank.

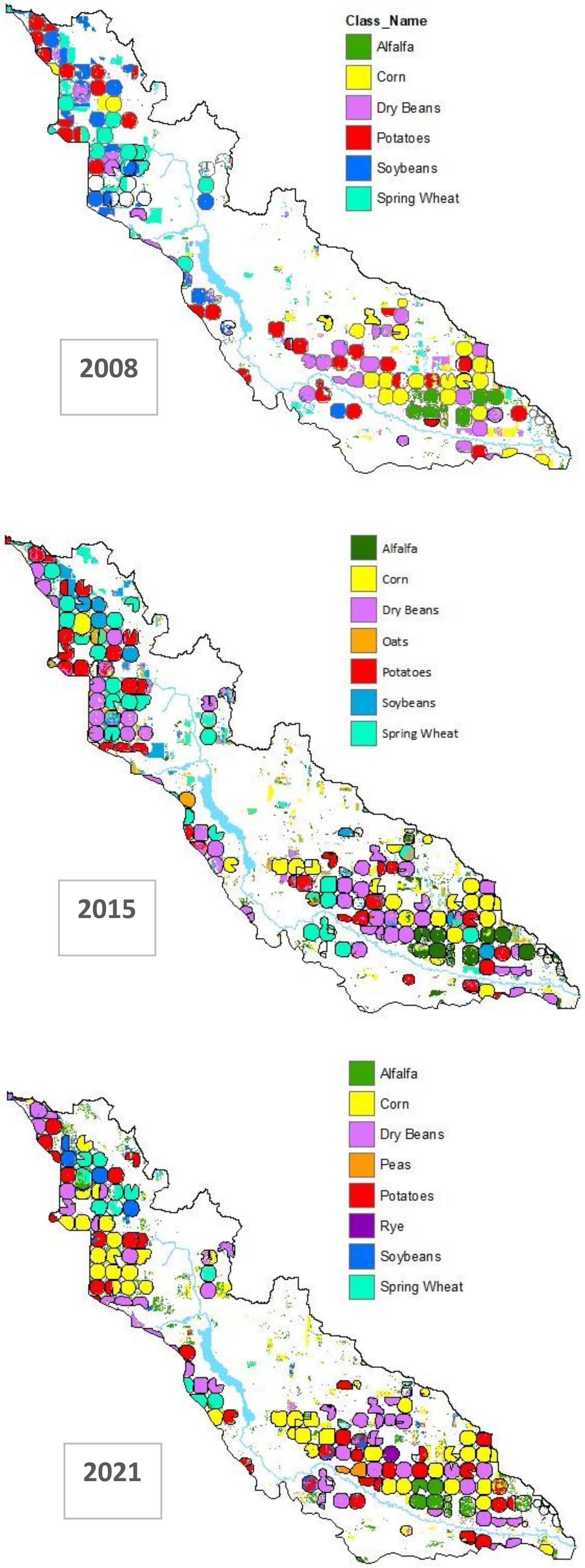
Row crop agriculture is substantially more-densely practiced in the area surrounding the Straight River than elsewhere in the Crow Wing River Watershed and other naturally forested watersheds nearby (Figure 9). Some of the common row crops grown in the fields surrounding the Straight River require significant inputs of nitrogen fertilizer, particularly potatoes and corn. Nitrate is water soluble, and easily moves through sandy soils. Once below the crop roots, nitrate will typically move through sandy subsoils and reach the shallow surficial aquifer. The nearby City of Park Rapids recently had to drill a new municipal well (MDH, 2013) due to groundwater nitrate-N concentrations above the Minnesota drinking water standard of 10 mg/L.

Figure 9. Land Use in the Crow Wing River Watershed (and the three other adjacent watersheds shown above). The arrow points to the Straight River Watershed. Source: Minnesota Department of Agriculture 2014 Cropland Database.



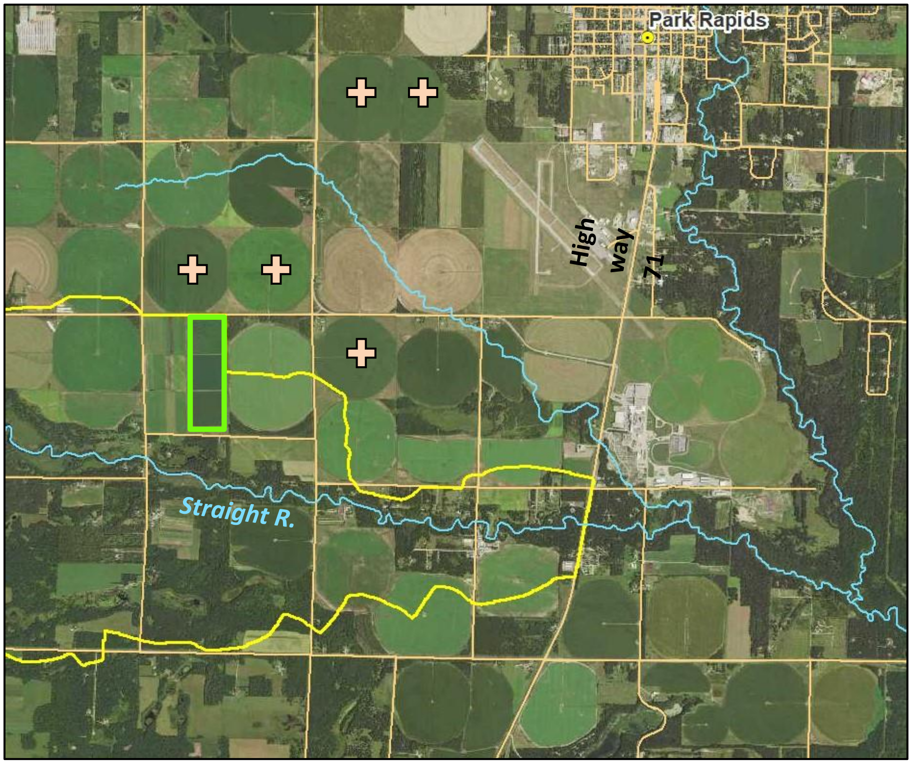
In order to see what the crop mix can be in a particular year; maps were made in GIS using yearly crop type data from MDA GIS layers. A random choice of one year was made for each of the three nitrate data sets. The acreages were not calculated, but the maps show there is a fairly even mix of corn, dry beans, potatoes, soybeans, and spring wheat, with lesser amounts of alfalfa and occasional small amounts of peas, rye, and oats (Figure 10).

Figure 10. Crops grown in the Straight River Subwatershed in 2008, 2015, and 2021, according to GIS data from MDA.



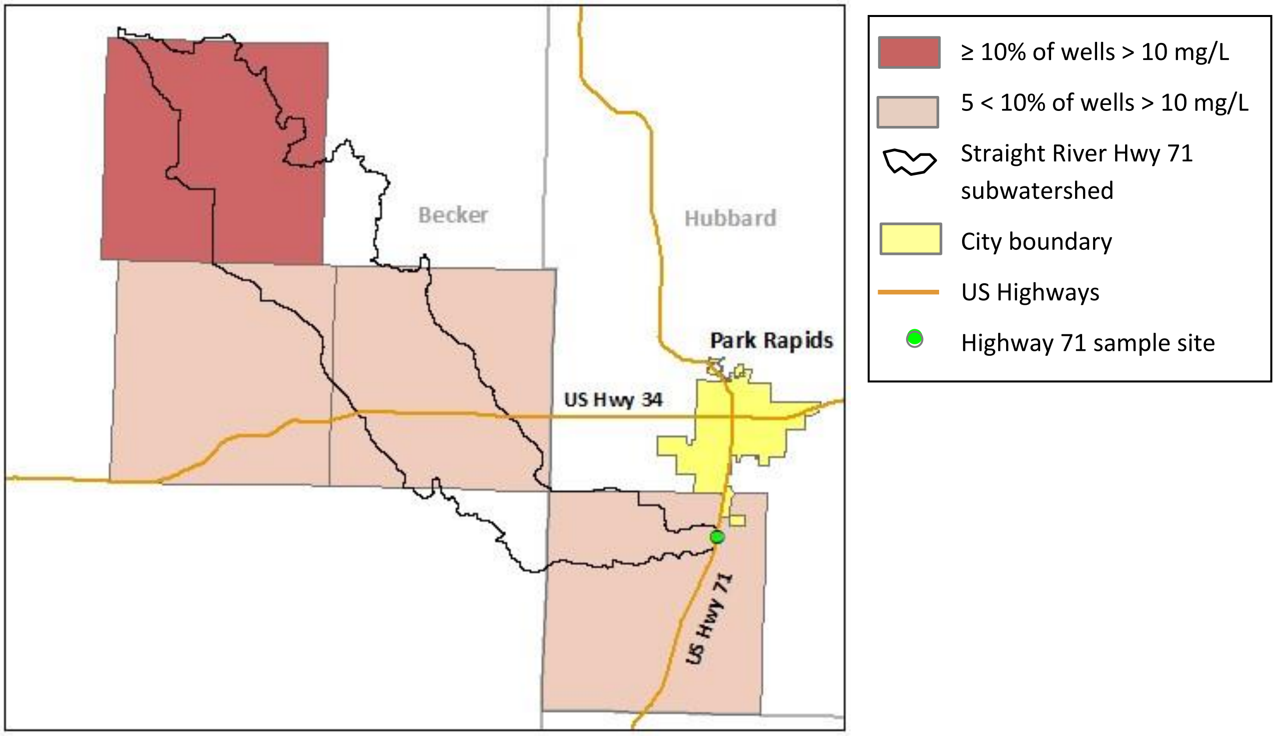
The City of Park Rapids municipal wastewater treatment ponds are located near the Straight River (Figure 11). After treatment in the ponds, the water is irrigated onto several nearby fields. These fields are outside of the surficial subwatershed boundary contributing to the river where it is sampled at US Highway 71. Generally, surficial aquifer groundwater follows the land's relief in its flow direction, and so any nitrate in the treated wastewater that enters groundwater should be contributing either to a location on the Straight River downstream of Highway 71, or to the Fishhook River (i.e., not part of the nitrate source measured at Highway 71).

Figure 11. Location of the Park Rapids municipal wastewater treatment ponds (green box) and fields where permitted treatment pond water is applied (✚). The surface drainage area of the Straight River for the site at Highway 71 is outlined in yellow.



As mentioned earlier, the nitrate-N concentration in the groundwater in the area surrounding the Straight River is elevated, in some cases beyond the drinking water standard (10 mg/L). In 2013, the Minnesota Department of Agriculture initiated a township-based private well nitrate testing project in areas with groundwater sensitivity based on soil/geology. Included in the project were several townships in the Straight River Subwatershed, sampled in 2016. One of the townships associated with the Straight River had greater than 10 percent of private wells testing at 10 mg/L or higher, and the other three had between 5-10 percent of wells testing at or above 10mg/L (MDA, 2022). Results of that sampling are shown in Figure 12. Groundwater input makes up a substantial amount of the flow of the Straight River (Stark et al., 1994). Thus, these groundwater inputs with elevated nitrate concentrations are a logical source of nitrate in the river.

Figure 12. Results of recent MDA township private well testing for nitrate, adapted from the Minnesota Department of Agriculture (2022). Only those townships that were both part of the testing project and likely contribute nitrate via groundwater to the Straight River down to the point of Highway 71 are shown in this graphic.



Details of chemistry monitoring methods

Nitrogen is found in many forms in the environment. In this study, the nitrogen measured is from part of the subset of nitrogen compounds referred to as “inorganic nitrogen”, which consists of nitrate and nitrite here, and does not include ammonia/ammonium for this report’s purposes. In the environment, bacteria quickly change nitrite to nitrate, a more stable form of inorganic nitrogen. The lab test used in the analyses of data found in this report is a “nitrate+nitrite N” analysis. It reports on the amount of nitrogen coming from those two nitrogen/oxygen molecules. Typically, almost all of this inorganic nitrogen in an ambient environmental sample will be in the form of nitrate. Therefore, the reference to inorganic nitrogen data (i.e., nitrate+nitrite N) will just be “nitrate-N”.

Following is a description of the chemistry monitoring that has occurred in the Straight River and other streams/rivers discussed in this report. In 2007, Minnesota, via the Minnesota Pollution Control Agency (MPCA) and its partners, began a monitoring program that cycles through the 80 HUC-8 scale watersheds in Minnesota every 10 years. The program is called IWM, and 68 sites (some larger streams had more than one location) within the Crow Wing River Watershed (which contains the Straight River) were sampled in 2010 and 2011. A second IWM effort occurred in the Crow Wing River Watershed in 2020-2021, with somewhat fewer sites (the smallest streams were dropped).

IWM sample visits that target biological communities in streams are visited once or twice, and a suite of chemistry parameters, including nitrate-N, is collected at those visits. A subset of IWM sites are targeted for repetitive chemistry monitoring. These sites, called 10X sites, are visited 10 times during the IWM effort. Nitrate-N (see description in the explanation of terms in the glossary at the front of the report) is one of the parameters collected at 10X sampling visits. Prior to the IWM program, very little chemistry monitoring had occurred in the Straight River. One nitrate sample had been collected by MPCA in 1980, and a few nitrate-N samples were collected by the USGS in the late 1980s (Stark et. al, 1994).

Some streams used for comparison in this report have also been sampled by county staff for their own projects. That data, if submitted to MPCA's EQuIS database, has also been used in this report. The MPCA samples are analyzed at either the Minnesota Department of Health (MDH) Environmental Laboratory or other private laboratories in Minnesota that are certified by the MDH Lab. All data in MPCA's EQuIS must be analyzed by MDH certified laboratories. The nitrate-N data in northern Minnesota has either had laboratory detection limits of 0.05 mg/L, 0.03 mg/L, or 0.02 mg/L, depending on the laboratory.

If a stream is found to be impaired after monitoring (i.e., not meeting a state standard for a parameter(s)), additional monitoring may be conducted to seek a cause for the impairment. Stressor Identification (SID) monitoring, including nitrate, was conducted at several sites on the Straight River in 2015 to 2016 and 2020 to 2022. Details of the various monitoring efforts are discussed within this report.

Health of the Straight River

As a result of the 2010-2011 Crow Wing River Watershed IWM effort, the Straight River has been assessed by MPCA as impaired (placed on Minnesota's 303(d) list) for aquatic life due to DO concentrations below the state coldwater (Class 2A) standard. A TMDL was written in 2014 to achieve the DO standard via stream water temperature reduction (MPCA, 2014a, Section 2.3.1.2). Subsequently, more monitoring was done on nutrients and DO percent saturation. The fish and macroinvertebrate communities in the river passed MPCA's health thresholds in both IWM projects (2010 and 2020) and thus are not considered impaired at this time. The 2010 DO impairment was confirmed again in the second cycle of the 2020 to 2021 IWM sampling.

Two factors related to the interplay of irrigated row crop agriculture with natural hydrological pathways may be contributing to this impairment, those being 1) the export of the agricultural fertilizer nitrate to the river via groundwater, contributing to excess plant life in the river (Figure 13 and Figure 14), and 2) possible reduction of groundwater input to the river, which could result in higher stream water temperatures (as water warms, it holds less oxygen). The DNR has recently been studying flow volumes and water temperature in the Straight River to assess the latter possibility. A discussion is found in their recent report (DNR 2024). Climate change also may be (or eventually be) having a negative impact on DO via increasing water temperatures.

Figure 13. A large mat of filamentous algae downstream of CR-123.

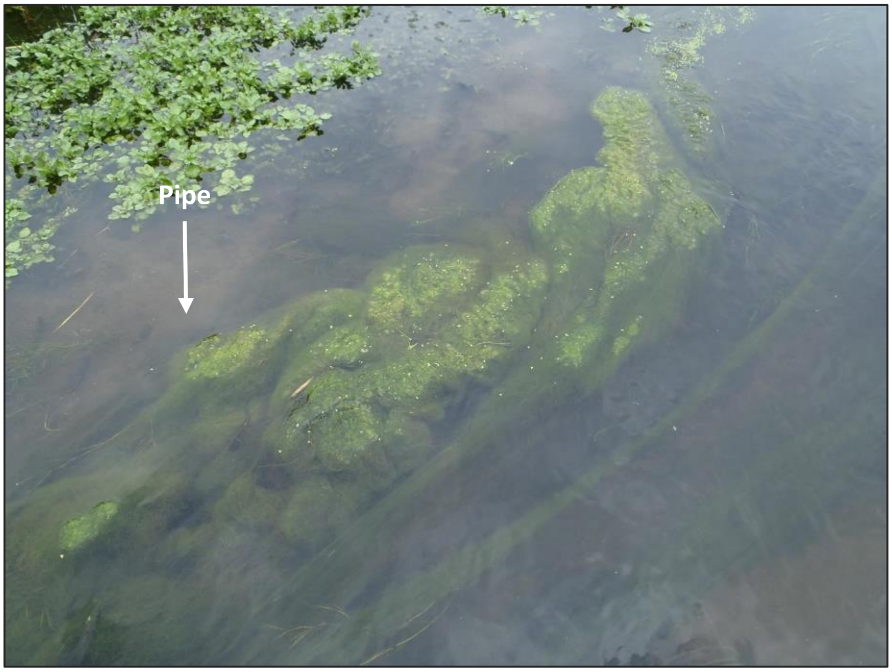


Figure 14. Filamentous algal growth on a vertical pipe, part of stream gaging equipment at Becker Line Road (117th), Sept. 14, 2016.

Follow-up monitoring and analysis post IWM-1

After MPCA's initial Crow Wing River Watershed IWM effort in 2010-2011 and subsequent formal assessment in 2012 of a DO impairment of the Straight River, follow-up sampling was done via the SID program to better understand phosphorus and nitrogen concentrations and dynamics in the Straight River. Often, the nutrients nitrogen and phosphorus play a significant role in oxygen deficiencies in surface waters, through the process called eutrophication (nutrient stimulation of excessive aquatic plant growth). It is not known for streams of this area whether the limiting nutrient for algae is nitrogen or phosphorus. Land use changes quantified above were evaluated and compared with nutrient data from various years of collection pertinent to the timing of the land use changes.

Additional water quality monitoring was conducted by MPCA's Watershed Unit SID staff in 2015-2016 in the river reach downstream of Straight Lake. Sampling was done in a longitudinal manner along the river's course to examine if and how water quality parameters change moving downstream. Several water chemistry parameters (total phosphorus, nitrate+nitrite-N, and field measurements of water temperature, DO, DO percent saturation, and conductivity) were repeatedly sampled at four locations in all calendar months. These sample sites were at CR-123, CR-125, Becker Line Road, and US Highway 71 (Figure 15), meaning four nested contributing subwatersheds could be examined separately in order to provide insight into sources of nitrate to the river. The CR-125 location was discontinued part way through the 2015-2016 effort due to its results being very similar to those at the adjacent site at CR-123, and thus the site was somewhat redundant. With the dropping of that site, there are three nested subwatersheds that were monitored (Figure 16). Two streamside springs were also sampled, one of them only once (due to difficult collecting conditions), and the other spring eight times.

Figure 15. The full Straight River Watershed boundary and the study's nutrient sampling locations. The Straight River enters the Fishhook River just south of Park Rapids.

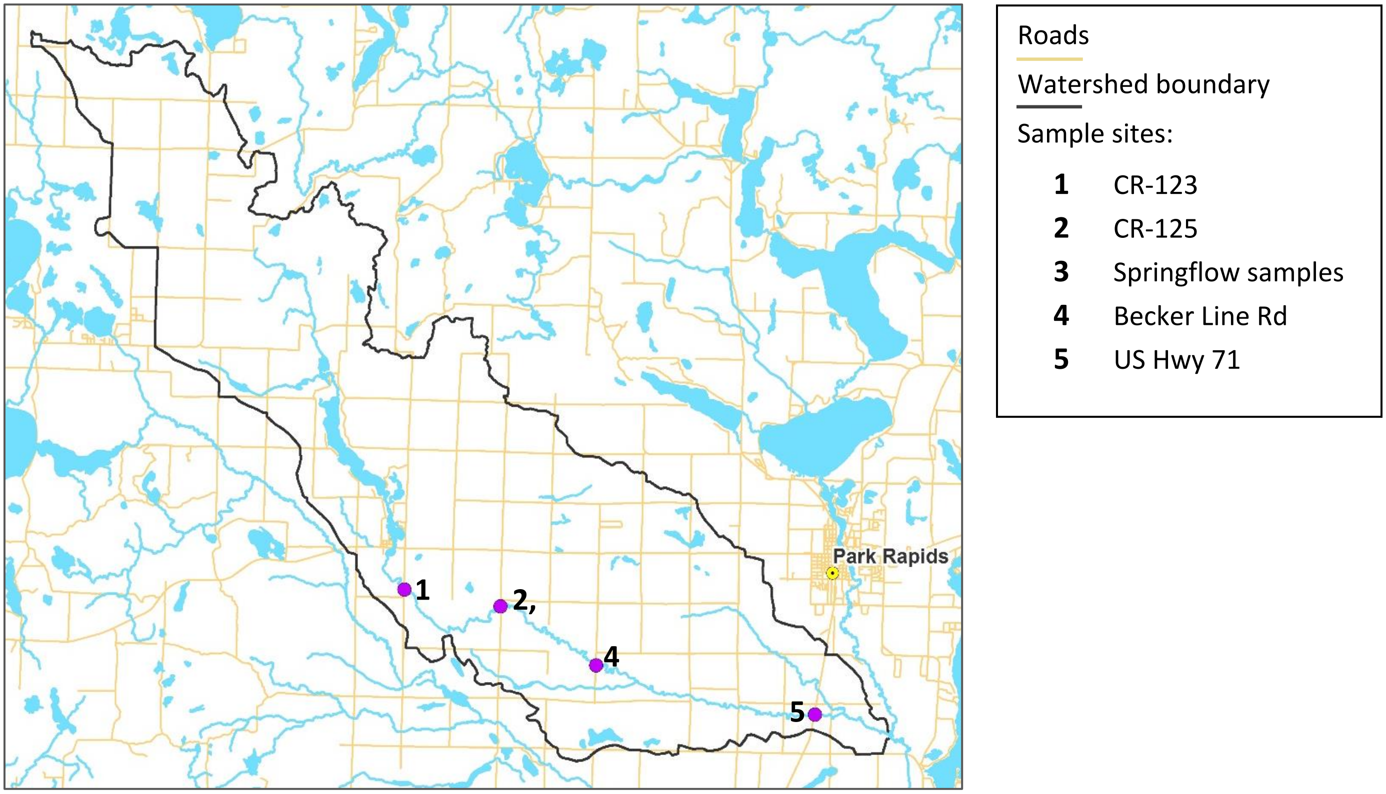
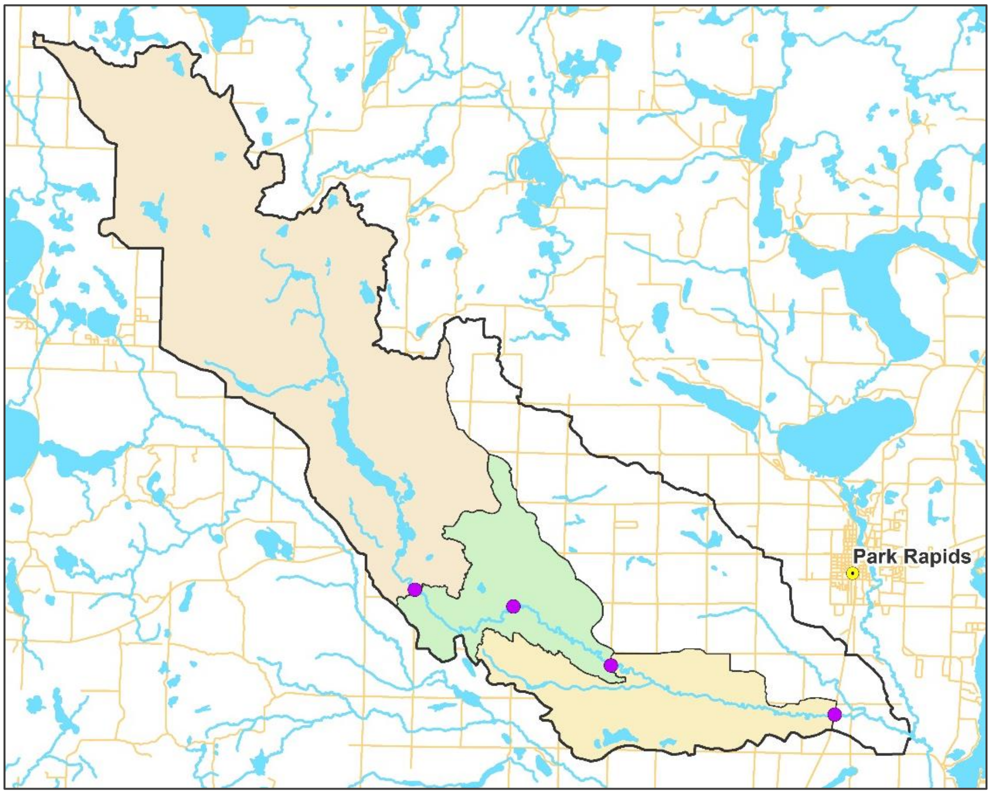


Figure 16. Subwatersheds for the sampled sites shown in Figure 15. The second site from the left was discontinued partway through the study as water chemistry results were very similar to the upstream site. Note that each site's subwatershed also contains the area of the one to the left of it. Also note that part of the Straight River Subwatershed does not contribute surface runoff to any of the sites (the uncolored area within the stronger black outline) but might contribute groundwater input.



In addition to sampling in order to understand the 2015 through 2016 nutrient dynamics in the river, historical data was utilized to look for time-related trends in nutrient concentrations. Another new dataset was collected in 2020 through 2022 in order to compare with the 2015 through 2016 dataset. Therefore, the data used and presented below for this study are from four sources: 1) historical data found in the MPCA's EQuIS water quality database 2) data collected as part of the 2010 Crow Wing River Watershed IWM, 3) the data collected by MPCA's SID staff in 2015-2016, and 4) a second set of data collected by MPCA's SID staff in 2020 through 2022. The 2015 through 2022 samples were analyzed at the MDH Environmental Laboratory. The data in EQuIS are from water samples analyzed at MDH certified laboratories. The results of this sampling provided three distinct, time-separated data sets to compare to determine if there are trends in river nitrate concentrations. These three data sets were intentionally separated by approximately five year gaps.

Water Quality Findings from IWM-1, IWM-2, and Stressor Identification

1. The nitrate concentration in the Straight River, especially at the US Highway 71 site, is much higher than nitrate concentrations in most other streams of the Crow Wing River/Pine River/Leech Lake River/Mississippi River - Headwaters Watersheds during the growing season, even though it is not at its annual high period (winter) (Figure 17). Stream nitrate levels in these natively-forested watersheds are very low with a few exceptions.

Nitrate values in the Straight River vary by time of year, being higher in the cold periods of the year, and lowest in mid-summer. Other regional monitored sites used for comparison do not have December through March samples so a generalization of nitrate for the complete annual seasonal pattern cannot be made for those streams. Recently at US Highway 71, concentrations of nitrate-N have been as high as 3.9 mg/L in winter (2021) and around 1.8 to 2.0 mg/L during the summertime low point (2021 and 2022); more data and details below. The reason for decreased levels of nitrate in summer are not fully known. Possibilities include strong uptake by row crops during that time of year, or uptake by aquatic plants during their prime growing period. The latter explanation was found in a stream with groundwater nitrate inputs and substantial filamentous algae, similar to the Straight River, in Wyoming (Eddy-Miller et al., 2013).

The levels of nitrate in the Straight River are anomalous within this region of Minnesota. The nitrate concentrations from samples taken during cycle 1 IWM biological monitoring visits (2010 through 2015) from four contiguous HUC-8 watersheds were compared with data from the Straight River (see Figure 17). The majority of these sites had nitrate-N concentrations less than the lab detection limit of either 0.02 or 0.05 mg/L, depending on the lab used (actual values are found in Appendix 1). Summary statistics for these sites are presented in Table 2. The Blueberry River, located a relatively short distance south of the Straight River and also in the Crow Wing River Watershed, has a record of 30 growing season samples from 10 years between 2000 - 2022 at the crossing of CSAH-16; the average concentration of nitrate-N was < 0.113 (< because numerous samples contributing to the average were below lab detection limits - for these, the lab detection limit was used in the calculation). Twelve of the 30 samples were below the lab's detection limit; four were below a concentration of 0.02 mg/L, seven were below a concentration of 0.03 mg/L, and one was below a concentration of 0.05 mg/L. Only seven sites (among 187 sampled) in this four-watershed area had nitrate-N levels above 0.50 mg/L. Only the Straight River site upstream of Straight Lake and a site on Stoney Brook (in the southeast Crow Wing River Watershed) had concentrations greater than 1.50 mg/L, with the upper Straight River nitrate-N concentration 25% greater than Stoney Brook's. One other site with a high value, the Fishhook River (1.24 mg/L), was located just downstream of where the Straight River enters. The sites in these watersheds with elevated nitrate (> 0.50 mg/L as defined here) were associated with adjacent crop or livestock agriculture.

Figure 17. Crow Wing River Watershed nitrate concentrations from all IWM-1 biological monitoring site visits in the Crow Wing R., Mississippi R - Headwaters, Leech Lake R., and Pine R. Watersheds (most sites have just one sample).

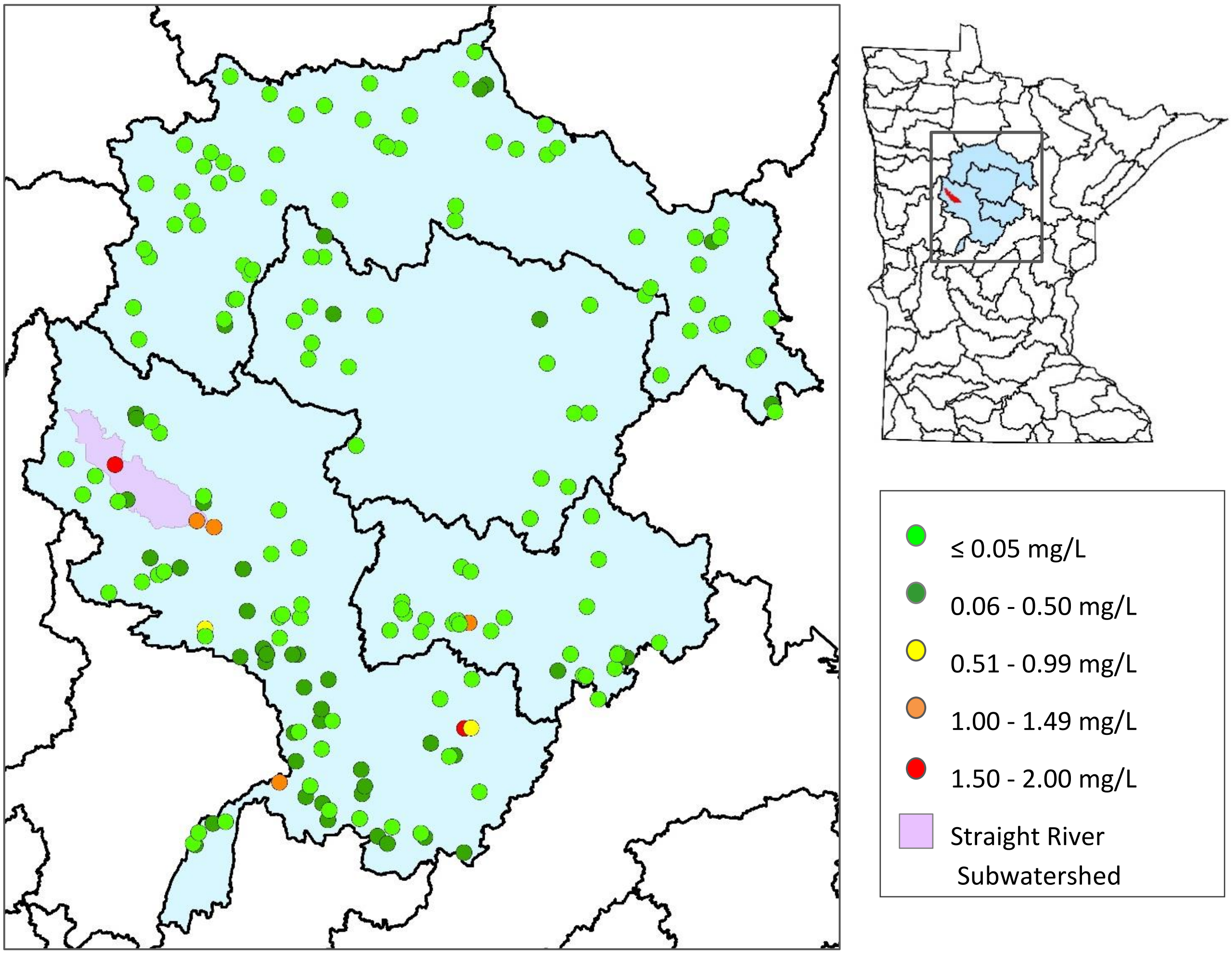


Table 2. Summary statistics of nitrate-N concentrations collected at IWM-1 biological monitoring visits from 2010 - 2015 from four contiguous HUC-8 scale watersheds (not including Straight River sites; see Figure 17). Most sites had one sample, while a number of sites had 2-4 samples. For sites with multiple samples, the values were averaged, with their average value used in creating the summary statistics. Straight River IWM samples from 2010 are also shown - each was a single sample.

Number of sites sampled	187
Total number of samples	259
Average concentration (mg/L)	< 0.123*
Standard deviation (mg/L)	0.211
Highest site average value (mg/L)	1.240
Highest single sample value (mg/L)	1.59
Lowest single sample value (mg/L)	0.007**
Number of samples < lab detection limit	171
Percent of samples < lab detection limit	66.0
Straight River (10UM060, at Bass Bay Ave) (mg/L)	1.99

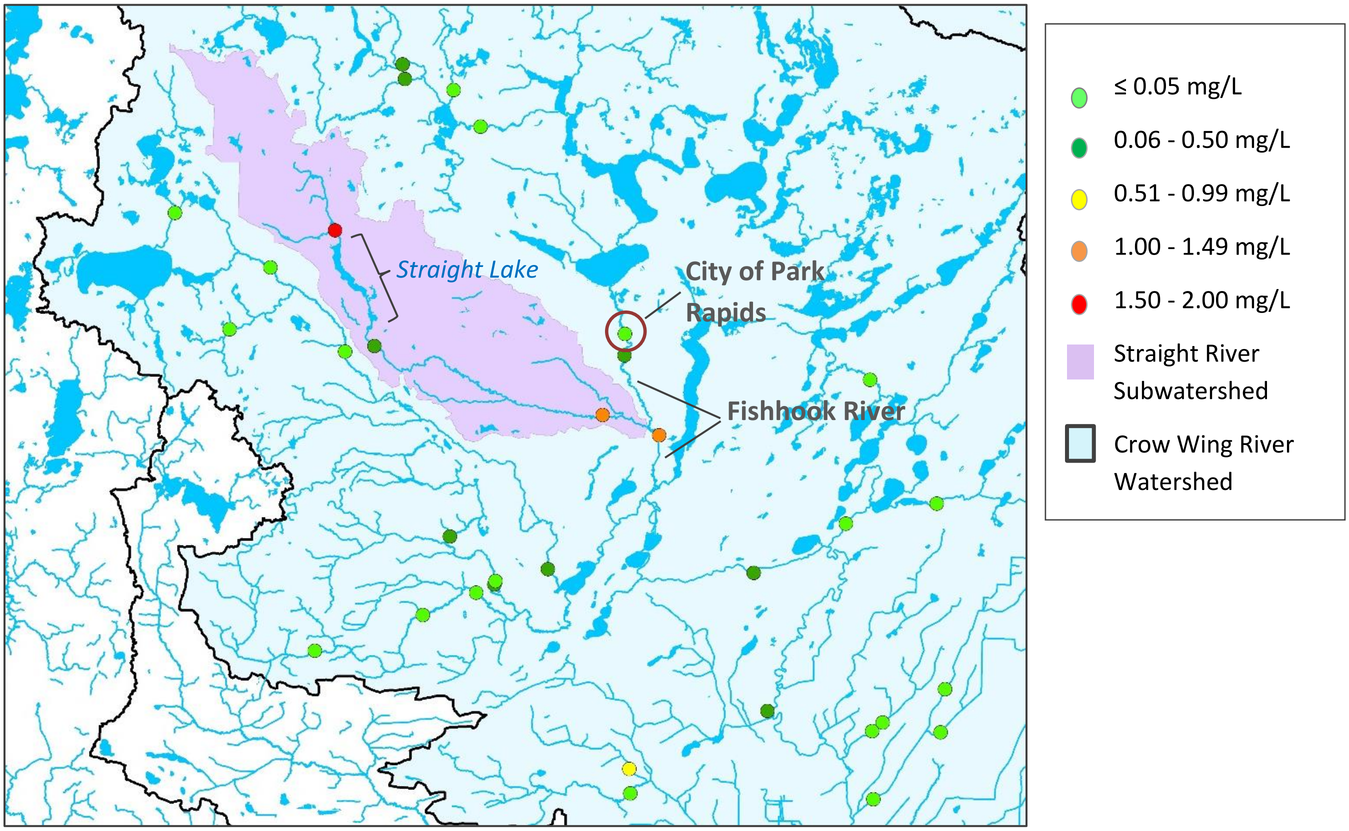
Straight River (10UM061, at CR-125) (mg/L)	0.188
Straight River (10UM060, at Hwy 71) (mg/L)	1.29

*The average is less than this value because there were many samples that measured less than the laboratory detection limit.

** A few samples from an early sampling year in the dataset were done by another lab and reported at a lower level (below the typical detection limit for samples done by other labs; 0.02 or 0.05 mg/L).

IWM sites more directly surrounding the Straight River Subwatershed had low nitrate-N levels in 2010 IWM sampling (Figure 18), though the Fishhook River also had a 2010 high reading (1.24 mg/L; and 1.16 mg/L, 2020; 0.77 mg/L, 2021) just downstream of where the Straight River enters it. Above this confluence, two Fishhook River biological monitoring sites had much lower nitrate-N, despite the sites being in (0.05 mg/L, 1999) or immediately downstream (0.087 mg/L, 2010; 0.035 mg/L, 2020) of the city of Park Rapids and thus being areas directly receiving urban stormwater runoff (presumably including available nitrogen). This latter site also was an intensive chemistry-monitoring site in 2010. The 11 samples from that effort in 2010 averaged 0.039 mg/L; none were near the concentration that was measured in the Fishhook River just downstream of the confluence with the Straight River. Nitrate from urban runoff appears to be minimal or only temporarily present (e.g., post rainfall), relative to the agricultural area of the Straight River. The higher nitrate in the lower part of the Fishhook River appears to be due to water inputs it receives from the Straight River.

Figure 18. Close-up of the Straight River Subwatershed area (the purple area) from Figure 9. Colored dots are the same 2010 IWM stream sample sites as in Figure 17.



The low nitrate-N level (0.19 mg/L) at the site a short way downstream of Straight Lake (Figure 18; study site 1 from Figure 15) is likely due to being close to the lake. At this site, much of the water in the river has just come from Straight Lake where nitrate input from the upper Straight River undergoes denitrification (i.e., nitrate is changed to nitrogen gas which dissipates to the atmosphere) or is tied up by algae or aquatic plants in the lake. Thus, the high nitrate-N in the river upstream of the lake (1.99 mg/L, 2010; 3.15 mg/L, 2020) is largely transformed to gaseous nitrogen in the lake (Loeks and Cotner, 2020) or incorporated into the lake's aquatic vegetation before it leaves the lake, and river nitrate levels in close proximity to the lake outlet have been reset to lower levels. The nitrate levels in the river below the lake increase again progressively at sites farther downstream (see Section 3).

Another comparison that can be made from sites with more robust data sets are the adjacent IWM 10X monitoring locations. These locations are on "medium-sized" streams, with "growing season" (May through September) sampling dates (Figure 19). Summary statistics for 17 such streams, including the Straight River, are shown in Table 3 and Figure 19. Of these sites, the Shell River is the only location that has anywhere near the nitrate concentrations in the upper and lower parts of the Straight River. The Shell River's sample site is on a reach that has many irrigated row crop fields nearby that are in the site's drainage area. At this location, the Shell River contains the water input from the Straight River (i.e., the Straight River is an upstream tributary to the Shell River via the Fishhook River). This analysis also finds the Straight River's nitrate content is much higher than these regional comparison streams.

Figure 19. IWM 10X chemistry monitoring sites used for comparison to the 10X site on the Straight River.

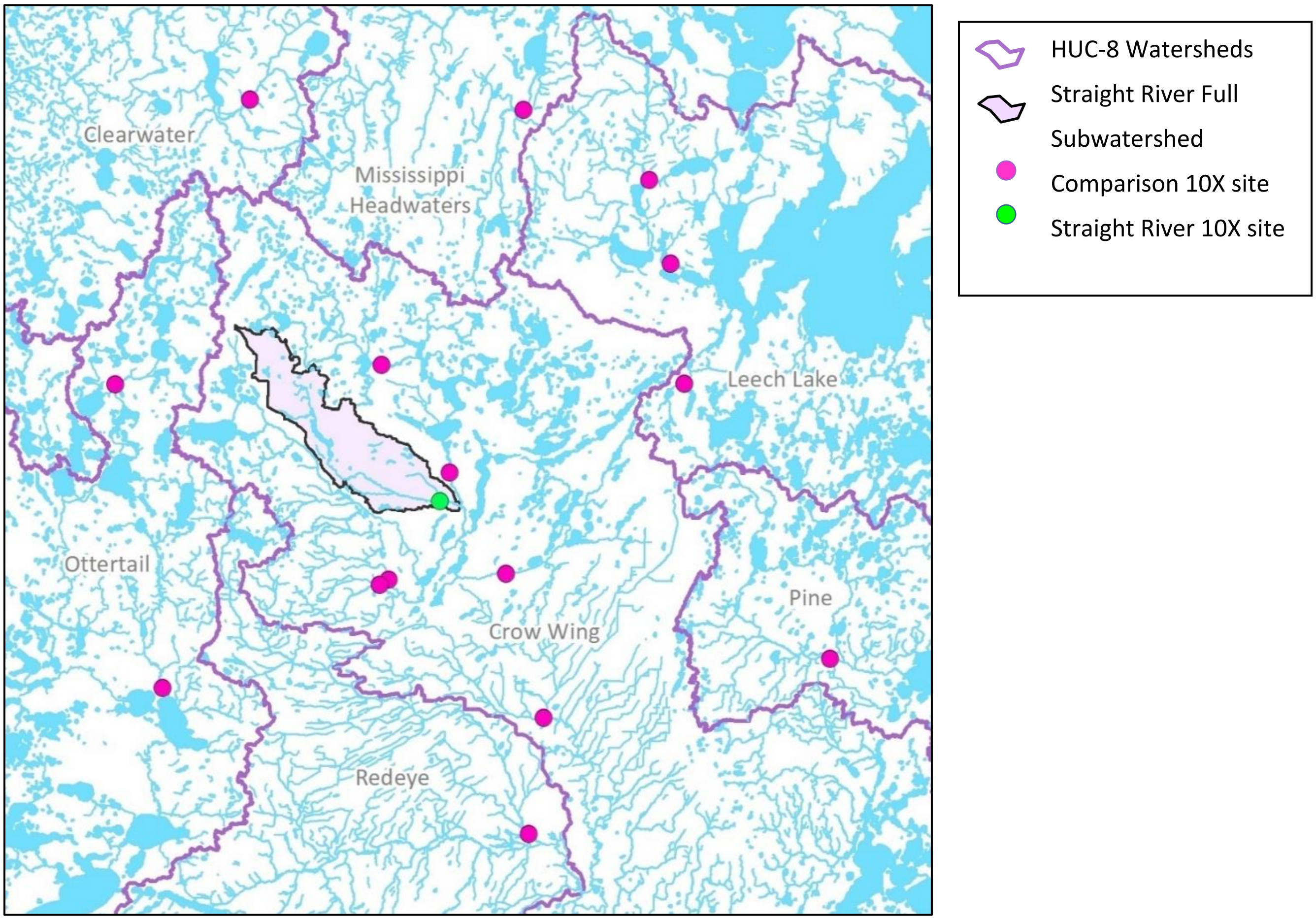


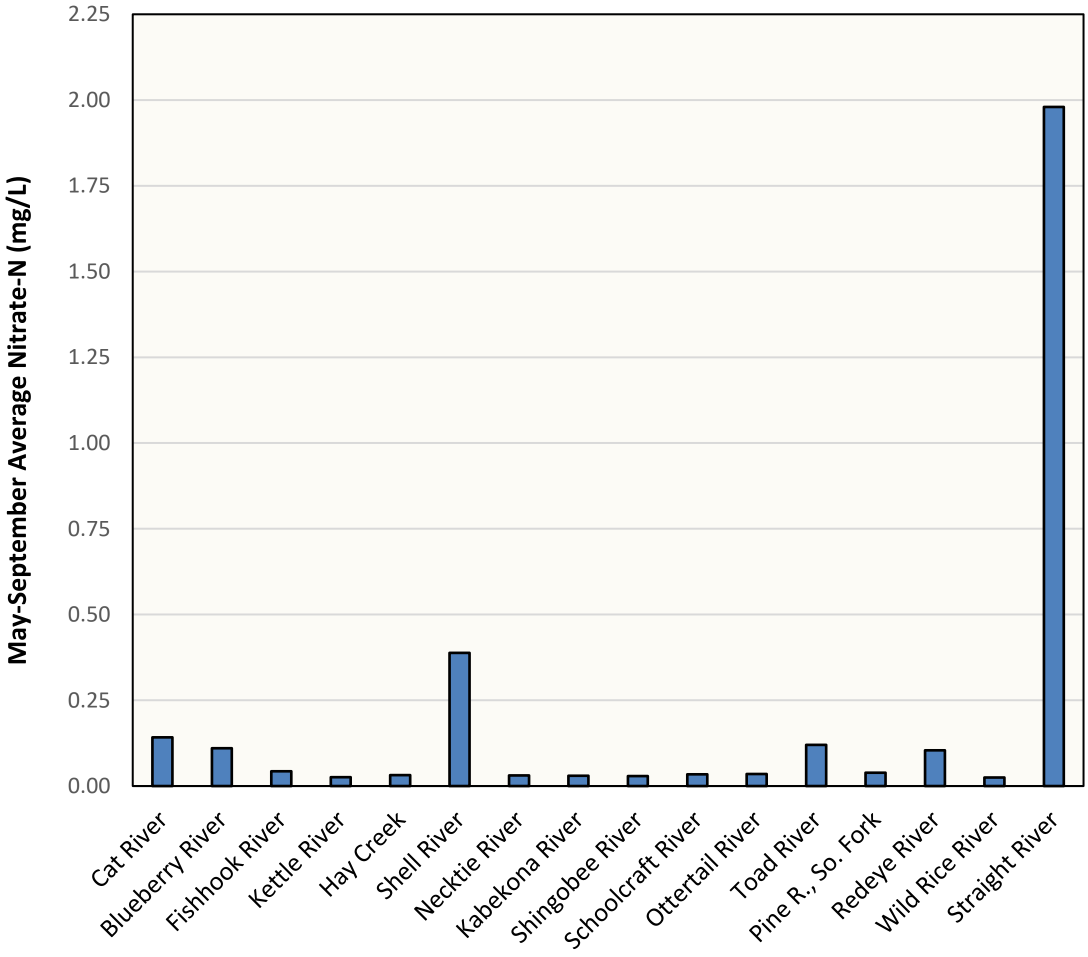
Table 3. Summary statistics from 17 IWM 10X sites surrounding the Straight River and including the Straight River. This dataset also contains a smaller number of samples collected by county water managers at some of the sites. The great majority of samples were collected from 2007 - 2020, and samples are from May through September. See Figure 19 for map of site locations.

Stream	HUC-8 watershed	EQuIS site number	# nitrate-N samples	Average nitrate-N (mg/L)	Highest nitrate-N concentration (mg/L)	# samples below lab detection limit and (%)
Cat River	Crow Wing R.	S002-408	22	0.142	0.29	0 (0%)
Blueberry River	Crow Wing R.	S003-501	31	< 0.110	0.36	14 (45.1%)
Fishhook River	Crow Wing R.	S006-251	11	< 0.043	0.08	6 (54.5%)
Kettle River	Crow Wing R.	S003-502	17	< 0.026	< 0.03	16 (94.1%)
Hay Creek	Crow Wing R.	S006-252	14	< 0.032	0.056	13 (92.9)
Shell River	Crow Wing R.	S003-442	123	0.388	0.83	0 (0%)
Necktie River	Leech Lake R.	S006-256	34	< 0.031	< 0.05	33 (97.1%)
Kabekona River	Leech Lake R.	S007-103	10	< 0.030	< 0.03	10 (100%)
Shingobee River	Leech Lake R.	S007-102	15	< 0.029	< 0.05	15 (100%)
Schoolcraft River	Mississippi Headwaters	S007-550	17	< 0.034	< 0.10	15 (88.2%)
Ottertail River	Ottertail R.	S003-937	13	< 0.035	< 0.05	13 (100%)
Toad River	Ottertail R.	S008-843	10	< 0.120	0.329	1 (10%)
Pine R., So. Fork	Pine R.	S007-101	10	< 0.039	0.091	7 (70%)
Redeye River	Redeye R.	S006-848	60	< 0.104*	2.98**	43 (71.7%)
Wild Rice River	Clearwater R.	S005-131	19	< 0.025	0.031	18 (94.7%)
Straight River	Crow Wing R.	S002-960	20	1.98	3.76 (July 7, 2020)	0 (0%)

*Without one extreme outlier, the value is < 0.056.

**Value is an extreme outlier. The second highest value is 0.12

Figure 20. Growing season (May - September) nitrate-N sample averages for IWM 10X chemistry monitoring stations.

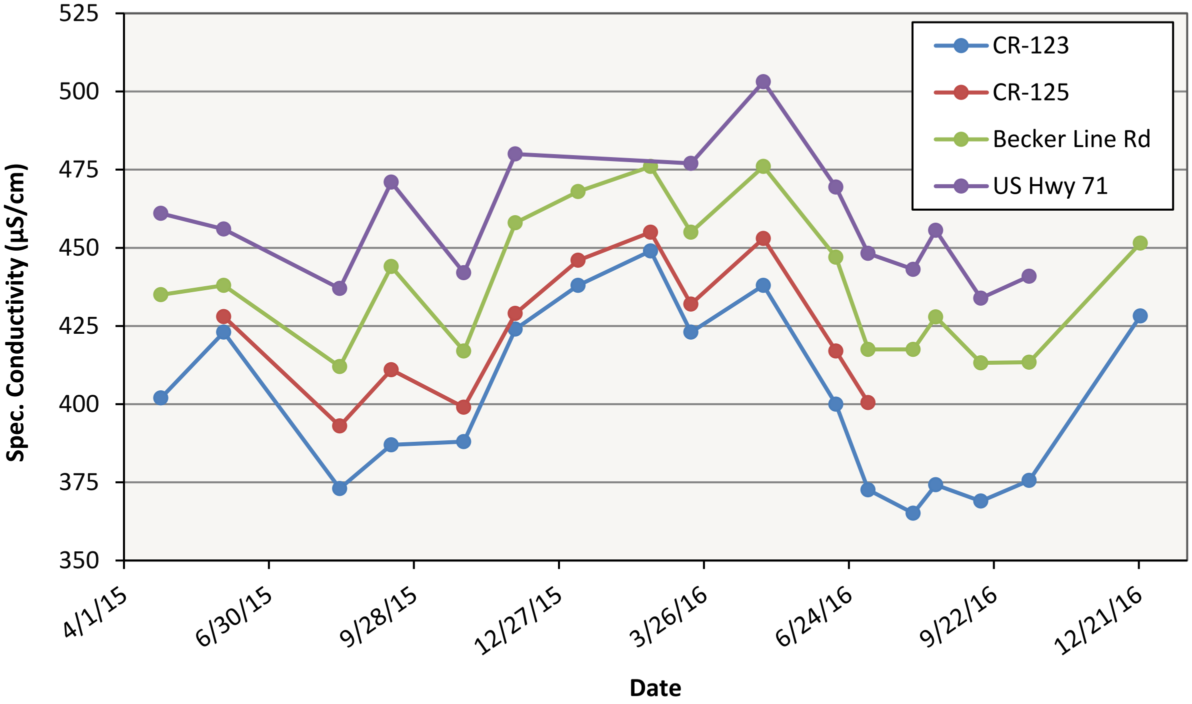


In summary, comparing the Straight River's nitrate data (more detail below) with stream nitrate data from the surrounding region shows that the Straight River's nitrate-N concentrations are highly abnormal among the region's streams.

2. The percentage of groundwater in the river increases progressively moving in the downstream direction.

The ratio of groundwater to surface water runoff within the stream consistently increases from upstream to downstream, based on specific conductivity measurements, which increase moving downstream (Figure 21). Groundwater has higher conductivity than surface water because groundwater spends much more time in contact with geologic materials where it picks up various elemental ions. This finding of increasing conductivity moving in the downstream direction in the Straight River aligns with the conclusion of Stark et al. (1994) regarding groundwater input being the predominant source of the Straight River's water.

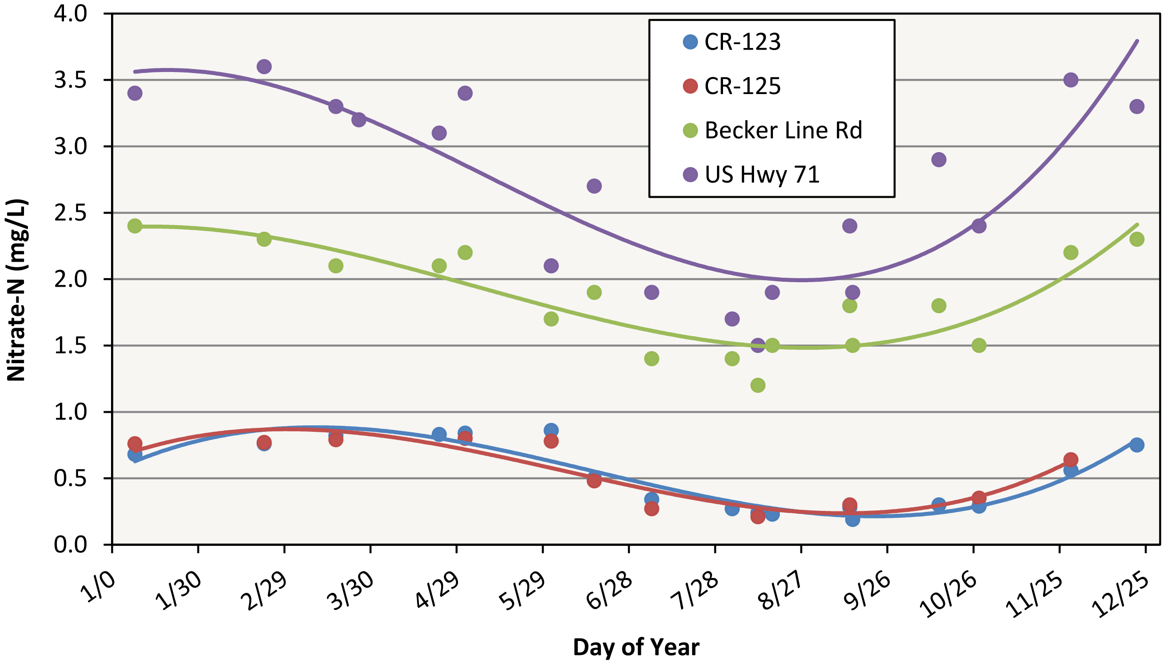
Figure 21. Specific conductivity at four sites along the Straight River during 4/23/2015 - 12/22/2016. The legend lists sample locations in upstream to downstream order.



3. Like the groundwater contributions, nitrate levels increase moving downstream in the River from the Straight River outlet to Highway 71 (Figure 22).

The two most upstream monitoring sites (at CR-123 and CR-125) were essentially the same in nitrate concentration, and so the second-most upstream site (CR-125) was dropped from monitoring after July 6, 2016. The aquifer around the Straight River also becomes more likely to be influenced by agricultural nutrients moving in a downstream direction, as agricultural acreage and density of irrigated fields increases as one moves east (downstream) along the Straight River corridor. Historical data from 5/23/1988, 8/24/1988, and 9/16/1980 found the same pattern of nitrate concentration increase moving in a downstream direction (Stark et al., 1994).

Figure 22. Nitrate concentrations at four sites along the Straight River during 2015-2016 (superimposed). Lines are 3rd order polynomial regressions. The legend lists sample locations in upstream to downstream order.



4. Phosphorus concentrations showed several interesting patterns.

Phosphorus in streams can have natural and anthropogenic sources. Unlike nitrate, groundwater transport of phosphorus would not be expected to be significant here since phosphorus readily binds to soil particles in the soil profile. Phosphorus sampling was conducted along with nitrate sampling in 2015 through 2016, but not in 2020 through 2022. The Highway 71 site had much more pre-existing phosphorus data than the other sites and will receive more focus here. Phosphorus levels in the Straight River are not atypical for streams in northern Minnesota, though the annual pattern is more uncommon. Many smaller northern Minnesota streams have phosphorus levels that peak in later parts of July and early August (unpublished MPCA data from an ongoing project). In the Straight River, that period of the year has minimum total phosphorus concentrations.

Total Phosphorus (TP) levels in early spring appear to be similar in the 2004 through 2010 and 2015 through 2016 datasets, but then concentrations appear to be lower from about June 1 through late October in the 2015 through 2016 set (Figure 23). This phenomenon was seen in many other locations of north central Minnesota in 2015 that were monitored by this report's author. It is hypothesized that this was due to the regionally dry conditions that began in winter 2014 through 2015, and continued through spring and summer, reducing the water contributions to the streams from riparian, hydrologically-connected wetlands (i.e., a lowered water table existed). Another possible explanation could be greater algal growth (more algal uptake of phosphorus) in recent years, as Straight River nitrate concentrations increased (discussed below).

Regarding longitudinal comparisons within the river, there is much dissimilarity in TP among sites from January to June, particularly the within-site variability at the lower three sites (Figure 24). After about June 1, the TP concentrations become much less variable within sites, and much more similar among sites. There is a period of rapid decline in TP concentrations that occurs between approximately May 20 through June 22 (Figure 25). This decline in phosphorus coincides with the period of seasonal proliferation of periphyton and filamentous algae (both are surface-attached) as water temperatures rise and daylight lengthens. Thus, it is suspected that algae play a large role in this seasonal pattern, as they increase their uptake of phosphorus. Following this period, the remainder of the summer has relatively stable levels of TP, perhaps related to the summer drop in stream nitrate concentrations (discussed below).

Figure 23. Total Phosphorus at US Hwy 71 (S002-960), 2004-2010 vs. 2015-2016. Curved lines are polynomial regression lines with accompanying R^2 values. The big spike in late winter is likely due to the decay of the very abundant filamentous algae that occurs in the Straight River - many tiny, suspended organic particles were observed in the water samples in latter parts of winter (i.e., late February/early March).

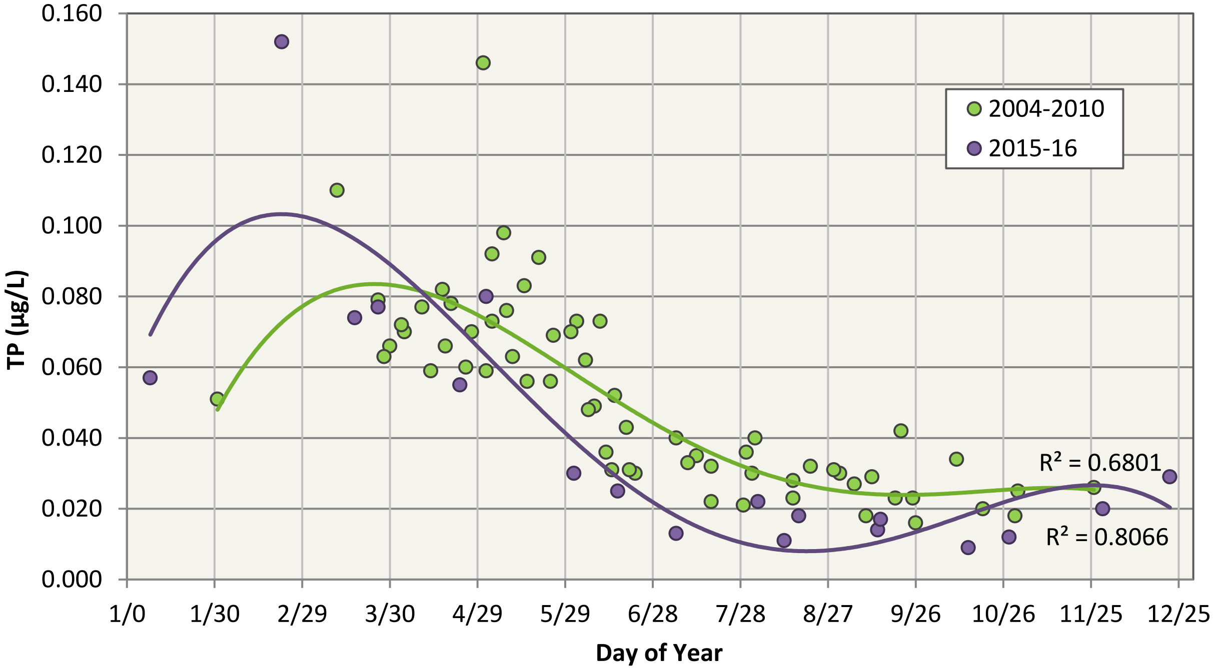


Figure 24. Seasonal patterns of TP concentration for the four longitudinal sites from 2015-2016 samples. The legend lists sites in upstream to downstream order.

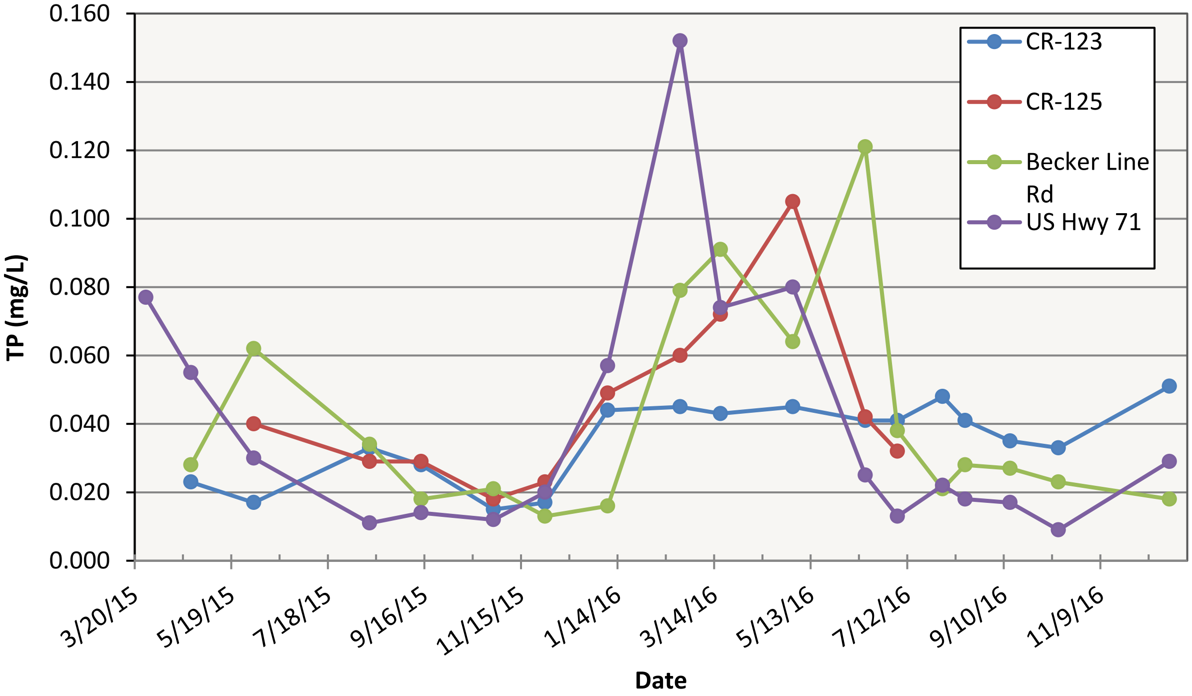
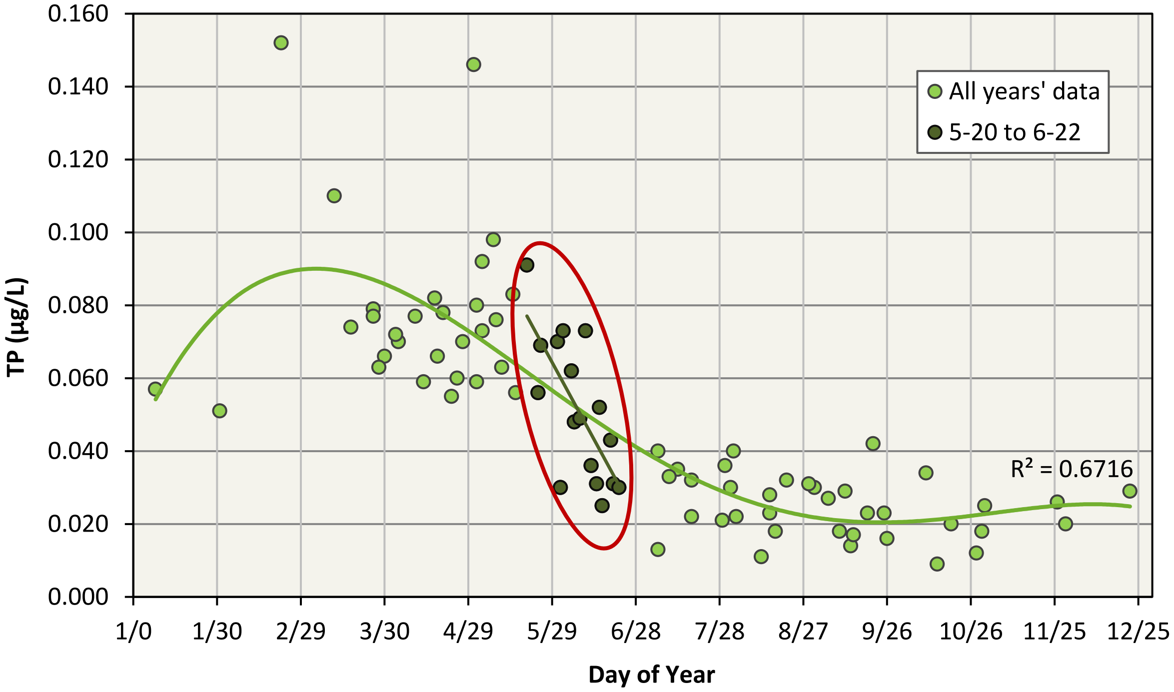


Figure 25. There is a rapid decline in TP concentration between May 20 to June 22 in the Straight River (the data points in the circled area). Data are from US Hwy 71 (S002-960), 2004-2010, 2015-2016, superimposed on an annual timescale. The line within the circle is a linear regression line of these dark green data points.



5. Comparison of nitrate datasets over time at State Highway 71

(a) Contrary to phosphorus, nitrate levels were higher at the Highway 71 sites during all seasons of 2015-2016 than in the corresponding 2004-2010 aggregated data (Figure 26).

This increase in Straight River nitrate concentration occurred in conjunction with increased conversion of uncultivated former farmlands to irrigated row crop agriculture in the Straight River Subwatershed (Figure 3, Figure 4, and Figure 5 above), including the period between 2010 and 2014 (the intervening period between the two datasets). It is plausible the higher 2015 through 2016 concentrations reflect the additional irrigation/fertilization from this new irrigated acreage. Additional analysis (e.g., nitrate level trends in area groundwater) could be conducted (if data is available) to better determine whether this apparent increase in nitrate in the Straight River's water is associated with agricultural change and increased irrigation.

The increase in nitrate between the 2004-2010 and 2015-2016 datasets was tested statistically, and the difference was found to be significant (Figure 26). Because of the sinuous pattern of the data, the year was broken into two time periods for significance-testing, spring, and summer (where good overlap of the two datasets occurred). Both seasons had highly statistically significant differences between data sets, with p-values of 0.003 and < 0.001 respectively (Mann-Whitney U Test).

(b) Nitrate levels in the 2020-2022 dataset appear to be moderately higher than the 2015-2016 dataset, suggesting nitrate levels in the river may be continuing to increase (Figure 27).

Most of the polynomial trendline for the 2020 through 2022 dataset is higher than the 2015 through 2016 line. The gap between the two trendlines is much less than that between the 2004 through 2010 and 2015 through 2016 trendlines. A few examples of the percent increases for 2020 through 2022 are approximately + 2.9% for March 30, + 22.2% for August 1, + 9.1% for October 1, and - 1.5 for November 11.

Figure 26. Significance testing of the first two datasets, broken into two time periods, each having many data points, (1) March 1 - May 31 and (2) June 1 - September 26.

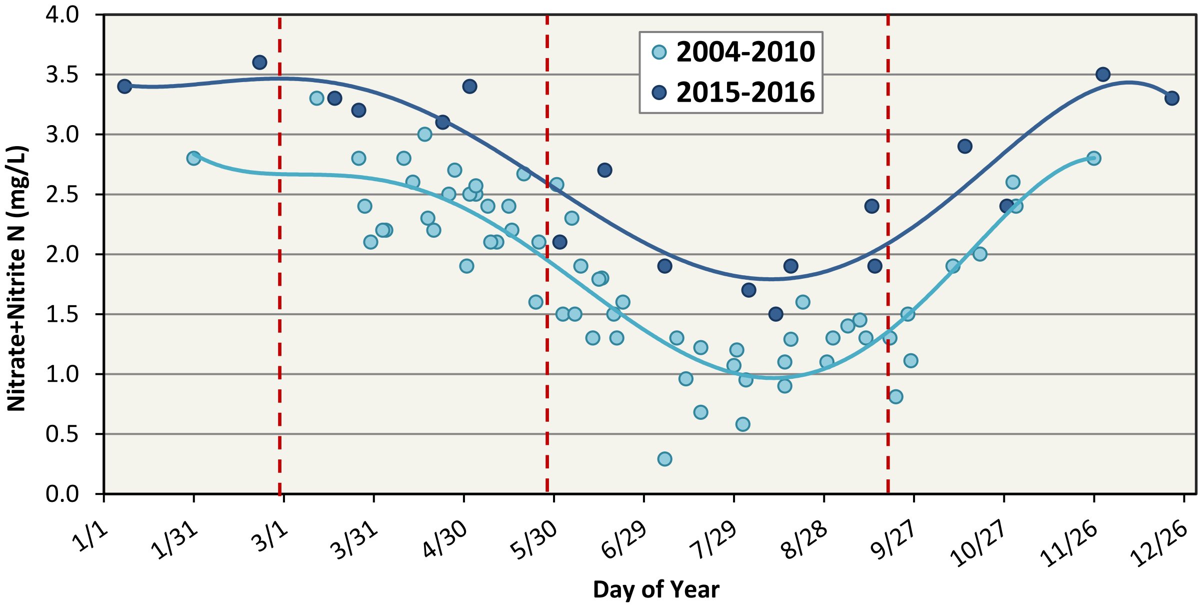
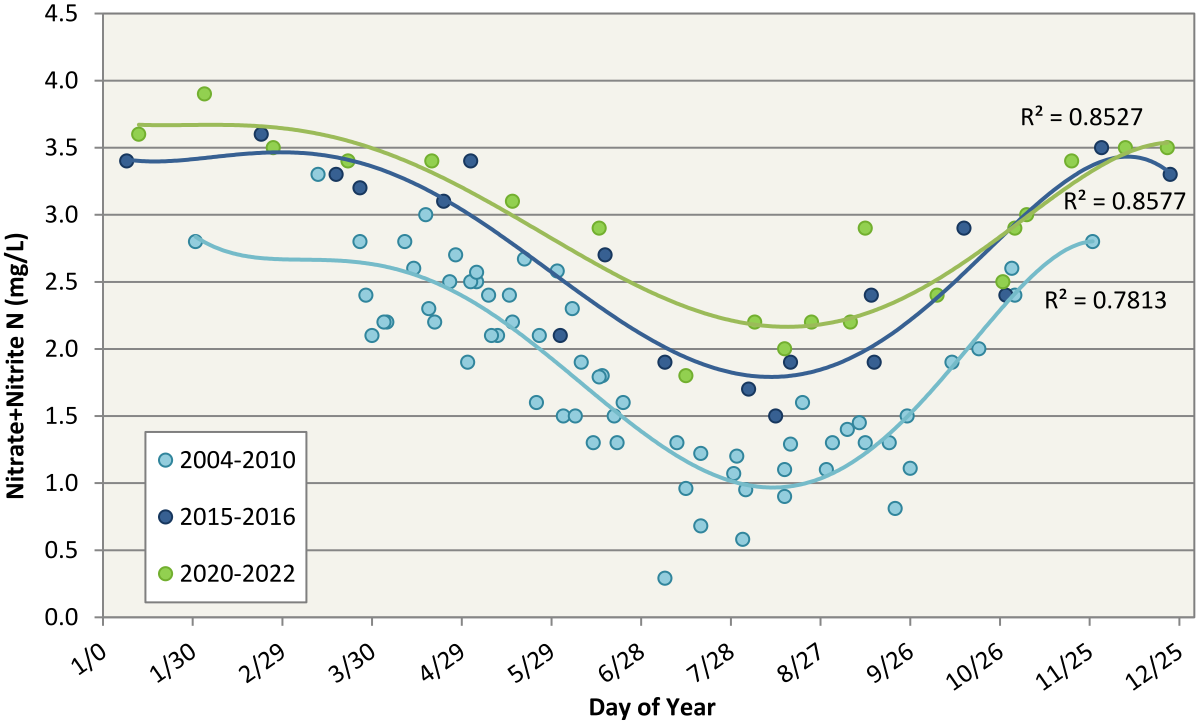
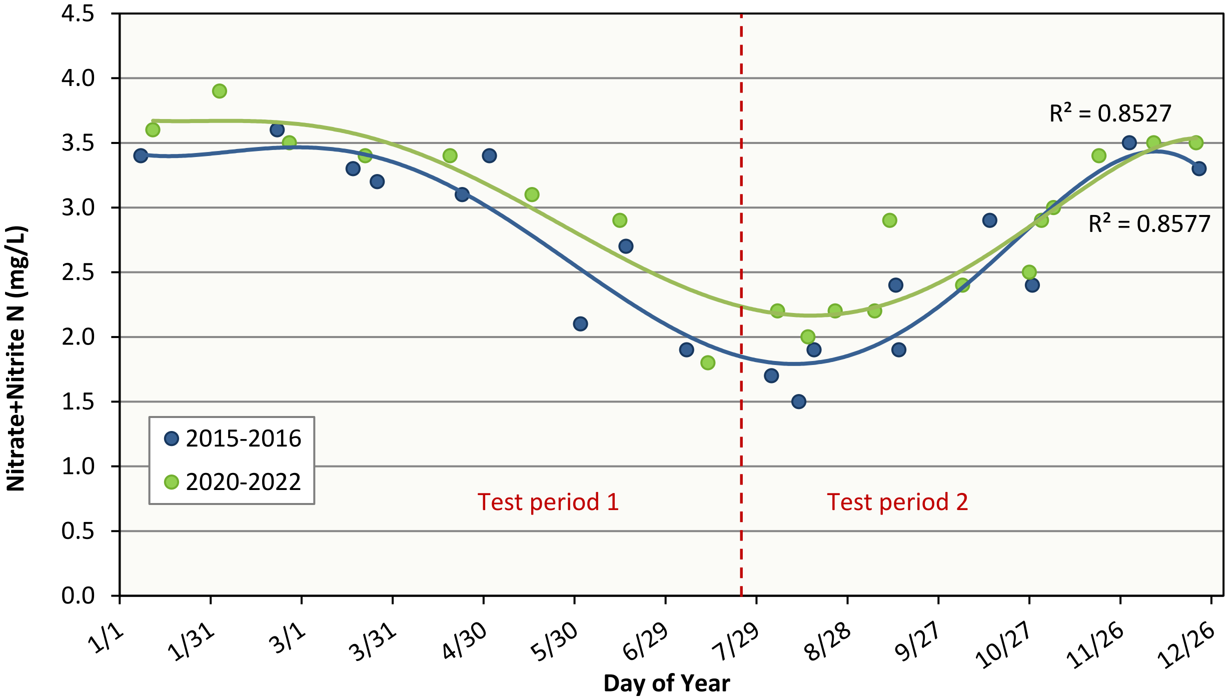


Figure 27. Straight River nitrate data at US Hwy 71 (S002-960), 2004-2010 vs. 2015-2016 vs. 2020-2022 periods. Curved lines are 4th order polynomial regression lines with accompanying R^2 values.



A nonparametric statistical test of the full datasets from 2015 through 2016 versus 2020 through 2022 was run and the datasets were not statistically different ($p = 0.251$). Statistical testing using a similar split-season approach as previously described (but with somewhat different date ranges due to balanced, year-round sampling - Figure 28) showed that the differences in the nitrate values of the January through July and August through December periods of 2015 through 2016 versus 2020 through 2022 datasets were not statistically significantly different ($p = 0.300$ and 0.333 respectively). So, it cannot be determined with high confidence from these data that nitrate concentrations have increased in the *most recent* sample period, though graphical analysis shows it may have. However, the current dataset suggests that no recent improvement has occurred in the elevated river nitrate concentrations over that period of time. Additionally, the maximum nitrate concentration of the complete dataset from years 2004 through 2022 occurred on February 3, 2021 (3.9 mg/L).

Figure 28. Statistical significance testing of the second versus third datasets, showing where the two test periods were separated for the Straight River at US Highway 71 in 2015-2016 vs. 2020-2022.



(c) <u>IWM 10X monitoring of nitrate at US Hwy 71 found higher average concentrations (statistically significant) in cycle 2 (2020-2021) than in cycle 1 (2010)</u>.

Another comparison of like datasets was made between the cycle 1 10X monitoring at US Highway 71 and cycle 2 10X monitoring of the site. Nitrate-N values are shown in Table 4. A nonparametric Mann-Whitney U statistical test of the two datasets found a statistically-significant increase of nitrate in the more recent sample set (Table 4). In looking at the values within the two datasets, each had a measurement that appeared out of the normal range for that year. The 2010 dataset had one very low value, and the 2021 dataset had one quite high value. A second statistical test was run with these two values removed. Those data point removals would make it more difficult to find a statistically-significant difference between the two periods. This second analysis of the difference between years however was again statistically-significant (Table 4).

There is a potential caveat to this comparison, in that parts of the 2010 growing season precipitation were above normal in 2010, leading to periods of high flow in area streams. This may have diluted nitrate in the Straight River as more than normal surface runoff relative to groundwater inputs likely occurred. However, the increase in surface runoff would also be a mechanism of delivering nitrate to the river, and perhaps leaching more nitrate into groundwater from agricultural fields which then moves to the river. It is not known where the balance would be between precipitation dilution of river nitrate versus increased surface (and perhaps groundwater) delivery of nitrate to the river from abundant precipitation.

Table 4. Nitrate-N sample results and statistical analyses from IWM 2010 and IWM 2020-2021 from the Straight River at US Hwy 71.

2010	Nitrate-N (mg/L)	2020-2021	Nitrate-N (mg/L)	Mann-Whitney U statistic	p value
5/5/2010	2.57	5/26/2020	2.95		
5/21/2010	2.67	6/4/2020	2.90		
6/1/2010	2.58	7/7/2020	3.76*		
6/15/2010	1.79	8/3/2020	2.00		
7/7/2010	0.29*	9/14/2020	2.01		
7/19/2010	1.22	9/29/2020	2.59		
7/30/2010	1.07	6/8/2021	2.78		
8/16/2010	1.10	7/12/2021	1.66		
8/18/2010	1.29	8/10/2021	1.71		
9/10/2010	1.45	9/9/2021	2.20		
9/27/2010	1.11	9/14/2021	2.25		
Average	**1.558**		**2.437**	**6.728**	**0.009**
Average**	**1.685**		**2.305****	**4.806****	**0.028****

*A data point that was removed for the second statistical test.

**With one data point removed.

6. Comparison of nitrate datasets over time at CR-123 and Becker Line Road

Nitrate levels at the two upstream sites in this study are somewhat lower than at Highway 71 and have had much less historical sampling. There isn't an early set of data for these sites (i.e., 2004-2010) like there is for the Highway 71 site. The CR-123 site had one sample collected at the IWM-1 biological monitoring visit. No samples were collected at Becker Line Road prior to 2015. However, the latter two of the three dataset periods have had equal sampling efforts with Highway 71, and a comparison of those periods for the two sites are shown in Figure 29 and Figure 30.

Figure 29. Nitrate-N samples from S008-793 (County Road 123 near Straight Lake, site 1 in Figure 12), 2015-2016 compared to 2020-2022.

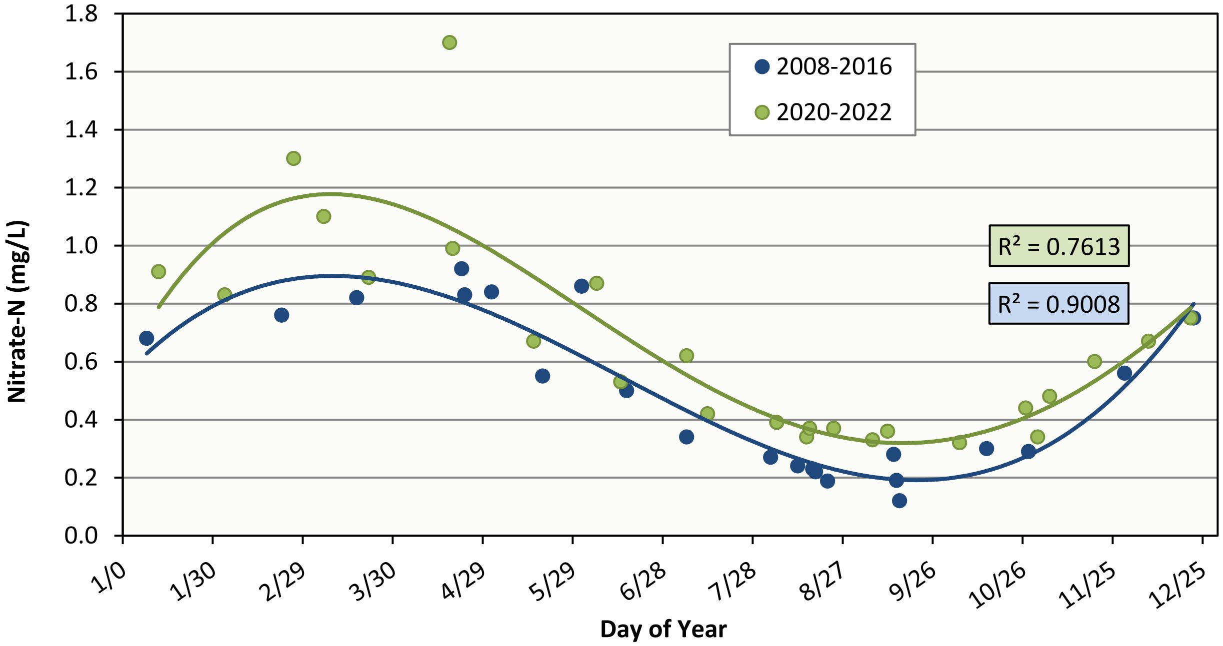
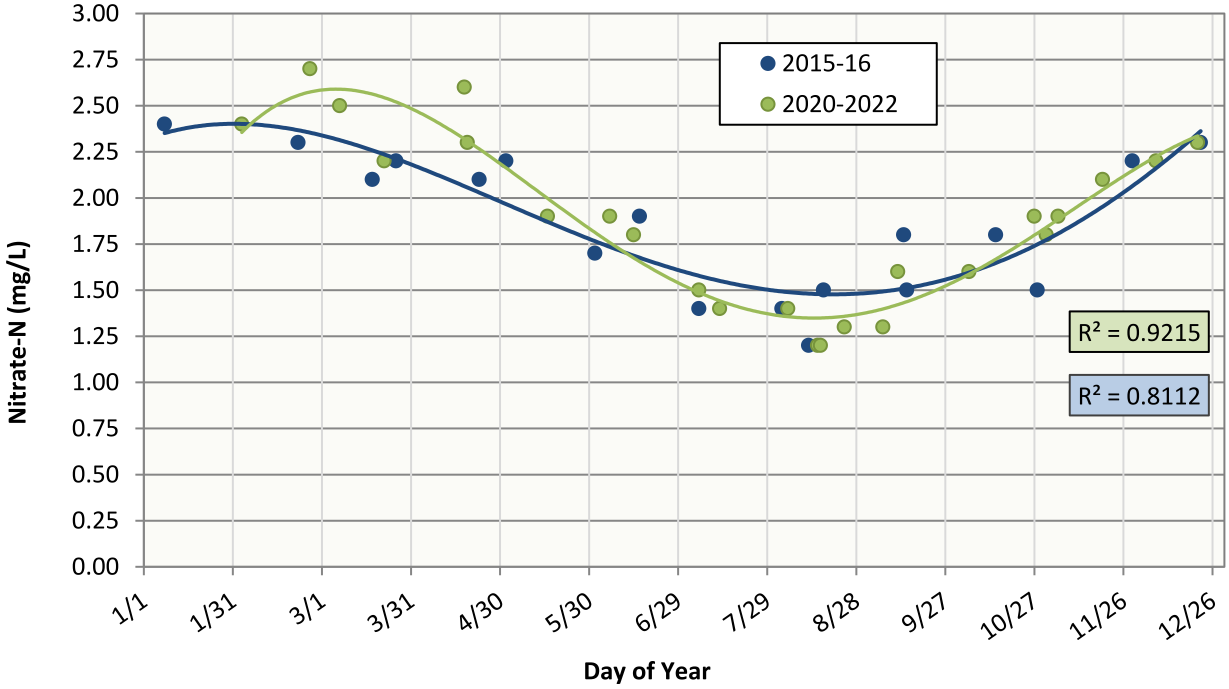


Figure 30. Nitrate-N samples from S008-454 (Becker Line Road, site 4 in Figure 12), 2015-2016 compared to 2020-2022.



Statistical testing of the two time periods at these two sites was conducted, again using the nonparametric Mann-Whitney test. Neither site showed a statistical change between the two time periods at a 95% confidence threshold. However, the p-value of the test for the County Road 123 site (p = 0.088) was close to being significant and would be if a 90% confidence threshold were used. Thus, there is fairly good evidence to suggest that the nitrate levels at County Road 123 have increased in recent years. Regardless, nitrate levels have not shown improvement in the most recent sampling period.

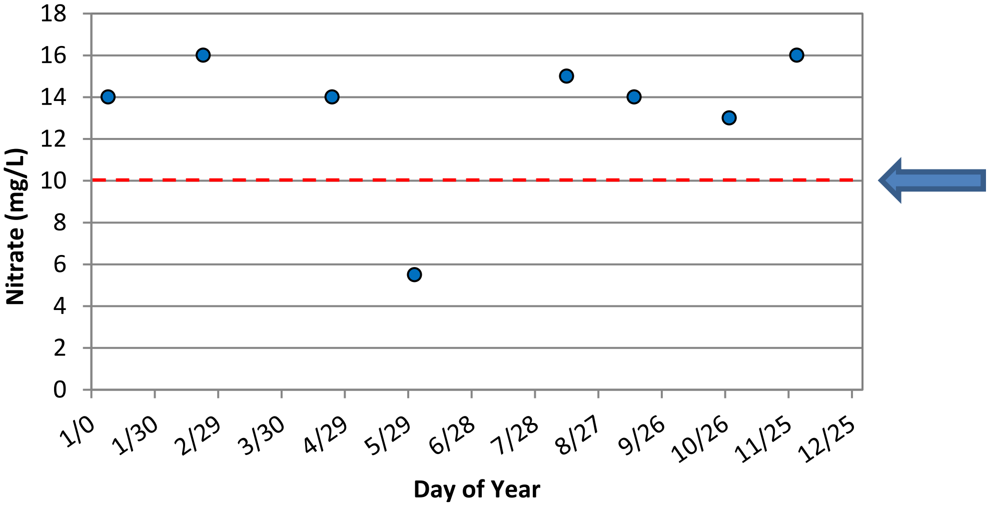
7. Nitrate levels in a streamside spring-outlet (i.e., a groundwater input to the river) in 2015 was quite elevated in nitrate (i.e., above the MN drinking water standard).

No isolated spring-water was sampled prior to 2015, so no time-lapse comparison can be made. The large spring located at CR-125 is easily sampled as isolated spring-water. Nitrate concentrations are very elevated in this spring's water, typically about 13-16 mg/L (Figure 31). There is a home located at the top of the hill near the spring, and without detailed information about the location of this home's septic system, it can't be ruled out as a contributor to this nitrate. However, these nitrate values are similar to the standard-exceeding values found in the recently decommissioned Park Rapids municipal well (i.e., > 10 mg/L).

Testing groundwater can be done to determine whether a septic influence is occurring. A sample for chloride/bromide ratio was collected for this purpose on 11/30/15. The Cl/Br ratio is a recommended analysis to help determine whether septic systems are contributing to nutrients in groundwater. The ratio from this one sample was 738.2, and the chloride concentration was 25.1 mg/L. Per Katz et al. (2011), this ratio does fall into a range where septic contributions could be occurring. However, the chloride concentration itself was relatively low for the range found for septic-contaminated groundwater (Katz et al., 2011). At this point, any contribution of nitrate in the spring samples from the home site's septic is inconclusive. More samples need to be collected and analyzed for Cl/Br. Sampling for Boron may be informative as well. Additional sources of Cl also need to be considered (road salt, pesticides, etc.).

The other spring sample that was clearly spring water was at Becker Line Road, flowing into the river from about 20 meters from the southwest corner of the bridge. The nitrate concentration in that sample was 3.0 mg/L (only one spring-flow sample was collected here). There is no adjacent home site here, and importantly there is less agricultural acreage on the landscape above the groundwater that would be discharging here. Installation of near channel piezometers at various locations longitudinally along the river would be very informative in determining groundwater nitrate levels just before this water is discharged to the river.

Figure 31. Nitrate concentrations in the large streamside spring flowing into the Straight River at 125th St. Data is from 2015-2016. The sample from 5/29 is thought to be diluted with stream water due to the relatively high stream stage on this date.



Minnesota's drinking water nitrate standard.

8. Evidence of eutrophication: DO % saturation is elevated in summer, though infrequently at site 1 (the most upstream site, where nitrate is lowest).

DO percent saturation levels above 100% (in equilibrium with the atmosphere) can occur in very turbulent water or when aquatic plants are overly abundant and rapidly photosynthesizing (releasing oxygen). The former condition does not occur in the Straight River. All sites had DO percent saturation values substantially above 100% in mid- or late summer (Figure 32). At US Highway 71, DO percent saturation over 100% can occur during mid-day hours from about May 1 through mid-October (Figure 33).

These over-saturated DO measurements point to observed excess algae and macrophyte growth as the cause of the DO percent saturation values exceeding 100% saturated (there are no situations on the Straight River where high turbulence could be responsible for supersaturated DO). This further suggests that the excess algal growth is contributing to, if not fully responsible, for the DO impairment in the Straight River. DO drops nightly in all streams as aquatic plants/algae undergo respiration (use oxygen) during dark periods. The more plant growth in the stream, the more the DO concentration can drop. Also, proliferation of plants saps oxygen from the water because they eventually die and the bacteria that decompose plant material use oxygen. The degree of DO loss due to decay depends on how much of the dead plant material is relatively quickly flushed downstream vs being retained in the stream. In general, the Straight River has a clean, sandy bottom, so much of the dead plant material may be moving on downstream to other water bodies, rather than accumulating to decay in the river. The author has observed fine particulate material in samples collected in late winter and spring, suggesting much organic material is being transported downstream. The drop in DO percent saturation in the fall is likely due to reduced photosynthesis by algae as sun angles get lower, fewer hours of sunlight occur, colder water decreases metabolism, and more decay is happening as aquatic plants and algae senesce.

Figure 32. Longitudinal DO percent saturation in 2016. The legend lists sites by their location, in upstream to downstream order.

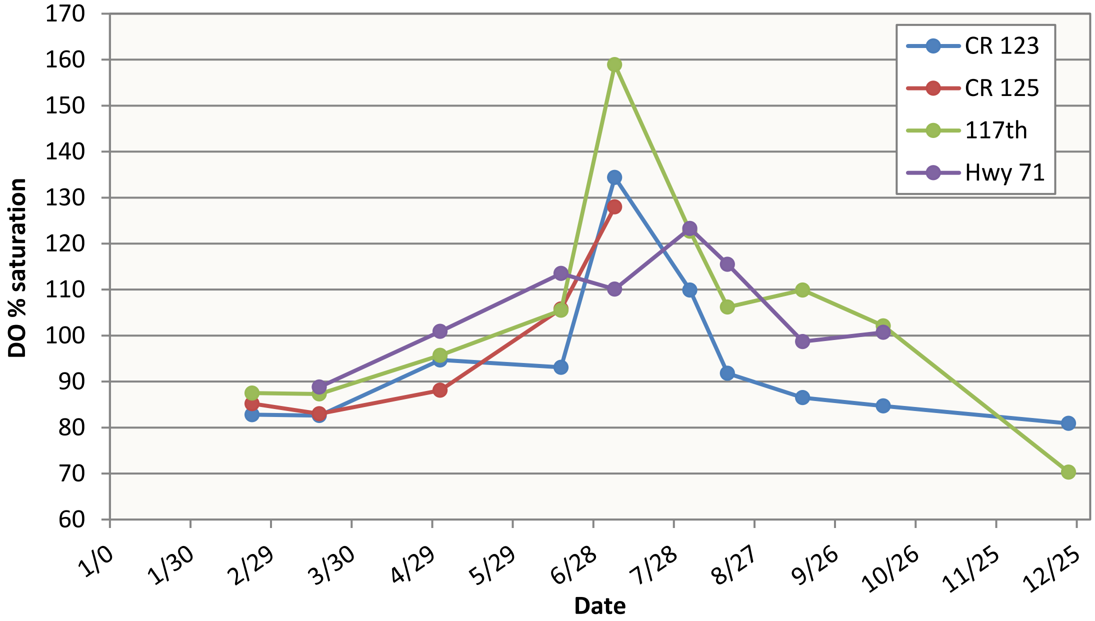
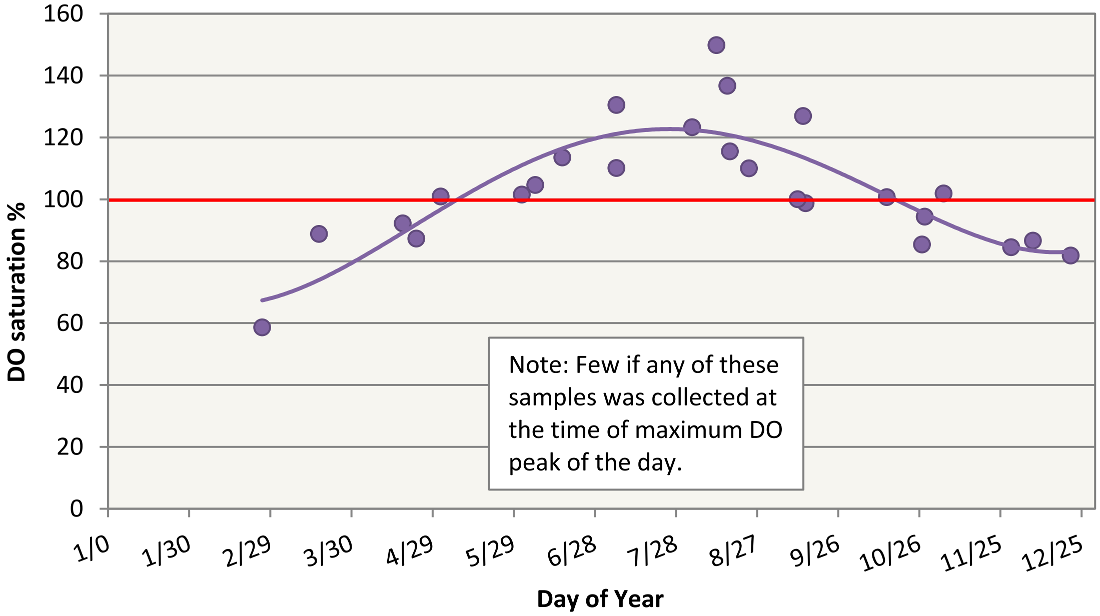


Figure 33. DO percent saturation values at US Hwy 71 in 2015-2016 and 2020-2022, with measurement times after 11:00 A.M. Data from these years are superimposed on an annual time scale. The line is a polynomial regression line with an R^2 of 0.7154.



9. Nitrate concentrations in the lower end of the Straight River are approaching levels that may be toxic to aquatic organisms.

In addition to being a plant nutrient, nitrate can be toxic to aquatic organisms at certain levels. The concentrations of nitrate in portions of the Straight River are approaching levels that best available science (as of 2023) suggest are chronically toxic to some aquatic organisms. Minnesota does not have an aquatic life use nitrate standard as of the writing of this document; however, toxicity studies have recently been conducted in partnership with U.S. Environmental Protection Agency (EPA). The draft proposed nitrate criteria for protection of aquatic life include an acute value (maximum standard) of 60 mg/L nitrate-N for a one-day duration concentration for all Class 2 waters (includes most streams). Additionally, the draft chronic values are 8 mg/L nitrate-N for Class 2B (warmwater) and 5 mg/L nitrate-N for Class 2A (coldwater, which includes the Straight River) for concentrations based on four-day duration. Compare the coldwater standard to the numerous 3+ mg/L samples collected during winter months in the lower part of the Straight River (i.e., at US Hwy 71; Figure 27above). For more details see: Aquatic Life Water Quality Standards Draft Technical Support Document for Nitrate https://www.pca.state.mn.us/sites/default/files/wq-s6-13.pdf.

Minnesota's Class 1 waters, designated for domestic consumption (drinking water), have a nitrate water quality standard of 10.0 mg/L (Minn. Stat. 7050.0222, subp. 3).

Conclusions

Nitrate concentrations in the Straight River are much higher than those monitored in streams and rivers elsewhere in the four-watershed, natively-forested north central Minnesota area discussed in this study. The exceptions were a couple other intensively agricultural (though nonirrigated) locations. Most other streams in the Crow Wing River Watershed and the three adjacent watersheds to the north and or east (with similar landscapes, soils, etc.) have nitrate levels below lab detection limits (0.05 or 0.02 mg/L depending on lab used). Thus, levels in the Straight River are many, many times higher than is typical in this region's stream waters.

Several findings lead to a plausible conclusion that irrigated row crop agriculture, and its local intensification, have and are contributing significant amounts of nitrate to the Straight River:

- Groundwater nitrate concentrations are known to be high in the Straight River's Watershed,
- Streamwater nitrate concentration increases moving downstream in the Straight River just as the groundwater proportion of stream flow increases moving in the downstream direction,
- The monitored streamside spring at CR-125 had consistently high nitrate concentrations, much higher than the stream water at any site, though potential for some contribution from a nearby home cannot be ruled out.
- Higher stream nitrate concentrations in regional streams are co-located with areas of relatively high row crop agricultural land densities and/or farm animal production,
- The region has very low natural background of nitrate in areas where little agriculture is practiced,
- The landscape patterns of irrigated agricultural acreage parallel the Straight River and are in close proximity to the river,
- Irrigated agriculture has increased significantly here since the early 1990's, and
- The timelines of cropping intensification and increasing levels of nitrate concentrations in the Straight River correlate.

Nitrate concentrations were well above natural background levels in the years prior to 2011 and increased significantly by 2016. Sampling in 2020 through 2022 showed that nitrate levels may have increased a small amount from 2015 through 2016 levels based on graphical interpretation, though the data from 2020 is not statistically-significantly higher. Nitrate levels have possibly stabilized recently (but are not declining from the elevated levels) as new conversion to irrigated acreage has slowed.

The Straight River is formally listed on Minnesota's 303(d) impaired waters (in 2010) list for failing to meet the coldwater DO aquatic life standard, though the actual measured fish and macroinvertebrate communities are still meeting their respective standards. Elevated nitrate is most likely contributing to undesirable levels of plant life, attached algae in specific. The excess algae lowers DO via respiration and decay (i.e., eutrophication) and may in-turn be limiting the potential of the aquatic organism communities in the Straight River. Possible alterations in groundwater volume inputs to the river may be an exacerbating factor influencing aquatic species as well, by raising stream water temperature. Studies by DNR on the river's flow volume are ongoing. Nitrate levels are approaching a level that may be toxic to certain aquatic organisms, based on recent nitrate toxicity studies by the EPA and analysis by MPCA (MPCA, 2022).

Minnesota has developed a river nutrient reduction strategy which has a goal of substantially reducing nitrate and phosphorus in Minnesota's streams and rivers (MPCA, 2014b and 2020). In order to achieve our nitrate reduction goals in the state, significant reductions will be needed in nitrate-polluted waters throughout much of the state. Efforts to date in the Straight River Watershed to reduce nitrate loss from fertilized fields to the river via groundwater have not shown success yet (as of 2022) in the river, based on monitoring of nitrate in the Straight River, though these nitrate-leaching reduction efforts are relatively new. As MPCA primarily has surface water protection responsibilities, other state agencies have done monitoring of groundwater nitrate in the Straight River Watershed. Groundwater nitrate concentration trends will be informative to further interpreting the results presented in the present report. Findings from those studies will shed light on whether stream nitrate levels should be improving, and when that may happen. A report on the monitoring that has occurred recently as part of the Straight River Groundwater Management Zone is expected to be released soon.

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Appendix

Appendix 1. Nitrate data from four HUC-8 scale watersheds (Crow Wing R., Leech Lake R., Mississippi R. - Headwaters, and Pine R.) used to compare with Straight River nitrate data.

HUC-8 code	HUC-8 watershed	Stream name	Biological site code	Latitude	Longitude	Nitrate	Avg.	# of Samp.
07010106	Crow Wing R.	Kettle Cr.	00UM009	46.76514	-95.20550	< 0.050	< 0.050	1
07010106	Crow Wing R.	Mosquito Cr.	00UM013	46.39991	-94.62869	0.080	0.080	1
07010106	Crow Wing R.	Crow Wing R.	00UM024	46.38150	-94.72912	0.240	0.240	1
07010106	Crow Wing R.	Blueberry R.	00UM025	46.78451	-95.14922	0.100		
07010106	Crow Wing R.	Blueberry R.	00UM025	46.78451	-95.14922	0.050		
07010106	Crow Wing R.	Blueberry R.	00UM025	46.78451	-95.14922	0.038		
07010106	Crow Wing R.	Blueberry R.	00UM025	46.78451	-95.14922	0.020	0.052	4
07010106	Crow Wing R.	Crow Wing R.	00UM026	46.64277	-94.88040	0.108		
07010106	Crow Wing R.	Crow Wing R.	00UM026	46.64277	-94.88040	0.060	0.084	2
07010106	Crow Wing R.	Shell R.	00UM027	46.79254	-94.94645	0.276		
07010106	Crow Wing R.	Shell R.	00UM027	46.79254	-94.94645	0.230	0.253	2
07010106	Crow Wing R.	Bear Cr.	00UM096	46.32431	-95.04317	< 0.050	< 0.050	1
07010106	Crow Wing R.	Stoney Br.	09UM086	46.52000	-94.35300	0.866	0.866	1
07010106	Crow Wing R.	Swan Cr.	10EM086	46.41150	-94.76141	< 0.050		
07010106	Crow Wing R.	Swan Cr.	10EM086	46.41150	-94.76141	< 0.050	< 0.050	2
07010106	Crow Wing R.	Shell R.	10EM133	46.90578	-95.27247	< 0.050	< 0.050	1
07010106	Crow Wing R.	Little Partridge R.	10EM150	46.34481	-94.97512	< 0.050	< 0.050	1
07010106	Crow Wing R.	Kettle Cr.	10UM040	46.77795	-95.16417	< 0.050	< 0.050	1
07010106	Crow Wing R.	Fish Hook R.	10UM043	46.90795	-95.05244	0.087	0.087	1
07010106	Crow Wing R.	Hay Cr.	10UM044	47.02915	-95.17067	0.056		
07010106	Crow Wing R.	Hay Cr.	10UM044	47.02915	-95.17067	< 0.050	< 0.053	2
07010106	Crow Wing R.	Crow Wing R.	10UM045	46.89807	-94.85864	< 0.050	< 0.050	1

HUC-8 code	HUC-8 watershed	Stream name	Biological site code	Latitude	Longitude	Nitrate	Avg.	# of Samp.
07010106	Crow Wing R.	Crow Wing R.	10UM046	46.82031	-94.87499	< 0.050	< 0.050	1
07010106	Crow Wing R.	Cat R.	10UM047	46.62939	-94.88354	0.293	0.293	1
07010106	Crow Wing R.	Crow Wing R.	10UM048	46.50490	-94.80586	0.156	0.156	1
07010106	Crow Wing R.	Crow Wing R.	10UM049	46.32487	-94.46615	0.112	0.112	1
07010106	Crow Wing R.	Partridge R.	10UM050	46.41683	-94.83992	1.150	1.150	1
07010106	Crow Wing R.	Gull R.	10UM051	46.40718	-94.32913	< 0.050	< 0.050	1
07010106	Crow Wing R.	Crow Wing R.	10UM052	46.29940	-94.36566	0.200	0.200	1
07010106	Crow Wing R.	Shell R.	10UM053	46.94995	-95.33325	< 0.050	< 0.050	1
07010106	Crow Wing R.	Shell R.	10UM055	46.79173	-95.10822	0.079	0.079	1
07010106	Crow Wing R.	Kettle Cr.	10UM057	46.74424	-95.28951	< 0.050	< 0.050	1
07010106	Crow Wing R.	Blueberry R.	10UM059	46.80783	-95.18598	0.344	0.344	1
07010106	Crow Wing R.	Dinner Cr.	10UM063	47.04840	-95.19292	< 0.050	< 0.050	1
07010106	Crow Wing R.	Basswood Cr.	10UM064	47.06143	-95.23375	0.089	0.089	1
07010106	Crow Wing R.	Indian Cr.	10UM065	47.05364	-95.23153	0.065	0.065	1
07010106	Crow Wing R.	Bender Cr.	10UM070	46.83227	-94.80399	0.081		
07010106	Crow Wing R.	Bender Cr.	10UM070	46.83227	-94.80399	< 0.050	< 0.066	1
07010106	Crow Wing R.	Cat R.	10UM071	46.68521	-95.04026	1.000	1.000	1
07010106	Crow Wing R.	Kitten Cr.	10UM072	46.67201	-95.03904	< 0.050	< 0.050	1
07010106	Crow Wing R.	Trib. to Crow Wing R.	10UM076	46.70879	-94.85056	< 0.050		
07010106	Crow Wing R.	Trib. to Crow Wing R.	10UM076	46.70879	-94.85056	< 0.050	< 0.050	2
07010106	Crow Wing R.	Big Swamp Cr.	10UM077	46.67204	-94.84822	< 0.050	< 0.050	1
07010106	Crow Wing R.	Tower Cr.	10UM078	46.52701	-94.73861	0.091	0.091	1
07010106	Crow Wing R.	Martin Cr.	10UM079	46.54806	-94.73685	0.082	0.082	1
07010106	Crow Wing R.	Farnham Cr.	10UM080	46.60038	-94.72075	0.092	0.092	1
07010106	Crow Wing R.	Swan Cr.	10UM081	46.47768	-94.73419	< 0.050	< 0.050	1
07010106	Crow Wing R.	Little Partridge Cr.	10UM085	46.34116	-95.00753	0.076	0.076	1
07010106	Crow Wing R.	County Ditch 15	10UM086	46.30268	-95.05086	0.130	0.130	1
07010106	Crow Wing R.	Trib. to Crow Wing R.	10UM087	46.36972	-94.71165	< 0.050	< 0.050	1
07010106	Crow Wing R.	Mosquito Cr.	10UM089	46.35575	-94.63303	< 0.050	< 0.050	1
07010106	Crow Wing R.	Sevenmile Cr.	10UM090	46.34234	-94.55009	0.063		
07010106	Crow Wing R.	Sevenmile Cr.	10UM090	46.34234	-94.55009	< 0.050	< 0.057	2
07010106	Crow Wing R.	Pillager Cr.	10UM091	46.33216	-94.47601	0.075		
07010106	Crow Wing R.	Pillager Cr.	10UM091	46.33216	-94.47601	< 0.050	< 0.063	2
07010106	Crow Wing R.	Stoney Br.	10UM092	46.51909	-94.37000	1.590		
07010106	Crow Wing R.	Stoney Br.	10UM092	46.51909	-94.37000	1.150		

HUC-8 code	HUC-8 watershed	Stream name	Biological site code	Latitude	Longitude	Nitrate	Avg.	# of Samp.
07010106	Crow Wing R.	Stoney Br.	10UM092	46.51909	-94.37000	0.680	1.140	3
07010106	Crow Wing R.	Mayo Cr.	10UM093	46.60604	-94.35300	0.092		
07010106	Crow Wing R.	Mayo Cr.	10UM093	46.60604	-94.35300	< 0.050	< 0.071	2
07010106	Crow Wing R.	Cory Br.	10UM096	46.49183	-94.45547	0.062	0.062	1
07010106	Crow Wing R.	Home Br.	10UM097	46.47114	-94.39415	0.067	0.067	1
07010106	Crow Wing R.	Stoney Br.	10UM098	46.57027	-94.43376	< 0.050	0.050	1
07010106	Crow Wing R.	Trib. to Crow Wing R.	10UM099	46.58579	-94.78267	0.088	0.088	1
07010106	Crow Wing R.	Big Swamp Cr.	10UM101	46.73229	-94.79396	< 0.050		
07010106	Crow Wing R.	Big Swamp Cr.	10UM101	46.73229	-94.79396	< 0.050	< 0.050	2
07010106	Crow Wing R.	Trib. to Big Swamp Cr.	10UM102	46.70894	-94.79678	< 0.050	< 0.050	1
07010106	Crow Wing R.	Trib. to Crow Wing R.	10UM103	46.65255	-94.88950	0.845		
07010106	Crow Wing R.	Trib. to Crow Wing R.	10UM103	46.65255	-94.88950	0.560		
07010106	Crow Wing R.	Trib. to Crow Wing R.	10UM103	46.65255	-94.88950	0.320		
07010106	Crow Wing R.	Trib. to Crow Wing R.	10UM103	46.65255	-94.88950	0.320		
07010106	Crow Wing R.	Trib. to Crow Wing R.	10UM103	46.65255	-94.88950	0.288	0.467	5
07010106	Crow Wing R.	Trib. to Beaver Cr.	10UM106	46.64324	-94.81356	0.256	0.256	1
07010106	Crow Wing R.	Beaver Cr.	10UM107	46.64362	-94.80132	0.361	0.361	1
07010106	Crow Wing R.	Swan Cr.	10UM108	46.52774	-94.70816	< 0.050	< 0.050	1
07010106	Crow Wing R.	Mosquito Cr.	10UM109	46.44252	-94.63194	0.080	0.080	1
07010106	Crow Wing R.	Crow Wing R.	10UM110	46.71833	-94.93312	0.156	0.156	1
07010106	Crow Wing R.	Crow Wing R.	10UM111	46.39244	-94.77175	0.208	0.208	1
07010106	Crow Wing R.	Crow Wing R.	10UM112	46.45471	-94.79957	0.148	0.148	1
07010106	Crow Wing R.	Fishhook R.	10UM113	46.86537	-95.02364	1.240	1.240	1
07010106	Crow Wing R.	Crow Wing R.	10UM117	46.35242	-94.71434	0.264	0.264	1
07010106	Crow Wing R.	Trib. to Mosquito Cr.	10UM119	46.41333	-94.62190	0.076	0.076	1
07010106	Crow Wing R.	Crow Wing R.	10UM120	46.31284	-94.56116	0.236	0.236	1
07010106	Crow Wing R.	Blueberry R.	10UM121	46.78262	-95.15010	0.169	0.169	1
07010106	Crow Wing R.	Trib. To Crow Wing R.	13UM184	46.65116	-94.88976	0.845		
07010106	Crow Wing R.	Trib. To Crow Wing R.	13UM184	46.65116	-94.88976	0.681		
07010106	Crow Wing R.	Trib. To Crow Wing R.	13UM184	46.65116	-94.88976	0.320	0.615	3
07010106	Crow Wing R.	Trib. to Crow Wing R.	15UM211	46.64749	-94.88315	0.591	0.591	1
07010106	Crow Wing R.	Trib. to Crow Wing R.	98NF023	46.71358	-94.84234	0.017	0.017	1
07010106	Crow Wing R.	Trib. to Cat R.	98NF121	46.63687	-94.94811	0.133	0.133	1
07010106	Crow Wing R.	Fish Cr.	99UM011	46.97782	-95.40982	< 0.050		
07010106	Crow Wing R.	Fish Cr.	99UM011	46.97782	-95.40982	< 0.050	< 0.050	2

HUC-8 code	HUC-8 watershed	Stream name	Biological site code	Latitude	Longitude	Nitrate	Avg.	# of Samp.
07010106	Crow Wing R.	Trib. to Bear Cr.	99UM012	46.30527	-95.05618	< 0.050	< 0.050	1
07010106	Crow Wing R.	Farnham Cr.	99UM022	46.50702	-94.79380	0.064		
07010106	Crow Wing R.	Farnham Cr.	99UM022	46.50702	-94.79380	< 0.050	< 0.057	2
07010106	Crow Wing R.	Home Br.	99UM027	46.46899	-94.40756	< 0.050	< 0.050	1
07010106	Crow Wing R.	Fish Hook R.	99UM031	46.91952	-95.05247	< 0.050	< 0.050	1
07010106	Crow Wing R.	Trib. to Shell R.	99UM047	46.91606	-95.36394	< 0.050	< 0.050	1
07010106	Crow Wing R.	Crow Wing R.	99UM062	46.32559	-94.58721	0.250	0.250	1
07010102	Leech Lake R.	Boy R.	00UM012	47.07895	-94.10055	0.052		
07010102	Leech Lake R.	Boy R.	00UM012	47.07895	-94.10055	< 0.050		
07010102	Leech Lake R.	Boy R.	00UM012	47.07895	-94.10055	< 0.050	< 0.051	3
07010102	Leech Lake R.	Kabekona R.	09UM084	47.23292	-94.82990	< 0.050		
07010102	Leech Lake R.	Kabekona R.	09UM084	47.23292	-94.82990	< 0.050		
07010102	Leech Lake R.	Kabekona R.	09UM084	47.23292	-94.82990	< 0.050		
07010102	Leech Lake R.	Kabekona R.	09UM084	47.23292	-94.82990	< 0.050	< 0.050	4
07010102	Leech Lake R.	Necktie R.	09UM085	47.38422	-94.75630	0.080		
07010102	Leech Lake R.	Necktie R.	09UM085	47.38422	-94.75630	0.056	0.068	2
07010102	Leech Lake R.	Boy R.	12UM086	46.96324	-94.18304	< 0.050	< 0.050	1
07010102	Leech Lake R.	Necktie R.	12UM088	47.24681	-94.72887	0.200	0.200	1
07010102	Leech Lake R.	Boy R.	12UM089	47.16677	-94.17244	< 0.050		
07010102	Leech Lake R.	Boy R.	12UM089	47.16677	-94.17244	< 0.050	< 0.050	2
07010102	Leech Lake R.	Kabekona R.	12UM090	47.15379	-94.68612	< 0.050	< 0.050	1
07010102	Leech Lake R.	Shingobee R.	12UM091	47.01529	-94.66230	0.100		
07010102	Leech Lake R.	Shingobee R.	12UM091	47.01529	-94.66230	< 0.050		
07010102	Leech Lake R.	Shingobee R.	12UM091	47.01529	-94.66230	0.020	< 0.057	3
07010102	Leech Lake R.	Sucker Branch	12UM094	47.16615	-94.79072	< 0.050	< 0.050	1
07010102	Leech Lake R.	Bungashing Cr.	12UM096	47.34757	-94.75613	< 0.050	< 0.050	1
07010102	Leech Lake R.	Pokety Cr.	12UM097	47.25910	-94.78989	< 0.050	< 0.050	1
07010102	Leech Lake R.	Kabekona R.	12UM102	47.19494	-94.78301	< 0.050	< 0.050	1
07010102	Leech Lake R.	Spring Cr.	12UM106	46.89211	-94.21010	0.200		
07010102	Leech Lake R.	Spring Cr.	12UM106	46.89211	-94.21010	< 0.050	< 0.125	2
07010102	Leech Lake R.	Trib to Northby Cr.	12UM107	46.94881	-94.11353	< 0.050	< 0.050	1
07010102	Leech Lake R.	Swift R.	12UM109	47.07995	-94.06128	< 0.050		
07010102	Leech Lake R.	Swift R.	12UM109	47.07995	-94.06128	< 0.050	< 0.050	2
07010102	Leech Lake R.	Sixmile Br.	12UM110	47.27092	-94.06357	< 0.050	< 0.050	1
07010102	Leech Lake R.	Leech Lake R.	12UM112	47.24428	-94.19321	0.200	0.200	1

HUC-8 code	HUC-8 watershed	Stream name	Biological site code	Latitude	Longitude	Nitrate	Avg.	# of Samp.
07010102	Leech Lake R.	Leech Lake R.	12UM113	47.28920	-93.92050	< 0.050		
07010102	Leech Lake R.	Leech Lake R.	12UM113	47.28920	-93.92050	< 0.050	< 0.050	2
07010102	Leech Lake R.	Steamboat R.	12UM138	47.24557	-94.62101	0.064		
07010102	Leech Lake R.	Steamboat R.	12UM138	47.24557	-94.62101	< 0.050	< 0.057	2
07010102	Leech Lake R.	Bungashing Cr.	98NF011	47.34663	-94.78960	0.007	0.007	1
07010101	Miss. R. - Headwaters	Unnamed ditch	00UM001	47.53949	-95.12640	< 0.050	< 0.050	1
07010101	Miss. R. - Headwaters	Nicollet Cr.	00UM002	47.19315	-95.23087	< 0.050	< 0.050	1
07010101	Miss. R. - Headwaters	Third R.	00UM007	47.54456	-94.26144	0.072		
07010101	Miss. R. - Headwaters	Third R.	00UM007	47.54456	-94.26144	< 0.050	< 0.061	2
07010101	Miss. R. - Headwaters	Pigeon R.	00UM008	47.58834	-94.18702	< 0.050	< 0.050	1
07010101	Miss. R. - Headwaters	Mississippi R.	00UM010	47.39754	-95.14623	< 0.050		
07010101	Miss. R. - Headwaters	Mississippi R.	00UM010	47.39754	-95.14623	< 0.050	< 0.050	2
07010101	Miss. R. - Headwaters	Birch Cr.	00UM011	47.23312	-95.01148	< 0.050		
07010101	Miss. R. - Headwaters	Birch Cr.	00UM011	47.23312	-95.01148	< 0.050		
07010101	Miss. R. - Headwaters	Birch Cr.	00UM011	47.23312	-95.01148	< 0.050	< 0.050	3
07010101	Miss. R. - Headwaters	Sucker Cr.	09UM083	47.24923	-95.24776	0.056		
07010101	Miss. R. - Headwaters	Sucker Cr.	09UM083	47.24923	-95.24776	< 0.050	< 0.053	2
07010101	Miss. R. - Headwaters	Mississippi R.	10EM082	47.24074	-93.71914	< 0.050		
07010101	Miss. R. - Headwaters	Mississippi R.	10EM082	47.24074	-93.71914	< 0.050	< 0.050	2
07010101	Miss. R. - Headwaters	Mississippi R.	10EM113	47.33944	-95.21011	0.060		
07010101	Miss. R. - Headwaters	Mississippi R.	10EM113	47.33944	-95.21011	< 0.050	< 0.055	1
07010101	Miss. R. - Headwaters	Grant Cr.	10EM165	47.51088	-95.02394	< 0.050	< 0.050	1
07010101	Miss. R. - Headwaters	Mississippi R.	13UM023	47.25079	-93.59247	< 0.050	< 0.050	1
07010101	Miss. R. - Headwaters	Mississippi R.	13UM024	47.23770	-93.73418	< 0.050	< 0.050	1
07010101	Miss. R. - Headwaters	Mississippi R.	13UM025	47.22730	-93.80276	< 0.050	< 0.050	1
07010101	Miss. R. - Headwaters	Mississippi R.	13UM026	47.30282	-93.90669	< 0.050	< 0.050	1
07010101	Miss. R. - Headwaters	Mississippi R.	13UM027	47.44259	-94.41634	< 0.050	< 0.050	1
07010101	Miss. R. - Headwaters	Mississippi R.	13UM028	47.44881	-94.71799	< 0.050	< 0.050	1
07010101	Miss. R. - Headwaters	Mississippi R.	13UM029	47.45040	-94.90393	< 0.050	< 0.050	1
07010101	Miss. R. - Headwaters	Mississippi R.	13UM030	47.42318	-95.10193	< 0.050	< 0.050	1
07010101	Miss. R. - Headwaters	Alcohol Cr.	13UM100	47.26924	-94.98140	< 0.050	< 0.050	1
07010101	Miss. R. - Headwaters	Bear Cr.	13UM102	47.35330	-95.22402	< 0.050	< 0.050	1
07010101	Miss. R. - Headwaters	Castle Cr.	13UM103	47.55680	-94.31928	< 0.050	< 0.050	1
07010101	Miss. R. - Headwaters	Deer R.	13UM105	47.34438	-93.78279	< 0.050	< 0.050	1
07010101	Miss. R. - Headwaters	Deer R.	13UM106	47.38525	-93.74759	0.052	0.052	1

HUC-8 code	HUC-8 watershed	Stream name	Biological site code	Latitude	Longitude	Nitrate	Avg.	# of Samp.
07010101	Miss. R. - Headwaters	Farley Cr.	13UM110	47.53557	-94.18053	0.100		
07010101	Miss. R. - Headwaters	Farley Cr.	13UM110	47.53557	-94.18053	< 0.050	< 0.075	2
07010101	Miss. R. - Headwaters	Fishermans Br.	13UM111	47.39261	-93.94431	0.100		
07010101	Miss. R. - Headwaters	Fishermans Br.	13UM111	47.39261	-93.94431	< 0.050	< 0.075	2
07010101	Miss. R. - Headwaters	Frontenack Cr.	13UM112	47.32906	-94.96462	< 0.050	< 0.050	1
07010101	Miss. R. - Headwaters	Grant Cr.	13UM114	47.47369	-95.03493	< 0.050	< 0.050	1
07010101	Miss. R. - Headwaters	Gull R.	13UM116	47.65597	-94.64742	< 0.050		
07010101	Miss. R. - Headwaters	Gull R.	13UM116	47.65597	-94.64742	< 0.050	< 0.050	2
07010101	Miss. R. - Headwaters	Hennepin Cr.	13UM117	47.39841	-95.08663	< 0.050	< 0.050	1
07010101	Miss. R. - Headwaters	Island Lake Cr.	13UM119	47.39306	-93.72815	< 0.050	< 0.050	1
07010101	Miss. R. - Headwaters	Little Mississippi R.	13UM122	47.45661	-95.12924	0.100		
07010101	Miss. R. - Headwaters	Little Mississippi R.	13UM122	47.45661	-95.12924	< 0.050	< 0.075	2
07010101	Miss. R. - Headwaters	Lydick Br.	13UM125	47.41628	-94.41799	< 0.050	< 0.050	1
07010101	Miss. R. - Headwaters	Moose Cr.	13UM129	47.65762	-94.34326	< 0.050	< 0.050	1
07010101	Miss. R. - Headwaters	North Turtle R.	13UM130	47.54195	-94.56687	< 0.050	< 0.050	1
07010101	Miss. R. - Headwaters	North Turtle R.	13UM131	47.60055	-94.54036	< 0.050	< 0.050	1
07010101	Miss. R. - Headwaters	Pigeon R.	13UM132	47.54780	-94.15379	< 0.050	< 0.050	1
07010101	Miss. R. - Headwaters	Schoolcraft R.	13UM134	47.32202	-94.94128	0.100		
07010101	Miss. R. - Headwaters	Schoolcraft R.	13UM134	47.32202	-94.94128	< 0.050		
07010101	Miss. R. - Headwaters	Schoolcraft R.	13UM134	47.32202	-94.94128	0.020	< 0.057	3
07010101	Miss. R. - Headwaters	Schoolcraft R.	13UM135	47.26817	-94.98787	0.068		
07010101	Miss. R. - Headwaters	Schoolcraft R.	13UM135	47.26817	-94.98787	< 0.050	< 0.059	2
07010101	Miss. R. - Headwaters	Schoolcraft R.	13UM136	47.22262	-95.00904	0.092	0.092	1
07010101	Miss. R. - Headwaters	Smith Cr.	13UM137	47.08566	-93.58125	< 0.050	< 0.050	1
07010101	Miss. R. - Headwaters	Sugar Br.	13UM141	47.17632	-93.63589	0.100		
07010101	Miss. R. - Headwaters	Sugar Br.	13UM141	47.17632	-93.63589	< 0.050		
07010101	Miss. R. - Headwaters	Sugar Br.	13UM141	47.17632	-93.63589	< 0.050	< 0.067	3
07010101	Miss. R. - Headwaters	Third R.	13UM142	47.64958	-94.35831	0.088	0.088	1
07010101	Miss. R. - Headwaters	Trib. to Deer R.	13UM145	47.39284	-93.79159	< 0.050	< 0.050	1
07010101	Miss. R. - Headwaters	Trib. to Grant Cr.	13UM146	47.52704	-95.05694	0.100		
07010101	Miss. R. - Headwaters	Trib. to Grant Cr.	13UM146	47.52704	-95.05694	< 0.050	< 0.075	2
07010101	Miss. R. - Headwaters	Trib. to Grant Cr.	13UM147	47.50216	-95.07533	0.100		
07010101	Miss. R. - Headwaters	Trib. to Grant Cr.	13UM147	47.50216	-95.07533	< 0.050	< 0.075	2
07010101	Miss. R. - Headwaters	Trib. to Lake Bemidji	13UM148	47.52605	-94.88634	< 0.050		
07010101	Miss. R. - Headwaters	Trib. to Lake Bemidji	13UM148	47.52605	-94.88634	< 0.050	< 0.050	2

HUC-8 code	HUC-8 watershed	Stream name	Biological site code	Latitude	Longitude	Nitrate	Avg.	# of Samp.
07010101	Miss. R. - Headwaters	Trib. to Lt. Miss. R.	13UM149	47.46928	-95.22409	0.128		
07010101	Miss. R. - Headwaters	Trib. to Lt. Miss. R.	13UM149	47.46928	-95.22409	< 0.050	< 0.089	2
07010101	Miss. R. - Headwaters	Turtle R.	13UM153	47.54501	-94.59827	< 0.050	< 0.050	1
07010101	Miss. R. - Headwaters	Turtle R.	13UM154	47.59158	-94.66291	< 0.050	< 0.050	1
07010101	Miss. R. - Headwaters	Turtle R.	13UM155	47.61480	-94.76386	< 0.050	< 0.050	1
07010101	Miss. R. - Headwaters	Turtle R.	13UM156	47.63328	-94.90775	< 0.050	< 0.050	1
07010101	Miss. R. - Headwaters	Turtle R.	13UM157	47.66259	-95.01208	< 0.050	< 0.050	1
07010101	Miss. R. - Headwaters	Third R.	13UM160	47.66654	-94.40896	< 0.050	< 0.050	1
07010101	Miss. R. - Headwaters	Vermillion R.	13UM161	47.14844	-93.87753	< 0.050		
07010101	Miss. R. - Headwaters	Vermillion R.	13UM161	47.14844	-93.87753	< 0.050	< 0.050	2
07010101	Miss. R. - Headwaters	Smith Cr.	14UM101	47.09913	-93.58958	0.100	0.100	1
07010101	Miss. R. - Headwaters	Turtle R.	15EM050	47.59727	-94.83744	< 0.050	< 0.050	1
07010101	Miss. R. - Headwaters	Sugar Br.	15UM400	47.18288	-93.62709	< 0.050	< 0.050	1
07010101	Miss. R. - Headwaters	Sugar Br.	15UM401	47.18488	-93.62506	< 0.050	< 0.050	1
07010101	Miss. R. - Headwaters	Moose Cr.	99UM001	47.71541	-94.37399	< 0.050	< 0.050	1
07010101	Miss. R. - Headwaters	Grant Cr.	99UM006	47.49106	-94.98773	< 0.050	< 0.050	1
07010101	Miss. R. - Headwaters	Turtle R.	99UM021	47.55234	-94.61282	< 0.050	< 0.050	1
07010101	Miss. R. - Headwaters	SchoolCraft R.	99UM026	47.31296	-94.94683	< 0.050	< 0.050	1
07010101	Miss. R. - Headwaters	Island Lake Cr.	99UM036	47.41460	-93.72484	< 0.050	< 0.050	1
07010101	Miss. R. - Headwaters	Mississippi R.	99UM066	47.27399	-93.78481	< 0.050	< 0.050	1
07010105	Pine R.	Little Pine R.	00UM017	46.65651	-93.97946	0.120		
07010105	Pine R.	Little Pine R.	00UM017	46.65651	-93.97946	< 0.050		
07010105	Pine R.	Little Pine R.	00UM017	46.65651	-93.97946	< 0.050	< 0.073	3
07010105	Pine R.	Pine R.	12UM114	46.57386	-94.02853	< 0.050	< 0.050	1
07010105	Pine R.	Pine R.	12UM115	46.70986	-94.39324	0.200		
07010105	Pine R.	Pine R.	12UM115	46.70986	-94.39324	< 0.050	< 0.125	2
07010105	Pine R.	Pine R., South Fork	12UM116	46.70388	-94.40369	< 0.050	< 0.050	1
07010105	Pine R.	Little Pine R.	12UM117	46.62886	-93.98695	< 0.050		
07010105	Pine R.	Little Pine R.	12UM117	46.62886	-93.98695	< 0.050	< 0.050	2
07010105	Pine R.	Daggett Br.	12UM118	46.73747	-94.06059	< 0.050	< 0.050	1
07010105	Pine R.	Pine R.	12UM119	46.80410	-94.38508	< 0.050	< 0.050	1
07010105	Pine R.	Pine R., South Fork	12UM120	46.74029	-94.53587	< 0.050		
07010105	Pine R.	Pine R., South Fork	12UM120	46.74029	-94.53587	< 0.050	< 0.050	2
07010105	Pine R.	Pine R., South Fork	12UM121	46.70968	-94.47320	0.096		
07010105	Pine R.	Pine R., South Fork	12UM121	46.70968	-94.47320	< 0.050	< 0.073	2

HUC-8 code	HUC-8 watershed	Stream name	Biological site code	Latitude	Longitude	Nitrate	Avg.	# of Samp.
07010105	Pine R.	Daggett Br.	12UM123	46.89735	-94.05232	< 0.050	< 0.050	1
07010105	Pine R.	Mud Br.	12UM124	46.64827	-93.95643	0.200	0.200	1
07010105	Pine R.	Pine R.	12UM125	46.69184	-94.30592	< 0.050	< 0.050	1
07010105	Pine R.	Mud Br.	12UM127	46.67545	-93.87417	< 0.050		
07010105	Pine R.	Mud Br.	12UM127	46.67545	-93.87417	< 0.050	< 0.050	2
07010105	Pine R.	Daggett Br.	12UM128	46.82125	-94.03231	< 0.050	< 0.050	1
07010105	Pine R.	Willow Cr.	12UM129	46.71567	-94.27314	0.056		
07010105	Pine R.	Willow Cr.	12UM129	46.71567	-94.27314	< 0.050	< 0.053	2
07010105	Pine R.	Pine R.	12UM131	46.65314	-94.10141	< 0.050	< 0.050	1
07010105	Pine R.	Bungo Cr.	12UM132	46.71981	-94.52888	0.084		
07010105	Pine R.	Bungo Cr.	12UM132	46.71981	-94.52888	< 0.050	< 0.067	2
07010105	Pine R.	Wilson Cr.	12UM133	46.68830	-94.48659	< 0.050		
07010105	Pine R.	Wilson Cr.	12UM133	46.68830	-94.48659	< 0.050	< 0.050	2
07010105	Pine R.	Lizzie Cr.	12UM135	46.79660	-94.36137	< 0.050	< 0.050	1
07010105	Pine R.	Bungo Cr.	12UM139	46.68962	-94.56553	0.092		
07010105	Pine R.	Bungo Cr.	12UM139	46.68962	-94.56553	< 0.050		
07010105	Pine R.	Bungo Cr.	12UM139	46.68962	-94.56553	< 0.050	< 0.064	3
07010105	Pine R.	Brittan Cr.	12UM140	46.72779	-94.53639	< 0.050		
07010105	Pine R.	Brittan Cr.	12UM140	46.72779	-94.53639	< 0.050	< 0.050	2
07010105	Pine R.	Pelican Br.	12UM141	46.62355	-94.13301	0.324	0.324	1
07010105	Pine R.	Pine R.	12UM149	46.61458	-94.06063	0.200		
07010105	Pine R.	Pine R.	12UM149	46.61458	-94.06063	< 0.050	< 0.125	2
07010105	Pine R.	Pine R.	15EM095	46.70307	-94.38727	< 0.050	< 0.050	1
07010105	Pine R.	Little Pine R.	15UM117	46.65359	-93.98120	< 0.050	< 0.050	1
07010105	Pine R.	Pine R.	99UM037	46.61615	-94.06803	< 0.050	< 0.050	1
07010105	Pine R.	Arvig Cr.	99UM042	46.70562	-94.36293	1.100		
07010105	Pine R.	Arvig Cr.	99UM042	46.70562	-94.36293	0.152	0.626	2
Straight River samples								
07010106	Crow Wing R.	Straight R.	10UM041	46.87552	-95.06852	1.290	1.290	1
07010106	Crow Wing R.	Straight R.	10UM060	46.97094	-95.28315	1.990	1.990	1
07010106	Crow Wing R.	Straight R.	10UM061	46.90932	-95.24959	0.188	0.188	1