Straight River (Hubbard County, MN) Nutrient Study

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Background on the Straight River, the surrounding landscape, and changes occurring in recent years

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 exceptionally sandy soils, which continue to be sand to depths of up to 70 feet or more below the ground surface. Such soils allow for the formation of substantial surficial aquifers. The Straight River lies above the Pineland Sands Aquifer. Aquifer characteristics have been described in detail in a USGS study (Stark et al., 1994). 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 groundwater via many springs along its course (Photo 1). Concerning developments in the quality of the Straight River have received significant attention. The Straight River was featured in a prominent article in the Minneapolis Star-Tribune on December 31, 2016 titled, *A great river, at risk*, about water quality of the upper Mississippi River Basin, in which the Straight River flows.

Photo 1. A large spring-water channel that enters the Straight River downstream of CR-123.

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 with irrigation. Many of the historical agricultural fields had been placed into CRP in the last 20-30 years due to the difficulty in growing crops and the susceptibility of these sandy soils to wind erosion. In recent years, there has been a significant and steady conversion of these set-aside and/or non-row-crop fields to center-pivot irrigated row cropping (Figures 1, and 2). Relatively more changes happened in the subwatershed above Straight Lake in the 1992-2009 period, while the newest changes (2010-2016) have happened more so in the lower part of the subwatershed (downstream of Straight Lake). In some cases, these conversions also result in forest patches being converted to row crop agriculture (Figure 4), as removing these plots results in getting 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 5). The distances of these six fields was 373, 340, 305, 202, 182, and 151 feet at their nearest field edge to the river bank.

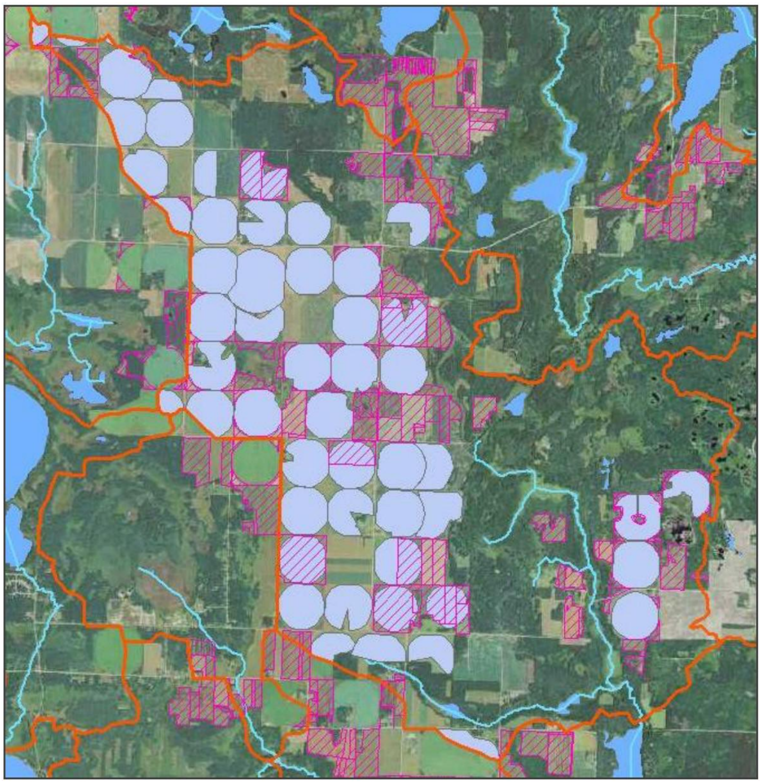

Figure 1. The Upper Straight River subwatershed (above Straight Lake), a HUC-12 scale watershed. Irrigated fields are current as of 2013 aerials. The areas where cross-hatching overlies the irrigated fields appear to be acreage converted from CRP/perennial grasses to irrigated crops from 1991-2013.

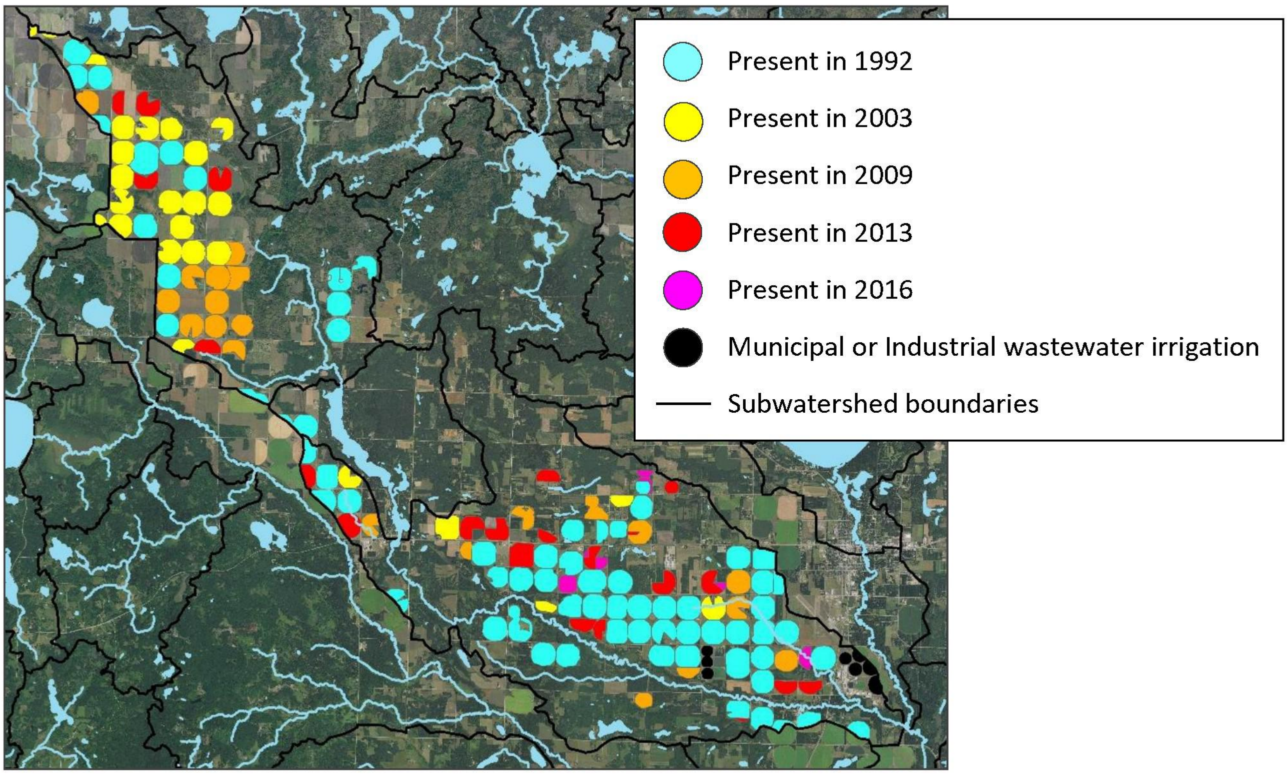

Figure 2. Irrigated acreage change over time from that present in 1992 to 2016 in the Straight River subwatershed. Any new irrigation in 2016 may be incomplete due to limitation of available aerial photography. These changes are cumulative, so in 2016, all colors denoting irrigated cropland were operating as irrigated row crops.

Figure 3. 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 4. Measured distances from field edge to nearest river bank. Distances in feet are labeled on the photos..

Some of the common row crops grown in the fields surrounding the Straight River require heavy inputs of nitrogen fertilizer, particularly potatoes and corn, as well as soybeans. Nitrate is a water soluble molecule, and easily moves through sandy soils where it eventually reaches the shallow surficial aquifer. The nearby City of Park Rapids recently had to drill a new municipal well due to groundwater nitrate concentrations above the Minnesota drinking water standard of 10 mg/L.

As a result of the 2010-2011 Crow Wing River Watershed Intensive Watershed Monitoring effort, the Straight River has been assessed by MPCA as impaired (placed on the 303(d) list) for aquatic life due to dissolved oxygen concentrations below the state coldwater standard. Two factors related to the interplay of irrigated agriculture may be contributing to this impairment, those being export of agricultural fertilizer nitrate to the river via groundwater, contributing to excess plant life in the river (Photos 2and 3), and possible reduction of groundwater input to the river, resulting in higher stream water temperatures (as water warms, it holds less oxygen). The DNR Fisheries office in Park Rapids is currently studying flow volumes and water temperature in the Straight River.

Photo 2. A large mat of filamentous algae downstream of CR-123.

Photo 3. Algal growth on a vertical pipe, part of stream gaging equipment at Becker Line Road, Sept. 14, 2016.

Reason for further study

After the initial Crow Wing River IWM effort, follow-up sampling was done 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 of eutrophication (stimulation of excessive plant growth).

New monitoring Information

Additional water quality monitoring of the Straight River was conducted by MPCA's Watershed Unit SID staff in 2015-2016. Sampling was done in a longitudinal manner along the river's course. Several water chemistry parameters (total phosphorus, nitrate+nitrite-N, and instantaneous temperature, dissolved oxygen, dissolved oxygen % saturation, and conductivity) were repeatedly sampled at four locations (in all calendar months) along the Straight River, downstream of Straight Lake. The four sample sites were at CR-123, CR-125, Becker Line Road, and State Hwy. 71 (Figure 6), meaning four nested contributing subwatersheds (Figure 7) could be examined separately in order to provide insight into sources of nitrate to the river. Four streamside springs were also sampled, three of them only once (due to difficult collecting conditions), and the fourth about 6 times. A very limited dataset of water quality parameters exists from the period of 1980-1990 for several sites, some coinciding with the sites sampled in the current effort. Data presented below are from three sources: 1) the data collected by MPCA's SID staff in 2015 and 2016, 2) data collected as part of the 2010 Crow Wing River Watershed IWM, and 3) historical data found in the MPCA's EQuIS water quality database. The 2015-2016 samples were analyzed at the Minnesota Dept. of Health Environmental Laboratory. The data in EQuIS were analyzed at MN Dept. of Health certified laboratories.

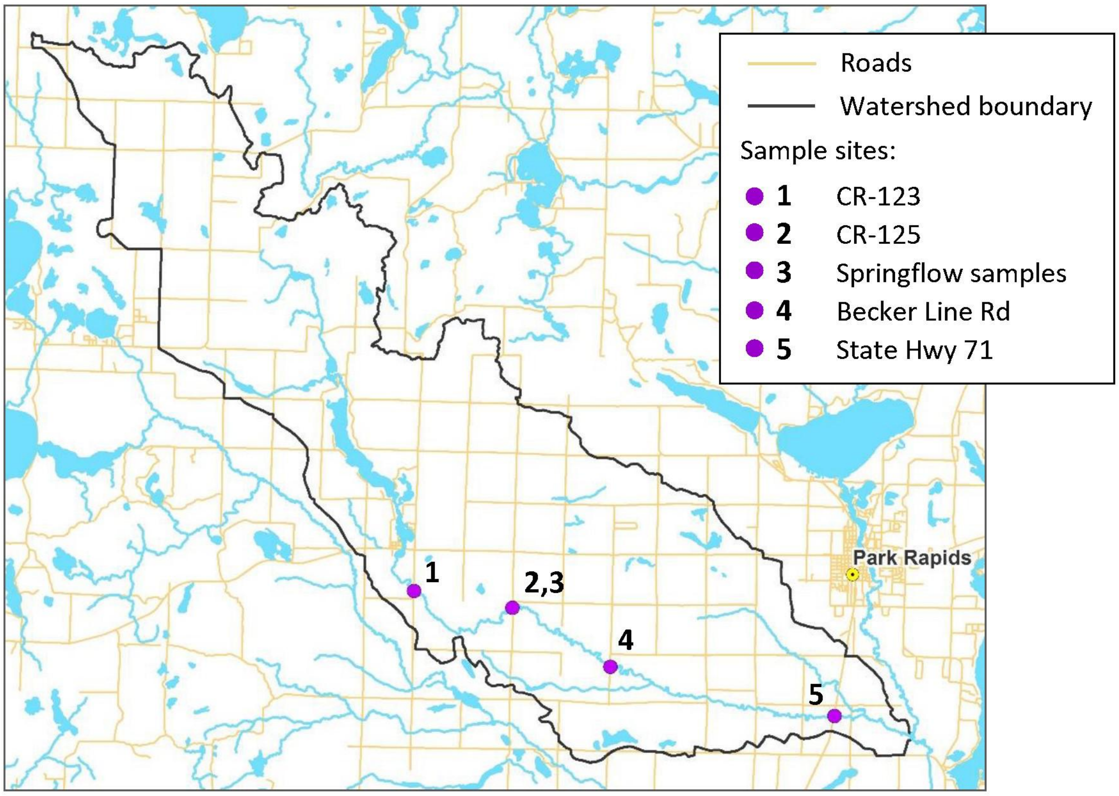

Figure 5. The full Straight River Watershed boundary and the study's nutrient sampling locations. The Straight River enters the Fish Hook River just south of Park Rapids.

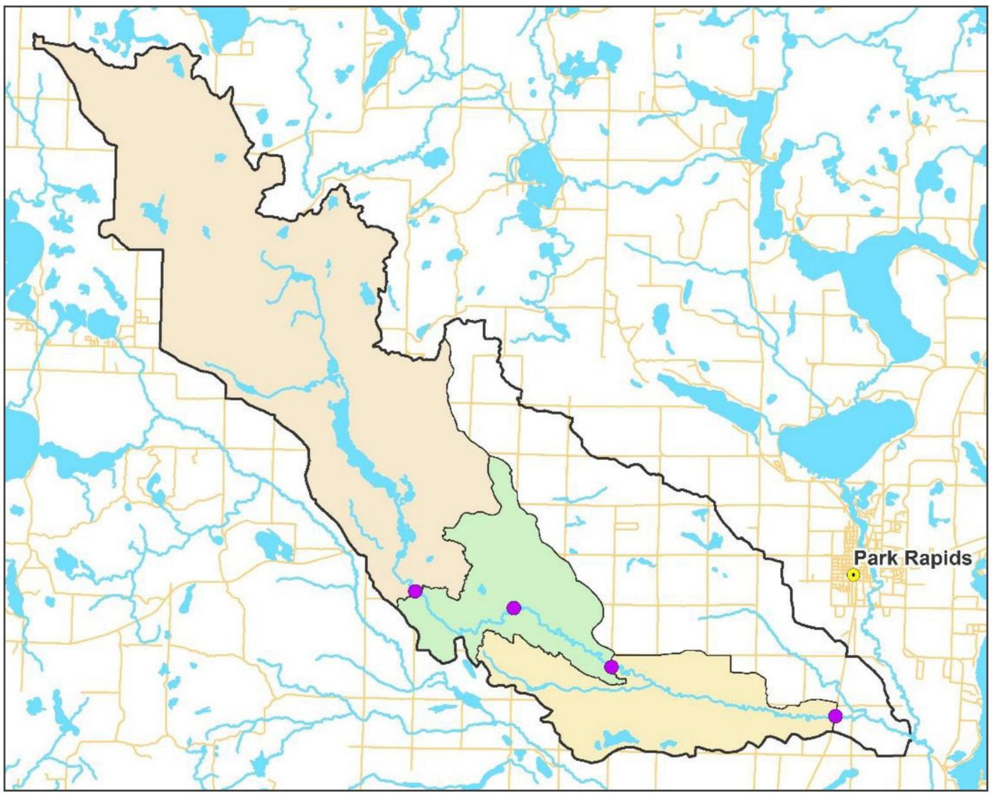

Figure 6. Subwatersheds for the sampled sites shown in Figure 2. The second site from the left was discontinued partway through the study as water chemistry results were very similar to the upstream site. Note that each site's

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 black outline), but may contribute groundwater input.

Land use analysis

The changes in acreage of irrigated row cropped fields shown in figure 2 above were quantified using GIS tools (Table 1 and Figure 7).

Table 1. Acreages of irrigated fields in the Straight River subwatershed beginning in 1992 through 2016.

Year	Added acres	Total Acres
1992		8297.8
2003	2620.8	10918.6
2009	2134.3	13052.9
2013	1708.2	14761.1
2016	228.1	14989.2

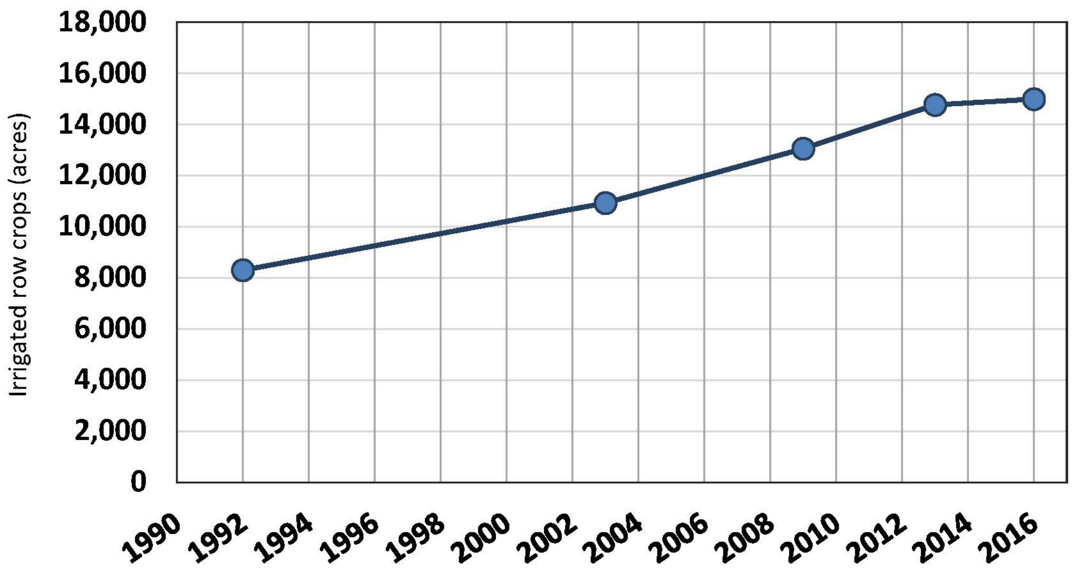

Figure 7. Graph of the changes in acreage of irrigated row cropped fields shown in figure 2 and table 1 above.

Water Quality Findings:

1. **The nitrate concentration in the Straight River in summer is at least *100 times higher* than in most other areas of the Crow Wing River/Pine River/Leech Lake River/Mississippi River - Headwaters Watersheds** (Figure 8). The majority of sites had concentrations less than the lab's detection limit of 0.05 mg/L. (in some cases 0.02 mg/L). The Blueberry River, which lies a relatively short distance south of the Straight River, recorded a nitrate concentration of < 0.02 mg/L. Only seven sites in this four-watershed area had nitrate above 0.50 mg/L (among 190 tested sites). Only the upper Straight River and a site on Stoney Brook (in the southeast Crow Wing Watershed) had a concentration of greater than 1.50 mg/L, and the upper Straight River nitrate concentration was 25% greater that Stoney Brook's. In winter, the nitrate level almost doubles in the Straight River (see below). Sites with elevated nitrate (0.50 mg/L as defined here), were associated with adjacent crop or livestock agriculture.

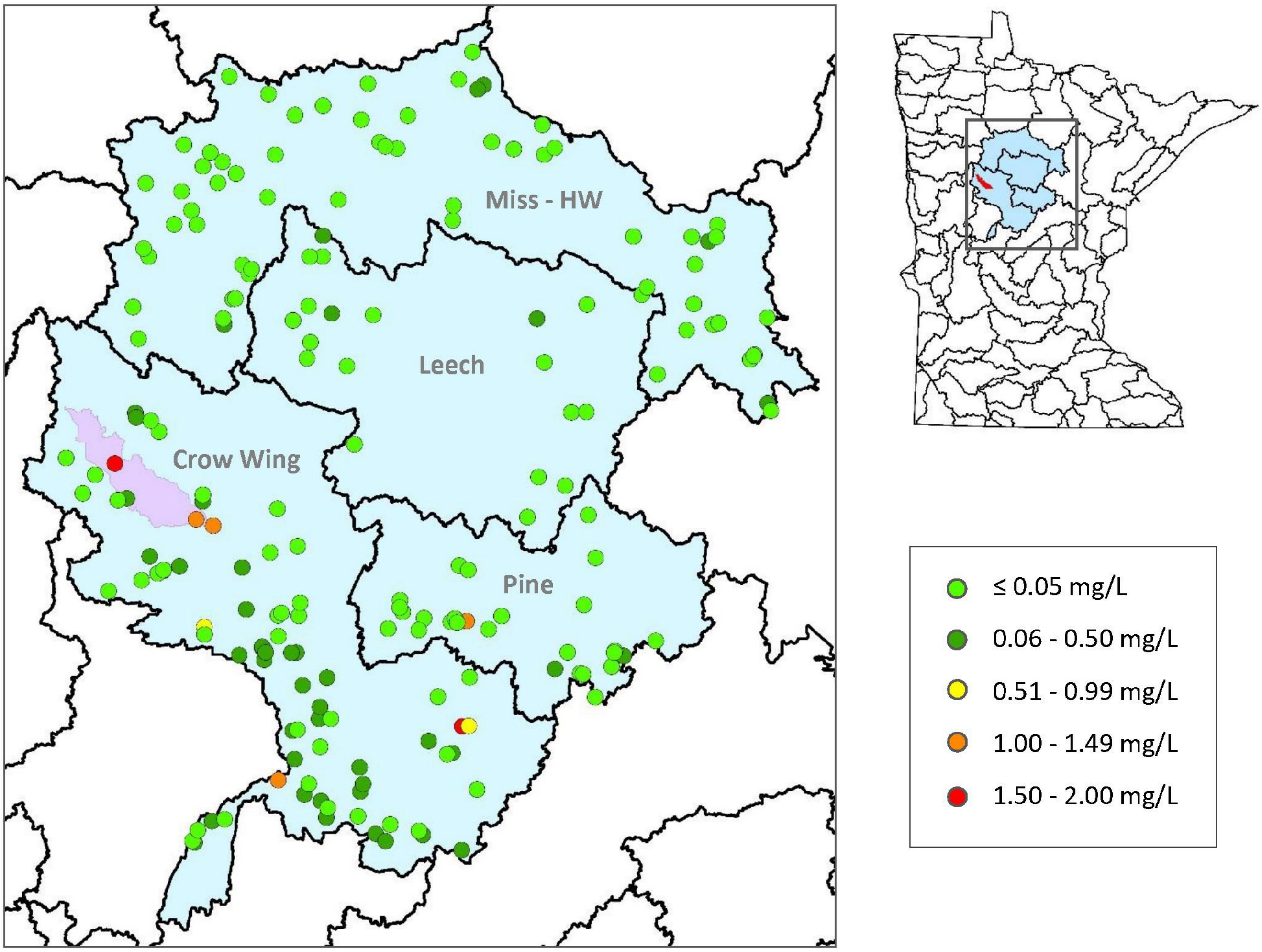

Figure 8. Crow Wing River Watershed nitrate concentrations from all IWM biological monitoring sites in the Crow Wing R., Mississippi R - Headwaters, Leech Lake R., and Pine R. Watersheds.

All sites surrounding the Straight River subwatershed had low nitrate levels (Figure 9). The Fish Hook River also had a high reading, just downstream of where the Straight River enters into it. Above the confluence of the Straight River, the Fish Hook's two monitoring sites had much lower nitrate. This upper part of the Fish Hook River, above the Straight River confluence, would receive runoff from the city of Park Rapids. In fact, the site with the lower nitrate concentration is right in the heart of the city. Nitrate in urban runoff appears to be minimal, relative to the agricultural area of the Straight River. Thus, the higher nitrate in the lower part of the Fish Hook River is likely due to water inputs from the Straight River. The low-nitrate site at about the middle of the Straight River is likely due to the influence the close-proximity, upstream Straight Lake, where nitrate from the upper Straight River is apparently processed.

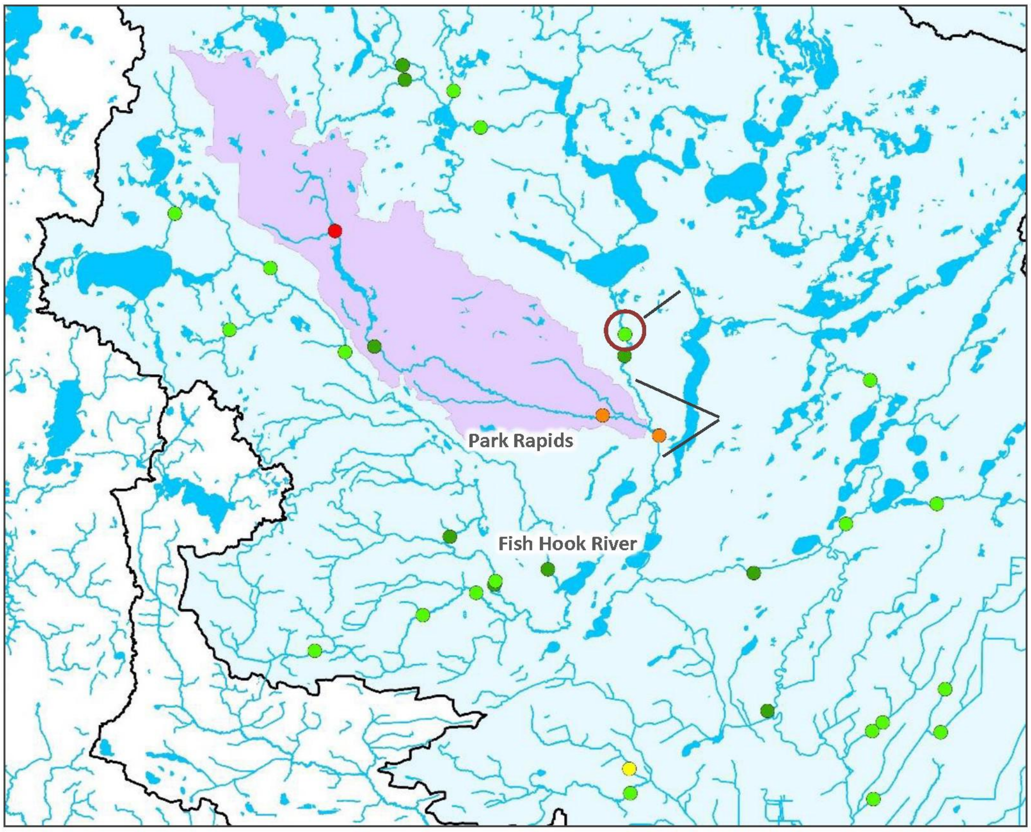

Figure 9. Close-up of the Straight River subwatershed area from Figure 8.

2. **Row crop agriculture is substantially more-densely practiced in the area surrounding the Straight River than elsewhere in the Crow Wing River Watershed** (Figure 10). Irrigated row crop agriculture, and thus row crop agriculture in general, has increased over time in the area surrounding the Straight River. Many fields that were enrolled in CRP (thus idle) were brought into row crop usage by adding center pivot irrigation systems.

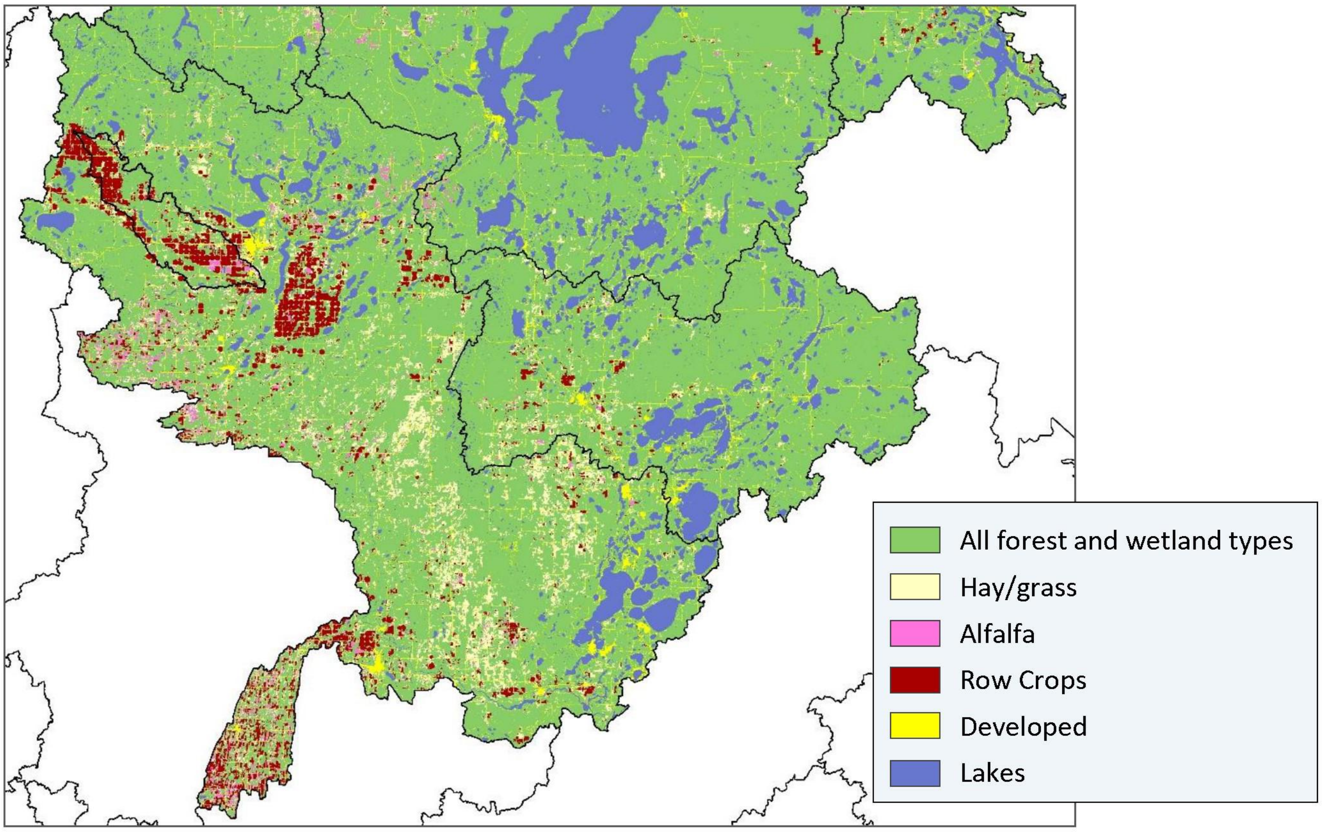

Figure 10. Land Use in the Crow Wing River Watershed (and the three other adjacent watersheds shown above). Source: Minnesota Department of Agriculture 2014 Cropland Database.

3. **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 conductivity measurements, which increase moving downstream (Figure 11). Groundwater has higher conductivity than surface water, because groundwater spends much more time in contact with geologic materials.

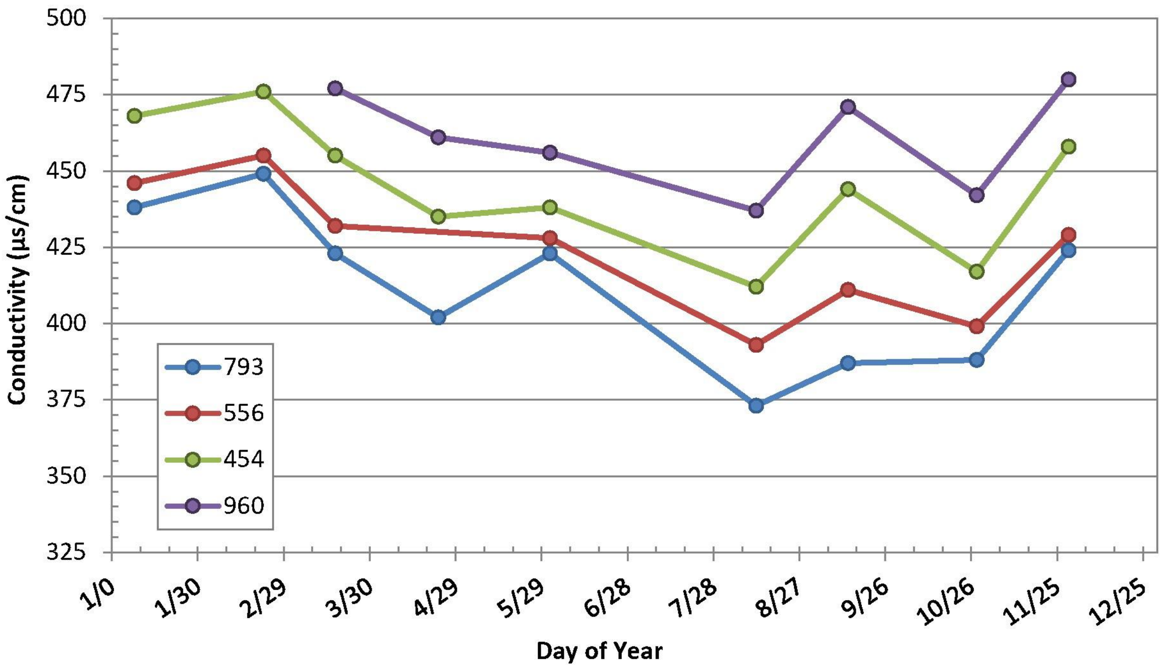

Figure 11. Conductivity at four sites along the Straight River during 4/23/2015 - 3/18/2016. Legend lists sites in upstream to downstream order.

4. **Like the groundwater contributions, nitrate levels increase moving downstream** (Figure 12). The two most upstream sites were essentially the same in nitrate concentration, and so the second-most upstream site was dropped from monitoring in 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. 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).

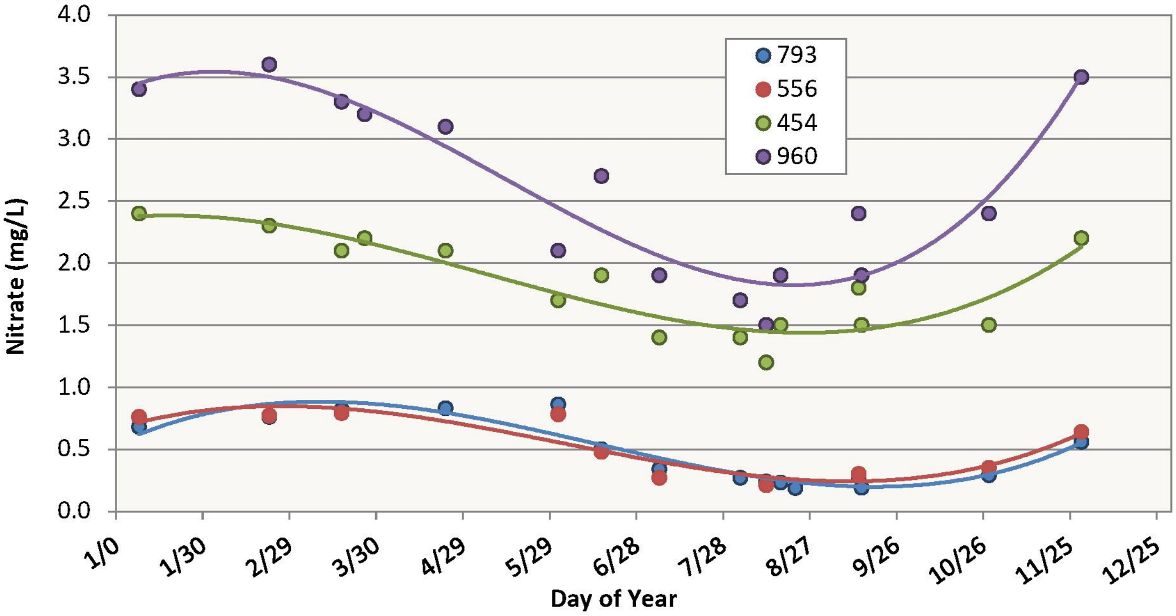

Figure 12. Nitrate concentrations at four sites along the Straight River during 2015-2016. Lines are 3rd order polynomial regressions. Legend lists sites in upstream to downstream order.

5. **Phosphorus concentrations showed several interesting patterns.** Phosphorus levels were lower in 2015-2016 than the 2004-2010 aggregated data (Figure 13). This phenomenon was seen in many different 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 2014-2015, and continued through spring and summer, reducing the water contributions to the streams from wetlands/wetland soils (i.e., a lowered water table existed). It also may be due in part to increased algal growth in the Straight River, made possible by increased nitrogen input to the river.

   There is much dissimilarity among sites from January to June, particularly within-site variability at the lower three sites (Figure 14). After about June 1, the phosphorus concentrations become much less variable within sites, and much more similar among sites. It is suspected that algae play a big role in this pattern, as they would generally start to proliferate in late spring, and thus increase their usage of phosphorus.

   There is a period of rapid decline in the TP concentrations that the data show occurring between approximately May 20 - June 22 (Figure 15). This coincides with the period of new growth of algae as water temperatures rise and days lengthen. Following this period, the remainder of the summer has relatively stable levels of TP.

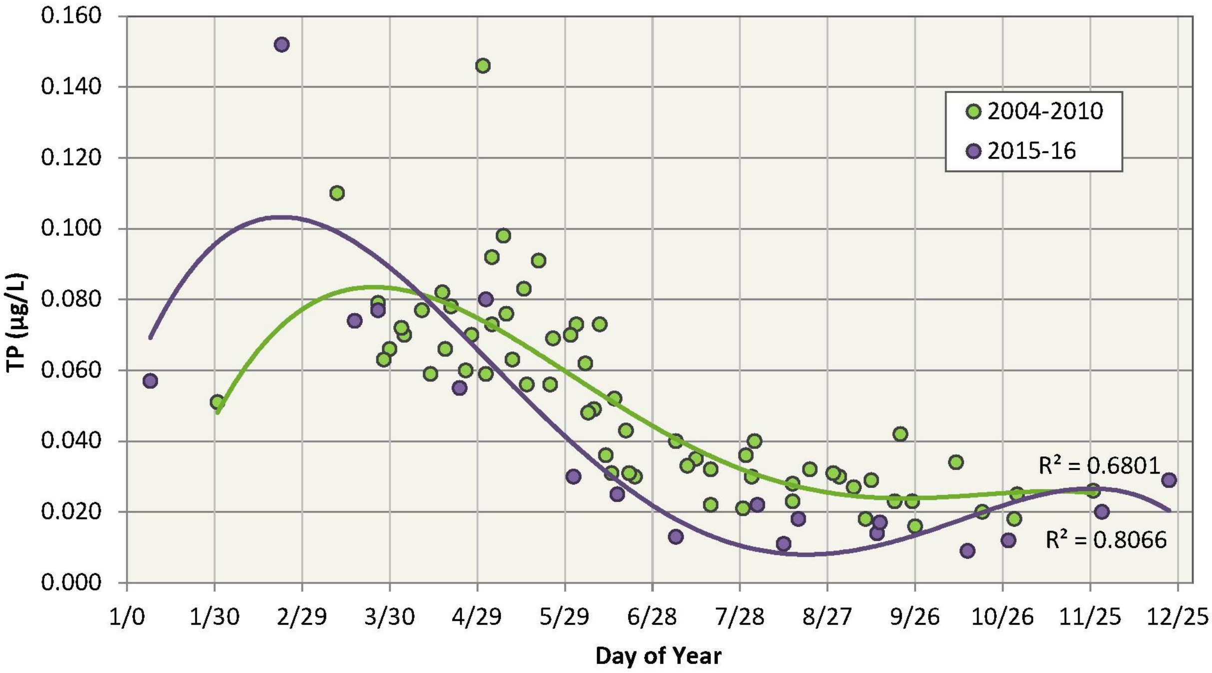

Figure 13. Total Phosphorus at Hwy 71 (S002-960), 2004-2010 vs. 2015-2016. Curved lines are polynomial regression lines with accompanying R^2 values. The big spike in late winter is likely due to the decay of the very abundant filamentous algae that occurs in the Straight River - many tiny, suspended organic particles were observed in the water samples in latter parts of winter (i.e., late Feb./early March).

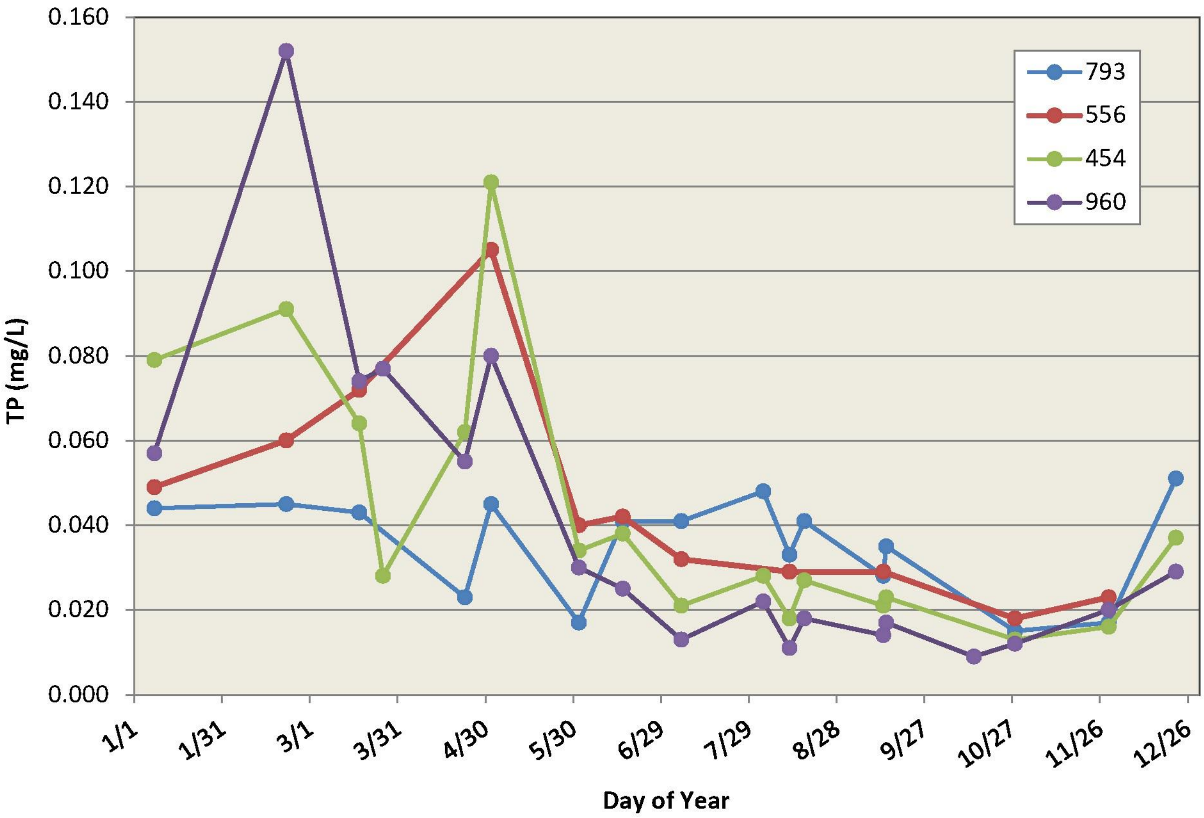

Figure 14. Pattern of TP concentration for the four longitudinal sites from 2015-2016 samples. Legend lists sites in upstream to downstream order.

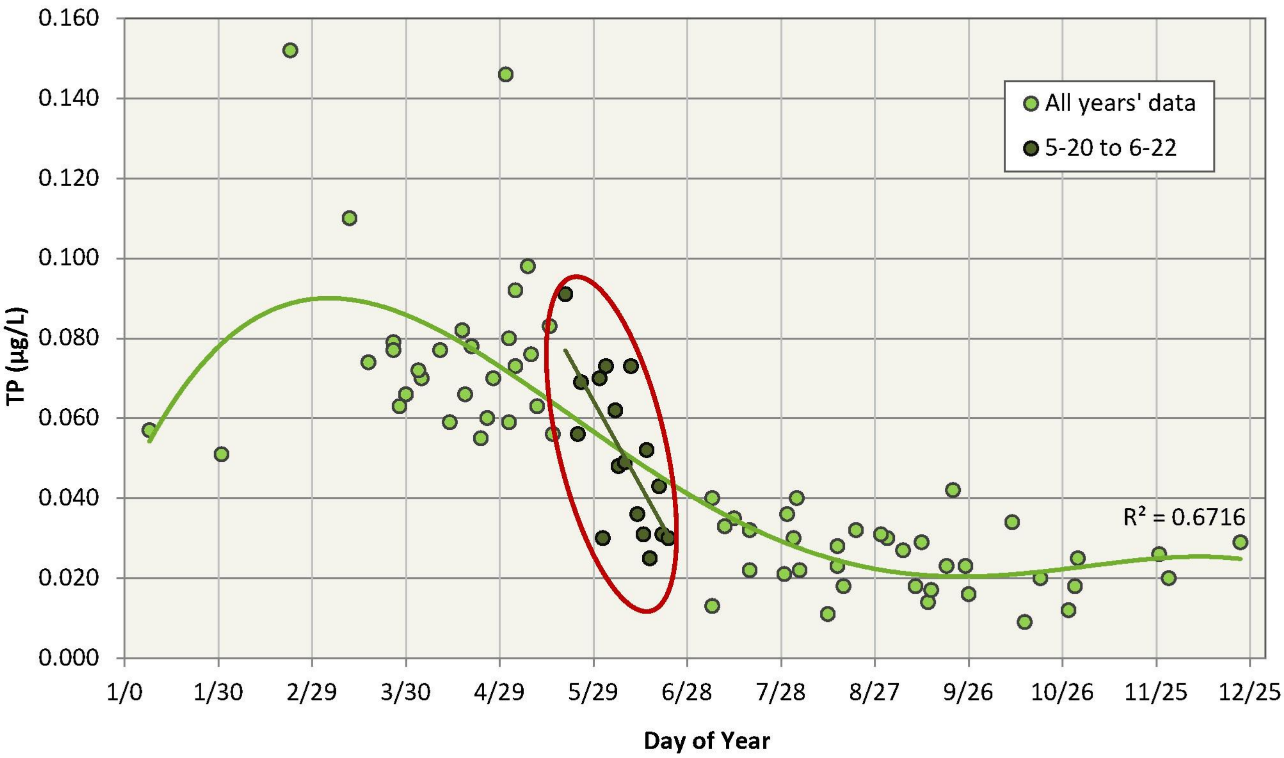

Figure 15. There is a rapid decline in TP concentration between May 20 to June 22 (the data points in the circled area). Data are from State Hwy 71 (S002-960), 2004-2010, 2015-2016. The line within the circle is a linear regression line of these data points.

6. **Contrary to phosphorus, nitrate levels were higher at all periods of 2015-2016 than in the 2004-2010 aggregated data** (Figure 16). The meeting of the trendlines in late November is somewhat misleading, due to the fact that no December samples were taken in the 2004-2010 dataset. This would cause the line to curve under the 2015-2016 trendline (as estimated by the dotted line). This increase in Straight River nitrate concentration occurred in conjunction with increased conversion of fallow farm lands to irrigated row crop agriculture in the Straight River subwatershed (Figures 1, 2, and 3 above), including the period between 2010 and 2013. It is plausible the higher 2015-2016 concentrations reflect the additional irrigation/fertilization from this new irrigated acreage. Additional analysis (e.g., water table elevations, 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 increased irrigation.

   The increase in nitrate between the two sample datasets was tested statistically, and difference was found to be significant (Figure 17). Because of the sinuous pattern of the data, the year was broken into two time periods for significance-testing, spring and summer. Both seasons had highly statistically significant differences between data sets, with p-values of 0.003 and < 0.000 respectively (Mann-Whitney U Test).

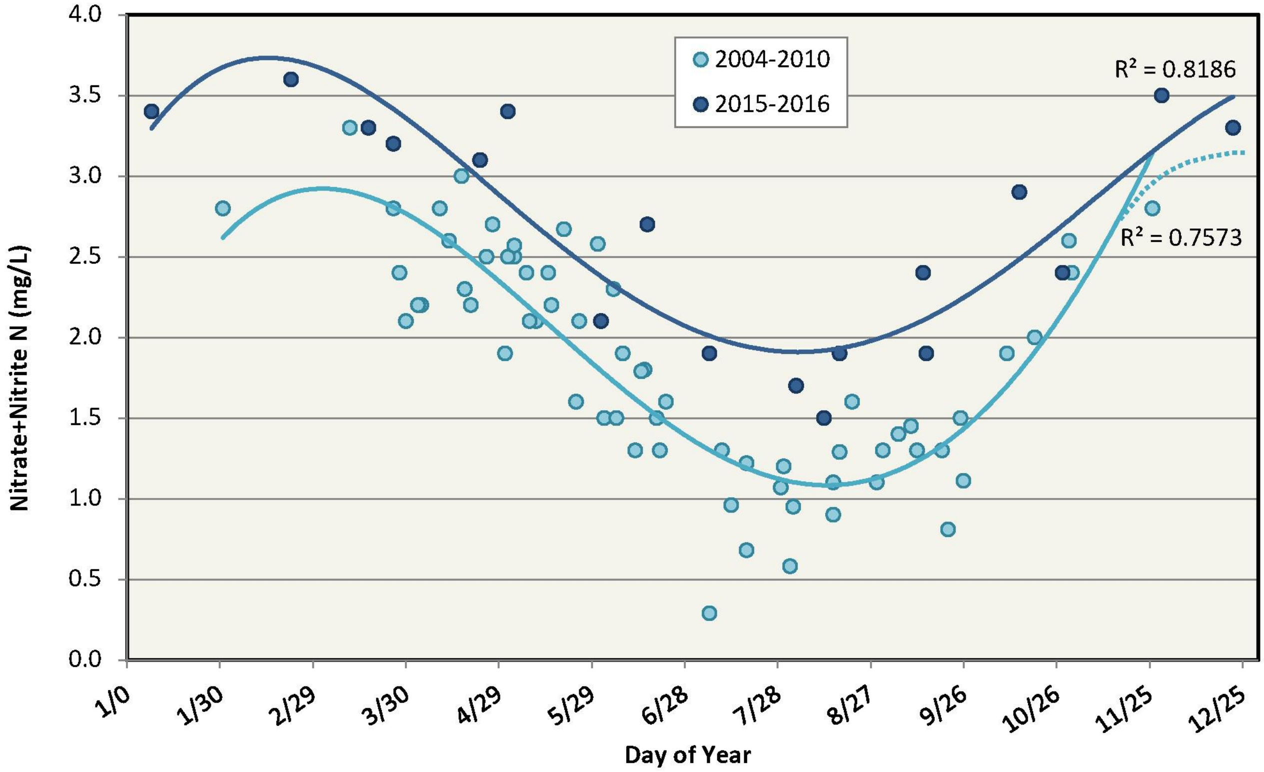

Figure 16. Nitrate data at Hwy 71 (S002-960), 2004-2010 vs. 2015-2016 periods. Curved lines are 4th order polynomial regression lines with accompanying R^2 values.

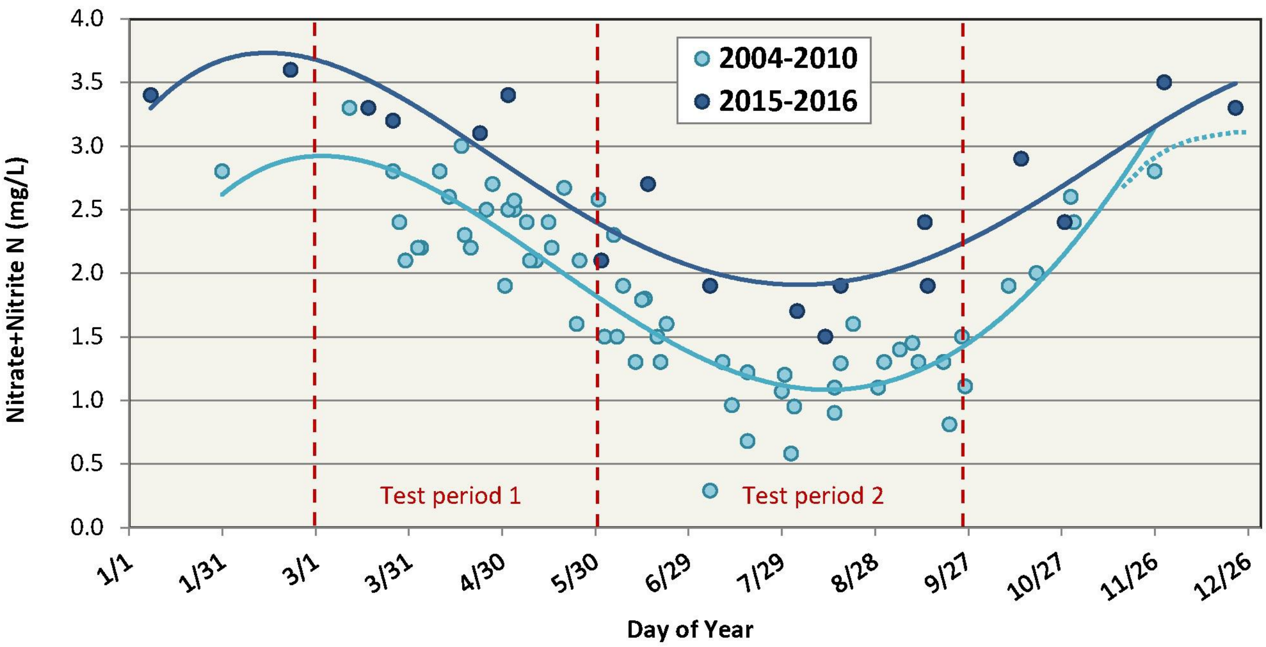

Figure 17. Significance testing of the two datasets, broken into two time periods with many data points, spring (1) and summer (2).

7. **Nitrate in the multi-sampled, streamside spring-outlet water (i.e., groundwater inputs) in 2015 was very high in nitrate** (above the MN drinking water standard - Figure 18). These spring-water sites were not previously sampled, so no time-lapse comparison can be made. The large spring located at 125th is the one that is most easily sampled as spring-water. Nitrate concentrations are very high in this spring's water,

typically about 13-16 mg/L. There is a home located at the top of the hill near the spring, and sampling should be done to rule out this home's septic system as a contributor to this nitrate. However, these nitrate values are similar to the standard-exceeding (> 10 mg/L) values found in the recently-decommissioned Park Rapids municipal well. 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 may be occurring. However, the chloride concentration itself was relatively low for the range found for septic-contaminated groundwater, and the nitrate levels are much higher than typically 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 117th, flowing in from the south side of the river. The nitrate concentration in that sample was 3.0 mg/L. There is no adjacent home site here, and there is less agricultural acreage on the landscape above the groundwater that would be discharging here.

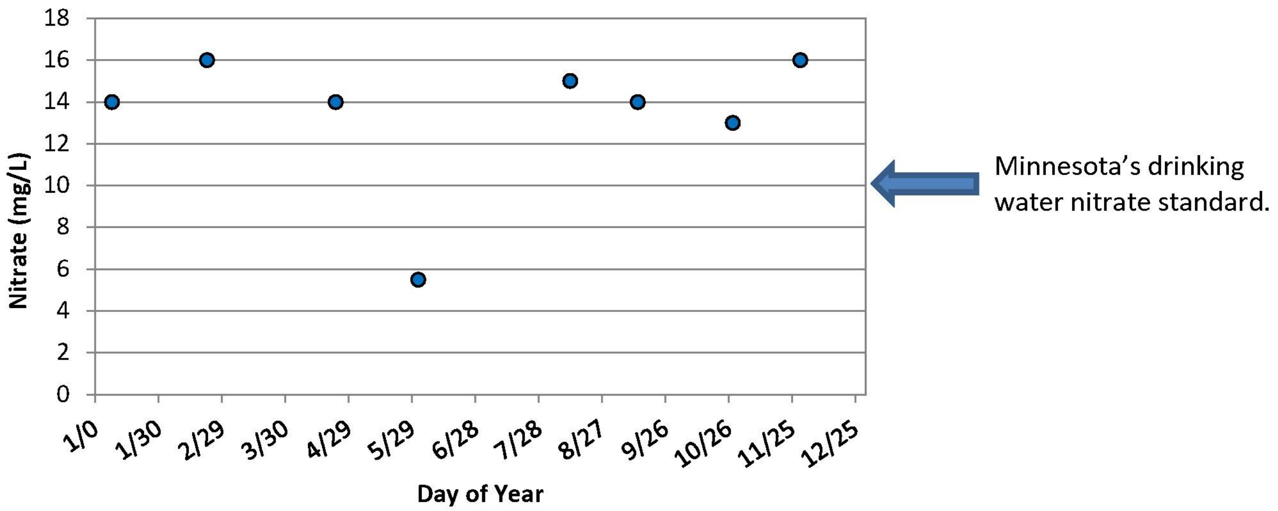

Figure 18. Nitrate concentrations in the large streamside spring flowing into the Straight River at 125th St. Data is from 2015-2016. The sample from 5/29 is thought to be diluted with stream water due to the relatively high stream stage on this date.

8. **DO % saturation is elevated in summer, though infrequently at site 1 (the most upstream site - where nitrate is lowest).** DO % 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 (produces oxygen). All sites had DO % saturation values significantly above 100% in mid- or late summer (Figure 19).

   These over-saturated DO measurements point to observed excess algae and macrophyte growth as the cause of the DO % 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 material 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 waterbodies, 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.

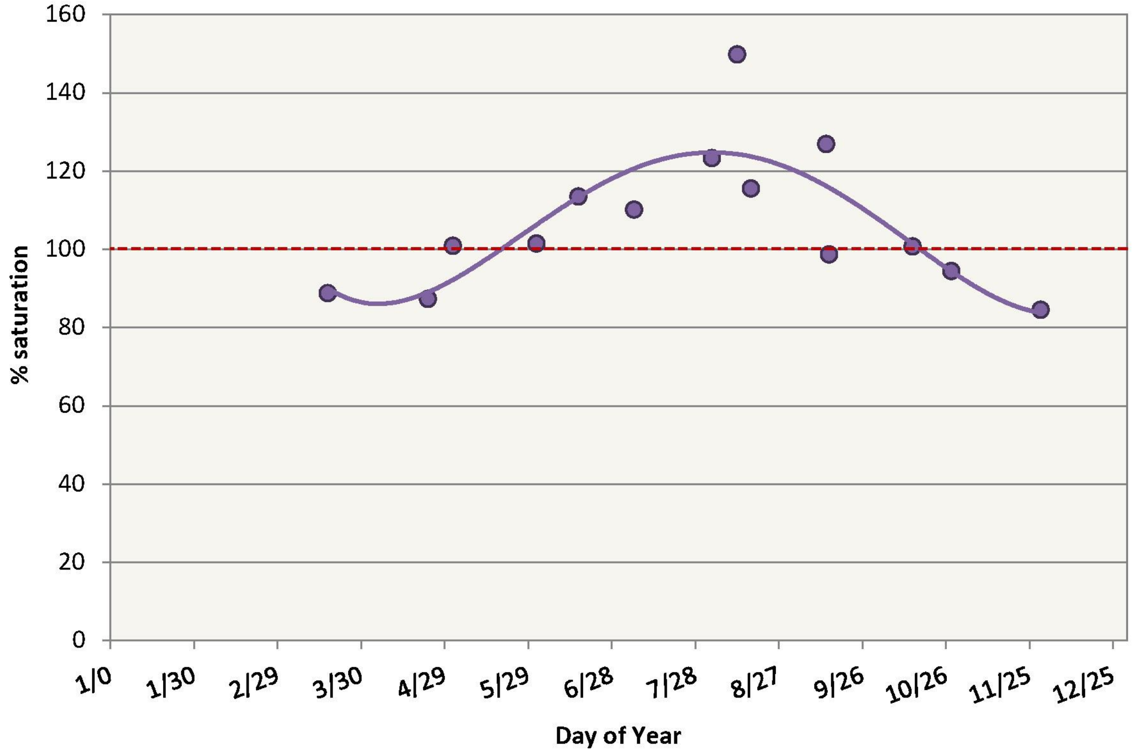

Figure 19. Longitudinal DO % saturation in 2016 at Highway 71, the downstream site. The trendline has a R^2 of 0.6793.

Conclusions

Nitrate concentrations in the Straight River are much higher than elsewhere in the four-watershed north central Minnesota area discussed in this study, with the exception of the near-mouth portion of the Partridge River subwatershed, and the upper portion of the Stoney Brook subwatershed (both also within the Crow Wing River Watershed). The Partridge River subwatershed has a relatively high density of feedlots and pastured acreage, and a fair amount of row crop agriculture. 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 mg/L). Thus, levels in the Straight River are as much as 100 times higher than is typical this area's streamwater.

Putting bullets 1 and 2 together, it is logical to conclude that the increasing nitrate concentration, as one moves downstream in the Straight River, is coming from groundwater inputs, which also increase moving in the downstream direction. The monitored spring at CR-125 had consistently high nitrate concentrations, much higher than the stream water at any site. Higher stream nitrate concentrations in these watersheds are co-located with the areas of relatively high row crop agricultural land densities and/or farm animal production. The landscape patterns of irrigated agricultural acreage, the proximity of agricultural fields to the Straight River, the increase in irrigated agriculture in recent years, and the correlating patterns and levels of nitrate concentrations in the Straight River lead to a plausible conclusion that agriculture, and its intensification are contributing significant amounts of nitrate to the Straight River, that nitrate concentrations in the river are increasing in recent years, and that this nitrate is contributing to the river's impairment of aquatic life use. Nutrient stimulation of plant life in the Straight River has altered the river's DO regime. Possible alterations in groundwater inputs to the river may be an exacerbating factor as well. Studies on the flow volume aspect are ongoing. Nitrate levels are approaching a level that may be toxic to aquatic organisms (based on early work on a definite nitrate standard, which is under development currently).

References:

Katz, B.G., S.M. Eberts, and L.J. Kauffman. 2011. **Using Cl/Br ratios and other indicators to assess potential impacts on groundwater from septic systems: A review and examples from principal aquifers in the United States.** Journal of Hydrology, 397:151-166.

Stark, J.R., D.S. Armstrong, and D.R. Zwilling. 1994. **Stream-Aquifer Interactions in the Straight River Area, Becker and Hubbard Counties, Minnesota.** Water-Resources Investigations Report 94-4009, U.S. Geological Survey, Mounds View, MN. 83 pp.

This has some really nice maps and stats regarding nitrate in Minnesota groundwater...
http://www.gwpc.org/sites/default/files/event-sessions/Mulla_DavidFINAL.pdf