An Assessment of Representative Lake Superior Basin Tributaries
2002

Minnesota Pollution Control Agency

With Cooperation From:

U.S. Geological Survey
Minnesota Department of Natural Resources
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Executive Summary

The beauty and unique setting of Lake Superior's North Shore have made the region a popular recreation destination. It is likely that the numbers of all-season recreationists drawn to the North Shore will continue to increase over the years to come. A substantial part of their recreational experience is due to the quality of the environment. Unfortunately, the same natural features that draw recreationists to the North Shore can make it more susceptible to degradation from the increased attention. For example, cool and cold water fisheries (such as trout) have low tolerances for increased temperatures and the quantities of sediment and nutrients that can originate from typical urban settings.

The purpose of this report is to begin assessing the quality of a representative number of North Shore tributaries along the corridors extending from (1) Duluth to Two Harbors and (2) Two Harbors to the Canadian border. Study findings include:

- While the impact of tourism on the area's economy is substantial, with tourists spending approximately $275 million dollars in 2000 along the north shore area, the impacts of development on the area's sensitive water resources has not been studied. Surprisingly few data have been collected for the North Shore streams over the past 30 years in the systematic manner needed to define present conditions and detect water quality trends over time.
- Six North Shore streams (Amity, Talmadge, French, Sucker, Poplar, and Brule Rivers) were intensely monitored using state-of-the-art computerized stream monitoring techniques that included continuously recording of stream flows coupled with statistically defined sampling in calendar year 2002.
- Flow weighted mean concentrations of water chemistry parameters typically associated with non-point source pollution and eutrophication (total phosphorus and total suspended solids), are greatest in the Duluth to Two Harbors corridor, and decrease farther up the North Shore. This is likely due to a combination of natural watershed variation (size, soils, and slopes etc.) and land use changes such as urbanization.
- Stream total phosphorus concentrations exceeding 75 ug P/L have been associated with nuisance algal growths in other studies (EPA, 2000). Concentrations were 122 ug/L for Amity, and 95 ug/L for the Sucker and Talmadge Rivers.
- Study sites on the Poplar River were chosen upstream and downstream of the lower river valley. Poplar River loading for total phosphorus and total suspended solids increased by factors of about two-fold and six-fold when comparing upstream to river mouth loading rates. While upstream conditions mimicked runoff quality of the pristine Brule River, the downstream station was more similar to loading rates of the Talmadge, French and Sucker Rivers. Increased watershed management activities within the lower Poplar River are strongly recommended.
- Mercury levels in the Poplar River exceeded the state standard, and mercury and suspended sediment levels were strongly correlated. Reducing sediment loss rates in the lower Poplar River will be beneficial for reduction of total mercury quantities into Lake Superior.

- Historical data from the early 1970's suggests that water quality has declined, except in the Brule River- a watershed that has maintained relatively pristine conditions.
- Historical trends in rainbow trout (1973-95) indicate juveniles did not decline in the Talmadge and Sucker Rivers; conversely the juvenile population has declined in the Poplar since 1989.
- The findings of this study need to be considered within the context of predicted climate changes of the next decades that will likely have significant impacts upon the cool and cold water North Shore streams, watersheds and fisheries.
- Given these findings, it is recommended that long-term monitoring of a representative number of North Shore streams continue in order to track water quality trends and to help provide accurate and up to date information for local decision makers.

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Introduction

Overview

Minnesota's North Shore is a highly-valued, scenic region along Lake Superior, the largest freshwater lake in the world. The North Shore stretches 160 miles from Duluth to the Canadian border, where high quality surface water resources are plentiful and enjoyed by a large and growing travel and tourism industry, valued to be in the hundreds of millions of dollars. Lake Superior and its North Shore stream cool and cold water fisheries are also dependent upon maintenance of excellent water quality.

There are 27 primary streams along the North Shore (North Shore Streams), draining an area of 2,184 square miles (MPCA, 1976). The St. Louis River watershed, draining 3,640 square miles, and the Nemadji River watershed of 447 square miles (Figure 1), were considered southern shore streams and are not part of this assessment.

The Minnesota Pollution Control Agency (MPCA) is the lead agency responsible for assessing the quality of Minnesota's waters and works closely with citizens, local units of government, Minnesota Department of Natural Resources (DNR) and interested parties to supply requested water management information. As a part of these ongoing partnerships, the MPCA works closely with the county water planners of Lake, Cook, St. Louis and Carlton Counties of the North Shore, where primary issues of concern have included:

- Protection of cold/cool water fisheries;
- Protection of quality natural experiences associated with premium tourism;
    - Prevention of nuisance water quality conditions; and
- Assessment of climate change impacts

The MPCA has organized its water management programs by major river basins including the Lake Superior Basin. A draft basin plan was recently completed by the MPCA and affiliated partners (MPCA, 2003). For this basin, short- and long-term monitoring needs were assessed by MPCA staff (Wilson, et al., 1999) with the following recommendations:

- Begin long-term monitoring of flows and water chemistry in a representative number of 27 North Shore tributaries.
- Begin long-term monitoring of the Nemadji River.
- Continue monitoring of the St. Louis River.
- Determine the magnitudes of point and nonpoint sources of pollution in the St. Louis River.

The report further recommended that the first priority was to allocate monitoring resources to streams located between Duluth and Two Harbors. The second priority included those streams between Two Harbors and Grand Portage / Canadian border (Poplar, Baptism, Beaver, Temperance, Pigeon and Brule Rivers). Prior to this study, only two North Shore streams had continuous flow gauging (U.S. Geological Survey sites on the Pigeon and Knife Rivers).

The purpose of this North Shore streams assessment project is to begin long-term water quality and streamflow monitoring of representative North Shore streams to:

- assess current water quality conditions using state-of-the-art monitoring techniques;
- provide baseline information for detection of water quality trends over time; and
- assist in the development of stream protection and remediation management options for public, private, and commercial interests.

This study was designed to determine the rates of non-point source pollution on select North Shore streams. Non-point source pollution originates from diffuse sources and can be difficult to quantify. Conversely, "point source" pollution enters a waterway directly through a conveyance such as a wastewater pipe from specific municipal, industrial and/or commercial wastewater facilities. A stream's "load" is the total mass of a pollutant leaving a watershed sampling station and is usually measured in pounds per year. Non-point source loads include a stream's natural levels plus all amounts originating from silviculture, urban and agricultural areas. Stream loading is the product of its streamflow multiplied by the concentration of the substance. These factors help assess eutrophication - the artificial enrichment of water bodies caused by human activities generating excessive additions (beyond natural variability) of water volumes, plant nutrients, sediments and organic matter that combine to produce increased algae, rooted aquatic plants, reduced water clarity and altered streambeds.

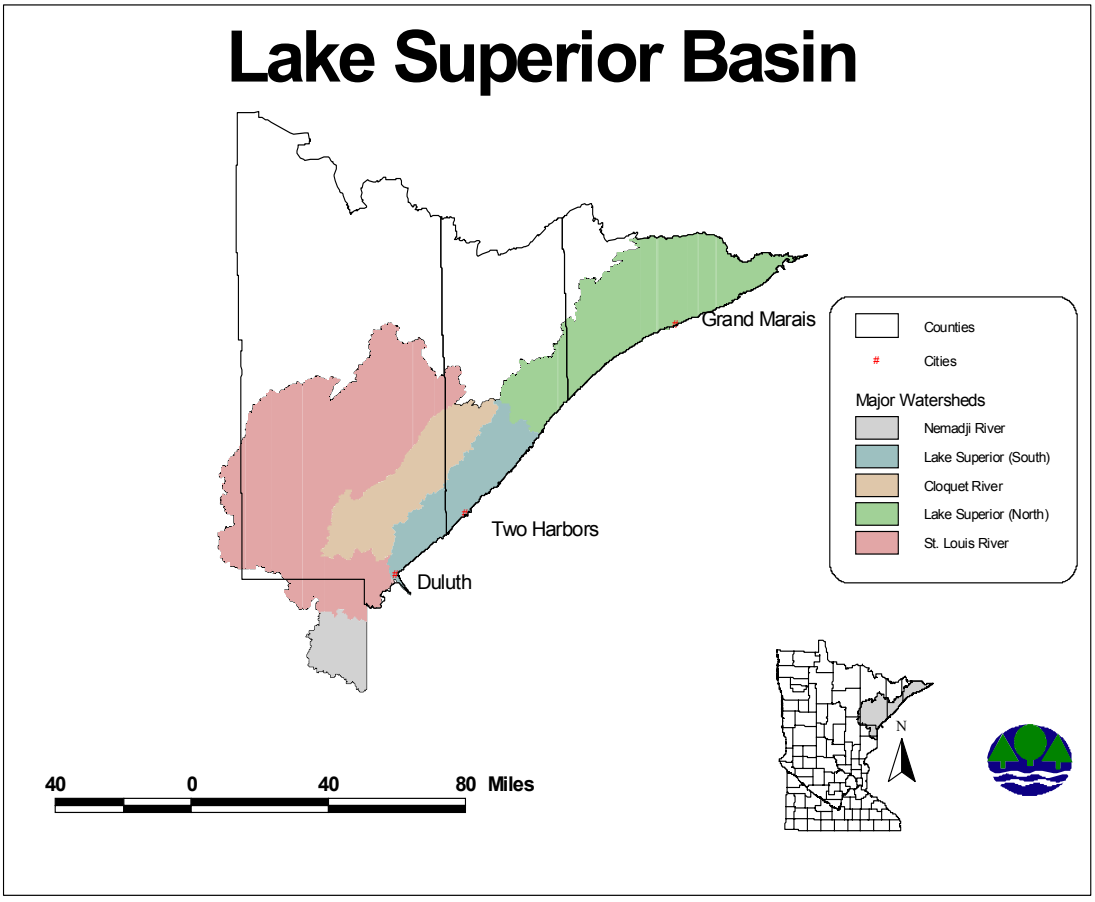


Figure 1. Minnesota's Portion of the Lake Superior Basin

Geomorphology and Climate

The North Shore Streams are deeply entrenched and characterized by swift flows, many rapids and waterfalls, and especially steep gradients before entering Lake Superior (Olcott et. al., 1978). Glacial soils in this area are thin and highly erodible, especially the clay soils in the southern half of the North Shore. Minnesota's shoreline is rocky and bedrock is the major surficial geologic type; however more than half of the coastal zone is composed of erodible glacial and post-glacial deposits in the form of glacial till, sand, gravel, clays and silts (Johnston et al., 1991). The nature of the North Shore stream flows vary as a function of several factors, including the amount of upland wetlands and lakes, with southern streams having faster runoff responses (e.g. flashy) as compared to the more moderate runoff responses of the northern tributaries (Waters, 1977).

Lake Superior moderates the North Shore's climate. Summers are short and cool, and winters have usually been long and snowy. Average annual precipitation varies from 26 inches inland to 28 inches along the Shore (Figure 3), and the median snowfall is 70 inches (Minnesota Department of Natural Resources, 1999); the highest in the state. The north shore area has, on average, the highest amounts of runoff in Minnesota (Figure 2) due to the sleep slopes, bedrock outcrops, clay–dominated soils, and abundant precipitation. The 2002 calendar year was drier than normal; precipitation on the North Shore was 4-10 inches below normal levels (Figures 4 and 5).

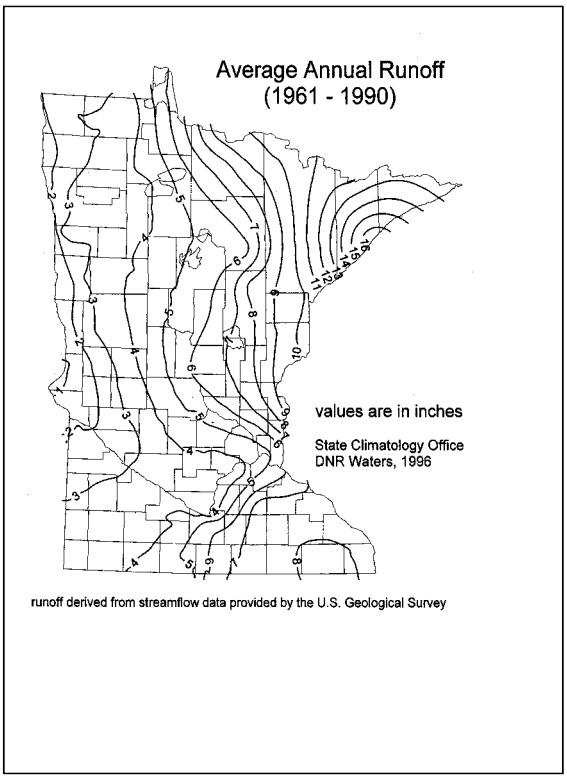


Figure 2. Average Annual Runoff in Minnesota, 1961-1990

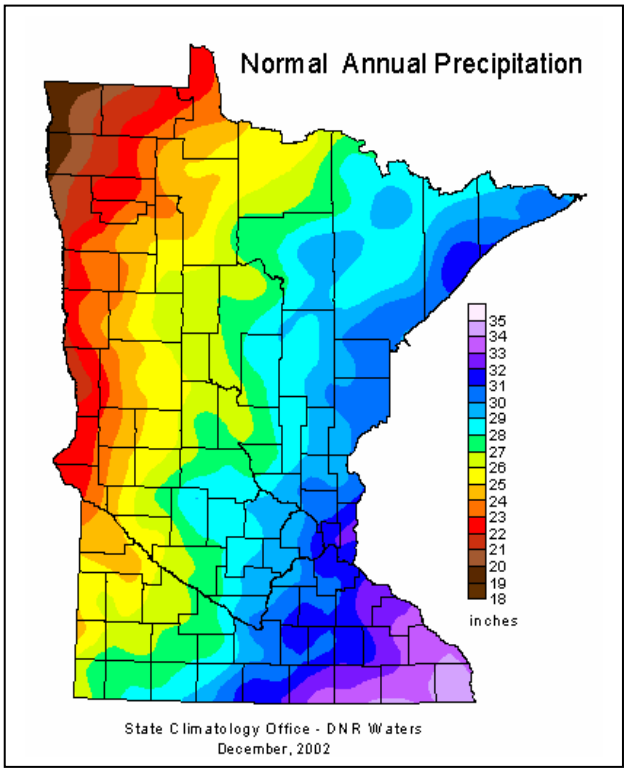


Figure 3. Normal Annual Precipitation

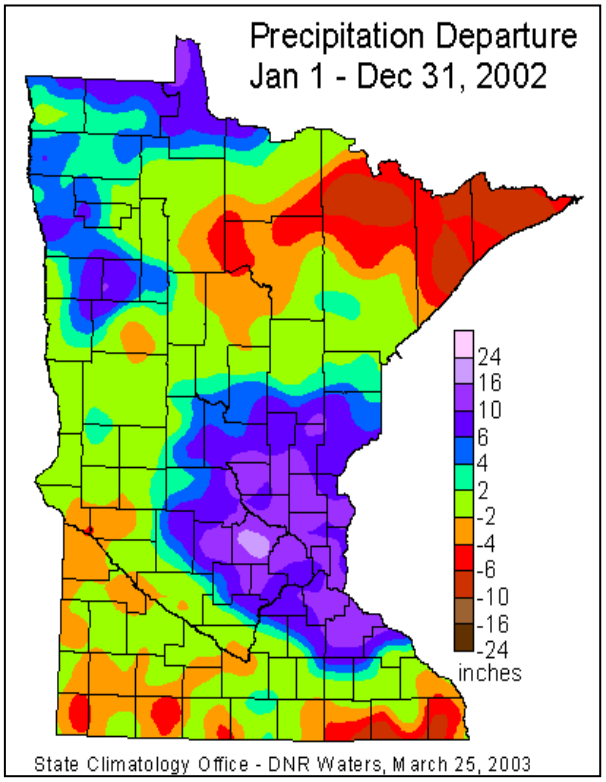


Figure 4. Precipitation departure from normal levels, 2002.

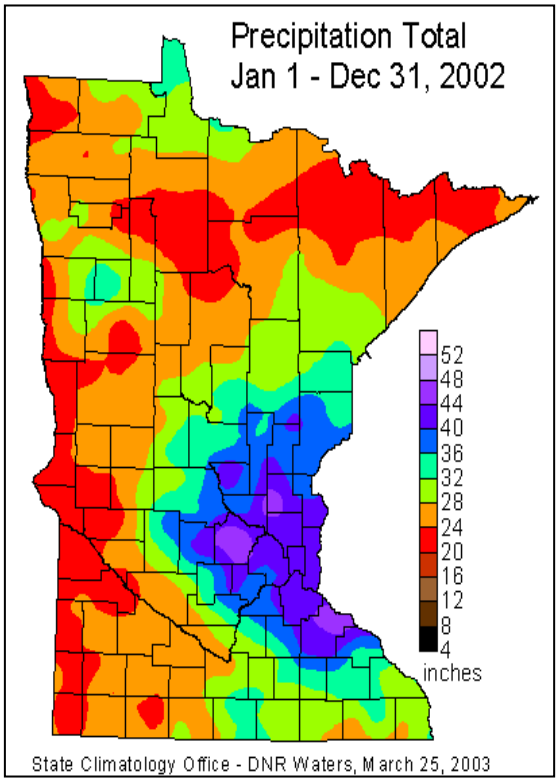


Figure 5. 2002 Precipitation totals

While 37 percent of Minnesota's total land is forested, the Lake Superior watershed is 95 percent forested (Minnesota Department of Natural Resources, 1999). Prior to European settlement, the North Shore drainage basin was dominated by aspen / birch (52%) and pine (37%), with smaller amounts of spruce / fir and maple / basswood (Johnston, et al., 1991).

Demographics

Demographic data for North Shore cities and townships from the 1990 and 2000 Census were compiled for St. Louis, Lake and Cook Counties in Table 1 (Minnesota State Planning, 2003). Duluth is the largest urban area on the North Shore, smaller cities and towns dot the North Shore coast. Duluth's population (in 2000) of nearly 87,000 is more than four times the combined population of all the remaining cities and townships along the Shore (20,034) (Table 1). Development is increasing on the North Shore and it is shown in the recent population figures. From 1990 to 2000, 15 of 17 North Shore municipalities had increasing populations, some increasing as much as 30 to 50 percent (Table 1). Only two municipalities had declining populations (Two Harbors and Tofte Township), and they fell by only one and two percent, respectively.

Table 1. Population of North Shore Area Cities and Townships

County	Municipality	1990 Population	2000 Population	Percent Change (1990 to 2000)
Cook	Grand Marais	1,171	1,353	16 %
Cook	Lutsen Township	240	360	50 %
Cook	Schroeder Township	174	187	8 %
Cook	Tofte Township	231	226	-2 %
Cook	Cook Co. Unorganized	2,052	3,042	48 %
Lake	Beaver Bay	147	175	19%
Lake	Silver Bay	1,894	2,068	9 %
Lake	Two Harbors	3,651	3,613	-1.0 %
Lake	Beaver Bay Township	511	582	14 %
Lake	Crystal Bay Township	460	607	32 %
Lake	Silver Creek Township	1,097	1,178	7 %
Lake	Lake Co. Unorganized	1,961	2,072	6 %
St. Louis	Duluth	85,493	86,918	2 %
St. Louis	Duluth Township	1,561	1,723	10 %
St. Louis	Lakewood Township	1,799	2,013	12 %
St. Louis	Alden Township	147	198	35 %
St. Louis	Normanna Township	462	637	38 %

Sources: U.S. Census, Minnesota Planning, and St. Louis Co. Planning Department

Travel and Tourism along the North Shore

Tourism is a major sector of the national, state, and local economy. In 1995, travel and tourism were estimated to have provided $746 billion to the U.S. gross domestic product (GDP), about 10% of U.S. output, making travel and tourism the second largest contributor to GDP just behind combined wholesale and retail trade (Houston, 1995). In 2001, tourism related gross sales in Minnesota were $9.8 billion, comparable to agriculture in its contribution to the gross state product (Minnesota Office of Tourism, 2001).

The natural beauty of the Great Lakes Shore, with large tracts of relatively undeveloped land, good highway access, and proximity of population centers, have promoted recreation and tourism related travel (Allardice and Thorp, 1995). In the North Shore area, economic figures related to tourism were obtained from the Minnesota Department of Revenue. In 2000, tourism gross sales were nearly $275 million dollars (Table 2). Clearly tourism is a major and growing part of the region's economy, and these economic growth factors are very significant to the region's stability, given the recent decline of the taconite industry.

Table 2, Tourism Gross Sales in the North Shore Area, 1996-2000

Gross Sales, Tourism [1]	1996	1998	2000
Cook County	31,843,165	37,006,306	34,680,301
Lake County	21,110,912	18,107,300	15,082,276
Combined Total	$52,954,077	$55,113,606	$49,762,577

Gross Sales, Tourism	1996	1998	2000
City of Duluth	153,069,941	174,754,912	191,621,071
City of Grand Marais	14,047,520	15,444,807	17,279,785
City of Two Harbors	10,917,380	13,524,108	16,122,867
Combined Total	$177,917,380	$203,723,827	$225,023,723

1. Data in the above two tables depicts information from the Minnesota Department of Revenue, Sales and Use Tax Reports. For the purpose of this report, Gross Sales, Tourism were determined by combining the gross annual sales of three industries (58 – retail: eating, drinking, 70 – hotels: lodging places, and 79 – amusement & recreation) for an approximation of gross sales from tourism. This approach was suggested by Minnesota Department of Trade and Economic Development staff.

The North Shore area is a popular all-season tourism destination because of its scenery, moderate climate, recreational opportunities, and historical significance. Tourism is one of the three "T's" sustaining our region- timber, taconite, and tourism; and people visit this area for its open, ruggedly natural environment (Minnesota Sea Grant, 2001). A partial listing of North Shore recreational opportunities include (MPCA, 1997):

- Eight State Parks
- Numerous campgrounds and wayside rests
- Superior Hiking Trail
- North Shore State Trail
- North Shore Bike Trail (Gitchi Gami Trail)
- Canoeing, sailing and sea kayaking
- Shipwrecks attractive to divers
- Scenic tours by boat and train
- Stream steelhead and trout fishing
- Lake Superior motor boating and charter boat fishing
- Access to Isle Royal and numerous lakes
- Interesting geology including agates and Thompsonite
- Several historical and cultural sites including Split Rock Lighthouse, Grand Portage National Monument, Tofte Fishing Museum, and Cross River Heritage Center

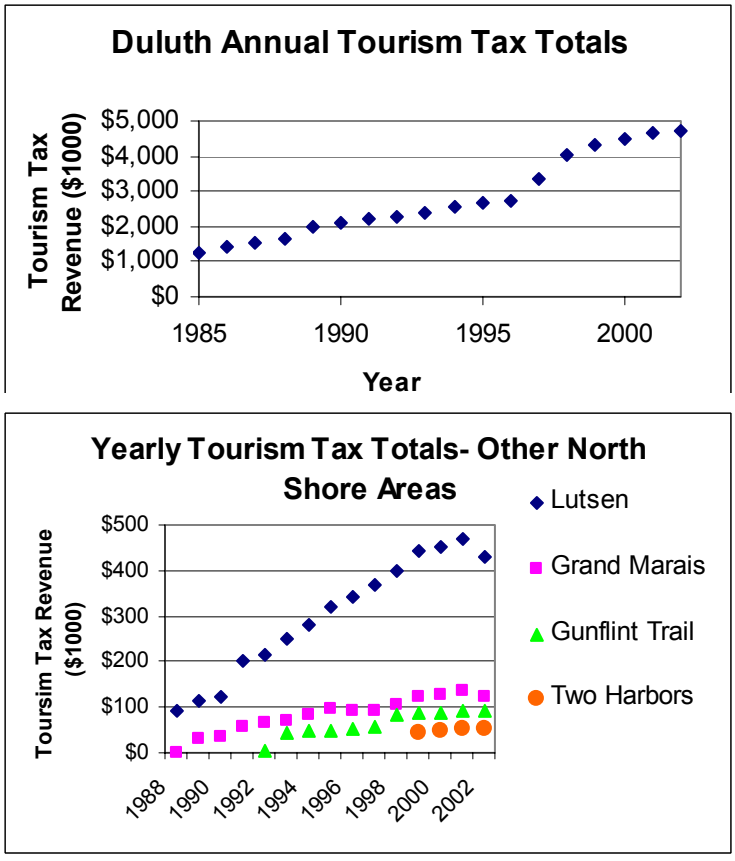
As travel and tourism are heavily dependent upon the quality of the recreational experience, a primary Minnesota "product" will be to maintain the quality of our North Shore recreational areas so as to compete with premium recreational areas of the region (Wisconsin, Michigan, Canada, and western states). As was shown for northern Minnesota lakes, recreationists will seek alternative bodies of water, or reduce their level of activities, in response to perceived water pollution – with algae often used as an indicator of pollution by recreationists (Larson, 1980). Reductions in the number of recreationists will reduce the income and employment attributable to travel and tourism. A recent study found that for lakes in north central Minnesota, water quality has a positive relationship with property prices, and management of the quality of lakes is important to maintaining the natural and economic assets of the region (Krysel, et. al., 2003).

In a similar way, Lake Tahoe (California and Nevada) has been a significant travel and tourist all-season destination for a long time. More tourism and travel income resulted in greater urban growth, more jobs, new housing units, stores and roads. More people meant more sewage wastes, more solid wastes, and fuel consumption. The loss of 75% of its wetlands and 50% of its meadows to roads and housing also resulted in much more runoff and increased loading of phosphorus and sediments into Lake Tahoe (Goldman, 1989). All told, Lake Tahoe has undergone a remarkable degradation with an average loss of lake transparency of about 1 foot / year and the development of unsightly algal scums on the near-shore areas (Goldman, 1989). In response, the states formed a Tahoe Regional Planning Agency to regulate development within the basin – but only after considerable degradation had already occurred.

The North Shore's economic vitality appears to be strong as a drive along the coast reveals much new construction and development. While this report is not an economic assessment in the academic sense, the authors wanted to tabulate an abbreviated list of economic indicators as related to water quality. Future academic economic summaries of the travel and tourism industries would be a welcome addition and better serve the region's decision makers. All data shown below was complied directly from the government entity described. The data have not been edited, modified, or statistically analyzed.

Tourism revenues provide perhaps the best overall economic indicator of tourism. Duluth has collected a tourism tax since 1985. The annual tourism tax amounts were estimated based on the combined totals of the lodging and city sales taxes collected by the city. As can be seen in Figure 6, annual tax totals have increased over the years to values approaching $5 million per year. 2002 was the 14th consecutive year of record tourism revenue (personal communication- Barb Oswell, Duluth Convention and Visitors Bureau, 2003).

Figure 6. Tourism Tax Revenues in Duluth and other North Shore Areas



Municipal lodging and sales taxes collected by Lutsen, Grand Marais, Gunflint Trail and Two Harbors were obtained from 1988 to 2002. Revenues tend to increase every year, but some of these increases reflect an increase in tax rates (Figure 6). For example, many of these municipalities increased taxes from 2% to 3% over the period of record. The combined total in the North Shore area for 2002 approached $700,000 - despite what appears to be a drop-off in revenue due to poor winter conditions.

Minnesota state parks are a large draw to the North Shore area. Park visitor numbers provide a good indicator of overall tourism trends in the area. The authors chose to collect data on a subset of parks, with a range of visitor counts. Combined visitor counts have recently totaled about 1.1 million visitors annually for Cascade River, Gooseberry Falls and Split Rock Lighthouse facilities (Figure 7). Broad usage patterns are less easily discerned due to a variety of differences including modifications in year-to-year counting techniques. But, nonetheless, these are favored state facilities that receive heavy usage. Operation and maintenance expenses were not tabulated in this effort. For comparison, the Minneapolis Chain of Lakes Regional Park receives over 5.5 million visitors per year and years of decline were arrested by a massive water quality restoration effort costing local, state and federal governments about $10.5 million over ten years of watershed implementation (Minnesota Pollution Control Agency, 2002).

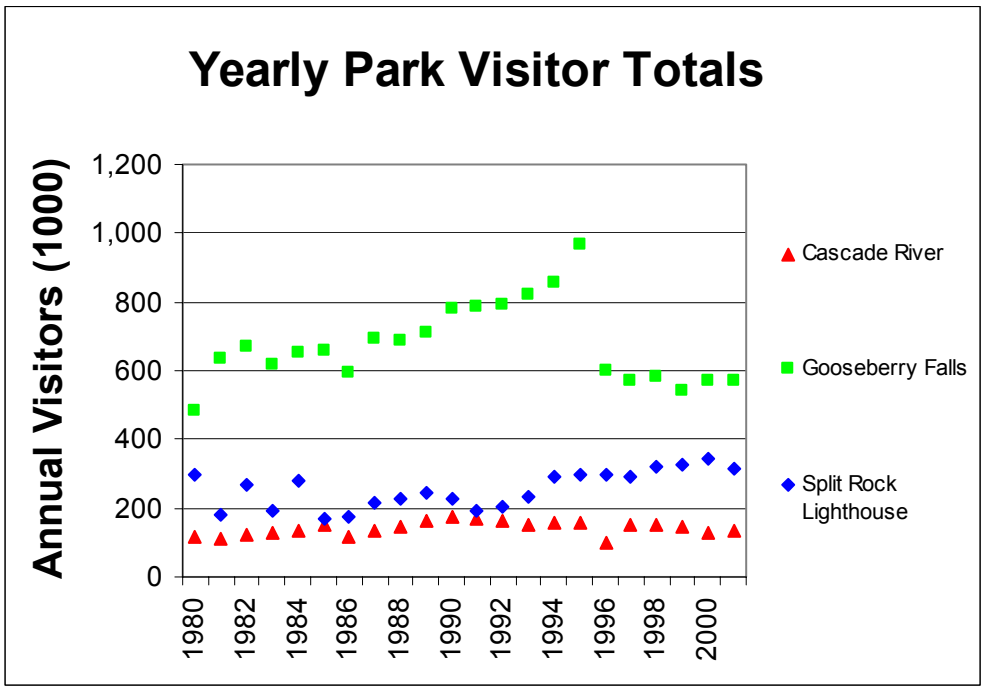
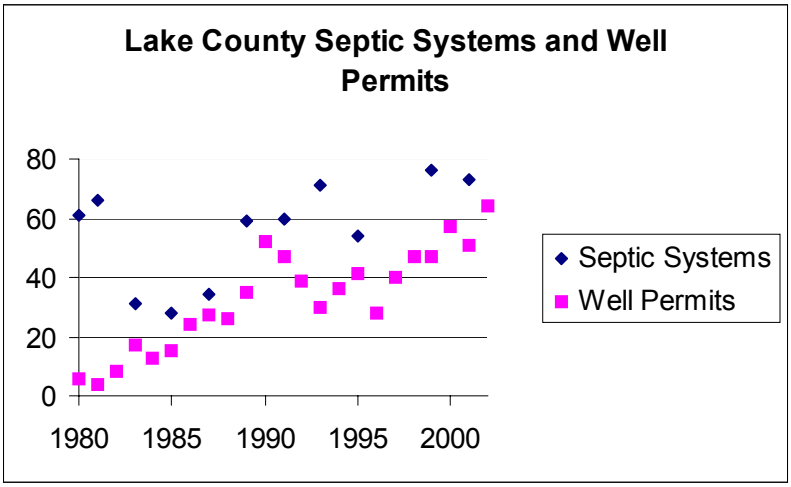


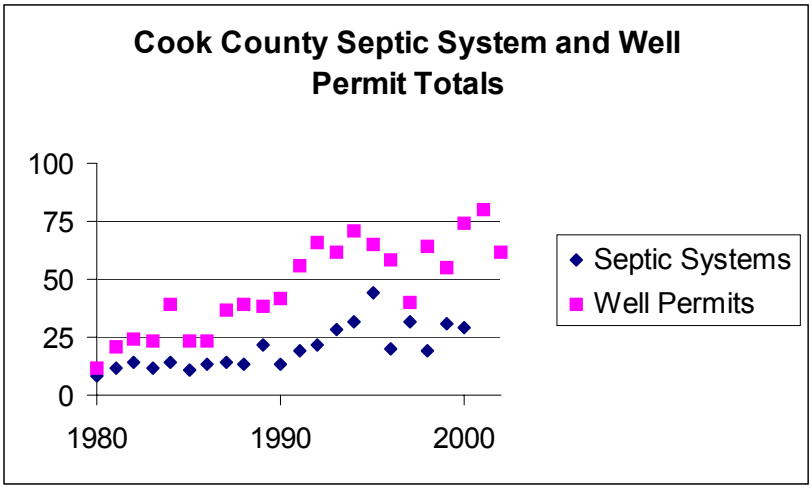
Figure 7. Select State Park Visitor Totals, 1980-2000

Installations of new drinking water wells and septic systems can serve as an excellent indicator of growth, because they are essential for most new residential and commercial developments. Data were compiled for Lake and Cook Counties from 1980- 2001. The well data was retrieved from the Minnesota Geological Survey's County Well Index. The septic system data was retrieved from county permit files. Septic system data were chosen as an indicator, in part, because it was one parameter in which the two counties maintained similar datasets (as opposed to building permits). The goal was to count all new or replaced septic systems installed over 20 years time in the Lake Superior watershed.

The data for each county are shown in Figure 8. As expected, there is a strong correlation between the installations of drinking water wells and septic systems (Figure 8). As may be observed, there is an increasing trend in the number of new wells and septic systems for Cook and Lake Counties over the 21 year accounting time period (please note these are *not* cumulative).

Figure 8. Lake and Cook County Well and Septic System Permit Totals, 1980-2000





Methods

As resources are limited, a subset of the 27 North Shore watersheds was chosen for this study covering a variety of landuses from semi-urban to near pristine. The study streams needed to have varying watershed areas and landuses representative of the Lake Superior Basin. Primary reference stream choice criteria included:

- Designated trout streams;
- Representative streams of the more developed Duluth to Two Harbors corridor;
- Representative streams of the more pristine Two Harbors to the Canadian border corridor;
- Streamflow gauging site with free-flowing, stable cross sectional area;
- Streams varying in drainage area;
- Safe stream monitoring access for streamflow determination and water sampling, given the high stream velocities occurring during peak flows;
- Monitoring location reasonably close to Lake Superior for accurate determination of loads to the lake; and
- Clustered site locations to promote efficient field access for sampling and equipment maintenance.

Standard assessment methods were employed to determine stream flows and loads using public domain software that has been subjected to extensive peer review (Walker, 1999). To properly estimate this on an annual basis, average daily streamflow is coupled with a statistically defined number of water quality samples. Accurate load estimates require collecting approximately 15-25 samples per year with the majority of them taken at higher loading time periods such as spring snowmelt and heavy runoff events. Hence snowmelt and "storm chasing" insures that the annual estimate will be as accurate as possible.

Watershed Descriptions

Amity Creek

Amity Creek is on the northern edge of the city of Duluth, draining an area of 16 mi^2. The main branch of Amity Creek flows southeasterly, until it meets the East Branch, then the stream flows through Lester and Amity city parks, where it meets the Lester River at the extreme northern edge of Duluth. The Creek's average stream gradient of 69.2 feet per mile, among the greatest of the study rivers, and was exceeded only by the French River's gradient (of 70.4 feet). Amity Creek is one of the least urbanized streams in the city of Duluth, but the most urbanized, in terms of population, in this study. The monitoring site is located on Occidential Boulevard on the first bridge upstream from Superior Street. Staff from the city of Duluth also periodically sampled a second monitoring site in the headwaters of the watershed, so water quality comparisons could be determined upstream and downstream of city limits. The Amity Creek monitoring was conducted in conjunction with a project currently monitoring several Duluth area streams (Axler and Lonsdale, 2003 – www.duluthstreams.org).

Talmadge River
The Talmadge River is located primarily in Lakewood Township in St. Louis County. It is located in the more developed region between Duluth and Two Harbors. The stream has a comparatively small watershed (only 5.4 mi^2; Table 3) with an average stream gradient of 66.3 feet per mile of stream. The majority of the watershed is forested, with rural residential development scattered throughout. The monitoring site is located at Cant Road, approximately 2 miles upstream from Lake Superior.

French River
The French River originates in Normanna Township adjacent to the Sucker River drainage. The watershed is not as developed as other streams in the Duluth to Two Harbors corridor. Urban landuse makes up only .01 % of the watershed (Table 3). As mentioned earlier, this watershed has the greatest stream gradient with an average drop of about 70.4 feet per stream mile. Like many other streams in the area, clay soils and sleep clay banks are common. The DNR operates a fish hatchery near the river's outlet to Lake Superior. The monitoring site was located adjacent to the hatchery, about 100 yards upstream from Lake Superior.

Sucker River
The Sucker River originates at the outlet of Paradise Lake in a wetland area of Alden Township. The watershed is one of largest in the Duluth to Two Harbors corridor (39 mi^2- Table 3). The headwaters of the river are relatively pristine, in the lower portions of the watershed, rural residential development is more prevalent. Among the study rivers, the Sucker River had an intermediate gradient of 50.9 feet per mile of stream. The River flows into Lake Superior near the community of Palmers in Duluth Township. The monitoring site is located on Old North Shore Road, approximately one mile upstream from Lake Superior (Figure 9).

Figure 9. Sucker River Monitoring Site

Poplar River
The Poplar River watershed covers an area of about 114 square miles and originates from the Boundary Waters Canoe Area, Hilly Lake area, and includes the Tait Lake/Tait River watershed, and Pike Lake and Caribou Lake watersheds. By the time it reaches the upstream monitoring site, the river has traveled about 23 miles with an average gradient of 20.3 feet per mile of stream, lowest of the study rivers. Significant drops in elevation occur, and by its mouth, the gradient has increased to nearly 41 feet per mile of stream. Most of the development has occurred in the lower Poplar River area, representing about 3.5% of the total watershed area. The Poplar River has the highest percentage of urban land use of the study streams. This area

includes homes and condos, year-round hotels and lodging facilities, as well as golf and ski facilities. Study sites were chosen above and below the lower reach of the Poplar River, separated by about 3 miles.

Figure 10. Poplar River "Downstream" Site at Superior National Golf Course

Figure 11. Poplar "Upstream" Site Looking toward Lutsen Mountains

Brule River

The Brule River was chosen because it is likely the most pristine large watershed on the North Shore. The river originates in the Boundary Waters Canoe Area, flowing through several lakes. Almost the entire watershed is federal or state public land. It flows through Judge Magney State Park as it cascades down the hillside toward Lake Superior. The monitoring site is located on the Highway 61 bridge, about 200 yards upstream from Lake Superior (Figure 12).

Figure 12. Brule R. at Judge Magney State Park, looking upstream

Table 3. Watershed Information for the streams studied

Watershed	Land Use Percentage [1]					Watershed Area (mi^2)	Stream Length in miles (% River Miles Sampled)	Stream Gradient (ft/mile)
	forest	urban	pasture	water	wetland			
Amity Creek	70.8	2	14.0	0.9	11.0	16.3	9.8 (96%)	69.2
Talmadge River	76.1	0.1	3.2	1.4	18.1	5.4	4.6 (87%)	66.3
French River	90.1	0.01	0.05	4.9	4.2	19.6	11.2 (100%)	70.4
Sucker River	86.0	0.6	0.3	7.4	5.3	39.1	15.7 (94%)	50.9
Poplar River upstream	N/A	N/A	N/A	N/A	N/A	112.3	22.7 (89%)	20.5
Poplar River downstream	81.2	3.5	10.4	0.2	2.8	114.0	25.5 (100%)	40.8
Brule River	75.4	0.3	4.3	1.3	18.1	270.1	40.3 (99%)	30.3

1. Data from the MN DNR (1995)

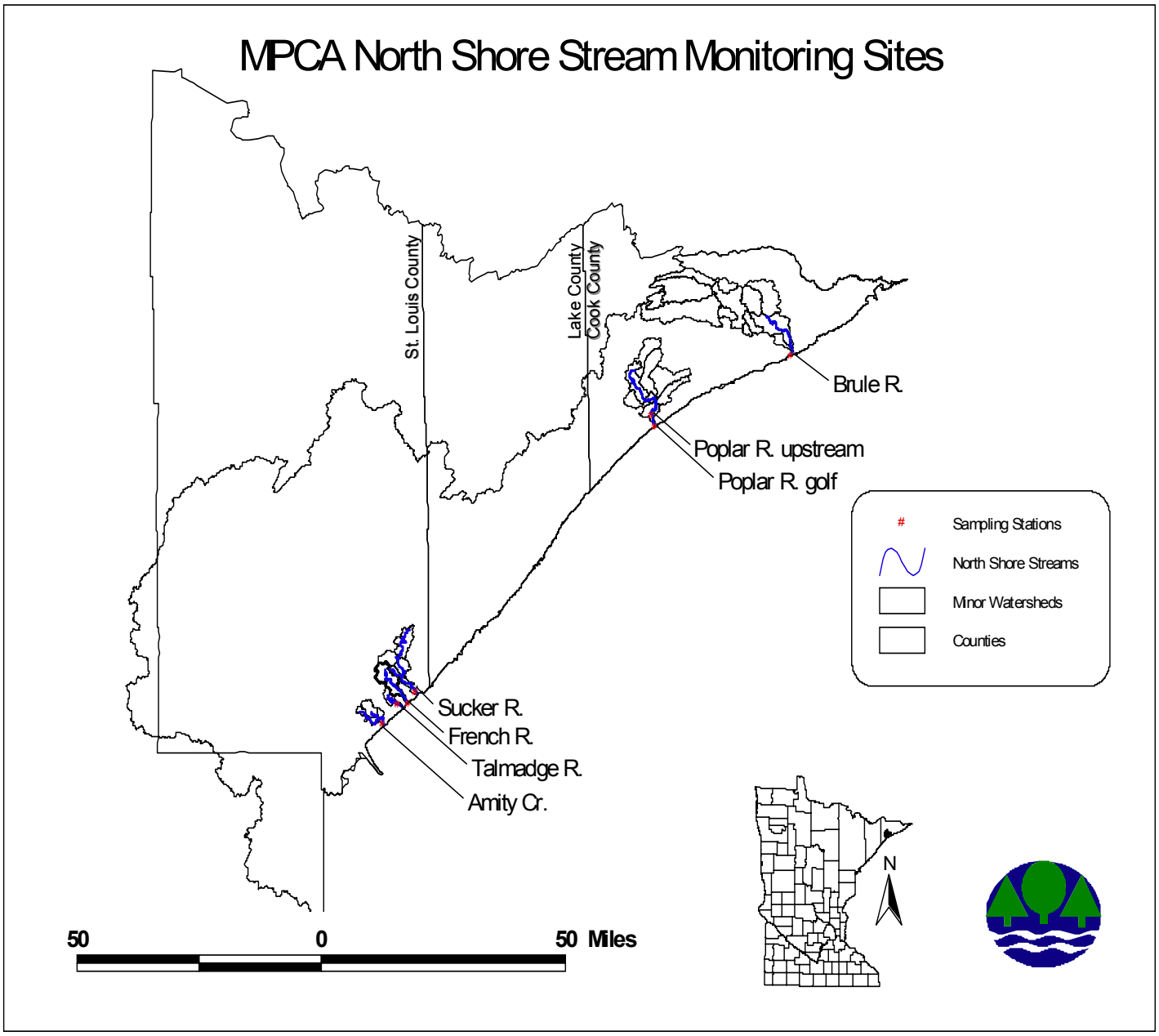


Figure 13. Watershed and sampling site locations

Streamflow Measurement

Stream stage (elevation) was monitored continuously using automated equipment. Ultrasonic sensors were mounted on the bridge directly over the stream's thalweg, or section of main flow. These sensors compute the elevation of the water surface by measuring the time required for an acoustic signal to travel to the water surface and back. Measurements are taken every 3 minutes. An average of these individual measurements is computed and stored in the memory of the datalogger at 15 minute intervals. Thus, each day, 96 individual measurements of stream stage are stored. The sensors have an accuracy of +/- 0.03 feet. The data were downloaded at regular intervals (2-3 weeks) with a portable storage module, or over a phone line, and stored by MPCA staff for analysis.

A rating curve, or a mathematical relationship between stream stage (stream water level) and stream flow rate (discharge, in cubic feet per second or cfs), was determined for each stream. Multiple measurements of streamflow and stage, taken concurrently, over a range of high to low flows are required to construct rating curves. MPCA and U.S. Geological Survey (USGS) staff measured streamflow using established USGS protocols (Rantz, 1986). USGS staff took the measurements during the high flow events, such as snowmelt. MPCA staff measured streamflow under lower conditions, when the streams were wadeable. At the end of the field season, USGS staff compiled the data and constructed the rating curves, using established methods (Rantz, 1986). An example rating curve is included in Appendix 4.

During the field season, MPCA staff performed periodic maintenance checks on the accuracy of the automated stage data by manually measuring stage with a steel tape and comparing this to the instantaneous datalogger value. The margin of error in the manual measurement was estimated at 1-3 inches because the elevation of water surface can vary due to waves and turbulence (at higher flow events), high winds affecting the placement of the steel tape on the exact top water surface, and random measurement error. No systematic significant errors at any of the monitoring sites were detected in 2002. The stage dataset was also screened for random errors, which occur rarely, due to power surges or power failures. Detected errors were filtered out of the datasets before computations were done.

Mean daily streamflow values were computed from the elevation data (which had been screened and filtered). In the spring, corrections had to be made based on ice flow. In the winter of 2001-02 the smaller streams froze nearly to the stream bed. During the spring breakup, melting snow flows over the solid shelf ice on the stream channel. The sensor reads the elevation of the flowing water *plus* the elevation of solid ice below it. A correction, called an ice shift, had to be made so just the elevation of the water was measured. This was done for each day shelf ice was visible, approximately the first 3-5 days of the spring snowmelt in 2002.

Unfortunately, two instances of vandalism occurred at our sites during the summer of 2002. The sensors and dataloggers at the Amity Creek and the Sucker River were destroyed and a significant amount of stream stage data was lost. Amity Creek was not monitored from May 14 – July 30, and the Sucker River was not monitored from July 31 – October 29th. All equipment was replaced as soon as possible. To fill in the missing data, we simulated the missing stage data using data from our nearest monitoring station (Talmadge River). The Talmadge River is located only 5 miles from the two other sites and is very similar hydrologically and with respect to land use (Table 3), slope and soils. Standard regression analyses were conducted to simulate the missing data, regressing the Talmadge River (independent) stage to the corresponding dates of data from Amity and Sucker River. This was done over the entire large dataset, including 13,000 to 23,000 instantaneous measurements. The resulting regressions were statistically sound and provide excellent quality data for the missing time periods (Figure 14 and 15, with R^2 values of 0.94 and 0.71, respectively).

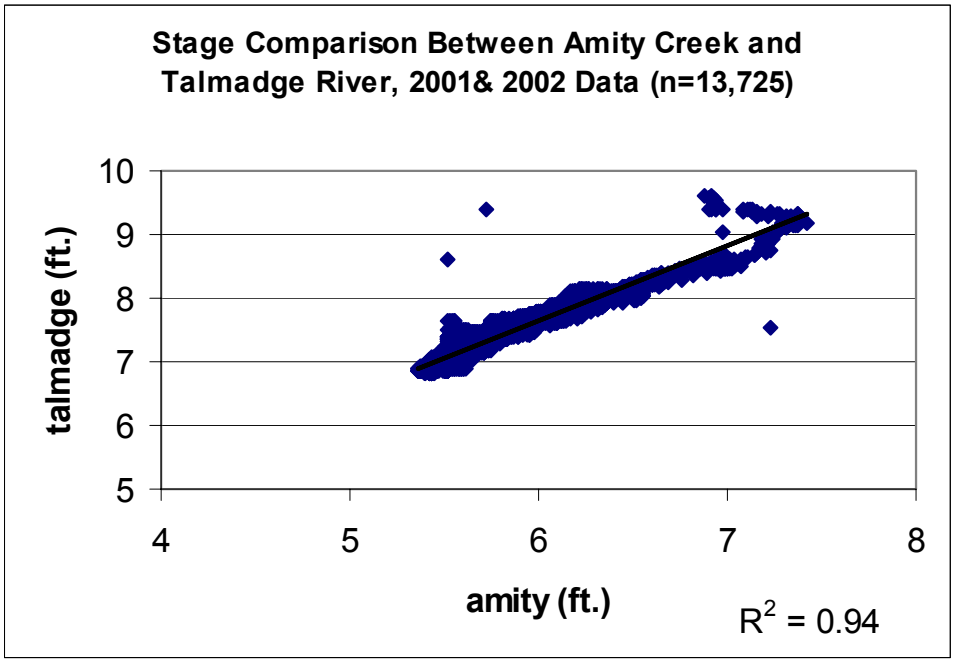


Figure 14. Stream stage comparisons between Amity and Talmadge Rivers.

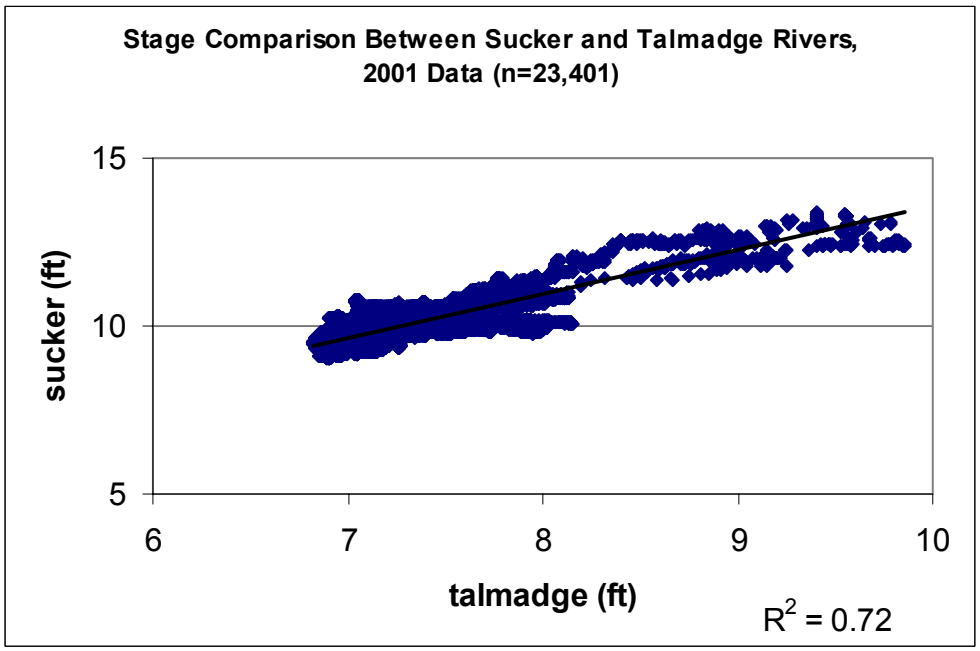


Figure 15. Stream stage comparisons between Sucker and Talmadge Rivers

Water Quality Sampling

Water quality sampling was conducted according to approved MPCA quality assurance procedures (MPCA, 2000). Grab samples were collected mid-stream at the point of greatest flow. This was done from a bridge using a weighted bucket during high flows. The bucket was rinsed with ambient water twice before sample collection. During lower flows, when streams were wadeable, water was collected directly into the sample bottles. As mentioned above, our protocol calls for stream sampling over a range of flows, with most samples collected at higher flows. Our general guideline for a "rain event" sample was when precipitation exceeded one-half inch in 24 hours.

Samples were analyzed at the Minnesota Department of Health's chemical laboratory in Minneapolis for the following parameters: alkalinity, chloride, Kjeldahl nitrogen, nitrite + nitrate nitrogen, total phosphorus, ortho-phosphorus, total solids, total volatile solids, total suspended solids, total dissolved solids, and turbidity. Additionally, in the field, measurements of stream temperature, dissolved oxygen, pH, conductivity, and stream clarity (transparency) were collected. Select quality assurance samples - field blanks and duplicates, were also collected to test the accuracy of our sampling techniques. Summarized results, including quality assurance data, are shown in Appendix 3.

During 2002, the city of Duluth staff took additional water quality samples from Amity Creek at a location just upstream of city limits for comparison with the MPCA monitoring site (downstream). To ensure collection of timely high flow samples, Karen Evens, Cook County water planner, periodically collected samples at the Poplar and Brule river sites. MPCA sampling and laboratory protocols were followed.

Mercury Sampling

Mercury sampling of the Poplar River was conducted under contract with the Metropolitan Council Environmental Services' Dr. Steven Balogh. Samples were collected at two sites on the Poplar River near Lutsen, Minnesota, between April 15 and October 14, 2002. Thirteen samples were collected at the Lutsen resort, near the mouth of the river. Five additional samples were collected at a site upstream of the developed area ('Poplar – Upstream'). All samples were collected in rigorously acid-cleaned Teflon bottles using appropriately clean sampling procedures to minimize the risk of contamination. Following an acid/permanganate digestion of the whole water sample, total mercury (THg) was determined in each sample by cold vapor atomic fluorescence spectrometry with preconcentration by single gold-trap amalgamation. Ancillary water quality parameters (total suspended sediments (TSS), volatile suspended sediments (VSS), dissolved organic carbon (DOC), calcium, chloride, sulfate, chlorophyll a, chlorophyll b, and chlorophyll c) were determined in separate samples obtained at the same time as the samples for THg analysis.

Loading Calculations

Loading calculations were determined using the computer model FLUX, a standard assessment technique developed by the US Army Corps of Engineers (Walker, 1999). In order to estimate loads using FLUX, two input files (daily flows and sample concentrations) are required. FLUX is an interactive program designed for use in estimating the loadings of nutrients or other water quality parameters passing a tributary sampling station over a given time period. Using six calculation techniques, FLUX maps the streamflow / concentration relationship developed from the sample record onto the entire flow record to calculate total mass discharge and associated error statistics (Walker, 1999).

Estimates of loads and flow weighted mean concentrations were made for: total phosphorus, total nitrogen, total chloride, and total suspended solids- principal indicators of non-point source pollution. Further data analyses were conducted on the model outputs. Loads were divided by the stream drainage area to compute yields. Finally, yields were divided by runoff amounts (in inches) to calculate yields 'normalized' for precipitation, because precipitation amounts vary along the North Shore area.

Results and Discussion

Amity Creek

Amity Creek, with a watershed of 16.3 mi^2 located on the northern edge of the city of Duluth, is the most urbanized stream in this assessment. The 2002 hydrograph is shown in Figure 16 with the red triangle symbols marking dates of water quality sampling. A view of the hydrograph shows the spring snowmelt peak of about 300 cubic feet per second (cfs) in April, after which flows quickly receded to very low baseflows in the 5-30 cfs range (Figure 16). Occasional storm events generated rapid stream flow increases throughout the spring and early summer, with a peak annual flow of 350 cfs immediately following a 3 inch rain storm in early July. The rest of the summer was characterized by relatively dry weather and low flows, as measured flows were less than 50 cfs (Figure 16). Base flows, the flows occurring between storm events, were quite low with typical values in the 2-5 cfs range which are quite low for maintenance of riffles and pools. Annual runoff totaled about 11.5 inches in 2002.

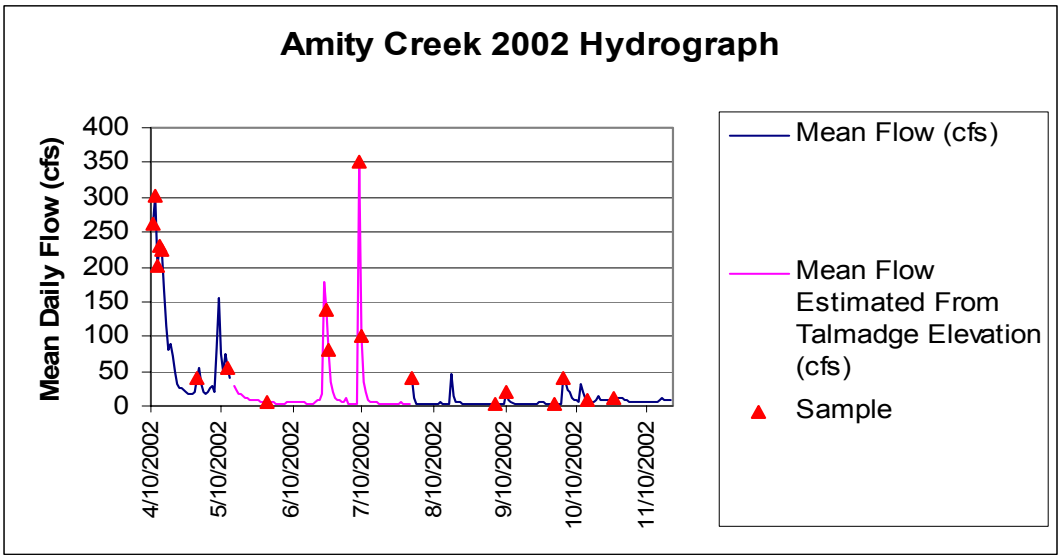


Figure 16. Amity Creek 2002 Hydrograph and Sampling dates

Chloride (Cl) levels are often used as a conservative tracer in streams as well as an indicator of human impact in a watershed. Chloride is commonly found in wastewater and road salt runoff, and levels tend to be low in undeveloped or undisturbed areas. The flow weighted mean (FWM) chloride concentration noted for Amity Creek (16 milligrams per liter -mg/L) was more than twice as high as any other North Shore stream (Table 7.). In a similar fashion, the annual FWM total suspended solids or TSS (an overall indicator of soil erosion) concentration was estimated to be 72 mg/L, nearly two times greater than other streams monitored in this assessment. Alkalinity is a rough indicator of stream productivity and mineral content, and water "hardness" expressed as calcium carbonate. For all streams, but most pronounced on Amity, alkalinity levels were highest during the baseflow. During baseflow, groundwater makes up most of the streamflow discharge. During runoff events, the higher alkalinity groundwater is diluted by snowmelt or precipitation runoff.

Tables 5-8 shows the flow weighted mean concentrations monitored in 2002 by each stream broken down by analyte. It is evident that the highest flows are associated with the highest levels of erosion / non point source contributions. For example, on Amity Creek, TSS concentrations averaged 29, 69, and 3 mg/l during snowmelt, rainstorms, and baseflow respectively (see Appendix 3 for a statistical summary). Higher streamflows are associated with higher nutrient and sediment levels because: 1) at high flow, the stream can carry more suspended material simply because there is more water in the channel, 2) the high turbulence increases stream-bank erosion and channel scouring and more readily maintains suspension and transport of solids in the water column, 3) nitrogen and phosphorus are bound to the fine grained suspended particles, thus their concentrations follow patterns in suspended sediment (Anderson et. al, 2000).

In 2002, city of Duluth staff took water quality samples at an additional Amity site, upstream of city limits for comparison purposes (Table 4). Standard MPCA assessment protocols were followed. Fewer samples were collected at the upstream site, but a general pattern was evident, as arithmetic mean concentrations of nutrients, total suspended sediments and chloride were all higher at the downstream site. This likely occurred because of increases in population, bank erosion, and stream gradient from the headwaters of the river to the outlet. Above the ridge line, Amity Creek is a very small stream with limited rural-residential development. At the downstream site, the stream borders an urban area, and flows through a steep, clay-dominated river valley.

Table 4. Water quality comparison between 'Upstream' (Riley Rd.) and 'Downstream' (7 Bridges) sites on Amity Creek in 2002.

Site	# of Samples	Total Suspended Solids (mg/L)				Total Chloride (mg/L)				Total Phosphorus (mg/L)			
		mean	median	max	min	mean	median	Max	Min	mean	median	max	min
Amity 'Up'	9	5.8	3.6	18	1	8.9	7.4	17	4.9	.047	.056	.079	.012
Amity 'Down'	20	44.5	21	330	1	16.4	18	25	5.1	.072	.066	.261	.007

Site	# of samples	Total Alkalinity (mg/L)				Total Nitrogen (mg/L)			
		mean	median	max	Min	Mean	median	max	min
Amity'Up'	9	37.6	29	72	19	.97	.98	1.39	.67
Amity'Down'	20	57	49	110	20	.99	1.07	1.58	.36

FLUX outputs for total phosphorus, total nitrogen, total chloride, and total suspended sediments at all sites are shown in Tables 5-8. In 2002, Amity Creek had the highest flow weighted mean concentration of TSS, total phosphorus, and total chloride (Figure 17), despite having the second lowest streamflow volume. These results reflect the combined effects of the watershed's comparatively steep gradients and urban areas. Amity Creek watershed is very efficient at moving sediment from its watershed. However, sediment movement occurs mainly during rare, high flow events (Figures 17, 18). Amity also had the highest runoff coefficient, although all Duluth to Two Harbors corridor streams had similar runoff estimates.

Table 5. 2002 FLUX Output- Total Phosphorus

Site	Total Stream Flow Volume (m^3 X 10^6)	Load (lbs)	Flow Weighted Mean Concentration (ug/L)	Yield (lbs/mi^2)	Normalized Yield (lbs/mi^2/inch runoff)	Runoff Coefficient [2]
Amity	12.32	3,306	122	201	17	.38
Talmadge	3.62	759	95	139	13	.35
French	14.02	1,912	62	97	8	.37
Sucker 2001	30.64	6,403	95	164	13	.36
Sucker 2002	28.38	3,309	53	84	7	.38
Poplar-down	43.51	5,214	54	45	7	.22
Poplar-up	42.88 [1]	2,289	24	20	3	N / A
Brule	82.83	3,826	21	14	3	.21

[1] streamflow estimated based on drainage area difference from gauged 'Poplar- Down' Station
[2] Runoff coefficient- portion of total annual precipitation that becomes streamflow. Multiply this number by 100 to express this as a percent. For example 38% of the total precipitation that fell in the Amity Creek watershed became flow in the stream.

Table 6. 2002 FLUX Output- Total Suspended Solids

Site	Total Stream Flow Volume (m^3 X 10^6)	Load (tons)	Flow Weighted Mean Concentration (mg/L)	Yield (lbs/mi^2)	Normalized Yield (lbs/mi^2/inch runoff)	Runoff Coefficient
Amity	12.32	984	72	120,092	10,516	.38
Talmadge	3.62	171	43	62,952	6,234	.35
French	14.02	648	42	66,125	6,081	.37
Sucker 2001	30.64	1,681	49	86,213	7,221	.36
Sucker 2002	28.38	477	15	24,494	2,215	.38
Poplar-down	43.51	1,474	30	25,872	4,459	.22
Poplar-up	42.88 [1]	251	5	4,482	772	N / A
Brule	82.83	600	6	4,447	954	.21

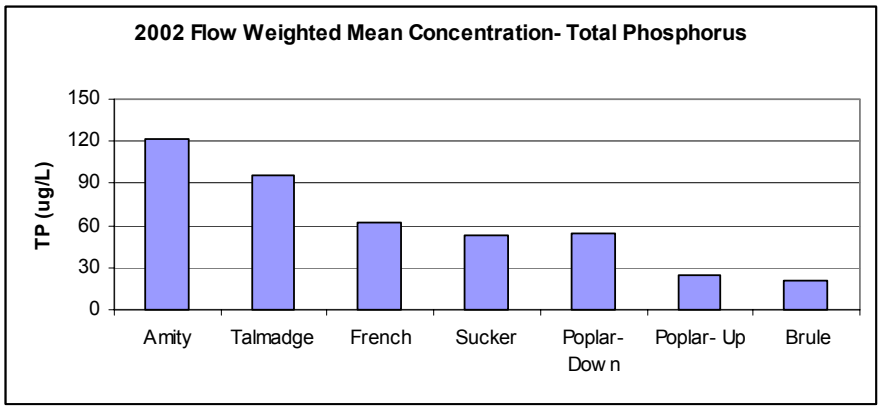
[1] streamflow estimated based on drainage area difference from gauged Poplar- Down Station

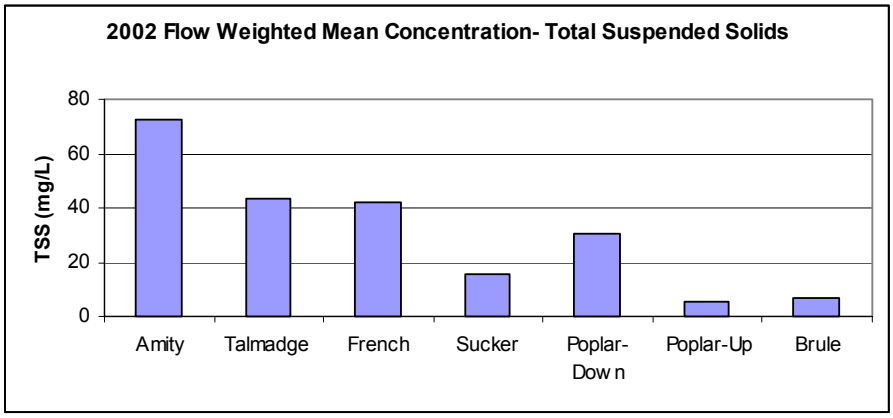
Table 7. 2002 FLUX Output- Total Chloride

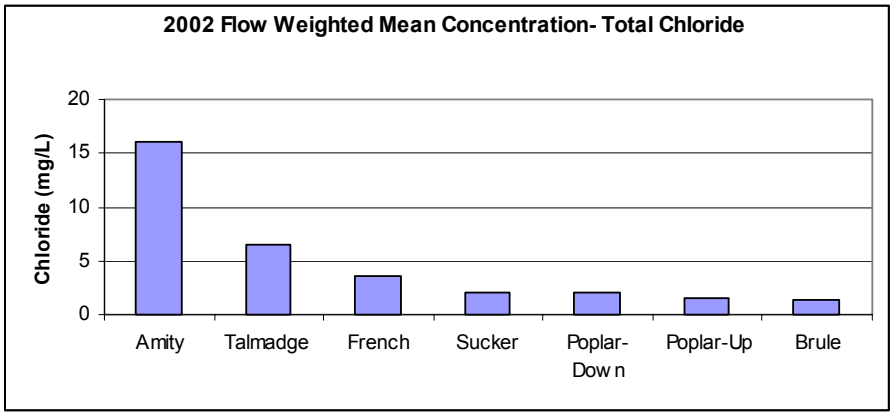
Site	Total Stream Flow Volume (m^3 X 10^6)	Load (tons)	Flow Weighted Mean Concentration (mg/L)	Yield (lbs/mi^2)	Normalized Yield (lbs/mi^2/inch runoff)	Runoff Coefficient
Amity	12.32	217	16.0	26,493	2,320	.38
Talmadge	3.62	26	6.58	9,615	952	.35
French	14.02	56	3.67	5,775	531	.37
Sucker	28.38	63	2.04	3,265	295	.38
Poplar-down	43.51	96	2.02	1,695	292	.22
Poplar-up	42.88 [1]	72	1.54	1,292	222	N / A
Brule	82.83	130	1.43	964	206	.21

Table 8. 2002 FLUX Output- Total Nitrogen

Site	Total Stream Flow Volume (m^3 X 10^6)	Load (tons)	Flow Weighted Mean Concentration (mg/L)	Yield (lbs/mi^2)	Normalized Yield (lbs/mi^2/inch runoff)	Runoff Coefficient
Amity	12.32	14	1.06	1,751	153	.38
Talmadge	3.62	4	1.07	1,563	154	.35
French	14.02	12	0.79	1,243	114	.37
Sucker	28.38	27	0.89	1,424	128	.38
Poplar-down	43.51	40	0.84	705	121	.22
Poplar-up	42.88 [1]	37	0.79	663	114	N / A
Brule	82.83	61	0.68	458	98	.21







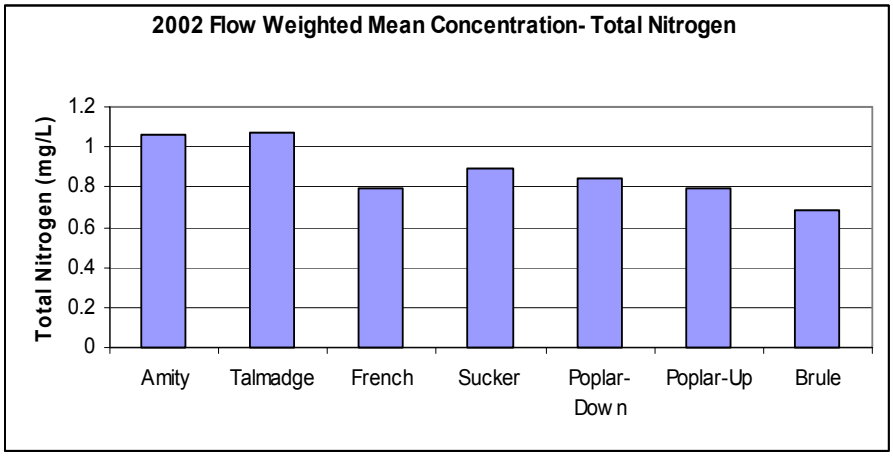
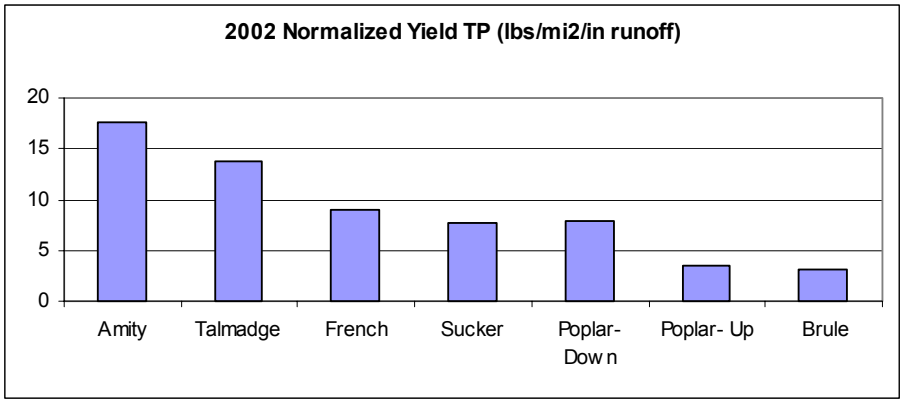
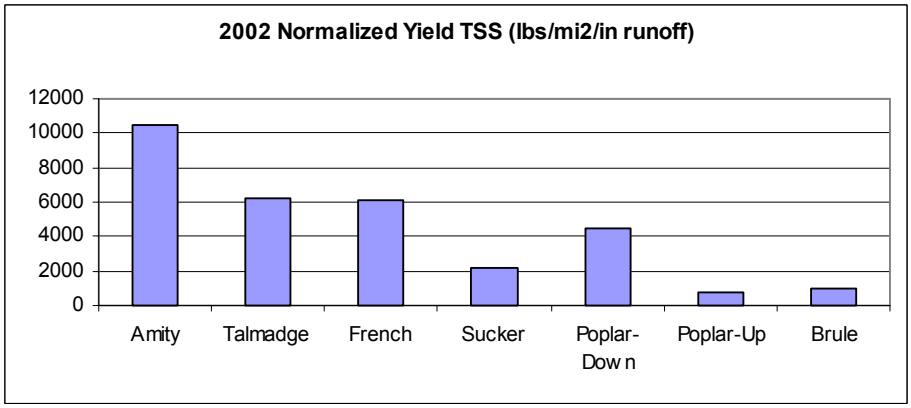
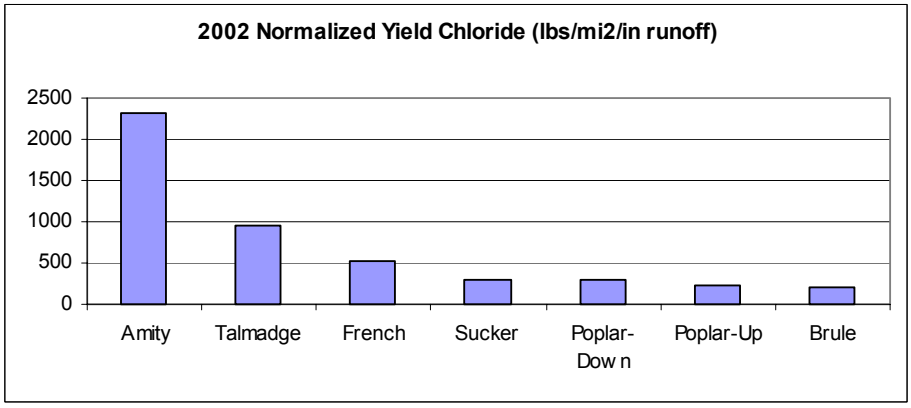


Figure 17. Graphs of Flow Weighted Mean Concentrations







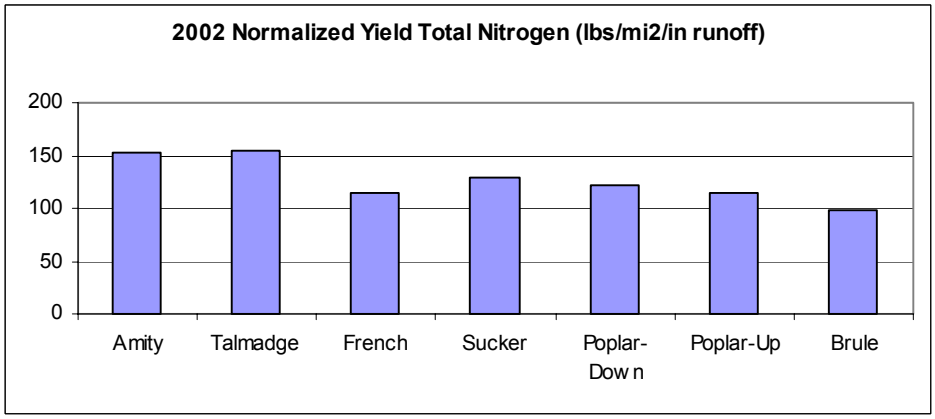


Figure 18. Graphs of Normalized Yields (pounds/mi^2/inch runoff)

Talmadge River

The Talmadge River watershed is the smallest in this study, covering only 5.8 mi^2, and correspondingly had the lowest annual streamflow volume of 3.62 Hm^3 (3.62 million cubic meters or 10.2 inches of runoff). Flows in the Talmadge are extreme and can vary considerably in response to rainfall events. During dry periods flows can be quite low (less than 1 cfs) and the channel can become dry (Figure 19).

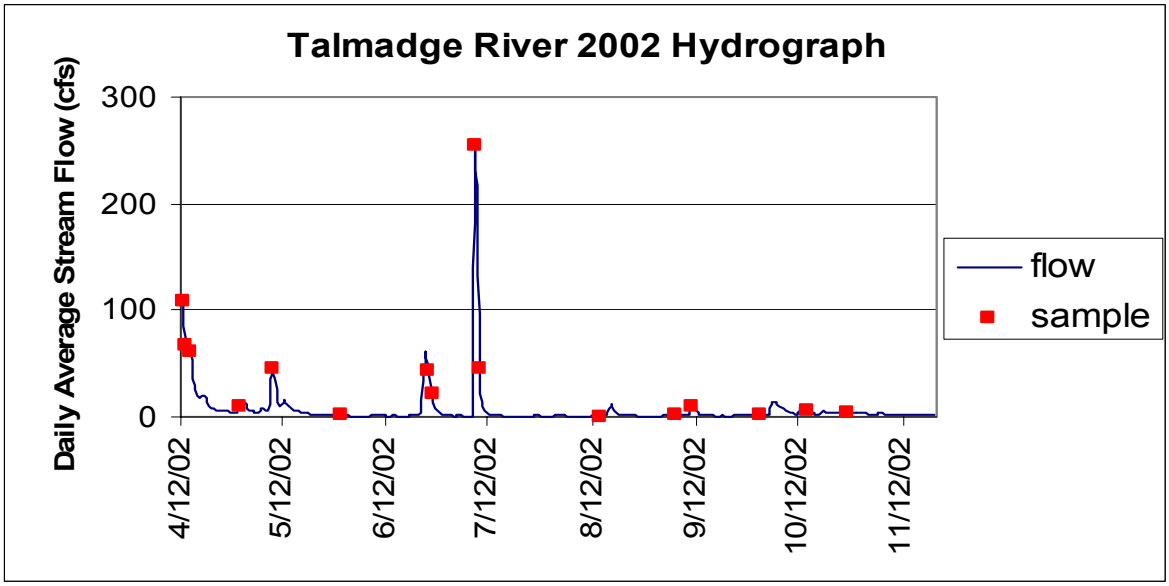


Figure 19. 2002 Talmadge River Hydrograph and Sampling Schedule

The Talmadge had the second highest FWM total phosphorus, total suspended solids, chlorides and total nitrogen concentrations of 95 ug P/L, 43 mg TSS /L, 6.6 mg chloride/L, and 1.07 mg N/L in 2002. Although the sources are unknown, water quality impacts are evident. Large growths of attached algae (periphyton) were evident on the stream bottom, a symptom of nutrient over-enrichment (Figure 20). This is consistent with other investigations that found nuisance algal levels may occur at total phosphorus concentrations greater than 75 ug P/L (EPA, 2000). Algae growth of this extent was not seen on any other North Shore stream - perhaps enhanced by the extreme low flows providing optimal growing conditions (sunlight, abundant nutrients, and appropriate substrate).

Figure 20. Periphyton (algae) mats in the Talmadge River

French River

The French River, which drains a relatively small watershed area (19.6 mi^2), had a measured annual volume of 14.2 Hm^3 (or about 11 inches of runoff). The annual hydrograph was similar in appearance to Amity Creek. The snowmelt peak lasted for most of April, the rest of the year flows were intermittently high followed quickly by extended base flows of about 5-10 cfs. Streamflow was monitored by the DNR, adjacent to their French River Fish Hatchery (Figure 21).

French River FWM concentrations for all analytes were intermediate between those of the Talmadge River (closer to Duluth) and Sucker Rivers (closer to Two Harbors). FWM concentrations of total phosphorus, total suspended sediment, chloride, and total nitrogen were 62 ug/L, 42 mg/L, 3 mg/L, and 0.79 mg/L respectively.

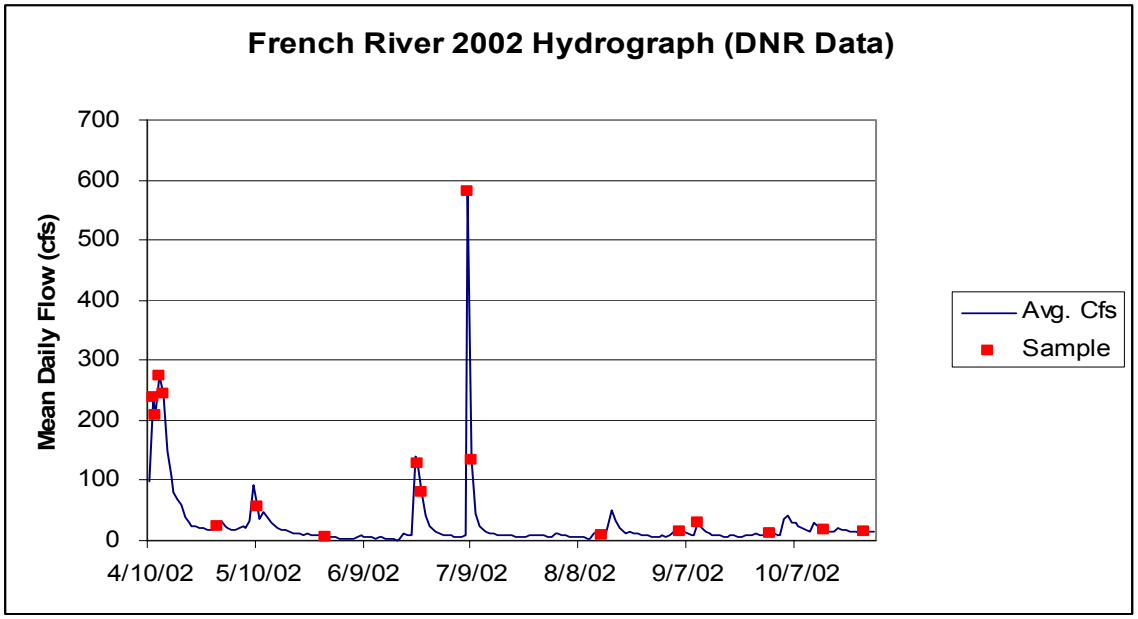


Figure 21. 2002 French River Hydrograph and Sampling schedule (streamflow data courtesy of the DNR)

Sucker River

The Sucker River, with a watershed of 39.1 mi^2, had a measured annual volume of 28.4 Hm^3 (or about 11 inches of runoff). The 2002 hydrograph shows the spring snowmelt peak of about 300 cfs in April, after which flows quickly receded to very low baseflows in the 10-50 cfs range (Figure 23). Occasional storm events generated rapid stream flow increases noted throughout the spring and early summer time period, with peak annual flows of 350 cfs being noted immediately following a 3 inch rain storm in early July. The rest of the summer was characterized by relatively dry weather and low flows, as measured flows were less than 50 cfs. Base flows were quite low with typical values in the 10 cfs range, which may be quite low for maintenance of fisheries habitat in riffles and pools.

The Sucker River has the most extensive dataset in this study- including continuous streamflow data for both 2001 and 2002. The two hydrographs are markedly different (Figures 22 and 23), although the total streamflow volumes for the two years are very similar: 30 versus 28 million cubic meters (Table 5). In 2001, snowmelt flows were very high, and the high flows were

sustained by rains immediately following snowmelt. These early rains caused the highest flows of the year because the ground was still frozen, and rainfall was translated into runoff. The rest of 2001 was very dry, with essentially no large rainstorms. In 2002, snowfall was below normal, thus snowmelt flows were less than half those of 2001. Although two large storms in mid-summer of 2002 caused peak flows to equal those of the 2002 snowmelt**,** peak flows were about one-half of the measured values of 2001.

Annual flow weighed mean concentrations from the Sucker River in 2002 for total phosphorus, total suspended solids, chloride, and total nitrogen continue the pattern of declining values as streams are further from the Duluth metropolitan area. That is, analyte FWM values were less than those of the French River, but higher than the Poplar-Upstream and Brule River. This difference likely reflects changing land uses, slopes and soil conditions. Annual FWM values for TP, TSS, chloride and TN were 53 ug /L, 15 mg/l, 2.0 mg/L and 0.890 mg N/L, respectively.

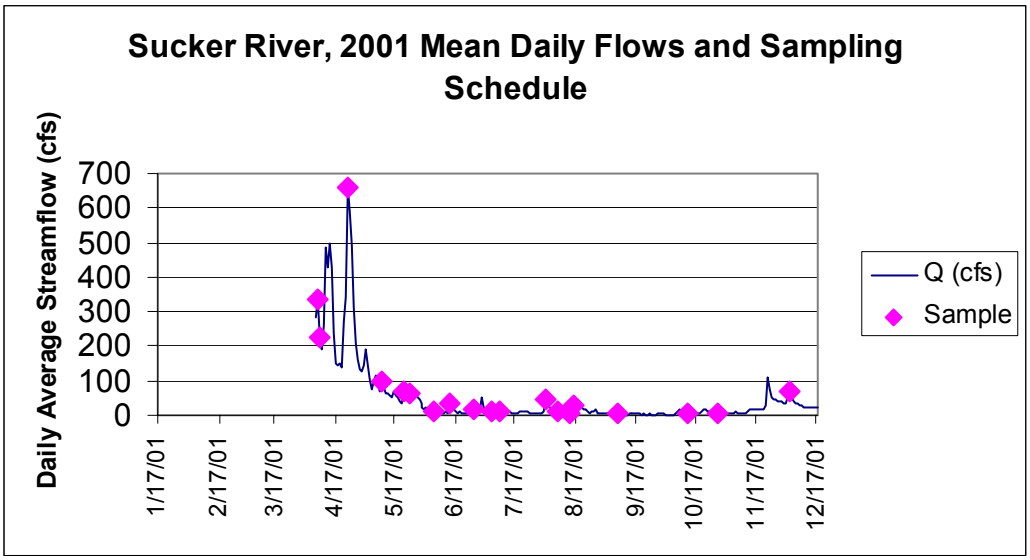


Figure 22. 2001 Sucker River Hydrograph and Sampling Schedule

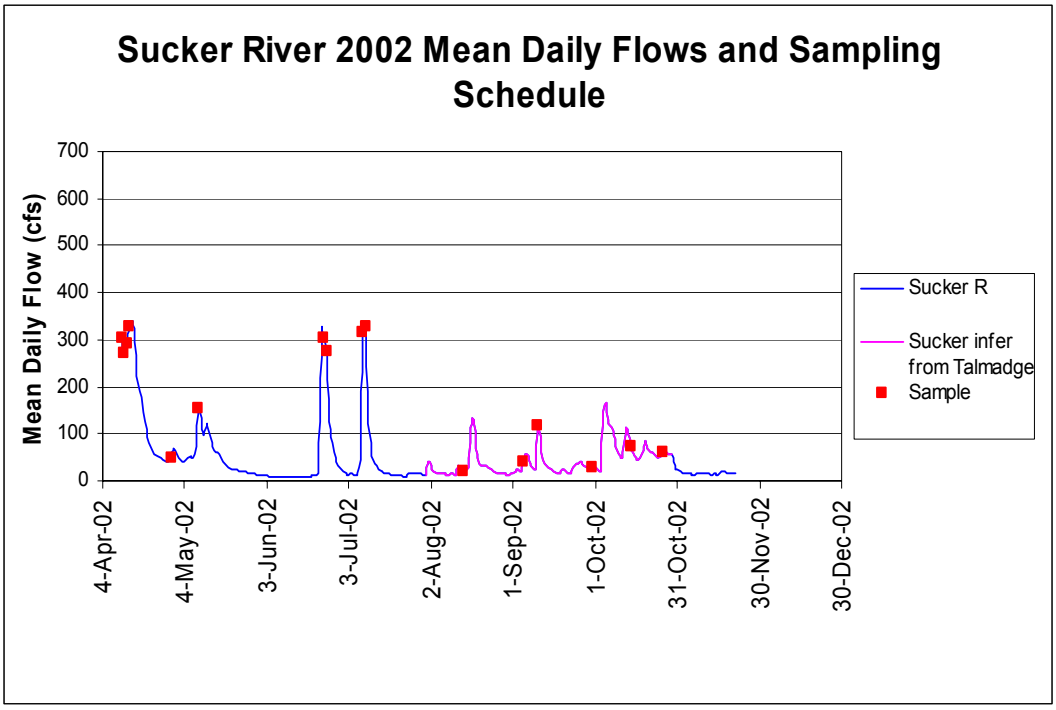


Figure 23. 2002 Sucker River Hydrograph and Sampling Schedule

Two years of data for the Sucker River allow a brief examination of the year-to-year variabilities of flow and related runoff characteristics. In 2001 versus 2002, loads of total phosphorus were almost twice as high and TSS loads were nearly three times higher- despite nearly identical total flow volumes and runoff coefficients (the fraction of precipitation that becomes streamflow). The *timing* of the high flow events is likely a main factor in this difference. During the high flows of the snowmelt in 2001, the streams carry a winter's worth of runoff and pollutants (such as road sand, salt, and atmospheric deposition) associated with the snowpack as well as the previous year accumulations. In 2002, the highest flows came later in the year, after the ground had thawed (to allow infiltration) and the vegetation was established, which filtered runoff. These higher flows (2002) carried less TSS and nutrients as compared to 2001. In 2001, most of the summer flows were quite low, and therefore, carried less nutrients and sediments. As an example of the extreme changes in water quality with respect to flow, in 2002 the TSS concentration averaged 47 mg/L during snowmelt and 1.5 mg/L during baseflow. Considerable year-to-year variation was noted as flow weighted mean concentrations in 2001 were about 2-3 times those noted in 2002 for total phosphorus and total suspended solids, respectively.

The observed 2002 streamflow patterns for Amity, French, Talmadge and Sucker Rivers were very similar:

- These streams respond very quickly to the snowmelt, where the highest annual flows typically occur.
- Storm flow events quickly occur after rain storms and the streams typically return to their baseflow levels in a day or two.
- Baseflow (dry-weather) levels are very low, typically ranging from <1 - 10 cubic feet per second.

These conditions are influenced by many factors including upland watershed storage (upstream lakes and wetlands), drainage areas, slopes, landuses and soil types. It should be noted that clay soils dominate the watersheds of Amity, Talmadge, Sucker, and French Rivers.

Poplar River

The Poplar River, with a watershed of 114 mi^2, had a measured annual volume of 43.51 Hm^3 (or about 5.8 inches of runoff). The 2002 hydrograph shows a somewhat different pattern than observed in the streams in the Duluth to Two Harbors corridor, with a greater snowmelt peak of about 600 cfs and much greater baseflows being noted throughout the growing season (Figure 24). However, the annual stream hydrograph shows the typical "North Shore" pattern - highest sustained flows during snowmelt, occasional high flow spikes after rain events, with baseflow making up the majority of the ice-free year.

Occasional storm events generated more gradual storm hydrographs than observed in the smaller watersheds of this study. Base flows were in the 25 to 100 cfs range (Figure 24) or about 2-3 times those flows noted for the Duluth to Two Harbors area streams in 2002. Flow was not monitored at the Poplar – Upstream site because of the extreme rapids and elevation slopes at the monitoring site (Figure 11). Streamflow was estimated to be nearly identical to the gauged station 3 river miles downstream. Flows at the Upstream station were estimated to be 3 percent lower than those at the downstream site, based on the small difference in drainage area.

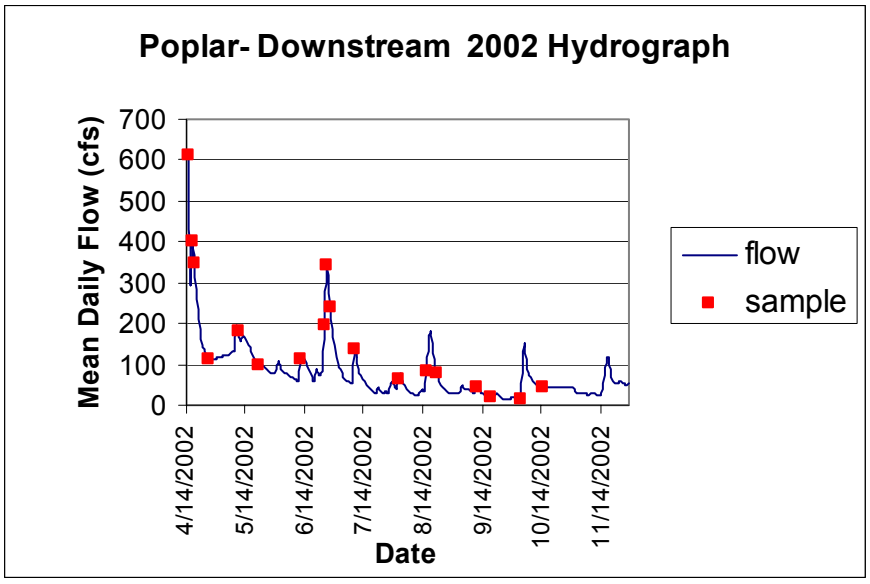


Figure 24. 2002 Poplar River 'Downstream' Hydrograph and Sampling Schedule

Annual flow weighed mean concentrations from the Poplar River-Upstream station for total phosphorus, total suspended solids, chloride and total nitrogen continue the pattern of declining values as streams are further from the Duluth Metropolitan Area. Poplar River-Upstream annual FWM values for TP, TSS, chloride and TN were 24 ug P/L, 5.3 mg/l, 1.54 mg/L and 790 ug N/L, respectively.

The downstream Poplar River annual FWM concentrations were much higher than those at the upstream site. Total phosphorus concentrations doubled (54 ug P/L versus 24 ug P/L) while total suspended solids concentrations increased six-fold (e.g. 30.8 mg/L versus 5.34 mg/L). Slight increases in chloride and total nitrogen were also monitored at the downstream site, as annual FWM's were 2.0 mg/L and 840 ug N/L, respectively. In general, the downstream Poplar River site water quality values were closer in magnitude to those of the Sucker River.

Water quality can vary greatly over the seasons. In general, during low flow periods, water quality conditions are similar between the upstream and downstream sites; turbidity, sediment, and nutrient levels are low. During high flows, there is a consistent and significant increase in TSS concentrations and mass loadings at the downstream site, as shown in the photos in Figure 25. For example, TSS concentrations averaged 3.5 and 4.1 mg/L at the upstream and downstream sites, respectively, during baseflow conditions. During snowmelt, this difference was 6.5 versus 85.1 mg/L; and during rain events it was 5.8 versus 25.5 mg/L. Other parameters also showed this pattern. Chloride concentrations doubled during snowmelt, and phosphorus concentrations doubled after rain events (Appendix 3). Nitrogen levels did not increase as substantially.

Figure 25. Upstream and Downstream Poplar River sites after a significant rainfall, 7/30/01

Mass Loads

In 2002, the amount of total suspended solids lost between the upstream and downstream stations, a distance of 2.7 river miles, was on the order of 1,112 tons (e.g. 1,341 tons downstream versus 229 tons upstream). In a similar fashion, the mass of total phosphorus and chlorides entering the watershed between the two stations were estimated to be on the order of 1,330 kg P and 21,855 kg chlorides. Hence, there are substantial loading sources occurring in the Poplar River between the two stations. Examination of time series loading confirms that most of the total suspended solids mass loads occurred during the peak flow events of spring melt and storm events. The contributions from the permitted wastewater facility were not calculated as a part of this study.

Sources of this erosion and nutrient loading are numerous. The river makes several sharp turns, causing bank erosion, as it winds through its valley (Figure 26). Some of this bank erosion could be termed "natural", although the water volumes and runoff rates are increased due to human activity (land use change) in the valley, such as gully erosion (Figure 27), exposed clay soils, open areas (i.e. removal of the trees), impervious surfaces (roads, roof tops and parking lots), and treated wastewater.

Figure 26. Eroding stream bank in the Poplar River Valley (note wastewater ponds in background)

Figure 27. Gully erosion at Lutsen Mountain Ski Area

Brule River

The Brule River, the largest of the assessed North Shore Streams with a watershed area of 270.1 mi^2, also had the greatest measured annual volume of 82.83 Hm^3 in 2002 (or about 4.8 inches of runoff). The 2002 hydrograph shows sustained flows during snowmelt, with flows generally receding throughout the growing season with baseflow making up the majority of the monitored flows (Figure 28). Summer storms did not elevate stream flows substantially over the growing season, in stark contrast to the smaller watersheds closer to Duluth. Base flows were in the 75 to 200 cfs range.

The Brule had the lowest flow weighted mean concentration and normalized yields of total phosphorus, TSS, total nitrogen, and total chloride (Figures 17,18). Given the low development and populations and abundance of lakes in the headwaters, the Brule River water quality parameters are quite excellent and as such, represent minimally impacted conditions.

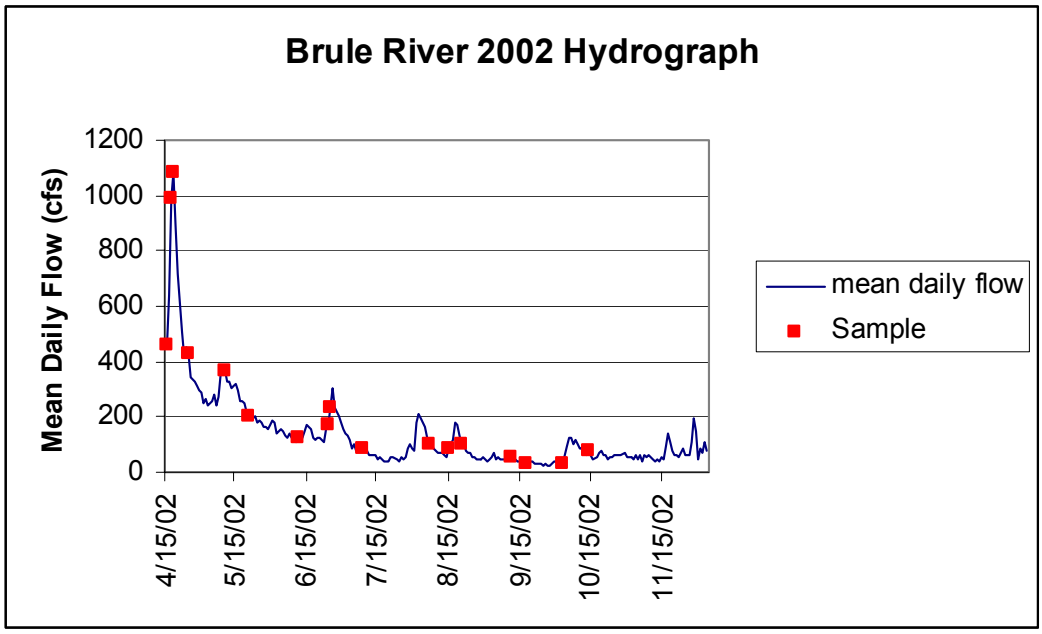


Figure 28. 2002 Brule River Hydrograph and Sampling Schedule

Mercury Sampling in the Poplar River Valley (Contributed by Dr. Steven Balogh, Metropolitan Council)

Results at the downstream location showed a strong correlation between total mercury (THg) and TSS concentrations (Figure 29), indicating that sediment source areas in the watershed are linked to THg source areas. The highest THg and TSS concentrations were observed during increased

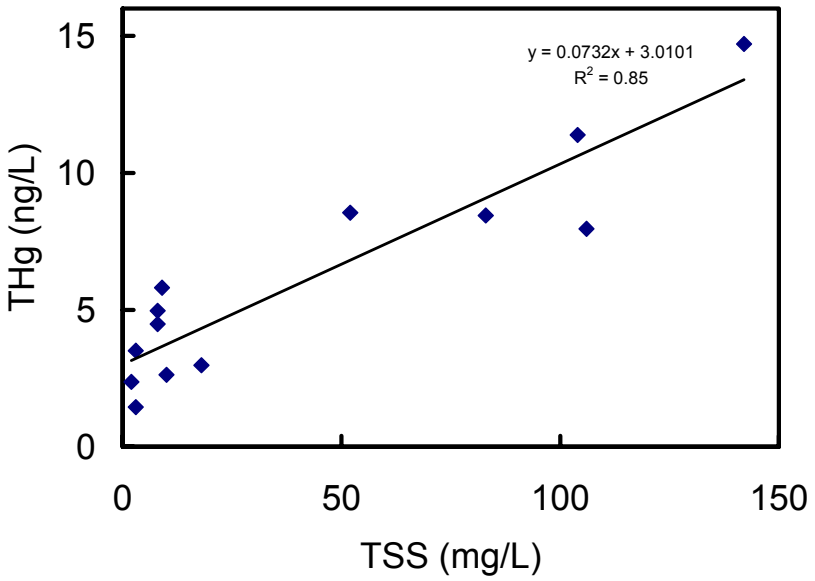
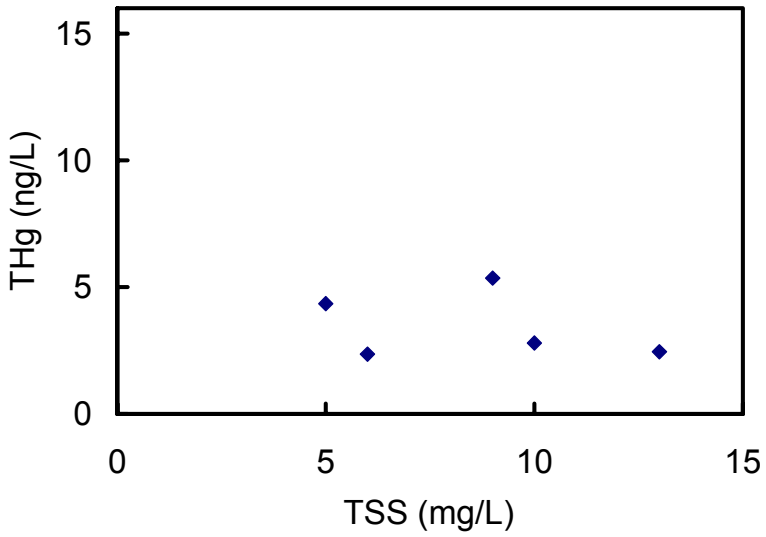


Figure 29. Variation of THg concentrations with TSS concentrations at the downstream site.

streamflow following spring snowmelt and summer precipitation events. During these hydrological events, suspended sediments are delivered to the river via surface runoff throughout the watershed, but especially from areas where natural land cover has been disturbed. The best linear least-squares fit of the THg-TSS data yields a regression equation of THg (ng/L)=0.073*TSS (mg/L) + 3.01 (r^2=0.85). The slope of the regression line (0.073 ng/mg or 73 ng/g) gives an estimate of the mass of Hg associated with each gram of sediment entering the river. The concentration of THg in mineral soil near Lutsen was previously reported as 42.8 ng/g, and that in organic forest floor material was 363 ng/g (Nater and Grigal, 1992). It is probable that elevated TSS and THg concentrations in the Poplar River result from erosive mobilization of watershed soils into the stream during precipitation runoff events.

As described above, increased THg concentrations are associated with increased TSS concentrations in the Poplar River at the downstream site. No similar correlation was observed at the upstream site (Figure 30). At this location, TSS and THg concentrations were low (14 mg/L and 2.80 ng/L, respectively) even during the summer precipitation event that we sampled.

Figure 30. Variation of THg concentrations with TSS concentrations at the upstream site.



More data is needed to clarify the relationship between THg and TSS concentrations at this site.

The State of Minnesota has established a chronic water quality standard of 1.3 ng/L for THg in surface waters in the Lake Superior basin, based on a wildlife health risk assessment. Concentrations of THg in the Poplar River exceeded this standard level in all samples from both the upstream and downstream locations. Based on our regression analysis of the THg-TSS data at the downstream site, even samples containing no suspended sediments (TSS=0 mg/L) will have a THg concentration of 3.01 ng/L. At the upstream site, the mean THg concentration was 3.46 ng/L as TSS concentrations varied from less than 2 mg/L to 14 mg/L. Total Hg concentrations at the downstream site on the Poplar River vary primarily in response to natural variability in precipitation intensity and location, the location of erosive runoff during stormflow or snowmelt, and the distribution of surface soil THg concentrations in the basin. Additional data is needed to characterize the influences contributing to variation in THg concentrations at the upstream site. At both sites, however, it appears that THg concentrations will consistently exceed the state water quality standard during the open water season.

Strong correlations between THg and TSS concentrations have previously been observed in other Minnesota rivers. The relationship is particularly strong in the Minnesota River and its tributaries where extensive cultivation and artificial drainage systems deliver large quantities of eroded soil into the river during stormflow events (Balogh et al., 1997, 1998, 2002, 2003). The relationship is less evident in undisturbed watersheds such as the St. Croix River basin, where TSS concentrations are seldom elevated even during hydrological events (Balogh et al., 1998). The Poplar River results shown above fit well with previous observations indicating that the disturbance of natural land cover (for cultivation, development, etc.) increases the delivery of both suspended sediments and mercury to streams in the watershed.

2002 Monitoring Summary

In summary:

- Flow weighted mean concentrations of water chemistry parameters indicative of non-point source pollution (total phosphorus and total suspended solids), are greatest in the Duluth to Two Harbors corridor, and decreased in streams farther up the North Shore-likely due to a combination of natural watershed variation and land use change (i.e. development).
- For the monitored North Shore streams, high flow events contribute the majority of the annual pollutant loadings.
- Sediment, nutrient, and mercury loadings increased in the Poplar River valley, and sources are numerous. Eutrophication in the Poplar River valley is significant compared to the upstream monitoring site, and further data about impacts to cold water fisheries need to be collected.
- The Brule River is relatively pristine and exhibited low concentrations of typical eutrophication measures.
- Total Nitrogen levels were relatively stable among all sites. This suggests that nitrogen is not bound to soil particles, and likely comes from more fixed sources such as groundwater or atmospheric deposition.

Historical Stream Water Quality and Trend Detection

Status and Trends in North Shore Stream Fisheries (Contributed by Deserae Hendrickson and Steve Persons, DNR Area Fisheries Managers in French River and Grand Marais, respectively)

Most streams on Minnesota's North Shore support two types of fisheries. Streams support fisheries for resident stream trout (brook or brown trout) in their upper reaches (and in the lower reaches as well, in some cases). In addition, they support fisheries for anadromous species, such as rainbow trout and Chinook salmon, in their lower reaches. Anadromous species spawn in streams, but juvenile fish leave the stream and return to Lake Superior to grow to adulthood. Water quality affects both types of fishery; however, only the anadromous fisheries will be considered here, since monitoring stations for this study were located, for the most part, in or near the anadromous reaches of the streams.

To spawn successfully, anadromous species are dependent on suitable substrates in the stream. Eggs are deposited in loose gravels, and must be supported by oxygenated water flowing through the gravels. Trout and salmon require cold water for survival, and good juvenile production is dependent on a steady supply of invertebrates, produced in clean riffles. The ability of North Shore streams to support anadromous fish populations would be most likely to be adversely affected by increases in water temperature or increases in sedimentation.

Although several anadromous species can be found in North Shore streams, the largest fisheries are centered around rainbow trout and Chinook salmon. Chinook salmon can reproduce in some North Shore streams, but the fishery is heavily supplemented by stocking. Stocked Chinook salmon leave the streams very quickly, and their contribution to the fishery is most reliant on the Lake Superior environment. Rainbow trout populations have been naturalized in North Shore streams since the turn of the century. Although rainbow trout (kamloop and steelhead strains)

are still stocked in fairly high numbers, successful natural reproduction is crucial to maintaining rainbow trout fisheries, particularly steelhead fisheries, in many streams. Rainbow trout juveniles (including those stocked as fry) reside in North Shore streams for one or two years, before migrating to Lake Superior. Changes in stream water quality would have the greatest affect rainbow trout fisheries because of their greater dependence on the stream environment for natural reproduction and juvenile production.

The status of rainbow trout fisheries in North Shore streams has been monitored by the DNR by direct observation of the fishery (through angler creel surveys) and by monitoring of natural reproduction and juvenile production through stream population assessments. Unfortunately, in both cases long term monitoring data are scant. Creel survey data were collected on individual North Shore streams in 1961-1967 (Hassinger, Hale, and Woods 1974) and in 1981-1983 (Close and Siesennop 1984, Persons 1984). Annual spring creel surveys of the anadromous fishery on selected North Shore streams have been done since 1992 (Morse 2000, Ostzeski and Morse 2001, Ostazeski 2002). Stream population assessment data for some streams has been collected at irregular intervals since the 1960s; however, standard assessment methods and equipment have only been employed since the 1970s or 1980s (depending on the management area).

Changes in anadromous fisheries have occurred since the 1960s; however, relating those changes to specific changes in water quality, climate, or management strategies and activities is very difficult because all have changed concurrently. Fishing pressure on North Shore streams increased, and angler reports indicated that steelhead numbers declined through the 1970s and 1980s (Schreiner 2003). Development has increased throughout the watershed, but in some areas, logging activity has declined or been more intensely regulated to reduce adverse effects on water quality. Mean water temperatures in Lake Superior, which can affect growth of anadromous fish, have fluctuated. Various fish species and strains of fish have been stocked in streams along the North Shore, followed by reductions in stocking and a shift to stocking larger fish. Fishing regulations have changed, becoming much more restrictive over time.

Between the 1960s and 1981-82, spring anadromous fishing pressure on North Shore streams increased, on average, by over 300% (Close and Siesennop 1984), but through the 1990s fishing pressure declined (Ostazeski 2002). Among the study streams, creel survey data for all three periods are available only for the Brule and Sucker Rivers. On the Brule River, average estimated fishing pressures for the spring anadromous fishery in 1961-1967, 1981-1983, and 2000-2002 were 486, 3,319, and 339 angler-hours, respectively. Average estimated fishing pressures for the same periods on the Sucker River were 802, 8,153, and 5,524 angler-hours, respectively. Average estimated catch rates for rainbow trout in 1961-1967 on the Brule and Sucker Rivers were 0.07 and 0.04 fish/angler-hour, respectively. Average estimated catch rates for the same streams in 2000-2002 were 0.32 and 0.30 fish/angler-hour, respectively. The increases in catch rates on these two streams indicate that if there have been declines in water quality, the effect has been masked or mitigated by social, managerial, climatic, or other environmental changes.

Changes in reproductive success for rainbow trout (particularly for wild steelhead) can be inferred from the results of standard population assessments done regularly over time. Among the study streams, those data are available only for the Talmadge and Sucker Rivers. Evidence suggests that abundance of juvenile steelhead did not decline in those streams between 1973 and 1995 (Jones 1996). On the other hand, scantier data available from the Poplar River shows that while juvenile steelhead were present in fair numbers in that stream in 1983 and 1989, there has been almost no reproduction of steelhead in that stream since 1994 (DNR stream files). The decline in juvenile steelhead numbers in the Poplar River has been accompanied by an increase in the number of smallmouth bass observed in assessments, and strong anecdotal evidence for an increase in siltation in the lower reaches of that river. It has not been accompanied by a decrease in rainbow trout fishing success; average rainbow trout catch rates in 1981-1983 and 2000-2002 were 0.05 and 0.27 fish/angler-hour, respectively.

Concerns about the status of anadromous fisheries, and the steelhead fishery in particular, are greatest on the western half of Minnesota's North Shore. Fishing pressure in that area remains high, and development pressures are also high. Restoration of some wild steelhead populations along that portion of the North Shore has proven difficult, with the Knife River providing the best case in point. Along the eastern half of the North Shore, development and fishing pressure are less, and a fairly high proportion of the landscape is relatively undisturbed, under state, federal, or county ownership. On that part of the North Shore, anadromous rainbow trout populations appear to be fairly stable.

Water Quality Trends

There are few previous detailed studies of the North Shore streams to serve as water quality benchmarks. The MPCA, and other organizations, have collected a fair amount of historical water quality data, but the majority of this data is unsuitable for comparison to these 2002 findings because of the lack of continuous flow data or reduced sampling due to program reductions.

The most comprehensive analytical survey was conducted by the MPCA in the 1970s (MPCA, 1976). Since that time, the Western Lake Superior Sanitary District conducted periodic monitoring of several streams on the southern half of the Shore, but that monitoring ended in 1991. A recent intense watershed investigation was conducted by the EPA (Detenbeck, 2000) focused on second and third order streams on the north and south shore of Lake Superior. The MPCA's long-term stream legacy water quality monitoring program, the Milestone Program, includes 5 North Shore streams, but monitoring was recently scaled back due to budget shortfalls.

A review of data from the EPA's STORET database revealed that several north shore streams are exceeding the EPA proposed oligotrophic stream phosphorus criteria of 25 ug/L (EPA, 2000). This trend is most prominent in streams from Duluth to Two Harbors (which includes all streams from the Lester River to the Knife River). MPCA Milestone data, used in this assessment, generally reflects lower flow conditions rather than flow-based sampling.

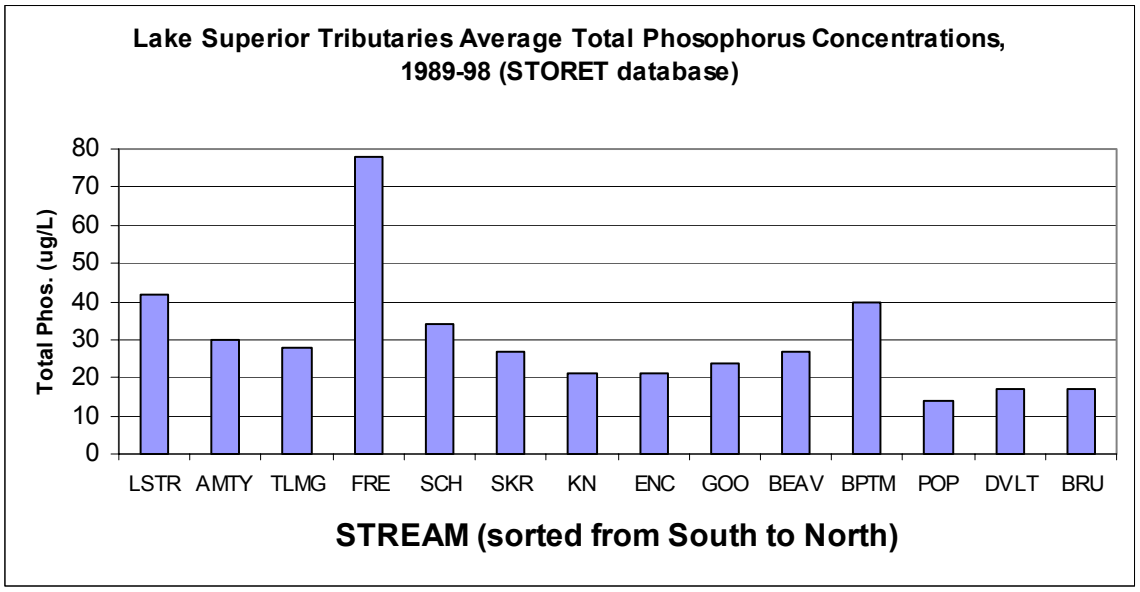


Figure 31. Phosphorus Concentrations in North Shore Streams, 1989-98.
Data from EPA's STORET Database (www.epa.gov/storet). Key to stream name abbreviations can be found in Appendix 1.

The most comprehensive historical dataset available for comparison with this 2002 study is the North Shore streams loading study done by the MPCA from 1973-75 (MPCA, 1976). The MPCA study was sponsored by the EPA in order to provide information to the International Joint Commission (Kathy Svanda, Minnesota Department of Health, personal communication, 2003). During the 3 year study, approximately 30 samples and instantaneous streamflow measurements were collected, although no sites had continuously recorded streamflows. Sampling was focused during snowmelt and after significant rain events, similar to this study.

To further address the comparability of the 1970s and 2002 datasets, a comparison of streamflows from a long-term monitoring site was conducted. For this purpose, the Baptism River was chosen- there the US Geological Survey operated a continuous streamflow monitoring station from 1928 – 1993 (Mitton et al., 2002). The Baptism River's long term annual mean streamflow is about 168 cubic feet per second (cfs). The annual mean streamflow values for 1973-75 were 256, 155, and 163 cfs, respectively (Figure 32.), indicating that flows were average to above average during this time period.

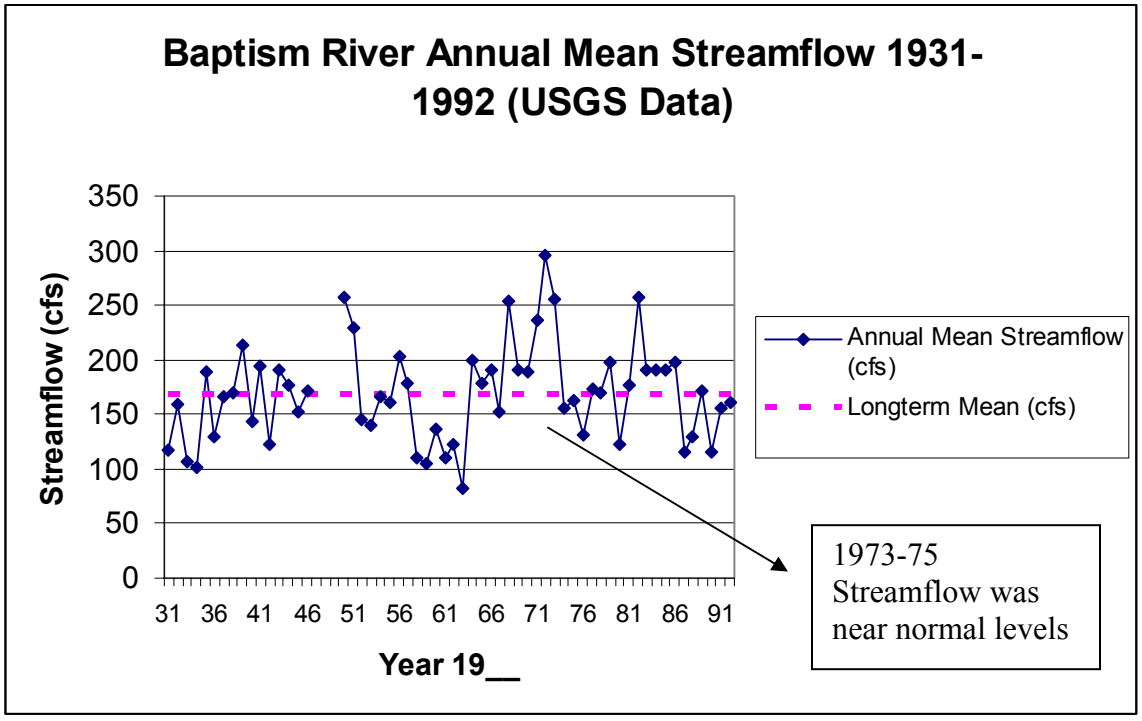


Figure 32. Baptism River Annual Mean Streamflow, 1931-92. Source: US Geological Survey (http://waterdata.usgs.gov/nwis/sw)

Similarly, precipitation patterns from 1973-75 were also within normal levels (Figure 33). Thus, we concluded that 1973-75 were typical years and that the historical data are not from extreme wet or dry periods; and therefore the most appropriate available dataset for comparisons with the 2002 data.

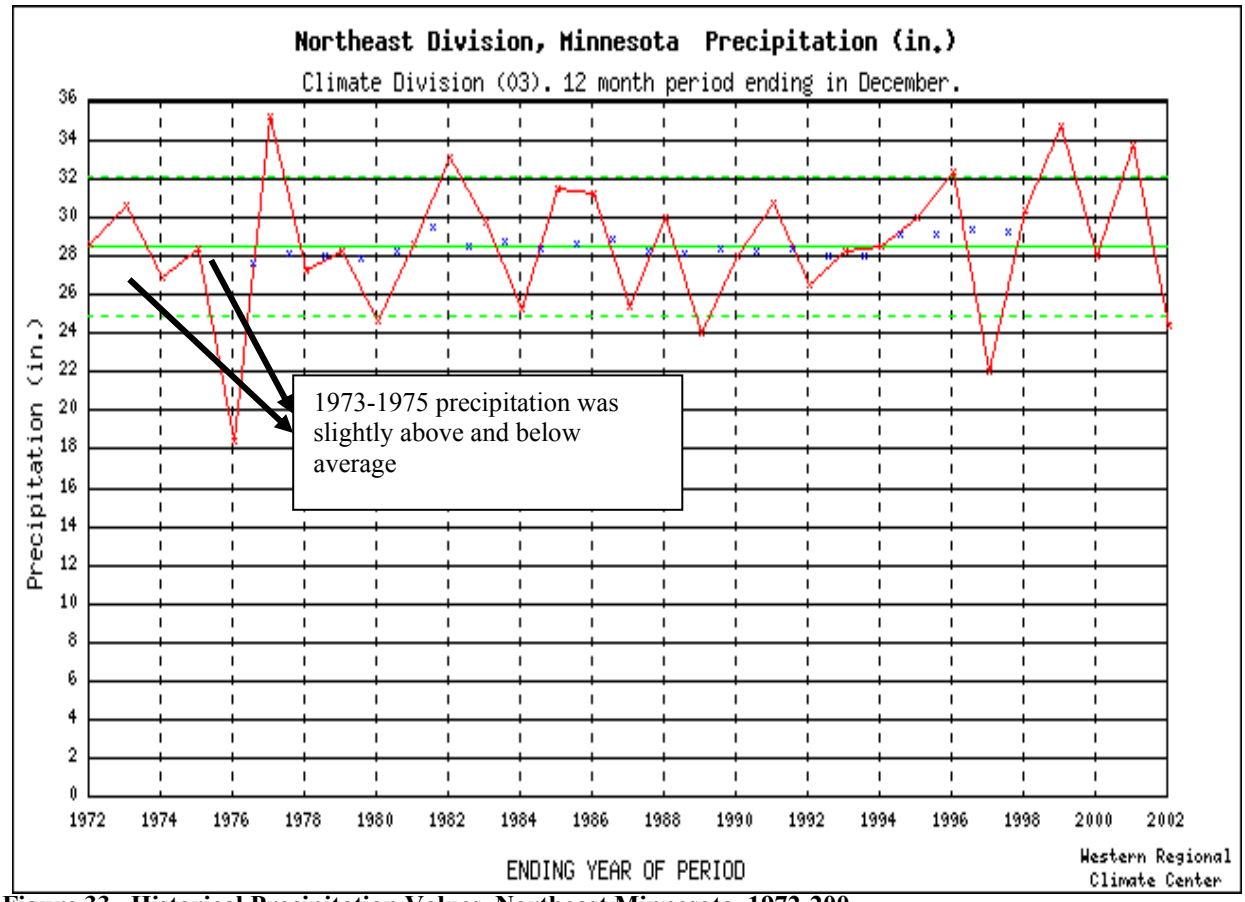


Figure 33. Historical Precipitation Values, Northeast Minnesota, 1972-200 (http://www.wrcc.dri.edu/cgi-bin/divplot1_form.pl?2003)
green – average (solid), ± sigma (dashed)
red – 12 month period
blue – 10 year running mean

Typical statistics (i.e. flow weighted mean concentrations) were prepared for the 1973-75 period and for this study's 2002 results. For the 1973-75 period, estimates of flow weighted mean concentrations were calculated (computed as total load divided by total streamflow volume for the 30 sample dates). 2002 FWM concentrations were computed by the FLUX computer model. Four streams were sampled during both time periods- the French, Sucker, Poplar and Brule Rivers.

Graphs of 1970s and 2002 FWM concentrations of total phosphorus and total suspended sediments are shown in Figures 34 and 35. Phosphorus concentrations were greater for the French and Poplar Rivers since the 1970s, while apparently decreasing on the Brule River. No significant change was evident for the Sucker River.

FWM concentrations of total suspended solids (an overall indicator of erosion) increased substantially since the 1970s on all streams, except the relatively unimpacted Brule River. Overall increases in TP and TSS were most pronounced on the French and Poplar Rivers. The causes of these changes should be further investigated so as to be able to define cause and effect pathways from improved future management of these streams. The lack of several years of data preclude assessment of year-to-year variabilities in this report. Long term monitoring will provide an improved basis for evaluation variability and assessing trends.

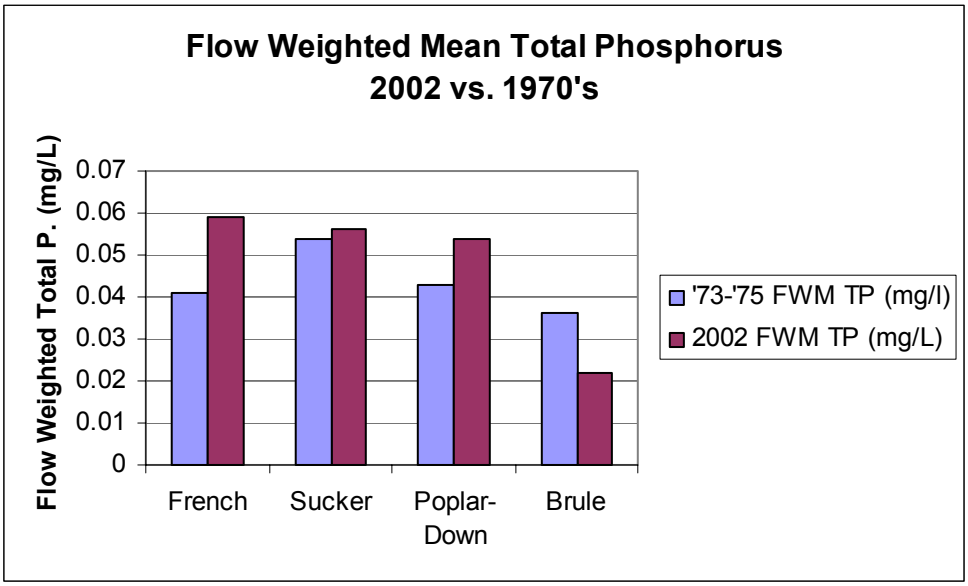


Figure 34. Flow Weighted Mean Total Phosphorus Concentrations, 2002 and 1973-75

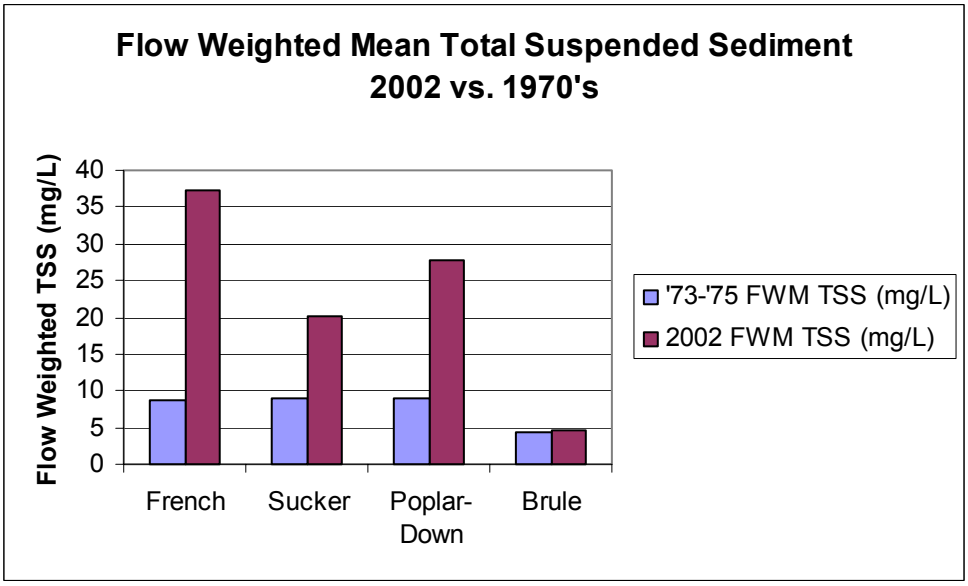


Figure 35. Flow Weighted Mean TSS Concentrations, 2002 and 1973-75

North Shore and Climate Changes

By the end of the 21st Century, significant changes to climate in the Great Lakes region are predicted to occur (Kling et. al., 2003) as the result primarily of the burning of fossil fuels and the emission of carbon dioxide gas into the atmosphere. It is likely that these changes will have impacts upon the Lake Superior watershed potentially including:

- Increases of 5-12 degrees F in winter and 5-20 degrees F in summer which may change the all-season mix of outdoor activities;
- Increases in extreme storm events;
- Later ice on and earlier ice off our area lakes and streams;
- Decline of cold water fisheries as cool and warm water fisheries expand;
- Lower water levels.

As these possible impacts can have substantial implications for the North Shore and its economies, they reinforce the need for maintaining North Shore tributary monitoring and timely conveyance of information to local decision makers. Increased precipitation intensities, for example, may indicate increased likelihood of periodic flooding and hence, the need for better urban best management practices, in order to minimize increased sediment and nutrient loads, as well as increases to receiving stream temperatures. Climate variability (shifting precipitation, wet-dry cycles and seasonal impacts) may complicate efforts to track water quality trends unless detailed long-term datasets are developed over a range of watershed areas and characteristics. For example, altering peak spring snowmelt flows, as was observed for the Sucker River in 2002, may have fisheries implications as well as those previously noted for water quality parameters. Storm water potential impacts, resulting from developed and developing areas to these very sensitive streams is beyond the scope of this investigation, but should be examined in the future.

Conclusions and Recommendations

- Historically, there have been few continuous river gauging stations of North Shore streams to base stream sampling efforts for trend detection. At present, the USGS maintains a continuous gauge at the Pigeon River and the Knife River (near Two Harbors).
- This study installed and operated sites on six representative North Shore rivers, which will serve as a baseline for detection of future water quality and quantity trends.
- Travel and tourism are important components of the region's economy (tourists spent $275 million in the North Shore area in 2000) but few economic summaries appear to be available to assist in defining cost-benefits for watershed and river management alternatives.
- Previous Minnesota studies have shown that travel and tourism are typically dependent upon the quality of the natural environment experience as tourists have high expectations for clean air and water, beautiful scenery, and a quiet, peaceful outdoor experience.
- Socioeconomic data show a large increase in development in the last 20 years, many of these changes are occurring in small increments (5, 10, 20 acres at a time). Cumulative impacts of this development were beyond the scope of this study, but should be assessed in the future, given this study's findings.

- For this study, river impacts were greatest for rivers closest to Duluth and declined going up the coast toward the Brule River. Watersheds with the highest concentrations of total phosphorus and sediments also tended to have smaller drainage areas.
- Flow weighted mean concentrations of total phosphorus in 2002 for Amity and Talmadge watersheds, 122 ug P/L and 95 ug P/L, exceeded levels regarded as forming nuisance algal growth (at > 75 ug P/L). Sucker River also exceeded the nuisance level in 2001 with total phosphorus FWM concentrations of 95 ug P/L.
- Historical data suitable for comparison to this study are limited. Limited data from the 1970s indicate increases in flow weighted mean total phosphorus and substantial increases in total suspended solids concentrations. However, year-to-year variabilities for North Shore streams need to be better defined.
- Trends in reproductive success of rainbow trout in the study streams were provided by the DNR. For the Talmadge and Sucker Rivers, evidence suggests that the abundance of juveniles did not decline between 1973 and 1995. Conversely, the abundance of juveniles has declined in the Poplar River since 1989 and this has been accompanied by an increase in smallmouth bass populations and strong anecdotal evidence of increased siltation in the lower reaches of the River.
- Monitored total suspended solids and total phosphorus loadings occurring in the lower reach of the Poplar River strongly suggest the need for the increased use of watershed best management practices.
- Mercury levels at Upstream and Downstream Poplar River sites exceed Minnesota's water quality standard of 1.3 nanograms per liter, although levels were higher at the Downstream site particularly during high flow events. Mercury levels were strongly correlated to TSS levels, and the results are consistent with previous investigations indicating that the disturbance of natural land cover increases the delivery of both suspended sediments and mercury to streams.
- The findings of this study need to be considered within the context of Great Lakes regional climate changes which are predicted to potentially cause substantial changes in the Lake Superior Basin with increased summer and winter temperatures (e.g. 6-15 degrees F), increased extreme precipitation events, changes in stream flow patterns and declines in cold water fisheries (Kling et al., 2003).
- Cold water fisheries streams are extremely sensitive to nutrient, sediment and temperature impacts, and hence increased vigilance and watershed management planning is strongly recommended to prevent their impairment.
- The challenges of increased recreational and development pressures along with unknown climate change variabilities strongly suggest that additional monitoring and assessment of the North Shore tributaries are needed for providing timely practical management alternatives to local decision makers.
- Future North Shore stream monitoring should include representative sites for continuously recorded stream temperatures as well as conductivity, pH and dissolved oxygen.
- Storm water runoff impacts from developed and developing areas to these very sensitive streams should be examined.

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Appendix 1. North Shore Stream List

"Major" Lake Superior Basin Streams From Duluth to Grand Portage

	Abbreviation	Stream Name
1.	SLR	St. Louis River
2.	NEM	Nemadji River
3.	LSTR	Lester River
4.	AMTY	Amity Creek
5.	TLMG	Talmadge River
6.	FRE	French River
7.	SCH	Schmidt Creek
8.	SKR	Sucker River
9.	LKN	Little Knife River
10.	KN	Knife River
11.	STE	Stewart River
12.	ENC	Encampment River
13.	GOO	Gooseberry River
14.	SPLT	Split Rock River
15.	BEAV	Beaver River
16.	BPTM	Baptism River
17.	MANT	Manitou River
18.	CARI	Caribou River
19.	ISL	Island River
20.	CRO	Cross River
21.	TEM	Temperance River
22.	ONI	Onion River
23.	POP	Poplar River
24.	CAS	Cascade River
25.	DVLT	Devil Track River
26.	KAD	Kadunce River
27.	FLT	Flute Reed River
28.	BRU	Brule River
29.	RES	Reservation River
30.	PIG	Pigeon River

Appendix 2. Data Sources and Specifics on North Shore Development Indicators:

Census/Population Data

Population data was compiled for St. Louis, Lake and Cook counties, as well as the townships that comprise the counties (1990 and 2000 data only) from the Minnesota Planning website. Population information was obtained from Minnesota Planning for the incorporated and unincorporated areas of Lake and Cook Counties. St. Louis county data for those townships that are part of the Lake Superior South watershed were also obtained.

Minnesota Geological Survey New Well Construction Data

The well information was obtained from the Minnesota Geological Survey (MGS) County Well Index (CWI). The CWI is a compilation of data from approximately 300,000 water wells drilled in the state, most completed drilled since 1974. This information is mostly records of wells, but it also contains some records for monitoring wells and exploratory borings.

For this report, two groups of data were obtained for Lake and Cook Counties. The data for "located" wells (i.e., well locations that have been field located and verified by MGS) were combined with the data from "unlocated" wells (i.e., well locations identified by well drilling contractor, but not field verified by MGS). This was done because there are many more unlocated wells in Northeastern Minnesota and unlocated wells may include those wells that were completed in recent years. The well data for both Lake and Cook counties was plotted on a map. Only those wells locations within the Lake Superior North and South watersheds were included in the dataset used in the study.

The well and septic data are somewhat related because a new dwelling that requires a well will most probably also requires an ISTS. There are some variables, such as replacement rates of ISTS and wells, plus a number of wells may be monitoring & not drinking water wells.

Individual Septic Treatment System (ISTS) Information

Septic system data was chosen as an indicator, in part, because it was one parameter in which the two counties maintained similar data (as opposed to bldg permits). The goal was to count all new or replaced septic systems installed over time. Records for inspections, percolation tests, privies, composting toilets and system repairs were not counted. Septic system information was obtained from the Lake County Land Use office and from the Cook County Planning and Zoning Department. Cook County was obtained electronically and was then sorted by year. Only system installation and replacement was counted. Nine records were deleted from the Cook County dataset due to a lack of information to determine the appropriate activity being performed.

Permits were counted for only those septic systems located within the two main watersheds that drain directly to Lake Superior (Lake Superior North and Lake Superior South watersheds). The public land survey data (section, township and range) was used to determine those permitted systems located within these watersheds.

For Lake County, the data was not readily available in electronic format, but was available in paper format. To reduce the workload to county staff, every other year of data was collected. This information is maintained by the Lake County Land Use office. The 1997 data was not used, because the information available did not include data to determine system location.

Duluth Tourism Tax

This information was obtained from the Duluth Convention and Visitors Bureau, from Barb Oswell. The data obtained is a combination of the lodging tax and the city sales tax.

Two Harbors Sales Tax and Lodging Tax

This information was obtained from the City Treasurer of Two Harbors, Jill Baumann. The lodging tax (Bed & Breakfasts, camping, hotels and motels) has always been set at 3%. The City sales tax was established in 1999 at 0.5%. Because the tax was established mid-year, 1999 sales tax data was not obtained.

Lutsen-Tofte Tourism Tax

The Cook County Lodging Tax Report was obtained through the Lutsen-Tofte Tourism Association thanks to Pat Christopherson. The tax report displays the yearly lodging tax totals compounded by the Lutsen-Tofte, Grand Marais, and Gunflint Trail Tourism Associations. With the exception of the Lutsen-Tofte area, the lodging tax records date back to 1997. The Lutsen-Tofte area tax records go back to 1988. Some of the fairly large increases in tax revenues can be attributed to increases in the tax . Lutsen-Tofte increased its lodging tax from 2% to 3% on January 1, 1991. The city of Grand Marais increased their 2% tax to 3% on July 1, 1991. The Gunflint Trail Association raised their 2% tax to 3% on December 1, 1997.

DNR State Park Visitor Information

The following visitor totals for the years 1980 to the present were collected with the help of Minnesota Department of Natural Resources (DNR) staff Paul Sundberg, Dennis Thompson, and Phil Leversedge.

The number of visitors is determined for each park using one of two methods. For one method, three vehicle counts are conducted per day (morning, afternoon, evening) to determine a daily average. This number is then multiplied by 3.2, the average person per vehicle that has been determined by DNR visitor studies. The other method uses an automatic vehicle counter (compression tube counters) that counts the number of visitor vehicles per day. This number is then multiplied by 3.2 persons per vehicle for the daily visitor count. The person per vehicle count was changed from 4 to 3.2 in approximately 1986 after a review of past visitor data.

Mn/DOT Highway 61 Traffic Data

Traffic count data was collected at the Minnesota Department of Transportation (Mn/DOT), with the help of staff person Gene Stevens. The data includes average daily traffic counts (AADT) for various sections along Highway 61 that are calculated biannually.

Mn/DOT defines AADT as the number of vehicles using a specific segment of roadway during a 24-hour period. The volume is adjusted to account for seasonal variations throughout the year and typically represents weekday (Tuesday-Wednesday-Thursday) conditions.

Mn/DOT average daily traffic count data for various locations on TH 61 was collected as part of the study but was not used in the report. There seems to be many factors that may make the use of the data difficult to interpret. Some examples include in-town traffic versus through-traffic, data variability depending on which locations are used (e.g., in-town counts versus west/east of town counts). The Mn/DOT correction of the data for seasonal variability prohibits analyzing the data for seasonal trends (i.e., traffic count changes that are a reflection of seasonal patterns of traffic, including tourists.

County Building Permits

Lake County issues land alteration permits that encompass activities beyond building construction, such as grading and driveway construction. Cook county Land use permits are used for building construction/modification. Because the two permits are issued for different activities, this information could not be compared directly between counties.

Appendix 3. Water Quality Data Summary Statistical Summary 2002 Water Chemistry Data.

Site	Number of Samples	Total Suspended Solids (mg/L)				Total Chloride (mg/L)				Total Phosphorus (mg/L)			
		mean	median	max	min	mean	median	max	min	mean	median	max	min
Amity	20	44.51	21	330	1	16.48	18	25	5.1	.072	.066	.261	.007
Talmadge	17	23.67	8.8	240	1	7.16	7.2	11	4.1	.07	.053	.337	.018
Sucker	18	24.72	13	87	1	2.61	1.8	13	1.1	.063	.058	.161	.009
French	17	34.03	7.6	270	1	4.31	3.9	14	2.6	.059	.033	.331	.007
Poplar-down	20	30.87	9.3	200	2.4	1.98	1.85	3.7	1	.054	.026	.264	.003
Poplar-up	18	5.48	4.6	12	1.6	1.48	1.45	2	1.1	.024	.021	.051	.011
Brule	17	5.08	2	29	1	1.51	1.4	2.5	1	.022	.013	.073	.007

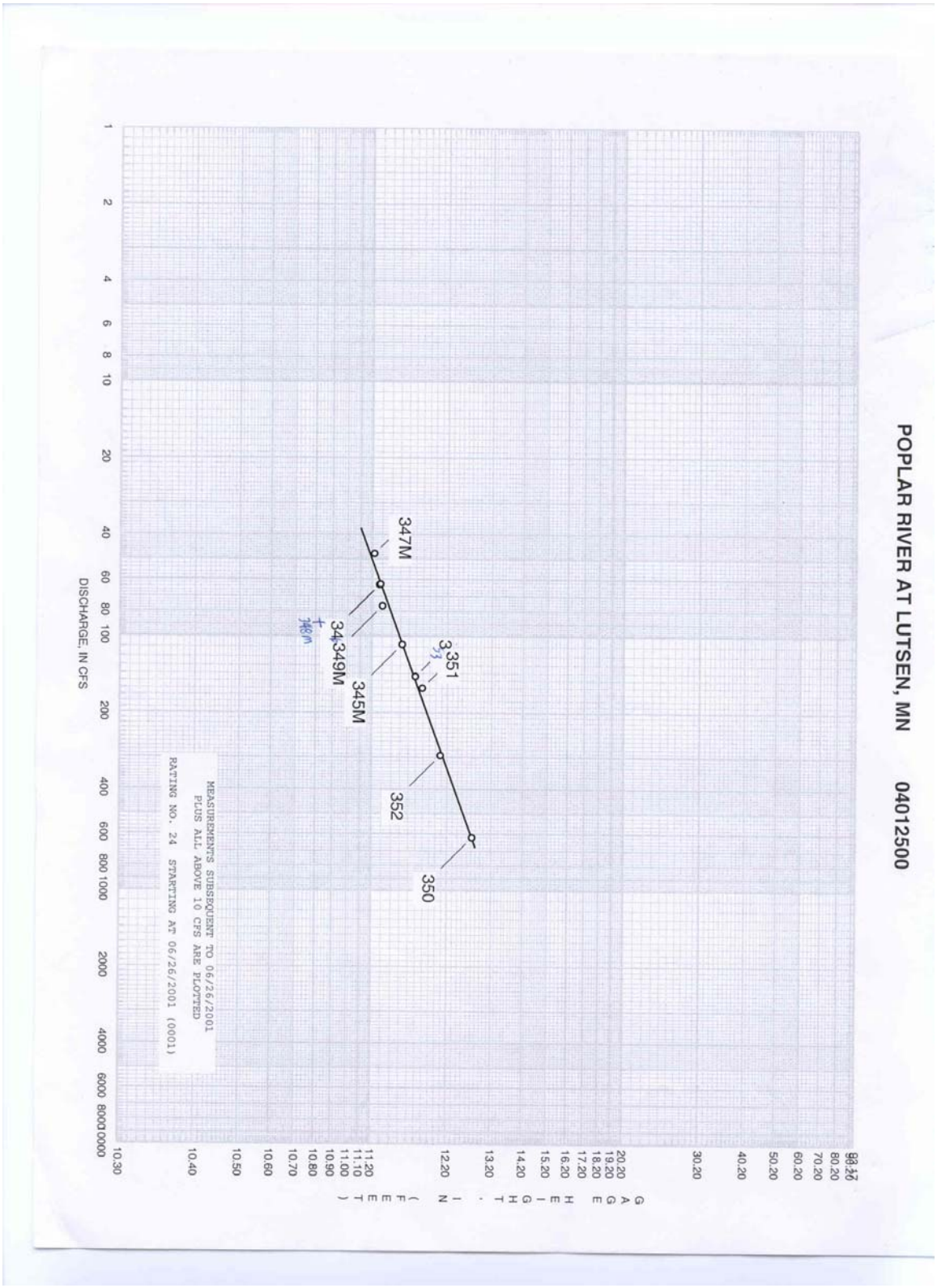
Site	Number of samples	Total Alkalinity (mg/L as $CaCO_3$)				Total Nitrogen (mg/L)			
		mean	median	max	min	mean	median	max	min
Amity	20	57	49	110	20	.997	1.075	1.58	.36
Talmadge	17	45.88	34	93	18	1.04	1.14	1.55	.54
Sucker	18	44.44	33.5	88	17	.952	.96	1.55	.41
French	17	43.05	36	86	17	.864	.92	1.51	.42
Poplar-down	20	26.2	24	40	10	.833	.725	1.64	.15
Poplar-up	18	24.72	23	37	16	.838	.77	1.54	.45
Brule	17	17.52	16	25	10	.68	.56	1.36	.33

2002 Data Summarized by Season / Event. Snow= snowmelt, Rain= rain events, base= summer baseflow

Site	Total Suspended Solids (mg/L)			Chloride (mg/L)			Total Phosphorus (mg/L)			Alkalinity (mg/L as $CaCO_3$)			Total Nitrogen (mg/L)		
	snow	rain	base	snow	rain	base	snow	rain	base	snow	rain	base	snow	rain	base
Amity	29.2	69	3	10.8	17.4	22.2	.09	.08	.011	25.8	63.1	86.3	1.26	1.0	.43
Talmadge	22.2	34.2	1.35	5.42	7.02	9.22	.081	.086	.021	19.2	44.8	74.7	1.14	1.18	.65
Sucker	47.5	19.2	1.5	2.65	1.92	1.55	.106	.057	.014	24.5	43.4	73.5	1.23	.98	.485
French	45.2	49	1.12	6.07	3.7	3.88	.098	.071	.01	19	41.7	64.4	1.07	.976	.514
Poplar-down	85.1	25.5	4.1	2.67	1.87	1.77	.13	.048	.015	19.7	27.8	30.2	1.42	.813	.515
Poplar-up	6.5	5.88	3.5	1.4	1.44	1.67	.038	.023	.016	17.5	25.7	29.5	1.32	.746	.585
Brule	14.9	2.2	1.53	1.17	1.63	1.67	.052	.016	.009	10.5	20.3	19.6	1.17	.596	.46

Quality Assurance Data, 2001 and 2002

Date	Site	Sample Type [1]	TSS (mg/L)	Total Chloride (mg/L)	Total P. (ug/L)	Total Alkalinity (mg/L)	Total Nitrogen
6/26/01	Sucker	Sample (baseflow)	1.2	1.3	13	74	.62
6/26/01	Sucker	Duplicate	1.0	1.7	16	74	.62
6/26/01	Sucker	Blank	1.0	1.0	2	10	.15
4/12/02	Sucker	Sample (snowmelt)	65	5.3	145	23	1.55
4/12/02	Sucker	Duplicate	76	13	139	17	1.46
4/18/02	Poplar-Down	Sample (snowmelt)	200	3.7	264	23	1.64
4/18/02	Poplar-Down	Blank	2.4	< 1	3	< 10	< 15
8/27/01	Brule	Sample (baseflow)	< 1	1.7	10	18	.49
8/27/01	Brule	Duplicate	< 1	1.5	10	19	.48

1. **Sample- this water sample was considered representative and therefore used in the FLUX model calculations; Duplicate- a duplicate sample was collected; Blank- de-ionized water was poured into sampler, then into bottles.**

Appendix 4. Example of USGS Rating Curve, Poplar River