# LAND USE/LAND COVER AND HYDROLOGIC EFFECTS ON NORTH SHORE TRIBUTARY WATER QUALITY

A THESIS SUBMITTED TO THE FACULTY OF THE GRADUATE SCHOOL
OF THE UNIVERSITY OF MINNESOTA

BY

Andrea Bernice Crouse

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF
MASTER OF SCIENCE

Richard P. Axler and George E. Host, Advisors

August 2013

**Acknowledgements**

The following people deserve recognition for their contributions to this project. I would like to thank my committee members, Dr. Richard Axler, Dr. George Host, Dr. Karen Gran, and Dr. Lucinda Johnson. Their help and guidance through the project have been invaluable. I would also like to thank Dr. Ronald Regal for assistance with statistical analysis throughout this project. Elaine Ruzycki, Jerry Henneck, Jeremy Erickson, Jennifer Olker, Will Bartsch, Dan Breneman, Tiffany Sprague, Katy Feldt,and Margy Bell of the Natural Resources Research Institute (NRRI) provided assistance with various aspects of this project. Additionally, Gerry Sjerven, and Paul Meysembourg from NRRI provided assistance with Geographic Information System analysis. Tom Hollenhorst from EPA-MED and Terry Brown from NRRI worked on development of the stressor gradients and offered advice throughout the project. This project would not have been possible without the many researchers at NRRI, UMD, EPA-MED, MPCA, and the volunteer stream monitors who gathered the water quality data and made it accessible for this study. Finally, I would like to thank Minnesota Sea Grant-UMD, the National Science Foundation GK-12 Fellowship (PI: Dr. Carmen Latterell, UMD Mathematics and Statistics Dept.), the UMD Biology Department, and NRRI-UMD for funding this project.

**Dedication**

This thesis is dedicated to my soon-to-be wife, Jen. Without her constant support, encouragement, and understanding this would not have been possible. And to my parents, Pam and Byron, who provided experiences early in my life which connected me to our fresh water resources and instilled a sense of responsibility to work towards understanding and preserving them.

**Abstract**

Although they are inextricably linked, the impact of meteorological events and climate variations on water quality have not yet been fully explored. Streams considered for this study are facing increased developmental pressures and have, thus far, remained relatively pristine, although some are already listed as “Impaired”. Through use of accumulated water quality data for Duluth and North Shore (Minnesota, USA) streams and GIS analysis of watershed characteristics, empirical models which explain the variability of water quality data, stratified by hydrologic regime, and mediated by landscape characteristics were analyzed. Multivariate statistical found correlations between measures of particulate-related and soluble water quality: sorted by hydrologic regime (i.e. snowmelt, storm events and baseflow); and mediated by landscape metrics. Measures of development at the local scale, including % impervious, were shown to be significantly correlated with increased particulate-related water quality metrics during high flow periods. Wetland cover at the whole watershed scale was negatively correlated with particulate-related water quality metrics, though at the local scale wetlands were positively correlated with soluble water quality metrics. Relationships between water quality metrics and measures of forest cover and stand type were shown to be strongly influenced by the scale at which analyses were performed. Regression analyses indicated that local land use/land cover (LULC) metrics best predicted particulate-related and soluble water quality metrics during high flow periods. During baseflow periods, whole watershed LULC metrics were the best predictors of particulate-related water quality metrics. Results suggested that road salt applied during the winter months may be stored in the soils or groundwater and released into urban trout streams during rain periods. The soluble water quality parameters were less clearly linked to just a few LULC characteristics and a there was no clear pattern for differences between whole vs. local watershed analysis. Soluble nutrients also exhibited seasonal variability. These analyses are an important step towards improving watershed planning and management policies by providing a tool for forecasting the impacts of land use decisions on water quality with known accuracy.

## Contents

## List of Tables

## List of Figures

## Introduction:

The land use and cover (LULC) along the North Shore and within the City of Duluth metropolitan area impact in-stream and near-shore freshwater habitats (Anderson et al., 2000). The streams flowing into Lake Superior and the St. Louis River carry sediments, excess nutrients, salts, and other dissolved and particulate pollutants which degrade habitat in critical areas. Degradation of aquatic habitat and biotic diversity in the streams and the nearshore waters of Lake Superior at stream mouths will adversely affect our ability to use and enjoy these freshwater resources. It will also negatively impact a growing economy based largely on tourism and recreation as well as the historic Lake Superior fishing industry, and Native American rights to hunt, fish, and gather as stated in the 1854 Treaty (1854 Treaty Authority, 2012).

### Hydrology, landscapes, and water quality

Streams along the North Shore of Lake Superior and the Duluth hillside are in relatively pristine condition. Low population density coupled with densely forested watersheds and numerous municipal and state parks through which these streams flow have contributed to their good water quality. The unique topography of the region, including steep bedrock escarpments, creates a high density of stream corridors in relatively narrow, heavily forested watersheds (Richards and Host, 1994). The North Shore streams of Lake Superior are highly valued for their aesthetic beauty and recreational opportunities. Cool, clear waters flow down gently sloping headwaters before reaching the steeper inclines of the streams' lower sections, offering spectacular waterfall viewing and habitat for terrestrial and aquatic organisms alike (Anderson et al., 2003, Fitzpatrick et al., 2006). Of the hundreds of streams along the North Shore, 152 are designated cold-water trout streams, 16 of which flow through the city of Duluth, intersecting highways, city parks, residential neighborhoods, and business districts before discharging to the St. Louis River Estuary or the western arm of Lake Superior (MDNR, 2007). These are low-nutrient, high oxygen, cold water aquatic ecosystems inhabited by communities of organisms that are extremely sensitive to watershed disturbances (Waters, 1980). However, along the North Shore of Lake Superior and within the city of Duluth dozens of streams have been listed as "Impaired" under section 303(d) of the Clean Water Act. These are streams that are too polluted or degraded to meet water quality standards set by states, territories, or tribes. In this region streams have been listed as "Impaired" chiefly for turbidity, but also for fish-mercury, temperature, chloride, and cold-water aquatic life (MPCA, 2010).

The study of aquatic systems is intricately linked to landscape and many terrestrial stressors are delivered to surface water through hydrological processes (King et al., 2005, Hollenhorst et al., 2007, Ruzycki et al., 2011). Shortly after ice-off, spring snowmelt delivers a flush of road salts and other atmospherically-deposited pollutants accumulated over the course of the winter to streams. Storm water flowing into Duluth and North Shore streams, overland or through storm sewers, carries pollutants, such as sediments, nutrients, and salts from roads, parking lots, and lawns into the stream channel and eventually into the pristine waters of ultra-oligotrophic Lake Superior. The high peak flows associated with rainstorms cause increased erosion rates along stream banks affecting channel morphology as well as increasing nutrients and other particulate-associated pollutants in the stream. Water temperature is similarly influenced by weather events. Not only will air temperature have a direct effect on water temperature, but storm water flowing over warmed surfaces delivers warmer water to the historically cool and cold water of the region's trout streams, directly influencing everything from metabolic rates of aquatic organisms to nutrient cycling (Poole and Berman, 2001). The mediating variable between high flows caused by meteorological events and resulting water quality (WQ) is the landscape. Landscape variables, including slope, soils, stand composition (conifer vs. deciduous); measures of development including percent urban/impervious surface, population density, and stream-road crossings; and measures of watershed storage capacity as determined by percent wetland cover, have quantifiable roles in determining WQ in associated streams (Swank and Douglass, 1974, Detenbeck et al., 2003, Brazner et al., 2005, Danz et al., 2007, Dosskey et al., 2010). Land use and land cover (LULC) will exacerbate or moderate the impact of weather events on in-stream WQ.

The study region is characterized by unique geomorphology. Relatively low-gradient headwater streams flow through wetlands and supraglacial drift characterized as sandy loamy, silty loam, clay loam, or clay till at elevations of about 1,200 feet (MSL). Most of the elevation change occurs in the middle and lower reaches which have extremely steep slopes and confined bedrock valleys (Anderson et al., 2003, Fitzpatrick et al., 2006). Urbanization is concentrated in the upper, flatter, area of the watershed and in a narrow band <1 km inland from Lake Superior. Urban development, including logging and subsequent shifts in vegetation, in these areas (generally about 600 feet above current Lake Superior levels of ~600 feet MSL) has contributed to increased run-off and flood peaks resulting in channel widening (Fitzpatrick et al., 2006). Local research has noted variation in stream flows within the study region with southern streams showing a more rapid runoff response than those in the north (Anderson et al., 2003). Even within a watershed there can be challenges to assessing relationships between LULC and WQ as both change along the length of the stream (Anderson et al., 2000, Fitzpatrick et al., 2006, Erickson, 2010).

Increasing urbanization in and around Duluth and along the North Shore, compounded by the predicted effects of climate change, has put the water quality of these sensitive streams in jeopardy. In the early 1990s, over 50 new lodging establishments were constructed along Lake Superior's North Shore, and from 1990-2010 Cook County, MN experienced a 25% population increase (MPCA, 2000, MN Dept. of Administration, 2011). Anthropogenic alterations in the watershed, such as increased impervious surfaces and riparian vegetation loss, have often been linked to reduced stream health as indicated by increased turbidity, sedimentation, sediment and nutrient loading, excessive peak flows and temperatures (Bunn et al., 1999, MPCA, 2000, Poole and Berman, 2001, Walsh et al., 2005, Zaimes et al., 2006, Danz et al., 2007). Seventeen of 27 major North Shore tributaries are now listed as Impaired, primarily for turbidity and fish-mercury (MPCA, 2010). Communities along the North Shore of Lake Superior may increasingly face 'tipping points'- points at which beaches require advisories due to indicator bacteria exceedances, and trout can no longer survive in a stream due to inadequate baseflows, thermal stress, high turbidity and sedimentation (Raleigh, 1982, Eaton and Scheller, 1996, Trebitz et al., 2007, Host and Axler, 2009). Various reasons have been hypothesized for these declines in WQ, including increased development pressure (MPCA, 2000, Danz et al., 2007, Niemi et al., 2011), logging (Likens et al., 1970, Woodwell et al., 1975, Whittaker et al., 1979, Verry, 1986, Friedman and Reich, 2005), naturally occurring erosion and slumping of stream banks (Zaimes et al., 2006, Wolter et al., 2006, Brown et al., 2009) and climate change (Galatowitsch et al., 2009, Noyes et al., 2009), all of which are known or predicted to be affecting the North Shore of Minnesota.

Much research has focused on the interactions between landscape and WQ (Johnson and Host, 2010, Dosskey et al., 2010); however much of the variability in North Shore tributary WQ remains unexplained (Richards and Host, 1994, Johnson, 2010). This work uses LULC metrics as predictors of WQ in new empirical statistical models that focus on the effect of inter-annual and intra-annual differences in weather and climate. This approach makes it possible to correct for temporal (seasonal) variations as well as inter-annual variation in weather patterns.

## Objectives:

In this study we assessed the influence of seasonal variations in weather leading to different flow regimes (hydrologic regime); and differences in inter-annual precipitation and snow accumulation (precipitation regime) on WQ as mediated by LULC in watersheds along the Minnesota portion of the western arm of Lake Superior. The specific objectives of the project were to:

1. assess the influence of LULC characteristics on WQ in western Lake Superior tributaries;

2. assess the influence of meteorological regimes (i.e. hydrology and precipitation) on WQ in western Lake Superior tributary watersheds;

3. build empirical models to predict WQ during each hydrologic regime (snowmelt, rain periods, base flow) based on LULC;

4. assess the spatial and temporal scales over which LULC and weather patterns are best related.

## Hypotheses:

Due to the various physical and chemical properties of the WQ parameters assessed we chose to categorize them into particulate-related or soluble metrics (see Table 1).

### Land Use/Land Cover

H1) If water quality is affected by LULC then:

*Particulates*

H1-a: as watershed % development increases, WQ parameters related to particulates will display a predictable and statistically significant increase;

H1-b: as watershed % forest and/or % wetland increases, WQ parameters related to particulates will display a predictable and statistically significant decrease;

*Soluble*

H1-c: as watershed % development increases, soluble WQ parameters will display a predictable and statistically significant increase;

H1-d: as watershed % forest and/or % wetland increases, soluble nutrient concentrations will decrease;

H1-e: as watershed % development increases, specific electrical conductivity (EC25) and chloride ($Cl^-$) will increase during snowmelt periods and decrease during rain periods.

### Hydrologic Regime

H2) If water quality is affected by hydrologic regime then:

H2-a: WQ values will differ between snowmelt, storm events, and baseflow periods;

H2-b: high flows due to rain storms and snowmelt will exacerbate LULC influences on both particulate and soluble WQ.

### Precipitation Regime

H3: If water quality is affected by inter-annual variability in weather (Water Year precipitation regime) then:

H3-a: the strength of interactions between landscape and aquatic ecosystems will vary depending on prevailing and antecedent weather (precipitation regime);

H3-b: normalizing WQ metrics to total water year-accumulated precipitation will decrease variability in regression analyses as compared to regressions without weather-normalized WQ data.

## Methods:

### Study Region

The 37 Western Lake Superior tributary streams, composed of 61 watersheds and containing 80 sampling sites, included in this study are shown in Figure 1 and listed in

Appendix A and B. These streams and sample sites were chosen based on availability of long-term, contemporaneous water quality data. Study watersheds drain a combined area of 5,320 $km^2$ ranging in size from 0.83 $km^2$ to 685 $km^2$ with a mean of 87 $km^2$ and median of 35 $km^2$.

Watersheds for each sample site were delineated using ArcHydro (Maidment, 2002), based on a 10 m Digital Elevation Model (Figure 1). Each sample site was associated with watersheds defined at two scales, a "whole" watershed which include the entire drainage upstream of the sample site (median size of 35.4 $km^2$), and a "local" watershed (median size of 1.12 $km^2$). The local watershed polygons were generated by mapping the part of the DEM which slopes towards the stream using the undivided sections of the stream network between stream confluences instead of the entire stream network (Figure 2). ArcMap 9.3 (Environmental Systems Research Institute, Redlands, CA USA) was used to summarize the area and LULC of each watershed, focusing on the 2006 NLCD and the *Sediment SumRel* component within the 61 watersheds. This landscape data were used to develop empirical models for predicting WQ.

## Landscape Data

Characteristics of each watershed were determined using the 2006 National Land Cover Database (NLCD) (MDNR, 2006, USGS, 2010, MNGeo, 2010) and the *Sediment SumRel* components (Brown et al., 2011).

The *SumRel* is an integrated measure reflecting landscape stressors, including point sources, road density, population density, % urban, and % agricultural. This metric was developed for the Great Lakes Basin and is summarized for (>13,000) contributing watersheds across the Basin (Host et al., 2011). This set of landscape stress indicators was more recently modified to include additional erosion-related metrics (Appendices I-L). The *Sediment SumRel* stressor gradient is based on 15 components of human disturbance including the 5 *SumRel* components (Brown et al., 2011):

- population density (U.S. Census Bureau 2002)
- point source pollution permit density (NPDES database, EPA 2012)
- road density (USGS TIGER data, U.S. Census Bureau 2002)
- % urban (2001 USGS National Land Cover Dataset, Homer et al. 2004)
- % agriculture (2001 USGS National Land Cover Dataset, Homer et al. 2004)

With additional data specific to erosion prediction for the *Sediment SumRel* (Brown et al., 2011):

- stream/road intersections (count within ArcHydro subcatchments, 2008 MNDoT roads, ArcHydro streams)
- percent canopy coverage (NLCD 2001)
- percent wetland (National Wetland Inventory 1974-1988)
- percent impervious (NLCD 2001)
- stream channel slope (10m digital elevation data)
- stream context slope (10m digital elevation data)
- stream channel sedimentary erosion potential (State Soil Geographic Database 2001)
- stream context sedimentary erosion potential (State Soil Geographic Database 2001)
- stream channel KFFACT (STATSGO 2001 and 2006 NLCD, NRCS)
- stream context KFFACT (STATSGO 2001 and 2006 NLCD, NRCS)

"Stream Context" refers to the area of a corridor approximately 100 m either side of the stream. The "K factor" represents the inherent susceptibility of a soil type to erosion and is used in the Revised Universal Soil Loss Equations (Renard et al., 1991).

The Anderson Level III 2006 NLCD categories of development, forest, and wetland were combined to create a summed category for each (Appendix H). The summed development layer was highly correlated with % impervious used in the *Sediment SumRel* ($R^2 = 0.99$ $p<0.0001$), which is to be expected as both layers are derived from the same dataset. In our analyses we used the % impervious measurement from the *Sediment SumRel*. Forest types (deciduous, conifer, and mixed) were summed to create an all-inclusive forest layer. Emergent and woody wetland categories were also combined. Analyses were performed with combined and individual NLCD classifications. All 2006 NLCD data (proportional data) were transformed using ArcSine Square Root (angular) transformation which spreads out data on the upper and lower ends of the measures while compressing data in the middle.

Higher resolution soil K values were determined for St. Louis county streams using the 2011-2012 Natural Resources Conservation Services (NRCS) Soil Survey Geographic Database (SSURGO, 2012) (Appendix L). In the absence of reported values a weighted average, based on the length of the border each unknown soil map units shared with known units, was used to estimate a K factor values (Bartsch, 2012). Unfortunately, SSURGO data had not been released for Lake and Cook counties at the time of this study (Feb. 2013). Separate, exploratory analyses were run with watersheds included in the SSURGO coverage to assess the relationship between particulate-related water quality and high resolution soil data (Appendix L). Data not shown.

**Water Quality Data**

Water quality data were compiled from various sources to create a combined database of grab water samples and automated sensor data from gaged sites to be used as dependent variables in statistical analyses (Table 1). The WQ database includes samples from 80 unique samples sites within the 37 streams included in this study and span the years 1996-2010. Data from a variety of sources were used- including:

- volunteer stream monitoring sites in the Flute Reed River, Lester River, and sites monitored along Tischer Creek by Duluth Public School science classes (1996-2010);
- UMD studies- nine thesis-related studies and two TMDL studies (1996-2010); www.LakeSuperiorStreams.org project (sensor and grab samples); intensive seasonal grab samples;
- MPCA Surface Water Assessment studies (2008-2010); MN Milestone and North Shore Loading studies (2002-2010)
- Mid-Continent Ecology Lab (EPA-MED) studies (1996-1999)

The resulting database contained 4,446 unique, contemporaneous observations.

All WQ grab data used almost identical field collection methods, standard laboratory analysis, and quality assurance/quality control methods, whether generated by MN agency staff, University of MN Duluth staff, or EPA-MED staff (e.g. (Ruzycki et al., 2013 In Press). All WQ data are now accessible through the MPCA's electronic access database (http://www.pca.state.mn.us/index.php/data/surface-water-data.html).

WQ metrics were grouped by hydrological regime (hereafter referred to as snowmelt=SNOW, storm events=RAIN, and baseflow=BASE) which allows for analysis of WQ responses to meteorological regimes across a gradient of LULC. It also allowed us to create empirical models to more accurately quantify the LULC characteristics of North Shore and Duluth streams needed to maintain high WQ necessary for indigenous aquatic organisms across a gradient of LULC, hydrologic regimes, and climatic variation (Detenbeck et al., 2003, Bedan and Clausen, 2009). These analyses can help identify specific landscape activities posing a significant threat to WQ in this region.

Sensor data from 5 intensively monitored Duluth streams (Amity Creek, Chester Creek, Tischer Creek, Miller Creek, and Kingsbury Creek), two North Shore streams (Knife River and Poplar River), and additional storm sampling grab samples along Amity Creek (K. Gran UMD Geology Dept., unpublished data) were condensed into a daily mean and median for each stream (n=10,490). Each day was assigned to a hydrologic regime. Winter baseflow data were removed (n=2,651) in order to limit the impact of winter salting events on BASE samples. A Water Year (Oct. 1 through Sep. 30) median for each stream, hydrologic regime, and WQ metric was calculated so it could be compared to grab sample data from less intensively (<10 samples per year) monitored streams. Sensor WQ data was quality assured following guidelines used by USGS for various North Shore stream programs (Axler et al., 2007). Flow gaging was either quality assured by the MPCA, MDNR, USGS (Anderson et al., 2003) or by the

LakeSuperiorStreams.org project following similar protocols (http://www.lakesuperiorstreams.org/streams/QA_QC.html).

WQ measurements were grouped as particulate or soluble (Table 1) with particulate-related metrics including: turbidity (Turb), total suspended solids (TSS), transparency tube (T-tube), and total phosphorus (TP). TP was grouped with particulate-associated parameters because phosphorus in most natural waters is adsorbed to inorganic solids (Allan and Castillo, 2009). Transparency tube data were analyzed as the inverse of the values (1/T-tube) to ensure that expected positive correlations with LULC stressors represent a decrease in clarity. "Soluble" WQ metrics include: dissolved oxygen (DO), ortho-phosphate (OP), total nitrogen (TN), dissolved inorganic nitrogen (DIN), ammonium-N ($NH_4^+$-N), nitrite/nitrate-N ($NO_2/NO_3^-$-N), specific electrical conductivity (EC25), and chloride ($Cl^-$). TN was placed in the soluble category because in these relatively pristine streams, most of the nitrogen is in the form of refractory organic compounds (R. Axler, personal communication). All non-normally distributed WQ data were $\log_{10}$ transformed prior to analysis.

Each WQ sample was categorized by watershed ID, site ID (as defined by individual studies), Water Year (WY), calendar season, precipitation regime, and hydrologic regime. Median, mean, and standard deviation for particulate-related WQ in each stream during each hydrologic regime can be found in Appendices P-R and for soluble WQ in Appendices S-U. Methods used and criteria applied are described below.

## Hydrology and Weather

### *Precipitation Regime*

Three National Weather Service weather stations along the North Shore provided precipitation, temperature, and snow pack data for the study region over the time period in which the water samples were collected (Table 2, Figure 1). These stations are approximately evenly distributed along the North Shore of Lake Superior, capturing the variety of weather that occurs from the southern end near Duluth to the northern end near the Canadian border. The streams were assigned to one of the weather stations based on proximity and typical path of storm events. Mean, median, standard deviation, standard error, and 95% confidence intervals (CI) for precipitation and snow pack for each WY and weather station were calculated (Table 2, Figure 3). The 30 year precipitation mean for the region was 0.5" higher than the calculated mean for the time period of this data set; therefore, we used the mean value as calculated for the time period included in our study.

Precipitation regimes (dry, average, and wet years) were determined following three approaches: 1) the three wettest and driest years as determined by the combined average for all three weather stations and applied to all streams, 2) the three wettest and driest years as determined by each individual weather station and applied to the nearest streams, and 3) the years above and below the 95% CI at each weather station and applied to the nearest streams. Any year not designated as "wet" or "dry" was defined as "average". A precipitation regime was then associated with WQ for each watershed and WY.

All three approaches were assessed using two-tailed t-tests comparing the mean values of each water quality variable for wet, dry, and average years. We ultimately used the second method for analyses which assigned “wet” and “dry” based on the three wettest and driest years specific to each of the three weather stations because it identified the strongest differences in WQ metrics between each precipitation regime (Table 2). At the Duluth station 1996, 1999, and 2010 were the wettest years while 1998, 2003, and 2007 were the driest. At the Wolf Ridge station the wettest years were 1999, 2001 and 2008 while the driest years were 2000, 2003, and 2009. At the Grand Marias station the wettest years were 1999, 2001, and 2008 while the three driest years were 1998, 2003, and 2004 (Table 2, Figure 3).

*Hydrologic Regime*

WQ measures were separated into three categories based on hydrologic regimes as determined by weather: snowmelt, rain periods, and base flow (here-after referred to as SNOW, RAIN, and BASE respectively) SNOW (n=821), RAIN (n=1288), and BASE (n=2012). These categories were chosen based on the increasingly common approach to stream sampling which includes event based sampling due to the importance of high flow conditions in determining pollutant loading to surface waters (MPCA, 2011). This approach not only decreases variability in the WQ dataset but allows increased accuracy in assessing the influence of LULC types on WQ metrics, particularly particulate-related metrics, which are washed into streams during high flow periods (Anderson et al., 2003, Ruzycki et al., 2011, Ruzycki et al., 2013 In Press). Though some of the sampling included in our dataset pre-dates the event-based sampling approach we were able to use meteorological data to reconstruct the conditions which would have qualified the samples into one of the categories currently used. WQ samples and weather were also grouped by

USGS WY (October 1st of one year through September 30th of the following year) and by within-year periods to account for the hydrological cycle: autumn storms, snow accumulation/melt, spring storms, summer storms, and summer baseflow.

Snowmelt occurred most often in late March-early April and was categorized by increase in air temperature concurrent with decrease in snowpack and increased stage height or flow as measured by the nearest gaged stream. Infrequent rain events that occurred during the winter on top of snow (rain on snow) or during snowmelt were considered SNOW.

Rain period data (RAIN) were identified by precipitation in conjunction with individual flow or stage height measurements of the nearest gaged streams. During the leaf-free seasons (winter and spring) smaller precipitation totals constituted RAIN as indicated by clearly observable changes in WQ of gaged streams, presumably due to decreased water absorption by vegetation and reduced interception by the canopy. During these periods rain accumulation in one day of $\geq$ 0.3 inches, accompanied by a rise in the stage height of the stream, as determined by the nearest gauged stream, constituted RAIN. During the leaf out (growing) season rain accumulation in one day of $\geq$ 0.5 inches constituted RAIN. To account for multi-day impacts of large events on WQ, rain periods that were >1.00 inches in one day were given the designation of “RAIN” for two consecutive days (i.e. day of 1” rainfall and the following day were both coded as “RAIN”).

Because baseflow could occur throughout the year with great variability in various WQ metrics, only periods after snowmelt in the spring (often in mid-late April) through October 20 that were not included as RAIN were used. Removing all winter baseflow WQ data between Oct. 20 and April 20 of each WY reduced the variability in BASE periods where major ions, chloride and EC25, were strongly affected by winter deicing activities. It is noted that baseflow conditions, in a strict hydrological sense usually refers to periods dominated by groundwater relative to overland flow. Our classification of BASE conditions did not hold strictly to this since the exact magnitude of various discharge source(s) was not available for the dataset analyzed. Instead our classification of BASE served to define those samples taken while the hydrograph was relatively low and was based on the hydrograph of the nearest gaged stream and weather conditions at the time of and prior to sampling.

## Statistical Approach

To test the hypothesis that water quality is affected by LULC we performed mixed model regressions (Table 3). This technique allowed us to account for auto-correlation between sample sites within the same stream and avoid issues of pseudoreplication. Streams, our experimental units, were coded as a random effect while LULC metrics were fixed effects in the models. We used these mixed models to 'control' for differences in statistical units (streams) without reducing all of the WQ measurements to means or another summary statistic across all sampling periods and years. We expected that streams had inherently different characteristics influencing their WQ, so we needed to control for these differences in order to investigate the effects of LULC, hydrologic regime, and precipitation regime. In a mixed model we can do this by adding stream into the model. Alpha was adjusted down to 0.001 to account for the number of regressions performed to test this hypothesis (0.05/36 tests = 0.001). The adjusted $R^2$ values reported in Tables 3 and 4 are for fixed effects.

To test the hypothesis that water quality is affected by hydrologic regime we performed two-tailed t-tests to assess differences in each water quality variable across SNOW, RAIN, and BASE periods (Table 5, Figure 4). To account for the number of tests run to test this hypothesis we adjusted alpha from 0.05 down to 0.002 for all t-tests (0.05/24 tests = 0.002).

To test the hypothesis that water quality is affected by inter-annual variability in weather (here-after, the precipitation regime) we performed two-tailed t-tests to assess differences in each water quality variable across dry, average, and wet WYs using a subset of 13 streams with long-term and contemporaneous WQ data from the lower reaches of the stream near the discharge to Lake Superior (Figure 1B, Table 6 and 7). These streams included (from NE to SW): Flute Reed, Brule, Poplar, Beaver, Knife, Sucker, Talmadge, Amity, Tischer, Chester, Miller, and Kingsbury. To account for the number of tests run to test this hypothesis we adjusted alpha from 0.05 to 0.002 for all t-tests (0.05/24 tests = 0.002). To further analyze the impact of precipitation regime, WQ metrics were normalized to WY rain accumulation and WY snow accumulation (according to the nearest NWS station), and each analysis was performed with the original WQ values as well as the WQ data normalized to WY precipitation and snow.

The same subset of 13 streams used to assess water quality response to precipitation regimes was used to build models which were then applied to the full dataset (Figure 1B). Mixed-model regressions were performed to analyze the relationship between LULC (measures of development, forest, and wetland) and WQ (particulates and soluble; Tables 3-4). Forward stepwise regression was performed to determine which of the individual LULC components, including watershed area, the *Sediment SumRel* index (See METHODS), and 2006 NLCD had the strongest relationship to WQ metrics. We then manually removed selected variables to find the smallest number of predictors that still maintained the highest $R^2$ and lowest p-value for the model (Table 8). Model evaluations included Akaike information criterion (AIC) and inference plots. The analyses were first performed without removing outliers and then with a modified data set that removed outliers more than 2 standard deviations from the mean. All analyses were done in JMP Version 9 (SAS Institute Inc., 1989-2011) and verified by additional analysis in SAS with the same results (data not shown). All statements of significance assume $p \leq 0.05$ unless otherwise noted.

## Results:

### LULC and Particulate-associated water quality

*% Impervious Surface*

Local measures of watershed imperviousness were better predictors of particulates, and correlations were strongest during high flow periods. TSS and turbidity both showed significant positive correlations with local measures of % impervious during RAIN and SNOW. TP was significantly correlated with local measures of imperviousness during SNOW only, and also showed significant correlations with whole watershed measures of imperviousness during all hydrologic regimes. T-tube did not show any significance with measures of imperviousness at any scale. Based on the Bonferroni correction, only TP during BASE was significantly related to whole watershed measures of imperviousness (Table 3, Appendix C).

*% Canopy Cover*

TSS and TP were both positively correlated with local measures of canopy cover (*Sediment SumRel*) during SNOW and RAIN. Turbidity was positively correlated with local measures of canopy cover during SNOW only. TP was negatively related to whole watershed canopy cover RAIN and BASE, but most strongly during BASE. Based on the Bonferroni correction TSS and TP during SNOW were the only particulate-related metrics related to canopy cover and only at the local scale (Table 3).

*Forest Type*

Particulates were negatively correlated with % conifer; specifically, TP was negatively correlated with % conifer in all hydrologic regimes, while TSS was correlated during high flows and turbidity was only correlated during SNOW. T-tube was not significantly correlated with % conifer. TSS and turbidity both had positive correlations with deciduous forests in all hydrologic regimes except for BASE turbidity. TP was positively correlated with deciduous forest only for RAIN. Again, high flow periods had the highest significance. Based on the Bonferroni correction only turbidity during RAIN was significantly related deciduous and no particulate-related metrics were related to conifers (Table 3).

*% Wetland*

TSS was positively related to local measures of wetland in during RAIN and negatively related to whole watershed measures during all seasons. Turbidity was positively related to local measures of wetland during BASE and negatively related to whole watershed wetland cover during high flow periods. TP was positively related to local measures of wetland during SNOW but negatively related during BASE. T-tube was negatively related to both local and whole watershed measures of wetland in all hydrologic regimes. TSS was negatively related to whole watershed measures of wetland in all hydrologic regimes as was and T-tube, while turbidity was only during high flow periods. TP was negatively related to whole watershed wetland in SNOW and RAIN only. Based on Bonferroni corrections only TSS and turbidity during RAIN were significantly, negatively related to whole watershed wetland cover and no particulate-related measures were related to local wetland cover (Table 3).

*Predictive modeling for particulate-related water quality*

TSS was best predicted by local stream slope [as defined by the *Sediment SumRel*] during high flows. During BASE, % wetland and % barren were the best predictor of TSS. Including stream as a random variable improved all models except BASE turbidity and TP. Including WY improved RAIN TSS models (Table 8).

Turbidity was best predicted by local stream slope during SNOW and RAIN. However, SNOW models also included local bank sediment erosion potential and RAIN models included mean local bank KFFACT and was improved by including WY and stream as random variables. BASE turbidity was predicted by % barren and was also improved by including WY and stream as random variables (Table 8).

T-tube was predicted by mean local stream slope during RAIN, and % wetland and % barren over the whole watershed during BASE. TP was predicted by local stream slope in all hydrologic regimes with the addition of whole watershed % shrub during BASE (Table 8). Inclusion of WY improved RAIN models only.

Including local area in models lowered AIC and BIC values slightly, however $R^2$ values responded in a less consistent way with some increasing (Turb. during SNOW moved from $R^2$=0.18 to 0.20) and others decreasing (TSS during BASE moved from $R^2$=0.27 to 0.24). Accumulated area was never selected by the models. The inclusion of random effects in these models, which take area into account, was more useful than area alone.

**LULC and Soluble water quality**

*% Impervious Surface*

Nutrient and other soluble WQ metrics were positively related to local measures of imperviousness as well: OP, DIN (RAIN only), $NH_4^+$-N, and $Cl^-$ during all hydrologic regimes; TN during SNOW; and EC25 during SNOW. Based on Bonferroni corrections, OP (during high flow periods) was significantly related to local measures of imperviousness as was EC25 and $Cl^-$ during SNOW (Table 4, Appendix D).

Many nutrients and soluble WQ metrics were positively correlated with whole watershed imperviousness: OP, $NH_4^+$-N, EC25, and $Cl^-$ during all hydrologic regimes (except OP during BASE); DIN during RAIN and BASE. Based on Bonferroni corrections $NH_4^+$-N during RAIN and EC25, and $Cl^-$ during all hydrologic regimes were significantly related to whole watershed measures of imperviousness (Table 4, Appendix D).

*% Canopy Cover*

Except for DO, soluble WQ metrics were positively correlated with local measures of canopy cover but negatively correlated with whole watershed measures. DO was positively correlated with whole watershed measures of canopy cover during RAIN and BASE and negatively correlated with local measures of canopy cover during the same hydrologic regimes. Local measures of canopy cover were positively correlated with: OP during SNOW and RAIN; $NH_4^+$-N in all hydrologic regimes; and EC25 and $Cl^-$ during high flows. Based Bonferroni corrections, OP and EC25 were positively related to local measures of canopy cover during SNOW while only DO was during RAIN (Table 4, Appendix D).

OP was negatively correlated with whole watershed measures of canopy cover during RAIN, as was DIN during BASE ($p=0.06$). $NH_4^+$-N, EC25 and $Cl^-$ were negatively related to whole watershed canopy cover during all hydrologic regimes. Based on Bonferroni corrections EC25 and $Cl^-$ were negatively correlated with whole watershed measures of canopy cover as was $NH_4^+$-N during RAIN (Table 4, Appendix D).

*Forest Type*

Soluble metrics did not show the same, inverse, relationship with conifer cover that particulates did. Based on Bonferroni corrections soluble metrics were only related to deciduous forest type. $NO_2/NO_3^-$-N was related to deciduous and during RAIN and BASE while DIN was significantly related to deciduous cover during RAIN only (Table 4, Appendix D).

*% Wetland*

Overall, soluble WQ metrics were positively related to local measures of wetland and negatively related to whole watershed measures. DO was positively related to local measures of wetland during BASE but not related to measures of whole watershed wetland during any hydrologic regime. OP was positively related to local measures of wetland in all hydrologic regimes. TN was positively related to local wetland cover during high flows and negatively related to whole watershed wetland cover, but only during RAIN. DIN was positively related to local wetland cover during RAIN and BASE and negatively related to whole watershed wetland cover during the same hydrologic regimes. $NH_4^+$-N was positively related to local wetland cover during BASE and negatively related to whole watershed wetland cover during RAIN only. $NO_2/NO_3^-$-N was positively related to local wetland during all hydrologic regimes and negatively related to whole watershed wetland during RAIN and BASE. EC25 was positively related to local wetland during RAIN only and negatively related to whole watershed wetland during all hydrologic regimes except during RAIN. $Cl^-$ was positively related to local wetland, and negatively related to whole watershed wetland in all hydrologic regimes except for SNOW at the whole watershed scale. Based on Bonferroni corrections $Cl^-$ was positively related to local measures of wetland in all hydrologic regimes. OP, DIN, and $NO_2/NO_3^-$-N were positively related to local wetland cover during RAIN and BASE conditions. Only $Cl^-$ and EC25 were negatively related to whole watershed measures of wetland cover and only during BASE (Table 4, Appendix D).

*Predictive Modeling for soluble water quality*

The best predictors of DO during SNOW were local stream and bank slope, and during RAIN local percent canopy cover. Accumulated percent canopy cover, local people/$km^2$, and local bank slope were the best predictors during BASE. OP was predicted by local stream slope in all hydrologic regimes. TN was predicted by percent open (2006 NLCD) during SNOW. Including WY as a random variable improved the model during SNOW. During RAIN local percent wetland was the best predictor, and during BASE percent shrub was the best predictor. DIN was predicted by percent deciduous during SNOW, while during RAIN local percent wetland was the best predictor, and during BASE percent developed low and combined forest type were the best predictors. $NH_4^+$-N was predicted by accumulated road-stream intersections during SNOW, the combination of all development levels during RAIN, and accumulated road-stream intersections during BASE. $NO_2/NO_3^-$-N was predicted by local stream slope during SNOW and local percent wetland during RAIN and BASE (Table 8).

EC25 was predicted by the combined development levels in all hydrologic regimes. $Cl^-$ was predicted by percent open during SNOW, local percent wetland and combined measure of development during RAIN, and percent pasture and local measures of bank slope during BASE (Table 8).

**Hydrologic Regime**

*Particulate-associated water quality parameters*

All measures of particulates had significantly different mean values across each hydrologic regime except for turbidity and TSS between SNOW and RAIN. Particulates were also always higher during high flow periods (Table 5, Figures 4-5).

*Soluble water quality parameters*

Soluble WQ metrics had significantly different mean values in each hydrologic regime, although there were some exceptions including DO (not significantly different in any hydrologic regime), $NH_4^+$-N (not significantly different between RAIN and BASE), and $Cl^-$ (only RAIN and BASE were significantly different) (Table 5, Figure 4).

**Precipitation Regime**

Normalizing WQ metrics to precipitation accumulation in each WY did not improve analyses with LULC as compared to analyses run with non-precipitation-normalized WQ metrics (hypothesis H3-b).

Although three approaches were taken to define the WY precipitation regime, the method that was most effective (relatively) in finding significant differences between WQ metrics in each category was that which compared data grouped by the three driest, three wettest, and the remainder (average) WYs based on individual precipitation data from three National Weather Service Stations. What follows are the results summary of these two-tailed t-tests.

*Particulate-associated water quality parameters*

There were more significant differences for particulate WQ metrics when looking at dry precipitation regimes (dry vs. wet and dry vs. average) partially supporting hypothesis H3-a, however only turbidity (dry vs. average), T-tube (wet vs. average) and TP (wet vs. dry and average vs. dry) showed significantly different values for various precipitation regimes. Particulates tended to be lower during SNOW in wet years than dry years. During RAIN specifically, but high flow periods in general, mean values were higher during dry years and lower in wet years. During BASE, particulates again tended to be lower in wet years than dry years (Table 6, Figure 6).

*Soluble water quality parameters*

Wet years were more different than either average or dry years for nearly all the soluble WQ metrics and ions, lending additional support to hypothesis H3-a. Additionally, RAIN samples tended to have more significance than other hydrologic regimes when analyzing differences in soluble WQ metrics during each precipitation regime. Specifically, OP showed significant differences in wet years vs. both dry and average years in all hydrologic regimes. TN values were significantly different during SNOW for wet vs. dry and dry vs. average precipitation regimes. DIN values were significantly different during RAIN and BASE for wet vs. dry and wet vs. average precipitation regimes. $NH_4^+$-N values were significantly different between wet vs. dry and wet vs. average precipitation regimes during RAIN only. $NO_2/NO_3^-$-N values were significantly different during all precipitation regimes during RAIN. EC25 values were different between wet and dry precipitation regimes only during RAIN. $Cl^-$ values were significantly different between all precipitation regimes during RAIN and between wet vs. dry and wet vs. average during BASE. Further, mean values for many soluble metrics and ions were higher during dry years and these differences were more pronounced during RAIN (Table 7).

## Discussion:

### Landscape variables, collinearity, and issues of scale

Both particulate and soluble WQ metrics were shown to be significantly correlated to land use/land cover metrics though the strength of the correlations varied by hydrologic regime and spatial assessment (Tables 3, 4). Analyses were done with LULC data from both the local (sub) watershed and the whole (accumulated) watersheds (Figure 2, Tables 9, 10) and the impact of scale in the analyses was significant, in some cases reversing the slope of the correlation. However correlations between LULC metrics may, in some cases, explain what at first appeared to be an issue of scale.

Regression analyses were run for several of the LULC characteristics to explore issues of potential collinearity. Of particular interest was the mean stream slope calculated for the *Sediment SumRel* due to its prevalence in predictive models (Figure 11, Table 8). We found that it was strongly correlated with local and whole watershed measures of population density ($r= 0.40$ $p<0.0001$ and $r=0.45$ $p<0.0001$ respectively), local measures of imperviousness ($r=0.37$ $p<0.0001$), bank sediment erosion potential ($r= -0.41$ $p<0.0001$) and stream sediment erosion potential ($r= -0.39$ $p<0.0001$). The relationship between slope and erosion potential of stream banks and in-steam channels is likely due to the increased stream power associated with increased slope. Similarly, measures of imperviousness and population are positively correlated, and both are likely to increase stream-flow, particularly during high flow periods, as infiltration is reduced. The summed 2006 NLCD classification was highly correlated with measures of imperviousness used in the Sediment SumRel (r=0.96 p=<0.0001).

Many of the landscape metrics were correlated with each other in expected ways at the whole watershed scale (i.e. positive correlations between population density and % imperviousness, and between conifer and % canopy; negative correlation between % canopy and % imperviousness; Figure 7). However, we also found that deciduous tree cover was positively, albeit weakly, correlated to population density. This might be due to the location of deciduous tree cover in the Southern section of the study area, where the largest concentration of development also occurs, versus the Northern area which is predominantly conifer forest cover and undeveloped. Several urban streams (Miller, Chester, Tischer, Keene, Kingsbury) were responsible for the direction of the correlations between deciduous stands and WQ metrics (Tables 3 and 4, Figure 8). Further, local % canopy was positively correlated to local % imperviousness ($R^2$=0.75, Figure 7). Results likely reflect the influence of urban streams which exist in watersheds characterized by high % imperviousness though the stream channel may be heavily forested thanks to the many city parks surrounding these streams (Figures 7 and 8). Erickson (Erickson, 2010) came to the same conclusion in a recent study of stream metabolism in a subset of the present study streams where there were additional unexpected associations between LULC and % canopy and stream primary production.

*Urban park effect*

Urban streams, characterized by a seemingly incongruent mix of high % imperviousness at the whole and local watershed scale and high canopy cover, particularly deciduous cover, at the local scale is unique to this study region (Figures 7 and 8). Duluth, MN has 16 designated trout streams within the city limits, one of which, Miller Creek, also has the highest proportion of impervious surface of all the streams included in our analyses (17% whole watershed and up to 54% of the local watershed area; Figure 9). Other streams, such as Tischer (9.6%), Chester (9.1%), Kingsbury (7.0%), and Keene (6.6%) all have over 6% impervious surface at the whole watershed scale (Figure 9). Yet these streams remain mostly heavily forested (between 45-84% at the local level; Figure 10). It begs the question as to which LULC exerts the strongest influence on WQ, and in what hydrologic regime or season. There are significant areas in which canopy covers impervious surfaces. Percent canopy is determined remotely during the growing season by a measure of total reflectance at a wavelength indicating chlorophyll-a. Impervious surfaces are estimated using both satellite data as well as USGS Tiger line data, allowing for measurements of impervious cover under canopy. Therefore, it is possible for both canopy cover and impervious surface measures to be high.

The response of WQ to measures of urbanization (% impervious, people/$km^2$, stream-road crossings/$km^2$) was varied. We would expect urbanization to cause an increase in in-stream nutrient levels as fertilizers applied to lawns and golf courses are more concentrated in urban settings. Additionally, as development alters the shape and size of a watershed, nutrients from leaves and other organic matter may enter the stream channel more quickly than in an undisturbed watershed. It appears that the largely intact and predominantly deciduous riparian zone found along many of the urban streams in the city of Duluth mediates the influence of watershed-scale measures of urbanization. Several of Duluth's cold-water trout streams have city parks established around portions of them, creating a wooded riparian zone even in those streams with relatively high imperviousness that would suggest higher levels of WQ degradation. Similarly, homeowners often maintain some degree of vegetation on their property for aesthetic, if not environment, value. It is only in highly commercial zones that vegetation is disturbed. Recent work in this region found similar urban forest effects when assessing the impact of increasing urbanization on stream metabolism and nutrient metrics. Erickson (2010, In Review) found seasonal influences, in particular significant canopy cover and shading, and subsequent leaf-fall in highly urbanized streams confounded predicted results with regard to community respiration and gross primary productivity.

Nutrients in these streams (TN, $NO_2/NO_3^-$-N, $NH_4^+$-N, and $PO_4^{-3}$—P) showed significant seasonal differences in previous studies (Johnson et al., 1997). Anderson et al. found both nutrients and sediments were positively related to stream flows, in particular, snowmelt. However, in a limited study of several Duluth area streams, TP was routinely below expected values during SNOW, and $NO_2/NO_3^-$-N often exceeded expectations during BASE condition (Anderson et al., 2000). Because the study sites did not contain expected sources of soluble nitrogen, such as agricultural areas or glacial outwash, they hypothesized the source of the excess nitrate/nitrite was groundwater discharge. N and P limitation was found to be stream and season specific for each of nine Duluth area and

North Shore streams (Allen and Hershey, 1996, Wold and Hershey, 1999). And, in addition to seasonal TP variation, strong between-stream differences in empirical models were found predicting TP from turbidity measures in four Duluth trout streams (Ruzycki et al., 2011, Ruzycki et al., 2013 In Press).

### Land Use/Cover influences on Water Quality

Mixed model results found similar adjusted $R^2$ values for each WQ metric across LULC metrics (Table 3-4). These "odd" similarities are attributed to both the strong influence of random effects (those characteristics within each stream that are not accounted for by our selected fixed effects) on the models and covariance between LULC metrics used as fixed effects. Given the amount of within stream variability of LULC characteristics, it is likely that the fixed effects of different land use variables all might explain a similar amount of the total variation. The role of surficial geology and geomorphic differences between watersheds are not accounted for in the fixed effects and may be a source of the strong random effect signal seen in these results. In fact, these specific geomorphic characteristics did not have as dramatic an effect on soluble WQ metrics as they did on particulate WQ metrics, which would be expected if we were essentially underestimating erosional factors (Table 4). Further, the variability of a WQ metric within a single stream was often high, particularly during high flow periods (Appendices M-U). For example, of the 66 TSS samples taken from Amity Creek during snowmelt the median value was 21 mg/L while the SD was 60 mg/L. During rain period sampling there were 70 samples with a median of 17 mg/L and a SD of 105 mg/L. We accounted for much of the variability in our dataset through normalizations, stratification by hydrologic and precipitation regimes, and through the use of appropriate statistical tests. However, it must be noted that the underlying data, both the LULC and WQ data, were highly variable.

*Imperviousness and particulate-related water quality*

Particulate-related WQ metrics, specifically TSS and turbidity, were positively correlated to measures of development at all scales (Table 3) and the correlations were strongest at the local scale. These correlations were also most significant during high flow periods of SNOW and RAIN. This supported hypotheses H1-a and H2-b related to measures of development and particulates, and hydrologic regime, respectively.

The increased significance of local % imperviousness as compared with whole watershed imperviousness with regard TSS and turbidity is not surprising. Richards et al. found that LULC within a 100m buffer of streams was more important than whole watershed LULC in the prediction of particulate-related WQ (Johnson et al., 1997). North Shore and Duluth streams tend to run clear during baseflow, but muddy during high flows. Impervious surfaces limit the amount of water that infiltrates the soil and increase the volume and speed at which snowmelt and storm water enters the stream (Arnold Jr. and Gibbons, 1996, Burcher et al., 2007, Brown et al., 2009). Not only does the water carry particulates that have washed in from the watershed, but it increases the stream velocity and discharge causing the stream to erode its own banks (Brabec et al., 2002, Fitzpatrick et al., 2006, Bedan and Clausen, 2009).

*Forest cover and particulate-related water quality*

The impact of forest cover and type was significantly influenced by scale (Tables 3, 4). At the whole watershed scale only TP showed the expected negative correlation to % canopy, most strongly during SNOW but also during RAIN and BASE, that were predicted by hypotheses H1-b and H2-b. As with measures of imperviousness, we expected the local watershed characteristics to influence particulate-related WQ more strongly than whole watershed characteristics due to the small size of the streams included in this study as per Buck et al. (Buck et al., 2004). We did see the influence of whole watershed scale with regard to canopy cover, however local measures of canopy cover were positively correlated with TSS and TP during SNOW and RAIN (high flow periods). Further, deciduous cover was positively correlated with all measures of particulate-related WQ metrics during RAIN, to TSS and turbidity during SNOW, and to TSS during BASE (but negatively correlated with soluble WQ metrics as discussed below). Because in our study area deciduous tree cover was positively correlated with population density it seems likely that these “contrary to expectation” results may be due to the increased presence of deciduous trees in the southern reaches of the study region (where development is most concentrated) and expansive city park areas in the urban watersheds (Figure 8).

*Wetland cover and particulate-related water quality*

Overall, particulate-related WQ parameters were negatively correlated with wetland cover at both the local and whole watershed scale during all hydrologic regimes as predicted by H1-b (Table 2). However, there were two exceptions to this. Both TP and TSS were positively correlated to local wetland cover, but negatively correlated with whole watershed wetland cover during SNOW and RAIN, respectively. The role of high flows in both of these instances suggest that wetlands close to the stream channel are temporarily connected to the stream channel during high flows, thus becoming a source of particulates rather than a sink. Wetlands at the whole watershed scale may be holding water back during high flow periods, dampening flood peaks and lowering erosion downstream.

*Imperviousness and soluble water quality*

The influence of scale was less consistent with regard to soluble WQ metrics (Table 4). Development was positively correlated to soluble WQ metrics as predicted by hypothesis H1-c due to the increased concentration of nutrient inputs in urban settings. Additionally, the influence of LULC increased during high flows (H2-b) though this was not as pronounced for soluble metrics as for particulate-related metrics. OP and $NH_4^+$-N were significantly correlated to measures of imperviousness during all hydrologic regimes and at all scales (with the exception of OP during BASE which was only correlated at the local scale). Wayland et al. (Wayland et al., 2002) found that it can take decades for soluble chemicals deposited away from the stream channel to reach the stream, traveling centimeters per day through groundwater. This could account for the influence of whole watershed LULC on soluble WQ and possible delays in delivery to the stream channel not seen with particulate-related metrics. Additionally, in a Michigan catchment study (Allan and Johnson, 1997), TN, $NO_2/NO_3^-$-N, and OP were not predicted better by riparian zone LULC then by whole watershed LULC. It must be noted, however, that groundwater flow is significantly different in Michigan than in this study area.

Ions (EC25 and $Cl^-$) were positively correlated to imperviousness at both the local and whole watershed scale during SNOW (H1-e), but during RAIN and BASE EC25 was only significantly correlated to imperviousness at the whole watershed scale. The hypothesis that salts would be negatively correlated to imperviousness during RAIN due to dilution from the extra inputs of low ion rainwater (hypothesis H2-c) was not supported. While the $R^2$ value for EC25 was lowest during RAIN, concentrations of $Cl^-$ were highest during RAIN. This unexpected result may indicate that salt is stored in the local soils or ground water as seen in the Minneapolis, MN metropolitan area's Shingle Creek, rather than flushed out as was previously thought (Wenck Associates, 2006). Erickson et al. (Erickson, 2010) found a strong positive association between $Cl^-$ and urbanization, as well as between $Cl^-$ and community respiration in a subset of Duluth and North Shore streams which were included in this study.

*Forest cover and soluble water quality*

We found a similar negative correlation between whole watershed canopy cover and soluble WQ metrics as predicted by hypothesis H1-d (Table 4). DO was positively, albeit weakly, related to % canopy in the whole watershed during RAIN and BASE but negatively correlated with local % canopy during the same hydrologic regimes. This may be due to increased water temperatures during summer baseflow (Poole and Berman, 2001) and rain periods but could also be related to the positive correlation with other nutrients which increase primary productivity and presumably net oxygen production

(Allan and Castillo, 2009). Interestingly, we found that soluble WQ metrics (OP, TN, DIN, and $NO_2/NO_3^-$-N) were positively correlated with deciduous tree cover particularly during RAIN (Table 3). The fact that these nutrients were positively correlated with deciduous cover but not conifer or canopy cover during RAIN further supports the idea that deciduous cover acts as a surrogate for urbanization at the local scale, with associated higher concentrations of nutrients rapidly entering the stream as they are flushed off impervious surfaces. OP and $NH_4^+$-N were significantly positively correlated with local % canopy during nearly all hydrologic regimes (with the exception of OP during BASE). This is similar to the result found for measures of imperviousness earlier, and so the influence of scale may be significantly affecting the sign of correlations.

Positive correlations between % canopy and nutrients at the local scale may have more to do with urban stream inputs than a causal relationship between canopy and nutrients (Walsh et al., 2005). Indeed, the results of similar analyses done at the whole watershed scale resulted in predicted correlation between canopy cover and nutrients, namely, as watershed canopy cover increases soluble WQ metrics will decrease. Again we believe that canopy and forest cover relationships to WQ are confounded by the urban park effect.

*Wetland cover and soluble water quality*

Spatial distribution of wetland cover within a watershed has a stronger impact on results for soluble WQ metrics however. During SNOW there was no relationship between the percentage of wetlands in the entire watershed and soluble WQ, but there were positive correlations with OP, TN, and $NO_2/NO_3^-$-N at the local scale (Table 3).

Presumably wetlands are saturated with water for much of the spring and surrounding soils may be frozen for part of this period. During RAIN whole watershed wetland cover was inversely and strongly correlated with all soluble WQ metrics except DO concentration as predicted by hypothesis H1-d (Table 3). However, all of these, with the exception of $NH_4^+$-N and DO, were positively correlated with local measures of wetland cover during RAIN suggesting connectivity between local wetlands and the stream channel during high flows as was also seen for particulate-related WQ parameters.

Generally, wetlands tend to be net exporters of dissolved organic matter though the strength of these LULC and WQ associations may depend on instream cycling (Detenbeck et al., 2004). High flow periods may temporarily connect wetlands to the stream channel when they are in close proximity, releasing stored nutrients in both dissolved and particulate forms, as well as sediment. The strong positive correlations between soluble WQ metrics and local watershed wetland cover during BASE (Table 4) may be due to the sourcing of soluble nutrients in wetlands which then provide much of the water to streams during baseflow periods. The strong positive correlation between local wetlands and chloride ($R^2$=0.92) remains a question worth further exploration.

Clearly, the spatial location of wetlands in the watersheds of North Shore streams has a strong influence on WQ. North Shore streams are characterized by gently sloping headwaters with significant wetland cover which increase in slope as they approach the confluence with Lake Superior, as opposed to most streams where headwaters are steep and gradually decrease in slope before ending in wetlands in the lower watersheds. Bedrock bluffs and outcrops dominate the steep lower reaches of these streams

(Fitzpatrick et al., 2006). As development occurs in the relatively level headwaters of these streams, extensive wetland cover is typically replaced with impervious surfaces. This may decrease the stream's natural resilience to disturbances that increase runoff during storm events and snowmelt since wetlands act as a holding chamber for excess water, allowing particles to settle out and a portion of their nutrient load to become immobilized (Detenbeck et al., 2003, Morley et al., 2011). Decreasing wetland cover in their headwaters leads to increased flashiness and bank overflows during high flows. Wetlands also help maintain water flow during baseflow periods when low water volume, higher temperature, and possibly lower DO concentration can impair the survival of aquatic organisms, in these cold water trout streams (Morley et al., 2011).

## Precipitation regime and hydrology

We did not see the effect of precipitation regime as predicted by hypotheses H3-a or H3-b. However, mean values for both particulate-related and soluble WQ metrics were in fact higher during high flow periods of dry years. This could be due to the buildup of particulates on terrestrial surfaces (including soil storage) during dry years which are subsequently flushed into the stream during RAIN and SNOW. Perhaps during wet years the buildup is reduced, allowing for a more even pattern of soluble and particulate-related concentrations throughout the year. A longer-term WQ and weather data set may be necessary to better understand these relationships.

### Predictive models

*Mixed model approach*

Prediction within a single watershed is easier than prediction across watersheds since multiple sample sites within the same stream could be grouped together for analysis. For that reason, streams were treated as a random variable in the mixed models, greatly increasing the predictive power of the models by accounting for variability due to individual stream characteristics that were not determined by fixed (LULC) effects.

*Particulate-related water quality metrics*

The role of local landscape metrics in predicting particulate-related WQ metrics was unequivocal with strong relationships in all hydrologic regimes. Local stream slope was the best predictor of TSS, turbidity, and TP during SNOW and RAIN. Transparency tube was also best predicted by local stream slope during RAIN and by local bank slope during SNOW runoff (Table 8). The positive association between stream slope and particulates has been seen in many studies and is a core variable in the stream power equations and the Revised Universal Soil Loss Equation (RUSLE) (Renard et al., 1991, Allan and Castillo, 2009) High local slope causes high shear stress and higher erosive power for streams. Thus, this association could be illustrating that orientation of steepest slopes near the mouth of these streams.

*Soluble water quality metrics*

The soluble WQ parameters were less clearly linked to just a few LULC characteristics and a there was no clear pattern for differences between whole vs. local watershed analysis. Many soluble WQ metrics (DO, OP, and $NO_2/NO_3^-$-N) were best predicted by local stream slope during SNOW conditions though some were best predicted by whole watershed land use characteristics (Table 8). The increased effect of local LULC during high flow periods on soluble water quality parameters is expected due to the increased rate of delivery to the stream channel and the potential connection of wetlands to the stream channel during these hydrologic periods. Further, the specific LULCs selected for SNOW models may be acting as surrogates for development which is often correlated with increased nutrients.

During RAIN, soluble WQ metrics were again best predicted by local watershed characteristics (Table 8). As with the SNOW models, the increased significance of local LULC metrics during high flows was expected due to the increased rate of delivery to the stream channel and the shorter retention time in the soils during these hydrologic periods. As discussed previously, wetlands may be temporarily connected to the stream channel during rain periods, making them a source, instead of a sink, for dissolved nutrients and ions.

During BASE, some soluble WQ metrics were best predicted by whole watershed characteristics and with only OP and $NO_2/NO_3^-$-N being best predicted by local watershed characteristics. The fact that many of the soluble WQ metrics were best predicted by whole watershed LULC during BASE not only further supports our explanation about the role of local LULC during high flow periods, but it suggests that the slower movement of soluble WQ metrics through ground water may connect whole watershed LULC metrics during low flow periods (Table 8). As mentioned previously, in a study containing a subset of the watersheds we analyzed, Anderson et al. found that $NO_2/NO_3^-$-N often exceeded expectations during BASE conditions, which they attributed to groundwater discharge (Anderson et al., 2000).

## Missing explanatory variables and future directions

Several variables were not accounted for in our analyses, one of which is the role of historical land use and in this region in particular, extensive logging (Verry, 1986, Friedman and Reich, 2005). Brown et al. (2009) argued that accounting for legacy land use is critical for linking WQ to LULC. Additionally, high resolution SSURGO soil data is currently available for only a small subset of our study area (those watersheds being in St. Louis County, Appendix L). We anticipate that access to this data for the entire North Shore of Lake Superior will greatly improve particulate-related models. Antecedent weather conditions are also not accounted for in our analyses beyond our approach of defining precipitation regime. Soil saturation levels clearly influence the magnitude of WQ responses to meteorological regimes as evidenced by the dramatic sediment loading in regional streams in June 2012, when an intense rainstorm (10" in 24 hrs) followed an unusually wet month (Czuba et al., 2012). Inclusion of these variables may improve future analyses of WQ responses to LULC and meteorological regimes.

The influence of stand age and stream order on WQ was also not examined in this study. Loss of mature forest has been positively correlated with increased TP, turbidity, and TSS, and suggested to result from increased bank erosion in western Lake Superior streams (Detenbeck et al., 2004). Stream order was shown to be a factor with regard to the impact of stand age on dissolved nitrogen concentrations and loads. Young forests were associated with a decrease in total dissolved nitrogen levels which was attributed to an increase in uptake by terrestrial vegetation during early growth stages (Detenbeck et al., 2003).

Further classification of the hydrograph might also help reduce variability in predicting WQ data. With regard to hydrologic regime, RAIN could be defined for periods beyond the date of actual rain fall if stage height remained elevated. Some of the gaged streams showed especially flashy responses to rain events (e.g. Tischer Creek) and even small amounts of rainfall, often not considered RAIN by our definition (See METHODS), produced high turbidity for a short period of time (usually <1 day). In contrast, Kingsbury and Amity Creeks showed a longer duration storm signal than other streams, retaining high turbidity well after stage height had returned to baseflow levels as compared to other Duluth streams (e.g. Tischer, Chester, and Miller Creeks). Defining better rules for hydrologic regime specific to watershed responses as discussed above, and accounting for different duration and magnitude storm events, would likely improve model accuracy.

## Conclusion:

The spatial distribution of LULC types within a watershed, in concert with weather events, have a strong influence on the water quality of the associated surface waters. Wetland located in the headwaters of North Shore streams are acting as sinks for sediments and nutrients, while wetlands located closer to the stream channel may become sources of sediment and nutrients during high flow periods. Local measures of impervious surfaces were strongly linked to particulates, particularly during high flow periods as we expected. Soluble metrics and nutrients were also most strongly linked to local measures of imperviousness though these water quality metrics were less responsive to hydrologic periods. The influence of forest type on particulates was notable with negative correlations between conifer and particulate measures during high flows, but the underlying reasons and possible cross-correlations remain unclear based on these analyses.

Public land management and private land owners may have a significant impact on WQ based on land management practices at the local scale. Therefore, education and outreach on best management practices (BMPs) at a local scale is critical as development continues on these desirable lands along the North Shore coast line and near stream channels. Recent work by Tu (2011) found that adverse impacts of land use changes on WQ were more substantial in less-urbanized areas than in highly urbanized cities. The North Shore of Lake Superior just might be one of those less-urbanized areas susceptible to water quality degradation. The region still maintains relatively pristine waters in some of the most sensitive streams but it is facing increased developmental pressures concurrent with the effects of climate change which are predicted to bring extreme precipitation events and subsequent changes in stream flow patterns (Kling et al., 2003, Galatowitsch et al., 2009).

Understanding the quantitative impact that weather, particularly precipitation, has on WQ as mediated by various LULC can provide land use managers and municipalities with the information necessary to create appropriate (i.e. minimum impact) guidelines for future development along the North Shore of Lake Superior and within the city of Duluth. Availability and access to fresh water resources is no longer something that should be taken for granted, even in regions such as Northern Minnesota, known for its abundant and high quality lakes and streams. Indeed, protecting the remaining fresh water is a growing challenge in the face of increasing development pressures which are growing at an even faster rate than the population (MN Dept. of Administration, 2011, MPCA, 2000). What draws development to the North Shore is the aesthetic beauty, recreational opportunities, and serenity offered by the relatively pristine natural resources. To degrade the water and forest habitats through development uninformed about the relationship of weather, landscape, and WQ is also to degrade one of the largest economic opportunities the region has to offer. If we work to understand the interconnectedness of weather, landscape and water we will be able to develop in sustainable ways, ways that allow future generations to enjoy the same, even improved, access to outdoor recreation, natural resources, and serenity in Northern Minnesota's watersheds.

**Table 1: Water quality parameters and groupings used in analyses.**

| Water quality parameters tested: | Data grouped by: |
|---|---|
| **Particulates** | • Location |
| • Turbidity (muddiness) | ArcHydro watersheds |
| • Total Suspended Sediment (TSS) | • Hydrologic Regime |
| • Transparency Tube (T-Tube) | • Water Year and Precipitation Regime |
| • Total Phosphorus (TP) | |
| **Soluble** | |
| • Dissolved Oxygen (DO) | **Analyses Run (JMP stats software):** |
| • Total Nitrogen (TN) | • Two-tailed T-tests |
| • Orthophosphate (OP) | • Pearson Correlations |
| • Dissolved Inorganic Nitrogen (DIN) | • Linear Regressions |
| • Ammonium-N ($NH_4^+$-N) | • Mixed Model Regression |
| • [Nitrate+Nitrite]-N ($NO_2/NO^-_3$-N) | • Forward Step Regression |
| **Other** | |
| • Specific Electrical Conductivity (EC25) | |
| • Chloride ($Cl^-$) | |

**Table 2: Water Year snowpack, snowfall, and precipitation at each National Weather Service station used to define the precipitation regime. All values are shown in inches. Bold values indicate the three highest and lowest precipitation totals at each weather station during the period of study which were used to define the precipitation regime.**

| | Duluth | | | Wolf Ridge | | | Grand Marais | | |
|---|---|---|---|---|---|---|---|---|---|
| Water Year | snowpack max (in) | snowfall (in) | precip total (in) | snowpack max (in) | snowfall (in) | precip total (in) | snowpack max (in) | snowfall (in) | precip total (in) |
| 1996 | 30 | 135.3 | **36.2** | 48 | 124.3 | 34.8 | 52 | 125.0 | 25.9 |
| 1997 | 37 | 127.9 | 26.0 | 46 | 119.2 | 30.5 | 40 | 87.9 | 19.9 |
| 1998 | 22 | 80.1 | **25.2** | 25 | 53.1 | 27.8 | 18 | 43.1 | **17.3** |
| 1999 | 18 | 90.2 | **44.0** | 30 | 86.0 | **44.0** | 20 | 69.8 | **33.3** |
| 2000 | 16 | 55.5 | 26.3 | 16 | 40.5 | **23.1** | 18 | 32.5 | 20.3 |
| 2001 | 30 | 99.3 | 33.3 | 53 | 104.6 | **38.2** | 33 | 93.0 | **32.2** |
| 2002 | 15 | 86.0 | 32.2 | 34 | 69.8 | 28.4 | 5 | 14.4 | 19.8 |
| 2003 | 12 | 56.3 | **25.4** | 12 | 45.2 | **19.8** | 5 | 15.6 | **18.1** |
| 2004 | 33 | 109.9 | 27.9 | 41 | 105.1 | 28.7 | 26 | 40.8 | **19.4** |
| 2005 | 45 | 91.5 | 27.8 | 57 | 132.4 | 35.4 | 41 | 62.4 | 24.0 |
| 2006 | 23 | 89.2 | 30.8 | 37 | 76.1 | 38.0 | 10 | 41.9 | 19.8 |
| 2007 | 27 | 80.7 | **24.3** | 22 | 36.8 | 30.0 | 9 | 27.0 | 23.8 |
| 2008 | 20 | 80.0 | 34.6 | 26 | 54.6 | **39.8** | 27 | 61.2 | **38.4** |
| 2009 | 19 | 73.6 | 26.8 | 36 | 124.1 | **25.8** | 40 | 75.6 | 26.2 |
| 2010 | 28 | 65.2 | **36.2** | 36 | 47.3 | 36.5 | 7 | 16.2 | 24.6 |
| Mean: | 24.4 | 88.0 | 30.4 | 34.6 | 81.3 | 32.1 | 23.4 | 53.8 | 24.2 |
| Median: | 23.0 | 86.0 | 27.9 | 36.0 | 76.1 | 30.5 | 20.0 | 43.1 | 23.8 |
| SD: | 9.0 | 23.0 | 5.6 | 13.1 | 34.5 | 6.7 | 15.1 | 32.3 | 6.2 |

**Table 3: Mixed model regressions of particulate-related water quality parameters in North Shore streams and landscape variables during each hydrologic regime. All Adjusted $R^2$ values are for fixed effects and are significant at †= p<0.05 or ‡=p<0.01 and – indicates a negative slope. Bold values indicate significance at p<0.001 (Bonferroni adjusted alpha). TSS, Turbidity, and Total-P values were $log_{10}$ transformed before statistical analysis. Landscape data were summarized for immediate subcatchments above sample points ("Local") and for the entire watershed above a sample point. "Canopy" includes all NLCD forest types (conifer, deciduous, mixed).**

| Hydrologic Regime | | | | % Impervious | | % Forest Cover | | | | % Wetland | | Population Density (people/km$^2$) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | N | Local | Watershed | Canopy Local | Canopy Watershed | Conifer | Deciduous | Local | Watershed | Local | Watershed |
| **High Flow** | **Snowmelt** | **TSS** | 662 | 0.16† | | **0.19‡** | | -0.16† | 0.16† | 0.16 | -0.16† | 0.16 | 0.15 |
| | | **Turbidity** | 668 | 0.17† | | 0.17‡ | | -0.15† | 0.17‡ | | -0.16‡ | | |
| | | **T-tube** | 521 | | | | | -0.08 | 0.08 | -0.09† | -0.08† | | |
| | | **Total-P** | 602 | 0.34‡ | 0.33 | **0.34‡** | -0.33 | -0.33† | | 0.33‡ | -0.33† | 0.33‡ | 0.33† |
| | **Rain period** | **TSS** | 813 | 0.2† | 0.19 | 0.20† | -0.19 | -0.19‡ | 0.20‡ | 0.20† | **-0.20‡** | **0.20‡** | 0.20‡ |
| | | **Turbidity** | 915 | 0.23‡ | | 0.23 | | -0.22 | **0.24‡** | | **-0.24‡** | **0.24‡** | 0.24‡ |
| | | **T-tube** | 711 | | | | | -0.12 | 0.12‡ | -0.12† | -0.12† | | |
| | | **Total-P** | 790 | | 0.25† | 0.25† | -0.25† | -0.24‡ | 0.25† | 0.25 | -0.25† | 0.24† | 0.24‡ |
| | **Base flow** | **TSS** | 806 | 0.27 | | | | | 0.26† | 0.27 | -0.27‡ | 0.27 | |
| | | **Turbidity** | 1028 | | | | -0.16 | | | 0.16† | -0.16 | | |
| | | **T-tube** | 1022 | | | | | | | -0.14‡ | -0.14† | | |
| | | **Total-P** | 828 | | **0.17‡** | | -0.17‡ | -0.17‡ | | -0.19† | | | **0.15‡** |

**Table 4: Mixed model regressions of soluble water quality parameters in North Shore streams and landscape variables during each hydrologic regime. All Adjusted $R^2$ values are for fixed effects and are significant at †= $p<0.05$ or ‡= $p<0.01$ and – indicates a negative slope. Bold values indicate significance at $p<0.001$ (Bonferroni adjusted alpha). All parameters were $log_{10}$ transformed before statistical analysis. Landscape data were summarized for immediate subcatchments above sample points ("Local") and for the entire watershed above a sample point. "Canopy" includes all NLCD forest types (conifer, deciduous, mixed).**

| Hydrologic Regime | | | | % Impervious | | % Forest Cover | | | | % Wetland | | Population Density (people/km$^2$) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | N | Local | Watershed | Canopy Local | Canopy Watershed | Conifer | Deciduous | Local | Watershed | Local | Watershed |
| High flow | Snowmelt | **DO** | 419 | | 0.03 | | | | | | | | |
| | | **Ortho-P** | 302 | **0.41‡** | 0.39‡ | **0.40‡** | | | | 0.39† | -0.39 | **0.40‡** | 0.39‡ |
| | | **Total-N** | 302 | 0.25† | 0.25 | | | | 0.25 | 0.25† | | 0.25† | 0.25† |
| | | **DIN** | 273 | 0.46 | | | | 0.47† | 0.47† | | | 0.45 | 0.46 |
| | | **Ammonium-N** | 255 | 0.34† | 0.34‡ | 0.34‡ | -0.34‡ | | | 0.35 | | 0.34‡ | 0.34‡ |
| | | **[Nitrate+Nitrite]-N** | 493 | 0.42 | 0.42 | | | 0.43† | 0.43† | 0.42† | | 0.42† | 0.42† |
| | | **EC25** | 606 | **0.76‡** | **0.76‡** | **0.76‡** | **-0.75‡** | 0.76† | 0.76† | | -0.76‡ | **0.76‡** | **0.76‡** |
| | | **$Cl^-$** | 502 | **0.86‡** | **0.86‡** | 0.86‡ | **-0.86‡** | -0.86 | | **0.86‡** | -0.86 | **0.86‡** | **0.86‡** |
| | Rain period | **DO** | 522 | | -0.10 | **-0.09‡** | 0.11† | 0.12 | | | | | |
| | | **Ortho-P** | 483 | **0.48‡** | 0.48‡ | 0.48† | -0.48† | 0.48† | 0.48† | **0.48‡** | -0.48‡ | **0.49‡** | **0.48‡** |
| | | **Total-N** | 594 | | | | | 0.24† | | 0.23‡ | -0.24† | 0.25‡ | |
| | | **DIN** | 513 | 0.54† | 0.54† | | | 0.55 | **0.55‡** | **0.55‡** | -0.54† | 0.54† | 0.54† |
| | | **Ammonium-N** | 489 | 0.26‡ | **0.26‡** | 0.26‡ | **-0.28‡** | | | 0.28† | -0.28 | 0.27‡ | 0.27‡ |
| | | **[Nitrate+Nitrite]-N** | 489 | 0.45 | | | | 0.46 | **0.46‡** | **0.47‡** | -0.45† | 0.46‡ | 0.46‡ |
| | | **EC25** | 885 | | **0.72‡** | 0.72† | **-0.72‡** | | | 0.72‡ | -0.71 | -0.72 | |
| | | **$Cl^-$** | 548 | 0.90† | **0.90‡** | 0.90† | **-0.90‡** | | | **0.91‡** | -0.90‡ | | **0.90‡** |
| | Bas | **DO** | 756 | | | -0.06† | 0.06† | 0.07† | | 0.09‡ | | 0.09† | |
| | | **Ortho-P** | 421 | 0.37† | 0.37 | | | | | **0.37‡** | | 0.38‡ | 0.38† |

| Hydrologic Regime | | | % Impervious | | % Forest Cover | | | | % Wetland | | Population Density (people/km$^2$) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | N | Local | Watershed | Canopy Local | Canopy Watershed | Conifer | Deciduous | Local | Watershed | Local | Watershed |
| **Base flow** | **Total-N** | 539 | | 0.39 | | | | | | | 0.40† | |
| | **DIN** | 434 | 0.52 | 0.53‡ | | -0.53 | 0.54† | 0.54‡ | **0.58‡** | -0.53† | | 0.53‡ |
| | **Ammonium-N** | 412 | 0.38† | 0.38‡ | 0.38‡ | -0.39‡ | | | 0.40‡ | | 0.38† | 0.38† |
| | **[Nitrate+Nitrite]-N** | 412 | | | | | | **0.41‡** | **0.45‡** | -0.41‡ | | 0.40‡ |
| | **EC25** | 1133 | | **0.82‡** | | **-0.82‡** | 0.82† | 0.82† | | **-0.82‡** | | **0.82‡** |
| | **$Cl^-$** | 534 | 0.88‡ | **0.88‡** | | **-0.88‡** | | | **0.92‡** | **-0.89‡** | | **0.88‡** |

**Table 5: P-values from two-tailed T-test comparisons of mean values for each water quality metric in each hydrologic regime. Bold values meet the criteria set by the Bonferroni adjusted alpha suggesting significance at $p<0.002$. Blanks indicate $p>0.1$. Also see Figure 4.**

| | Water Quality | Snow v. Rain | Rain v. Base | Base v. Snow | Snowmelt n, mean (SD) | Rain period n, mean (SD) | Baseflow n, mean (SD) |
|---|---|---|---|---|---|---|---|
| **Particulate** | **Turbidity (NTU)** | | **<0.0001** | **<0.0001** | 668, 22.0 (37.9) | 915, 32.4 (78.4) | 1028, 5.8 (27.3) |
| | **TSS (mg/L)** | 0.04 | **<0.0001** | **<0.0001** | 662, 25.3 (44.1) | 813, 28.8 (59.0) | 806, 3.49 (5.16) |
| | **T-Tube ($cm^{-1}$)** | **0.0006** | **<0.0001** | **<0.0001** | 521, 59.8 (30.4) | 711, 58.8 (33.1) | 1122, 89.1 (21.0) |
| | **Total-P (mg/L)** | **0.0006** | **<0.0001** | **<0.0001** | 602, 0.066 (0.071) | 790, 0.060 (0.072) | 828, 0.024 (0.050) |
| **Soluble** | **DO (mg/L)** | **<0.0001** | **<0.0001** | **<0.0001** | 419, 13.6 (5.20) | 522, 10.2 (1.68) | 756, 9.83 (1.87) |
| | **OP (mg/L)** | **0.0002** | **<0.0001** | **<0.0001** | 302, 0.014 (0.013) | 483, 0.014 (0.035) | 421, 0.008 (0.006) |
| | **Total-N (mg/L)** | **<0.0001** | **<0.0001** | **<0.0001** | 467, 1.036 (0.552) | 594, 0.819 (0.333) | 539, 0.564 (0.241) |
| | **DIN (mg/L)** | **<0.0001** | **0.0003** | **<0.0001** | 273, 0.449 (0.330) | 513, 0.180 (0.222) | 434, 0.145 (0.222) |
| | **Ammonium-N (mg/L)** | **<0.0001** | | **<0.0001** | 255, 0.090 (0.139) | 489, 0.031 (0.053) | 412, 0.025 (0.042) |
| | **[Nitrate+Nitrite]-N (mg/L)** | **<0.0001** | **<0.0001** | **<0.0001** | 493, 0.325 (0.236) | 649, 0.140 (0.182) | 679, 0.112 (0.187) |
| **Salt** | **EC25 (uS/cm)** | **<0.0001** | **<0.0001** | **<0.0001** | 606, 225 (403) | 885, 187 (60) | 1133, 239 (218) |
| | **$Cl^-$ (mg/L)** | | **<0.0001** | 0.007 | 502, 37.0 (115) | 548, 19.1 (30.4) | 534, 17.8 (36.1) |

**Table 6: P-values from two-tailed T-tests comparing mean values for each particulate-related water quality metric in each hydrologic regime by precipitation regime. Right three column show the mean (± standard deviation) for the water quality parameters. Streams analyzed for this analysis are from a subset of the data with a long-term WQ data record (>10 years of data). Bold values meet the criteria set by the Bonferroni adjusted alpha suggesting significance at p<0.002. Blanks indicate p>0.1. Also see Figure 6.**

| Water Quality (Particulates) | p-values | | | n, Mean concentration (±SD) | | |
|---|---|---|---|---|---|---|
| | wet v. dry | wet v. average | dry v. average | Wet year | Dry year | Average year |
| **Turbidity (NTU)** | | | | | | |
| snow | | 0.04 | | 80, 32.3 (49.8) | 170, 23.2 (31.0) | 418, 20.4 (37.6) |
| rain | | 0.02 | | 229, 25.1 (76.4) | 168, 35.7 (82.1) | 468, 35.5 (79.3) |
| base | 0.04 | | **0.001** | 220, 4.0 (3.4) | 234, 4.5 (8.6) | 464, 7.1 (36.5) |
| **TSS (mg/L)** | | | | | | |
| snow | 0.02 | | 0.02 | 118, 27.8 (57.2) | 150, 29.6 (44.6) | 394, 24.4 (42.6) |
| rain | | | | 229, 25.7 (46.8) | 153, 35.3 (81.8) | 468, 30.1 (55.9) |
| base | | | | 135, 3.1 (2.5) | 207, 3.2 (4.6) | 464, 3.5 (4.9) |
| **T-Tube ($cm^{-1}$)** | | | | | | |
| snow | 0.04 | **<0.0001** | 0.02 | 56, 41.3 (27.5) | 126, 48.4 (27.3) | 339, 63.7 (30.0) |
| rain | | | | 192, 57.6 (34.0) | 91, 57.0 (34.3) | 487, 59.2 (32.1) |
| base | | | | 210, 84.7 (24.7) | 168, 93.9 (16.0) | 743, 47.8 (21.7) |
| **Total-P (mg/L)** | | | | | | |
| snow | **<0.0001** | | **<0.0001** | 77, 0.067 (0.084) | 152, 0.105 (0.092) | 373, 0.061 (0.63) |
| rain | 0.006 | | 0.03 | 189, 0.051 (0.058) | 157, 0.078 (0.085) | 444, 0.066 (0.078) |
| base | | | | 159, 0.025 (0.039) | 185, 0.022 (0.020) | 484, 0.029 (0.029) |

**Table 7: P-values from two-tailed T-tests comparing mean values for each soluble water quality metric in each hydrologic regime by precipitation regime. Right three column show the mean (± standard deviation) for the water quality parameters. Streams analyzed for this analysis are from a subset of the data with a long-term WQ data record (>10 years of data). Blanks indicate p>0.1. Bold values meet the criteria set by the Bonferroni adjusted alpha suggesting significance at p<0.002.**

| Water Quality (Soluble) | p-values | | | n, Mean concentration (±SD) | | |
|---|---|---|---|---|---|---|
| | wet v. dry | wet v. average | dry v. average | Wet year | Dry year | Average |
| **DO (mg/L)** | | | | | | |
| snow | | 0.02 | | 55, 14.0 (2.0) | 95, 13.5 (1.1) | 269, 13.2 (1.7) |
| rain | | | **0.0004** | 71, 10.2 (1.6) | 68, 11.0 (2.2) | 383, 10.0 (1.6) |
| base | 0.04 | | | 105, 9.4 (1.6) | 152, 10.3 (2.4) | 499, 9.7 (1.8) |
| **OP (mg/L)** | | | | | | |
| snow | **0.0002** | **0.0003** | | 24, 0.008 (0.003) | 90, 0.015 (0.014) | 188, 0.015 (0.014) |
| rain | **<0.0001** | **<0.0001** | | 153, 0.008 (0.006) | 89, 0.026 (0.088) | 241, 0.016 (0.013) |
| base | **<0.0001** | **<0.0001** | | 87, 0.007 (0.004) | 114, 0.010 (0.006) | 220, 0.010 (0.003) |
| **Total-N (mg/L)** | | | | | | |
| snow | **<0.0001** | | **<0.0001** | 71, 0.992 (0.362) | 122, 1.570 (0.900) | 274, 0.973 (0.322) |
| rain | 0.04 | | | 158, 0.784 (0.190) | 140, 0.916 (0.376) | 296, 0.830 (0.292) |
| base | 0.04 | 0.05 | | 99, 0.646 (0.226) | 153, 0.578 (0.203) | 287, 0.585 (0.207) |
| **DIN (mg/L)** | | | | | | |
| snow | | | | 59, 0.404 (0.207) | 82, 0.524 (0.444) | 132, 0.536 (0.273) |
| rain | **<0.0001** | **<0.0001** | 0.02 | 174, 0.071 (0.069) | 107, 0.324 (0.262) | 232, 0.227 (0.161) |
| base | **0.004** | **<0.0001** | | 115, 0.191 (0.410) | 114, 0.180 (0.173) | 205, 0.204 (0.197) |
| **Ammonium-N (mg/L)** | | | | | | |
| snow | | | | 59, 0.103 (0.122) | 66, 0.170 (0.262) | 130, 0.104 (0.101) |
| rain | **<0.0001** | **<0.0001** | | 164, 0.020 (0.028) | 103, 0.055 (0.101) | 222, 0.038 (0.043) |
| base | 0.05 | | | 107, 0.024 (0.023) | 100, 0.032 (0.030) | 205, 0.038 (0.069) |
| **[Nitrate+Nitrite]-N (mg/L)** | | | | | | |
| snow | 0.04 | | 0.01 | 77, 0.364 (0.249) | 129, 0.282 (0.207) | 287, 0.352 (0.210) |
| rain | **<0.0001** | **<0.0001** | **0.0002** | 177, 0.058 (0.057) | 130, 0.252 (0.204) | 342, 0.156 (0.130) |
| base | | 0.03 | | 138, 0.151 (0.347) | 170, 0.115 (0.132) | 371, 0.134 (0.161) |

| Water Quality (Soluble) | p-values | | | n, Mean concentration (±SD) | | |
|---|---|---|---|---|---|---|
| | wet v. dry | wet v. average | dry v. average | Wet year | Dry year | Average |
| **EC25 (uS/cm)** | | | | | | |
| snow | | | | 73, 253 (235) | 160, 367 (715) | 373, 210 (275) |
| rain | **0.0002** | 0.04 | 0.01 | 221, 178 (147) | 158, 233 (177) | 506, 199 (165) |
| base | 0.02 | | 0.04 | 234, 295 (230) | 244, 213 (148) | 654, 276 (256) |
| **$Cl^-$ (mg/L)** | | | | | | |
| snow | | | 0.02 | 72, 43.7 (78.1) | 132, 76.6 (210) | 298, 30.9 (73.0) |
| rain | **<0.0001** | **<0.0001** | **0.0005** | 88, 7.80 (15.2) | 118, 30.8 (35.0) | 342, 21.1 (32.3) |
| base | **<0.0001** | **<0.0001** | | 94, 9.10 (21.5) | 148, 22.9 (53.0) | 292, 24.0 (37.0) |

**Table 8: Results from forward stepwise regressions to select LULC metrics in mixed model regressions predicting water quality metrics during each hydrologic regime (HR): S=Snowmelt, R=Rain Period, and B=Baseflow. Adjusted $R^2$ values significant at †= p<0.05 or ‡=p<0.01. NS indicates p>0.1**

| HR | WQ metric | n | LULC metric used | Random Effects: $R^2$ adj. | | |
|---|---|---|---|---|---|---|
| | | | | None | Stream | WY & Stream |
| S | TSS | 662 | Stream slope-local | **0.015‡** | **0.16†** | NS |
| R | TSS | 813 | Stream slope-local | **0.09‡** | **0.19‡** | **0.20‡** |
| B | TSS | 806 | Barren, % Wetland | **0.034‡** | **0.27‡** | **0.27‡** |
| S | Turbidity | 668 | Bank erosion potential-local, Stream slope-local | **0.054‡** | **0.18‡** | **0.18‡** |
| R | Turbidity | 915 | Stream slope-local , Bank KFFACT-local | **0.14‡** | **0.26‡** | **0.27‡** |
| B | Turbidity | 1028 | Barren | **0.011‡** | **0.15** | **0.17†** |
| S | T-Tube | 521 | Bank slope-local | **0.030‡** | **0.09†** | **0.10†** |
| R | T-Tube | 711 | Stream slope-local | **0.026‡** | **0.12‡** | **0.12‡** |
| B | T-Tube | 1122 | Barren, % Wetland | **0.080‡** | **0.13‡** | NS |
| S | Total-P | 602 | Stream slope-local | **0.02‡** | **0.33** | **0.35†** |
| R | Total-P | 790 | Stream slope-local | **0.13‡** | **0.24‡** | **0.26‡** |
| B | Total-P | 828 | Stream slope-local , % shrub | **0.020‡** | 0.18 | NS |
| S | DO | 419 | Stream slope-local , Bank slope-local | **0.032‡** | **0.13** | 0.13 |
| R | DO | 522 | % Canopy-local | **0.12‡** | **0.25‡** | **0.26‡** |
| B | DO | 756 | % Canopy, Population-local , Bank slope-local | **0.09‡** | **0.18‡** | **0.18‡** |
| S | Ortho-P | 302 | Stream slope-local | **0.18‡** | **0.37‡** | **0.37‡** |
| R | Ortho-P | 483 | Stream slope-local | **0.35‡** | **0.47‡** | NS |
| B | Ortho-P | 421 | Stream slope-local | **0.15‡** | **0.37‡** | NS |
| S | Total-N | 467 | Develop open | **0.07‡** | **0.24‡** | **0.30‡** |
| R | Total-N | 594 | % Wetland- local | **0.06‡** | **0.23‡** | **0.24‡** |
| B | Total-N | 539 | Shrub | **0.09‡** | **0.39‡** | **0.39‡** |
| S | DIN | 273 | % Deciduous | **0.011†** | **0.47†** | NS |
| R | DIN | 513 | % Wetland- local | **0.15‡** | **0.54‡** | NS |
| B | DIN | 434 | Develop low, Forest (sum) | **0.31‡** | **0.52‡** | **0.54‡** |
| S | Ammonium-N | 255 | Road/stream intersections | **0.10‡** | **0.34†** | **0.34†** |
| R | Ammonium-N | 489 | Develop (sum) | **0.19‡** | **0.27‡** | **0.27‡** |
| B | Ammonium-N | 412 | Road/stream intersections | **0.14‡** | **0.38‡** | **0.40‡** |
| S | Nitrate-N | 493 | Stream slope-local | **0.098‡** | **0.42‡** | **0.43‡** |
| R | Nitrate-N | 649 | % Wetland- local | **0.15‡** | **0.47‡** | **0.49‡** |
| B | Nitrate-N | 679 | % Wetland- local | **0.13‡** | **0.45‡** | **0.46‡** |
| S | EC25 | 606 | Develop (sum) | **0.70‡** | **0.76‡** | **0.76‡** |
| R | EC25 | 885 | Develop (sum) | **0.56‡** | **0.72‡** | **0.72‡** |
| B | EC25 | 1133 | Develop (sum) | **0.57‡** | **0.82‡** | **0.83‡** |
| S | $Cl^-$ | 502 | Develop open | **0.75‡** | **0.86‡** | **0.87‡** |
| R | $Cl^-$ | 548 | % Wetland- local, Develop (sum) | **0.76‡** | **0.90‡** | **0.91‡** |
| B | $Cl^-$ | 534 | Pasture, Bank slope-local | **0.37‡** | **0.92‡** | **0.92‡** |

**Table 9: Watershed scale at which particulate-related WQ is best predicted in each hydrologic regime.**

| Hydrologic Regime | | | Watershed Scale | |
|---|---|---|---|---|
| | | | **Local** | **Whole** |
| **High flow** | **Snowmelt** | **TSS** | | x |
| | | **Turbidity** | | x |
| | | **T-tube** | | x |
| | | **Total-P** | x | x |
| | **Rain period** | **TSS** | x | |
| | | **Turbidity** | x | |
| | | **T-tube** | x | |
| | | **Total-P** | x | |
| | **Baseflow** | **TSS** | x | |
| | | **Turbidity** | x | |
| | | **T-tube** | x | |
| | | **Total-P** | x | |

**Table 10: Watershed scale at which soluble WQ is best predicted in each hydrologic regime.**

| Hydrologic Regime | | | Watershed Scale | |
|---|---|---|---|---|
| | | | Local | Whole |
| High flow | Snowmelt | DO | x | x |
| | | Ortho-P | x | |
| | | Total-N | | x |
| | | DIN | | x |
| | | Ammonium-N | | x |
| | | [Nitrate+Nitrite]-N | x | |
| | | EC25 | | x |
| | | $Cl^-$ | x | x |
| | Rain period | DO | x | |
| | | Ortho-P | x | |
| | | Total-N | x | |
| | | DIN | x | |
| | | Ammonium-N | | x |
| | | [Nitrate+Nitrite]-N | x | |
| | | EC25 | | x |
| | | $Cl^-$ | x | x |
| | Baseflow | DO | x | |
| | | Ortho-P | x | |
| | | Total-N | | x |
| | | DIN | | x |
| | | Ammonium-N | | x |
| | | [Nitrate+Nitrite]-N | x | |
| | | EC25 | | x |
| | | $Cl^-$ | | x |

**Table 11: Conclusion summaries containing hypotheses and study results.**

| Hypotheses | | Study Conclusions |
|---|---|---|
| **Land Use/Cover** | | |
| **Particulate-related water quality metrics** | | |
| H1-a: as watershed % development increases WQ metrics related to sediment will display a predictable and statistically significant increase |  | True at all scales and influenced by hydrologic regime |
| H1-b: as watershed % forest and/or % wetland increases WQ parameters related to sediment will display a predictable and statistically significant decrease |  | At whole watershed scale, but LULC in urban streams is more complex, strongest during rain periods |
| **Soluble water quality metrics** | | |
| H1-c: as watershed % development increases soluble components will display a predictable and statistically significant increase |  | True at all scales, less influenced by hydrologic regime than particulates |
| H1-d: as watershed % forest and/or % wetland increases WQ parameters related to soluble nutrients will decrease |  | At whole watershed scale, but LULC in urban streams is more complex, strongest during rain periods |
| H1-e: as watershed % development increases ions (EC25 and $Cl^-$) will increase during snowmelt periods but decrease during rain periods |  | Negative correlation during rain periods was not found, but positive relationships with development was found in all hydrologic regimes |
| **Intra and inter-Annual Weather** | | |
| **Intra-Annual Weather (Hydrologic Regime)** | | |
| 2-a: WQ values will be different between snowmelt, storm events, and baseflow periods |  | True based on two-tailed t-tests and regressions run with and without hydrologic regime |
| 2-b: high flows due to rain storms and snowmelt will exacerbate LULC influences on WQ |  | Increased significance (lower p and higher $R^2$ values) during snowmelt and rain periods in most analyses |
| **Inter-Annual Weather** | | |
| H3-a: significant differences in mean WQ metrics between wet years and dry years |  | Mean values were generally higher during high flow periods of wet years than dry years |
| H3-b: normalizing WQ metrics to total Water Year accumulated rain will decrease variability in regression analyses vs. regressions without weather-normalized WQ data |  | Normalized data increased p and decreased $R^2$ values |

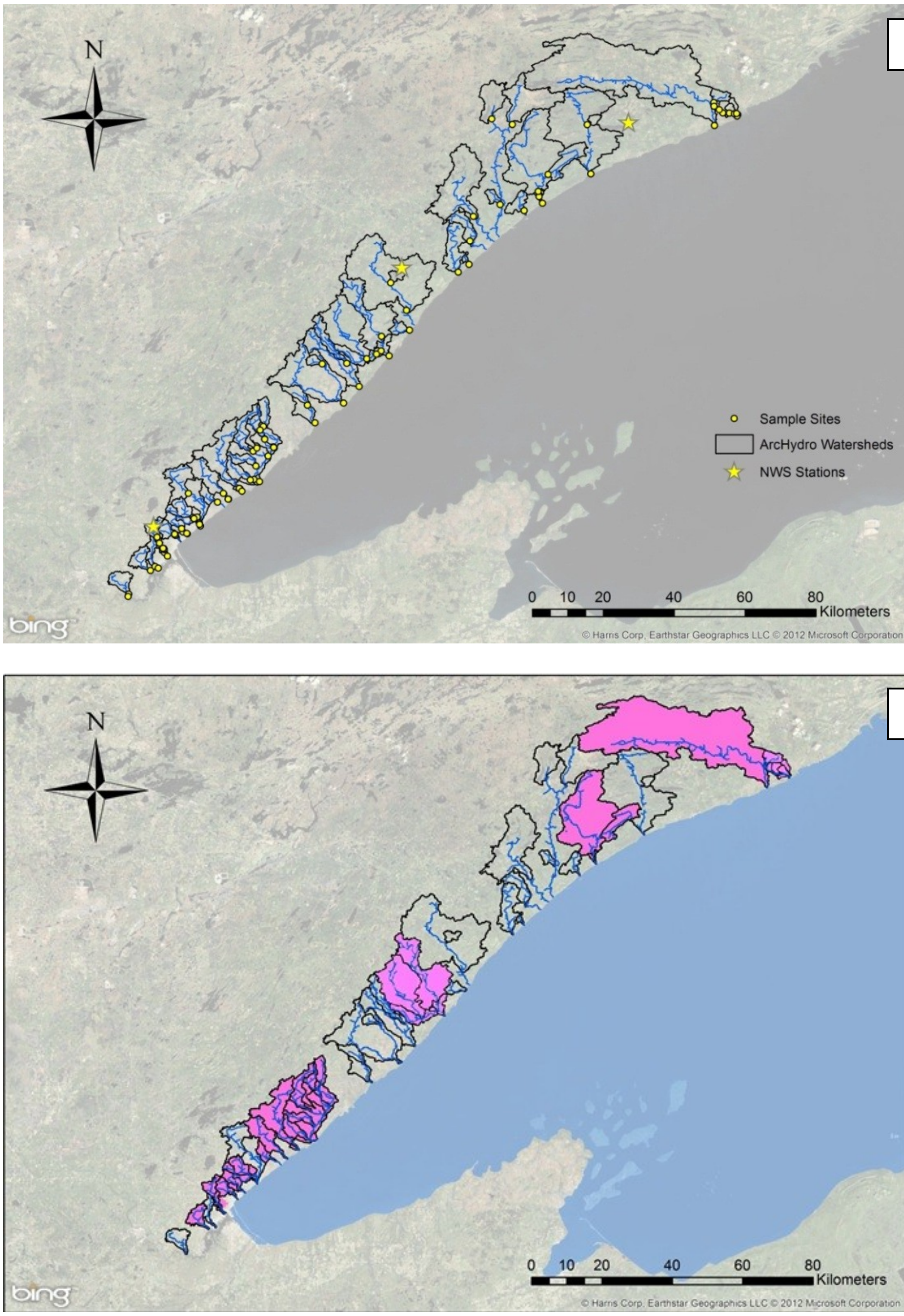



**Figure 1, Panel A & Panel B: Panel A; ArcHydro watersheds, sample sties, and National Weather Service stations.**

**Panel B; Subset of streams used for analysis of between-year differences due to long term (>10 years) stream sampling. Streams included (from North to South): Flute Reed, Brule, Poplar, Beaver, Knife, Sucker, French, Talmadge, Amity, Tischer, Chester, Miller, and Kingsbury**

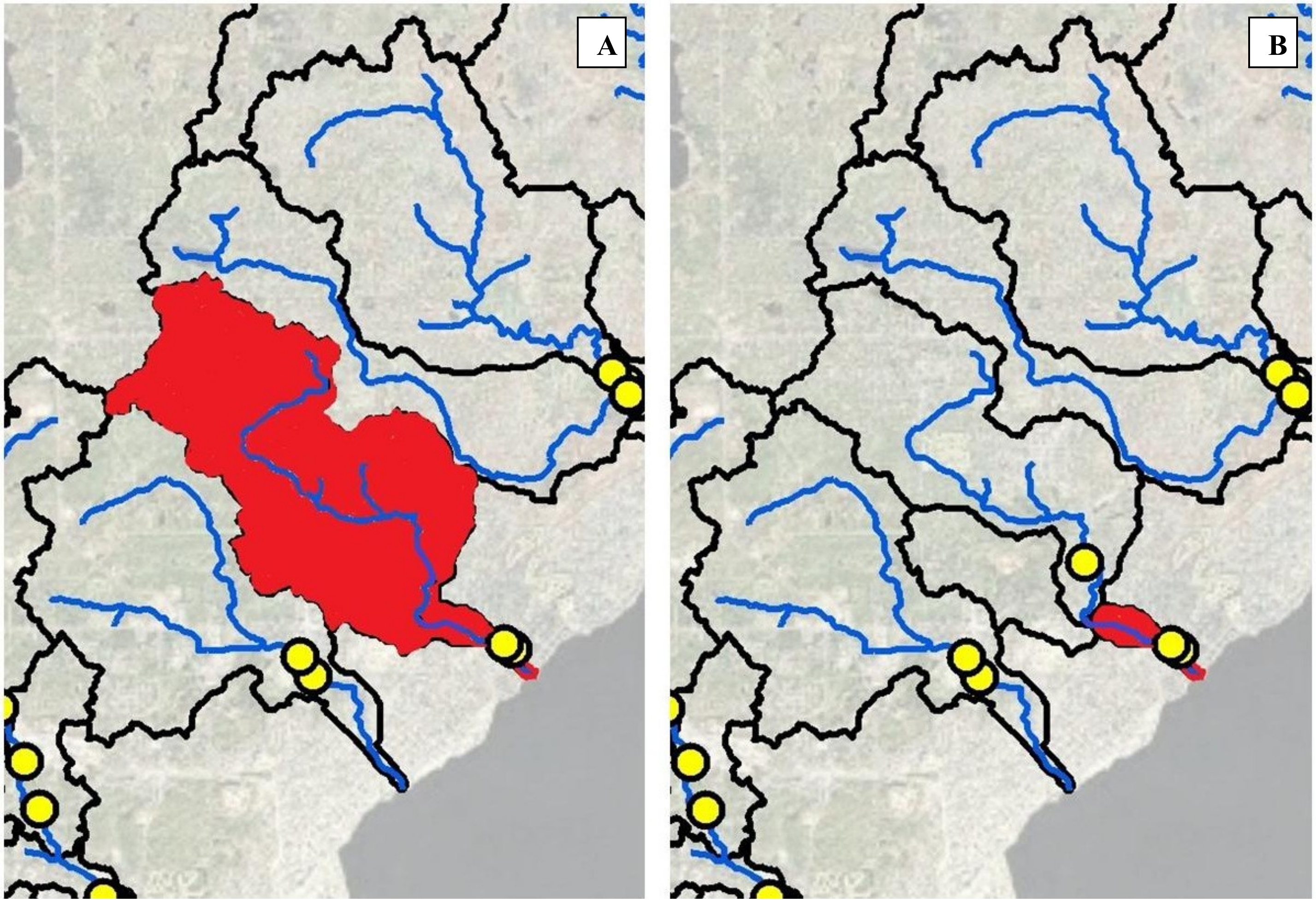



**Figure 2: Whole (panel A) and local (sub) (panel B) watershed area for Miller Creek. Land use/cover upstream from the sample site at the mouth of Miller Creek, and other watersheds included in this study, was analyzed at the whole and local watershed level.**

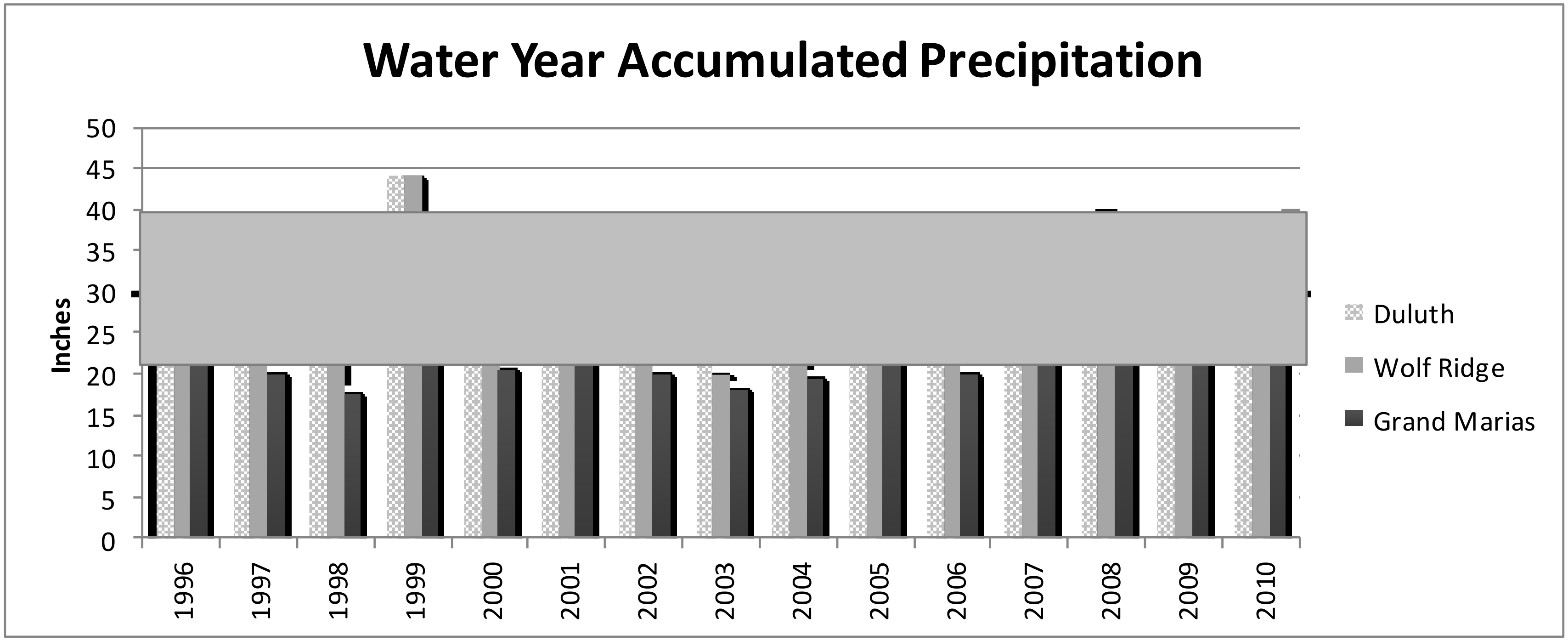



**Figure 3: Accumulated Water Year precipitation at each National Weather Service station. Dashed line indicates the mean precipitation (29 inches) for the region during the study period and grey box indicates the 95% confidence interval.**

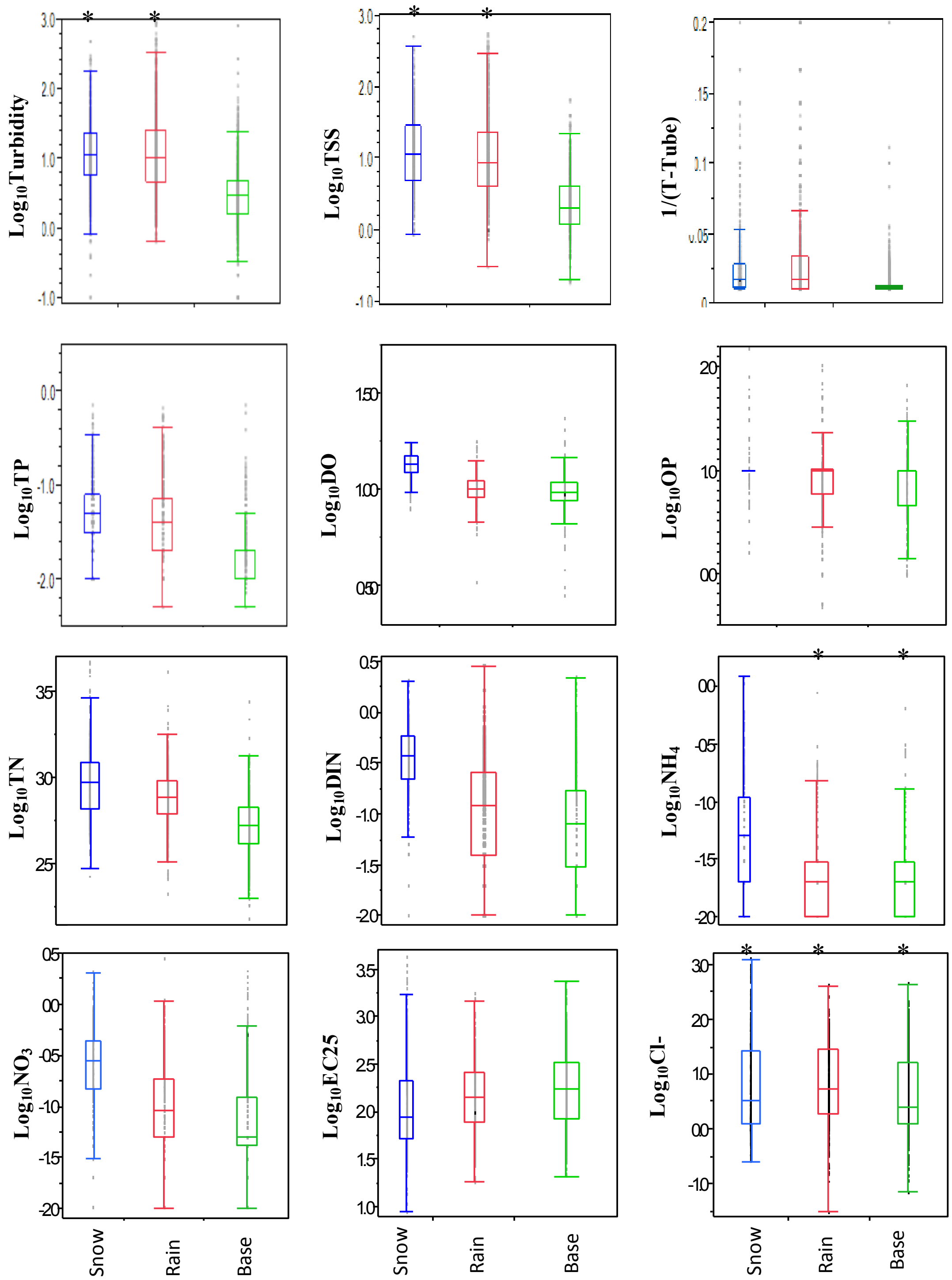



**Figure 4: Box plots illustrating the differences between hydrologic regimes in particulate-related and soluble water quality metrics. Plots include data points, median line, boxing of the interquartile range and whiskers indicating the upper and lower quantiles. Because nearly all values are statistically distinct * indicates values that were *not* significantly different from each other based on Bonferroni corrections.**

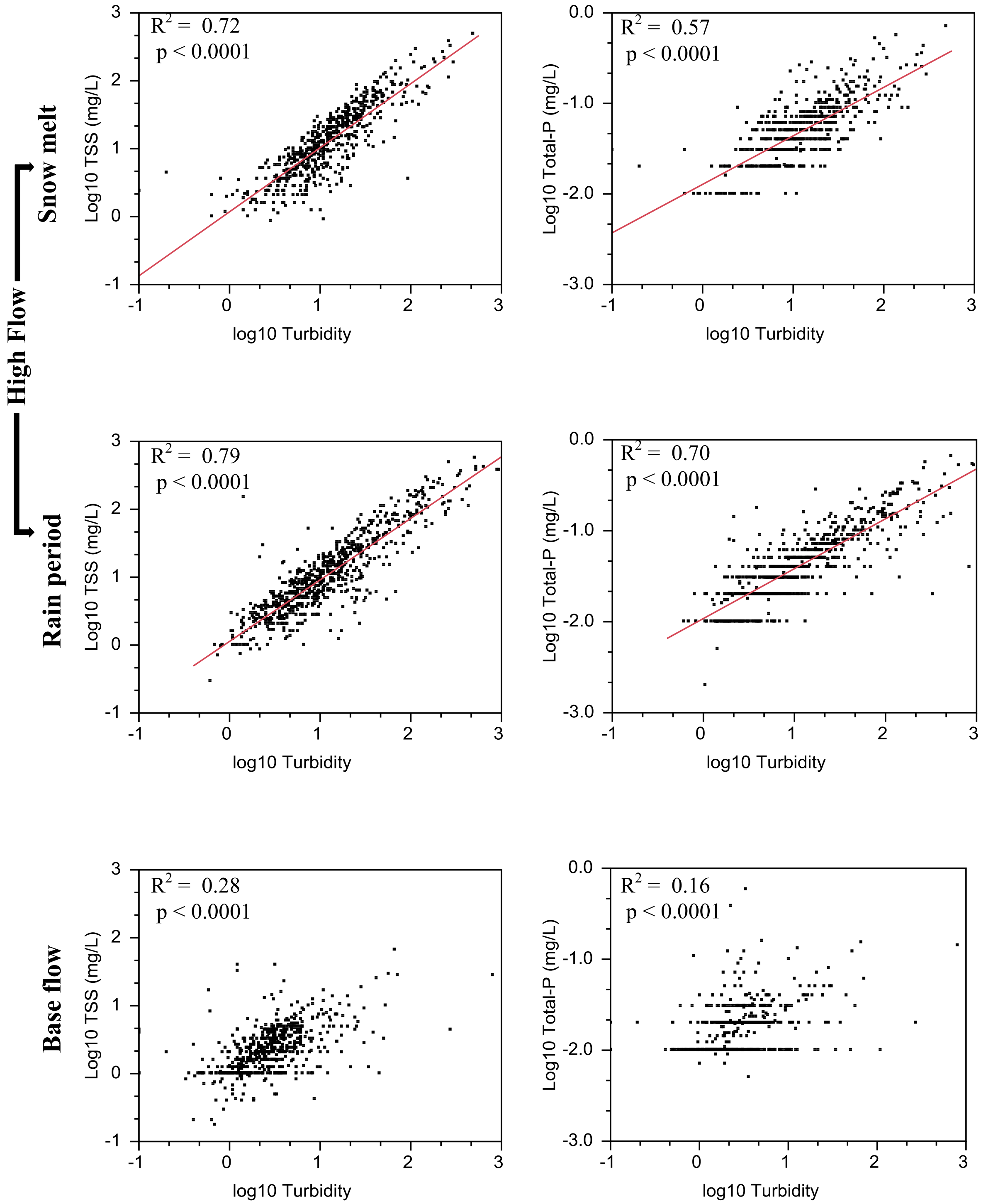



**Figure 5: Adjusted $R^2$ values indicate the strength of the relationship between particulate-related water quality metrics at different hydrologic regimes in North Shore streams. Note closer relationships between metrics during high flow periods.**

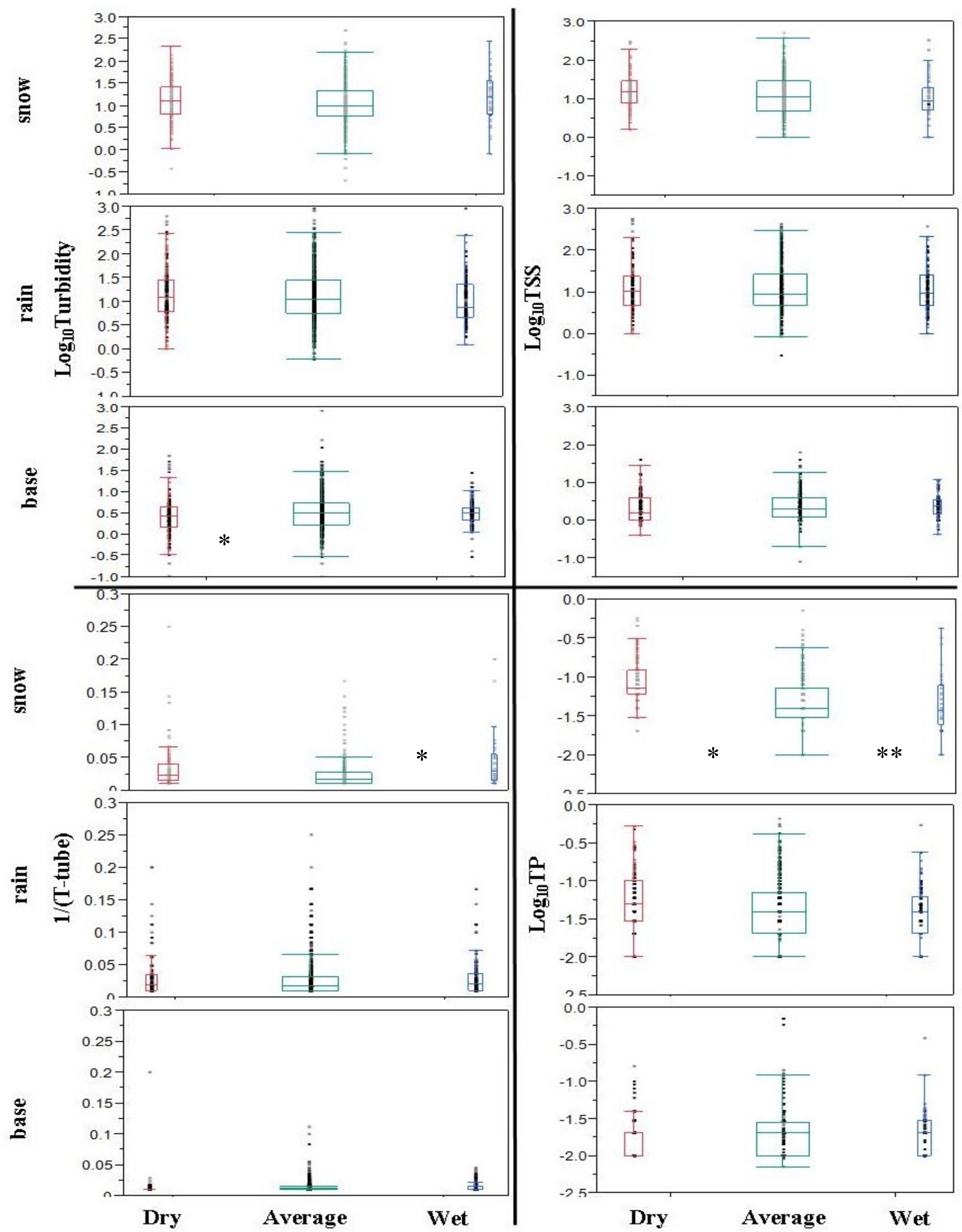



**Figure 6: Boxplots showing inter-annual variation in particulate-related water quality during each hydrologic regime. Plots include data points, median line, boxing the interquartile range and whiskers indicating the upper and lower quantiles. Streams analyzed for this analysis are from a subset of the data with a long-term WQ data record. * indicates values that were significantly different based on Bonferroni corrections. ** indicates dry and wet years were significantly different from each other.**

**Whole watershed LULC regressions** **Local watershed LULC regressions**

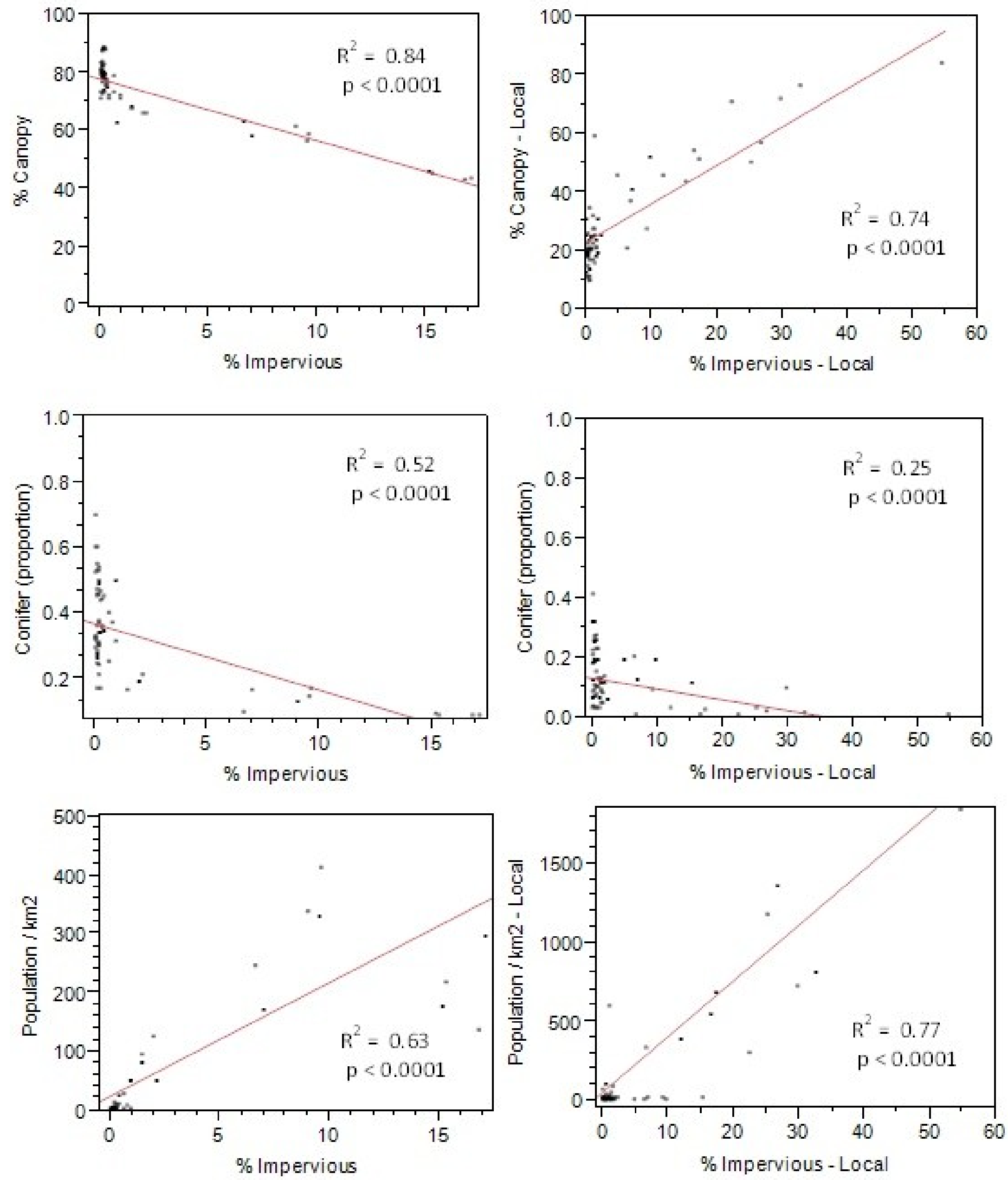



**Figure 7: Relationship between LULC characteristics at the whole and local watershed scale. Notice the inverse relationship between canopy cover and imperviousness at the whole watershed scale and the positive relationship at the local scale. The correlations between deciduous and % impervious cover was significant, but had an $R^2$ <0.01 at both the local and whole watershed scale (see figure 8 for more correlations with deciduous cover).**

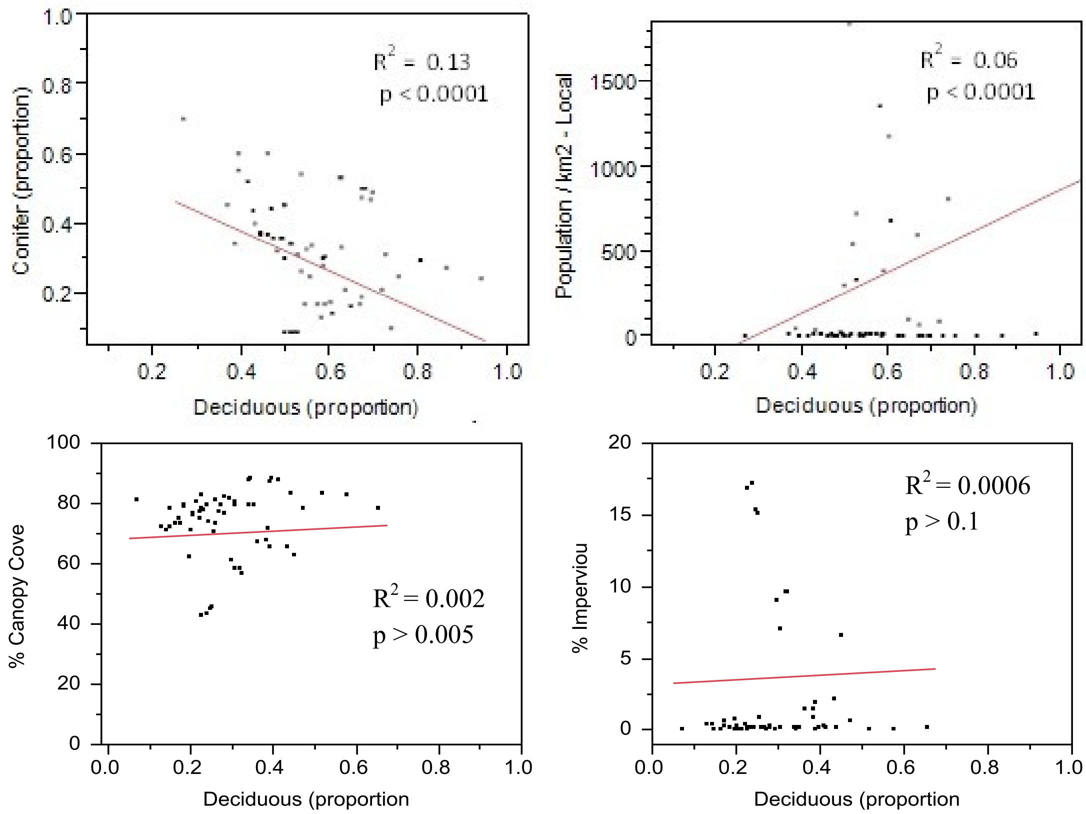



**Figure 8: Relationship between forest cover types (conifer and canopy % v. deciduous) and between forest types and measures of development (local population and % impervious) over the whole watershed. Urban streams are responsible for the positive slope in the regression of population density and deciduous tree cover.**

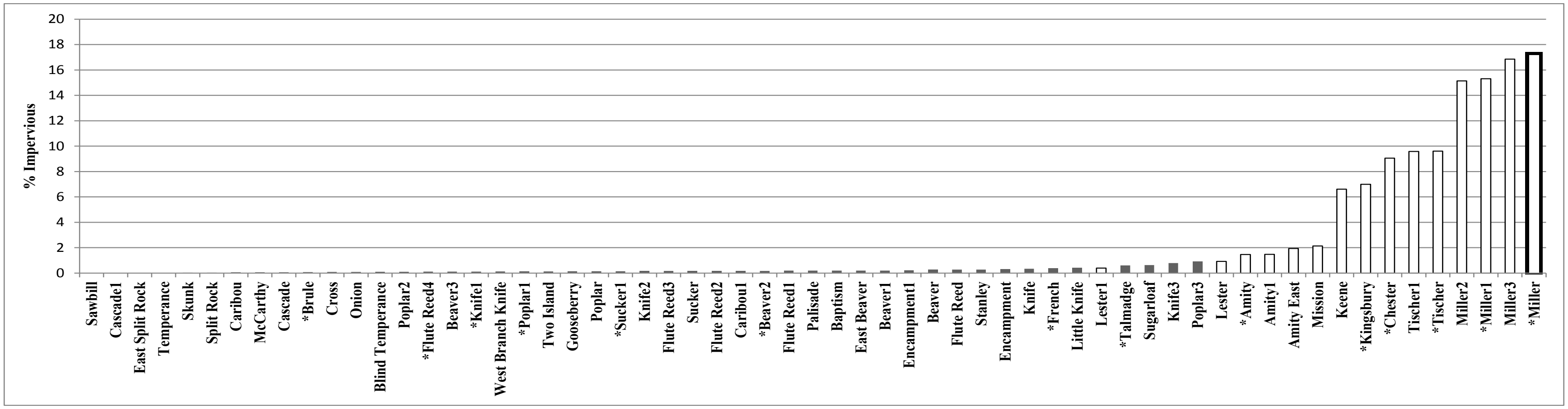



**Figure 9: % Imperviousness within each watershed, from 2001 NLCD. * indicates streams with a long term water quality data set. White bars indicate streams within the city limits of Duluth, MN.**

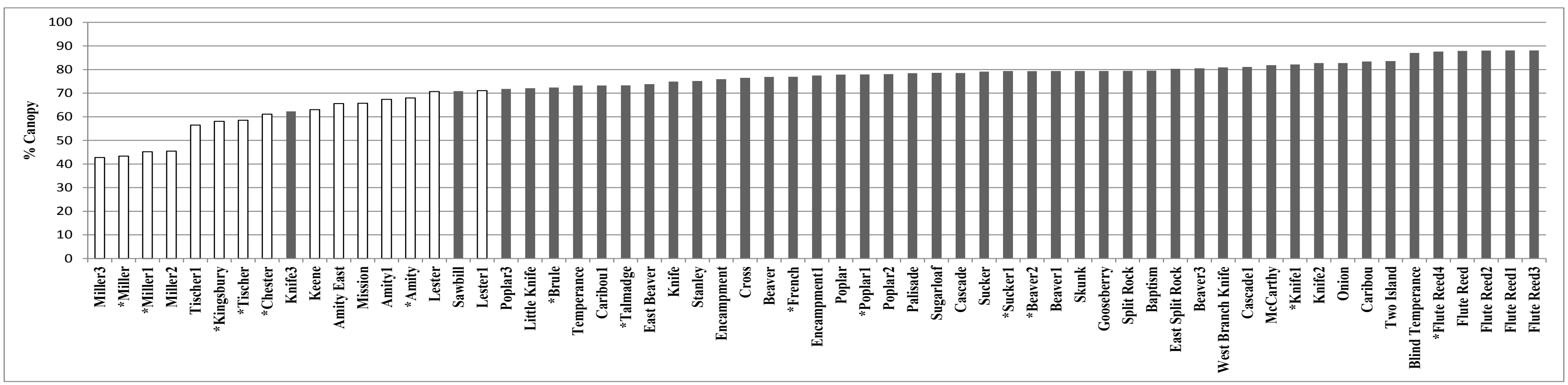



**Figure 10: % Canopy within each watershed from 2001 NLCD. * indicates streams with a long term water quality data set. White bars indicate streams within the city limits of Duluth, MN.**

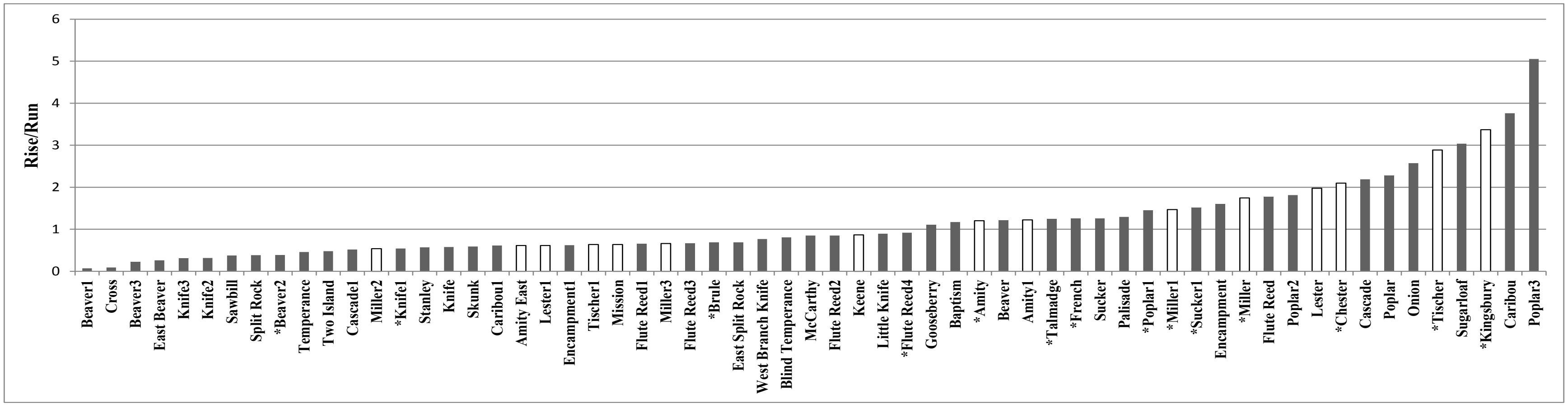



**Figure 11: Mean local stream slope. * indicates streams with a long term water quality data set. White columns indicate streams within the city limits of Duluth, MN.**

## Bibliography

1854 Treaty Authority, 2012. http://1854treatyauthority. org/about/history. htm 2012, 1.

Allan, D.J., Castillo, M.M., 2009. Stream Ecology: Structure and function of running waters.

Allan, J., Johnson, L., 1997. Catchment-scale analysis of aquatic ecosystems. Freshwat. Biol. 37, 107-111.

Allen, N.S., Hershey, A.E., 1996. Seasonal Changes in Chlorophyll a Response to Nutrient Amendments in a North Shore Tributary of Lake Superior. J. N. Am. Benthol. Soc. 15, 170-178.

Anderson, J., Estabrooks, T., McDonnell, J., 2000. Duluth Metropolitan Area Streams Snowmelt Runoff Study. Minnesota Pollution Control Agency .

Anderson, J., Evenson, M., Estabrooks, T., Wilson, B., 2003. A water quality assessment of trout streams on Lake Superior's North Shore. Minnesota Pollution Control Agency 2, 1-8.

Arnold Jr., C.L., Gibbons, C.J., 1996. Impervious surface coverage. Journal of the American Planning Association 62, 243.

Axler, R., Hagley, C., Host, G., Schomberg, J., 2007. LakeSuperiorStreams.org: making stormwater and stream data come alive for citizens, students, teachers, contractors, resource agencies, decision-makers and scientists. Proceedings U. S. Department of the Interior, U. S. Geol. Survey 5th Nat. Water Quality Monitoring Conference May 7-11, 2006, San Jose, CA.

Bartsch, W.M., 2012. Relationship between water quality and anthropotenic landscape stressors in the St. Louis River watershed and estuary.

Bedan, E.S., Clausen, J.C., 2009. Stormwater Runoff Quality and Quantity From Traditional and Low Impact Development Watersheds. JAWRA Journal of the American Water Resources Association 45, 998-998-1008.

Brabec, E., Schulte, S., Richards, P.L., 2002. Impervious Surfaces and Water Quality: A Review of Current Literature and Its Implications for Watershed Planning. Journal of Planning Literature 16, 499-514.

Brazner, J.C., Tanner, D.K., Detenbeck, N.E., Batterman, S.L., Stark, S.L., Jagger, L.A., Snarski, V.M., 2005. Regional, watershed, and site-specific environmental influences on fish assemblage structure and function in western Lake Superior tributaries. Canadian Journal of Fisheries & Aquatic Sciences 62, 1254-1270.

Brown, T.N., Host, G.E., Johnson, L.B., 2011. Lake Superior Sediment Assessment. NRRI/TR-2011/35, Natural Resources Research Institute, U. of Minnesota, Duluth, MN 55811, 1-32.

Brown, L.R., Cuffney, T.F., Coles, J.F., Fitzpatrick, F., McMahon, G., Steuer, J., Bell, A.H., May, J.T., 2009. Urban streams across the USA: lessons learned from studies in 9 metropolitan areas. Journal of the North American Benthological Society 28, 1051-1051-1069.

Buck, O., Niyogi, D.K., Townsend, C.R., 2004. Scale-dependence of land use effects on water quality of streams in agricultural catchments. Environmental Pollution 130, 287-299.

Bunn, S.E., Davies, P.M., Mosisch, T.D., 1999. Ecosystem measures of river health and their response to riparian and catchment degradation. Freshwat. Biol. 41, 333-345.

Burcher, C.L., Valett, H.M., Benfield, E.F., 2007. The Land-Cover Cascade: Relationships Coupling Land and Water. Ecology 88, 228-242.

Czuba, C.R., Fallon, J.D., Kessler, E.W., 2012. Floods of June 2012 in northeastern Minnesota: US Geological Survey Scientific Investigations Report. USGS Survey 2012–5283, 1-42.

Danz, N.P., Niemi, G.J., Regal, R.R., Hollenhorst, T., Johnson, L.B., Hanowski1, J.M., Axler, R.P., Ciborowski, J.J.H., Hrabik, T., Brady, V.J., Kelly, J.R., Morrice, J.A., Brazner, J.C., Howe, R.W., Johnston, C.A., 2007. Integrated Measures of Anthropogenic Stress in the U.S. Great Lakes Basin. Environmental Management 39, 631-631-647.

Detenbeck, N.E., Elonen, C.M., Taylor, D.L., Anderson, L.E., Jicha, T.M., Batterman, S.L., 2004. Region, landscape, and scale effects on Lake Superior Tributary water quality. JAWRA Journal of the American Water Resources Association 40, 705-720.

Detenbeck, N.E., Elonen, C.M., Taylor, D.L., Anderson, L.E., Jicha, T.M., Batterman, S.L., 2003. Effects of hydrogeomorphic region, catchment storage and mature forest on baseflow and snowmelt stream water quality in second-order Lake Superior Basin tributaries. Freshwat. Biol. 48, 912-927.

Dosskey, M.G., Vidon, P., Gurwick, N.P., Allan, C.J., Duval, T.P., Lowrance, R., 2010. The Role of Riparian Vegetation in Protecting and Improving Chemical Water Quality in Streams. JAWRA Journal of the American Water Resources Association 46, 261-261-277.

Eaton, J.G., Scheller, R.M., 1996. Effects of Climate Warming on Fish Thermal Habitat in Streams of the United States. Limnology and Oceanography 41 (5), 1109-1115.

Erickson, J., 2010. Determining the Effects of Urbanization on Stream Metabolism of Duluth Streams. Masters Thesis , 1-1-11.

Fitzpatrick, F.A., Peppler, M.C., DePhilip, M.M., Lee, K.E., 2006. Geomorphic Characteristics and Classification of Duluth-Area streams, Minnesota. 5029.

Friedman, S.K., Reich, P.B., 2005. Regional Legacies of Logging: Departure from Presettlement Forest Conditions in Northern Minnesota. Ecological Applications 15 (2), 726-744.

Galatowitsch, S., Frelich, L., Phillips-Mao, L., 2009. Regional climate change adaptation strategies for biodiversity conservation in a midcontinental region of North America. Biological Conservation 142, 2012-2022.

Hollenhorst, T.P., Brown, T.N., Johnson, L.B., Ciborowski, J.J.H., Host, G.E., 2007. Methods for Generating Multi-scale Watershed Delineations for Indicator Development in Great Lake Coastal Ecosystems. J. Great Lakes Res. 33, 13-26.

Host, G.E., Brown, T.N., Hollenhorst, T.P., Johnson, L.B., Ciborowski, J.J.H., 2011. High-resolution assessment and visualization of environmental stressors in the Lake Superior basin. Aquatic Ecosystem Health and Management 14 (4), 376-385.

Host, G., Axler, R., 2009. Weather and Water: Combining broadcast meteorology and stream data animations to protect Lake Superior's streams. Grant # 0648-0362.

Johnson, L.B., 2010. Predicting nearshore and coastal ecological conditions from landscape data: issues of data scale and resolution. Ecology of Lake Superior Conference, MED-EPA Duluth, MN .

Johnson, L.B., Host, G.E., 2010. Recent developments in landscape approaches for the study of aquatic ecosystems. Journal of the North American Benthological Society 29, 41-41-66.

Johnson, L., Richards, C., Host, G., Arthur, J., 1997. Landscape influences on water chemistry in Midwestern stream ecosystems. Freshwat. Biol. 37, 193-208.

King, R.S., Baker, M.E., Whigham, D.F., Weller, D.E., Jordan, T.E., Kazyak, P.F., Hurd, M.K., 2005. Spatial Considerations for Linking Watershed Land Cover to Ecological Indicators in Streams. Ecol. Appl. 15, 137-153.

Kling, G.W., Hayhoe, K., Johnson, L.B., Magnuson, J.J., Polasky, S., Robinson, S.K., Shuter, B.J., Wander, M.M., Wuebbles, D.J., Zak, D.R., Lindroth, R.L., Moser, S.C., Wilson, M.L., 2003. Confronting Climate Change in the Great Lakes Region: Impacts to our Communities and Ecosystems. Union of Concerned Scientists and Ecological Society of American .

Likens, G.E., Bormann, F.H., Johnson, N.M., Fisher, D.W., Pierce, R.S., 1970. Effects of Forest Cutting and Herbicide Treatment on Nutrient Budgets in the Hubbard Brook Watershed-Ecosystem. Ecol. Monogr. 40, 23-47.

Maidment, D.R., 2002. Arc Hydro: GIS for water resources.

MDNR, 2007. North Shore Trout Streams: Minnesota Department of Natural Resources. 2010.

MDNR, 2006. MNDNR GAP Forestry (Minnesota Department of Natural Resources Gap Analysis Plan). 2010.

MN Dept. of Administration, 2011. Minnesotal Population Change by County 1990-2010. 2012.

MNGeo, 2010. Minnesota Land Use and Cover Information. 2010.

Morley, T.R., Reeve, A.S., Calhoun, A.J.K., 2011. The Role of Headwater Wetlands in Altering Streamflow and Chemistry in a Maine, USA Catchment. JAWRA Journal of the American Water Resources Association 47, 337-349.

MPCA, 2011. Major Watershed Load Monitoring Standard Operating Procedure: Surface Water Quality Sampling. Minnesota Pollution Control Agency wq-cm1-02, 1-32.

MPCA, 2010. Minnesota Pollution Control Agency 303(d) List of Impaired Waters. 2010.

MPCA, 2000. Minnesota Pollution Control Agency, North Shore land use issues: The real costs of growth. St Paul, MN 55455 2, 1-1-5.

Niemi, G.J., Reavie, E.D., Peterson, G.S., Kelly, J.R., Johnston, C.A., Johnson, L.B., Howe, R.W., Host, G.E., Hollenhorst, T.P., Danz, N.P., Ciborowski, J.J.H., Brown, T.N., Brady, V.J., Axler, R.P., 2011. An integrated approach to assessing multiple stressors for coastal Lake Superior. Aquatic Ecosystem Health and Management 14 (4), 1-21.

Noyes, P.D., McElwee, M.K., Miller, H.D., Clark, B.W., Van Tiem, L.A., Walcott, K.C., Erwin, K.N., Levin, E.D., 2009. The toxicology of climate change: Environmental contaminants in a warming world. Environ. Int. 35, 971-986.

Poole, G.C., Berman, C.H., 2001. An Ecological Perspective on In-Stream Temperature: Natural Heat Dynamics and Mechanisms of Human-CausedThermal Degradation. Environmental Management 27, 787-787-802.

Raleigh, R.F., 1982. Habitat Suitability Index Models: Brook Trout. US Dept. Int. , Fish WIldl. Serv. FWS/OBS-82/10.24, 42.

Renard, K.G., Foster, G.R., Weesies, G.A., Porter, J.P., 1991. RUSLE: Revised universal soil loss equation. Journal of Soil and Water Conservation 46, 30--33.

Richards, C., Host, G., 1994. Examining land use influences on stream habitats and macroinvertebrates: A GIS approach. Water Resources Bulletin 30, 729-729-738.

Ruzycki, E.R., Axler, R.P., Host, G.E., Henneck, J.R., Will, N.R., 2013 In Press. Estimating sediment and nutrient loads in four western Lake Superior streams. JAWRA Journal of the American Water Resources Association .

Ruzycki, E.R., Axler, R.P., Henneck, J.R., Will, N.R., Host, G.E., 2011. Estimating mercury concentrations and loads from four western Lake Superior watersheds using continuous in-stream turbidity monitoring. Aquat. Ecosyst. Health Manage. 14, 422-432.

SAS Institute Inc., 1989-2011. JMP. Version 9.

SSURGO, 2012. SSURGO (Soil Survey Geographic Database) for Northeast MN and Northwest WI. 2012, http://soildatamark.nrcs.usda.gov.

Swank, W.T., Douglass, J.E., 1974. Streamflow Greatly Reduced by Converting Deciduous Hardwood Stands to Pine. Science 185, 857-859.

Trebitz, A.S., Brazner, J.C., Brady, V.J., Axler, R., Tanner, D.K., 2007. Turbidity Tolerances of Great Lakes Coastal Wetland Fishes. N. Am. J. Fish. Manage. 27, 619-633.

Tu, J., 2011. Spatially varying relationships between land use and water quality across an urbanization gradient explored by geographically weighted regression. Appl. Geogr. 31, 376-392.

USGS, 2010. USGS (United States Geographic Survey) Land Cover Institute. 2010, http://landcover.usgs.gov/.

Verry, E.S., 1986. Forest Harvesting and Water: The Lake States Experience. Water Resources Bulletin 22, 1039-1047.

Walsh, C.J., Allison H. Roy, Feminella, J.W., Cottingham, P.D., Groffman, P.M., II, R.P.M., 2005. The Urban Stream Syndrome: Current Knowledge and the Search for a Cure. J. N. Am. Benthol. Soc. 24, 706-723.

Waters, T.F., 1980. The Streams and RIvers of Minnesota, 1 ed. University of Minnesota Press, St. Paul, MN.

Wayland, K.G., Hyndman, D.W., Boutt, D., Pijanowski, B.C., Long, D.T., 2002. Modelling the impact of historical land uses on surface-water quality using groundwater flow and solute-transport models. Lakes & Reservoirs: Research & Management 7, 189-199.

Wenck Associates, I., 2006. Shingle Creek Chloride TMDL Report. Minnesota Pollution Control Agency 1240-34, 1-83.

Whittaker, R.H., Likens, G.E., Bormann, F.H., Easton, J.S., Siccama, T.G., 1979. The Hubbard Brook Ecosystem Study: Forest Nutrient Cycling and Element Behavior. Ecology 60, 203-220.

Wold, A.P., Hershey, A.E., 1999. Spatial and Temporal Variability of Nutrient Limitation in 6 North Shore Tributaries to Lake Superior. J. N. Am. Benthol. Soc. 18, 2-14.

Wolter, P., Johnston, C.A., Niemi, G.J., 2006. Land Use Land Cover Changes in the U.S. Great Lakes Basin 1992 to 2001. Journal of Great Lakes Research 32, 607-607-628.

Woodwell, G.M., Whittaker, R.H., Houghton, R.A., 1975. Nutrient Concentrations in Plants in the Brookhaven Oak-Pine Forest. Ecology 56, 318-332.

Zaimes, G.N., Schultz, R.C., Isenhart, T.M., 2006. Riparian land uses and precipitation influences on stream bank erosion in central Iowa. Journal of the American Water Resources Association 42, 1752-1752-1688.

# Appendices

**Appendix A: Water quality grab sample site locations. The watershed or sub-watershed that each site is located within is distinguished by the name. Superscripts indicate sub-watersheds moving inland from the mouth of the stream. Stream names containing the same superscript are in the same sub-watershed. Sites that include sonde data in addition to grab samples are noted.**

| Stream name | Site ID | Latitude | Longitude |
|---|---|---|---|
| Amity (sonde) | 2038001 | 46.84512 | -92.01089 |
| Amity East | 2037001 | 46.85572 | -92.02936 |
| Amity$^{1}$ | 2038002 | 46.85900 | -92.01700 |
| Baptism | 1092001 | 47.37437 | -91.22688 |
| Beaver | 2006009 | 47.25980 | -91.29520 |
| Beaver$^{1}$ | 2006001 | 47.27299 | -91.32477 |
| Beaver$^{2}$ | 2006002 | 47.26490 | -91.34200 |
| Beaver$^{3}$ | 2006003 | 47.25400 | -91.37900 |
| Blind Temperance | 1052001 | 47.63600 | -90.86600 |
| Brule | 1022001 | 47.81860 | -90.05150 |
| Caribou | 1080001 | 47.46792 | -91.02979 |
| Caribou$^{1}$ | 1080002 | 47.70903 | -90.68302 |
| Cascade | 1053001 | 47.70720 | -90.52250 |
| Cascade$^{1}$ | 1053002 | 47.83200 | -90.53000 |
| Chester | 2040001 | 46.81430 | -92.09890 |
| Chester (sonde) | 2040002 | 46.81721 | -92.10158 |
| Cross | 1075001 | 47.60830 | -90.96770 |
| East Beaver | 2001001 | 47.31000 | -91.32200 |
| East Split Rock | 2019001 | 47.24310 | -91.45320 |
| Encampment | 2015001 | 47.09375 | -91.57607 |
| Encampment$^{1}$ | 2015002 | 47.13900 | -91.60300 |
| Flute Reed | 9003903 | 47.84380 | -89.96250 |
| Flute Reed | 9004283 | 47.84010 | -89.96580 |
| Flute Reed$^{1}$ | 9004856 | 47.84650 | -89.97200 |
| Flute Reed$^{1}$ | 9004937 | 47.84650 | -89.97490 |
| Flute Reed$^{2}$ | 9004853 | 47.84880 | -89.99360 |
| Flute Reed$^{3}$ | 9004235 | 47.84980 | -90.01870 |
| Flute Reed$^{3}$ | 9004855 | 47.85810 | -90.03130 |
| Flute Reed$^{4}$ | 9004235 | 47.87670 | -90.05050 |
| Flute Reed$^{4}$ | 9004278 | 47.86750 | -90.05030 |
| French | 2032001 | 46.90390 | -91.90100 |
| French | 2032002 | 46.91890 | -91.91950 |
| French | 2032003 | 46.90411 | -91.90218 |
| Gooseberry | 2012001 | 47.14290 | -91.46800 |
| Keene | 2002001 | 46.73554 | -92.17531 |
| Keene | 2002009 | 46.73130 | -92.16370 |
| Kingsbury (sonde) | 3186001 | 46.72573 | -92.19237 |
| Knife | 2026009 | 46.94730 | -91.78568 |

| Stream name | Site ID | Latitude | Longitude |
| --- | --- | --- | --- |
| Knife[1] (sonde) | 2009001 | 47.05558 | -91.76359 |
| Knife[1] (sonde) | 2026001 | 47.05450 | -91.76330 |
| Knife[2] | 2009002 | 47.08730 | -91.76830 |
| Knife[3] (sonde) | 2020001 | 47.03457 | -91.73071 |
| Lester | 2033009 | 46.83723 | -92.00609 |
| Lester[1] | 2033001 | 46.92003 | -92.04901 |
| Little Knife | 2030001 | 47.03370 | -91.73100 |
| Little Knife | 2030009 | 46.95180 | -91.81900 |
| McCarthy | 2009003 | 47.07810 | -91.78000 |
| Miller | 3001005 | 46.76170 | -92.12970 |
| Miller[1] | 3001001 | 46.77850 | -92.14120 |
| Miller[1] | 3001004 | 46.77944 | -92.14081 |
| Miller[1] | 3001019 | 46.78160 | -92.14500 |
| Miller[1] | 3001049 | 46.78078 | -92.14236 |
| Miller[1] (sonde) | 3001002 | 46.77944 | -92.14081 |
| Miller[2] | 3001003 | 46.80203 | -92.16183 |
| Miller[2] | 3001009 | 46.79497 | -92.15858 |
| Miller[3] | 3001029 | 46.81010 | -92.16700 |
| Mission | 3010001 | 46.66646 | -92.27387 |
| Mission | 3010009 | 46.66030 | -92.27570 |
| Onion | 1066001 | 47.61900 | -90.77700 |
| Palisade | 2055001 | 47.32400 | -91.21700 |
| Poplar | 1063005 | 47.63640 | -90.70740 |
| Poplar[1] | 1063003 | 47.65341 | -90.71917 |
| Poplar[2] | 1063004 | 47.66690 | -90.72220 |
| Poplar[3] (sonde) | 1063001 | 47.66328 | -90.71328 |
| Sawbill | 1068001 | 47.85403 | -90.88901 |
| Skunk | 2011001 | 47.24300 | -91.54500 |
| Split Rock | 2010001 | 47.18400 | -91.40920 |
| Split Rock | 2010009 | 47.25980 | -91.29520 |
| Stanley | 2023001 | 46.98700 | -91.79800 |
| Sucker | 2031009 | 46.92369 | -91.85085 |
| Sucker[1] | 2031001 | 46.93060 | -91.85810 |
| Sugarloaf | 1097001 | 47.48713 | -90.98880 |
| Talmadge | 2035001 | 46.89680 | -91.94190 |
| Temperance | 1076001 | 47.83800 | -90.81200 |
| Tischer | 2039001 | 46.81800 | -92.05520 |
| Tischer | 2039004 | 46.81885 | -92.05704 |
| Tischer (sonde) | 2039002 | 46.82232 | -92.07061 |
| Tischer[1] | 2039003 | 46.83128 | -92.07569 |
| Two Island | 1079001 | 47.54600 | -90.98300 |
| West Branch Knife | 2022001 | 47.02450 | -91.80730 |

**Appendix B: Number of water quality grab samples in each hydrologic regime by watershed and site ID. * indicates watersheds with long term water quality data. Sonde data is noted within parentheses.**

| Stream name | Watershed ID | Site ID | N | Snow melt | Rain period | Base flow |
|---|---|---|---|---|---|---|
| *Amity (sonde) | 31036466 | 2038001 | 369 (27) | 85 | 111 | 200 |
| Amity East | 31036341 | 2037001 | 32 | 5 | 14 | 13 |
| Amity[1] | 31036326 | 2038002 | 18 | 2 | 7 | 9 |
| Baptism | 22011810 | 1092001 | 34 | 11 | 3 | 20 |
| Beaver | 22012278 | 2006009 | 9 | 0 | 1 | 8 |
| Beaver[1] | 22012232 | 2006001 | 19 | 9 | 3 | 7 |
| *Beaver[2] | 22012244 | 2006002 | 53 | 9 | 9 | 35 |
| Beaver[3] | 22012296 | 2006003 | 31 | 1 | 16 | 14 |
| Blind Temperance | 22009979 | 1052001 | 19 | 1 | 6 | 12 |
| *Brule | 22007634 | 1022001 | 166 | 48 | 41 | 77 |
| Caribou | 22011270 | 1080001 | 20 | 9 | 3 | 8 |
| Caribou[1] | 22009302 | 1080002 | 15 | 1 | 7 | 7 |
| Cascade | 22009269 | 1053001 | 20 | 9 | 3 | 8 |
| Cascade[1] | 22007777 | 1053002 | 14 | 2 | 5 | 7 |
| *Chester | 31036987 | 2040001 | 32 | 3 | 10 | 19 |
| *Chester (sonde) | 31036987 | 2040002 | 163 (27) | 51 | 75 | 37 |
| Cross | 22010227 | 1075001 | 14 | 2 | 3 | 9 |
| East Beaver | 22012109 | 2001001 | 8 | 1 | 2 | 5 |
| East Split Rock | 22012354 | 2019001 | 33 | 3 | 10 | 20 |
| Encampment | 31032914 | 2015001 | 19 | 4 | 3 | 12 |
| Encampment[1] | 31032334 | 2015002 | 24 | 1 | 14 | 9 |
| Flute Reed | 22007315 | 9003903 | 17 | 0 | 3 | 14 |
| Flute Reed | 22007315 | 9004283 | 92 | 10 | 30 | 52 |
| Flute Reed[1] | 22007234 | 9004856 | 12 | 0 | 3 | 9 |
| Flute Reed[1] | 22007234 | 9004937 | 12 | 0 | 3 | 9 |
| Flute Reed[2] | 22007237 | 9004853 | 37 | 3 | 6 | 28 |
| Flute Reed[3] | 22007233 | 9004235 | 68 | 4 | 13 | 51 |
| Flute Reed[3] | 22007233 | 9004855 | 11 | 0 | 2 | 9 |
| *Flute Reed[4] | 22006835 | 9004236 | 24 | 1 | 5 | 18 |
| *Flute Reed[4] | 22006835 | 9004278 | 46 | 2 | 9 | 35 |
| *French | 31035723 | 2032001 | 126 | 41 | 48 | 37 |
| *French | 31035723 | 2032002 | 31 | 1 | 18 | 12 |
| *French | 31035723 | 2032003 | 4 | 0 | 0 | 4 |
| Gooseberry | 31032212 | 2012001 | 29 | 9 | 4 | 16 |
| Keene | 36000247 | 2002001 | 4 | 0 | 0 | 4 |
| Keene | 36000247 | 2002009 | 34 | 2 | 8 | 24 |
| *Kingsbury (sonde) | 31037901 | 3186001 | 171 (27) | 51 | 80 | 40 |
| Knife | 31035065 | 2026009 | 3 | 0 | 1 | 8 |
| *Knife[1] (sonde) | 31033543 | 2009001 | 10 (10) | 2 | 4 | 4 |
| *Knife[1] (sonde) | 31033543 | 2026001 | 145 (9) | 14 | 38 | 93 |
| Knife[2] | 31033053 | 2009002 | 31 | 2 | 9 | 20 |
| Knife[3] (sonde) | 31033901 | 2020001 | 7 (7) | 1 | 3 | 3 |
| Lester | 31036559 | 2033009 | 9 | 0 | 1 | 8 |

| Stream name | Watershed ID | Site ID | N | Snow melt | Rain period | Base flow |
|---|---|---|---|---|---|---|
| Lester[1] | 31035556 | 2033001 | 44 | 3 | 24 | 17 |
| Little Knife | 31033901 | 2030001 | 69 | 7 | 18 | 44 |
| Little Knife | 31035071 | 2030009 | 32 | 2 | 10 | 20 |
| McCarthy | 31033237 | 2009003 | 36 | 3 | 10 | 23 |
| *Miller | 31037433 | 3001005 | 111 | 35 | 22 | 54 |
| *Miller[1] | 31037257 | 3001001 | 32 | 2 | 10 | 20 |
| *Miller[1] | 31037257 | 3001004 | 9 | 2 | 3 | 4 |
| *Miller[1] | 31037257 | 3001019 | 32 | 1 | 15 | 16 |
| *Miller[1] | 31037257 | 3001049 | 4 | 0 | 0 | 4 |
| *Miller[1] (sonde) | 31037257 | 3001002 | 42 (9) | 3 | 6 | 33 |
| Miller[2] | 31037116 | 3001003 | 90 | 0 | 30 | 60 |
| Miller[2] | 31037116 | 3001009 | 39 | 1 | 12 | 26 |
| Miller[3] | 31036923 | 3001029 | 89 | 26 | 19 | 44 |
| Mission | 31038874 | 3010001 | 4 | 0 | 0 | 4 |
| Mission | 31038874 | 3010009 | 22 | 0 | 5 | 17 |
| Onion | 22010143 | 1066001 | 12 | 2 | 3 | 7 |
| Palisade | 22012011 | 2055001 | 13 | 1 | 6 | 6 |
| Poplar | 22009995 | 1063005 | 15 | 2 | 3 | 10 |
| *Poplar[1] | 22009865 | 1063003 | 199 | 61 | 50 | 88 |
| Poplar[2] | 22009751 | 1063004 | 125 | 43 | 40 | 42 |
| Poplar[3] (sonde) | 22009769 | 1063001 | 40 (11) | 6 | 15 | 19 |
| Sawbill | 22007440 | 1068001 | 17 | 2 | 10 | 5 |
| Skunk | 31030812 | 2011001 | 51 | 5 | 17 | 29 |
| Split Rock | 22012526 | 2010001 | 20 | 9 | 3 | 8 |
| Split Rock | 22012278 | 2010009 | 9 | 0 | 1 | 8 |
| Stanley | 31034607 | 2023001 | 18 | 1 | 7 | 10 |
| Sucker | 31035442 | 2031009 | 9 | 0 | 1 | 8 |
| *Sucker[1] | 31035415 | 2031001 | 265 | 67 | 103 | 95 |
| Sugarloaf | 22011076 | 1097001 | 19 | 9 | 3 | 7 |
| *Talmadge | 31035804 | 2035001 | 176 | 50 | 61 | 65 |
| Temperance | 22007788 | 1076001 | 15 | 2 | 7 | 6 |
| *Tischer | 31036814 | 2039001 | 32 | 2 | 10 | 20 |
| *Tischer | 31036814 | 2039004 | 4 | 0 | 0 | 4 |
| *Tischer (sonde) | 31036814 | 2039002 | 223 (27) | 59 | 92 | 72 |
| Tischer[1] | 31036716 | 2039003 | 87 | 9 | 22 | 56 |
| Two Island | 22010764 | 1079001 | 12 | 3 | 3 | 6 |
| West Branch Knife | 31034133 | 2022001 | 37 | 3 | 13 | 21 |

**Appendix C: Mixed model regressions relating particulate-related water quality parameters in North Shore streams to landscape variables in each hydrologic regime. Bold values represent adjusted $R^2$ values significant at Bonferroni corrected $p<0.001$, †= $p<0.05$, and ‡=$p<0.01$. - indicates a negative slope.**

| Hydrologic Regime | | | % Impervious | | % Forest Cover | | | | % Wetland | | Population Density (people/km$^2$) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | N | Local | Watershed | Canopy Local | Canopy Watershed | Conifer | Deciduous | Local | Watershed | Local | Watershed |
| High Flow – Snowmelt | **TSS** | 662 | 0.16† | 0.15 | **0.19‡** | 0.15 | -0.16† | 0.16† | 0.16 | -0.16† | 0.16 | 0.15 |
| | **Turbidity** | 668 | 0.17† | 0.15 | 0.17‡ | 0.15 | -0.15† | 0.17‡ | 0.15 | -0.16‡ | 0.15 | 0.15 |
| | **T-tube** | 521 | 0.09 | 0.08 | 0.09 | 0.09 | -0.08 | 0.08 | -0.09† | -0.08† | 0.09 | 0.08 |
| | **Total-P** | 602 | 0.34‡ | 0.33 | **0.34‡** | -0.33 | -0.33† | 0.33 | 0.33‡ | -0.33† | 0.33‡ | 0.33† |
| High Flow – Rain period | **TSS** | 813 | 0.2† | 0.19 | 0.20† | -0.19 | -0.19‡ | 0.20‡ | 0.20† | **-0.20‡** | **0.20‡** | 0.20‡ |
| | **Turbidity** | 915 | 0.23‡ | 0.23 | 0.23 | 0.23 | -0.22 | **0.24‡** | 0.23 | **-0.24‡** | **0.24‡** | 0.24‡ |
| | **T-tube** | 711 | 0.12 | 0.12 | 0.12 | 0.12 | -0.12 | 0.12‡ | -0.12† | -0.12† | 0.12 | 0.12 |
| | **Total-P** | 790 | 0.24 | 0.25† | 0.25† | -0.25† | -0.24‡ | 0.25† | 0.25 | -0.25† | 0.24† | 0.24‡ |
| Base flow | **TSS** | 806 | 0.27 | 0.26 | 0.26 | 0.27 | 0.26 | 0.26† | 0.27 | -0.27‡ | 0.27 | 0.26 |
| | **Turbidity** | 1028 | 0.15 | 0.15 | 0.15 | -0.16 | 0.15 | 0.15 | 0.16† | -0.16 | 0.16 | 0.15 |
| | **T-tube** | 1022 | 0.13 | 0.14 | 0.13 | 0.14 | 0.14 | 0.14 | -0.14‡ | -0.14† | 0.14 | 0.14 |
| | **Total-P** | 828 | 0.17 | **0.17‡** | 0.17 | -0.17‡ | -0.17‡ | 0.17 | -0.19† | 0.17 | 0.17 | **0.15‡** |

**Appendix D: Mixed model regressions relating soluble water quality parameters in North Shore streams to landscape variables in each hydrologic regime. Bold values represent adjusted $R^2$ values significant at Bonferroni corrected p<0.001, †= p<0.05, and ‡=p<0.01. - indicates a negative slope.**

| Hydrologic Regime | | | | % Impervious | | % Forest Cover | | | | % Wetland | | Population Density (people/km$^2$) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | N | Local | Watershed | Canopy Local | Canopy Watershed | Conifer | Deciduous | Local | Watershed | Local | Watershed |
| High flow | Snowmelt | **DO** | 419 | 0.04 | 0.03 | 0.15 | 0.03 | 0.04 | 0.04 | 0.04 | **-0.03** | 0.11 | **0.04** |
| | | **Ortho-P** | 302 | **0.41‡** | 0.39‡ | **0.40‡** | 0.39 | 0.39 | **-0.39‡** | 0.39† | -0.39 | **0.40‡** | 0.39‡ |
| | | **Total-N** | 302 | 0.25† | 0.25 | 0.25 | 0.24 | 0.26 | 0.25 | 0.25† | 0.25 | 0.25† | 0.25† |
| | | **DIN** | 273 | 0.46 | 0.46 | 0.46 | 0.46 | 0.47† | 0.47† | 0.46 | 0.46 | 0.45 | 0.46 |
| | | **Ammonium-N** | 255 | 0.34† | 0.34‡ | 0.34‡ | -0.34‡ | 0.35 | 0.35 | 0.35 | 0.35 | 0.34‡ | 0.34‡ |
| | | **[Nitrate+Nitrite]-N** | 493 | 0.42 | 0.42 | 0.42 | 0.42 | 0.43† | 0.43† | 0.42† | 0.42 | 0.42† | 0.42† |
| | | **EC25** | 606 | **0.76‡** | **0.76‡** | **0.76‡** | **-0.75‡** | 0.76† | 0.76† | 0.76 | -0.76‡ | **0.76‡** | **0.76‡** |
| | | **$Cl^-$** | 502 | **0.86‡** | **0.86‡** | 0.86‡ | **-0.86‡** | -0.86 | 0.86 | **0.86‡** | -0.86 | **0.86‡** | **0.86‡** |
| | Rain period | **DO** | 522 | 0.10 | -0.10 | **-0.09‡** | 0.11† | 0.12 | 0.11 | 0.11 | 0.11 | 0.25 | 0.11 |
| | | **Ortho-P** | 483 | **0.48‡** | 0.48‡ | 0.48† | -0.48† | 0.48† | 0.48† | **0.48‡** | -0.48‡ | **0.49‡** | **0.48‡** |
| | | **Total-N** | 594 | 0.24 | 0.24 | 0.24 | 0.24 | 0.24† | 0.24 | 0.23‡ | -0.24† | 0.25‡ | 0.24 |
| | | **DIN** | 513 | 0.54† | 0.54† | 0.54 | 0.54 | 0.55 | **0.55‡** | **0.55‡** | -0.54† | 0.54† | 0.54† |
| | | **Ammonium-N** | 489 | 0.26‡ | **0.26‡** | 0.26‡ | **-0.28‡** | 0.28 | 0.28 | 0.28† | -0.28 | 0.27‡ | 0.27‡ |
| | | **[Nitrate+Nitrite]-N** | 489 | 0.45 | 0.45 | 0.45 | 0.45 | 0.46 | **0.46‡** | **0.47‡** | -0.45† | 0.46‡ | 0.46‡ |
| | | **EC25** | 885 | 0.71 | **0.72‡** | 0.72† | **-0.72‡** | 0.71 | 0.71 | 0.72‡ | -0.71 | -0.72 | 0.72 |
| | | **$Cl^-$** | 548 | 0.90† | **0.90‡** | 0.90† | **-0.90‡** | 0.90 | 0.90 | **0.91‡** | -0.90‡ | 0.90 | **0.90‡** |
| Base flow | | **DO** | 756 | 0.07 | -0.07 | -0.06† | 0.06† | 0.07† | 0.07 | 0.09‡ | 0.07 | 0.09† | 0.08 |
| | | **Ortho-P** | 421 | 0.37† | 0.37 | 0.37 | 0.37 | 0.38 | 0.37 | **0.37‡** | 0.38 | 0.38‡ | 0.38† |
| | | **Total-N** | 539 | 0.39 | 0.39 | 0.39 | 0.39 | 0.39 | 0.39 | 0.39 | 0.40 | 0.40† | 0.39 |
| | | **DIN** | 434 | 0.52 | 0.53‡ | 0.53 | -0.53 | 0.54† | 0.54‡ | **0.58‡** | -0.53† | 0.53 | 0.53‡ |

| Hydrologic Regime | | | % Impervious | | % Forest Cover | | | | % Wetland | | Population Density (people/km$^2$) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | N | Local | Watershed | Canopy Local | Canopy Watershed | Conifer | Deciduous | Local | Watershed | Local | Watershed |
| **Base flow** | **Ammonium-N** | 412 | 0.38† | 0.38‡ | 0.38‡ | -0.39‡ | 0.39 | 0.38 | 0.40‡ | 0.39 | 0.38† | 0.38† |
| | **[Nitrate+Nitrite]-N** | 412 | 0.40 | 0.40 | 0.41 | 0.40 | 0.41 | **0.41**‡ | **0.45**‡ | -0.41‡ | 0.40 | 0.40‡ |
| | **EC25** | 1133 | 0.82 | **0.82**‡ | 0.82 | **-0.82**‡ | 0.82† | 0.82† | 0.82 | **-0.82**‡ | 0.82 | **0.82**‡ |
| | **$Cl^-$** | 534 | 0.88‡ | **0.88**‡ | 0.88 | **-0.88**‡ | 0.88 | 0.88 | **0.92**‡ | **-0.89**‡ | 0.88 | **0.88**‡ |

**Appendix E: p-values from two-tailed T-tests comparing mean values for each particulate-related water quality metric in each hydrologic regime by precipitation regime. Bold values meet the criteria set by the Bonferroni adjusted alpha suggesting significance at p<0.002.**

| | wet v. dry | wet v. average | dry v. average | Wet year mean (SD) | Dry year mean (SD) | Average year mean (SD) | % Difference Wet to Dry |
|---|---|---|---|---|---|---|---|
| **Turbidity (NTU)** | | | | | | | |
| snow | 0.4 | 0.04 | 0.07 | 32.3 (49.8) | 23.2 (31.0) | 20.4 (37.6) | 39 % |
| rain | 0.06 | 0.02 | 0.9 | 25.1 (76.4) | 35.7 (82.1) | 35.5 (79.3) | 30 % |
| base | 0.04 | 0.5 | **0.001** | 4.0 (3.4) | 4.5 (8.6) | 7.1 (36.5) | 11 % |
| **TSS (mg/L)** | | | | | | | |
| snow | 0.02 | 0.5 | 0.02 | 27.8 (57.2) | 29.6 (44.6) | 24.4 (42.6) | -6 % |
| rain | 0.9 | 0.9 | 0.8 | 25.7 (46.8) | 35.3 (81.8) | 30.1 (55.9) | 27 % |
| base | 0.3 | 0.9 | 0.08 | 3.1 (2.5) | 3.2 (4.6) | 3.5 (4.9) | 3 % |
| **T-Tube ($cm^{-1}$)** | | | | | | | |
| snow | 0.04 | **<0.0001** | 0.02 | 41.3 (27.5) | 48.4 (27.3) | 63.7 (30.0) | 15 % |
| rain | 0.9 | 0.7 | 0.8 | 57.6 (34.0) | 57.0 (34.3) | 59.2 (32.1) | 1 % |
| base | 0.2 | 0.4 | 0.5 | 84.7 (24.7) | 93.9 (16.0) | 47.8 (21.7) | 10 % |
| **Total-P (mg/L)** | | | | | | | |
| snow | **<0.0001** | 0.5 | **<0.0001** | 0.067 (0.084) | 0.105 (0.092) | 0.061 (0.63) | 36 % |
| rain | 0.006 | 0.2 | 0.03 | 0.051 (0.058) | 0.078 (0.085) | 0.066 (0.078) | 35 % |
| base | 0.3 | 0.9 | 0.4 | 0.025 (0.039) | 0.022 (0.020) | 0.029 (0.029) | 14 % |

**Appendix F: p-values from two-tailed T-tests comparing mean values for each soluble water quality metric in each hydrologic regime by precipitation regime. Bold values meet the criteria set by the Bonferroni adjusted alpha suggesting significance at p<0.002.**

| | wet v. dry | wet v. average | dry v. average | Wet year mean (SD) | Dry year mean (SD) | Average year mean (SD) |
|---|---|---|---|---|---|---|
| **DO (mg/L)** | | | | | | |
| snow | 0.6 | 0.4 | 0.04 | 14.0 (2.0) | 13.5 (1.1) | 13.2 (1.7) |
| rain | 0.1 | 0.4 | 0.2 | 10.2 (1.6) | 11.0 (2.2) | 10.0 (1.6) |
| base | 0.02 | 0.1 | 0.2 | 9.4 (1.6) | 10.3 (2.4) | 9.7 (1.8) |
| **OP (mg/L)** | | | | | | |
| snow | **0.0002** | **0.0003** | 0.6 | 0.008 (0.003) | 0.015 (0.014) | 0.015 (0.014) |
| rain | **<0.0001** | **<0.0001** | 0.9 | 0.008 (0.006) | 0.026 (0.088) | 0.016 (0.013) |
| base | **<0.0001** | **<0.0001** | 0.6 | 0.007 (0.004) | 0.010 (0.006) | 0.010 (0.003) |
| **Total-N (mg/L)** | | | | | | |
| snow | **<0.0001** | 0.8 | **<0.0001** | 0.992 (0.362) | 1.570 (0.900) | 0.973 (0.322) |
| rain | 0.04 | 0.5 | 0.07 | 0.784 (0.190) | 0.916 (0.376) | 0.830 (0.292) |
| base | 0.04 | 0.05 | 0.7 | 0.646 (0.226) | 0.578 (0.203) | 0.585 (0.207) |
| **DIN (mg/L)** | | | | | | |
| snow | 0.4 | 0.06 | 0.2 | 0.404 (0.207) | 0.524 (0.444) | 0.536 (0.273) |
| rain | **<0.0001** | **<0.0001** | 0.02 | 0.071 (0.069) | 0.324 (0.262) | 0.227 (0.161) |
| base | 0.004 | **<0.0001** | 0.3 | 0.191 (0.410) | 0.180 (0.173) | 0.204 |
| **Ammonium-N (mg/L)** | | | | | | |
| snow | 0.2 | 0.4 | 0.5 | 0.103 (0.122) | 0.170 (0.262) | 0.104 (0.101) |
| rain | **<0.0001** | **<0.0001** | 0.08 | 0.020 (0.028) | 0.055 (0.101) | 0.038 (0.043) |
| base | 0.05 | 0.08 | 0.6 | 0.024 (0.023) | 0.032 (0.030) | 0.038 (0.069) |
| **Nitrate+Nitrite (mg/L)** | | | | | | |
| snow | 0.04 | 0.6 | 0.01 | 0.364 (0.249) | 0.282 (0.207) | 0.352 (0.210) |
| rain | **<0.0001** | **<0.0001** | **0.0002** | 0.058 (0.057) | 0.252 (0.204) | 0.156 (0.130) |
| base | 0.2 | 0.03 | 0.5 | 0.151 (0.347) | 0.115 (0.132) | 0.134 (0.161) |
| **EC25 (uS/cm)** | | | | | | |
| snow | 0.5 | 0.2 | 0.4 | 253 (235) | 367 (715) | 210 (275) |
| rain | **0.0002** | 0.04 | 0.01 | 178 (147) | 233 (177) | 199 (165) |
| base | 0.02 | 0.4 | 0.04 | 295 (230) | 213 (148) | 276 (256) |
| **$Cl^-$ (mg/L)** | | | | | | |
| snow | 0.2 | 0.8 | 0.02 | 43.7 (78.1) | 76.6 (210) | 30.9 (73.0) |
| rain | **<0.0001** | **<0.0001** | **0.0005** | 7.80 (15.2) | 30.8 (35.0) | 21.1 (32.3) |
| base | **<0.0001** | **<0.0001** | 0.6 | 9.10 (21.5) | 22.9 (53.0) | 24.0 (37.0) |

**Appendix G: Pearson product-moment correlations coefficients relating local stream slope to other LULC metrics. All values are significant at p<0.0001 unless noted as not significant (NS). Bold values represent correlations with an R>0.30**

| | (local) Stream slope |
|---|---|
| (local) bank slope | 0.26 |
| (local) % Wetland | 0.26 |
| (local) Road/stream intersections | **0.31** |
| (local) % Canopy | **0.31** |
| (local) Stream KFFACT | -0.09 |
| (local) Stream Erosion Potential | **-0.39** |
| (local) Bank KFFACT | -0.08 |
| (local) Bank Erosion Potential | **-0.41** |
| (local) % Impervious | **0.37** |
| (local) People/km$^2$ | **0.40** |
| Bank KFFACT | NS |
| Bank Erosion Potential | -0.06 |
| % Canopy | -0.22 |
| Stream Erosion Potential | -0.06 |
| NPDE Sources | -0.15 |
| Stream KFFACT | NS |
| People/km$^2$ | **0.45** |
| Bank Slope | NS |
| % Impervious | 0.23 |
| Stream Slope | NS |
| Road-Stream Intersections | 0.07 |
| % Wetland | -0.16 |
| Develop Open | **0.32** |
| Develop Low | **0.38** |
| Develop Medium | 0.24 |
| Develop High | 0.11 |
| Barren | -0.04 |
| Deciduous | 0.24 |
| Conifer | -0.17 |
| Mixed Forest | **-0.32** |
| Shrub | -0.24 |
| Grass | -0.09 |
| Pasture | NS |
| Crop | -0.24 |
| Wetland Woody | -0.13 |
| Wetland Emergent | 0.19 |
| Develop Sum | **0.31** |
| Wetland Sum | -0.08 |

| | (local) Stream slope |
|---|---|
| Forest Sum | -0.18 |
| Cultivated Sum | **0.31** |

**Appendix H Local and accumulated watershed area (km2) and summed 2006 NLCD classifications (see METHODS). * indicates watersheds with long term water quality data.**

| | | Watershed Area | | 2006 NLCD | | |
|---|---|---|---|---|---|---|
| Stream name | Watershed ID | Local area ($km^2$) | Accumulated area ($km^2$) | % Develop (sum) | % Wetland (sum) | % Forest (sum) |
| *Amity | 31036466 | 1.28 | 41.74 | 1.8 | 14.6 | 43.6 |
| Amity East | 31036341 | 0.15 | 14.20 | 3.1 | 13.8 | 46.3 |
| Amity[1] | 31036326 | 0.67 | 35.85 | 1.9 | 16.0 | 41.3 |
| Baptism | 22011810 | 0.78 | 326.38 | 0.2 | 35.4 | 55.0 |
| Beaver | 22012278 | 0.11 | 316.02 | 0.5 | 29.3 | 55.9 |
| Beaver[1] | 22012232 | 0.28 | 169.27 | 0.4 | 32.4 | 57.1 |
| *Beaver[2] | 22012244 | 3.68 | 167.12 | 0.3 | 32.8 | 56.8 |
| Beaver[3] | 22012296 | 0.52 | 136.31 | 0.2 | 35.1 | 56.4 |
| Blind Temperance | 22009979 | 2.26 | 11.64 | 0.0 | 13.5 | 83.4 |
| *Brule | 22007634 | 0.76 | 685.03 | 0.1 | 17.5 | 60.9 |
| Caribou | 22011270 | 0.53 | 58.95 | 0.0 | 20.4 | 69.1 |
| Caribou[1] | 22009302 | 2.24 | 45.80 | 0.1 | 11.8 | 68.9 |
| Cascade | 22009269 | 0.30 | 287.28 | 0.0 | 25.3 | 64.7 |
| Cascade[1] | 22007777 | 1.05 | 7.67 | 0.0 | 26.1 | 60.6 |
| *Chester | 31036987 | 2.68 | 17.90 | 17.0 | 17.7 | 33.6 |
| Cross | 22010227 | 3.14 | 172.43 | 0.1 | 24.1 | 56.4 |
| East Beaver | 22012109 | 2.24 | 133.90 | 0.5 | 27.6 | 52.3 |
| East Split Rock | 22012354 | 1.28 | 35.41 | 0.0 | 39.7 | 51.5 |
| Encampment | 31032914 | 1.46 | 44.70 | 0.3 | 22.4 | 58.5 |
| Encampment[1] | 31032334 | 0.81 | 19.89 | 0.4 | 36.4 | 46.3 |
| Flute Reed | 22007315 | 0.19 | 39.99 | 0.3 | 6.7 | 83.4 |
| Flute Reed[1] | 22007234 | 1.26 | 29.46 | 0.1 | 8.3 | 84.5 |
| Flute Reed[2] | 22007237 | 0.09 | 27.39 | 0.1 | 8.4 | 84.6 |
| Flute Reed[3] | 22007233 | 1.78 | 20.91 | 0.1 | 11.5 | 82.1 |
| *Flute Reed[4] | 22006835 | 1.17 | 15.96 | 0.0 | 12.6 | 80.8 |
| *French | 31035723 | 1.81 | 50.95 | 0.2 | 26.2 | 52.1 |
| Gooseberry | 31032212 | 2.35 | 192.74 | 0.1 | 28.8 | 55.3 |
| Keene | 36000247 | 1.34 | 15.11 | 11.9 | 17.4 | 47.7 |
| *Kingsbury | 31037901 | 0.90 | 24.19 | 13.7 | 28.3 | 35.7 |
| Knife | 31035065 | 1.59 | 224.96 | 0.2 | 20.8 | 58.1 |
| *Knife[1] | 31033543 | 0.52 | 37.66 | 0.0 | 18.3 | 61.2 |
| Knife[2] | 31033053 | 0.41 | 19.11 | 0.0 | 14.2 | 63.0 |
| Knife[3] | 31033901 | 0.96 | 17.37 | 0.9 | 18.4 | 50.3 |
| Lester | 31036559 | 0.05 | 137.87 | 1.0 | 22.8 | 46.4 |
| Lester[1] | 31035556 | 0.65 | 51.37 | 0.2 | 37.9 | 39.5 |
| Little Knife | 31035071 | 0.80 | 24.00 | 0.0 | 22.4 | 55.1 |
| McCarthy | 31033237 | 0.68 | 13.42 | 0.0 | 24.9 | 56.2 |
| *Miller | 31037433 | 0.76 | 24.40 | 31.9 | 15.7 | 25.3 |
| *Miller[1] | 31037257 | 1.16 | 22.23 | 30.7 | 16.4 | 26.2 |
| Miller[2] | 31037116 | 2.19 | 20.26 | 30.4 | 17.9 | 26.7 |
| Miller[3] | 31036923 | 0.97 | 16.11 | 30.7 | 20.2 | 24.0 |

| Stream name | Watershed ID | Watershed Area | | 2006 NLCD | | |
|---|---|---|---|---|---|---|
| | | Local area ($km^2$) | Accumulated area ($km^2$) | % Develop (sum) | % Wetland (sum) | % Forest (sum) |
| Mission | 31038874 | 1.49 | 28.12 | 3.2 | 11.4 | 54.8 |
| Onion | 22010143 | 1.72 | 22.44 | 0.0 | 18.7 | 77.4 |
| Palisade | 22012011 | 0.97 | 14.35 | 0.1 | 7.6 | 82.9 |
| Poplar | 22009995 | 0.12 | 295.12 | 0.1 | 24.1 | 61.9 |
| *Poplar[1] | 22009865 | 1.12 | 294.35 | 0.0 | 24.1 | 61.9 |
| Poplar[2] | 22009751 | 1.25 | 290.61 | 0.0 | 24.4 | 61.7 |
| Poplar[3] | 22009769 | 0.83 | 0.83 | 1.5 | 18.6 | 71.0 |
| Sawbill | 22007440 | 2.44 | 55.63 | 0.0 | 15.6 | 66.4 |
| Skunk | 31030812 | 2.14 | 10.04 | 0.0 | 22.0 | 55.7 |
| Split Rock | 22012526 | 0.73 | 113.45 | 0.0 | 31.9 | 55.3 |
| Stanley | 31034607 | 1.13 | 18.68 | 0.0 | 15.1 | 63.9 |
| Sucker | 31035442 | 0.22 | 98.25 | 0.1 | 28.0 | 56.9 |
| *Sucker[1] | 31035415 | 1.21 | 96.32 | 0.0 | 28.5 | 56.8 |
| Sugarloaf | 22011076 | 1.25 | 3.65 | 0.8 | 12.2 | 54.9 |
| *Talmadge | 31035804 | 1.46 | 13.88 | 0.1 | 19.4 | 52.9 |
| Temperance | 22007788 | 0.37 | 108.87 | 0.0 | 23.5 | 60.3 |
| *Tischer | 31036814 | 0.71 | 18.84 | 15.3 | 10.8 | 38.2 |
| Tischer[1] | 31036716 | 1.41 | 14.19 | 15.4 | 11.5 | 36.4 |
| Two Island | 22010764 | 2.08 | 32.54 | 0.1 | 25.7 | 66.3 |
| West Branch Knife | 31034133 | 0.87 | 36.61 | 0.0 | 25.5 | 59.0 |

**Appendix I: 2006 NLCD LULC classifications for each watershed.**

| | 2006 NLCD | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Development Classes | | | | Forest Classes | | | Wetland Classes | | | | | | | |
| Stream name | % High | % Low | % Medium | % Open | % Decid. | % Conifer | % Mixed | % Emergent | % Woody | % Barren | % Crop | % Grass | % Pasture | % Shrub | % Water |
| *Amity | 0.0 | 1.6 | 0.1 | 7.4 | 38.2 | 2.7 | 2.7 | 3.0 | 11.6 | 0.0 | 0.7 | 0.4 | 6.8 | 24.3 | 0.5 |
| Amity East | 0.0 | 2.8 | 0.2 | 7.7 | 38.8 | 3.4 | 4.1 | 2.2 | 11.6 | 0.0 | 0.3 | 0.5 | 7.7 | 19.7 | 1.1 |
| Amity[1] | 0.0 | 1.8 | 0.1 | 6.9 | 36.1 | 2.6 | 2.6 | 3.4 | 12.6 | 0.0 | 0.8 | 0.4 | 7.2 | 24.8 | 0.6 |
| Baptism | 0.0 | 0.1 | 0.0 | 1.9 | 23.5 | 11.0 | 20.5 | 0.5 | 34.9 | 0.0 | 0.0 | 0.8 | 0.0 | 5.8 | 0.8 |
| Beaver | 0.1 | 0.4 | 0.1 | 1.5 | 28.0 | 10.9 | 17.0 | 1.0 | 28.3 | 1.2 | 0.1 | 1.7 | 0.5 | 6.7 | 2.7 |
| Beaver[1] | 0.1 | 0.3 | 0.0 | 1.2 | 30.6 | 8.9 | 17.6 | 1.4 | 31.0 | 0.2 | 0.1 | 0.5 | 0.6 | 6.5 | 1.0 |
| *Beaver[2] | 0.1 | 0.2 | 0.0 | 1.1 | 30.5 | 8.7 | 17.5 | 1.4 | 31.4 | 0.2 | 0.1 | 0.5 | 0.6 | 6.6 | 1.0 |
| Beaver[3] | 0.0 | 0.2 | 0.0 | 0.8 | 30.4 | 7.5 | 18.5 | 1.2 | 33.9 | 0.3 | 0.1 | 0.6 | 0.0 | 5.4 | 1.0 |
| Blind Temperance | 0.0 | 0.0 | 0.0 | 2.0 | 38.8 | 20.5 | 24.1 | 0.1 | 13.4 | 0.0 | 0.0 | 0.0 | 0.0 | 1.0 | 0.0 |
| *Brule | 0.0 | 0.1 | 0.0 | 1.4 | 14.7 | 27.2 | 19.0 | 0.7 | 16.9 | 0.0 | 0.0 | 0.3 | 0.0 | 10.3 | 9.5 |
| Caribou | 0.0 | 0.0 | 0.0 | 0.8 | 51.8 | 8.3 | 9.0 | 0.3 | 20.1 | 0.0 | 0.0 | 1.1 | 0.0 | 8.4 | 0.2 |
| Caribou[1] | 0.0 | 0.0 | 0.0 | 2.6 | 25.7 | 26.4 | 16.8 | 0.0 | 11.8 | 0.0 | 0.0 | 0.3 | 0.0 | 2.2 | 14.1 |
| Cascade | 0.0 | 0.0 | 0.0 | 1.2 | 14.7 | 31.9 | 18.1 | 0.5 | 24.8 | 0.0 | 0.0 | 0.3 | 0.0 | 4.1 | 4.5 |
| Cascade[1] | 0.0 | 0.0 | 0.0 | 0.7 | 6.9 | 41.4 | 12.3 | 1.2 | 24.9 | 0.0 | 0.0 | 0.0 | 0.0 | 12.7 | 0.0 |
| *Chester | 1.1 | 12.0 | 3.9 | 19.3 | 29.8 | 1.6 | 2.3 | 4.9 | 12.8 | 0.0 | 0.1 | 0.2 | 0.8 | 10.7 | 0.4 |
| Cross | 0.0 | 0.1 | 0.0 | 1.7 | 20.4 | 12.2 | 23.7 | 0.2 | 23.8 | 0.0 | 0.0 | 0.9 | 0.0 | 6.4 | 10.5 |
| East Beaver | 0.1 | 0.3 | 0.1 | 1.5 | 24.2 | 11.1 | 17.1 | 0.6 | 27.0 | 2.6 | 0.1 | 3.4 | 0.0 | 7.0 | 5.0 |
| East Split Rock | 0.0 | 0.0 | 0.0 | 0.4 | 21.3 | 9.8 | 20.5 | 1.0 | 38.7 | 0.0 | 0.0 | 1.4 | 0.0 | 6.4 | 0.6 |
| Encampment | 0.0 | 0.2 | 0.1 | 2.3 | 20.2 | 18.3 | 20.0 | 1.6 | 20.8 | 0.0 | 0.3 | 1.0 | 1.9 | 13.2 | 0.2 |
| Encampment[1] | 0.0 | 0.3 | 0.1 | 2.1 | 26.7 | 2.7 | 16.9 | 2.1 | 34.3 | 0.0 | 0.2 | 1.6 | 0.2 | 12.5 | 0.3 |
| Flute Reed | 0.0 | 0.3 | 0.0 | 2.1 | 40.9 | 20.1 | 22.4 | 0.7 | 6.1 | 0.0 | 0.0 | 0.0 | 0.0 | 6.7 | 0.8 |
| Flute Reed[1] | 0.0 | 0.1 | 0.0 | 2.0 | 39.4 | 22.9 | 22.2 | 0.9 | 7.4 | 0.0 | 0.0 | 0.0 | 0.0 | 4.2 | 0.8 |
| Flute Reed[2] | 0.0 | 0.1 | 0.0 | 1.9 | 41.2 | 22.0 | 21.4 | 1.0 | 7.4 | 0.0 | 0.0 | 0.0 | 0.0 | 4.2 | 0.9 |
| Flute Reed[3] | 0.0 | 0.1 | 0.0 | 2.0 | 34.2 | 25.5 | 22.4 | 1.5 | 10.1 | 0.0 | 0.0 | 0.0 | 0.0 | 3.0 | 1.3 |
| *Flute Reed[4] | 0.0 | 0.0 | 0.0 | 1.9 | 33.8 | 25.4 | 21.6 | 1.7 | 11.0 | 0.0 | 0.0 | 0.0 | 0.0 | 3.2 | 1.5 |
| *French | 0.1 | 0.2 | 0.0 | 2.7 | 22.1 | 12.0 | 18.0 | 2.7 | 23.5 | 0.0 | 0.0 | 0.3 | 2.7 | 15.4 | 0.5 |
| Gooseberry | 0.0 | 0.1 | 0.0 | 1.4 | 35.0 | 4.3 | 16.0 | 1.1 | 27.7 | 0.0 | 0.1 | 0.6 | 0.1 | 12.6 | 0.9 |

| | 2006 NLCD | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Development Classes | | | | Forest Classes | | | Wetland Classes | | | | | | | |
| Stream name | % High | % Low | % Medium | % Open | % Decid. | % Conifer | % Mixed | % Emergent | % Woody | % Barren | % Crop | % Grass | % Pasture | % Shrub | % Water |
| Keene | 0.3 | 9.2 | 2.3 | 16.4 | 45.1 | 1.0 | 1.7 | 4.7 | 12.7 | 0.1 | 0.0 | 0.4 | 1.6 | 4.5 | 0.1 |
| *Kingsbury | 1.0 | 9.6 | 3.1 | 13.3 | 30.6 | 2.7 | 2.5 | 4.2 | 24.1 | 0.4 | 0.0 | 0.0 | 4.0 | 4.3 | 0.3 |
| Knife | 0.0 | 0.1 | 0.0 | 2.8 | 22.2 | 12.3 | 23.7 | 1.1 | 19.7 | 0.1 | 0.3 | 0.5 | 3.3 | 13.6 | 0.3 |
| *Knife[1] | 0.0 | 0.0 | 0.0 | 1.8 | 27.7 | 5.9 | 27.6 | 1.3 | 17.0 | 0.2 | 0.2 | 0.9 | 0.4 | 16.8 | 0.2 |
| Knife[2] | 0.0 | 0.0 | 0.0 | 2.3 | 22.6 | 8.5 | 31.9 | 0.7 | 13.6 | 0.1 | 0.0 | 0.9 | 0.1 | 19.1 | 0.2 |
| Knife[3] | 0.1 | 0.8 | 0.0 | 6.5 | 19.7 | 12.8 | 17.9 | 1.7 | 16.7 | 0.4 | 0.7 | 0.9 | 5.5 | 16.2 | 0.2 |
| Lester | 0.0 | 0.9 | 0.1 | 5.1 | 25.2 | 9.3 | 11.9 | 2.4 | 20.4 | 0.1 | 0.4 | 0.2 | 6.3 | 16.6 | 1.1 |
| Lester[1] | 0.0 | 0.2 | 0.0 | 3.5 | 14.1 | 11.2 | 14.3 | 3.2 | 34.7 | 0.2 | 0.3 | 0.2 | 6.2 | 9.6 | 2.2 |
| Little Knife | 0.0 | 0.0 | 0.0 | 2.9 | 12.8 | 18.9 | 23.4 | 0.8 | 21.6 | 0.2 | 0.6 | 0.4 | 4.3 | 13.7 | 0.4 |
| McCarthy | 0.0 | 0.0 | 0.0 | 1.2 | 29.2 | 2.8 | 24.3 | 2.5 | 22.3 | 0.0 | 0.0 | 0.7 | 1.1 | 15.6 | 0.3 |
| *Miller | 6.6 | 14.4 | 10.9 | 22.0 | 23.6 | 0.7 | 0.9 | 4.5 | 11.2 | 0.0 | 0.1 | 0.3 | 0.7 | 4.0 | 0.2 |
| *Miller[1] | 6.9 | 13.1 | 10.7 | 21.2 | 24.5 | 0.7 | 1.0 | 4.7 | 11.8 | 0.0 | 0.1 | 0.3 | 0.7 | 4.2 | 0.2 |
| Miller[2] | 7.3 | 11.9 | 11.2 | 19.1 | 25.1 | 0.8 | 0.9 | 5.1 | 12.8 | 0.0 | 0.1 | 0.3 | 0.7 | 4.6 | 0.2 |
| Miller[3] | 8.8 | 10.5 | 11.4 | 18.2 | 22.6 | 0.7 | 0.7 | 5.8 | 14.3 | 0.0 | 0.1 | 0.4 | 0.9 | 5.3 | 0.2 |
| Mission | 0.3 | 2.1 | 0.9 | 8.2 | 43.2 | 4.3 | 7.3 | 1.9 | 9.5 | 0.0 | 0.4 | 0.4 | 9.8 | 11.6 | 0.1 |
| Onion | 0.0 | 0.0 | 0.0 | 1.1 | 57.6 | 7.2 | 12.7 | 0.0 | 18.6 | 0.0 | 0.0 | 0.0 | 0.0 | 2.6 | 0.2 |
| Palisade | 0.0 | 0.1 | 0.0 | 1.0 | 65.2 | 5.7 | 11.9 | 0.0 | 7.6 | 0.0 | 0.0 | 0.1 | 0.0 | 6.6 | 1.8 |
| Poplar | 0.0 | 0.0 | 0.0 | 2.0 | 22.8 | 19.1 | 19.9 | 0.1 | 23.9 | 0.0 | 0.0 | 0.3 | 0.0 | 4.5 | 7.3 |
| *Poplar[1] | 0.0 | 0.0 | 0.0 | 1.9 | 22.8 | 19.1 | 20.0 | 0.1 | 24.0 | 0.0 | 0.0 | 0.3 | 0.0 | 4.5 | 7.3 |
| Poplar[2] | 0.0 | 0.0 | 0.0 | 1.8 | 22.5 | 19.1 | 20.1 | 0.1 | 24.2 | 0.0 | 0.0 | 0.2 | 0.0 | 4.4 | 7.4 |
| Poplar[3] | 0.0 | 0.2 | 1.3 | 0.0 | 38.5 | 22.9 | 9.6 | 1.3 | 17.3 | 0.0 | 0.0 | 0.5 | 0.0 | 7.8 | 0.5 |
| Sawbill | 0.0 | 0.0 | 0.0 | 0.2 | 19.7 | 31.7 | 15.0 | 0.1 | 15.5 | 0.0 | 0.0 | 0.1 | 0.0 | 1.3 | 16.5 |
| Skunk | 0.0 | 0.0 | 0.0 | 0.6 | 34.0 | 10.4 | 11.3 | 0.6 | 21.4 | 0.0 | 0.0 | 0.1 | 0.2 | 21.3 | 0.1 |
| Split Rock | 0.0 | 0.0 | 0.0 | 0.8 | 26.9 | 10.1 | 18.3 | 1.4 | 30.6 | 0.0 | 0.0 | 1.1 | 1.2 | 9.3 | 0.5 |
| Stanley | 0.0 | 0.0 | 0.0 | 2.7 | 16.9 | 17.7 | 29.3 | 0.7 | 14.4 | 0.0 | 0.0 | 0.1 | 4.2 | 13.6 | 0.4 |
| Sucker | 0.0 | 0.0 | 0.0 | 1.9 | 18.2 | 13.3 | 25.4 | 1.1 | 26.9 | 0.0 | 0.1 | 0.7 | 1.1 | 10.6 | 0.8 |
| *Sucker[1] | 0.0 | 0.0 | 0.0 | 1.8 | 18.4 | 12.8 | 25.6 | 1.1 | 27.3 | 0.0 | 0.1 | 0.7 | 1.1 | 10.3 | 0.8 |
| Sugarloaf | 0.0 | 0.8 | 0.0 | 2.0 | 46.9 | 6.0 | 2.0 | 0.0 | 12.2 | 0.0 | 0.6 | 0.0 | 0.0 | 9.7 | 1.5 |
| *Talmadge | 0.0 | 0.1 | 0.0 | 4.7 | 17.3 | 15.0 | 20.6 | 1.6 | 17.8 | 0.0 | 0.0 | 0.5 | 3.4 | 18.9 | 0.2 |

| | 2006 NLCD | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Development Classes | | | | Forest Classes | | | Wetland Classes | | | | | | | |
| Stream name | % High | % Low | % Medium | % Open | % Decid. | % Conifer | % Mixed | % Emergent | % Woody | % Barren | % Crop | % Grass | % Pasture | % Shrub | % Water |
| Temperance | 0.0 | 0.0 | 0.0 | 1.2 | 16.1 | 24.8 | 19.3 | 0.8 | 22.6 | 0.0 | 0.0 | 1.1 | 0.0 | 4.1 | 9.9 |
| *Tischer | 0.8 | 12.7 | 1.8 | 28.3 | 31.8 | 2.8 | 3.5 | 3.8 | 7.0 | 0.0 | 0.0 | 1.1 | 0.2 | 5.7 | 0.4 |
| Tischer[1] | 0.6 | 13.3 | 1.5 | 28.7 | 32.1 | 2.0 | 2.3 | 3.5 | 8.0 | 0.0 | 0.0 | 1.5 | 0.1 | 6.0 | 0.3 |
| Two Island | 0.0 | 0.1 | 0.0 | 2.0 | 43.9 | 9.1 | 13.3 | 0.1 | 25.6 | 0.0 | 0.1 | 0.1 | 0.0 | 4.4 | 1.3 |
| West Branch Knife | 0.0 | 0.0 | 0.0 | 1.6 | 25.9 | 6.6 | 26.5 | 1.8 | 23.7 | 0.1 | 0.1 | 1.0 | 0.7 | 11.7 | 0.3 |

**Appendix J: Local Sediment SumRel components for each watershed. See METHODS for description of SumRel and its components (Brown et al., 2011).**

| | Local *Sediment SumRel* Components | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Stream name | Bank slope | Bank KFFACT | Bank sediment erosion potential | Stream slope | Stream KFFACT | Stream sediment erosion potential | People/km$^2$ | Road-stream crossings | % Impervious | % Wetland | % Canopy |
| *Amity | 10.8 | 0.27 | 0.48 | 1.20 | 0.27 | 0.47 | 596 | 5 | 1.1 | 1.00 | 22.3 |
| Amity East | 7.2 | 0.27 | 0.31 | 0.62 | 0.27 | 0.50 | 66 | 0 | 0.0 | 0.99 | 24.7 |
| Amity[1] | 7.2 | 0.27 | 0.25 | 1.22 | 0.27 | 0.46 | 99 | 2 | 0.4 | 1.00 | 34.4 |
| Baptism | 7.3 | 0.07 | 0.50 | 1.17 | 0.07 | 0.50 | 2 | 1 | 1.8 | 1.03 | 18.7 |
| Beaver | 16.6 | 0.20 | 0.30 | 1.21 | 0.16 | 0.50 | 13 | 2 | 15.3 | 1.00 | 43.1 |
| Beaver[1] | 9.3 | 0.27 | 0.50 | 0.07 | 0.27 | 0.50 | 8 | 1 | 9.1 | 0.95 | 27.1 |
| *Beaver[2] | 11.4 | 0.22 | 0.50 | 0.39 | 0.21 | 0.50 | 10 | 0 | 1.4 | 0.97 | 20.4 |
| Beaver[3] | 0.8 | 0.27 | 0.50 | 0.22 | 0.27 | 0.50 | 4 | 1 | 1.5 | 0.86 | 21.1 |
| Blind Temperance | 4.8 | 0.24 | 0.50 | 0.81 | 0.24 | 0.50 | 1 | 1 | 0.1 | 1.02 | 12.0 |
| *Brule | 20.6 | 0.16 | 0.50 | 0.69 | 0.16 | 0.50 | 1 | 1 | 0.6 | 0.97 | 11.1 |
| Caribou | 12.8 | 0.23 | 0.27 | 3.76 | 0.24 | 0.32 | 1 | 1 | 1.4 | 0.98 | 15.8 |
| Caribou[1] | 9.4 | 0.22 | 0.44 | 0.61 | 0.22 | 0.61 | 1 | 1 | 0.3 | 0.95 | 19.9 |
| Cascade | 16.0 | 0.16 | 0.41 | 2.19 | 0.16 | 0.40 | 5 | 1 | 0.2 | 0.97 | 14.2 |
| Cascade[1] | 7.6 | 0.11 | 0.50 | 0.52 | 0.11 | 0.50 | 1 | 1 | 0.1 | 0.97 | 18.7 |
| *Chester | 14.4 | 0.24 | 0.16 | 2.10 | 0.24 | 0.19 | 1354 | 15 | 26.7 | 1.02 | 56.8 |
| Cross | 2.6 | 0.24 | 0.00 | 0.09 | 0.24 | 0.00 | 1 | 1 | 0.1 | 0.83 | 19.0 |
| East Beaver | 10.0 | 0.18 | 0.30 | 0.26 | 0.18 | 0.32 | 11 | 1 | 1.4 | 0.99 | 17.8 |
| East Split Rock | 5.1 | 0.27 | 0.50 | 0.69 | 0.27 | 0.50 | 2 | 1 | 0.4 | 0.96 | 20.4 |
| Encampment | 12.7 | 0.26 | 0.47 | 1.61 | 0.26 | 0.50 | 10 | 1 | 0.3 | 1.01 | 18.8 |
| Encampment[1] | 4.6 | 0.07 | 0.50 | 0.62 | 0.08 | 0.50 | 1 | 0 | 0.4 | 0.96 | 19.9 |
| Flute Reed | 4.7 | 0.18 | 0.00 | 1.77 | 0.11 | 0.00 | 1 | 2 | 6.2 | 0.94 | 20.8 |
| Flute Reed[1] | 7.2 | 0.25 | 0.48 | 0.65 | 0.25 | 0.48 | 1 | 2 | 0.5 | 0.97 | 10.2 |
| Flute Reed[2] | 7.7 | 0.27 | 0.50 | 0.85 | 0.27 | 0.50 | 1 | 0 | 0.0 | 0.86 | 11.1 |
| Flute Reed[3] | 6.8 | 0.27 | 0.50 | 0.66 | 0.27 | 0.50 | 1 | 1 | 0.3 | 0.97 | 10.7 |
| *Flute Reed[4] | 7.5 | 0.22 | 0.46 | 0.92 | 0.22 | 0.48 | 1 | 1 | 0.5 | 0.98 | 9.7 |

| Stream name | Local *Sediment SumRel* Components | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Bank slope | Bank KFFACT | Bank sediment erosion potential | Stream slope | Stream KFFACT | Stream sediment erosion potential | People/km$^2$ | Road-stream crossings | % Impervious | % Wetland | % Canopy |
| *French | 8.0 | 0.27 | 0.50 | 1.25 | 0.27 | 0.50 | 29 | 5 | 1.0 | 0.98 | 31.9 |
| Gooseberry | 11.6 | 0.27 | 0.49 | 1.10 | 0.27 | 0.50 | 1 | 1 | 1.3 | 0.96 | 25.2 |
| Keene | 3.6 | 0.21 | 0.38 | 0.87 | 0.21 | 0.39 | 800 | 15 | 32.6 | 0.98 | 76.3 |
| *Kingsbury | 10.2 | 0.25 | 0.18 | 3.37 | 0.25 | 0.20 | 384 | 6 | 11.8 | 0.99 | 45.4 |
| Knife | 4.5 | 0.25 | 0.50 | 0.58 | 0.27 | 0.50 | 15 | 5 | 6.9 | 0.95 | 40.6 |
| *Knife[1] | 4.0 | 0.27 | 0.50 | 0.54 | 0.27 | 0.50 | 15 | 1 | 0.0 | 0.73 | 19.2 |
| Knife[2] | 4.6 | 0.17 | 0.50 | 0.32 | 0.17 | 0.50 | 1 | 0 | 0.0 | 0.93 | 18.7 |
| Knife[3] | 1.9 | 0.27 | 0.50 | 0.31 | 0.27 | 0.50 | 7 | 2 | 1.3 | 0.97 | 58.9 |
| Lester | 5.6 | 0.27 | 0.50 | 1.97 | 0.27 | 0.50 | 723 | 1 | 29.9 | 0.88 | 71.7 |
| Lester[1] | 6.9 | 0.25 | 0.83 | 0.62 | 0.25 | 1.00 | 44 | 1 | 1.2 | 0.95 | 27.4 |
| Little Knife | 4.8 | 0.27 | 0.50 | 0.89 | 0.27 | 0.50 | 11 | 1 | 0.3 | 0.85 | 25.7 |
| McCarthy | 2.9 | 0.10 | 0.50 | 0.85 | 0.10 | 0.50 | 9 | 0 | 0.0 | 0.80 | 19.4 |
| *Miller | 8.3 | 0.20 | 0.36 | 1.75 | 0.21 | 0.39 | 1839 | 14 | 54.5 | 1.04 | 84.1 |
| *Miller[1] | 14.4 | 0.25 | 0.00 | 1.47 | 0.25 | 0.00 | 544 | 3 | 16.5 | 1.01 | 53.8 |
| Miller[2] | 6.3 | 0.25 | 0.13 | 0.54 | 0.25 | 0.12 | 332 | 5 | 6.6 | 1.00 | 36.7 |
| Miller[3] | 2.7 | 0.25 | 0.44 | 0.66 | 0.25 | 0.50 | 296 | 9 | 22.3 | 0.91 | 70.4 |
| Mission | 13.8 | 0.27 | 0.32 | 0.64 | 0.27 | 0.43 | 84 | 3 | 1.5 | 1.03 | 23.5 |
| Onion | 9.4 | 0.22 | 0.26 | 2.57 | 0.22 | 0.27 | 1 | 1 | 0.5 | 1.01 | 16.7 |
| Palisade | 13.6 | 0.27 | 0.36 | 1.30 | 0.27 | 0.50 | 13 | 1 | 2.3 | 1.00 | 24.8 |
| Poplar | 16.1 | 0.17 | 0.50 | 2.27 | 0.17 | 0.50 | 1 | 1 | 9.8 | 0.94 | 51.8 |
| *Poplar[1] | 15.9 | 0.17 | 0.50 | 1.45 | 0.17 | 0.50 | 1 | 0 | 4.8 | 1.01 | 45.4 |
| Poplar[2] | 24.6 | 0.18 | 0.23 | 1.81 | 0.19 | 0.29 | 1 | 1 | 0.7 | 1.01 | 20.7 |
| Poplar[3] | 15.3 | 0.16 | 0.07 | 5.05 | 0.16 | 0.10 | 1 | 1 | 0.9 | 0.96 | 27.1 |
| Sawbill | 1.8 | 0.15 | 0.36 | 0.38 | 0.15 | 0.32 | 1 | 2 | 0.1 | 0.76 | 30.7 |
| Skunk | 3.3 | 0.24 | 0.50 | 0.59 | 0.25 | 0.50 | 1 | 1 | 0.2 | 0.85 | 17.5 |
| Split Rock | 12.2 | 0.24 | 0.54 | 0.38 | 0.24 | 0.83 | 11 | 1 | 0.8 | 0.97 | 20.0 |
| Stanley | 6.7 | 0.27 | 0.50 | 0.57 | 0.27 | 0.50 | 13 | 0 | 0.0 | 0.91 | 20.8 |

| Stream name | Local *Sediment SumRel* Components | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Bank slope | Bank KFFACT | Bank sediment erosion potential | Stream slope | Stream KFFACT | Stream sediment erosion potential | People/km$^2$ | Road-stream crossings | % Impervious | % Wetland | % Canopy |
| Sucker | 12.1 | 0.27 | 0.50 | 1.26 | 0.24 | 0.50 | 11 | 1 | 1.8 | 1.00 | 30.6 |
| *Sucker[1] | 10.4 | 0.27 | 0.50 | 1.51 | 0.27 | 0.50 | 11 | 3 | 0.7 | 0.97 | 24.4 |
| Sugarloaf | 6.2 | 0.17 | 0.15 | 3.04 | 0.19 | 0.25 | 1 | 8 | 0.9 | 1.01 | 16.6 |
| *Talmadge | 8.2 | 0.27 | 0.49 | 1.24 | 0.27 | 0.50 | 30 | 1 | 0.4 | 0.97 | 23.4 |
| Temperance | 3.0 | 0.15 | 0.50 | 0.46 | 0.16 | 0.50 | 1 | 1 | 0.4 | 0.89 | 22.4 |
| *Tischer | 6.9 | 0.25 | 0.35 | 2.89 | 0.25 | 0.37 | 1174 | 7 | 25.2 | 0.95 | 50.0 |
| Tischer[1] | 4.9 | 0.25 | 0.00 | 0.64 | 0.25 | 0.00 | 679 | 11 | 17.3 | 1.03 | 51.1 |
| Two Island | 7.4 | 0.20 | 0.34 | 0.48 | 0.20 | 0.40 | 1 | 1 | 0.4 | 0.99 | 13.4 |
| West Branch Knife | 5.4 | 0.27 | 0.50 | 0.77 | 0.27 | 0.50 | 8 | 1 | 0.3 | 0.94 | 17.7 |

**Appendix K: Accumulated Sediment SumRel components for each watershed. See METHODS for description of SumRel and its components (Brown et al., 2011).**

| Stream name | Accumulated *Sediment SumRel* Components | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Bank slope | Bank KFFACT | Bank sediment erosion potential | Stream slope | Stream KFFACT | Stream sediment erosion potential | People/km$^2$ | Road-stream crossings | % Impervious | % Wetland | % Canopy | NPDES density |
| *Amity | 160.7 | 11.12 | 19.74 | 32.00 | 11.64 | 21.37 | 95 | 48 | 1.5 | 10.3 | 68.0 | 44 |
| Amity East | 41.1 | 2.84 | 4.14 | 6.18 | 2.84 | 4.44 | 125 | 13 | 1.9 | 10.9 | 65.6 | 10 |
| Amity[1] | 99.3 | 8.97 | 15.76 | 19.81 | 9.48 | 17.40 | 82 | 37 | 1.5 | 11.5 | 67.3 | 36 |
| Baptism | 999.5 | 71.22 | 138.50 | 192.71 | 71.61 | 143.07 | 1 | 111 | 0.2 | 32.3 | 79.5 | 340 |
| Beaver | 988.3 | 72.69 | 141.39 | 188.93 | 73.66 | 144.59 | 2 | 69 | 0.3 | 27.8 | 76.8 | 326 |
| Beaver[1] | 434.4 | 40.18 | 81.85 | 88.90 | 40.42 | 82.60 | 2 | 27 | 0.2 | 28.1 | 79.3 | 166 |
| *Beaver[2] | 413.2 | 39.08 | 79.85 | 82.09 | 39.32 | 80.60 | 2 | 24 | 0.2 | 28.4 | 79.3 | 162 |
| Beaver[3] | 328.9 | 33.50 | 68.91 | 67.43 | 33.77 | 69.72 | 1 | 17 | 0.1 | 30.7 | 80.6 | 140 |
| Blind Temperance | 32.2 | 3.30 | 6.50 | 9.11 | 3.29 | 6.50 | 1 | 2 | 0.1 | 10.4 | 87.0 | 12 |
| *Brule | 3246.0 | 120.52 | 56.46 | 474.55 | 120.50 | 57.98 | 1 | 140 | 0.1 | 23.4 | 72.4 | 695 |
| Caribou | 268.5 | 10.88 | 0.27 | 38.65 | 10.89 | 0.32 | 1 | 10 | 0.1 | 16.2 | 83.4 | 54 |
| Caribou[1] | 80.6 | 8.35 | 14.33 | 20.12 | 8.36 | 14.80 | 1 | 6 | 0.2 | 24.5 | 73.3 | 32 |
| Cascade | 1184.5 | 52.32 | 113.40 | 172.02 | 52.27 | 113.90 | 2 | 52 | 0.1 | 24.9 | 78.5 | 279 |
| Cascade[1] | 36.1 | 1.02 | 4.50 | 6.26 | 1.02 | 4.50 | 1 | 2 | 0.0 | 19.6 | 81.1 | 8 |
| *Chester | 43.6 | 2.77 | 3.06 | 7.43 | 2.77 | 3.17 | 338 | 31 | 9.1 | 13.4 | 61.1 | 10 |
| Cross | 431.7 | 29.66 | 37.01 | 59.45 | 29.63 | 37.49 | 0 | 26 | 0.1 | 31.0 | 76.4 | 166 |
| East Beaver | 428.8 | 28.58 | 54.76 | 78.50 | 29.37 | 56.77 | 3 | 36 | 0.2 | 29.2 | 73.8 | 142 |
| East Split Rock | 63.4 | 6.93 | 14.50 | 15.72 | 6.88 | 14.50 | 1 | 5 | 0.0 | 34.6 | 80.3 | 28 |
| Encampment | 120.6 | 8.67 | 19.58 | 25.84 | 8.66 | 19.79 | 5 | 28 | 0.3 | 19.9 | 75.9 | 40 |
| Encampment[1] | 36.0 | 4.37 | 10.44 | 8.26 | 4.37 | 10.50 | 1 | 11 | 0.2 | 30.2 | 77.4 | 20 |
| Flute Reed | 226.0 | 9.49 | 14.22 | 43.00 | 9.43 | 14.88 | 1 | 19 | 0.3 | 9.3 | 87.9 | 40 |
| Flute Reed[1] | 184.7 | 7.00 | 10.61 | 29.15 | 7.04 | 11.23 | 1 | 12 | 0.2 | 11.5 | 88.1 | 30 |
| Flute Reed[2] | 173.3 | 6.48 | 9.64 | 27.05 | 6.51 | 10.25 | 1 | 10 | 0.2 | 11.4 | 88.0 | 28 |
| Flute Reed[3] | 134.1 | 4.33 | 5.81 | 16.46 | 4.37 | 6.42 | 1 | 9 | 0.2 | 13.4 | 88.1 | 20 |
| *Flute Reed[4] | 110.3 | 3.26 | 3.83 | 12.77 | 3.29 | 4.42 | 1 | 6 | 0.1 | 15.1 | 87.5 | 16 |

| Stream name | Accumulated *Sediment SumRel* Components | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Bank slope | Bank KFFACT | Bank sediment erosion potential | Stream slope | Stream KFFACT | Stream sediment erosion potential | People/km$^2$ | Road-stream crossings | % Impervious | % Wetland | % Canopy | NPDES density |
| *French | 134.7 | 9.83 | 25.70 | 25.03 | 9.78 | 26.09 | 8 | 32 | 0.4 | 25.2 | 77.0 | 54 |
| Gooseberry | 515.1 | 46.35 | 92.08 | 109.55 | 46.75 | 93.02 | 1 | 29 | 0.1 | 24.4 | 79.4 | 196 |
| Keene | 99.4 | 4.75 | 2.74 | 23.83 | 4.74 | 2.28 | 244 | 42 | 6.6 | 13.3 | 63.0 | 18 |
| *Kingsbury | 75.3 | 6.35 | 8.67 | 12.46 | 6.35 | 9.29 | 171 | 40 | 7.0 | 22.2 | 58.1 | 24 |
| Knife | 662.0 | 47.24 | 108.41 | 128.23 | 47.43 | 109.29 | 8 | 88 | 0.3 | 19.1 | 74.9 | 218 |
| *Knife[1] | 115.8 | 5.26 | 14.78 | 22.86 | 5.37 | 15.34 | 3 | 15 | 0.1 | 18.4 | 82.1 | 30 |
| Knife[2] | 66.3 | 2.74 | 7.44 | 11.07 | 2.76 | 7.43 | 1 | 11 | 0.2 | 14.5 | 82.8 | 14 |
| Knife[3] | 29.4 | 4.09 | 7.50 | 7.49 | 4.09 | 7.50 | 7 | 6 | 0.8 | 13.8 | 62.3 | 14 |
| Lester | 455.8 | 37.12 | 65.79 | 86.77 | 37.65 | 66.73 | 50 | 98 | 0.9 | 18.9 | 70.7 | 150 |
| Lester[1] | 86.3 | 11.69 | 24.25 | 16.09 | 11.68 | 24.19 | 24 | 24 | 0.4 | 31.0 | 71.1 | 50 |
| Little Knife | 67.9 | 4.45 | 11.50 | 13.05 | 4.46 | 11.50 | 11 | 10 | 0.4 | 19.5 | 72.1 | 22 |
| McCarthy | 26.1 | 1.37 | 4.85 | 8.83 | 1.45 | 5.41 | 2 | 3 | 0.1 | 24.4 | 81.8 | 10 |
| *Miller | 113.8 | 6.73 | 9.45 | 22.30 | 6.74 | 9.65 | 296 | 76 | 17.2 | 13.1 | 43.4 | 26 |
| *Miller[1] | 71.8 | 5.77 | 9.09 | 8.97 | 5.77 | 9.26 | 217 | 54 | 15.3 | 14.1 | 45.2 | 22 |
| Miller[2] | 50.7 | 5.26 | 9.09 | 6.66 | 5.26 | 9.26 | 175 | 49 | 15.1 | 14.9 | 45.4 | 20 |
| Miller[3] | 26.2 | 4.24 | 8.44 | 5.12 | 4.24 | 8.50 | 136 | 37 | 16.9 | 16.6 | 42.8 | 16 |
| Mission | 310.3 | 5.08 | 6.17 | 36.23 | 5.10 | 6.00 | 49 | 65 | 2.1 | 9.0 | 65.7 | 28 |
| Onion | 89.9 | 6.50 | 0.26 | 21.43 | 6.50 | 0.27 | 1 | 3 | 0.1 | 16.8 | 82.8 | 24 |
| Palisade | 112.4 | 3.82 | 6.61 | 21.45 | 3.87 | 6.88 | 14 | 1 | 0.2 | 9.5 | 78.5 | 14 |
| Poplar | 699.9 | 60.68 | 140.38 | 147.09 | 60.71 | 142.79 | 1 | 50 | 0.1 | 27.4 | 77.9 | 282 |
| *Poplar[1] | 679.5 | 60.34 | 139.38 | 141.93 | 60.36 | 141.79 | 1 | 49 | 0.1 | 27.5 | 77.9 | 280 |
| Poplar[2] | 617.4 | 59.67 | 137.81 | 130.91 | 59.70 | 140.19 | 1 | 48 | 0.1 | 27.8 | 78.1 | 276 |
| Poplar[3] | 15.3 | 0.16 | 0.07 | 5.05 | 0.16 | 0.10 | 1 | 1 | 0.9 | 12.2 | 71.8 | 0 |
| Sawbill | 161.3 | 10.33 | 2.38 | 18.95 | 10.34 | 2.39 | 1 | 2 | 0.0 | 28.0 | 70.9 | 56 |
| Skunk | 23.4 | 2.68 | 5.50 | 7.82 | 2.69 | 5.50 | 1 | 1 | 0.0 | 13.9 | 79.4 | 10 |
| Split Rock | 323.3 | 24.85 | 48.35 | 59.88 | 25.12 | 49.34 | 2 | 17 | 0.0 | 27.4 | 79.5 | 98 |
| Stanley | 42.7 | 2.22 | 6.50 | 8.13 | 2.24 | 6.50 | 11 | 6 | 0.3 | 14.0 | 75.1 | 12 |

| Stream name | Accumulated *Sediment SumRel* Components | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Bank slope | Bank KFFACT | Bank sediment erosion potential | Stream slope | Stream KFFACT | Stream sediment erosion potential | People/km$^2$ | Road-stream crossings | % Impervious | % Wetland | % Canopy | NPDES density |
| Sucker | 255.9 | 22.18 | 52.51 | 51.61 | 22.07 | 52.35 | 4 | 37 | 0.2 | 26.2 | 79.1 | 102 |
| *Sucker[1] | 228.9 | 21.08 | 50.51 | 46.96 | 21.01 | 50.35 | 4 | 32 | 0.1 | 26.7 | 79.3 | 98 |
| Sugarloaf | 12.0 | 0.51 | 0.15 | 4.64 | 0.53 | 0.25 | 1 | 12 | 0.6 | 18.7 | 78.5 | 2 |
| *Talmadge | 38.6 | 3.76 | 7.27 | 9.91 | 3.75 | 7.31 | 28 | 16 | 0.6 | 15.0 | 73.3 | 14 |
| Temperance | 343.4 | 19.01 | 4.27 | 46.68 | 19.21 | 4.25 | 1 | 2 | 0.0 | 22.9 | 73.2 | 103 |
| *Tischer | 53.4 | 3.82 | 3.53 | 12.67 | 3.81 | 3.57 | 414 | 58 | 9.6 | 8.3 | 58.5 | 14 |
| Tischer[1] | 42.3 | 3.31 | 3.18 | 9.07 | 3.31 | 3.21 | 329 | 46 | 9.6 | 8.2 | 56.5 | 12 |
| Two Island | 124.6 | 5.78 | 0.34 | 16.83 | 5.73 | 0.40 | 1 | 9 | 0.1 | 23.3 | 83.6 | 28 |
| West Branch Knife | 84.3 | 7.14 | 17.33 | 17.93 | 7.06 | 17.47 | 3 | 12 | 0.1 | 23.3 | 80.9 | 34 |

**Appendix L: Mean K factor for St. Louis County streams, calculated using SSURGO dataset. These streams are also located within Duluth, MN city limits except for the Sucker, French, and Talmadge rivers which are 7.4 km, 3.1 km, and 0.7 km past Duluth city limits, respectively.**

| Stream name | Watershed ID | K factor (mean) |
|---|---|---|
| *Amity | 31036466 | 0.31 |
| Amity[1] | 31036326 | 0.23 |
| *Chester | 31036987 | 0.23 |
| *French | 31035723 | 0.21 |
| Keene | 36000247 | 0.21 |
| *Kingsbury | 31037901 | 0.18 |
| Lester | 31036559 | 0.24 |
| Lester[1] | 31035556 | 0.16 |
| *Miller | 31037433 | 0.24 |
| *Miller[1] | 31037257 | 0.23 |
| Miller[2] | 31037116 | 0.23 |
| Miller[3] | 31036923 | 0.19 |
| Mission | 31038874 | 0.29 |
| Sucker | 31035442 | 0.26 |
| *Sucker[1] | 31035415 | 0.20 |
| *Talmadge | 31035804 | 0.26 |
| *Tischer | 31036814 | 0.23 |
| Tischer[1] | 31036716 | 0.23 |

**Appendix M: Summary statistics for particulate-related water quality for each watershed during snowmelt.**

| | | TSS (mg/L) | | | | Turbidity (NTU) | | | | T-Tube ($cm^{-1}$) | | | | Total-P (mg/L) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Stream Name** | **Watershed ID** | **N** | **Median** | **Mean** | **Std Dev** | **N** | **Median** | **Mean** | **Std Dev** | **N** | **Median** | **Mean** | **Std Dev** | **N** | **Median** | **Mean** | **Std Dev** |
| Amity[1] | 31036326 | 2 | 14.67 | 14.67 | 4.48 | 2 | 13.28 | 13.28 | 1.59 | 0 | | | | 2 | 0.070 | 0.070 | 0.014 |
| *Amity | 31036466 | 66 | 21.00 | 35.86 | 59.77 | 75 | 18.00 | 28.12 | 42.77 | 60 | 43.5 | 47.4 | 25.6 | 56 | 0.080 | 0.097 | 0.076 |
| Amity East | 31036341 | 5 | 28.33 | 21.05 | 12.04 | 5 | 19.50 | 14.68 | 7.59 | 5 | 101.0 | 77.0 | 32.9 | 4 | 0.040 | 0.043 | 0.022 |
| Baptism | 22011810 | 11 | 6.80 | 9.33 | 8.85 | 11 | 3.60 | 5.83 | 4.99 | 11 | 60.0 | 68.5 | 20.3 | 11 | 0.020 | 0.026 | 0.014 |
| Beaver[1] | 22012232 | 9 | 11.00 | 18.87 | 23.49 | 9 | 22.70 | 34.30 | 46.32 | 8 | 78.5 | 66.8 | 34.2 | 9 | 0.030 | 0.036 | 0.021 |
| *Beaver[2] | 22012244 | 4 | 2.60 | 4.55 | 4.31 | 8 | 6.40 | 10.58 | 13.10 | 6 | 100.5 | 88.0 | 20.3 | 4 | 0.030 | 0.030 | 0.008 |
| Beaver[3] | 22012296 | 1 | 16.64 | 16.64 | | 1 | 9.14 | 9.14 | | 0 | | | | 1 | 0.020 | 0.020 | |
| Blind Temperance | 22009979 | 1 | 20.10 | 20.10 | | 1 | 18.00 | 18.00 | | 0 | | | | 1 | 0.050 | 0.050 | |
| *Brule | 22007634 | 40 | 6.80 | 9.07 | 10.08 | 47 | 6.45 | 8.89 | 12.01 | 40 | 71.5 | 74.2 | 23.9 | 41 | 0.030 | 0.034 | 0.018 |
| Caribou[1] | 22009302 | 1 | 2.00 | 2.00 | | 1 | 0.62 | 0.62 | | 0 | | | | 1 | 0.010 | 0.010 | |
| Caribou | 22011270 | 9 | 22.60 | 40.39 | 55.66 | 9 | 22.80 | 38.03 | 56.30 | 8 | 56.0 | 56.6 | 26.3 | 9 | 0.020 | 0.031 | 0.024 |
| Cascade[1] | 22007777 | 2 | 3.15 | 3.15 | 2.78 | 2 | 1.52 | 1.52 | 0.88 | 0 | | | | 2 | 0.010 | 0.010 | 0.000 |
| Cascade | 22009269 | 9 | 4.65 | 14.61 | 25.79 | 9 | 11.90 | 23.52 | 35.88 | 8 | 90.0 | 79.4 | 29.1 | 9 | 0.020 | 0.030 | 0.031 |
| *Chester | 31036987 | 41 | 11.00 | 14.97 | 14.87 | 49 | 7.80 | 17.84 | 29.20 | 35 | 85.0 | 71.3 | 32.0 | 43 | 0.060 | 0.082 | 0.090 |
| Cross | 22010227 | 2 | 2.22 | 2.22 | 0.14 | 2 | 1.53 | 1.53 | 0.11 | 0 | | | | 2 | 0.010 | 0.010 | 0.000 |
| East Beaver | 22012109 | 1 | 9.73 | 9.73 | | 1 | 14.20 | 14.20 | | 0 | | | | 1 | 0.050 | 0.050 | |
| East Split Rock | 22012354 | 0 | | | | 0 | | | | 0 | | | | 2 | 0.020 | 0.020 | 0.000 |
| Encampment[1] | 31032334 | 1 | 47.18 | 47.18 | | 1 | 22.40 | 22.40 | | 0 | | | | 1 | 0.130 | 0.130 | |
| Encampment | 31032914 | 4 | 7.75 | 21.16 | 29.75 | 4 | 20.45 | 28.80 | 22.55 | 4 | 48.5 | 53.3 | 35.6 | 4 | 0.035 | 0.050 | 0.041 |
| *Flute Reed | 22006835 | 0 | | | | 0 | | | | 3 | 79.0 | 80.3 | 5.1 | 0 | | | |
| Flute Reed[3] | 22007233 | 0 | | | | 0 | | | | 4 | 33.5 | 37.0 | 24.3 | 0 | | | |
| Flute Reed[2] | 22007237 | 0 | | | | 0 | | | | 3 | 16.0 | 15.7 | 9.5 | 0 | | | |
| Flute Reed | 22007315 | 6 | 36.50 | 56.83 | 60.69 | 0 | | | | 9 | 19.5 | 20.1 | 11.5 | 6 | 0.065 | 0.095 | 0.084 |
| *French | 31035723 | 42 | 21.00 | 28.93 | 28.13 | 42 | 14.00 | 17.61 | 11.92 | 29 | 40.0 | 45.0 | 24.4 | 41 | 0.060 | 0.067 | 0.031 |
| Gooseberry | 31032212 | 9 | 21.80 | 61.52 | 69.34 | 9 | 32.80 | 80.09 | 91.52 | 8 | 32.5 | 36.3 | 31.2 | 9 | 0.050 | 0.077 | 0.063 |
| Keene | 36000247 | 0 | | | | 2 | 4.50 | 4.50 | 3.82 | 2 | 96.5 | 96.5 | 6.4 | 2 | 0.024 | 0.024 | 0.011 |

| | | TSS (mg/L) | | | | Turbidity (NTU) | | | | T-Tube (cm$^{-1}$) | | | | Total-P (mg/L) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Stream Name** | **Watershed ID** | **N** | **Median** | **Mean** | **Std Dev** | **N** | **Median** | **Mean** | **Std Dev** | **N** | **Median** | **Mean** | **Std Dev** | **N** | **Median** | **Mean** | **Std Dev** |
| *Kingsbury | 31037901 | 41 | 15.00 | 28.08 | 34.54 | 49 | 19.30 | 27.08 | 28.95 | 35 | 50.0 | 53.8 | 32.1 | 41 | 0.060 | 0.085 | 0.094 |
| Knife[2] | 31033053 | 0 | | | | 0 | | | | 0 | | | | 1 | 0.010 | 0.010 | |
| *Knife[1] | 31033543 | 13 | 11.00 | 19.54 | 24.64 | 8 | 29.06 | 34.61 | 23.29 | 3 | 100.0 | 78.3 | 37.5 | 0 | | | |
| Knife[3] | 31033901 | 0 | | | | 1 | 25.57 | 25.57 | | 0 | | | | 0 | | | |
| Lester | 31035556 | 3 | 8.63 | 8.65 | 1.77 | 3 | 6.10 | 6.80 | 2.23 | 0 | | | | 3 | 0.060 | 0.053 | 0.021 |
| Little Knife | 31035071 | 7 | 4.00 | 6.14 | 3.72 | 0 | | | | 2 | 50.5 | 50.5 | 3.5 | 2 | 0.045 | 0.045 | 0.021 |
| McCarthy | 31033237 | 0 | | | | 0 | | | | 0 | | | | 2 | 0.010 | 0.010 | 0.000 |
| Miller[3] | 31036923 | 25 | 5.00 | 6.64 | 6.75 | 0 | | | | 1 | 101.0 | 101.0 | | 1 | 0.020 | 0.020 | |
| Miller[2] | 31037116 | 0 | | | | 0 | | | | 0 | | | | 1 | 0.025 | 0.025 | |
| *Miller[1] | 31037257 | 2 | 9.12 | 9.12 | 2.15 | 4 | 7.25 | 7.46 | 2.71 | 4 | 91.0 | 86.5 | 18.3 | 5 | 0.024 | 0.031 | 0.023 |
| *Miller | 31037433 | 29 | 10.00 | 26.38 | 61.29 | 4 | 15.70 | 47.78 | 72.02 | 4 | 98.9 | 77.7 | 43.9 | 5 | 0.050 | 0.086 | 0.090 |
| Onion | 22010143 | 2 | 4.94 | 4.94 | 0.86 | 2 | 8.04 | 8.04 | 0.69 | 0 | | | | 2 | 0.045 | 0.045 | 0.007 |
| Palisade | 22012011 | 1 | 13.18 | 13.18 | | 1 | 32.05 | 32.05 | | 0 | | | | 1 | 0.030 | 0.030 | |
| Poplar[2] | 22009751 | 43 | 4.40 | 7.13 | 7.35 | 42 | 4.45 | 5.32 | 3.38 | 32 | 98.0 | 86.9 | 17.2 | 42 | 0.020 | 0.030 | 0.016 |
| Poplar[3] | 22009769 | 2 | 26.35 | 26.35 | 3.32 | 6 | 28.87 | 28.52 | 16.91 | 0 | | | | 0 | | | |
| *Poplar[1] | 22009865 | 55 | 17.00 | 31.93 | 48.25 | 60 | 11.00 | 24.29 | 40.04 | 46 | 57.5 | 57.9 | 29.2 | 56 | 0.030 | 0.053 | 0.052 |
| Poplar | 22009995 | 1 | 30.00 | 30.00 | | 2 | 13.73 | 13.73 | 12.98 | 0 | | | | 0 | | | |
| Sawbill | 22007440 | 2 | 1.87 | 1.87 | 0.19 | 2 | 1.42 | 1.42 | 0.49 | 0 | | | | 2 | 0.010 | 0.010 | 0.000 |
| Skunk | 31030812 | 1 | 6.68 | 6.68 | | 1 | 5.63 | 5.63 | | 0 | | | | 3 | 0.030 | 0.027 | 0.015 |
| Split Rock | 22012526 | 9 | 11.60 | 22.41 | 25.94 | 9 | 20.20 | 26.51 | 18.64 | 8 | 57.0 | 57.8 | 34.4 | 9 | 0.040 | 0.040 | 0.024 |
| Stanley | 31034607 | 1 | 47.50 | 47.50 | | 0 | | | | 0 | | | | 1 | 0.150 | 0.150 | |
| *Sucker[1] | 31035415 | 63 | 20.00 | 35.43 | 40.69 | 63 | 13.00 | 20.69 | 19.82 | 55 | 50.0 | 52.7 | 27.0 | 63 | 0.060 | 0.081 | 0.058 |
| Sugarloaf | 22011076 | 8 | 4.58 | 9.29 | 11.74 | 9 | 7.05 | 8.69 | 7.26 | 9 | 101.0 | 86.2 | 23.5 | 9 | 0.020 | 0.020 | 0.010 |
| *Talmadge | 31035804 | 43 | 14.00 | 17.65 | 15.75 | 43 | 12.00 | 14.70 | 9.48 | 35 | 52.0 | 53.0 | 22.5 | 43 | 0.070 | 0.077 | 0.047 |
| Temperance | 22007788 | 2 | 2.15 | 2.15 | 0.39 | 2 | 1.30 | 1.30 | 0.13 | 0 | | | | 2 | 0.010 | 0.010 | 0.000 |
| Tischer[1] | 31036716 | 0 | | | | 9 | 6.47 | 23.95 | 43.22 | 9 | 73.0 | 65.0 | 30.8 | 0 | | | |
| *Tischer | 31036814 | 41 | 18.00 | 55.02 | 96.31 | 57 | 10.90 | 40.00 | 78.77 | 35 | 52.0 | 55.0 | 35.3 | 43 | 0.070 | 0.121 | 0.141 |
| Two Island | 22010764 | 2 | 2.67 | 2.67 | 1.07 | 3 | 1.26 | 4.29 | 5.55 | 0 | | | | 2 | 0.015 | 0.015 | 0.007 |
| West Branch | 31034133 | 0 | | | | 0 | | | | 0 | | | | 2 | 0.020 | 0.020 | 0.014 |

| | | TSS (mg/L) | | | | Turbidity (NTU) | | | | T-Tube ($cm^{-1}$) | | | | Total-P (mg/L) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Stream Name | Watershed ID | N | Median | Mean | Std Dev | N | Median | Mean | Std Dev | N | Median | Mean | Std Dev | N | Median | Mean | Std Dev |
| Knife | | | | | | | | | | | | | | | | | |

**Appendix N: Summary statistics for particulate-related water quality for each watershed during rain periods.**

| | | TSS (mg/L) | | | | Turbidity (NTU) | | | | T-Tube ($cm^{-1}$) | | | | Total-P (mg/L) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Stream Name** | **Watershed ID** | **N** | **Median** | **Mean** | **Std Dev** | **N** | **Median** | **Mean** | **Std Dev** | **N** | **Median** | **Mean** | **Std Dev** | **N** | **Median** | **Mean** | **Std Dev** |
| Amity[1] | 31036326 | 7 | 3.82 | 7.44 | 10.01 | 7 | 4.71 | 6.41 | 4.80 | 0 | | | | 7 | 0.010 | 0.019 | 0.020 |
| *Amity | 31036466 | 70 | 17.00 | 57.51 | 104.8 | 86 | 19.75 | 53.92 | 91.44 | 67 | 43.0 | 48.9 | 32.6 | 71 | 0.050 | 0.084 | 0.102 |
| Amity East | 31036341 | 11 | 9.29 | 47.59 | 70.56 | 13 | 10.80 | 34.08 | 50.24 | 10 | 70.5 | 62.4 | 39.5 | 7 | 0.030 | 0.036 | 0.025 |
| Baptism | 22011810 | 3 | 1.00 | 2.00 | 1.73 | 3 | 1.20 | 2.23 | 1.88 | 3 | 100.0 | 100.0 | 0.0 | 2 | 0.015 | 0.015 | 0.007 |
| Beaver[1] | 22012232 | 3 | 18.40 | 40.47 | 51.20 | 3 | 40.20 | 101.85 | 135.3 | 2 | 21.5 | 21.5 | 17.7 | 3 | 0.040 | 0.047 | 0.040 |
| *Beaver[2] | 22012244 | 3 | 15.00 | 37.53 | 51.07 | 8 | 8.10 | 25.57 | 38.15 | 8 | 101.0 | 80.6 | 37.8 | 3 | 0.050 | 0.070 | 0.062 |
| Beaver | 22012278 | 0 | | | | 0 | | | | 1 | 59.0 | 59.0 | | 0 | | | |
| Beaver[3] | 22012296 | 15 | 7.87 | 12.24 | 14.54 | 16 | 4.94 | 7.92 | 8.58 | 0 | | | | 15 | 0.030 | 0.036 | 0.030 |
| Blind Temperance | 22009979 | 6 | 13.81 | 16.81 | 17.43 | 6 | 6.16 | 7.20 | 4.79 | 0 | | | | 5 | 0.050 | 0.066 | 0.035 |
| *Brule | 22007634 | 30 | 4.30 | 6.29 | 8.02 | 36 | 4.93 | 8.25 | 8.75 | 36 | 99.0 | 80.9 | 23.4 | 32 | 0.020 | 0.025 | 0.014 |
| Caribou[1] | 22009302 | 6 | 3.01 | 27.73 | 61.05 | 6 | 3.06 | 2.81 | 1.28 | 0 | | | | 6 | 0.020 | 0.017 | 0.005 |
| Caribou | 22011270 | 3 | 86.60 | 130.53 | 156.2 | 3 | 133.20 | 152.78 | 162.3 | 3 | 35.8 | 47.9 | 48.2 | 3 | 0.020 | 0.027 | 0.031 |
| Cascade[1] | 22007777 | 5 | 1.79 | 2.30 | 1.69 | 4 | 1.36 | 1.41 | 0.12 | 0 | | | | 4 | 0.010 | 0.010 | 0.000 |
| Cascade | 22009269 | 3 | 17.80 | 40.93 | 55.26 | 3 | 23.60 | 52.05 | 69.35 | 3 | 48.2 | 55.1 | 42.9 | 3 | 0.040 | 0.067 | 0.074 |
| *Chester | 31036987 | 59 | 10.00 | 18.98 | 25.89 | 72 | 10.55 | 14.27 | 13.59 | 50 | 57.0 | 62.1 | 28.8 | 70 | 0.060 | 0.065 | 0.048 |
| Cross | 22010227 | 3 | 2.50 | 6.44 | 6.93 | 2 | 1.74 | 1.74 | 0.12 | 0 | | | | 2 | 0.010 | 0.010 | 0.000 |
| East Beaver | 22012109 | 2 | 2.93 | 2.93 | 0.67 | 2 | 1.62 | 1.62 | 0.30 | 0 | | | | 2 | 0.010 | 0.010 | 0.000 |
| East Split Rock | 22012354 | 0 | | | | 0 | | | | 0 | | | | 4 | 0.010 | 0.013 | 0.015 |
| Encampment[1] | 31032334 | 13 | 6.07 | 6.84 | 5.54 | 13 | 6.69 | 7.76 | 5.49 | 0 | | | | 14 | 0.030 | 0.044 | 0.024 |
| Encampment | 31032914 | 3 | 22.40 | 57.60 | 67.39 | 3 | 70.10 | 166.57 | 177.3 | 3 | 16.0 | 14.9 | 8.5 | 3 | 0.060 | 0.067 | 0.050 |
| *Flute Reed4 | 22006835 | 0 | | | | 0 | | | | 14 | 71.5 | 72.7 | 20.2 | 0 | | | |
| Flute Reed[3] | 22007233 | 0 | | | | 0 | | | | 15 | 45.0 | 44.2 | 22.0 | 0 | | | |
| Flute Reed[1] | 22007234 | 0 | | | | 0 | | | | 6 | 21.5 | 19.8 | 6.5 | 0 | | | |
| Flute Reed[2] | 22007237 | 0 | | | | 0 | | | | 6 | 28.5 | 37.4 | 21.7 | 0 | | | |
| Flute Reed | 22007315 | 4 | 4.50 | 8.50 | 10.54 | 0 | | | | 33 | 28.0 | 38.0 | 30.4 | 4 | 0.025 | 0.028 | 0.021 |
| *French | 31035723 | 62 | 4.80 | 16.84 | 38.56 | 60 | 8.15 | 13.61 | 21.79 | 38 | 78.5 | 71.2 | 28.8 | 62 | 0.030 | 0.042 | 0.047 |

| Stream Name | Watershed ID | TSS (mg/L) N | TSS Median | TSS Mean | TSS Std Dev | Turbidity (NTU) N | Turbidity Median | Turbidity Mean | Turbidity Std Dev | T-Tube ($cm^{-1}$) N | T-Tube Median | T-Tube Mean | T-Tube Std Dev | Total-P (mg/L) N | Total-P Median | Total-P Mean | Total-P Std Dev |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Gooseberry | 31032212 | 3 | 22.40 | 135.60 | 208.3 | 3 | 102.60 | 213.37 | 264.3 | 3 | 25.0 | 25.3 | 20.5 | 3 | 0.060 | 0.077 | 0.067 |
| Keene | 36000247 | 6 | 4.00 | 7.00 | 7.16 | 8 | 3.12 | 3.96 | 2.82 | 8 | 101.0 | 83.1 | 30.5 | 8 | 0.020 | 0.030 | 0.022 |
| *Kingsbury | 31037901 | 66 | 22.30 | 57.31 | 84.97 | 75 | 29.20 | 68.97 | 94.79 | 52 | 28.0 | 35.4 | 29.5 | 63 | 0.070 | 0.103 | 0.091 |
| Knife[2] | 31033053 | 0 | | | | 0 | | | | 0 | | | | 3 | 0.020 | 0.020 | 0.020 |
| *Knife1 | 31033543 | 31 | 6.00 | 26.07 | 40.02 | 24 | 26.00 | 39.27 | 43.85 | 10 | 60.3 | 56.0 | 40.6 | 0 | | | |
| Knife[3] | 31033901 | 0 | | | | 3 | 34.91 | 29.37 | 12.13 | 0 | | | | 0 | | | |
| Knife | 31035065 | 0 | | | | 0 | | | | 1 | 30.0 | 30.0 | | 0 | | | |
| Lester[1] | 31035556 | 24 | 3.38 | 9.29 | 12.77 | 24 | 3.10 | 4.57 | 4.33 | 0 | | | | 24 | 0.040 | 0.044 | 0.030 |
| Lester | 31036559 | 0 | | | | 0 | | | | 1 | 76.0 | 76.0 | | 0 | | | |
| Little Knife | 31035071 | 15 | 16.00 | 17.47 | 15.78 | 0 | | | | 5 | 22.0 | 22.2 | 11.9 | 3 | 0.030 | 0.030 | 0.010 |
| McCarthy | 31033237 | 0 | | | | 0 | | | | 0 | | | | 4 | 0.020 | 0.018 | 0.013 |
| Miller[3] | 31036923 | 10 | 3.00 | 4.80 | 4.05 | 3 | 3.05 | 8.83 | 10.46 | 9 | 101.0 | 86.7 | 23.7 | 9 | 0.040 | 0.043 | 0.024 |
| Miller[2] | 31037116 | 0 | | | | 35 | 5.00 | 11.35 | 11.40 | 33 | 100.0 | 76.9 | 30.6 | 10 | 0.034 | 0.060 | 0.055 |
| *Miller1 | 31037257 | 2 | 11.40 | 11.40 | 0.42 | 7 | 9.45 | 8.52 | 5.24 | 19 | 56.0 | 65.0 | 28.4 | 10 | 0.020 | 0.052 | 0.085 |
| *Miller | 31037433 | 17 | 9.00 | 19.49 | 22.39 | 7 | 24.30 | 21.94 | 18.31 | 3 | 27.0 | 48.7 | 45.5 | 9 | 0.040 | 0.057 | 0.051 |
| Mission | 31038874 | 1 | 113.00 | 113.00 | | 4 | 9.32 | 36.17 | 59.70 | 4 | 76.1 | 65.6 | 44.4 | 4 | 0.034 | 0.081 | 0.118 |
| Onion | 22010143 | 3 | 3.84 | 7.98 | 7.75 | 3 | 3.93 | 6.79 | 6.48 | 0 | | | | 3 | 0.010 | 0.013 | 0.006 |
| Palisade | 22012011 | 6 | 19.02 | 23.51 | 23.23 | 6 | 28.25 | 45.33 | 34.97 | 0 | | | | 6 | 0.085 | 0.110 | 0.080 |
| Poplar[2] | 22009751 | 40 | 5.10 | 6.82 | 5.30 | 37 | 5.50 | 6.90 | 5.47 | 29 | 88.0 | 81.1 | 20.3 | 36 | 0.030 | 0.030 | 0.028 |
| Poplar[3] | 22009769 | 10 | 16.00 | 19.56 | 15.42 | 15 | 18.00 | 25.44 | 17.75 | 10 | 39.0 | 53.8 | 28.3 | 3 | 0.040 | 0.050 | 0.026 |
| *Poplar[1] | 22009865 | 40 | 12.50 | 32.27 | 60.42 | 46 | 9.50 | 37.67 | 130.4 | 39 | 56.0 | 59.5 | 29.1 | 42 | 0.030 | 0.057 | 0.083 |
| Poplar | 22009995 | 3 | 6.10 | 14.37 | 18.54 | 3 | 41.00 | 27.50 | 23.82 | 3 | 101.0 | 78.0 | 39.8 | 0 | | | |
| Sawbill | 22007440 | 10 | 3.21 | 3.15 | 0.66 | 10 | 2.36 | 2.34 | 0.55 | 0 | | | | 10 | 0.020 | 0.019 | 0.009 |
| Skunk | 31030812 | 8 | 3.25 | 4.47 | 3.34 | 7 | 4.17 | 3.68 | 1.27 | 0 | | | | 12 | 0.020 | 0.020 | 0.012 |
| Split Rock | 22012526 | 3 | 6.00 | 41.87 | 65.35 | 3 | 68.40 | 98.61 | 110.1 | 2 | 22.9 | 22.9 | 19.7 | 3 | 0.040 | 0.057 | 0.057 |
| Stanley | 31034607 | 7 | 8.80 | 14.07 | 10.91 | 7 | 17.85 | 21.20 | 17.91 | 0 | | | | 7 | 0.050 | 0.051 | 0.029 |
| *Sucker[1] | 31035415 | 73 | 10.00 | 19.16 | 24.37 | 71 | 8.80 | 15.14 | 17.71 | 71 | 74.0 | 69.0 | 28.3 | 72 | 0.040 | 0.049 | 0.040 |
| Sucker | 31035442 | 0 | | | | 0 | | | | 1 | 100.0 | 100.0 | | 0 | | | |
| Sugarloaf | 22011076 | 3 | 9.00 | 41.07 | 62.87 | 3 | 4.80 | 144.51 | 245.5 | 3 | 91.8 | 68.3 | 48.9 | 3 | 0.020 | 0.053 | 0.076 |

| Stream Name | Watershed ID | TSS (mg/L) | | | | Turbidity (NTU) | | | | T-Tube ($cm^{-1}$) | | | | Total-P (mg/L) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | N | Median | Mean | Std Dev | N | Median | Mean | Std Dev | N | Median | Mean | Std Dev | N | Median | Mean | Std Dev |
| *Talmadge | 31035804 | 50 | 6.40 | 17.20 | 42.74 | 49 | 10.72 | 21.71 | 49.27 | 41 | 64.0 | 66.8 | 26.2 | 52 | 0.050 | 0.054 | 0.055 |
| Temperance | 22007788 | 7 | 3.36 | 3.22 | 1.40 | 7 | 2.28 | 2.37 | 0.35 | 0 | | | | 7 | 0.010 | 0.014 | 0.005 |
| Tischer[1] | 31036716 | 0 | | | | 21 | 7.87 | 21.70 | 37.93 | 19 | 50.0 | 57.9 | 34.8 | 0 | | | |
| *Tischer | 31036814 | 62 | 36.65 | 68.27 | 86.11 | 88 | 25.10 | 73.32 | 148.8 | 46 | 21.0 | 35.0 | 32.3 | 70 | 0.090 | 0.128 | 0.117 |
| Two Island | 22010764 | 2 | 2.94 | 2.94 | 1.20 | 3 | 2.18 | 7.47 | 9.38 | 0 | | | | 2 | 0.015 | 0.015 | 0.007 |
| West Branch Knife | 31034133 | 0 | | | | 0 | | | | 0 | | | | 3 | 0.020 | 0.020 | 0.010 |

**Appendix O: Summary statistics for particulate-related water quality for each watershed during baseflow.**

| Stream Name | Watershed ID | TSS (mg/L) | | | | Turbidity (NTU) | | | | T-Tube ($cm^{-1}$) | | | | Total-P (mg/L) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | N | Median | Mean | Std Dev | N | Median | Mean | Std Dev | N | Median | Mean | Std Dev | N | Median | Mean | Std Dev |
| Amity[1] | 31036326 | 9 | 1.97 | 2.46 | 1.24 | 8 | 2.12 | 2.07 | 0.62 | 0 | | | | 9 | 0.010 | 0.019 | 0.018 |
| *Amity | 31036466 | 36 | 2.20 | 4.43 | 6.25 | 54 | 3.59 | 8.78 | 18.12 | 66 | 100.0 | 91.8 | 20.9 | 43 | 0.020 | 0.021 | 0.013 |
| Amity East | 31036341 | 11 | 1.60 | 2.56 | 2.04 | 12 | 1.51 | 2.77 | 3.85 | 13 | 101.0 | 98.9 | 7.5 | 12 | 0.010 | 0.013 | 0.011 |
| Baptism | 22011810 | 19 | 1.00 | 1.47 | 0.97 | 20 | 1.65 | 1.96 | 1.43 | 19 | 100.0 | 95.8 | 12.6 | 19 | 0.010 | 0.017 | 0.023 |
| Beaver[1] | 22012232 | 7 | 7.20 | 6.84 | 2.80 | 7 | 10.30 | 10.21 | 3.65 | 7 | 91.0 | 85.8 | 18.9 | 7 | 0.020 | 0.019 | 0.011 |
| *Beaver[2] | 22012244 | 16 | 1.90 | 2.05 | 0.98 | 32 | 2.85 | 4.93 | 7.83 | 31 | 100.0 | 100.1 | 1.9 | 19 | 0.010 | 0.015 | 0.008 |
| Beaver | 22012278 | 0 | | | | 0 | | | | 8 | 57.0 | 58.8 | 15.4 | 0 | | | |
| Beaver[3] | 22012296 | 10 | 2.22 | 2.43 | 1.00 | 14 | 2.15 | 2.32 | 1.54 | 0 | | | | 10 | 0.020 | 0.030 | 0.032 |
| Blind Temperance | 22009979 | 9 | 1.99 | 2.36 | 1.36 | 12 | 1.84 | 2.13 | 1.00 | 0 | | | | 9 | 0.020 | 0.020 | 0.010 |
| *Brule | 22007634 | 45 | 1.20 | 1.67 | 0.85 | 75 | 1.70 | 2.52 | 2.98 | 61 | 100.0 | 93.4 | 14.9 | 52 | 0.010 | 0.013 | 0.006 |
| Caribou[1] | 22009302 | 7 | 2.66 | 5.48 | 7.55 | 7 | 2.27 | 2.39 | 0.98 | 0 | | | | 7 | 0.020 | 0.020 | 0.008 |
| Caribou | 22011270 | 8 | 2.31 | 3.71 | 3.55 | 8 | 2.94 | 4.05 | 3.34 | 7 | 101.0 | 92.3 | 18.7 | 8 | 0.010 | 0.006 | 0.005 |
| Cascade[1] | 22007777 | 6 | 1.06 | 1.33 | 0.80 | 7 | 1.33 | 1.73 | 1.15 | 0 | | | | 6 | 0.010 | 0.013 | 0.005 |
| Cascade | 22009269 | 8 | 0.90 | 1.14 | 1.04 | 8 | 1.15 | 1.12 | 0.22 | 7 | 101.0 | 101.0 | 0.0 | 8 | 0.010 | 0.009 | 0.004 |
| *Chester | 31036987 | 18 | 1.30 | 3.21 | 4.56 | 30 | 1.25 | 4.11 | 10.42 | 17 | 101.0 | 96.3 | 16.2 | 27 | 0.030 | 0.040 | 0.029 |
| Cross | 22010227 | 6 | 3.00 | 3.09 | 1.49 | 8 | 3.03 | 4.11 | 3.05 | 0 | | | | 5 | 0.020 | 0.020 | 0.007 |
| East Beaver | 22012109 | 3 | 4.40 | 11.47 | 14.95 | 6 | 2.31 | 12.27 | 21.80 | 0 | | | | 4 | 0.020 | 0.020 | 0.008 |
| East Split Rock | 22012354 | 3 | 1.30 | 4.99 | 7.51 | 0 | | | | 0 | | | | 6 | 0.020 | 0.017 | 0.005 |
| Encampment[1] | 31032334 | 9 | 2.55 | 2.73 | 1.13 | 9 | 2.34 | 2.65 | 1.44 | 0 | | | | 9 | 0.020 | 0.021 | 0.006 |
| Encampment | 31032914 | 10 | 1.75 | 2.04 | 0.95 | 10 | 2.63 | 3.71 | 2.93 | 12 | 101.0 | 101.0 | 0.0 | 12 | 0.010 | 0.008 | 0.006 |
| *Flute Reed[4] | 22006835 | 0 | | | | 0 | | | | 53 | 93.0 | 86.2 | 16.6 | 0 | | | |
| Flute Reed[3] | 22007233 | 0 | | | | 0 | | | | 60 | 60.0 | 66.1 | 20.4 | 0 | | | |
| Flute Reed[1] | 22007234 | 0 | | | | 0 | | | | 18 | 73.5 | 66.8 | 27.1 | 0 | | | |
| Flute Reed[2] | 22007237 | 0 | | | | 0 | | | | 28 | 38.0 | 41.5 | 16.4 | 0 | | | |
| Flute Reed | 22007315 | 27 | 3.00 | 3.82 | 2.73 | 1 | 3.97 | 3.97 | | 58 | 81.0 | 73.3 | 27.4 | 30 | 0.020 | 0.024 | 0.013 |
| *French | 31035723 | 38 | 1.00 | 1.39 | 0.90 | 41 | 1.40 | 2.56 | 3.34 | 28 | 100.0 | 95.1 | 14.5 | 41 | 0.010 | 0.015 | 0.010 |

| Stream Name | Watershed ID | TSS (mg/L) | | | | Turbidity (NTU) | | | | T-Tube ($cm^{-1}$) | | | | Total-P (mg/L) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | N | Median | Mean | Std Dev | N | Median | Mean | Std Dev | N | Median | Mean | Std Dev | N | Median | Mean | Std Dev |
| Gooseberry | 31032212 | 8 | 3.09 | 3.29 | 1.54 | 8 | 6.41 | 6.37 | 3.49 | 16 | 100.0 | 91.8 | 20.9 | 8 | 0.010 | 0.010 | 0.000 |
| Keene | 36000247 | 10 | 2.50 | 4.20 | 4.32 | 13 | 2.01 | 3.02 | 2.38 | 13 | 101.0 | 100.8 | 0.4 | 27 | 0.021 | 0.034 | 0.044 |
| *Kingsbury | 31037901 | 19 | 3.20 | 7.33 | 10.20 | 31 | 3.60 | 37.49 | 143.5 | 17 | 101.0 | 91.4 | 17.3 | 24 | 0.030 | 0.040 | 0.038 |
| Knife[2] | 31033053 | 3 | 2.29 | 6.93 | 8.91 | 0 | | | | 0 | | | | 6 | 0.010 | 0.013 | 0.005 |
| *Knife1 | 31033543 | 69 | 1.00 | 1.94 | 1.54 | 45 | 3.30 | 5.77 | 6.33 | 39 | 100.0 | 90.8 | 16.9 | 0 | | | |
| Knife[3] | 31033901 | 0 | | | | 3 | 25.26 | 23.76 | 6.51 | 0 | | | | 0 | | | |
| Knife | 31035065 | 0 | | | | 0 | | | | 8 | 100.0 | 76.6 | 33.2 | 0 | | | |
| Lester[1] | 31035556 | 13 | 3.56 | 3.12 | 1.83 | 17 | 1.90 | 18.50 | 66.37 | 0 | | | | 14 | 0.020 | 0.022 | 0.011 |
| Lester | 31036559 | 0 | | | | 0 | | | | 8 | 100.0 | 100.0 | 0.0 | 0 | | | |
| Little Knife | 31035071 | 36 | 6.00 | 8.69 | 11.74 | 0 | | | | 22 | 41.5 | 47.8 | 21.2 | 5 | 0.010 | 0.014 | 0.005 |
| McCarthy | 31033237 | 3 | 1.98 | 2.04 | 1.61 | 0 | | | | 0 | | | | 6 | 0.015 | 0.017 | 0.008 |
| Miller[3] | 31036923 | 20 | 1.00 | 2.65 | 3.80 | 4 | 4.12 | 4.05 | 0.33 | 21 | 101.0 | 94.4 | 16.2 | 21 | 0.030 | 0.036 | 0.022 |
| Miller[2] | 31037116 | 0 | | | | 72 | 3.55 | 4.45 | 2.57 | 70 | 101.0 | 97.2 | 11.7 | 21 | 0.024 | 0.041 | 0.078 |
| *Miller1 | 31037257 | 3 | 2.41 | 3.02 | 3.16 | 32 | 2.79 | 3.47 | 2.18 | 45 | 101.0 | 97.6 | 11.2 | 35 | 0.020 | 0.020 | 0.009 |
| *Miller | 31037433 | 21 | 2.00 | 4.26 | 6.25 | 8 | 6.58 | 5.44 | 2.05 | 26 | 101.0 | 98.9 | 7.1 | 25 | 0.020 | 0.020 | 0.009 |
| Mission | 31038874 | 8 | 4.00 | 6.13 | 4.76 | 14 | 2.65 | 4.53 | 3.81 | 14 | 101.0 | 97.4 | 11.4 | 17 | 0.015 | 0.020 | 0.020 |
| Onion | 22010143 | 6 | 3.93 | 3.95 | 1.53 | 6 | 2.95 | 3.13 | 1.87 | 0 | | | | 6 | 0.020 | 0.018 | 0.008 |
| Palisade | 22012011 | 6 | 18.32 | 24.31 | 25.71 | 6 | 5.44 | 14.96 | 25.44 | 0 | | | | 6 | 0.020 | 0.042 | 0.054 |
| Poplar[2] | 22009751 | 40 | 4.00 | 3.95 | 1.42 | 41 | 3.99 | 4.09 | 1.63 | 32 | 100.0 | 95.1 | 9.3 | 37 | 0.020 | 0.074 | 0.189 |
| Poplar[3] | 22009769 | 10 | 5.56 | 5.52 | 2.72 | 19 | 3.45 | 6.30 | 8.96 | 8 | 100.0 | 98.1 | 4.4 | 3 | 0.020 | 0.020 | 0.000 |
| *Poplar[1] | 22009865 | 60 | 3.10 | 3.92 | 3.07 | 86 | 3.60 | 5.91 | 8.09 | 72 | 100.0 | 95.7 | 10.9 | 68 | 0.020 | 0.016 | 0.006 |
| Poplar | 22009995 | 8 | 2.49 | 3.36 | 1.97 | 10 | 2.67 | 2.89 | 1.88 | 7 | 101.0 | 99.1 | 4.9 | 0 | | | |
| Sawbill | 22007440 | 4 | 2.45 | 2.74 | 1.06 | 5 | 1.71 | 1.89 | 0.82 | 0 | | | | 4 | 0.015 | 0.015 | 0.006 |
| Skunk | 31030812 | 8 | 2.67 | 4.46 | 4.52 | 6 | 1.20 | 1.19 | 0.44 | 0 | | | | 11 | 0.010 | 0.016 | 0.007 |
| Split Rock | 22012526 | 8 | 1.85 | 1.75 | 0.84 | 8 | 3.23 | 3.23 | 1.85 | 8 | 101.0 | 101.0 | 0.0 | 8 | 0.010 | 0.010 | 0.005 |
| Stanley | 31034607 | 9 | 4.40 | 5.08 | 3.33 | 9 | 7.84 | 10.03 | 9.34 | 0 | | | | 9 | 0.020 | 0.027 | 0.016 |
| *Sucker[1] | 31035415 | 53 | 1.60 | 2.15 | 1.43 | 60 | 2.00 | 2.86 | 4.06 | 72 | 100.0 | 99.1 | 2.7 | 60 | 0.015 | 0.018 | 0.010 |
| Sucker | 31035442 | 0 | | | | 0 | | | | 8 | 100.0 | 98.8 | 3.4 | 0 | | | |
| Sugarloaf | 22011076 | 7 | 0.50 | 0.53 | 0.32 | 7 | 0.67 | 0.72 | 0.21 | 7 | 101.0 | 101.0 | 0.0 | 7 | 0.010 | 0.006 | 0.005 |

| Stream Name | Watershed ID | TSS (mg/L) | | | | Turbidity (NTU) | | | | T-Tube ($cm^{-1}$) | | | | Total-P (mg/L) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | N | Median | Mean | Std Dev | N | Median | Mean | Std Dev | N | Median | Mean | Std Dev | N | Median | Mean | Std Dev |
| *Talmadge | 31035804 | 37 | 2.00 | 2.52 | 1.56 | 39 | 2.90 | 3.54 | 2.70 | 43 | 100.0 | 96.3 | 11.5 | 42 | 0.020 | 0.028 | 0.024 |
| Temperance | 22007788 | 5 | 2.36 | 2.80 | 2.79 | 6 | 1.67 | 2.62 | 2.22 | 0 | | | | 5 | 0.020 | 0.016 | 0.005 |
| Tischer[1] | 31036716 | 0 | | | | 51 | 2.97 | 6.30 | 9.63 | 49 | 101.0 | 86.7 | 26.7 | 0 | | | |
| *Tischer | 31036814 | 20 | 1.60 | 3.00 | 3.63 | 68 | 3.06 | 5.67 | 7.88 | 16 | 101.0 | 97.0 | 11.9 | 24 | 0.030 | 0.057 | 0.115 |
| Two Island | 22010764 | 4 | 1.95 | 1.91 | 0.33 | 6 | 3.37 | 9.72 | 15.45 | 0 | | | | 4 | 0.020 | 0.020 | 0.008 |
| West Branch Knife | 31034133 | 3 | 2.00 | 5.80 | 7.30 | 0 | | | | 0 | | | | 6 | 0.010 | 0.012 | 0.008 |

**Appendix P: Summary statistics for soluble water quality metrics related to nitrogen for each watershed during snowmelt.**

| | | Total-N (mg/L) | | | | DIN (mg/L) | | | | Ammonium-N (mg/L) | | | | [Nitrate+Nitrite]-N (mg/L) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Stream Name** | **Watershed ID** | **N** | **Median** | **Mean** | **Std Dev** | **N** | **Median** | **Mean** | **Std Dev** | **N** | **Median** | **Mean** | **Std Dev** | **N** | **Median** | **Mean** | **Std Dev** |
| Amity[1] | 31036326 | 2 | 1.022 | 1.023 | 0.159 | 2 | 0.560 | 0.560 | 0.113 | 2 | 0.065 | 0.065 | 0.021 | 2 | 0.495 | 0.495 | 0.092 |
| *Amity | 31036466 | 40 | 1.079 | 1.142 | 0.472 | 13 | 0.400 | 0.449 | 0.248 | 13 | 0.060 | 0.116 | 0.139 | 40 | 0.268 | 0.294 | 0.156 |
| Amity East | 31036341 | 4 | 0.555 | 0.669 | 0.326 | 4 | 0.190 | 0.290 | 0.293 | 4 | 0.015 | 0.018 | 0.017 | 4 | 0.175 | 0.273 | 0.276 |
| Baptism | 22011810 | 11 | 0.810 | 0.816 | 0.103 | 11 | 0.300 | 0.326 | 0.088 | 11 | 0.050 | 0.064 | 0.045 | 11 | 0.250 | 0.263 | 0.057 |
| Beaver | 22012232 | 9 | 0.669 | 0.722 | 0.196 | 9 | 0.210 | 0.290 | 0.185 | 9 | 0.020 | 0.020 | 0.016 | 9 | 0.180 | 0.270 | 0.173 |
| *Beaver[2] | 22012244 | 0 | | | | 4 | 0.320 | 0.363 | 0.209 | 4 | 0.030 | 0.048 | 0.043 | 7 | 0.310 | 0.437 | 0.449 |
| Beaver[3] | 22012296 | 1 | 0.686 | 0.686 | | 1 | 0.180 | 0.180 | | 1 | 0.010 | 0.010 | | 1 | 0.170 | 0.170 | |
| Blind Temperance | 22009979 | 1 | 2.582 | 2.582 | | 1 | 2.070 | 2.070 | | 1 | 0.020 | 0.020 | | 1 | 2.050 | 2.050 | |
| *Brule | 22007634 | 24 | 0.830 | 0.920 | 0.324 | 5 | 0.230 | 0.286 | 0.138 | 5 | 0.020 | 0.050 | 0.052 | 31 | 0.210 | 0.232 | 0.105 |
| Caribou[1] | 22009302 | 1 | 0.562 | 0.563 | | 1 | 0.180 | 0.180 | | 1 | 0.030 | 0.030 | | 1 | 0.150 | 0.150 | |
| Caribou | 22011270 | 9 | 0.606 | 0.725 | 0.238 | 9 | 0.310 | 0.396 | 0.184 | 9 | 0.010 | 0.012 | 0.012 | 9 | 0.310 | 0.383 | 0.174 |
| Cascade[1] | 22007777 | 2 | 0.461 | 0.461 | 0.274 | 2 | 0.160 | 0.160 | 0.141 | 2 | 0.025 | 0.025 | 0.021 | 2 | 0.135 | 0.135 | 0.120 |
| Cascade | 22009269 | 9 | 0.644 | 0.772 | 0.283 | 9 | 0.320 | 0.402 | 0.256 | 9 | 0.020 | 0.028 | 0.022 | 9 | 0.300 | 0.374 | 0.244 |
| *Chester | 31036987 | 41 | 0.995 | 1.201 | 0.883 | 40 | 0.530 | 0.561 | 0.378 | 40 | 0.080 | 0.154 | 0.255 | 41 | 0.410 | 0.400 | 0.201 |
| Cross | 22010227 | 2 | 0.733 | 0.733 | 0.151 | 2 | 0.205 | 0.205 | 0.177 | 2 | 0.025 | 0.025 | 0.021 | 2 | 0.180 | 0.180 | 0.156 |
| East Beaver | 22012109 | 1 | 0.878 | 0.878 | | 1 | 0.420 | 0.420 | | 1 | 0.040 | 0.040 | | 1 | 0.380 | 0.380 | |
| East Split Rock | 22012354 | 2 | 0.888 | 0.888 | 0.478 | 1 | 0.690 | 0.690 | | 1 | 0.030 | 0.030 | | 2 | 0.350 | 0.350 | 0.438 |
| Encampment[1] | 31032334 | 1 | 0.933 | 0.933 | | 1 | 0.350 | 0.350 | | 1 | 0.020 | 0.020 | | 1 | 0.330 | 0.330 | |
| Encampment | 31032914 | 4 | 0.475 | 0.472 | 0.034 | 4 | 0.040 | 0.035 | 0.017 | 4 | 0.000 | 0.000 | 0.000 | 4 | 0.040 | 0.035 | 0.017 |
| Flute Reed | 22007315 | 4 | 0.995 | 0.970 | 0.357 | 0 | | | | 0 | | | | 5 | 0.110 | 0.166 | 0.128 |
| French | 31035723 | 26 | 0.920 | 0.900 | 0.331 | 1 | 0.160 | 0.160 | | 1 | 0.010 | 0.010 | | 26 | 0.100 | 0.150 | 0.108 |
| Gooseberry | 31032212 | 9 | 0.627 | 0.615 | 0.126 | 9 | 0.090 | 0.132 | 0.094 | 9 | 0.010 | 0.016 | 0.012 | 9 | 0.080 | 0.117 | 0.084 |
| Keene | 36000247 | 0 | | | | 0 | | | | 0 | | | | 1 | 0.210 | 0.210 | |
| Kingsbury | 31037901 | 39 | 1.013 | 1.214 | 0.836 | 39 | 0.560 | 0.581 | 0.324 | 39 | 0.130 | 0.154 | 0.131 | 39 | 0.410 | 0.428 | 0.229 |

| | | Total-N (mg/L) | | | | DIN (mg/L) | | | | Ammonium-N (mg/L) | | | | [Nitrate+Nitrite]-N (mg/L) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Stream Name** | **Watershed ID** | **N** | **Median** | **Mean** | **Std Dev** | **N** | **Median** | **Mean** | **Std Dev** | **N** | **Median** | **Mean** | **Std Dev** | **N** | **Median** | **Mean** | **Std Dev** |
| Knife[2] | 31033053 | 1 | 0.471 | 0.471 | | 0 | | | | 0 | | | | 1 | 0.040 | 0.040 | |
| Lester[1] | 31035556 | 3 | 0.875 | 0.882 | 0.087 | 3 | 0.320 | 0.357 | 0.072 | 3 | 0.110 | 0.107 | 0.075 | 3 | 0.260 | 0.250 | 0.046 |
| Little Knife | 31035071 | 2 | 0.770 | 0.770 | 0.185 | 1 | 0.180 | 0.180 | | 1 | 0.030 | 0.030 | | 2 | 0.080 | 0.080 | 0.099 |
| McCarthy | 31033237 | 2 | 0.557 | 0.557 | 0.129 | 1 | 0.240 | 0.240 | | 1 | 0.020 | 0.020 | | 2 | 0.110 | 0.110 | 0.156 |
| Miller[3] | 31036923 | 0 | | | | 0 | | | | 0 | | | | 1 | 0.100 | 0.100 | |
| Miller[2] | 31037116 | 0 | | | | 1 | 0.280 | 0.280 | | 1 | 0.080 | 0.080 | | 1 | 0.200 | 0.200 | |
| *Miller[1] | 31037257 | 4 | 0.634 | 0.762 | 0.353 | 5 | 0.270 | 0.272 | 0.183 | 5 | 0.030 | 0.052 | 0.049 | 5 | 0.200 | 0.220 | 0.144 |
| *Miller | 31037433 | 3 | 1.130 | 1.124 | 0.484 | 3 | 0.510 | 0.497 | 0.300 | 3 | 0.060 | 0.103 | 0.121 | 4 | 0.325 | 0.345 | 0.184 |
| Onion | 22010143 | 2 | 1.718 | 1.718 | 0.005 | 2 | 1.405 | 1.405 | 0.304 | 2 | 0.020 | 0.020 | 0.000 | 2 | 1.385 | 1.385 | 0.304 |
| Palisade | 22012011 | 1 | 0.762 | 0.762 | | 1 | 0.210 | 0.210 | | 1 | 0.050 | 0.050 | | 1 | 0.160 | 0.160 | |
| Poplar[2] | 22009751 | 29 | 1.220 | 0.118 | 0.313 | 0 | | | | 0 | | | | 29 | 0.480 | 0.490 | 0.169 |
| *Poplar[1] | 22009865 | 39 | 1.070 | 1.142 | 0.344 | 15 | 0.420 | 0.387 | 0.098 | 15 | 0.050 | 0.050 | 0.020 | 46 | 0.430 | 0.432 | 0.155 |
| Sawbill | 22007440 | 2 | 0.446 | 0.446 | 0.207 | 2 | 0.140 | 0.140 | 0.057 | 2 | 0.015 | 0.015 | 0.007 | 2 | 0.125 | 0.125 | 0.049 |
| Skunk | 31030812 | 3 | 0.964 | 0.857 | 0.287 | 2 | 0.520 | 0.520 | 0.042 | 2 | 0.020 | 0.020 | 0.014 | 3 | 0.480 | 0.353 | 0.255 |
| Split Rock | 22012526 | 9 | 0.657 | 0.698 | 0.167 | 9 | 0.140 | 0.174 | 0.134 | 9 | 0.010 | 0.013 | 0.012 | 9 | 0.130 | 0.161 | 0.124 |
| Stanley | 31034607 | 1 | 0.630 | 0.630 | | 1 | 0.300 | 0.300 | | 1 | 0.130 | 0.130 | | 1 | 0.170 | 0.170 | |
| *Sucker | 31035415 | 43 | 0.910 | 0.925 | 0.327 | 3 | 0.310 | 0.297 | 0.140 | 3 | 0.090 | 0.093 | 0.045 | 43 | 0.120 | 0.162 | 0.111 |
| Sugarloaf | 22011076 | 9 | 0.571 | 0.616 | 0.171 | 9 | 0.150 | 0.202 | 0.156 | 9 | 0.020 | 0.018 | 0.014 | 9 | 0.130 | 0.184 | 0.144 |
| Talmadge | 31035804 | 25 | 1.160 | 1.289 | 0.549 | 1 | 0.500 | 0.500 | | 1 | 0.010 | 0.010 | | 25 | 0.220 | 0.257 | 0.194 |
| Temperance | 22007788 | 2 | 0.536 | 0.536 | 0.234 | 2 | 0.175 | 0.175 | 0.134 | 2 | 0.040 | 0.040 | 0.028 | 2 | 0.135 | 0.135 | 0.106 |
| Tischer | 31036814 | 41 | 1.152 | 1.323 | 0.705 | 40 | 0.580 | 0.653 | 0.329 | 40 | 0.090 | 0.145 | 0.141 | 41 | 0.510 | 0.500 | 0.232 |
| Two Island | 22010764 | 2 | 0.671 | 0.671 | 0.234 | 2 | 0.185 | 0.185 | 0.163 | 2 | 0.010 | 0.010 | 0.000 | 2 | 0.175 | 0.175 | 0.163 |
| West Branch Knife | 31034133 | 2 | 0.742 | 0.742 | 0.322 | 1 | 0.430 | 0.430 | | 1 | 0.020 | 0.020 | | 2 | 0.215 | 0.215 | 0.276 |

**Appendix Q: Summary statistics for soluble water quality metrics related to nitrogen for each watershed during rain periods.**

| | | Total-N (mg/L) | | | | DIN (mg/L) | | | | Ammonium-N (mg/L) | | | | [Nitrate+Nitrite]-N (mg/L) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Stream Name | Watershed ID | N | Median | Mean | Std Dev | N | Median | Mean | Std Dev | N | Median | Mean | Std Dev | N | Median | Mean | Std Dev |
| Amity[1] | 31036326 | 7 | 0.408 | 0.395 | 0.102 | 7 | 0.060 | 0.087 | 0.07 | 7 | 0.010 | 0.009 | 0.004 | 7 | 0.060 | 0.079 | 0.071 |
| *Amity | 31036466 | 49 | 0.840 | 0.879 | 0.480 | 30 | 0.110 | 0.168 | 0.17 | 30 | 0.010 | 0.017 | 0.018 | 48 | 0.090 | 0.149 | 0.149 |
| Amity East | 31036341 | 7 | 0.668 | 0.623 | 0.247 | 5 | 0.070 | 0.084 | 0.07 | 5 | 0.010 | 0.012 | 0.004 | 5 | 0.060 | 0.072 | 0.067 |
| Baptism | 22011810 | 2 | 0.535 | 0.535 | 0.120 | 0 | | | | 0 | | | | 2 | 0.080 | 0.080 | 0.042 |
| Beaver | 22012232 | 3 | 0.654 | 0.739 | 0.153 | 3 | 0.180 | 0.163 | 0.11 | 3 | 0.010 | 0.013 | 0.006 | 3 | 0.160 | 0.150 | 0.105 |
| *Beaver[2] | 22012244 | 0 | | | | 6 | 0.130 | 0.165 | 0.11 | 6 | 0.025 | 0.032 | 0.015 | 7 | 0.100 | 0.129 | 0.097 |
| Beaver[3] | 22012296 | 15 | 0.817 | 0.784 | 0.144 | 15 | 0.040 | 0.059 | 0.06 | 15 | 0.010 | 0.014 | 0.011 | 15 | 0.030 | 0.045 | 0.049 |
| Blind Temperance | 22009979 | 5 | 1.931 | 2.118 | 1.214 | 5 | 0.900 | 1.118 | 1.01 | 5 | 0.030 | 0.026 | 0.011 | 5 | 0.860 | 1.092 | 1.007 |
| *Brule | 22007634 | 13 | 0.580 | 0.615 | 0.117 | 6 | 0.160 | 0.165 | 0.10 | 7 | 0.020 | 0.044 | 0.040 | 20 | 0.065 | 0.097 | 0.065 |
| Caribou[1] | 22009302 | 6 | 0.526 | 0.518 | 0.057 | 6 | 0.090 | 0.083 | 0.02 | 6 | 0.035 | 0.032 | 0.015 | 6 | 0.055 | 0.052 | 0.012 |
| Caribou | 22011270 | 3 | 0.550 | 0.639 | 0.343 | 3 | 0.120 | 0.140 | 0.06 | 3 | 0.010 | 0.013 | 0.006 | 3 | 0.110 | 0.127 | 0.057 |
| Cascade[1] | 22007777 | 4 | 0.505 | 0.517 | 0.101 | 4 | 0.035 | 0.043 | 0.02 | 4 | 0.010 | 0.010 | 0.000 | 4 | 0.025 | 0.033 | 0.019 |
| Cascade | 22009269 | 3 | 0.542 | 0.612 | 0.292 | 3 | 0.070 | 0.137 | 0.12 | 3 | 0.010 | 0.010 | 0.010 | 3 | 0.070 | 0.127 | 0.107 |
| *Chester | 31036987 | 66 | 0.765 | 0.853 | 0.332 | 71 | 0.170 | 0.232 | 0.25 | 71 | 0.030 | 0.050 | 0.107 | 71 | 0.150 | 0.182 | 0.170 |
| Cross | 22010227 | 2 | 0.476 | 0.476 | 0.025 | 2 | 0.030 | 0.030 | 0.01 | 2 | 0.005 | 0.005 | 0.007 | 2 | 0.025 | 0.025 | 0.021 |
| East Beaver | 22012109 | 2 | 0.479 | 0.479 | 0.182 | 2 | 0.090 | 0.090 | 0.04 | 2 | 0.015 | 0.015 | 0.021 | 2 | 0.075 | 0.075 | 0.021 |
| East Split Rock | 22012354 | 2 | 0.736 | 0.736 | 0.093 | 8 | 0.020 | 0.035 | 0.03 | 8 | 0.010 | 0.010 | 0.008 | 8 | 0.010 | 0.025 | 0.030 |
| Encampment[1] | 31032334 | 14 | 0.849 | 0.884 | 0.241 | 14 | 0.120 | 0.171 | 0.14 | 14 | 0.015 | 0.016 | 0.010 | 14 | 0.105 | 0.155 | 0.143 |
| Encampment | 31032914 | 3 | 0.718 | 0.759 | 0.109 | 3 | 0.030 | 0.050 | 0.04 | 3 | 0.020 | 0.017 | 0.006 | 3 | 0.020 | 0.033 | 0.042 |
| Flute Reed | 22007315 | 1 | 1.130 | 1.130 | | 0 | | | | 0 | | | | 1 | 0.210 | 0.210 | |
| *French | 31035723 | 34 | 0.738 | 0.808 | 0.243 | 17 | 0.030 | 0.039 | 0.03 | 17 | 0.010 | 0.011 | 0.002 | 34 | 0.050 | 0.054 | 0.050 |
| Gooseberry | 31032212 | 3 | 0.749 | 0.739 | 0.275 | 3 | 0.040 | 0.060 | 0.06 | 3 | 0.010 | 0.017 | 0.012 | 3 | 0.030 | 0.043 | 0.051 |
| Keene | 36000247 | 0 | | | | 5 | 0.130 | 0.190 | 0.14 | 5 | 0.070 | 0.094 | 0.067 | 8 | 0.085 | 0.104 | 0.061 |
| *Kingsbury | 31037901 | 62 | 0.865 | 0.908 | 0.261 | 59 | 0.290 | 0.315 | 0.17 | 59 | 0.020 | 0.042 | 0.041 | 59 | 0.260 | 0.273 | 0.148 |
| Knife[3] | 31033053 | 2 | 0.701 | 0.701 | 0.130 | 6 | 0.020 | 0.027 | 0.02 | 6 | 0.010 | 0.010 | 0.006 | 7 | 0.010 | 0.027 | 0.030 |

| Stream Name | Watershed ID | Total-N (mg/L) | | | | DIN (mg/L) | | | | Ammonium-N (mg/L) | | | | [Nitrate+Nitrite]-N (mg/L) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | N | Median | Mean | Std Dev | N | Median | Mean | Std Dev | N | Median | Mean | Std Dev | N | Median | Mean | Std Dev |
| Lester[1] | 31035556 | 24 | 0.814 | 0.798 | 0.162 | 24 | 0.030 | 0.046 | 0.04 | 24 | 0.010 | 0.013 | 0.008 | 24 | 0.020 | 0.034 | 0.039 |
| Little Knife | 31035071 | 3 | 0.649 | 0.600 | 0.109 | 6 | 0.025 | 0.023 | 0.01 | 6 | 0.020 | 0.017 | 0.010 | 7 | 0.010 | 0.007 | 0.005 |
| McCarthy | 31033237 | 3 | 0.398 | 0.394 | 0.026 | 5 | 0.010 | 0.014 | 0.01 | 5 | 0.010 | 0.008 | 0.004 | 7 | 0.010 | 0.007 | 0.005 |
| Miller[3] | 31036923 | 0 | | | | 2 | 0.095 | 0.095 | 0.05 | 2 | 0.050 | 0.050 | 0.028 | 9 | 0.020 | 0.024 | 0.019 |
| Miller[2] | 31037116 | 0 | | | | 6 | 0.145 | 0.222 | 0.17 | 7 | 0.110 | 0.114 | 0.088 | 10 | 0.040 | 0.087 | 0.106 |
| *Miller[1] | 31037257 | 5 | 0.630 | 0.834 | 0.447 | 10 | 0.068 | 0.092 | 0.06 | 10 | 0.015 | 0.016 | 0.014 | 13 | 0.070 | 0.092 | 0.071 |
| Miller | 31037433 | 6 | 0.830 | 0.884 | 0.352 | 6 | 0.189 | 0.215 | 0.13 | 6 | 0.030 | 0.058 | 0.068 | 8 | 0.134 | 0.122 | 0.094 |
| Mission | 31038874 | 0 | | | | 1 | 0.070 | 0.070 | | 1 | 0.060 | 0.060 | | 2 | 0.015 | 0.015 | 0.007 |
| Onion | 22010143 | 3 | 0.990 | 0.979 | 0.095 | 3 | 0.210 | 0.303 | 0.18 | 3 | 0.010 | 0.017 | 0.021 | 3 | 0.200 | 0.287 | 0.159 |
| Palisade | 22012011 | 6 | 1.046 | 1.040 | 0.169 | 6 | 0.180 | 0.158 | 0.09 | 6 | 0.010 | 0.015 | 0.012 | 6 | 0.155 | 0.143 | 0.090 |
| Poplar[2] | 22009751 | 23 | 0.710 | 0.799 | 0.302 | 1 | 0.120 | 0.120 | | 1 | 0.010 | 0.010 | | 23 | 0.110 | 0.192 | 0.212 |
| *Poplar[1] | 22009865 | 24 | 0.850 | 0.900 | 0.316 | 7 | 0.190 | 0.347 | 0.34 | 7 | 0.020 | 0.034 | 0.018 | 31 | 0.130 | 0.194 | 0.200 |
| Sawbill | 22007440 | 10 | 0.396 | 0.438 | 0.144 | 9 | 0.020 | 0.029 | 0.02 | 9 | 0.010 | 0.011 | 0.009 | 10 | 0.010 | 0.020 | 0.016 |
| Skunk | 31030812 | 11 | 0.601 | 0.628 | 0.189 | 15 | 0.040 | 0.064 | 0.07 | 15 | 0.010 | 0.011 | 0.010 | 15 | 0.030 | 0.053 | 0.074 |
| Split Rock | 22012526 | 3 | 0.763 | 0.717 | 0.287 | 3 | 0.040 | 0.067 | 0.06 | 3 | 0.010 | 0.013 | 0.006 | 3 | 0.030 | 0.053 | 0.059 |
| Stanley | 31034607 | 6 | 0.907 | 0.854 | 0.186 | 6 | 0.140 | 0.140 | 0.05 | 6 | 0.035 | 0.037 | 0.014 | 6 | 0.105 | 0.103 | 0.053 |
| *Sucker[1] | 31035415 | 44 | 0.763 | 0.797 | 0.219 | 21 | 0.020 | 0.032 | 0.04 | 21 | 0.010 | 0.012 | 0.016 | 44 | 0.050 | 0.048 | 0.052 |
| Sugarloaf | 22011076 | 3 | 0.610 | 0.647 | 0.075 | 3 | 0.100 | 0.183 | 0.19 | 3 | 0.010 | 0.010 | 0.010 | 3 | 0.080 | 0.173 | 0.197 |
| *Talmadge | 31035804 | 31 | 0.891 | 0.943 | 0.200 | 11 | 0.090 | 0.128 | 0.09 | 11 | 0.010 | 0.013 | 0.009 | 31 | 0.050 | 0.096 | 0.083 |
| Temperance | 22007788 | 7 | 0.502 | 0.537 | 0.108 | 7 | 0.030 | 0.043 | 0.03 | 7 | 0.020 | 0.020 | 0.010 | 7 | 0.020 | 0.023 | 0.018 |
| *Tischer | 31036814 | 67 | 0.795 | 0.857 | 0.250 | 71 | 0.280 | 0.301 | 0.17 | 71 | 0.020 | 0.053 | 0.054 | 71 | 0.240 | 0.247 | 0.135 |
| Two Island | 22010764 | 3 | 0.519 | 0.568 | 0.176 | 3 | 0.160 | 0.163 | 0.05 | 3 | 0.010 | 0.013 | 0.006 | 3 | 0.150 | 0.150 | 0.040 |
| West Branch Knife | 31034133 | 4 | 0.654 | 0.623 | 0.200 | 8 | 0.015 | 0.023 | 0.03 | 8 | 0.010 | 0.008 | 0.007 | 8 | 0.010 | 0.015 | 0.023 |

**Appendix R: Summary statistics for soluble water quality metrics related to nitrogen for each watershed during baseflow.**

| | | Total-N (mg/L) | | | | DIN (mg/L) | | | | Ammonium-N (mg/L) | | | | [Nitrate+Nitrite]-N (mg/L) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Stream Name** | **Watershed ID** | **N** | **Median** | **Mean** | **Std Dev** | **N** | **Median** | **Mean** | **Std Dev** | **N** | **Median** | **Mean** | **Std Dev** | **N** | **Median** | **Mean** | **Std Dev** |
| Amity[1] | 31036326 | 9 | 0.323 | 0.343 | 0.093 | 7 | 0.070 | 0.073 | 0.035 | 9 | 0.010 | 0.012 | 0.008 | 7 | 0.060 | 0.059 | 0.038 |
| *Amity | 31036466 | 32 | 0.425 | 0.493 | 0.224 | 10 | 0.045 | 0.076 | 0.085 | 12 | 0.010 | 0.016 | 0.012 | 27 | 0.050 | 0.070 | 0.097 |
| Amity East | 31036341 | 11 | 0.378 | 0.374 | 0.124 | 11 | 0.050 | 0.062 | 0.064 | 11 | 0.000 | 0.005 | 0.005 | 11 | 0.050 | 0.057 | 0.066 |
| Baptism | 22011810 | 19 | 0.620 | 0.630 | 0.140 | 6 | 0.100 | 0.180 | 0.177 | 6 | 0.050 | 0.050 | 0.000 | 19 | 0.050 | 0.088 | 0.102 |
| Beaver[1] | 22012232 | 7 | 0.662 | 0.846 | 0.465 | 7 | 0.520 | 0.581 | 0.661 | 7 | 0.010 | 0.009 | 0.004 | 7 | 0.510 | 0.573 | 0.660 |
| *Beaver[2] | 22012244 | 1 | 0.741 | 0.741 | | 21 | 0.240 | 0.441 | 0.520 | 21 | 0.040 | 0.035 | 0.016 | 27 | 0.240 | 0.451 | 0.508 |
| Beaver[3] | 22012296 | 9 | 0.694 | 0.650 | 0.136 | 10 | 0.025 | 0.026 | 0.013 | 10 | 0.010 | 0.008 | 0.004 | 10 | 0.015 | 0.018 | 0.012 |
| Blind Temperance | 22009979 | 9 | 1.238 | 1.265 | 0.771 | 9 | 0.310 | 0.519 | 0.529 | 9 | 0.020 | 0.018 | 0.008 | 9 | 0.290 | 0.501 | 0.526 |
| *Brule | 22007634 | 28 | 0.485 | 0.518 | 0.123 | 16 | 0.090 | 0.104 | 0.041 | 21 | 0.050 | 0.038 | 0.021 | 45 | 0.050 | 0.066 | 0.030 |
| Caribou[1] | 22009302 | 6 | 0.493 | 0.470 | 0.049 | 5 | 0.080 | 0.076 | 0.021 | 7 | 0.020 | 0.020 | 0.008 | 5 | 0.060 | 0.056 | 0.021 |
| Caribou | 22011270 | 8 | 0.382 | 0.378 | 0.093 | 8 | 0.110 | 0.125 | 0.057 | 8 | 0.010 | 0.008 | 0.005 | 8 | 0.105 | 0.118 | 0.058 |
| Cascade[1] | 22007777 | 6 | 0.388 | 0.407 | 0.081 | 6 | 0.035 | 0.033 | 0.018 | 6 | 0.005 | 0.005 | 0.005 | 6 | 0.025 | 0.028 | 0.015 |
| Cascade | 22009269 | 8 | 0.353 | 0.353 | 0.048 | 8 | 0.060 | 0.079 | 0.050 | 8 | 0.010 | 0.006 | 0.005 | 8 | 0.050 | 0.073 | 0.053 |
| *Chester | 31036987 | 27 | 0.750 | 0.765 | 0.225 | 26 | 0.185 | 0.254 | 0.211 | 27 | 0.020 | 0.044 | 0.057 | 26 | 0.160 | 0.209 | 0.193 |
| Cross | 22010227 | 5 | 0.407 | 0.451 | 0.098 | 5 | 0.030 | 0.030 | 0.016 | 5 | 0.000 | 0.006 | 0.009 | 5 | 0.020 | 0.024 | 0.011 |
| East Beaver | 22012109 | 4 | 0.528 | 0.509 | 0.081 | 4 | 0.055 | 0.055 | 0.031 | 4 | 0.010 | 0.018 | 0.015 | 4 | 0.030 | 0.038 | 0.030 |
| East Split Rock | 22012354 | 6 | 0.600 | 0.607 | 0.098 | 8 | 0.035 | 0.040 | 0.023 | 8 | 0.010 | 0.011 | 0.006 | 8 | 0.020 | 0.029 | 0.021 |
| Encampment | 31032334 | 9 | 0.582 | 0.643 | 0.153 | 9 | 0.060 | 0.061 | 0.042 | 9 | 0.010 | 0.012 | 0.007 | 9 | 0.040 | 0.049 | 0.038 |
| Encampment[1] | 31032914 | 12 | 0.448 | 0.488 | 0.274 | 12 | 0.025 | 0.033 | 0.031 | 12 | 0.005 | 0.007 | 0.009 | 12 | 0.015 | 0.027 | 0.032 |
| Flute Reed | 22007315 | 1 | 0.694 | 0.694 | | 1 | 0.420 | 0.420 | | 1 | 0.020 | 0.020 | | 3 | 0.100 | 0.197 | 0.176 |
| *French | 31035723 | 27 | 0.440 | 0.486 | 0.197 | 9 | 0.030 | 0.030 | 0.014 | 9 | 0.010 | 0.013 | 0.011 | 25 | 0.050 | 0.045 | 0.040 |
| Gooseberry | 31032212 | 8 | 0.339 | 0.329 | 0.097 | 5 | 0.010 | 0.012 | 0.008 | 8 | 0.005 | 0.005 | 0.005 | 5 | 0.000 | 0.006 | 0.009 |
| Keene | 36000247 | 3 | 0.444 | 0.425 | 0.112 | 12 | 0.130 | 0.146 | 0.053 | 12 | 0.040 | 0.043 | 0.012 | 24 | 0.090 | 0.093 | 0.052 |
| *Kingsbury | 31037901 | 24 | 0.703 | 0.729 | 0.255 | 17 | 0.190 | 0.216 | 0.145 | 17 | 0.010 | 0.029 | 0.040 | 17 | 0.180 | 0.187 | 0.143 |
| Knife[2] | 31033053 | 6 | 0.320 | 0.343 | 0.083 | 8 | 0.045 | 0.046 | 0.030 | 8 | 0.015 | 0.014 | 0.007 | 9 | 0.030 | 0.036 | 0.028 |
| Lester[1] | 31035556 | 13 | 0.516 | 0.553 | 0.218 | 14 | 0.040 | 0.039 | 0.027 | 14 | 0.010 | 0.009 | 0.006 | 14 | 0.030 | 0.029 | 0.026 |

| | | Total-N (mg/L) | | | | DIN (mg/L) | | | | Ammonium-N (mg/L) | | | | [Nitrate+Nitrite]-N (mg/L) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Stream Name** | **Watershed ID** | **N** | **Median** | **Mean** | **Std Dev** | **N** | **Median** | **Mean** | **Std Dev** | **N** | **Median** | **Mean** | **Std Dev** | **N** | **Median** | **Mean** | **Std Dev** |
| Little Knife | 31035071 | 5 | 0.402 | 0.446 | 0.144 | 8 | 0.025 | 0.024 | 0.017 | 9 | 0.010 | 0.012 | 0.013 | 8 | 0.010 | 0.013 | 0.009 |
| McCarthy | 31033237 | 6 | 0.380 | 0.386 | 0.046 | 9 | 0.020 | 0.019 | 0.015 | 9 | 0.010 | 0.011 | 0.009 | 10 | 0.010 | 0.008 | 0.006 |
| Miller[3] | 31036923 | 0 | | | | 1 | 0.110 | 0.110 | | 2 | 0.040 | 0.040 | 0.000 | 18 | 0.045 | 0.094 | 0.134 |
| Miller[2] | 31037116 | 0 | | | | 11 | 0.190 | 0.249 | 0.196 | 13 | 0.040 | 0.083 | 0.164 | 19 | 0.100 | 0.122 | 0.098 |
| *Miller[1] | 31037257 | 9 | 0.611 | 0.637 | 0.099 | 19 | 0.200 | 0.267 | 0.178 | 19 | 0.030 | 0.069 | 0.092 | 35 | 0.160 | 0.201 | 0.167 |
| *Miller | 31037433 | 1 | 0.536 | 0.536 | | 3 | 0.140 | 0.137 | 0.045 | 4 | 0.065 | 0.070 | 0.029 | 25 | 0.090 | 0.087 | 0.051 |
| Mission | 31038874 | 2 | 0.277 | 0.277 | 0.178 | 1 | 0.070 | 0.070 | | 4 | 0.030 | 0.053 | 0.045 | 5 | 0.020 | 0.028 | 0.016 |
| Onion | 22010143 | 6 | 0.624 | 0.647 | 0.145 | 6 | 0.115 | 0.127 | 0.084 | 6 | 0.010 | 0.025 | 0.042 | 6 | 0.105 | 0.102 | 0.052 |
| Palisade | 22012011 | 6 | 0.583 | 0.610 | 0.282 | 5 | 0.120 | 0.094 | 0.060 | 6 | 0.010 | 0.022 | 0.034 | 5 | 0.030 | 0.070 | 0.064 |
| Poplar[2] | 22009751 | 26 | 0.546 | 0.605 | 0.146 | 1 | 0.050 | 0.050 | | 1 | 0.030 | 0.030 | | 26 | 0.060 | 0.094 | 0.066 |
| *Poplar[1] | 22009865 | 42 | 0.580 | 0.588 | 0.135 | 26 | 0.100 | 0.143 | 0.101 | 29 | 0.050 | 0.039 | 0.014 | 62 | 0.070 | 0.102 | 0.079 |
| Sawbill | 22007440 | 4 | 0.345 | 0.366 | 0.052 | 4 | 0.035 | 0.038 | 0.028 | 4 | 0.010 | 0.013 | 0.015 | 4 | 0.025 | 0.025 | 0.013 |
| Skunk | 31030812 | 11 | 0.348 | 0.350 | 0.058 | 16 | 0.035 | 0.037 | 0.027 | 16 | 0.010 | 0.009 | 0.007 | 16 | 0.025 | 0.028 | 0.022 |
| Split Rock | 22012526 | 8 | 0.350 | 0.354 | 0.082 | 8 | 0.010 | 0.014 | 0.012 | 8 | 0.010 | 0.006 | 0.005 | 8 | 0.005 | 0.008 | 0.009 |
| Stanley | 31034607 | 9 | 0.652 | 0.631 | 0.162 | 9 | 0.060 | 0.068 | 0.035 | 9 | 0.020 | 0.020 | 0.013 | 9 | 0.030 | 0.048 | 0.038 |
| *Sucker[1] | 31035415 | 30 | 0.575 | 0.559 | 0.152 | 11 | 0.010 | 0.015 | 0.009 | 14 | 0.010 | 0.013 | 0.016 | 31 | 0.050 | 0.038 | 0.027 |
| Sugarloaf | 22011076 | 7 | 0.463 | 0.484 | 0.068 | 7 | 0.090 | 0.143 | 0.107 | 7 | 0.010 | 0.009 | 0.004 | 7 | 0.080 | 0.134 | 0.108 |
| *Talmadge | 31035804 | 30 | 0.599 | 0.640 | 0.200 | 5 | 0.040 | 0.056 | 0.035 | 5 | 0.010 | 0.016 | 0.013 | 26 | 0.050 | 0.072 | 0.083 |
| Temperance | 22007788 | 5 | 0.427 | 0.436 | 0.037 | 5 | 0.050 | 0.054 | 0.026 | 5 | 0.010 | 0.014 | 0.011 | 5 | 0.030 | 0.040 | 0.031 |
| *Tischer | 31036814 | 25 | 0.610 | 0.628 | 0.140 | 23 | 0.310 | 0.270 | 0.111 | 24 | 0.020 | 0.024 | 0.025 | 23 | 0.270 | 0.246 | 0.107 |
| Two Island | 22010764 | 4 | 0.501 | 0.562 | 0.179 | 4 | 0.105 | 0.110 | 0.032 | 4 | 0.020 | 0.020 | 0.008 | 4 | 0.090 | 0.090 | 0.037 |
| West Branch Knife | 31034133 | 5 | 0.522 | 0.458 | 0.157 | 8 | 0.020 | 0.023 | 0.007 | 8 | 0.010 | 0.013 | 0.007 | 9 | 0.010 | 0.011 | 0.006 |

**Appendix S: Summary statistics for soluble water quality metrics for each watershed during snowmelt.**

| | | DO (mg/L) | | | | OP (mg/L) | | | | EC25 (uS/cm) | | | | Cl$^-$ (mg/L) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Stream Name** | **Watershed ID** | **N** | **Median** | **Mean** | **Std Dev** | **N** | **Median** | **Mean** | **Std Dev** | **N** | **Median** | **Mean** | **Std Dev** | **N** | **Median** | **Mean** | **Std Dev** |
| Amity[1] | 31036326 | 0 | | | | 2 | 0.009 | 0.009 | 0.000 | 0 | | | | 2 | 36.6 | 36.6 | 10.7 |
| *Amity | 31036466 | 49 | 13.60 | 13.60 | 1.88 | 24 | 0.010 | 0.018 | 0.014 | 65 | 149 | 175 | 91.7 | 51 | 17.0 | 21.7 | 14.7 |
| Amity East | 31036341 | 5 | 14.80 | 14.46 | 0.79 | 0 | | | | 5 | 148 | 139 | 37.1 | 3 | 11.9 | 14.1 | 8.1 |
| Baptism | 22011810 | 11 | 14.70 | 14.56 | 0.64 | 11 | 0.010 | 0.010 | | 11 | 58.0 | 61.4 | 21.5 | 1 | 1.2 | 1.2 | |
| Beaver[1] | 22012232 | 9 | 13.01 | 13.63 | 1.94 | 0 | | | | 9 | 69.4 | 74.3 | 22.1 | 9 | 2.7 | 3.1 | 1.7 |
| *Beaver[2] | 22012244 | 8 | 11.70 | 11.65 | 0.99 | 0 | | | | 8 | 92.5 | 274 | 320 | 2 | 24.1 | 24.1 | 31.0 |
| Beaver[3] | 22012296 | 0 | | | | 1 | 0.005 | 0.005 | | 1 | 38.6 | 38.6 | | 1 | 0.3 | 0.3 | |
| Blind Temperance | 22009979 | 0 | | | | 1 | 0.007 | 0.007 | | 0 | | | | 1 | 0.5 | 0.5 | |
| *Brule | 22007634 | 35 | 13.10 | 12.83 | 1.61 | 17 | 0.010 | 0.010 | 0.000 | 42 | 33.3 | 33.5 | 11.6 | 29 | 1.2 | 1.3 | 0.3 |
| Caribou[1] | 22009302 | 0 | | | | 1 | 0.002 | 0.002 | | 0 | | | | 1 | 2.1 | 2.1 | |
| Caribou | 22011270 | 9 | 13.10 | 24.62 | 33.65 | 0 | | | | 9 | 50.9 | 55.3 | 15.7 | 9 | 0.8 | 0.9 | 0.3 |
| Cascade[1] | 22007777 | 0 | | | | 2 | 0.002 | 0.002 | 0.000 | 2 | 30.3 | 30.3 | 0.2 | 2 | 0.5 | 0.5 | 0.0 |
| Cascade | 22009269 | 9 | 15.05 | 15.23 | 1.32 | 0 | | | | 9 | 39.4 | 46.9 | 17.6 | 9 | 0.8 | 0.8 | 0.2 |
| *Chester | 31036987 | 21 | 14.42 | 14.17 | 1.30 | 27 | 0.010 | 0.019 | 0.018 | 52 | 376 | 535 | 670 | 37 | 70.0 | 146.8 | 238 |
| Cross | 22010227 | 0 | | | | 2 | 0.006 | 0.006 | 0.004 | 2 | 38.5 | 38.5 | 2.5 | 2 | 0.3 | 0.3 | 0.1 |
| East Beaver | 22012109 | 0 | | | | 1 | 0.002 | 0.002 | | 0 | | | | 1 | 0.5 | 0.5 | |
| East Split Rock | 22012354 | 0 | | | | 2 | 0.008 | 0.008 | 0.001 | 1 | 25.0 | 25.0 | | 0 | | | |
| Encampment[1] | 31032334 | 0 | | | | 1 | 0.010 | 0.010 | | 0 | | | | 1 | 1.2 | 1.2 | |
| Encampment | 31032914 | 4 | 12.15 | 12.46 | 2.36 | 0 | | | | 4 | 57.6 | 63.2 | 19.6 | 4 | 1.6 | 2.2 | 1.4 |
| Flute Reed | 22007315 | 6 | 14.27 | 14.11 | 0.66 | 0 | | | | 0 | | | | 0 | | | |
| *French | 31035723 | 27 | 12.96 | 12.88 | 1.31 | 20 | 0.010 | 0.011 | 0.005 | 33 | 65.0 | 69.7 | 20.1 | 41 | 4.6 | 4.9 | 2.5 |
| Gooseberry | 31032212 | 8 | 12.67 | 13.20 | 2.37 | 0 | | | | 9 | 55.3 | 59.4 | 11.7 | 9 | 1.0 | 1.0 | 0.1 |
| Keene | 36000247 | 2 | 12.75 | 12.75 | 1.75 | 0 | | | | 2 | 251 | 251 | 86.3 | 0 | | | |
| *Kingsbury | 31037901 | 20 | 15.35 | 15.05 | 1.35 | 24 | 0.010 | 0.017 | 0.012 | 51 | 322 | 456 | 540 | 37 | 62.0 | 111.7 | 175 |
| Knife[2] | 31033053 | 0 | | | | 1 | 0.005 | 0.005 | | 1 | 35.0 | 35.0 | | 0 | | | |
| *Knife[1] | 31033543 | 4 | 11.68 | 11.71 | 1.11 | 0 | | | | 5 | 68.0 | 63.4 | 39.1 | 0 | | | |

| Stream Name | Watershed ID | DO (mg/L) | | | | OP (mg/L) | | | | EC25 (uS/cm) | | | | $Cl^-$ (mg/L) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | N | Median | Mean | Std Dev | N | Median | Mean | Std Dev | N | Median | Mean | Std Dev | N | Median | Mean | Std Dev |
| Knife[3] | 31033901 | 1 | 11.39 | 11.39 | | 0 | | | | 1 | 62.1 | 62.1 | | 0 | | | |
| Lester[1] | 31035556 | 0 | | | | 3 | 0.010 | 0.010 | 0.005 | 2 | 104 | 104 | 44.9 | 3 | 6.5 | 6.1 | 0.8 |
| Little Knife | 31035071 | 2 | 10.60 | 10.60 | 0.95 | 2 | 0.012 | 0.012 | 0.006 | 1 | 45.0 | 45.0 | | 0 | | | |
| McCarthy | 31033237 | 0 | | | | 2 | 0.009 | 0.009 | 0.006 | 1 | 50.0 | 50.0 | | 0 | | | |
| *Miller[1] | 31037257 | 3 | 14.45 | 14.49 | 0.61 | 2 | 0.006 | 0.006 | 0.001 | 5 | 476 | 403 | 140 | 2 | 193.8 | 193.8 | 212 |
| *Miller | 31037433 | 4 | 14.06 | 13.46 | 1.33 | 2 | 0.025 | 0.025 | 0.021 | 6 | 531 | 819 | 856 | 2 | 417.5 | 417.5 | 411 |
| Onion | 22010143 | 0 | | | | 2 | 0.007 | 0.007 | 0.001 | 1 | 75.5 | 75.5 | | 2 | 0.6 | 0.6 | 0.1 |
| Palisade | 22012011 | 0 | | | | 1 | 0.012 | 0.012 | 0.000 | 1 | 198 | 198 | | 1 | 1.5 | 1.5 | |
| Poplar[2] | 22009751 | 26 | 12.21 | 12.14 | 1.16 | 22 | 0.010 | 0.010 | 0.000 | 32 | 44.5 | 45.3 | 11.5 | 37 | 1.4 | 1.5 | 0.3 |
| Poplar[3] | 22009769 | 1 | 13.15 | 13.15 | | 0 | | | | 6 | 61.0 | 60.8 | 7.6 | 0 | | | |
| *Poplar1 | 22009865 | 45 | 13.10 | 13.02 | 1.39 | 32 | 0.010 | 0.018 | 0.026 | 49 | 57.0 | 68.3 | 82.0 | 45 | 1.6 | 1.8 | 0.7 |
| Poplar | 22009995 | 0 | | | | 0 | | | | 2 | 67.0 | 67.0 | 8.5 | 0 | | | |
| Sawbill | 22007440 | 0 | | | | 2 | 0.003 | 0.003 | 0.002 | 2 | 33.6 | 33.6 | 3.0 | 2 | 0.3 | 0.3 | 0.1 |
| Skunk | 31030812 | 0 | | | | 3 | 0.005 | 0.005 | 0.003 | 1 | 40.0 | 40.0 | | 1 | 0.5 | 0.5 | |
| Split Rock | 22012526 | 9 | 12.47 | 13.22 | 1.95 | 0 | | | | 9 | 43.2 | 51.3 | 16.5 | 9 | 0.9 | 0.9 | 0.2 |
| Stanley | 31034607 | 0 | | | | 1 | 0.012 | 0.012 | | 0 | | | | 1 | 1.4 | 1.4 | |
| *Sucker[1] | 31035415 | 45 | 13.50 | 13.21 | 1.51 | 37 | 0.010 | 0.010 | 0.001 | 51 | 67.0 | 69.1 | 20.9 | 52 | 1.6 | 2.4 | 3.3 |
| Sugarloaf | 22011076 | 9 | 12.20 | 13.17 | 1.67 | 0 | | | | 9 | 48.6 | 47.2 | 7.2 | 9 | 0.7 | 0.7 | 0.1 |
| *Talmadge | 31035804 | 26 | 13.40 | 12.98 | 1.44 | 25 | 0.010 | 0.012 | 0.006 | 32 | 85.3 | 86.0 | 24.9 | 42 | 7.3 | 8.3 | 5.0 |
| Temperance | 22007788 | 0 | | | | 2 | 0.003 | 0.003 | 0.002 | 2 | 25.6 | 25.6 | 1.6 | 2 | 0.4 | 0.4 | 0.1 |
| Tischer[1] | 31036716 | 0 | | | | 0 | | | | 9 | 277 | 412 | 235 | 0 | | | |
| *Tischer | 31036814 | 21 | 14.76 | 14.68 | 1.05 | 27 | 0.020 | 0.021 | 0.015 | 60 | 454 | 653 | 612 | 38 | 66.5 | 146.6 | 194 |
| Two Island | 22010764 | 0 | | | | 2 | 0.009 | 0.009 | 0.000 | 3 | 38.2 | 37.4 | 3.8 | 2 | 0.4 | 0.4 | 0.0 |
| West Branch Knife | 31034133 | 0 | | | | 2 | 0.010 | 0.018 | 0.014 | 1 | 40.0 | 40.0 | | 0 | | | |

**Appendix T: Summary statistics for soluble water quality metrics for each watershed during rain periods.**

| Stream Name | Watershed ID | DO (mg/L) | | | | OP (mg/L) | | | | EC25 (uS/cm) | | | | $Cl^-$ (mg/L) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | N | Median | Mean | Std Dev | N | Median | Mean | Std Dev | N | Median | Mean | Std Dev | N | Median | Mean | Std Dev |
| Amity[1] | 31036326 | 0 | | | | 7 | 0.006 | 0.006 | 0.002 | 7 | 288.1 | 286.9 | 17.0 | 7 | 19.0 | 18.8 | 1.07 |
| *Amity | 31036466 | 61 | 10.6 | 10.6 | 1.5 | 22 | 0.010 | 0.015 | 0.010 | 74 | 192.0 | 203.5 | 76.0 | 51 | 20.0 | 19.7 | 7.10 |
| Amity East | 31036341 | 10 | 10.5 | 10.7 | 1.1 | 0 | | | | 11 | 198.0 | 193.7 | 75.9 | 5 | 15.0 | 16.7 | 6.46 |
| Baptism | 22011810 | 3 | 9.6 | 10.0 | 0.8 | 3 | 0.010 | 0.010 | 0.000 | 3 | 105.0 | 99.7 | 27.4 | 0 | | | |
| Beaver[1] | 22012232 | 3 | 10.9 | 10.7 | 0.5 | 0 | | | | 3 | 62.8 | 99.2 | 70.4 | 3 | 1.9 | 5.5 | 6.57 |
| *Beaver[2] | 22012244 | 8 | 9.6 | 10.2 | 2.0 | 0 | | | | 8 | 153.0 | 321.4 | 492.0 | 1 | 2.3 | 2.3 | |
| Beaver | 22012278 | 0 | | | | 0 | | | | 1 | 101.2 | 101.2 | | 0 | | | |
| Beaver[3] | 22012296 | 1 | 8.7 | 8.7 | | 15 | 0.004 | 0.004 | 0.002 | 16 | 73.8 | 78.1 | 29.2 | 5 | 0.37 | 0.39 | 0.08 |
| Blind Temperance | 22009979 | 0 | | | | 5 | 0.008 | 0.008 | 0.002 | 6 | 74.4 | 181.2 | 273.8 | 1 | 0.52 | 0.52 | |
| *Brule | 22007634 | 31 | 10.1 | 10.4 | 2.0 | 14 | 0.010 | 0.010 | 0.000 | 36 | 44.5 | 53.6 | 64.1 | 24 | 1.5 | 1.6 | 0.43 |
| Caribou[1] | 22009302 | 1 | 10.8 | 10.8 | | 6 | 0.006 | 0.006 | 0.002 | 7 | 67.6 | 68.1 | 2.0 | 6 | 1.1 | 1.1 | 0.41 |
| Caribou | 22011270 | 3 | 10.7 | 10.1 | 1.2 | 0 | | | | 3 | 53.7 | 66.0 | 33.5 | 3 | 1.2 | 1.4 | 0.33 |
| Cascade[1] | 22007777 | 0 | | | | 4 | 0.004 | 0.004 | 0.001 | 4 | 39.2 | 41.3 | 10.1 | 0 | | | |
| Cascade | 22009269 | 3 | 11.3 | 10.6 | 1.2 | 0 | | | | 3 | 37.2 | 51.7 | 28.8 | 3 | 0.97 | 0.88 | 0.17 |
| *Chester | 31036987 | 39 | 9.4 | 9.4 | 1.9 | 43 | 0.020 | 0.016 | 0.009 | 71 | 272.0 | 278.1 | 83.8 | 51 | 47.0 | 49.0 | 19.0 |
| Cross | 22010227 | 0 | | | | 2 | 0.002 | 0.002 | 0.002 | 2 | 51.8 | 51.8 | 0.9 | 0 | | | |
| East Beaver | 22012109 | 0 | | | | 2 | 0.004 | 0.004 | 0.004 | 2 | 123.2 | 123.2 | 65.8 | 2 | 0.85 | 0.85 | 0.46 |
| East Split Rock | 22012354 | 0 | | | | 8 | 0.008 | 0.011 | 0.011 | 3 | 60.0 | 68.3 | 18.9 | 0 | | | |
| Encampment[1] | 31032334 | 0 | | | | 14 | 0.007 | 0.006 | 0.003 | 13 | 103.5 | 127.2 | 62.9 | 2 | 1.6 | 1.6 | 1.58 |
| Encampment | 31032914 | 3 | 11.0 | 11.0 | 0.0 | 0 | | | | 3 | 62.1 | 72.2 | 23.6 | 3 | 2.4 | 2.7 | 0.77 |
| *Flute Reed[4] | 22006835 | 3 | 9.7 | 10.5 | 1.9 | 0 | | | | 0 | | | | 0 | | | |
| Flute Reed[3] | 22007233 | 5 | 9.9 | 10.2 | 1.2 | 0 | | | | 0 | | | | 0 | | | |
| Flute Reed[1] | 22007234 | 6 | 10.2 | 10.9 | 1.3 | 0 | | | | 0 | | | | 0 | | | |
| Flute Reed[2] | 22007237 | 3 | 10.2 | 10.9 | 1.4 | 0 | | | | 0 | | | | 0 | | | |
| Flute Reed | 22007315 | 5 | 10.4 | 10.8 | 1.4 | 0 | | | | 0 | | | | 0 | | | |
| *French | 31035723 | 35 | 10.7 | 10.6 | 1.4 | 34 | 0.008 | 0.008 | 0.007 | 54 | 97.5 | 108.0 | 38.9 | 52 | 4.2 | 4.2 | 1.97 |

| Stream Name | Watershed ID | DO (mg/L) N | DO Median | DO Mean | DO Std Dev | OP (mg/L) N | OP Median | OP Mean | OP Std Dev | EC25 (uS/cm) N | EC25 Median | EC25 Mean | EC25 Std Dev | $Cl^-$ (mg/L) N | $Cl^-$ Median | $Cl^-$ Mean | $Cl^-$ Std Dev |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Gooseberry | 31032212 | 3 | 11.3 | 11.2 | 0.5 | 0 | | | | 4 | 77.4 | 78.5 | 23.9 | 3 | 1.1 | 1.1 | 0.28 |
| Keene | 36000247 | 8 | 9.4 | 9.4 | 0.9 | 0 | | | | 8 | 361.5 | 400.4 | 166.6 | 0 | | | |
| *Kingsbury | 31037901 | 37 | 10.6 | 10.5 | 1.5 | 32 | 0.020 | 0.026 | 0.021 | 63 | 299.0 | 312.9 | 120.4 | 49 | 50.0 | 61.7 | 39.3 |
| Knife[2] | 31033053 | 0 | | | | 7 | 0.007 | 0.007 | 0.003 | 1 | 50.0 | 50.0 | | 0 | | | |
| *Knife[1] | 31033543 | 21 | 10.0 | 10.1 | 0.9 | 0 | | | | 18 | 136.9 | 128.5 | 43.8 | 0 | | | |
| Knife[3] | 31033901 | 3 | 7.9 | 8.4 | 1.1 | 0 | | | | 3 | 167.4 | 194.7 | 58.2 | 0 | | | |
| Knife | 31035065 | 0 | | | | 0 | | | | 1 | 133.8 | 133.8 | | 0 | | | |
| Lester[1] | 31035556 | 0 | | | | 24 | 0.005 | 0.006 | 0.004 | 24 | 102.9 | 122.2 | 35.4 | 14 | 5.3 | 5.0 | 1.28 |
| Lester | 31036559 | 0 | | | | 0 | | | | 1 | 199.5 | 199.5 | | 0 | | | |
| Little Knife | 31035071 | 8 | 8.3 | 8.0 | 2.2 | 7 | 0.006 | 0.009 | 0.007 | 2 | 102.5 | 102.5 | 24.7 | 0 | | | |
| McCarthy | 31033237 | 0 | | | | 7 | 0.006 | 0.007 | 0.004 | 4 | 102.5 | 102.0 | 28.4 | 0 | | | |
| Miller[3] | 31036923 | 9 | 7.8 | 8.0 | 1.2 | 0 | | | | 3 | 316.0 | 337.0 | 128.8 | 0 | | | |
| Miller[2] | 31037116 | 5 | 8.8 | 10.2 | 3.4 | 0 | | | | 35 | 311.0 | 366.6 | 179.0 | 0 | | | |
| *Miller[1] | 31037257 | 5 | 10.4 | 10.3 | 0.8 | 8 | 0.007 | 0.009 | 0.006 | 11 | 386.5 | 423.0 | 151.7 | 2 | 45.6 | 45.6 | 2.62 |
| *Miller | 31037433 | 4 | 9.9 | 10.3 | 1.2 | 3 | 0.030 | 0.023 | 0.012 | 6 | 238.4 | 244.3 | 85.3 | 3 | 31.0 | 37.3 | 22.2 |
| Mission | 31038874 | 4 | 8.8 | 9.0 | 0.6 | 0 | | | | 4 | 428.5 | 415.0 | 168.0 | 0 | | | |
| Onion | 22010143 | 0 | | | | 3 | 0.012 | 0.012 | 0.007 | 3 | 61.4 | 58.0 | 7.1 | 3 | 0.22 | 0.20 | 0.04 |
| Palisade | 22012011 | 0 | | | | 6 | 0.018 | 0.020 | 0.011 | 6 | 88.3 | 90.8 | 14.7 | 6 | 2.8 | 2.8 | 1.06 |
| Poplar[2] | 22009751 | 29 | 9.4 | 10.0 | 2.2 | 23 | 0.010 | 0.010 | 0.000 | 29 | 58.0 | 62.6 | 28.4 | 35 | 1.6 | 1.6 | 0.39 |
| Poplar[3] | 22009769 | 9 | 10.5 | 10.6 | 1.7 | 0 | | | | 14 | 65.0 | 66.5 | 14.8 | 4 | 2.3 | 2.3 | 0.41 |
| *Poplar[1] | 22009865 | 36 | 9.8 | 10.3 | 1.7 | 24 | 0.010 | 0.012 | 0.005 | 39 | 63.0 | 80.1 | 106.5 | 41 | 1.8 | 2.1 | 1.15 |
| Poplar | 22009995 | 3 | 10.2 | 9.9 | 2.1 | 0 | | | | 3 | 78.8 | 76.3 | 12.2 | 0 | | | |
| Sawbill | 22007440 | 1 | 7.0 | 7.0 | | 10 | 0.003 | 0.003 | 0.001 | 10 | 32.6 | 33.4 | 3.0 | 1 | 0.03 | 0.03 | |
| Skunk | 31030812 | 0 | | | | 15 | 0.007 | 0.006 | 0.004 | 12 | 106.3 | 105.3 | 24.3 | 8 | 0.19 | 0.50 | 0.86 |
| Split Rock | 22012526 | 3 | 11.0 | 9.4 | 2.8 | 0 | | | | 3 | 39.1 | 65.2 | 46.5 | 3 | 1.4 | 1.5 | 0.33 |
| Stanley | 31034607 | 0 | | | | 6 | 0.006 | 0.006 | 0.004 | 6 | 114.8 | 131.2 | 52.1 | 0 | | | |
| *Sucker[1] | 31035415 | 39 | 10.4 | 10.3 | 1.1 | 48 | 0.010 | 0.010 | 0.009 | 64 | 94.2 | 104.9 | 40.6 | 50 | 1.8 | 2.2 | 2.74 |
| Sucker | 31035442 | 0 | | | | 0 | | | | 1 | 141.9 | 141.9 | | 0 | | | |
| Sugarloaf | 22011076 | 3 | 10.6 | 10.1 | 1.0 | 0 | | | | 3 | 43.9 | 59.3 | 37.0 | 3 | 0.83 | 0.75 | 0.23 |

| | | DO (mg/L) | | | | OP (mg/L) | | | | EC25 (uS/cm) | | | | Cl⁻ (mg/L) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Stream Name** | **Watershed ID** | **N** | **Median** | **Mean** | **Std Dev** | **N** | **Median** | **Mean** | **Std Dev** | **N** | **Median** | **Mean** | **Std Dev** | **N** | **Median** | **Mean** | **Std Dev** |
| *Talmadge | 31035804 | 29 | 10.3 | 10.3 | 1.3 | 32 | 0.010 | 0.036 | 0.131 | 45 | 112.1 | 128.6 | 49.1 | 52 | 7.1 | 7.7 | 4.72 |
| Temperance | 22007788 | 0 | | | | 7 | 0.001 | 0.002 | 0.002 | 7 | 26.9 | 27.5 | 1.3 | 0 | | | |
| Tischer[1] | 31036716 | 0 | | | | 0 | | | | 22 | 274.0 | 354.5 | 233.4 | 0 | | | |
| *Tischer | 31036814 | 39 | 9.8 | 9.9 | 1.6 | 42 | 0.020 | 0.025 | 0.018 | 91 | 255.6 | 298.5 | 218.9 | 51 | 38.0 | 48.4 | 53.6 |
| Two Island | 22010764 | 1 | 17.7 | 17.7 | | 2 | 0.003 | 0.003 | 0.000 | 3 | 61.7 | 73.8 | 21.9 | 1 | 0.51 | 0.51 | |
| West Branch Knife | 31034133 | 0 | | | | 8 | 0.005 | 0.006 | 0.002 | 5 | 92.0 | 89.4 | 27.1 | 0 | | | |

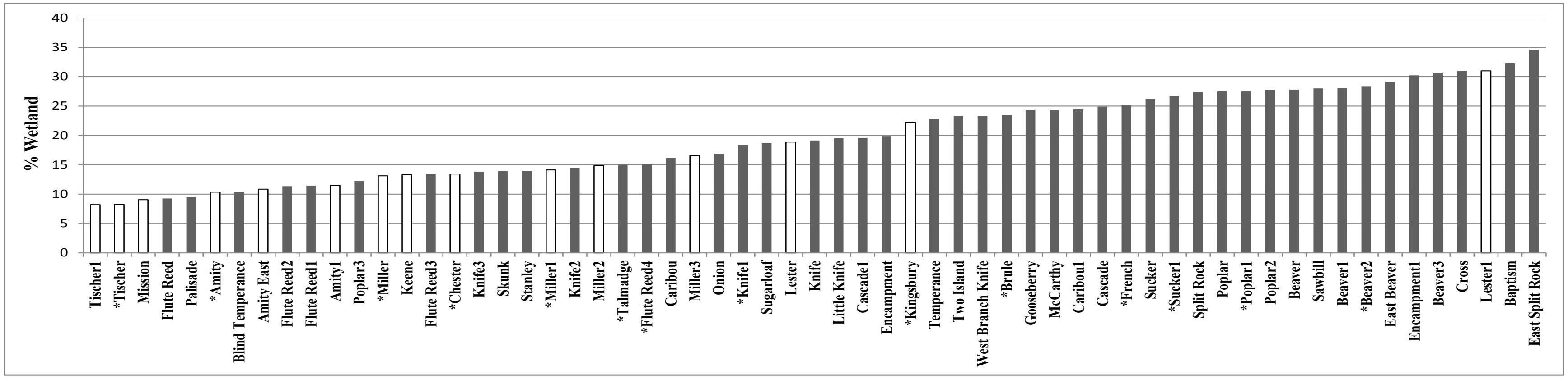
**Appendix U: Summary statistics for soluble water quality for each watershed during baseflow.**

| | | DO (mg/L) | | | | OP (mg/L) | | | | EC25 (uS/cm) | | | | $Cl^-$ (mg/L) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Stream Name** | **Watershed ID** | **N** | **Median** | **Mean** | **Std Dev** | **N** | **Median** | **Mean** | **Std Dev** | **N** | **Median** | **Mean** | **Std Dev** | **N** | **Median** | **Mean** | **Std Dev** |
| Amity[1] | 31036326 | 0 | | | | 9 | 0.005 | 0.009 | 0.008 | 9 | 294.5 | 278.9 | 36.8 | 9 | 19.2 | 19.4 | 3.02 |
| *Amity | 31036466 | 39 | 10.0 | 10.3 | 1.8 | 18 | 0.010 | 0.012 | 0.007 | 50 | 291.7 | 267.1 | 63.2 | 37 | 25.0 | 25.6 | 7.79 |
| Amity East | 31036341 | 13 | 9.9 | 10.1 | 1.5 | 0 | | | | 13 | 276.5 | 258.6 | 71.6 | 12 | 25.2 | 28.0 | 13.4 |
| Baptism | 22011810 | 20 | 10.5 | 10.8 | 1.6 | 19 | 0.010 | 0.010 | 0.000 | 20 | 78.0 | 85.6 | 32.0 | 6 | 2.3 | 2.5 | 0.66 |
| Beaver[1] | 22012232 | 7 | 10.4 | 10.0 | 1.0 | 0 | | | | 7 | 287.7 | 296.9 | 213.3 | 7 | 20.8 | 30.6 | 35.8 |
| *Beaver[2] | 22012244 | 31 | 9.7 | 10.0 | 2.0 | 0 | | | | 33 | 298.0 | 324.3 | 160.7 | 6 | 20.7 | 34.0 | 34.2 |
| Beaver | 22012278 | 1 | 9.4 | 9.4 | | 0 | | | | 8 | 265.0 | 248.5 | 120.0 | 0 | | | |
| Beaver[3] | 22012296 | 3 | 7.7 | 8.8 | 1.9 | 10 | 0.003 | 0.003 | 0.002 | 14 | 101.2 | 107.2 | 33.6 | 6 | 0.4 | 0.5 | 0.32 |
| Blind Temperance | 22009979 | 3 | 10.9 | 11.0 | 0.4 | 9 | 0.009 | 0.009 | 0.005 | 12 | 72.3 | 76.0 | 22.5 | 4 | 0.4 | 0.8 | 0.90 |
| *Brule | 22007634 | 56 | 9.1 | 9.5 | 1.8 | 27 | 0.010 | 0.010 | 0.000 | 64 | 47.0 | 47.0 | 11.6 | 40 | 1.5 | 1.5 | 0.42 |
| Caribou[2] | 22009302 | 0 | | | | 7 | 0.005 | 0.011 | 0.014 | 7 | 66.1 | 67.4 | 2.9 | 7 | 0.9 | 0.8 | 0.23 |
| Caribou | 22011270 | 8 | 10.6 | 10.4 | 0.7 | 0 | | | | 8 | 97.4 | 93.1 | 17.6 | 8 | 1.7 | 1.7 | 0.57 |
| Cascade[2] | 22007777 | 1 | 8.8 | 8.8 | | 6 | 0.002 | 0.002 | 0.002 | 7 | 53.9 | 86.3 | 88.9 | 5 | 0.7 | 0.8 | 0.45 |
| Cascade | 22009269 | 8 | 10.7 | 10.8 | 1.0 | 0 | | | | 8 | 53.2 | 57.9 | 19.2 | 8 | 0.8 | 0.8 | 0.23 |
| *Chester | 31036987 | 11 | 8.9 | 9.1 | 1.9 | 12 | 0.010 | 0.012 | 0.005 | 36 | 364.3 | 355.3 | 102.8 | 21 | 68.0 | 79.5 | 34.5 |
| Cross | 22010227 | 2 | 7.1 | 7.1 | 0.6 | 5 | 0.002 | 0.003 | 0.003 | 9 | 69.5 | 68.8 | 20.3 | 4 | 0.3 | 0.4 | 0.26 |
| East Beaver | 22012109 | 0 | | | | 4 | 0.009 | 0.017 | 0.021 | 5 | 77.8 | 82.3 | 19.8 | 4 | 0.6 | 0.6 | 0.11 |
| East Split Rock | 22012354 | 0 | | | | 8 | 0.007 | 0.007 | 0.001 | 9 | 100.0 | 98.9 | 31.2 | 0 | | | |
| Encampment[1] | 31032334 | 0 | | | | 9 | 0.005 | 0.006 | 0.004 | 9 | 92.9 | 145.7 | 93.2 | 4 | 1.1 | 1.2 | 0.58 |
| Encampment | 31032914 | 12 | 8.7 | 8.9 | 1.6 | 0 | | | | 12 | 187.1 | 188.4 | 48.4 | 12 | 5.7 | 9.3 | 12.6 |
| *Flute Reed[4] | 22006835 | 9 | 9.8 | 10.1 | 1.2 | 0 | | | | 0 | | | | 0 | | | |
| Flute Reed[3] | 22007233 | 18 | 10.0 | 10.1 | 1.1 | 0 | | | | 0 | | | | 0 | | | |
| Flute Reed[1] | 22007234 | 18 | 10.0 | 10.4 | 1.0 | 0 | | | | 0 | | | | 0 | | | |
| Flute Reed[2] | 22007237 | 9 | 10.1 | 10.5 | 0.9 | 0 | | | | 0 | | | | 0 | | | |
| Flute Reed | 22007315 | 23 | 10.4 | 10.8 | 1.5 | 1 | 0.009 | 0.009 | | 1 | 89.4 | 89.4 | | 0 | | | |
| *French | 31035723 | 26 | 9.6 | 10.1 | 1.8 | 25 | 0.010 | 0.009 | 0.006 | 36 | 170.6 | 158.0 | 43.2 | 41 | 4.4 | 4.8 | 4.22 |

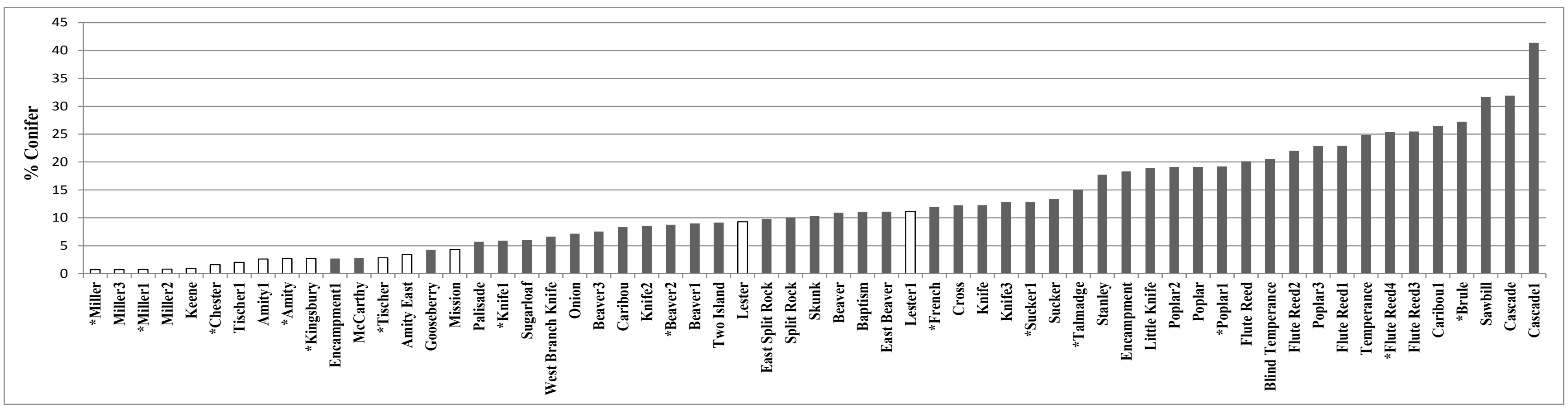
| Stream Name | Watershed ID | DO (mg/L) | | | | OP (mg/L) | | | | EC25 (uS/cm) | | | | $Cl^-$ (mg/L) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | N | Median | Mean | Std Dev | N | Median | Mean | Std Dev | N | Median | Mean | Std Dev | N | Median | Mean | Std Dev |
| Gooseberry | 31032212 | 8 | 9.9 | 9.6 | 1.2 | 0 | | | | 16 | 147.5 | 140.8 | 32.8 | 8 | 1.2 | 1.2 | 0.26 |
| Keene | 36000247 | 13 | 9.6 | 9.8 | 1.6 | 0 | | | | 13 | 489.0 | 492.9 | 124.0 | 4 | 63.1 | 68.7 | 32.0 |
| *Kingsbury | 31037901 | 11 | 9.9 | 9.7 | 1.3 | 4 | 0.010 | 0.013 | 0.005 | 27 | 407.0 | 452.4 | 173.4 | 19 | 78.0 | 89.0 | 39.4 |
| Knife[2] | 31033053 | 0 | | | | 9 | 0.005 | 0.006 | 0.002 | 8 | 97.5 | 92.8 | 25.9 | 0 | | | |
| *Knife[1] | 31033543 | 48 | 9.9 | 10.2 | 1.3 | 0 | | | | 42 | 177.5 | 175.3 | 35.8 | 0 | | | |
| Knife[3] | 31033901 | 3 | 8.9 | 9.1 | 1.4 | 0 | | | | 3 | 222.0 | 216.7 | 24.7 | 0 | | | |
| Knife | 31035065 | 0 | | | | 0 | | | | 8 | 161.2 | 149.6 | 27.9 | 0 | | | |
| Lester[1] | 31035556 | 3 | 8.3 | 9.2 | 1.6 | 14 | 0.005 | 0.004 | 0.002 | 17 | 179.0 | 161.7 | 41.0 | 12 | 4.5 | 4.1 | 1.10 |
| Lester | 31036559 | 0 | | | | 0 | | | | 8 | 208.2 | 200.2 | 26.3 | 0 | | | |
| Little Knife | 31035071 | 23 | 8.2 | 8.3 | 1.8 | 9 | 0.006 | 0.005 | 0.002 | 10 | 120.0 | 128.0 | 52.4 | 0 | | | |
| McCarthy | 31033237 | 0 | | | | 10 | 0.007 | 0.013 | 0.019 | 9 | 135.0 | 134.8 | 21.2 | 0 | | | |
| Miller[3] | 31036923 | 21 | 8.0 | 7.6 | 2.2 | 0 | | | | 4 | 453.0 | 458.8 | 112.0 | 0 | | | |
| Miller[2] | 31037116 | 14 | 8.8 | 8.8 | 1.8 | 0 | | | | 76 | 558.5 | 602.6 | 346.7 | 0 | | | |
| *Miller[1] | 31037257 | 28 | 9.8 | 10.1 | 1.1 | 8 | 0.005 | 0.005 | 0.002 | 42 | 511.0 | 567.6 | 196.6 | 4 | 154.0 | 150.1 | 58.2 |
| *Miller | 31037433 | 26 | 9.6 | 10.0 | 1.3 | 1 | 0.010 | 0.010 | | 7 | 466.0 | 461.9 | 62.0 | 1 | 60.0 | 60.0 | |
| Mission | 31038874 | 14 | 10.0 | 10.1 | 1.1 | 0 | | | | 14 | 437.5 | 471.0 | 123.6 | 3 | 80.6 | 78.1 | 6.34 |
| Onion | 22010143 | 0 | | | | 6 | 0.010 | 0.012 | 0.009 | 6 | 74.2 | 78.7 | 19.6 | 6 | 0.5 | 0.4 | 0.19 |
| Palisade | 22012011 | 0 | | | | 6 | 0.005 | 0.004 | 0.002 | 6 | 125.9 | 126.5 | 30.5 | 6 | 4.7 | 4.3 | 2.48 |
| Poplar[2] | 22009751 | 35 | 9.0 | 10.0 | 3.5 | 25 | 0.010 | 0.010 | 0.000 | 33 | 69.4 | 73.1 | 24.4 | 34 | 1.5 | 1.6 | 0.56 |
| Poplar[3] | 22009769 | 8 | 9.0 | 9.3 | 1.1 | 0 | | | | 16 | 74.0 | 73.9 | 7.5 | 3 | 1.9 | 1.8 | 0.21 |
| *Poplar[1] | 22009865 | 77 | 9.4 | 9.9 | 2.1 | 40 | 0.010 | 0.010 | 0.000 | 80 | 70.6 | 69.3 | 13.9 | 44 | 1.6 | 1.6 | 0.43 |
| Poplar | 22009995 | 6 | 8.9 | 9.1 | 1.3 | 0 | | | | 10 | 71.8 | 69.4 | 8.8 | 0 | | | |
| Sawbill | 22007440 | 1 | 7.9 | 7.9 | | 4 | 0.001 | 0.002 | 0.001 | 5 | 34.9 | 35.7 | 3.8 | 4 | 0.3 | 0.2 | 0.10 |
| Skunk | 31030812 | 1 | 9.8 | 9.8 | | 16 | 0.005 | 0.006 | 0.006 | 16 | 132.3 | 121.0 | 38.2 | 5 | 0.5 | 0.6 | 0.18 |
| Split Rock | 22012526 | 8 | 10.2 | 9.3 | 2.1 | 0 | | | | 8 | 145.8 | 141.0 | 36.8 | 8 | 2.5 | 2.3 | 0.80 |
| Stanley | 31034607 | 1 | 9.4 | 9.4 | | 9 | 0.010 | 0.008 | 0.006 | 10 | 133.3 | 149.2 | 58.3 | 5 | 9.9 | 9.1 | 4.46 |
| *Sucker[1] | 31035415 | 40 | 9.5 | 9.9 | 1.6 | 35 | 0.010 | 0.008 | 0.003 | 52 | 139.5 | 145.9 | 48.8 | 46 | 1.5 | 1.5 | 0.48 |
| Sucker | 31035442 | 0 | | | | 0 | | | | 8 | 158.4 | 146.6 | 23.7 | 0 | | | |
| Sugarloaf | 22011076 | 7 | 10.3 | 11.0 | 3.1 | 0 | | | | 7 | 80.9 | 80.4 | 13.8 | 7 | 0.6 | 0.8 | 0.29 |

| Stream Name | Watershed ID | DO (mg/L) | | | | OP (mg/L) | | | | EC25 (uS/cm) | | | | $Cl^-$ (mg/L) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | N | Median | Mean | Std Dev | N | Median | Mean | Std Dev | N | Median | Mean | Std Dev | N | Median | Mean | Std Dev |
| *Talmadge | 31035804 | 24 | 9.5 | 9.8 | 2.4 | 27 | 0.010 | 0.010 | 0.004 | 30 | 190.7 | 192.1 | 56.3 | 44 | 9.7 | 9.9 | 2.50 |
| Temperance | 22007788 | 1 | 9.1 | 9.1 | | 5 | 0.002 | 0.002 | 0.001 | 6 | 32.9 | 45.3 | 32.1 | 5 | 0.3 | 0.3 | 0.08 |
| Tischer[1] | 31036716 | 3 | 10.4 | 10.4 | 0.5 | 0 | | | | 55 | 315.6 | 346.0 | 160.7 | 1 | 130.7 | 130.7 | |
| *Tischer | 31036814 | 11 | 9.5 | 9.6 | 1.5 | 12 | 0.012 | 0.013 | 0.007 | 80 | 386.0 | 394.3 | 246.4 | 20 | 65.5 | 88.2 | 84.2 |
| Two Island | 22010764 | 2 | 7.8 | 7.8 | 0.3 | 4 | 0.002 | 0.002 | 0.002 | 6 | 81.0 | 72.9 | 27.9 | 4 | 0.6 | 0.6 | 0.33 |
| West Branch Knife | 31034133 | 0 | | | | 9 | 0.006 | 0.006 | 0.002 | 10 | 135.0 | 122.0 | 37.9 | 0 | | | |

**Appendix V: % Watershed in a National Wetland Inventory class other than upland. * indicates streams with a long term water quality data set. White bars indicate streams within the city limits of Duluth, MN.**




**Appendix W: % Conifer within each watershed, from 2006 NLCD. * indicates streams with a long term water quality data set. White bars indicate streams within the city limits of Duluth, MN.**



**Appendix X: % Deciduous within each watershed, from 2006 NLCD. * indicates streams with a long term water quality data set. White columns indicate streams within the city limits of Duluth, MN.**