Duluth Metropolitan Area Streams Snowmelt Runoff Study

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Executive Summary

The streams of the North Shore of Lake Superior are typically high gradient, and exhibit high flows coincident with snowmelt and spring rains. The streams within the Duluth Metropolitan Area (DMA) are no exception. Urbanization of watersheds can have dramatic impacts on both the hydrology and water quality of streams. During snowmelt these impacts can be severe, because of the variety of contaminants concentrated in the snowpack –including trace metals, road salt, sediment, and nutrients.

Four of the larger streams in the DMA were sampled to collect baseline water quality data during the snowmelt runoff period to improve our understanding of impact that may occur during or as a result of snowmelt. Amity, Miller, Keene, and Kingsbury Creeks were each sampled at three locations along the watershed's urbanization gradient. Samples were collected on the rise, peak, and fall of the snowmelt hydrograph, and during summer baseflow for comparison. Samples were analyzed for pollutants commonly found in urban runoff: fecal coliform bacteria, biochemical oxygen demand, total suspended solids, total dissolved solids, chloride, nitrogen, phosphorus, and zinc. Typically, concentrations of nutrients and sediment mirrored the pattern of discharge over the hydrograph: highest at the peak, lower but similar concentrations on the rise and fall, and lowest concentrations during summer baseflow. Concentrations were compared to water quality standards where available (e.g., chloride, fecal coliform bacteria, zinc). The total chloride and total zinc standards were not exceeded in any samples. Although the fecal coliform standard was not exceeded, high (>200) values were found in the Keene and Kingsbury Creek watersheds. For those parameters without standards (suspended sediment, nitrogen, and phosphorus), data were compared to the typical range (interquartile range) of concentrations for the Northern Lakes and Forests (NLF) ecoregion. This range was derived from data collected at minimally-impacted streams in the NLF. Phosphorus concentrations were below the 75th percentile of the NLF stream data in most samples. Nitrogen concentrations exceeded the 75th percentile in all snowmelt samples, and during baseflow in Keene and Kingsbury Creeks. Total suspended sediment concentrations were typically greater than the 75th percentile during snowmelt, but not during baseflow. Biochemical oxygen demand (BOD) concentrations exceeded the 4 mg/L detection limit only in the Miller Creek watershed, and some values exceeded minimum secondary treatment limits assigned to wastewater treatment facility discharges.

Yields (amount per unit area of watershed per time; e.g. kg/mi^2/day) of nutrients and sediments during snowmelt were approximately an order of magnitude higher than yields during baseflow. It was hypothesized that yields of nitrogen, phosphorus, and suspended sediment would increase as urbanization in the watershed increased. This was not always the case. Yields of these parameters were lowest in Amity and Miller Creeks, the watersheds with the lowest, and highest, percentage of urban land use. Kingsbury Creek was the only watershed where yields increased at sites from the headwaters to the confluence. A summary of recommendations and best management practices for the protection of surface waters during winter and snowmelt conditions is also included.

Introduction

The Streams of Duluth

The Duluth Metropolitan Area (DMA; Figure 1) is fortunate to possess abundant water resources, including 43 streams within the city limits. Historical and current land use practices have adversely impacted the water resources in the DMA. Channelization, under-grounding, and a lack of stormwater treatment have degraded streams. Urban land use practices, such as filling wetlands and increasing the amount of impervious surfaces (roads, rooftops, and parking lots), have altered streamflow patterns by concentrating and increasing the volume of runoff to streams. The land use practices identified above led to the following conclusion from a 1973 report on the Duluth streams: “The storm water removal system in the city of Duluth to a large extent makes use of the natural streams and ditches in the area as main truck lines to conduct the storm water from collection points to the [St. Louis] Bay or Lake [Lake Superior]” (US Army Corps of Engineers, 1973).

Urban stormwater impacts to DMA streams can be severe in the snowmelt runoff period for several reasons: 1. Duluth has one of the highest annual snowfall amounts in the state, averaging 79.5 inches per year (in 1998-99 Duluth received 90.2 inches), and many streams receive their highest annual flows during the snowmelt runoff period. 2. The area’s high gradient, thin soils and surficial and bedrock geology reduce the potential for infiltration 3. Because of the size of the stream’s drainage areas [comparatively small], the ability to store, retain, or retard flow for long periods is restricted (COE 1973).

Four of the largest watersheds in the DMA are Amity, Miller, Keene, and Kingsbury Creeks (Table 1, Figure 2). These streams were chosen for study by virtue of their varying land uses and documented water quality problems. Table 2 shows the percentages of principal land uses in the DMA watersheds (Figure 3 is a map of the data). Urbanization increases from the headwaters to the confluence. The State of Minnesota has designated all four streams as trout waters (Minnesota Rules, Chapter 7050.0470).

The main branch of Amity Creek flows southeasterly, until it meets the East Branch, then the stream flows through Lester and Amity city parks, where it meets the Lester River at the extreme eastern edge of the DMA. Amity Creek is one of the least urbanized streams in the DMA.

The headwaters of Miller Creek are in a wetland near a solid waste landfill. From there the creek flows past the Duluth International Airport, and then through a high-density commercial area that includes a large shopping center (Miller Hill Mall). Next the creek flows down the escarpment, through a city park, then is routed underground before entering St. Louis Bay in an industrial area near the outfall of the Western Lake Superior Sanitary District.

Keene Creek originates in a forested / sparsely populated area in the city of Hermantown. As the creek flows downstream, urban impacts increase. The creek enters St. Louis Bay in an industrial / commercial area near Grassy Point and the Interlake Superfund Site (Hallet Dock Slip 7).

Kingsbury Creek also originates in Hermantown, where the creek flows through Mogie Lake in Proctor and crosses the city on the southwest side of a railroad yard, then

Figure 1. Location of the Study Area
The Duluth Metropolitan Area

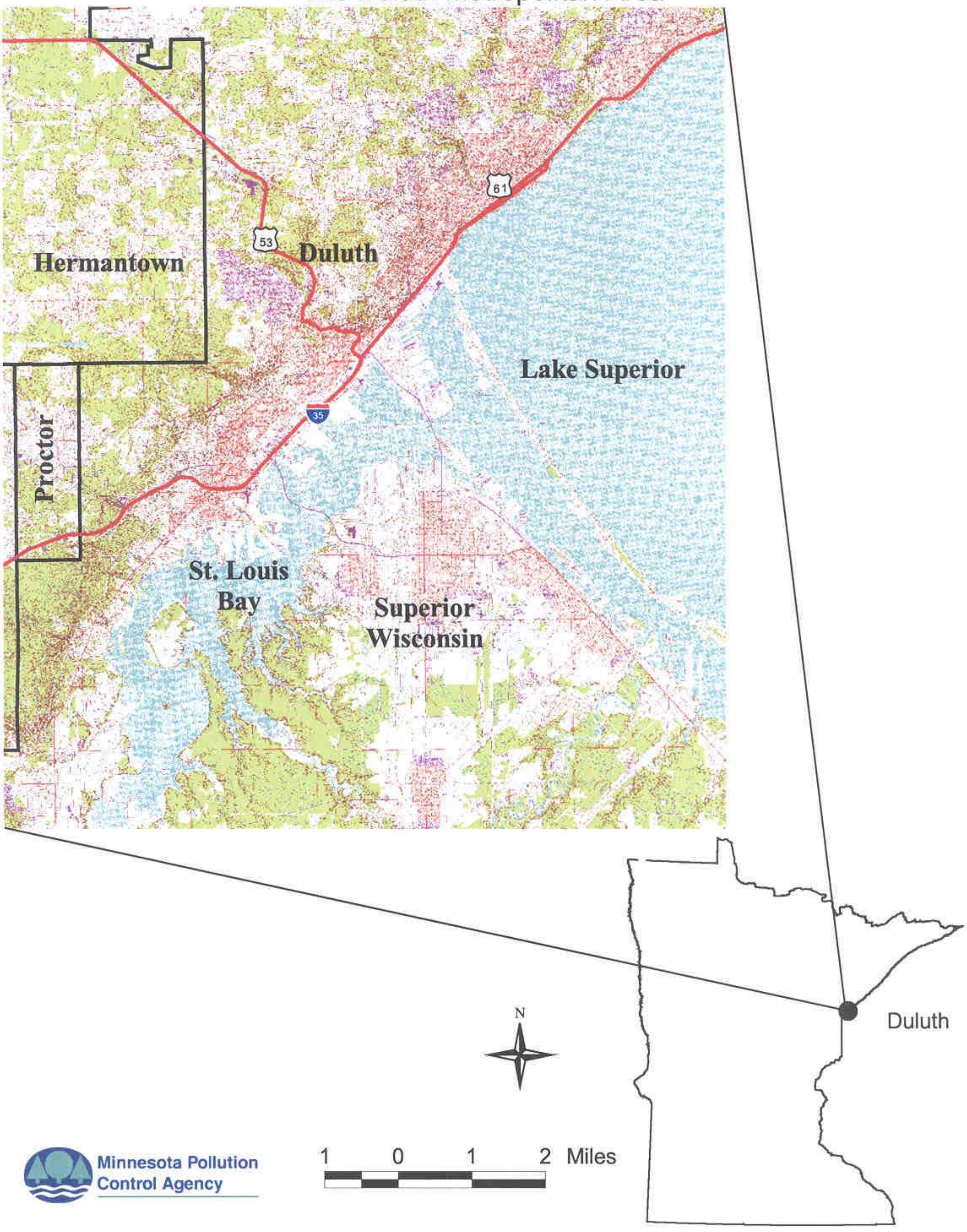

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Figure 2. Duluth Metropolitan Area Stream Sampling Sites

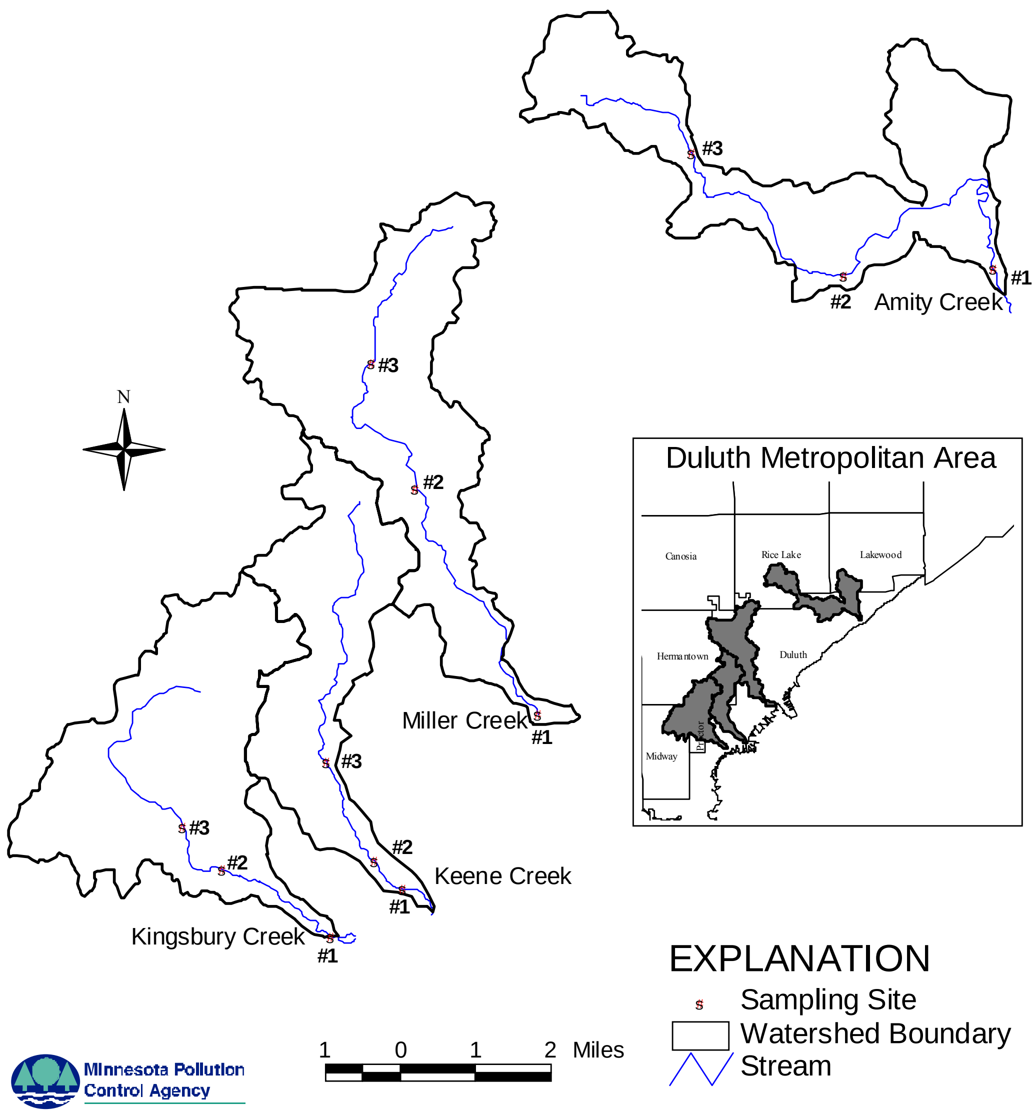
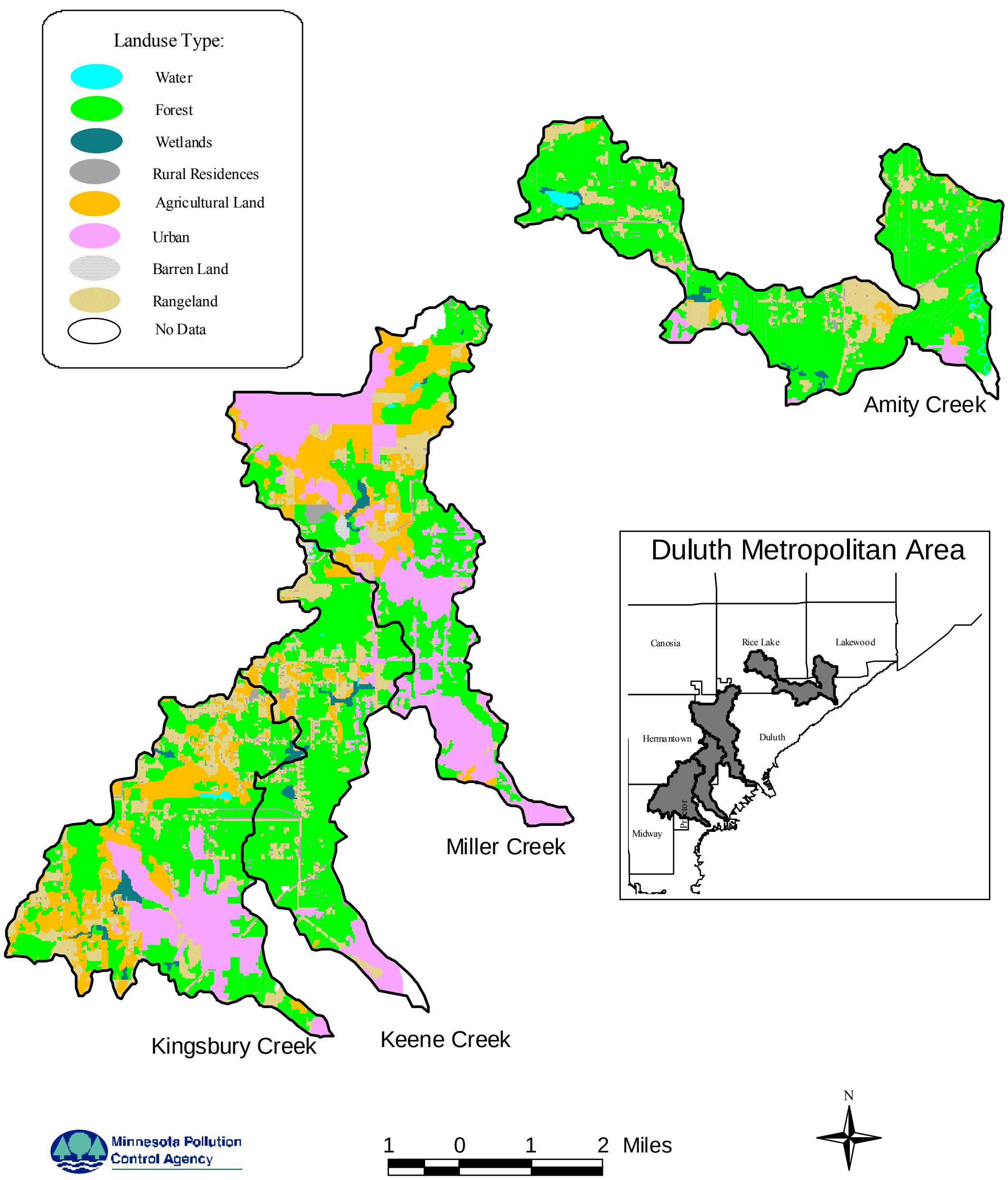


Figure 3. Land Uses in Select Duluth Metropolitan Area Stream Watersheds



it flows parallel to Highway 2, enters the Duluth city limits, crosses under I-35, flows through the Duluth Zoo, and empties into the St. Louis River (WLSSD, 1975).

Table 1. Watershed Characteristics of Select Duluth Streams

Stream	Watershed Area (mi^2) [COE, 1973]	Predominant Land Uses- 1973 [COE, 1973]	Predominant Land Use- 1995 [MNDNR, 1995]	Predominant Soil Type [COE, 1975]
Amity	16.59	Farm Land, Open, Forested	Forested	Red glacial till (heavy clay)
Miller	9.7	Forested, Commercial Industrial	Urban	Coarse textured acid glacial till (red sandy loam)
Keene	7.79	Forested, Residential Suburban	Forested	Coarse textured acid glacial till (red sandy loam)
Kingsbury	8.81	Forested, Farm Land, Open	Rangeland	Coarse textured acid glacial till (red sandy loam)

Table 2. Principal land uses upstream of the Duluth stream sampling sites. Data are presented as a percentage of the total watershed area (Data courtesy of the Minnesota Department of Natural Resources, 1995). Note- sites are listed in downstream order.

Site	Agriculture	Forest	Rangeland	Urban	Water	Wetland	Barren
Miller #3	.1	21.1	45	23.3	.4	4.1	5.9
Miller #2	.2	26	37.4	30.3	.2	3.4	2.4
Miller #1	.1	29	28.4	38	.2	2.5	1.8
Kingsbury #3	1.6	33.8	42.8	13	.4	8.5	<.1
Kingsbury #2	1.4	34.3	40.8	15.1	.3	8	<.1
Kingsbury #1	1.3	35.4	37.3	18.4	.3	7.1	.1
Keene #3	1.8	63.9	27.5	4.9	.2	1.8	<.1
Keene #2	1.8	64.7	24.5	7.2	.2	1.5	.1
Keene #1	1.7	62.5	24.1	10	.2	1.5	.1
Amity #3	1.9	72.8	17.6	1.1	2.4	4.2	<.1
Amity #2	1.7	70.8	17.1	4.6	1.5	4.4	<.1
Amity #1	1.8	70.5	21.2	2.3	.8	3.4	<.1

Previous Investigations

In comparison to Lake Superior and the St. Louis River System, there have been few water quality studies conducted on Duluth's streams. In 1972-73, The U.S. Army Corps of Engineers conducted the first study specifically on the streams of Duluth, "Duluth Area Storm Water Study Phase I- Alternative Methods of Managing Storm

Water Problems on Duluth Area Streams". This study was conducted because extensive flooding damage occurred in the DMA in August and September of 1972. Limited amounts of water quality data were collected from this study. A significant contribution from the study was detailed hydrological information on the streams, including unit hydrographs, and forecasted peak discharges. Until the report was complete, there was no known water quality information on any of the streams within Duluth (COE, 1973).

In the mid-1970's the Western Lake Superior Sanitary District (WLSSD) conducted studies on the water quality of Duluth's streams. One report was completed in 1974, "Duluth Creek Survey- Low Flow Conditions"; a second was completed in 1975, "Duluth Creek Survey- High Flow Conditions". Goals of these studies were to: 1. Locate sources of sewage contamination in Duluth Creeks and 2. Assess water quality in these streams under low (and high) flow conditions. Over 30 creeks were sampled for total coliform, fecal coliform, biochemical oxygen demand (BOD), and phosphorus. The low flow study revealed that a number of Duluth streams were "of poor water quality" (Western Lake Superior Sanitary District, 1975). Keene and Kingsbury Creeks were listed as a priority for future work, because samples had "moderate" violations of state water quality standards (Western Lake Superior Sanitary District, 1974). WLSSD continued sampling in some Duluth streams until the mid 1980's (Western Lake Superior Sanitary District, unpublished data).

The Minnesota Pollution Control Agency (MPCA, 1994) conducted an investigation of storm water impacts to Miller Creek, as part of the St. Louis River Remedial Action Plan. The purposes of the study were to: 1. Evaluate the impact of urban storm water runoff on Miller Creek, 2. Rank land uses according to the toxicity or runoff coming from each land use, and 3. Evaluate the pollutant loading contribution of Miller Creek to the St. Louis Bay. Water samples were collected from storm sewers and the Creek, during both snowmelt and rain storm events. It was concluded that for storm water, runoff from commercial / industrial and commercial land use areas is more likely to result in toxic effects in Miller Creek (due to metals and chloride) than runoff from residential areas; and that for snowmelt, concentrations of chloride, zinc, hardness, conductivity, and alkalinity were higher than during rain events (MPCA, 1994). Several toxicity tests were performed on samples from the creek, and none were found to be toxic to aquatic life (MPCA, 1994).

The MPCA conducted a study to characterize total suspended sediment loadings to the St. Louis River from six tributaries, including Miller, Keene and Kingsbury Creeks. (Johnson, 1997). Sediment load estimates for the Minnesota streams were similar, and are probably not significant contributors to the River (Johnson, 1997). However, Kingsbury and Mission Creeks may experience a higher suspended sediment loss from their watersheds on a per unit area basis (yield) than the other small tributaries (Johnson, 1997).

There have been several urban snowmelt runoff studies in the Twin Cities Metropolitan Area. Oberts (1982) shows that for a typical urban site [storm sewer] with fairly well mixed uses, a substantial amount (~ 65 %) of the annual solids, COD (chemical oxygen demand), nutrient, and total lead load, and essentially all of the chloride load can occur with the snowmelt and early spring rainfall events. Ayers, Brown, and Oberts (1985) studied the seasonality of runoff and loading rates to small

watersheds in the Twin Cities.   Data from their study are shown in Table 3. Note that about one-third of the annual load of pollutants enter streams during the snowmelt period.

Table 3. Distribution of Annual Precipitation, Runoff and Pollutant Loads by Season in Urban Areas of the Twin Cities Metropolitan Area. Data Presented as a Percentage of the Annual Load By Season (Ayers, et. al, 1985).

Group	Snowmelt	Spring	Summer	Fall	Winter
Precipitation	17	25	34	17	6
Runoff	31	22	32	10	5
Chemical Oxygen Demand	34	23	30	10	2
Total Suspended Sediment	34	20	33	8	5
Total Kjeldahl Nitrogen	33	22	32	10	3
Nitrate	33	21	32	9	4
Total Phosphorus	35	21	35	7	2
Total Lead	34	21	32	8	5

Impact of Snowmelt Runoff to Receiving Waters

Sources of snowpack pollution in urban areas come from a variety of sources, including the following (Novotny, 1999):
- Atmospheric pollutants scavenged and adsorbed by snowflakes
- Dry deposition of atmospheric pollutants
- Traffic emissions, including vehicle exhaust, worn vehicular parts, oil and grease, and corroded metals
- Urban litter (vegetative residues, pet and bird fecal wastes)
- Deteriorated infrastructure
- Deicing chemicals and abrasives

Managing stormwater pollution from these sources is a difficult task. Spring snowmelt runoff from urban areas can be particularly detrimental to surface waters because of the following winter problems with conventional Best Management Practices (from Oberts, 1990):
- The conveyance systems and soils are frozen
- Particle settling (in ponds) is reduced due to higher viscosity or flows at freezing or subfreezing (because of salting) and increased density
- Thick layers of ice inhibit the functioning of ponds
- Winter accumulation of pollutants of dissolved or dissociated pollutants in the snowpack can be washed away by a single snowmelt
- Large quantities of pollutants are not carried away by snowmelt and may remain on the urban surface, where they are subsequently washed away by spring runoff
- Street sweeping cannot be carried out when snow and ice are on streets

- Biodecompostion of deposited organics is minimal
- Dissolved fractions of some pollutants (for example metals) are higher because of higher salt contents

The biggest single issue regarding winter snowmelt pollution is the use of deicing chemicals or abrasive/salt mixtures (Novotny, 1999). The most common deicing chemical used today is sodium chloride (i.e. rock salt). During snowmelt, sodium chloride dissociates to form a sodium ion and a chloride ion. The chloride ion is toxic to aquatic biota at certain levels. Minnesota's chloride water quality standard for the long-term protection of aquatic life in trout waters is 230 milligrams per liter (Minnesota Rules, Chapter 7050.0222).

An associated concern is sediment runoff, which in urban areas is often primarily road sand during the snowmelt period. The principal pollutant in urban runoff is almost always suspended sediment (Laws, 1993). Sediment's primary impact is degrading aquatic habitats, by depositing on natural substrates used by biota. Pollutants that are bound to the fine sediments (silt and clay size), such as nutrients and heavy metals, also adversely impact receiving waters. Heavy metals, such as zinc or lead, are commonly found in urban runoff. Rock salt contains about 3-4 % zinc by weight; other sources of zinc include vehicle corrosion and vehicle emissions (Novotny, 1999). Other pollutants found in rock salt include lead, copper, chromium, and ferrocyanide anti-caking additives (Novotny, 1999). No thorough field monitoring study has been conducted to investigate cyanide levels in surface and groundwater as a result of the application of deicing salt (Paschka et. al., 1999).

A typical deicing chemical application rate (Novotny, 1999) is about 90 kg/km/storm (~ 319 pounds/mile/storm). The city of Duluth uses approximately 15,000 yd^3 of sand annually; and 11,500 tons of salt are ordered, with approximately 40% of that used depending on weather conditions (Marnie Lonsdale, City of Duluth Stormwater Utility, written communication, 1999). The City of Duluth has 573 miles of road that the Public Utility is responsible for maintaining; and in an average winter, 23 snowfalls require plowing (Bob Troolin, City of Duluth, electronic communication). Based on these average statistics, Duluth's estimated deicer application rate computes to 698/pounds/mile/storm. This is more than double the national average. This higher rate is probably due to Duluth's hilly topography.

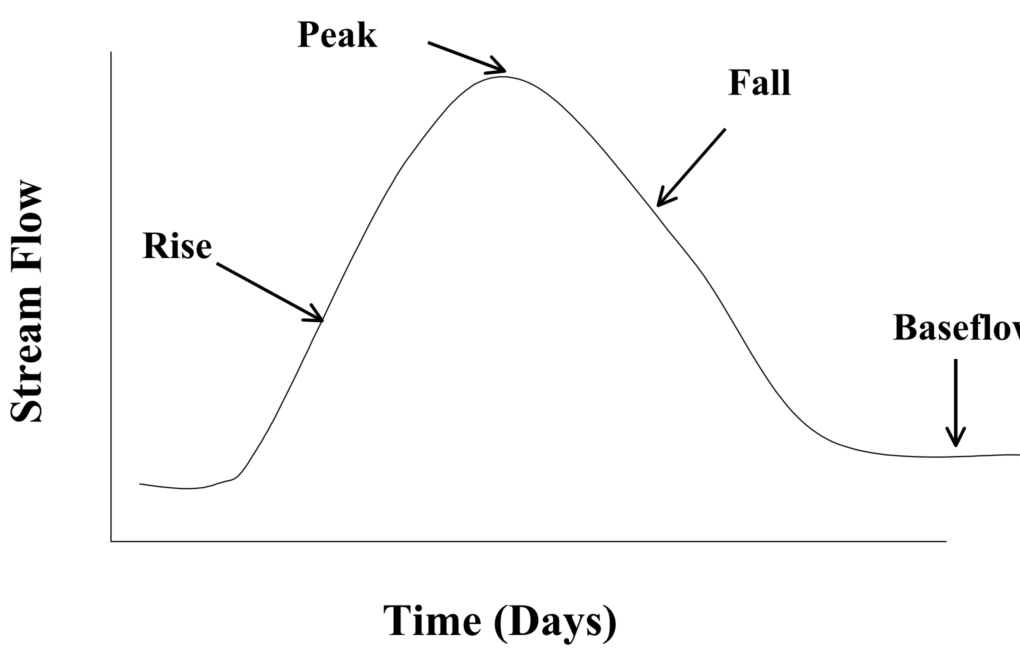
Purpose and Scope

This study was conducted because water quality information on the Duluth streams is extremely limited during the snowmelt runoff period, and because research has demonstrated that during snowmelt in urban areas, a large percentage of annual pollutant loads can reach and adversely impact receiving waters. The goal of the study was to develop baseline water quality information on four streams in the DMA during the snowmelt runoff period. A secondary goal was to compare pollutant yielding rates between snowmelt and baseflow periods among the sampling sites, thereby identifying stream reaches at risk of impairment.

Methods

Amity, Miller, Keene, and Kingsbury Creeks were sampled at 3 locations in their watersheds; near the headwaters, middle, and confluence with Lake Superior / St. Louis Bay (Figure 2, Appendix 3). At each stream, site #1 was the most downstream, site #2 was near the middle, and site #3 was near or in the headwaters of the watershed (Figure 2). Sites were selected that could be safely sampled (i.e. a bridge crossing), and had the correct hydrologic characteristics for stream flow measurements (see Rantz et. al, 1982). A series of three samples were collected at each site; on the rise, peak, and fall of the snowmelt hydrograph (Figure 4). Also, each site was sampled a fourth time during the summer baseflow (low flow) period for comparison purposes (Figure 4).

Figure 4. A Storm Hydrograph



Streamflow Measurements

Streamflow measurements were performed according to USGS protocol (Rantz et. al. 1982). If a site was wadable, a top-setting wading rod and Price "AA" or "pygmy" current meter was used, depending on stream depth. If a site was not wadable, discharge measurements were made from bridges using a bridgeboard, reel, and 25-pound sounding weight. On a few occasions streams were too turbulent to wade and the bridgeboard equipment could not be used. During these cases, streamflow measurements were estimated by measuring stream depths and surface velocities near each bank. These averages were calculated and extrapolated for the entire stream cross section, and high

water marks were noted. Velocity values were corrected for surface velocity, assuming that in a natural stream channel the average vertical velocity is approximately 85% of the surface velocity (Rantz et. al, 1982). On a subsequent visit, the stream channel cross section was observed, and corrections were made, if needed, to the previous streamflow estimate to make it as accurate as possible.

Water Quality Sampling

Water quality samples and discharge measurements were collected concurrently. Water quality samples were analyzed for a variety of conventional and toxic pollutants typically found in urban surface waters. The conventional parameters included total Kjeldahl nitrogen, nitrate plus nitrite nitrogen, total phosphorus (TP), total dissolved solids, total suspended solids (TSS), total chloride, biochemical oxygen demand (BOD) and hardness. For these parameters, depth and width integrated samples were collected. Research has shown that there can be statistically significant differences in data collected by surface grab versus integrated samples (Martin et. al 1992; Kammerer et. al, 1998). These differences can be pronounced during highflow periods, such as snowmelt runoff.

The stream cross section was divided into 4-6 points of equal width from which samples were collected. At each cross section, an integrated sampler with a ¼" inch nozzle was slowly moved from the water surface to the stream bottom until approximately 1 liter of water was collected. Each cross section sample was emptied into a churn splitter. The churn splitter was then used to mix the sample. Finally, the appropriate sample bottles were filled, and preserved if needed.

Fecal coliform bacteria and total zinc were grab sampled to reduce the possibility of sample contamination. For wadable sites, the sample bottle was dipped into the stream at the point of greatest depth and velocity; usually at the center of the stream. If the stream was not wadable, a bucket was used to collect the sample, again from the center of the stream.

In addition to water quality samples, other field data were collected. Specific conductivity, pH, and water temperature were measured. Stream clarity was determined using a MPCA Citizen Stream Monitoring Program transparency tube. At some non-wadable sites, stream stage was measured using a steel tape to indicate if stream level was rising or falling. At wadable sites, depth at the discharge measurement cross section was used to measure stream stage.

ERA Laboratories in Duluth, Minnesota analyzed the BOD and fecal coliform samples. A local lab was used because these samples needed to be analyzed within 24 hours of sample collection. The Minnesota Department of Health Laboratory in Minneapolis, MN analyzed all other samples.

Each of the 12 sites were visited often (daily in most cases) when weather conditions indicated that snowmelt was imminent. It was extremely important to sample the streams at iceout. These samples represented the "rise" sample discussed previously. At the sites, the three snowmelt event samples (rise, peak, and fall) were collected over approximately one week. The "peak" sampling event was an estimate of the peak snowmelt runoff, and does not indicate the actual peak flow, which could have occurred hours before or after the sampling event. The summer baseflow sample was collected in late September. Heavy rains throughout the summer delayed collection of this sample.

Quality Control / Quality Assurance

Several procedures were used in the field to minimize the possibly of sample contamination. The sampling equipment and churn splitter were thoroughly rinsed with de-ionized water between sites. The sampling equipment was triple rinsed with native stream water before the sample was collected.

Quality control / quality assurance (QA/QC) samples were also collected. These included both field duplicates and blanks. De-ionized water was used for the blank samples. For duplicates, an additional sample was collected immediately after the original. All data from the study, including QA/QC data, are listed in Appendix 1 and Appendix 2.

Data Analysis

This study was conducted to determine a baseline water quality assessment of DMA streams during the snowmelt runoff period. Two common ways to present water quality data are in loads (or yields), and concentrations. Conventional non-point source pollutants, such as nutrients and sediments, are often described by loading rate, because the amount (i.e. mass) of a pollutant delivered to a downstream confluence is of interest. Loading rates provide little comparison among sites, because values are dependent on streamflow. Pollutant yields are loading rates divided by drainage area. They provide results on a per unit area basis. This allows for direct comparison of pollutant amounts between different locations; either sites on the same stream, or among different streams.

Toxic water quality parameters, such as chloride and heavy metals, are often presented in terms of their concentration in surface waters. This is the case because aquatic biota are directly affected by instream concentrations of pollutants, and not loads or yields.

Instantaneous loading rates of total nitrogen, total phosphorus, and total suspended sediment were calculated from the concentrations and streamflow measurements. Loads were calculated as follows: Loading Rate *in* kg/day = (Concentration *in* mg/L)(streamflow *in* m^3/s)(86.4). "Total" nitrogen (TN) was assumed to be the sum of total Kjeldahl (ammonia plus organic N) nitrogen and nitrate (NO_3) nitrogen. Loading rates were divided by drainage area upstream of each site to determine yields.

The state chronic standard for zinc depends on instream hardness (calcium + magnesium) concentration. Thus, standards were calculated for each individual sample by the following formula (Minnesota Rules, Chapter 7050.0222,):
Exp. (0.8473[*ln*(total hardness mg/L)] +0.7615).

Results

At most sites, concentrations (mass of pollutant per volume of water; e.g. milligrams per liter) of sediment and total nutrients followed the pattern of discharge on the snowmelt hydrograph. Specifically, the highest concentrations were found in samples collected near peak flow, then they fell rapidly and were lowest during summer baseflow (Appendix 1). Exceptions to this trend occurred at sites Keene #1, and Miller #2.

The fecal coliform bacteria standard (200 colonies/100 ml) was periodically exceeded in Kingsbury and Keene Creeks. The standard was not exceeded at any sites on Miller or Amity Creeks.

BOD concentrations were below detection limits at all sites except Miller #3 and Miller #1. Miller #3 was the only site that had consistently detectable concentrations over the snowmelt period.

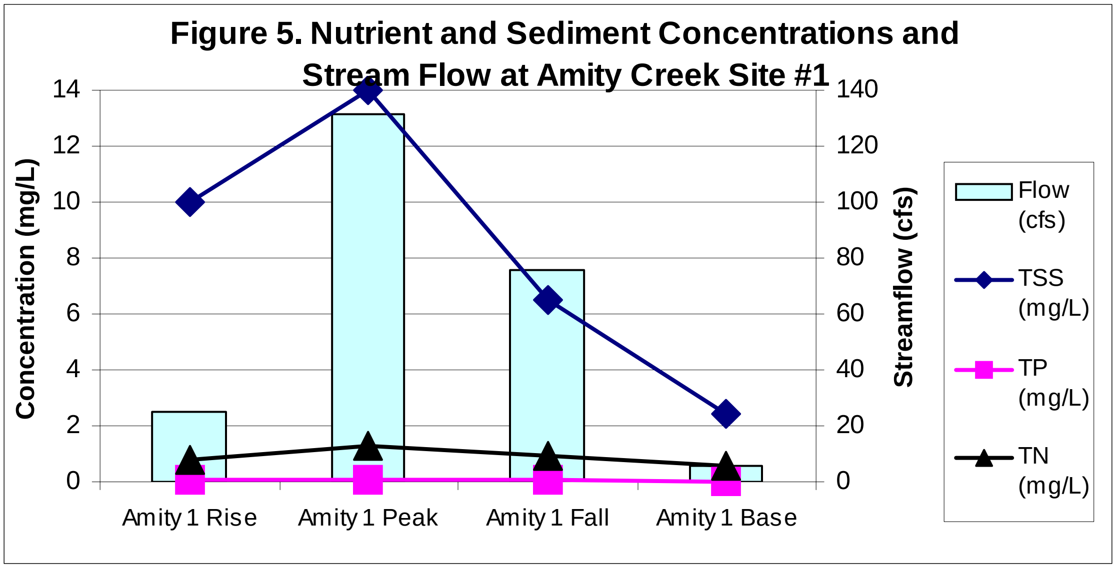
All instream zinc concentrations were below the state standard. Similarly, all instream chloride samples were also below the state's aquatic life standards for chloride; and the majority of the samples were less than 100 mg/L.

Discussion

<u>Nutrients and Total Suspended Sediment</u>

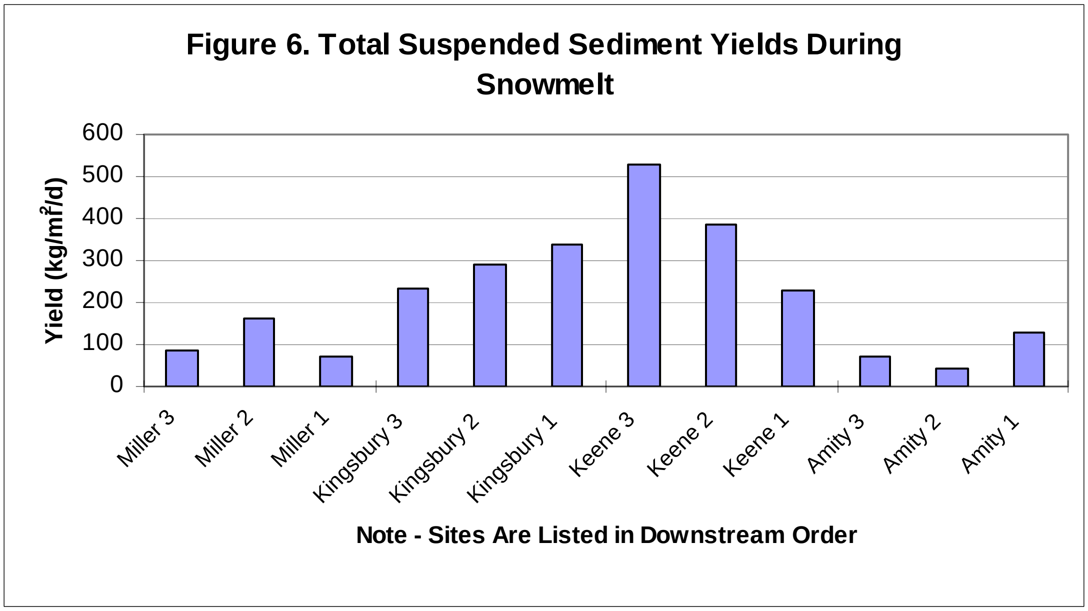
At all sites, the largest yields of nutrients and sediment occurred during the highest streamflows. This occurred during the "peak" sample for all sites except Miller #2 and Keene #1. At these two sites, the "rise" sample had a slightly higher streamflow than the "peak" sample, indicating the peak of snowmelt runoff occurred sooner than expected. Typically, concentrations of nutrients and sediment mirrored the pattern of discharge over the snowmelt hydrograph (Figure 4); highest at the peak, and with similar reduced concentrations at the rise and fall. Figure 5 illustrates this pattern at Amity Creek #1 during the sampling period. These patterns were evident because: 1) at high flow the stream can carry more suspended material simply because there is more water in the channel, 2) the high turbulence increases streambank erosion and channel scouring, and more readily maintains suspension and transport of solids in the water column, 3) nitrogen and phosphorus are bound to the fine grained suspended particles, and thus their concentrations follow patterns in suspended sediment. During baseflow, concentrations were lowest, most likely because of reduced streamflow. These results are to be expected considering that at peak snowmelt, flow ranged from 13 to 39 times higher than summer baseflow at the sites.

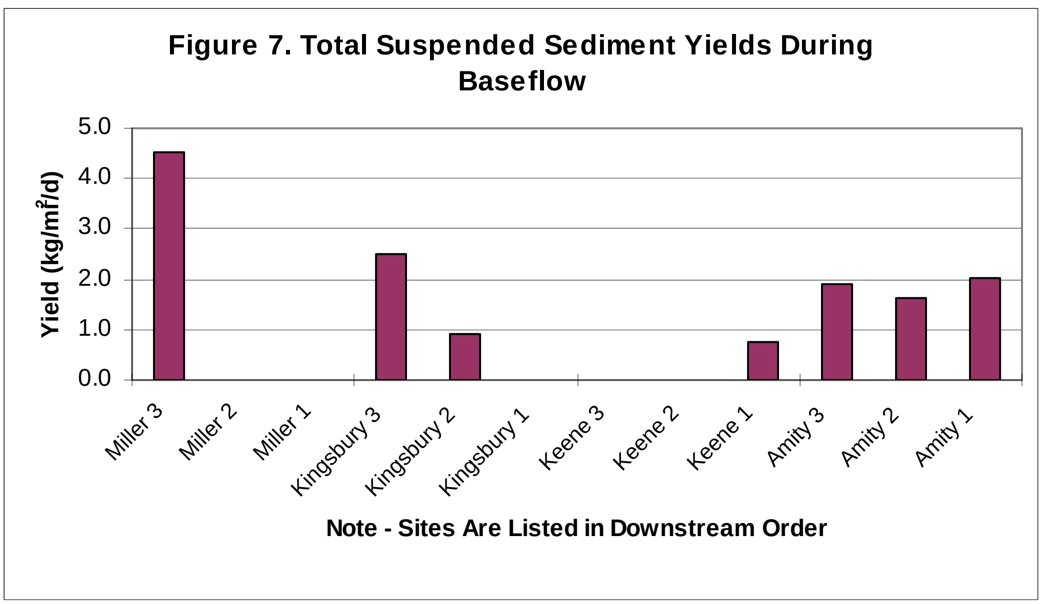
Concentrations of total phosphorus, total nitrate and nitrite nitrogen ($NO_2 + NO_3$), and TSS were compared to ecoregion expectations (McCollor and Heiskary, 1993), which are defined as the 75th percentile of data collected from 1970-92 at designated minimally impacted sites in the Northern Lakes and Forests ecoregion. The DMA is part of this ecoregion. Phosphorus concentrations were much lower than nitrogen, and concentrations were below ecoregion expectations (0.05 mg/L) in most samples. Conversely, $NO_2 + NO_3$ concentrations often exceeded the expectation (0.09 mg/L). High $NO_2 + NO_3$ concentrations can be found during baseflow at sites draining agricultural areas or glacial outwash (James Fallon, USGS, written communication, 2000). The DMA has very little agricultural land, and is not an outwash area. Therefore, during baseflow the $NO_2 + NO_3$ (a soluble form of nitrogen) is most likely coming from ground water recharge. At baseflow, this expectation was exceeded at Keene #2 and Keene #3 and all sites in Kingsbury Creek (Appendix 1). The TSS expectation (6 mg/L) was frequently exceeded by a wide margin during snowmelt, but not at baseflow at any site.



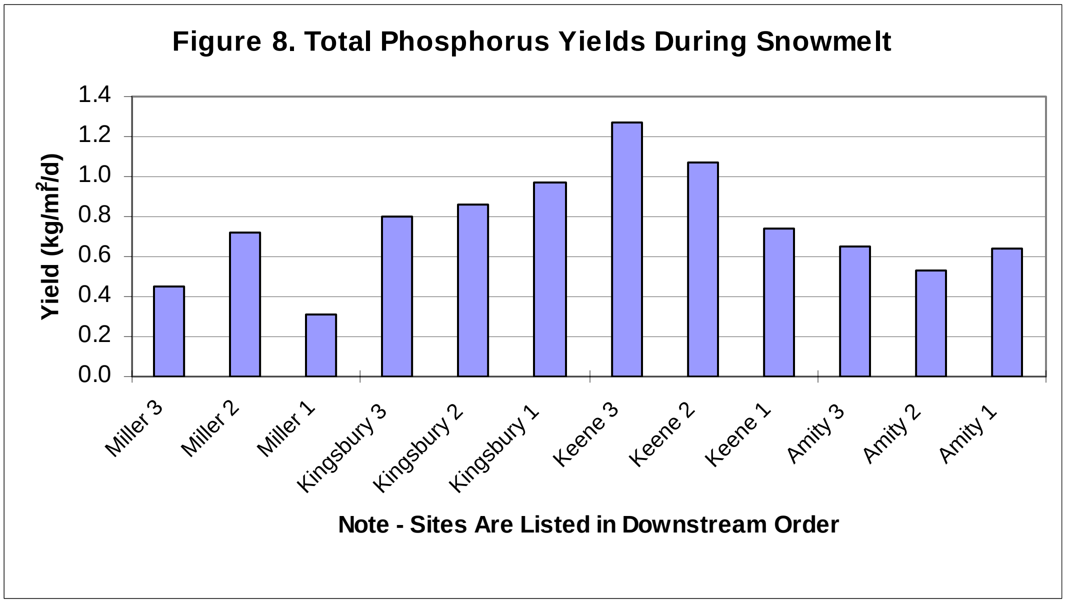
Average yields from the three separate snowmelt samples were calculated at each site. These results were compared to the baseflow sample. Caution should be used when comparing these results. *The single baseflow sample is indicative of stream conditions only at the time of sampling, and does not represent an integrated condition from a series of low-flow samples.* Yield data (in kilograms per mi^2 per day) are graphed for each stream. The sites are listed in downstream order; from the headwaters (site #3) to the confluence (site #1).

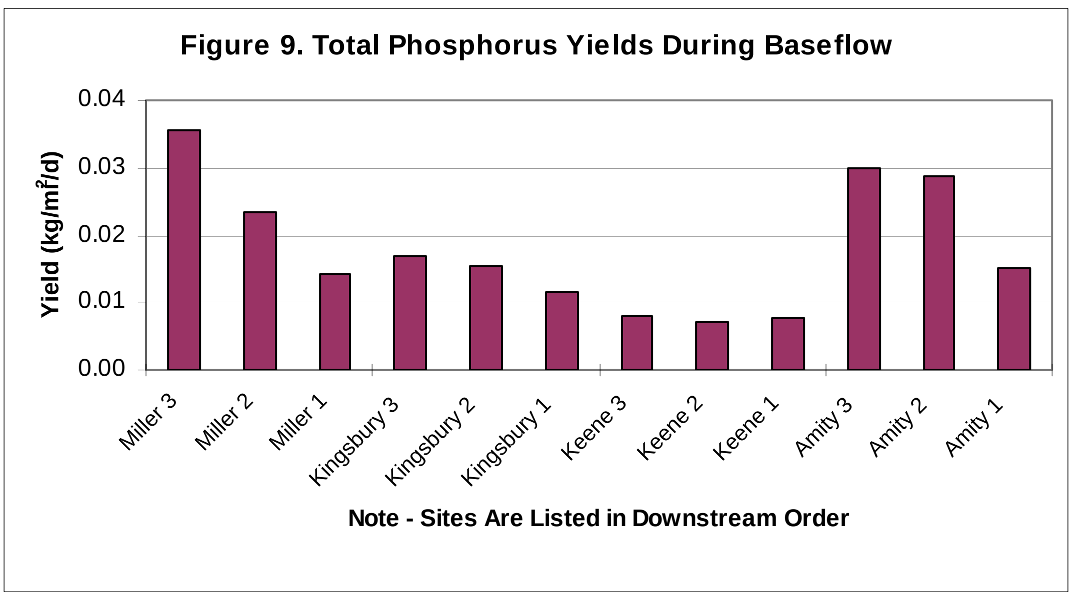
TSS yields from snowmelt and baseflow are shown in Figures 6 and 7. During snowmelt, yields were lowest in the Amity and Miller Creek watersheds, and highest in Keene and Kingsbury Creeks. During baseflow, TSS concentrations were often below detection, so yields could not be calculated. When detected, yields were considerably lower than during snowmelt; less than 3 kg/mi^2/day compared to approximately 300 kg/mi^2/day during snowmelt. The TSS data did not show a consistent pattern of an increase in yields as urbanization increases in all watersheds. The pattern did occur in the Amity and Kingsbury watersheds, but not in Keene and Miller. The highest yield during snowmelt was found in the most upstream (least urbanized) site in Keene Creek. The cause is unknown. The detected TSS concentrations in Amity Creek during baseflow may be due to the fact that it is the only watershed with easily erodible red clay as its dominant soil type.





Total phosphorus (TP) yields from snowmelt and baseflow are shown in Figures 8 and 9. During snowmelt, yields were similar among watersheds, ranging from about 0.4 – 1.2 kg/mi^2/day. There was no describable pattern in yielding rates with urbanization. Snowmelt yields were highest in Kingsbury and Keene Creeks. At baseflow, yields increased from downstream to upstream (Figure 9), while yields were lowest in Kingsbury and Keene Creeks. Yields during baseflow were about an order of magnitude lower than yields at snowmelt.





Total nitrogen yields from snowmelt and baseflow are shown in Figures 10 and 11. During the snowmelt period, yields decreased as the stream flowed downstream; again, an unexpected result. For every watershed except Miller Creek, the highest yields occurred at the headwaters site. During baseflow, yields were comparable among watersheds. Yields at baseflow were about an order of magnitude lower than yields at snowmelt (also seen in TP).

A high yield of TN during baseflow was seen at Miller #3, similar to the pattern in yields of TSS and TP. This high value may be due to increased biological activity (i.e.

algae growth). At this site, the gradient is reduced which would allow for periphyton (attached algae) to become established. This sample was collected in late September, when algae growth is high. Earlier in the season, both the reduced water temperature and increased stream velocity would inhibit algae growth (Steve Heiskary, MPCA, written communication, 2000). Amity, Keene, and Kingsbury Creeks also had the highest concentrations of TP and TN at the headwaters site during summer baseflow, also indicating that biological activity may be the cause (Figure 11).

Figure 10. Total Nitrogen Yields During Snowmelt

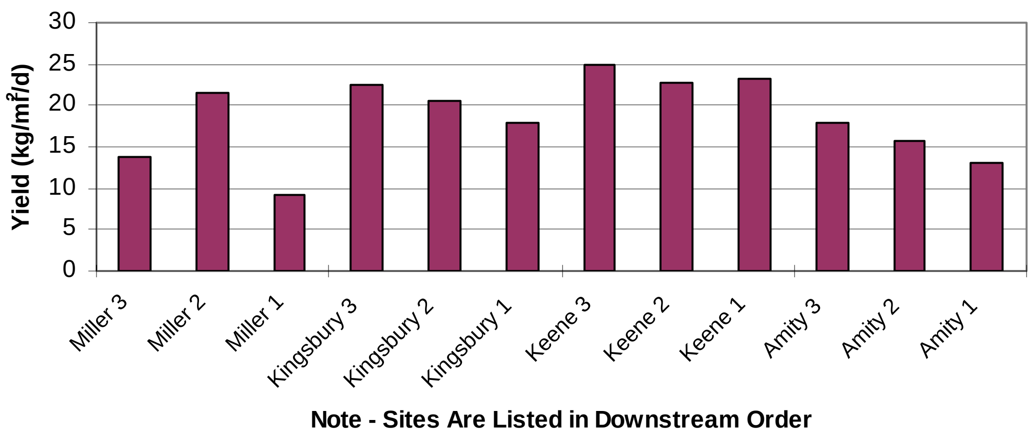
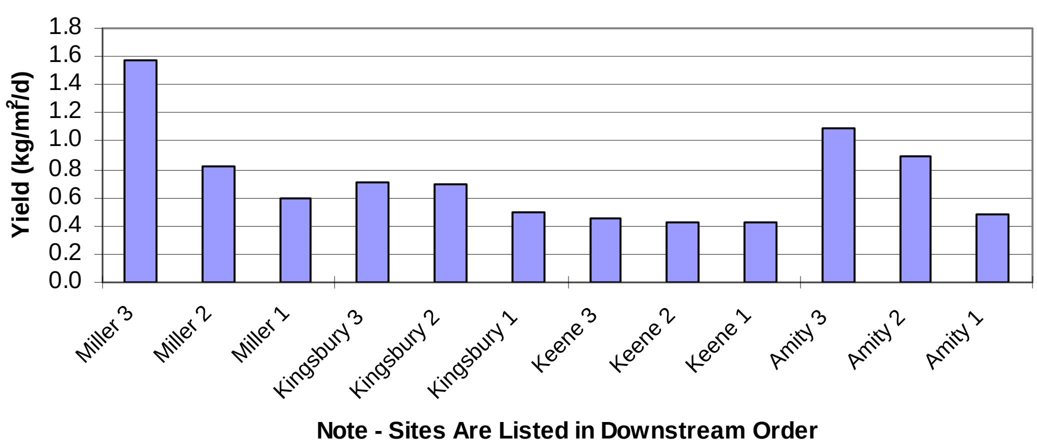


Figure 11. Total Nitrogen Yields During Baseflow

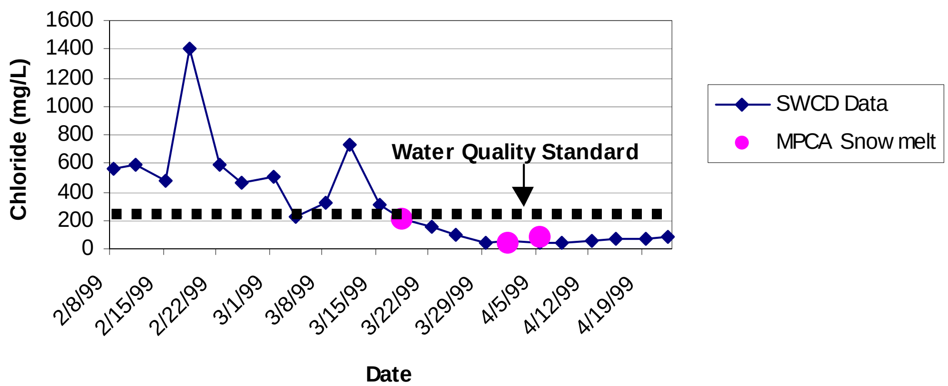


Chloride

All instream chloride samples were below the state's aquatic life chronic standard (230 mg/L), most likely because during snowmelt the high flows provided dilution; and during baseflow, no road salt was being applied that could runoff into the streams.

Chloride data from this study were compared to data collected by the South St. Louis County Soil and Water Conservation District (SWCD) as part of the Miller Creek Clean Water Partnership. The SWCD collected samples at Miller #1. Data from both projects is shown in Figure 12. SWCD data indicates that the water quality standard for protection of aquatic life (230 mg/L) was equaled or exceeded in all samples prior to MPCA's "rise" sample on 3/18/99. The SWCD collected samples under ice prior to snowmelt, throughout the snowmelt period, and after the stream channel was open. Prior to ice out (which occurred on or just before 3/18/99, when the "rise" sample was collected) meltwater was still reaching Miller Creek. These highly concentrated "first flush" melt events are probably what led to the extremely high chloride concentrations. After iceout, dilution brought the concentrations down again, as illustrated by data collected by both agencies (Figure 12).

Figure 12. Miller Creek Chloride Concentrations During Snowmelt at Site #1



Overall, the data show that chloride does not appear to be a problem at the streams studied *during snowmelt after ice-out*. But, the SWCD data does warrant concern, and further monitoring is needed, particularly under ice-cover. It would be useful to determine the contribution of chloride from natural (i.e. groundwater) and human (i.e. road deicer induced runoff) sources.

Fecal Coliform Bacteria

The state standard for fecal coliform is 200 colonies per 100 milliliters, calculated as the geometric mean of at least 5 samples per month. Based on this definition, data

from this study can not be used to determine if the standard was exceeded, because only 3 samples were collected at each site during snowmelt. But the data can be used to identify areas where future monitoring may be needed.

Samples from Keene and Kingsbury Creeks exceeded 200 colonies periodically, but the geometric mean never exceeded 200. The highest value was 650, at Keene #1 during baseflow. The upstream sites on Keene and Kingsbury Creeks had more samples over 200 colonies than sites further downstream in the watersheds. Possible sources of fecal coliform in these rural areas include septic systems, and pet or wildlife feces. Municipal sewage leaks or bypasses were not suspected sources because the BOD concentrations were below detection limits. Further monitoring is needed to investigate the source of the fecal coliform bacteria in this area. At the downstream sites in these watersheds, fewer exceedances occurred, probably due to dilution effects.

Data from this study were compared to fecal coliform data collected by WLSSD on Duluth's streams in the 1970's- mid 1980's (WLSSD, unpublished data). Data from this study show that fecal coliform concentrations have substantially decreased over the last 20 years in Amity, Miller, Keene, and Kingsbury Creeks.

Biochemical Oxygen Demand

BOD is an indicator of domestic sewage contamination, organic industrial wastes, or other forms of an organic matter in surface waters. BOD concentrations were only detected in the Miller Creek watershed. The only site with regularly detected concentrations was Miller #3, where they ranged from 6-54 mg/L. The State's minimum secondary treatment effluent limitation for municipal sewage is 25 mg/L (Minnesota Rules, Chapter 7050.0211). Miller #3 receives the runoff from the Duluth International Airport. All aircraft anti-icing and deicing chemicals used at airports today are based on formulations of either ethylene or propylene glycol (Novotny, 1999). These compounds can produce high levels of BOD as they breakdown in surface waters. The BOD concentrations at Miller #3 can be attributed to runoff of glycol from the Duluth airport (Scott Knowles, MPCA, personal communication, 1999). BOD was not detected at Miller #3 during baseflow. At Miller #1, the BOD was 100 mg/L during the "rise" sample. Its cause is unknown, although a sewage bypass is unlikely because fecal coliform bacteria were not detected in the same sample. BOD was not detected in any other samples from this site. In summary, with the exception of the headwaters of Miller Creek, BOD does not appear to be a concern in the DMA streams monitored, during snowmelt.

Zinc

Zinc concentrations did not exceed the state standard in any stream sample. They were often well below it; and most samples were below detection limits. Zinc does not appear to be a contaminant of concern in DMA streams during snowmelt.

DMA Data Compared to Minneapolis Chain of Lakes

Data from this study were compared to a recent monitoring effort conducted in another urban area in Minnesota (Table 4). This was done to put the DMA data in context. The external data set used for comparison is from the Minneapolis Chain of

Lakes Clean Water Parternship Project (Barr Engineering, 1992). Data were collected from the lakes themselves, the streams connecting the lakes, and storm sewers in the watershed, to develop nutrient budgets in the Chain of Lakes (COL). Data were collected from numerous sites over an entire year. The Minneapolis COL is located in a highly urbanized part of the Twin Cities Metropolitan Area. The percentage of urban land use in these watersheds is much greater than in the watersheds monitored for this DMA study. For reference, the Northern Lakes and Forests ecoregion expectations are also included in Table 4. These data are to be compared with the results from the DMA study, and not the Minneapolis COL data.

As stated previously, the TN and TSS concentrations in the DMA streams exceeded the NLF expectation, while TP often did not. Nitrogen concentrations from the DMA streams also exceeded those from the COL (Table 4). Additionally, NO_3 concentrations in the DMA streams exceeded the mean NO_3 concentration (.44 mg/L) in *storm sewers* sampled during runoff events in the COL watershed. The high concentrations of NO_3 in the DMA streams is a concern. Other parameters monitored in both the DMA and COL were considerably lower in the DMA (Table 4), probably due to the comparatively lower percentage of urban land use in the DMA. Additional data from the DMA streams are needed before a thorough statistical comparison of the two data sets can be made.

Table 4. Northern Lakes and Forests Ecoregion Expected Concentrations, and Average Concentrations of Selected Parameters from the Duluth Metropolitan Area Streams Snowmelt Study and the Minneapolis Chain of Lakes Clean Water Partnership.

Data Set	Specific Cond. (µs/cm)	TSS (mg/L)	NO_2NO_3 (mg/L)	TN (mg/L)	TP (mg/L)	Fecal Coliform (#/100ml)	BOD (mg/L)	Chloride (mg/L)
Ecoregion Expectation	270	6	.09	N/A[1]	.05	20	1.7	N/A
This Study (DMA Streams)	246	10.1	.52	1.1	.04	96	<4	35
MPLS. – Streams [2]	457	N/A	.17	.949	.08	N/A	N/A	91

[1] N/A- data not available. [2] Barr Engineering (1992).

Land Use and Water Quality

In the DMA, urban land use increases as water flows downstream. It was hypothesized that yields of TP, TN, and TSS would increase as urbanization increases; because urban waters typically have higher dissolved solids and nutrient concentrations (Perry and Vanderklein, 1997). Data from this study show that this was not always the case. Snowmelt yields of TN, TP, and TSS were lowest on Amity and Miller Creek, the watersheds with the lowest, and highest, percentages of urban land use. This was a perplexing result. Low yields were expected (and found) in the Amity Creek watershed

because of the high percentage of forested land (Figure 3). Higher yields were expected in the Miller Creek watershed, because of its increased percentage of urban land uses (Figure 3), and documented water quality problems. Results from this study indicate that urban snowmelt runoff may not be having as significant an impact in the Miller Creek watershed (with the exception of BOD). The low yields in Miller Creek may be a result of a combination of the impervious surfaces reducing soil erosion and stormwater ponds removing pollutants before they reach the stream. This study includes only one year of data, and additional years of data are needed to confirm this conclusion. Data from this report did show that the highest yields of nutrients and sediments were found at the site #2, where the stream bisects a highly urbanized portion of the DMA. In this reach of Miller Creek, the stream has been channelized, the riparian zone is greatly reduced or non-existent, and the stream receives the effluent from a large number of stormwater ponds. But overall, in Miller Creek, yields were lower than less urbanized watersheds (such as Kingsbury and Keene Creeks). This was an encouraging result for Miller Creek. Kingsbury Creek was the only watershed where yields increased at sites from the headwaters to the confluence. The cause of the higher yields in Keene and Kingsbury Creeks is unknown. They could be attributed to many factors such as varying deicer application rates, runoff from the Duluth Zoo or Interstate 35, or faulty septic systems. Further monitoring of these four DMA streams will continue in the near future. A goal is to establish a long term monitoring programs on at least one site per watershed. Table 5 lists a compilation of watershed protection techniques for snow and snowmelt conditions.

Table 5. Watershed Protection Techniques for Snow and Snowmelt Conditions (Modified from Novotny et al., 1999, Oberts, 1994, and WDNR, 1996)

□ **Use of Deicing Compounds**
- Use alternative deicing compounds such as $CaCl_2$ and/or CMA (calcium magnesium acetate) in sensitive areas.
- Designate and post "salt free" areas on roads next to streams, wetlands and other natural resource areas.
- Reduce use of deicing compounds through better operator training, equipment calibration, and careful application.
- Reduce use of salt by better application and using more environmentally safe chemicals in liquid form when snowstorm is imminent.
- Sweep accumulated salt and grit from roads and curb gutters as soon as practical after surface clears at the end of the season.
- Use modern advances in road condition monitoring and computerized estimations in determining application rates.

□ **Storage of deicing chemicals**
- Sand and salt storage piles should be protected by shelters or tarps and be constructed on impervious pads.
- Locate compound storage piles at least 30 meters (100 ft) from receiving water bodies and flood plains.
- Direct internal flow to collection systems and divert external flows around shelters and storage piles.
- For preventing freezing of abrasives, and mix salt with sand before winter.

□ **Dump snow onto pervious areas where it can infiltrate**
- Stockpile snow in flat areas at least 30 meters (100 ft) from receiving waters and flood plains.
- Plant stockpile areas with salt tolerant ground cover species. If needed, restore the soil damaged by sodium from salt by liming after the snow melts.
- Remove sediment and debris from dump areas periodically throughout the spring.
- Choose areas with soil-filtering capacity.
- Designate snow stockpile areas on pervious surfaces that drain to ponds to allow for melt water infiltration, capture and treatment.

□ **Blow snow from curbside onto adjacent pervious areas**
- Snow from streets, parking lots and sidewalks should not be plowed or blown into or immediately adjacent to streams, wetlands or lakes.

□ **Operate storm water ponds on a seasonal mode**
- Use modified storm water detention ponds for storage of the most polluted first flush snowmelt and direct it slowly to treatment by diverting it onto an infiltration area, if possible.
- Snow should not be placed directly into a conventionally operated storm water pond.

□ **Use level spreader and berms to spread melt water over vegetated areas**

□ **Intensive street cleaning in early spring can help remove particulates on road surfaces**

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Appendix 1. Water Quality Data

1999 Snowmelt Study Raw Data																		
			(cfs)	(C)		(us/cm)	(#/100ml)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(ug/L)	(mg/L)	(mg/L)
Site	Date	Time	Flow	Temp.	pH	Sp. Cond.	Fecal Col.	BOD	TSS	TDS	Tot. Cl	TP	TKN	Tot. NO2NO3	TN	Tot. Zn	Tot. Ca	Tot. Mg
Amity 1 Rise	3/23/1999	1430	24.8	0.8	8.27	301	30	<4	10	190	37	0.051	0.53	0.28	0.81	11	55	35
Amity 1 Peak	3/30/1999	1230	131.4	2.6	7.77	135	<10	<4	14	110	14	0.062	0.71	0.6	1.31	14	28	17
Amity 1 Fall	4/2/1999	930	75.9	1.1	7.3	130	60	<4	6.5	96	13	0.046	0.51	0.42	0.93	<10	27	16
Amity 1 Base	9/22/1999	945	5.6	10.9	7.52	210	10	<4	2.4	160	17	0.018	0.58	<.05	0.58	<10	65	38
Amity 2 Rise	3/19/1999	1330	1.6	2.1	8.1	402	<10	<4	1.8	230	63	0.023	0.46	0.3	0.76	<10	69	39
Amity 2 Peak	3/30/1999	800	33.4	1.3	8.2	129	27	<4	4.5	120	18	0.049	0.72	0.8	1.52	<10	30	17
Amity 2 Fall	4/2/1999	1000	25.4	1.1	8.42	115	<10	<4	2.8	120	13	0.037	0.6	0.44	1.04	<10	28	15
Amity 2 Base	9/22/1999	1200	2.3	12.24	7.6	195	10	<4	1.2	150	16	0.021	0.65	<.05	0.65	<10	55	32
Amity 3 Rise	3/25/1999	1445	2.3	0.2	7.04	263	10	<4	3	180	34	0.031	0.69	0.27	0.96	14	50	31
Amity 3 Peak	3/30/1999	915	24.2	0.4	6.86	111	<10	<4	5	100	13	0.05	0.81	0.64	1.45	<10	25	16
Amity 3 Fall	4/2/1999	1100	16.9	0.8	7.6	84	18	<4	5	84	11	0.041	0.65	0.38	1.03	<10	22	13
Amity 3 Base	9/22/1999	1100	1.6	10.5	7.22	134	82	<4	1.2	99	9.4	0.019	0.69	<.05	0.69	<10	40	25
Kingsbury 1 Rise	3/24/1999	1130	6.0	4	8.36	469	30	<4	4.5	280	81	0.026	0.52	0.54	1.06	12	69	37
Kingsbury 1 Peak	3/29/1999	1530	77.8	3	7.87	196	50	<4	44	120	29	0.108	0.87	0.69	1.56	21	31	19
Kingsbury 1 Fall	4/1/1999	1530	55.7	0.8	7.6	197	80	<4	3.5	110	30	0.035	0.63	0.53	1.16	10	31	16
Kingsbury 1 Base	9/23/1999	1130	2.0	13.54	8.22	355	220	<2	<1	260	57	0.021	0.77	0.13	0.9	<10	83	44
Kingsbury 2 Rise	3/25/1999	1310	8.6	3.5	7.85	378	80	<4	5	240	60	0.027	0.74	0.57	1.31	16	66	35
Kingsbury 2 Peak	3/29/1999	1300	91.8	2.8	6.52	172	40	<4	29	130	26	0.075	0.86	0.72	1.58	21	31	18
Kingsbury 2 Fall	4/2/1999	1230	31.9	1.3	6.6	197	27	<4	3	120	30	0.034	0.62	0.66	1.28	<10	31	17
Kingsbury 2 Base	9/23/1999	915	2.4	12.25	7.81	274	55	<2	1.2	210	37	0.02	0.76	0.15	0.91	<10	72	39
Kingsbury 3 Rise	3/17/1999	1500	1.6	8	7.77	567	530	<4	11	340	110	0.071	0.89	0.56	1.45	25	88	47
Kingsbury 3 Peak	3/29/1999	1730	85.9	1.2	7.24	155	40	<4	23	97	23	0.067	0.9	0.75	1.65	18	25	16
Kingsbury 3 Fall	4/1/1999	1300	42.3	0.4	6.92	132	209	<4	1.6	110	19	0.029	0.63	0.64	1.27	12	25	15
Kingsbury 3 Base	9/23/1999	830	2.2	12.23	7.29	238	10	<2	3.4	190	29	0.023	0.84	0.12	0.96	<10	67	36
Keene 1 Rise	3/29/1999	1100	46.6	3.3	8.02	185	91	<4	26	130	24	0.066	0.8	0.95	1.75	11	35	19
Keene 1 Peak	3/30/1999	930	44.3	1.1	7.8	172	150	<4	9	120	22	0.039	0.6	0.85	1.45	<10	32	17
Keene 1 Fall	4/2/1999	1330	19.1	2	7.78	237	100	<4	3.5	130	33	0.03	0.55	0.69	1.24	<10	41	22
Keene 1 Base	9/23/1999	1245	1.8	14.14	8.88	364	650	<2	1	250	50	0.01	0.56	<.05	0.56	<10	100	55
Keene 2 Rise	3/26/1999	1345	11.4	5.3	8.57	265	160	<4	16	170	33	0.044	0.57	0.51	1.08	<10	58	31
Keene 2 Peak	3/29/1999	1430	59.1	5.1	9.25	11	70	<4	39	110	17	0.1	1	0.85	1.85	15	32	17
Keene 2 Fall	4/1/1999	1330	26.7	0.8	7.84	141	73	<4	4.8	100	16	0.033	0.51	0.72	1.23	<10	31	17
Keene 2 Base	9/23/1999	1100	1.8	12.54	8.19	331	30	<2	<1	240	39	0.009	0.42	0.13	0.55	<10	97	53
Keene 3 Rise	3/15/1999	1115	1.4	6	7.9	365	10	<4	2.4	210	46	0.042	0.41	0.5	0.91	<10	78	45
Keene 3 Peak	3/29/1999	1315	43.7	6	7.98	125	370	<4	63	93	15	0.129	1.17	0.93	2.1	18	29	18
Keene 3 Fall	3/31/1999	1330	39.5	2.5	8.28	118	230	<4	7.8	90	12	0.043	0.55	0.76	1.31	<10	27	16
Keene 3 Base	9/23/1999	1000	1.3	12.11	7.88	259	<10	<2	<1	190	20	0.012	0.47	0.19	0.66	<10	83	46
Miller 1 Rise	3/18/1999	1430	10.7	4.7	8.18	887	130	100	11	510	210	0.059	0.81	0.38	1.19	22	99	50
Miller 1 Peak	3/30/1999	1630	48.4	3.6	7.9	249	10	<4	12	150	38	0.043	0.69	0.76	1.45	15	40	22
Miller 1 Fall	4/2/1999	1100	18.4	1.3	7.5	422	45	<4	5	230	82	0.046	0.58	0.61	1.19	12	53	27
Miller 1 Base	9/22/1999	1515	3.6	14.41	8.5	361	73	<4	<1	260	54	0.015	0.63	<.05	0.63	<10	97	53
Miller 2 Rise	3/29/1999	1000	63.2	2.7	7.56	227	20	<4	14	150	33	0.05	0.77	0.7	1.47	12	42	23
Miller 2 Peak	3/30/1999	1400	46.1	3.4	7.45	207	<10	<4	7.5	140	26	0.04	0.58	0.62	1.2	10	37	21
Miller 2 Fall	4/1/1999	1700	29.0	0.1	7.7	218	10	<4	3.5	120	28	0.034	0.64	0.48	1.12	18	38	21
Miller 2 Base	9/22/1999	1330	3.3				<10	<4	<1	210	30	0.02	0.7	<.05	0.7	<10	82	45
Miller 3 Rise	3/24/1999	1415	4.9	0.3	7.49	331	40	54	8.3	200	40	0.033	0.58	0.1	0.68	<10	62	36
Miller 3 Peak	3/29/1999	945	26.8		8.17	159	10	6	7	120	21	0.04	0.68	0.5	1.18	<10	41	23
Miller 3 Fall	4/2/1999	1130	10.3		7.7	169	27	34	6	220	23	0.031	0.73	0.43	1.16	<10	42	23
Miller 3 Base	9/22/1999	1415	1.9	11.98	7.51	250	20	<4	2.8	190	16	0.022	0.89	0.08	0.97	<10	80	44

Appendix 2. QA/QC Data

1999 Snowmelt Study Quality Control / Quality Assurance Data														
				(#/100ml)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(ug/L)	(mg/L)	(mg/L)
Site	Date	Time	QA/QC	Fecal Col.	BOD	TSS	TDS	Tot. Cl	TP	TKN	Tot. NO2NO3	Tot. Zn	Tot. Ca	Tot. Mg
Amity 1	3/30/1999	1231	duplicate	10	<4	12	110	14	0.062	0.66	0.58	10	28	17
Amity 2	4/2/1999	1001	duplicate	30	<4	3	71	13	0.039	0.68	0.44	<10	26	15
Amity 3	3/25/1999	1446	duplicate	<10	<4	3.5	170	33	0.033	0.57	0.27	16	51	30
Kingsbury 3	3/29/1999	1731	blank	<10	<4	2.5	<4	<1	<.002	<.1	<.05	<10	<5	<5
Keene 1	4/2/1999	1331	blank	<10	<4	<1	<4	<1	<.002	<.1	<.05	<10	<5	<5
Keene 2	3/29/1999	1431	blank	10	<4	<1	4	<1	<.002	<.1	<.05	<10	<5	<5

Appendix 3. Site Locations

Snowmelt Study Site List

Name	Location
Amity #1	Off Occidental Blvd. On first foot bridge in Lester Park
Amity #2	Jean Duluth Road
Amity #3	Bridge at intersection of Martin Road and Arnold Rd.
Kingsbury #1	On foot bridge on Western Waterfront Trail; off Grand and ~72nd Ave W.
Kingsbury #2	Boundary Ave in Proctor
Kingsbury #3	2nd St. in Proctor (W. of Intersection of Hwy 2)
Keene #1	57th Ave. W. Between Main and Raleigh St.
Keene #2	63rd Ave. W. and Bristol St. (Upstream of Keene Cr. City Park)
Keene #3	Intersection of St. Louis River Rd. and Skyline Parkway
Miller #1	26th Ave. W. (Near DTA Garage, S. of Michigan St.)
Miller #2	Village Mall Foot Bridge, near Bridgeman's, across from Mall
Miller #3	Swan Lake Road, just off Haines Rd.