Miller Creek Macroinvertebrate, Habitat, and Temperature Report

Photo: Nathan Schroeder, SSL SWCD

In support of the Miller Creek temperature TMDL study
prepared for the
South Saint Louis Soil and Water Conservation District

by

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June 2010

NRRI Technical Report Number NRRI/TR-2010/11

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Executive Summary

We sampled benthic macroinvertebrates and stream habitat at five locations in Miller Creek during late May 2008 as part of a TMDL (total maximum daily load) study on temperature. Data collected included: macroinvertebrate community composition, in-stream habitat for invertebrates and fish, stream bottom substrate types, and sediment particle size distribution. These data were linked with temperature logger data supplied by the South Saint Louis Soil and Water Conservation District (SSL SWCD) at or near these five sites, as well as additional sites (total of 27 stations) along the creek. Miller Creek macroinvertebrate and habitat samples were compared to data from several other streams where samples were collected during the early summer.

Use of macroinvertebrate communities to assess stream ecosystem condition relies on varying sensitivities of different taxa to the many different stressors to which they may be exposed (Rosenberg and Resh 1993). Benthic macroinvertebrates have been used extensively as a biological monitoring tool to assess water quality and habitat conditions (c.f., Rosenberg and Resh 1993) because of their widespread abundance, behavioral adaptations, and tolerance levels. However, use of macroinvertebrates to assess stream temperature issues is less common. Published studies examining temperature sensitivities are both few in number, and specific taxa are of no or limited interest. Indicator metrics of habitat condition that are generated include taxonomic based (on what is known about the sensitivity or tolerance of various taxa), feeding group (how and on what the invertebrates feed), behavior group (how invertebrates function and move in their environment), and tolerance value (a number from 0 to 10 that indicates the tolerance of each invertebrate taxon to anthropogenic stress [10 being most tolerant]). Huff created temperature correlations for macroinvertebrate taxa based on streams in central and southern Minnesota (D. Huff, personal communication). We used his data to create metrics for invertebrate taxa exhibiting warm and cool/cold temperature preferences. These metrics were calculated for each site. Most Miller Creek sites seem to have reasonably good habitat conditions for macroinvertebrates, although some sites are a bit shallow for fish. With the exception of the Miller Hill Mall (Mall) site, most Miller Creek sites have substrate of an appropriate size to create interstitial space for macroinvertebrates, with low amounts of embeddedness and fine sediments. The Lincoln Park (LP) site is a bit harsher because it has higher velocity water flowing partially over bedrock, which limits living space for macroinvertebrates. Stream shading is high at all but the Mall site, with some sites being almost completely shaded.

A series of in-stream temperature loggers (25 to 27, depending on the year) were deployed by SSL SWCD staff for the ice-free seasons of 2007-2009. Data were summarized by day and night categorical mean temperatures, daily maximum means, and daily maximum moving averages for all stations by year. During peak stream temperatures, several stations remained below the critical $20^{\circ C}$ threshold for salmonids, while others had many days of maximum temperatures above this threshold. Based on presence/absence of salmonids and temperature records used to establish tolerance estimates (Wehrly et al. 2007), maximum daily moving averages for every Miller Creek station, from 1 day to 63 days, did not exceed those values at any time over the period of record. However, maximum daily maximums and duration of peak temperatures seen in the data set leave no doubt that areas along Miller Creek become uninhabitable to trout. Correlating this information to stress and/or lethal conditions for trout is quite problematic due to the artificial settings and conditions under which most salmonid temperature preference/tolerance studies have been conducted. Applying set thresholds to a habitat that fluctuates both spatially and temporally is difficult, but the temperature logger data indicate that locations within Miller Creek can serve as refugia for trout.

A total of 116 macroinvertebrate taxa were collected from Miller Creek, with up to 62 taxa found at any one site. The macroinvertebrate community in Miller Creek does not compare particularly favorably to streams in less urban watersheds, with the exception of the Chambersburg site. The other four sites have low taxa counts and abundances of taxa considered sensitive to stress, particularly the EPT taxa (mayflies, stoneflies, caddisflies). Instead, these sites have high proportions of more tolerant taxa such as Chironomidae (Diptera) and oligochaete and nematode worms. Macroinvertebrate trait metrics also indicate that Miller Creek sites are experiencing stress. Several sites have very large proportions of collector-gathering insects that are able to survive by eating many different kinds of bits of detritus that wash downstream. These invertebrates are considered more tolerant to stress because they make use of an easily-available food resource that often increases with increasing amounts of nutrients added to streams. Conversely, there are few predatory insects in Miller Creek. Predators are considered more susceptible to stress because many of them are larger, more active invertebrates which use a more specialized food resource. The lack of leaf-shredding insects is surprising given the high amounts of stream shading at most sites. Most of the comparison sites have a higher proportion of shredding insects. There have been fewer studies of temperature preferences and/or requirements of macroinvertebrates than there have been for fish. However, using the data available to us, we found that the Lake Superior College (LSC) and LP sites both had higher numbers and proportions of cool/cold preference taxa than any of the other Miller Creek sites or the 2008 comparison sites (Amity and Mission Creeks). At LSC, nearly 20% of the invertebrate community was comprised of cold-preference taxa. There were few taxa at Kohls' department store (Kohls) or the Mall site that exhibited strong temperature preferences, based on the limited information available to us.

Our results suggest that the Mall site has some habitat problems, particularly with sand in the substrate, while the LP site is a harsher environment both naturally and likely due to development. The Kohls site is more open (less shaded) and has more taxa that prefer warm water than any of the other sites. However, these taxa make up a very small component of the community. The information on temperature and invertebrates that we have does not suggest that warm temperatures are driving invertebrate differences among sites. Our metrics do suggest that two of the sites (LSC and LP) supported more invertebrates preferring cooler water than did the other sites, including the comparison sites. But the converse does not seem to be true. Instead, the Mall and Kohls sites are comprised largely of invertebrates that do not have strong temperature preferences, prefer temperatures in the mid-range (between 18 and 21° C), or for which temperature preferences are not known. Although we do not have the data to identify what specifically is causing the macroinvertebrate community to appear in poorer condition than sites with less urban watersheds, we feel it safe to say that the amount of development in the Miller Creek watershed is the ultimate cause. Best management practices within the watershed and in the riparian zone which have been shown to reduce stream impacts are encouraged.

Introduction

Miller Creek has a total maximum daily load (TMDL) impairment for water temperature. Miller Creek is a designated trout stream that flows through the city of Duluth, Minnesota. Its headwaters near the Duluth International Airport flow through the Miller Hill Mall area, go down the escarpment, and enter the St. Louis River estuary. As the stream flows through the city, long sections are subsurface. The creek flows through areas with rather large amounts of development and impervious surfaces, reducing the ability of rainwater to soak into the ground, and increasing the flow of pavement-warmed stormwater into the stream. In addition, there are stormwater holding ponds located along and near the channel that have the potential to increase water temperature, as does the loss of canopy cover over the stream and riparian zone along a few reaches.

As water warms, its ability to hold dissolved gases, including oxygen, is reduced. A second effect of warm water on stream biota is the temperature itself, which can be above physiological thresholds for some taxa. Water temperature can also fluctuate above and below physiological thresholds, which may cause stress to organisms. Published studies of stream temperature tolerances have largely focused on stream fishes, primarily on cool/cold water fishes such as trout. Many of these studies have been done in laboratory settings with rather artificial and arbitrary test conditions for temperatures tested, rates of warm up and acclimation, and lengths of time the fish are held at or above temperatures of interest (U.S. EPA 1976). A few studies have attempted to correlate the presence or absence of cool/cold water fish with stream temperature at many sites in the field (Werhley et al. 2003, 2007). While this does not prove that temperature is the reason fish are present or absent, a high correlation (positive or negative) over a large number of sites suggests there may be a causal linkage.

Studies of temperature tolerances or preferences for aquatic macroinvertebrates are quite scarce and most of these report on only a few specific taxa of particular interest (e.g., Rossario 1991, Quinn et al. 1994, Cox and Rutherford 2000). However, Huff recently examined presence and abundance of macroinvertebrates at a number of stream sites in southern Minnesota, along with grab-sample water temperature data (D. Huff, personal communication). He was able to correlate water temperature with invertebrate abundance for a number of taxa, and used this to generate a median temperature ‘preference’ for these taxa. Based on these data, we created warm water and cool/cold water preference metrics.

Along with these temperature preferences, we also calculated ‘standard’ macroinvertebrate metrics on community composition, behavior, and feeding; stream and riparian zone habitat types and structure; and substrate and sediment composition and particle size distribution. Because aquatic macroinvertebrates are so sensitive to substrate type, we felt that this needed to be accounted for in our analyses to ensure that we were not confusing a change in invertebrate community composition due to substrate with a temperature causation or correlation.

Methods

Study Sites

Miller Creek TMDL study sites were selected to be near SSL SWCD water quality monitoring sites and by professional judgment in order to include highly productive riffle/run areas. The five biological sampling locations were also chosen to take advantage of proximity to tributaries in order to dissect the watershed into sub-basin units (Fig. 1, Table 1). Final site locations and sampling protocols were chosen in accordance with an earlier Quality Assurance Project Plan (QAPP, NRRI/TR-2007/16). All collections occurred in late May 2008.

Table 1. Miller Creek TMDL macroinvertebrate sampling effort for major habitats at site locations in the spring of 2008.

		UTM coordinates			Gear type (n)	
Site	Date	X	Y	Habitat	D-Net	Hess/core*
Kohls	28 May	563580	5184457	Riffle/run		6
				Bank/debris	3	
Mall	29 May	563926	5183578	Riffle/run		6
				Bank/debris	3	
				Pool		3*
Chambers	29 May	564300	5182408	Riffle/run		6
				Bank/debris	3	
LSC	28 May	565469	5181161	Riffle/run		6
				Bank/debris	3	
LP	28 May	565637	5180082	Riffle/run		6
				Bank/debris	3	
Total					15	33

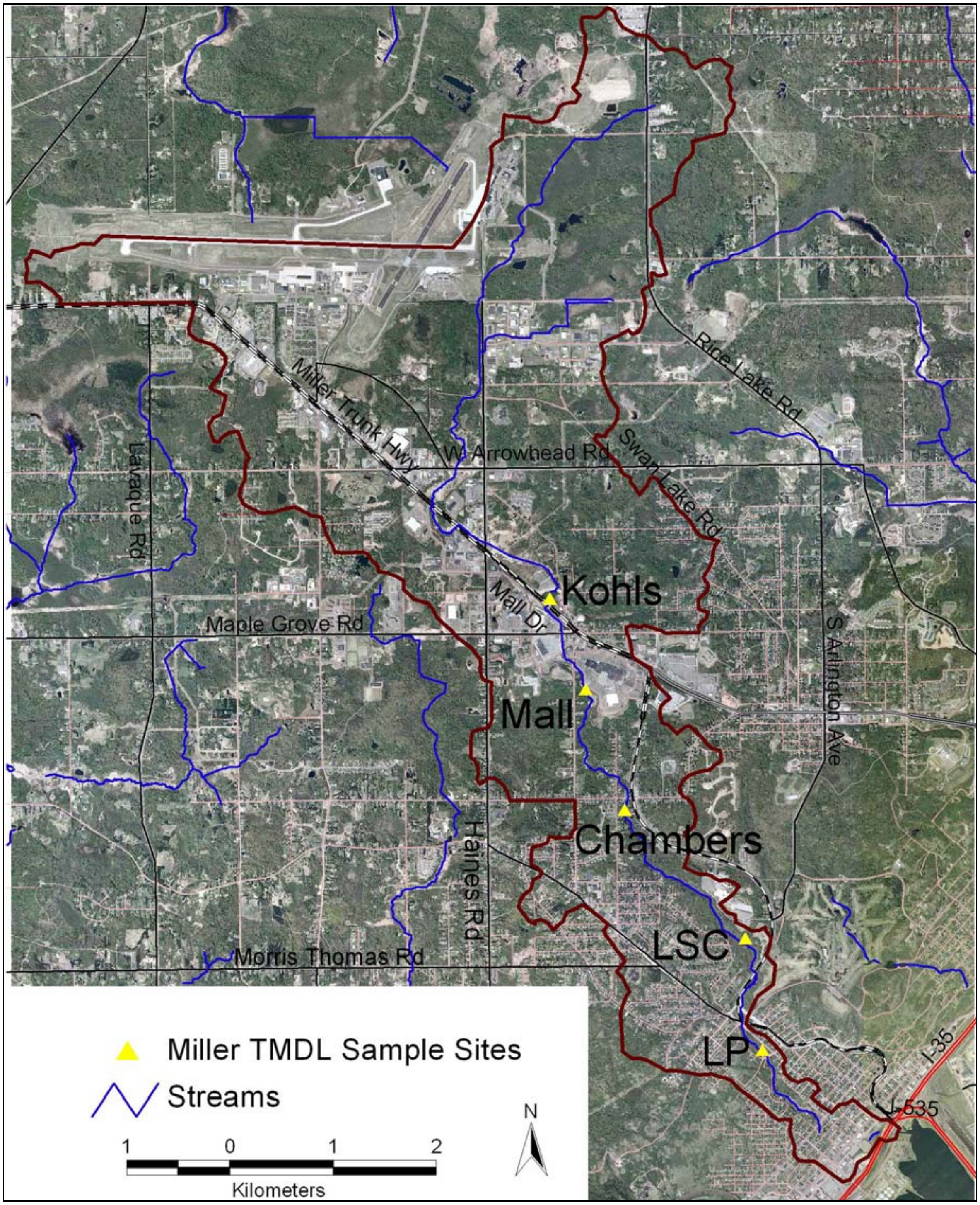

Figure 1. Location of Miller Creek TMDL macroinvertebrate sample sites: LP = Lincoln Park; LSC = Lake Superior College; Chambers = Chambersburg Rd; Mall = Miller Hill Mall; Kohls = Kohls department store.

Habitat Characteristics

Habitat data for the Miller Creek TMDL sites were collected both from transects established across the channel perpendicular to flow and from whole-reach observations. Transect point selection followed standard protocols (NRRI/TR-1999/37) and were spaced evenly based on calculations of mean wetted channel width. The area available for sampling at each location was between a minimum of 100 m to a maximum of 35x mean wetted width. When habitat features along a reach were homogenous, transects were placed at 10 m intervals (110 m minimum reach length). Evaluation of substrate characteristics, stream features, bank conditions, and available habitats occurred between each point. A schematic stream reach diagram noting habitat characteristics, cross-section measurements, unique structures, and sample locations was created on-site.

Transect points - Seven points evenly spaced along each transect were used to quantify size categories and proportion of each substrate (% coverage) within a grid. Points 1 and 7 along the transect were on the bank and represent bank conditions, while points 2 through 5 were in the wetted stream channel and describe the in-stream habitat. Point estimates were used to evaluate stream features, discharge rates, substrate type, most common substrate sizes, substrate embeddedness by fine particles, in-stream habitat cover, bank and riparian condition, landuse, stream shading, and riparian corridor extent.

Substrate - Within each grid (25 cm^2), the extent (in % surface area covered) and types of substrate particles were estimated for all particle size class categories. Classification schemes adhered to standardized particle size categories (e.g., Brusven and Prather 1974, Friedman and Sanders 1978, Gee and Bauder 1986). The extent large substrate particles (boulder, cobble, and gravel) were embedded by fine particles (sand, silt, clay) was also estimated (as %) at one point within each grid. An additional sediment depth measurement along each transect was recorded to determine the maximum depth of fine particle deposition using a sediment rod. This point was not random; rather, a subjective choice was made based on the amount of fine particle accumulation. This measurement was repeated to obtain a maximum reading per transect. Finally, fine sediments were collected using a 7.62 cm diameter core from three locations along the stream reach and brought to the laboratory for particle size analysis.

Flow - Stream discharge was estimated from flow recordings at 5 points on each transect. Water depth was recorded at each transect point and flow rates were recorded from a point equivalent to 60% of the total water depth. Instructions for flow-weighted averaging (FWA) are provided in the Marsch-McBirney Flow-mate operators’ manual.

In-stream cover - When transect lines intersected in-stream habitat cover, the type, size, and stability were described. Schematic diagrams of the size, shape, and dimensions of habitat cover, such as large boulders, islands, etc., were also recorded. Large woody debris (greater than 1 m in length and 10 cm dia.), such as debris dams, roots wads, etc., that intersected each transect were recorded in detail, noting length or surface area, stability, and position along each transect. Total amount of woody debris per reach was also estimated by counting the number of intact units (≥ 100 cm in length by 10 cm dia.). A reach survey quantitative habitat evaluation index (QHEI; Ohio EPA 1987) to rank overall stream condition was also completed for each site following the sampling event. QHEI categories include substrate, cover, channel type, riparian zone, width/depth ratio, and riffle/run quality; the gradient metric was not calculated or included in the final score.

Bank structure - Bank or shoreline structure and condition (stable or unstable) were evaluated on all transects by noting bank substrate type and the presence or absence of undercut banks. Bank-full width was recorded, as well as high water marks or indicators of flood extent.

Riparian corridor – Densiometer readings at a mid-stream point on each transect were used to estimate stream shading. Riparian width was estimated and vegetation type (ranked categories) noted. Adjacent riparian and landuse characteristics from 10-30 m and beyond were categorized.

Water Quality Parameters

Water chemistry parameters at each location were recorded with a YSI 556 multi-probe meter to establish baseline information on water temperature, dissolved oxygen, conductivity, pH, and oxidation-reduction potential (ORP) during the sampling effort. Water clarity observations were completed in triplicate using a transparency tube. Turbidity and total suspended solids were not sampled in this study.

Water Temperature

Temperature logger data from 27 stations on Miller Creek throughout the ice-free season in 2007-2009 were used in the following summaries. Depending on a particular unit (Onset Temperature Logger, TM), recordings took place at 15-minute intervals, although some periods were time stamped at 5- or 30-minute intervals. Data were transformed using Python™ script from a long-format Microsoft Excel (TM) by stations and year, to a comma-separated value (csv) format for processing in SAS (SAS 1988). With the exception of non-compatible date-stamps, and in rare cases where loggers appeared to be exposed to ambient atmospheric conditions, all data were used in the analysis to determine daily and nightly conditions, thresholds, and temperature/duration curves.

Macroinvertebrate Sampling

Benthic samples were collected using a multi-habitat sampling approach (Lenat 1988) during baseflow conditions (Table 1). Quantitative samples were collected from riffle and run habitats using a modified Hess (0.086 m^2). All quantitative samples were washed on-site through a 254-μm mesh net or sieve (App. 1). Where habitat was available, qualitative samples were collected from beneath bank or over-hanging vegetation, woody debris dams, boulder piles or rip-rap, or from sediments and aquatic vegetation in run and pool habitats using a D-frame kick net (mesh size: 500 μm; App. 2). The D-net effort was timed and measured (approx. 30 sec per sample and a 10 m distance). Extensive herbaceous bank vegetation and instream aquatic vegetation were swept when present, while wood dams and boulder piles were jabbed (*sensu* Barbour et al. 1999) to dislodge invertebrates. All invertebrates from each sample type were preserved in the field using Kahle's preservative, 10% formalin, or 70% ethyl alcohol.

Sample Processing

Benthic macroinvertebrates - Samples were processed by washing materials through two sieve sizes (4 and 0.25 mm) to separate contents into large and small size fractions. The large size fraction (>4 mm) was completely picked ('whole picked') for invertebrates. The amount of 4-0.25 mm fraction processed was determined individually by the picking time and the volume of material. All samples were either quarter, half, or whole picked. Invertebrates were removed from organic and inorganic sample materials under a dissecting microscope or a 2x magnification lens. Each completed sample was subject to quality assurance/quality control (QA/QC) inspection (100% inspection). Rejected samples were re-processed until QA/QC guidelines were passed. A subsample of the Chironomidae (Diptera) consisting of 30-100 individuals per sample was permanently mounted on slides for identification to genus. Other macroinvertebrates were identified to the lowest practical taxonomic level using appropriate keys (Hilsenhoff 1981, Wiederholm 1983, Brinkhurst 1986, Thorp and Covich 1991, Merritt and Cummins 1996). A reference collection was also established from invertebrates at all sites, and specimens were subject to a rigorous QA/QC inspection (further details available from NRRI/TR 99/37).

Sediment processing - Approximately 300 cm^3 of sediment from each depositional area was composited for each site (typically collected from 4 to 6 transects per site). Composite samples (approximately 1200-2000 cm^3 per site) were labeled and stored on ice and/or frozen prior to analysis. In the lab, thawed sediment samples were transferred to a basin and homogenized for 1 minute. A small amount of water was added to each sample to facilitate thorough mixing. Homogenized sediment in the mixing container was tamped to settle material uniformly. Sediment was sub-sampled in triplicate by extracting 250 cm^3 using a 5 cm (dia.) sediment core. Sub-samples were placed in labeled pans and dried (105° C) to a constant weight determined with a standard balance. Dried samples were ignited for 1 hour at 500° C. After samples cooled, reagent-grade water was added to re-wet ash and compensate for water weight not driven off from clay particles during the drying period (APHA 1992). Samples were dried to a constant weight at 105° C and re-weighed to determine the ash-free dry weight of each sub-sample.

Substrate particle size analysis - Dried sub-samples were run through a set of six sieves (4, 2, 0.5, 0.25, and 0.0625 mm) for 1 minute using a row-tapper to obtain six particle size fractions: 1) > 4 mm, 2) 4-2 mm, 3) 2-0.5 mm, 4) 0.5-0.25 mm, 5) 0.25-0.0625 mm, and 6) < 0.0625 mm. Sediment retained in each size fraction was weighed using a standard balance.

All data collected for this study will be provided as electronic files to SSL SWCD and posted on the Lake Superior stream website (http://www.lakesuperiorstreams.org/streams/miller.html).

Data Analyses

Comparisons among Miller Creek TMDL sites - Trait characteristics for each invertebrate taxon were derived from an NRRI-maintained database compiled from a variety of sources (Weiderholm 1983, Thorp and Covich 1991, Merritt and Cummins 1996). These traits consist of functional feeding group classifications, trophic levels, methods of locomotion, preferred habitats, and other processes or behavioral characteristics which help define aquatic invertebrate interactions with their environment. Invertebrate community metrics were generated based on known taxonomic sensitivities to environmental degradation (e.g., Ephemeroptera, Plecoptera, and Trichoptera [EPT] taxa) and on traits that may make select groups more or less sensitive (e.g., scraper-grazer feeders, burrowers, etc). Invertebrate metrics were compared among Miller Creek TMDL sites using a one-way ANOVA. Substrate, habitat, and water chemical/physical parameters were compared among sites in a similar fashion. Each invertebrate taxon was also assigned a tolerance value (0 to 10) indicating the taxon's overall level of tolerance of stressors. A value of 0 represents the least tolerant. Tolerance values came primarily from Hilsenhoff

(1987), and were supplemented by values from EPA (Barbour et al. 1999). Sensitive taxa were defined as taxa with a tolerance value of 3 or less, and tolerant taxa were those with a tolerance value of 7 or higher. Tolerance scores for entire sites were calculated by multiplying the tolerance value of each taxon by the abundance of that taxon per sample, summing the resulting products, and dividing by the total number of invertebrates per sample. This was done for quantitative riffle samples only because the most sensitive insects typically reside in riffles and quantitative samples help ensure comparability. Riffle sample scores were then averaged to generate site tolerance scores.

Temperature – Several methods were used to summarize the temperature records, but all techniques are based on hourly means and hourly maximum temperatures. To apply biological preferences, Salmonidae temperature thresholds were taken from the literature, and those consulted for this summary consist of MNDNR (Hendrickson personal communication, McCormick et al. 1972, Brown 1974, Werhly et al. 2007). These temperature thresholds were:

- MNDNR: >20 C = no growth; 8-20 C = maximum growth; 20-25 C = stress; > 25 C = mortality;
- McCormick et al. (1972): <15.4 C = maximum growth; 15.4-17.8 C = increased stress; >17.8 C = mortality;
- Werhly et al. 2007: <18.6 C = salmonids present; 18.6-26.1 C = indeterminate presence; >26.1 C = salmonids absent.

In one technique, data were stratified into day and night periods to reduce variability of daily means. Periods were designated as day from 8 a.m. to 8 p.m., and night as 8 p.m. to 8 a.m. the following day. Combining the data from all stations together removed specific habitat characteristics per station to gain a perspective on the overall temperature condition.

To determine the effects of temperatures on a fish assemblages and secondary responses of thermal stress, duration of exposure was summarized. This method incorporated an accumulation of time (in hours) where recordings exceed the 20° C reference point. Summations were performed by establishing a 20° C value to activate a switch and accumulate time until a record below 20° C ended the timer. In order to report those durations, summations were averaged by day and weekly periods over all 27 stations, or as weekly means by station.

Based on the recent work of Huff on temperature preferences of aquatic invertebrates in streams in southern Minnesota (D. Huff, personal communication), we created two temperature metrics. A warm water preference metric was calculated with warm water defined as median temperature preference greater than 21° C, while the cool/cold water preference metric defined cool/cold water preference as median temperature preference less than 18° C. Using these cutoffs, we calculated numbers and proportions of aquatic invertebrates with strong preferences for warm or cool/cold water at Miller Creek TMDL sites and for early summer-sampled sites in the 2008 dataset (see below on data comparisons). Invertebrates without a strong temperature preference, with a preference between 18 and 21° C, or whose temperature preference is not known were not included in the metric calculations.

Comparison with other sites – Miller Creek TMDL invertebrate samples and metrics were compared to other sites where invertebrate collection also occurred in the early summer.

Invertebrates sampled in 2008 on Amity (2 sites) and Mission Creeks were sampled identically to those on Miller Creek. An additional nine sites were sampled by NRRI personnel (Hershey et al.) in 1996 (Fig. 2).

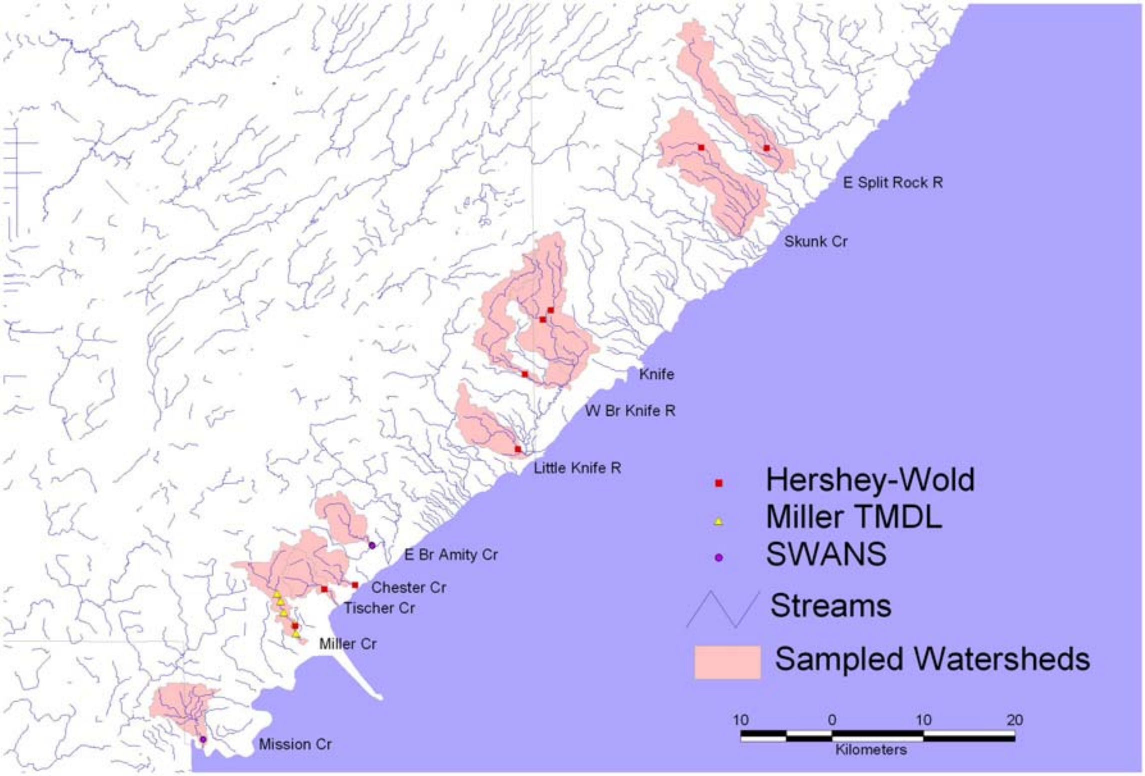

Figure 2. Location of Miller Creek TMDL macroinvertebrate sample sites and the comparison sites: Hershey-Wold sites were sampled in 1996, while SWANS sites were sampled in 2008. Macroinvertebrate samples at all sites were collected in early summer (late May – early June).

These include streams in Duluth (including Miller Creek just 300 m downstream from the LSC site) and up the North Shore. The 1996 samples also include macroinvertebrates collected quantitatively from riffles; however, the invertebrate identification was restricted primarily to insects (rather than all invertebrates), and the Chironomidae (midges) were not identified further than to family. Thus, many metrics and community comparisons had to be done only on the aquatic insects (rather than all invertebrates), and with the Chironomidae lumped at the family level rather than at the genus level. All streams were sampled in the early summer, as were the Miller Creek sites. In cases where it was vitally important to know chironomid genera or use the other macroinvertebrates in calculations, the 1996 sites were excluded.

Substrate composition data were collected differently in 1996 as well, with dominant and subdominant particle sizes noted rather than the % per major substrate type in each quadrat. In addition, no particle size or embeddedness measures were collected. The result of this difference in substrate data collection is that the sites sampled in 1996 appear to have significantly coarser substrate than they actually did, with much less fine sediments than was likely actually present.

In summary, data comparisons across studies are fraught with difficulties, most stemming from sample collection and processing differences for which there are no easy corrections, or for which no corrections exist at all. Thus, assessments and decisions using such comparisons should be made with caution. In undertaking these analyses, we have attempted to correct for biases whenever possible, and to make clear when we feel that bias may still exist. Studies for which we have not yet been able to correct for these differences have not been included in the comparison even though we have these data.

Results and Discussion

Habitat Conditions

Miller Creek sample locations above the escarpment to Lake Superior consisted primarily of slower flows meandering through alder bogs, where substrate is dominated by boulders and soft organic sediments. As Miller Creek approaches Highway 53 at Kohls, development increases and channel conditions are altered throughout the section (Table 2). Before the stream flows south of the Miller Hill Mall and into more residential development (Mall site), the stream moves through an engineered sediment trap designed to slow flows and deposit fine particles. Once the stream exits the Miller Hill sediment trap, it continues through a wetland complex, then the slope increases and the stream begins to increase flow. This middle section of the stream begins to cut through exposed bedrock at the Chambers and LSC sites (Table 2). The reach from Chambersburg to the LP site is primarily boulder substrate and cobbles. The stream channel downstream of LP enters an intensely developed area where it begins to flow for long distances underground.

Table 2. Miller Creek habitat characteristics measured at the TMDL sampling sites. Common substrates 1 and 2 represent the most common stream bed particles. % occurrence represents the mean % of quadrats per sampling site that contain the most commonly-occurring streambed substrate (these % sum to >100% because all particles sizes can occur in each quadrat). Sediment depth represents mean accumulation of depositional sediments along each transect. Occurrence of undercut banks is expressed as % of total observations evaluating bank structure within the sample reach. Riparian shading is expressed as Canopy cover (%), and an estimate of stand age is given as a mean circumference of trees at breast height (CBH). Large woody debris (LWD) values are expressed as meter length counts of logs greater than 10 cm dia. per transect. QHEI is a quality habitat evaluation index (Ohio EPA 1987).

Site	Common sub 1	Common sub 2	% occurrence	Sed depth (cm)	Undercut bank (%)	Canopy cover (%)	CBH (cm)	LWD (#/transect)	QHEI score*
Kohls	Boulder	Cobble	77/44	3.1±0.7	6.0	77.8±2.5 ^{b}	57.9	4.6	65
Mall	Sand	Pebble	68/57	11.8±2.0^{a}	5.7	56.1±5.4 ^{c}	23.8 ^{a}	3.6	61
Chambers	Cobble	Gravel	54/53	3.7±1.1	5.7	75.7±3.4 ^{b}	54.6	5.3	60
LSC	Boulder	Cobble	80/63	3.9±1.3	7.7	94.4±1.4 ^{a}	76.5	1.4	64
LP	Boulder	Cobble	69/59	3.1±0.8	7.4	87.8±2.5 ^{a}	94.3	4.5	64

*QHEI score was calculated without including the gradient component, worth 10 pts.

^{x}Denotes a significant difference based on a one-way ANOVA. Value $p \leq 0.05$. Numbers for sampling locations with the same letter, or no letter, were not different from one another based on Duncan's mean comparisons.

Overall, North Shore streams seem to have few, if any, problems related to nutrients or toxic substances. Instead, physical conditions seem to be most often responsible for the types of biota found. Comparing Miller Creek TMDL sites with the comparison sites shows that several of the

Miller Creek TMDL sites were among the narrowest in stream wetted width (Fig. 3, Table 3). The LP site is an oddity in that it is the furthest downstream of the Miller Creek sites and thus should be the widest and/or deepest; while it is the widest at bankfull, it is quite narrow during normal flows, and is braided in some sections. However, the water velocity is much higher than at the other sites due to its much steeper slope, allowing greater water volume to pass through the site than its width or depth would suggest (Table 3, Fig. 4). Otherwise, the stream sites are narrower upstream and wider downstream, as would be expected. Most of the Miller sites are narrower than the comparison sites; however, several of the sites (Mall, Chambersburg) are among the deepest at about 15 cm during baseflow. The LSC site compares closely in physical size to many of the comparison sites (Fig. 3).

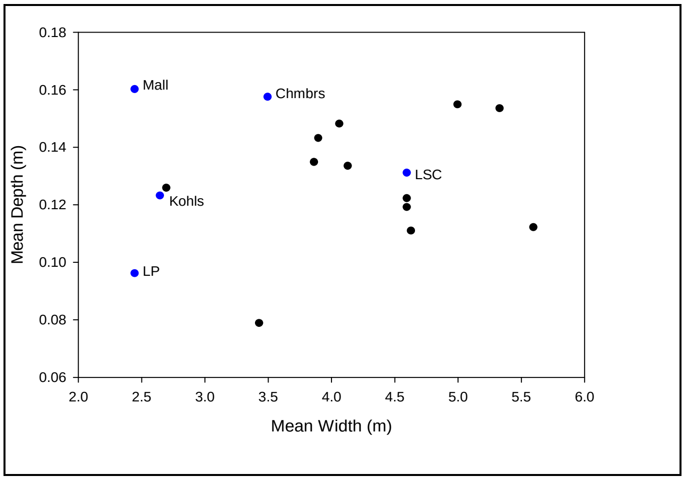

Figure 3. Relationship of stream channel width to depth for 17 Duluth and North Shore stream sites. Sites sampled for the Miller Creek TMDL are labeled and shown in blue.

Riparian corridors throughout the stream course are typically mixed forest, although buffer widths are highly variable, from 0 m to greater than 50 m depending on development. Because stream banks along Miller Creek are typically wooded, debris piles did occur at each sample location, although most were accumulations of branches and leaf organics. Relatively low volumes of large woody debris (> 10 cm in dia.) were noted (Table 2), and stream power at certain sections, or during periods of runoff, along the entire stream reach are likely sufficient to prevent buildup in the channel.

Canopy cover was high for most sections of the stream, with the LSC and LP sites having significantly more canopy cover than the Chambersburg and Kohls sites; these sites in turn had significantly more canopy cover than the Mall site (Table 2). The Mall site also had significantly smaller riparian trees because it flows through a wetland area, its banks were heavily manipulated, and the bank vegetation was dominated by willow, alder, grasses, and sedge vegetation. The Miller Creek sites were more shaded than many of the comparison sites (Table 3). Stream and riparian zone shading are known to be correlated with water temperature, especially in streams with limited amounts of groundwater input.

Table 3. Physical characteristics of Duluth and North Shore streams presented as means. Stream site code includes stream name, site name (if any), project abbreviation (see Methods), and year sampled (all sampling was done in early summer). Sites from the current study (Miller TMDL) are in blue. Depth and velocity (flow) were measured in riffles. 'Shade' represents mean percentage that the center of the stream channel was shaded.

Stream-site	Bankfull width (m)	Wet width (m)	Depth (m)	Flow (m/s)	Shade (%)
Miller-LP2008	9.66	2.45	0.10	0.92	88
Miller-Mall2008	7.14	2.45	0.16	0.23	56
Miller-Kohls2008	6.25	2.65	0.12	0.25	78
McCarthy-Hershey1996		2.70	0.13	0.39	43
Skunk-Hershey1996		3.43	0.08	0.13	82
Miller-Chambers2008	7.76	3.50	0.16	0.14	76
Chester-Hershey1996		3.87	0.13	0.19	75
Amity(A)-SWANS2008	13.5	3.90	0.14	0.23	67
Tischer-Hershey1996		4.07	0.15	0.16	85
Knife-Hershey1996		4.13	0.13	0.17	57
Miller-LSC2008	9.32	4.60	0.13	0.28	94
Amity(B)-SWANS2008	8.42	4.60	0.12	0.22	32
Mission-SWANS2008	12.06	4.60	0.12	0.12	48
West Knife-Hershey1996		4.63	0.11	0.24	33
E. Split Rock-Hershey1996		5.00	0.15	0.14	20
Miller-Hershey1996		5.33	0.15	0.27	90
Little Knife-Hershey1996		5.60	0.11	0.09	37

Current velocity is similar for the Miller TMDL sites and the comparison sites (Fig. 4), with the exception of LP, which had much higher velocity as the site flows over bedrock down the escarpment. High flows over bedrock are a particularly difficult situation for stream invertebrates as they have few refugia from flow or from predators. Only the Mall and LSC sites have much fine sediment (sand, silt, clay) in their substrate (Fig. 4), with the Mall site being among the highest in the dataset (Table 4).

Table 4. Miller Creek mean substrate size-class distribution as a % of surface area measured at the TMDL sampling sites. % coverage of each sediment class is based on a grid (25 cm^2), and estimated for all particle size class categories that occur. Classification schemes adhered to standardized particle size categories (e.g., Brusven and Prather 1974). Values are means and standard errors.

Site	Bedrock	Boulder	Cobble	Gravel	Pebble	Sand	Silt	Clay
Kohls	17.4±4.0	31.4±3.3	13.9±2.4	13.0±2.1	5.6±1.1	4.6±1.4	14.4±3.7	0.0±0.0
Mall	0.0±0.0	12.6±3.4	[a] 3.6±1.3	[a] 30.7±4.2	[a] 17.9±2.8	[a] 23.2±3.1	11.9±3.2	0.0±0.0
Chambers	7.9±2.9	28.3±3.8	19.2±2.7	17.5±2.5	5.9±1.5	7.0±2.0	14.3±3.8	0.0±0.0
LSC	0.0±0.0	44.4±4.0	17.3±2.4	14.9±2.4	5.1±1.2	3.9±1.5	14.5±3.7	0.0±0.0
LP	27.5±4.7	26.9±3.1	19.3±2.5	13.1±1.9	3.9±1.0	3.6±1.1	3.1±0.4	0.0±0.0

[x] Denotes a significant difference based on a one-way ANOVA. Value $p \leq 0.05$. Numbers for sampling locations with the same letter, or no letter, were not different from one another based on Duncan's mean comparisons.

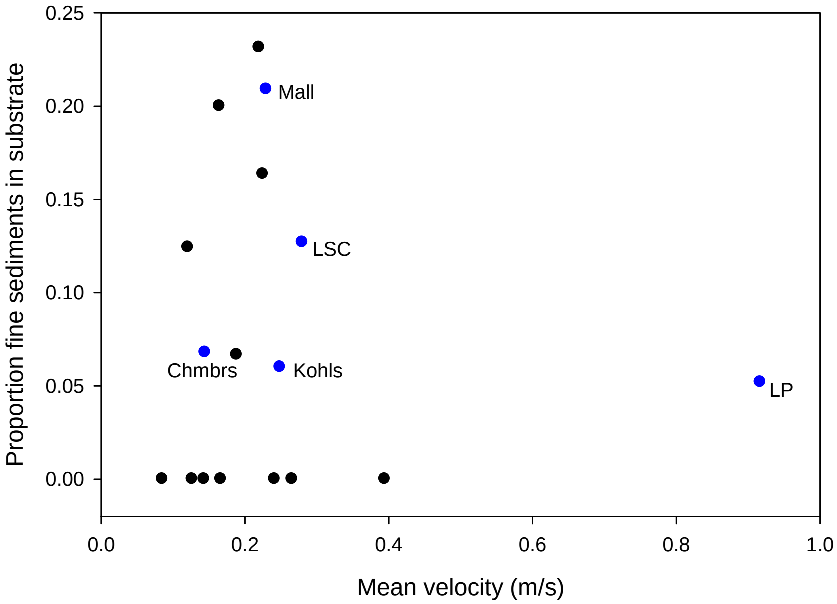

Figure 4. Relationship of current velocity in riffles to amount large substrates are surrounded by fine substrates (e.g., sand, silt, and clay). Sites from the Miller Creek TMDL are labeled and shown in blue.

Substrate Conditions

Riffles and runs are the most common feature throughout the stream course. Large substrates (Tables 2, 4, and 5; Fig. 5) consisting of boulders and cobbles occur more commonly within the sampling reaches than other materials. Boulders were recorded in 80% of the observations at LSC, compared to 24% at the Mall site, where smaller particle sizes dominated the stream bed (Tables 2, 4). Bedrock outcroppings were a common substrate at several sites, occurring in 44% of observations at the most downstream sites (LP), to nearly 12% of the observations at Chambers (Table 4, Fig. 5).

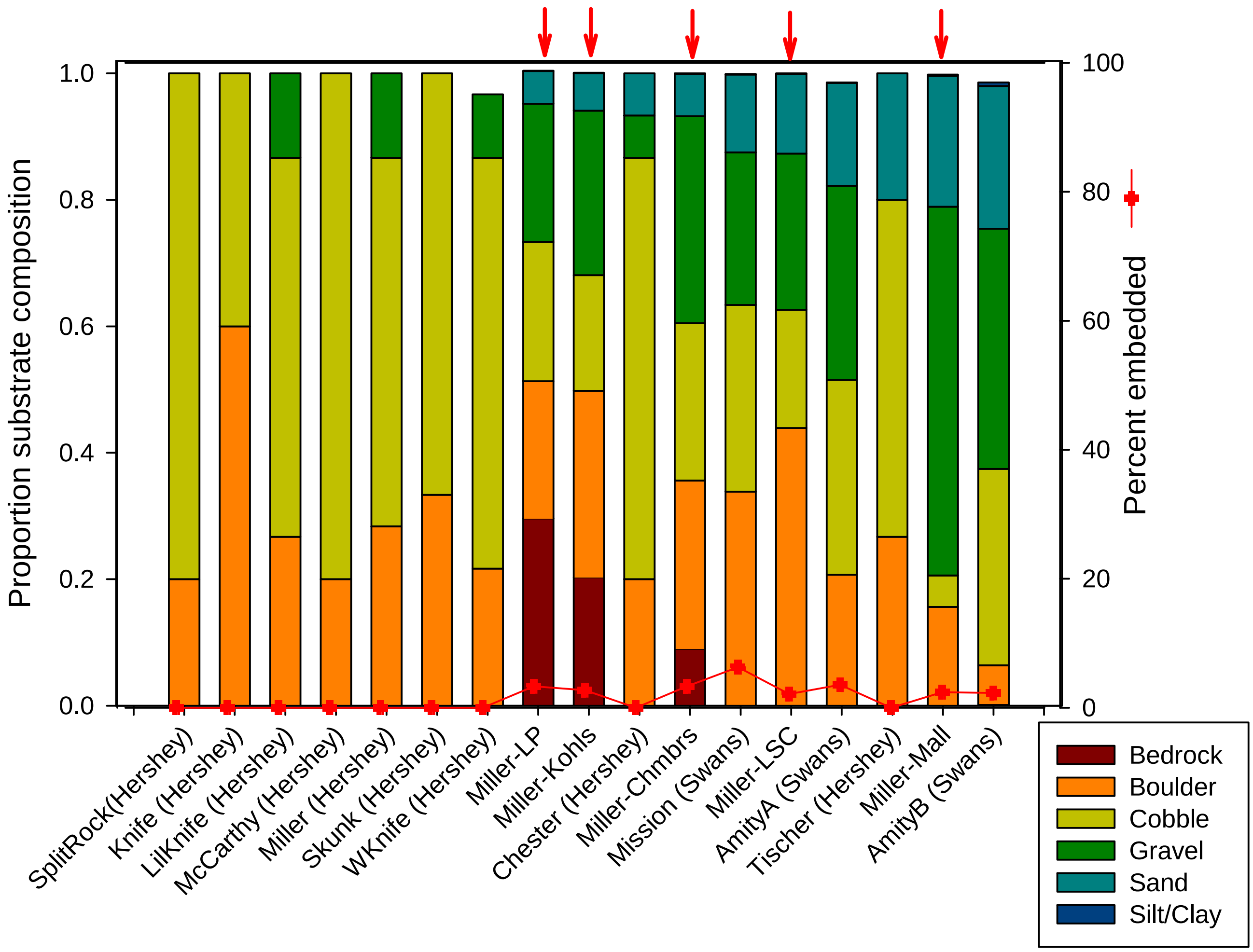

Figure 5. Average % substrate types in riffles for Duluth and North Shore streams, with average % riffle embeddedness shown as red dots. Sites from the current study are marked by arrows Hershey sites were sampled differently for substrate, making them appear coarser (see Methods). Hershey sites also had no embeddedness measurements taken.

Table 5. Substrate characteristics of Duluth and North Shore streams. Sites from the current study are shown in blue. Substrates were characterized as bedrock (bed), boulder (bldr), cobble (cbl), gravel (gvl), sand, and silt and clay (st/cl) and are expressed as %. Total fines (Tfines) are the sum of % of sand, silt, and clay. Depth of fines is the maximum depth of fine sediments in slow current areas. Embeddedness is the amount that large substrates (primarily cobbles and gravels) are surrounded by fine substrates.

Stream-site	Bed (%)	Bldr (%)	Cbl (%)	Gvl (%)	Sand (%)	St/cl (%)	Tfines (%)	Depth fines (m)	Embed (%)
McCarthy-Hershey1996	0	20	80	0	0	0	0		
Skunk-Hershey1996	0	33	67	0	0	0	0		
Knife-Hershey1996	0	60	40	0	0	0	0		
West Knife-Hershey1996	0	22	65	10	0	0	0		
E Split Rock-Hershey1996	0	20	80	0	0	0	0		
Miller-Hershey1996	0	28	48	13	0	0	0		
Little Knife-Hershey1996	0	27	60	13	0	0	0		
Miller-LP2008	30	22	22	22	5	0.02	5.2	0.06	3.3
Miller-Kohls2008	20	30	18	26	6	0.05	6	0.07	2.7
Chester-Hershey1996	0	20	67	6.7	6.7	0	6.7		
Miller-Chambers2008	9	27	25	33	6.7	0.09	6.8	0.10	3.3
Mission-SWANS2008	0	34	30	24	12	0.01	12.4	0.10	6.3
Miller-LSC2008	0	44	19	25	12.6	0.08	12.7	0.11	2.1
AmityA-SWANS2008	0	21	31	31	16	0.09	16.4	0.10	3.6
Tischer-Hershey1996	0	27	53	0	20	0	20		
Miller-Mall2008	0	16	5	58	21	0.2	21	0.23	2.4
AmityB-SWANS2008	0.3	6.1	31	38	23	0.6	23	0.38	2.3

Streambed material between sites was not different with respect to bedrock and boulders (Table 4). However, there was significantly more gravel, pebbles, and sand at the Mall site than at other Miller sites. Silt was not significantly different among sites, and no clay particles were recorded. Fine depositional particles were not different among locations at the 4 mm and larger category, but differences were observed between the 4-0.25 mm size fractions (Table 6). The 4-2 mm category contained significantly less material than the remaining sites; Kohls and the Mall had greater 2-1 mm deposits than the remaining locations. The 1-0.5 mm and 0.5-0.25 mm fractions were greatest at the Mall location, with no differences observed within the smallest size particles. Organic matter contained within the depositional sediments (expressed as AFDW) was relatively low, and no clay particles were observed.

Table 6. Miller Creek distribution of fine sediment particles. Values represent mean % of total mass for each size class (with standard errors). Particles were extracted from depositional areas within riffle/run habitats at sites using core tubes (7.62 mm) and classified based on schemes that adhere to standardized particle size categories (e.g., Gee and Bauder 1986).

Site	>4 mm	4-2	2-1	1-0.5	0.5-0.25	0.25-0.063	<0.063	AFDW
Kohls	60.7±4.3	17.6±1.7	^{a} 12.1±1.0	^{b} 5.3±0.6	2.2±0.2	0.7±0.1	0.2±0.0	0.8±0.1
Mall	50.4±2.9	14.9±0.6	^{a} 13.4±0.5	^{a} 11.4±0.9	^{a} 6.5±0.7	1.4±0.1	0.3±0.0	1.0±0.0
Chambers	66.1±2.8	17.3±1.7	8.8±0.8	3.5±0.3	1.6±0.1	0.7±0.0	0.2±0.0	1.2±0.1
LSC	66.8±1.9	^{a} 10.6±0.4	9.5±0.2	^{b} 6.6±0.7	^{b} 3.8±0.8	1.2±0.3	0.1±0.0	0.5±0.0
LP	70.7±2.5	14.9±1.2	8.1±0.8	3.1±0.4	1.1±0.1	0.3±0.0	0.1±0.0	0.7±0.3

x

Denotes a significant difference within a particle size comparison between sites. Value $p \leq 0.05$ is from the overall one-way ANOVA. Numbers for sampling locations with the same letter, or no letter, were not different from one another based on Duncan's mean comparisons.

Although embeddedness was quite low at all Miller sites, the depth of fine sediments deposited in slow water areas was high at the Mall site (maximum of 23 cm; Table 4). Substrates comprised largely of small gravels and sand have less interstitial space for invertebrates, fish eggs, and fish fry. At the other end of the spectrum, large amounts of bedrock in a stream bed can also reduce the amount of interstitial space for invertebrates and fish fry and eggs. In comparing substrate composition among sites, it is important to remember that the Hershey dataset included only dominant and subdominant substrates, thus overemphasizing the amounts of these substrates and not reporting the presence or amount of other substrates. In this case, that has resulted in the substrate appearing significantly coarser at the Hershey sites. Hershey data also did not include embeddedness measurements.

Temperature Thresholds for Stream Fish Assemblages

Daily mean temperatures are used to establish criteria to determine suitable conditions for Salmonidae growth and survival. Daily maximum temperature criteria have been used similarly to define thresholds by which individuals then enter into stress response. A host of temperature-dependent responses by stream fish assemblages (e.g., Elliott 1981, Hinz and Wiley 1998) complicate the process by which criteria are developed and management schemes implemented. Because stream fish assemblages can withstand short-term exposure to temperatures above a preferred temperature range, both range of temperature and duration of exposure become important factors in determining suitable conditions, and ultimately, maintaining a successful fishery.

Traditional methods in determining thermal tolerance use lethal temperatures and critical maximums in a laboratory setting. For decades, rigorous methods have been developed to establish behavioral response and mortality endpoints on a host of beneficial species (U.S. EPA 1976). Test replication is required for studies on thermal tolerances of Salmonidae, similar to the development of exposure/response curves in toxicological experiments with numerous aquatic organisms. All procedures used to develop criteria require standardized protocols. Consequently, testing procedures must use unnatural thermal conditions (e.g., constant upper lethal limits, or constant rate of increase to thermal maximums). Although a wealth of knowledge regarding fish physiology is gained from this work, and useful target endpoints can be established, the applicability of such techniques for evaluating intact stream assemblages has limitations (Selong et al. 2001, Wehrly et al. 2003).

Alternative approaches to evaluating thermal stream conditions apply regional field temperature data and distribution of intact fish populations (Wehrly et al. 2007). The utility of this approach is that variation in response mechanisms, which complicate establishing standard endpoints, is realized by the presence/absence of individuals. By using species observations and thermal conditions from the field, a species-dependent thermal niche is inherent in the criteria ultimately used to direct managerial decisions.

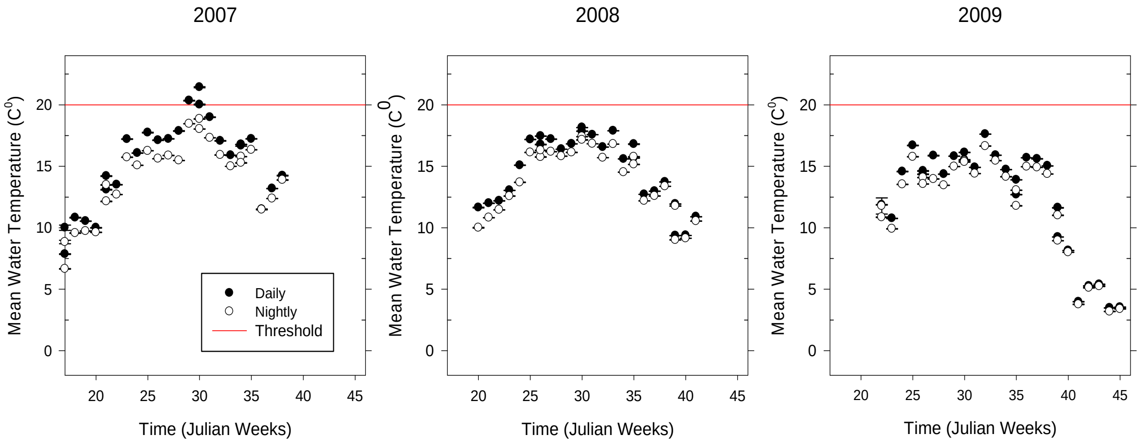

Figure 6. Mean day and night water temperatures per summer averaged across all 27 Miller Creek temperature logging stations for the summers of 2007-2009. The red line marks the 20° C temperature threshold for salmonids.

Daily and weekly averages by day and night suggest the thermal point of 20° C was only intermittently exceeded, and then only during 2007 (Fig. 6). Unfortunately, this coarse observation does not provide detail on the number of occurrences, or duration that temperatures rose above a 20° C reference point. Data from all 27 temperature stations plotted individually for daily maximum temperatures show that without exception, the 2007 season was by far warmer than the 2008 and 2009 seasons (Fig. 7). Water temperatures remained at or above the 20° C threshold for extended periods for most of July 2007 (Table 7, App. 3). Fortunately, several stations recorded temperatures that did not exceed the 20° C maximum daily threshold. Note that temperature loggers were put into the streams later in 2009, giving the appearance that water temperatures started out warmer in the early summer. This is simply an artifact of the sampling schedule.

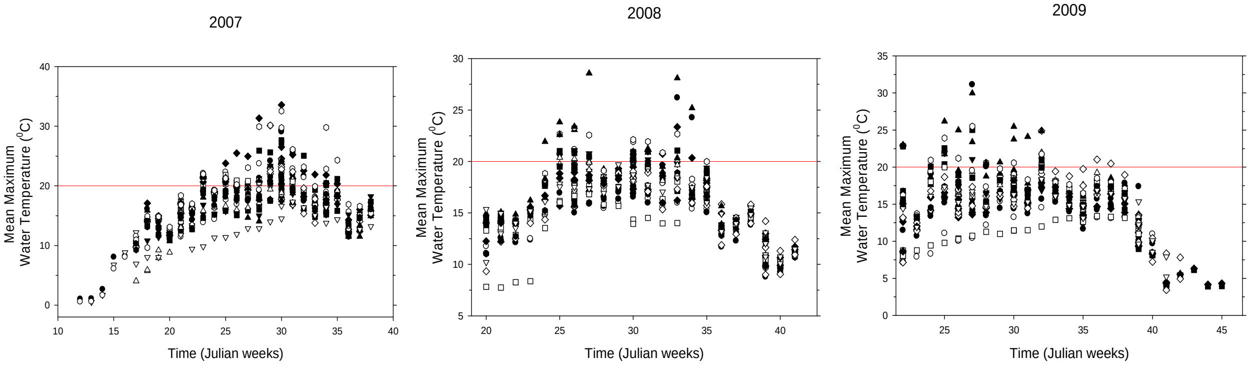

Figure 7. Mean maximum water temperatures for 25 to 27 Miller Creek temperature logging stations for the summers of 2007-2009. The red line marks a 2°0 C temperature threshold.

Table 7. Mean number of hours per week over the open-water season during which water temperatures in Miller Creek reached, or exceeded, 20 C. Values are based on accumulated time for 25-27 temperature recorders located through the river course. Recording devices were set at 5-30 minute intervals. Station specific averages throughout the season are available in App. 3.

	April				**May**				**June**			
Year	Wk1	Wk2	Wk3	Wk4	Wk1	Wk2	Wk3	Wk4	Wk1	Wk2	Wk3	Wk4
2007				0.3	0.3		27.1	3.1	28.7	15.0	25.3	18.7
2008	3.6	3.1	5.4	3.3	7.3	4.4	5.5	3.4	1.5	8.1	4.2	7.1
2009	2.8	4.0	0.1	2.9	0.1	2.2	0.9	1.9	3.4	5.0	4.7	7.0
	July				**August**				**September**			
	Wk1	Wk2	Wk3	Wk4	Wk1	Wk2	Wk3	Wk4	Wk1	Wk2	Wk3	Wk4
2007	58.8	34.8	19.9	16.7	2.0	1.2	10.2		0.1			
2008	5.5	2.9	3.5	2.6	3.3	5.2	3.2	7.3	5.4	3.0		
2009	4.6	4.0	4.8	3.8	3.7	6.4	4.3	9.2	1.1			

Data from all 27 stations on Miller Creek were applied to thermal tolerance estimates provided in the literature (Werhly et al. 2007). Reference temperature tolerances are based on the presence/absence of trout in 285 streams from Michigan and Wisconsin. Estimates used fish assemblage data and water temperatures recorded at 30- to 60-minute intervals at 171 sites, with remaining sites using temperature data collected on-site within a 5-year period. Exposures periods and estimates of thermal tolerance were based on daily means, mean daily maximums, and mean daily range for 3, 7, 14, 21, 28, 35, 42, 56, and 63 day moving averages (see methods in Werhly et al. 2007). Miller Creek station temperatures were processed with the same technique, although only 1, 3, 7, 21, and 63 day maximum means and maximum temperatures were plotted (Fig 8). While maximum daily mean temperatures did not exceed Werhly et al.'s thermal tolerances at any site over the three-year period of record, maximum daily maximums were exceeded at some sites over the three years. Appendix 3 shows exceedences by station in more detail.

Macroinvertebrates

Within-stream comparisons - Individual invertebrate parameters such as total taxa or total abundance represent standard biological metrics for describing populations, although such general metrics are not necessarily particularly informative about sites. Therefore, we often use a suite of metrics to identify subtle differences in community structure and overall stream condition when less complex observations are at first inconclusive or misleading. For example, more than 40 invertebrate metrics were examined, with over 20 suggesting a significant difference among sites. It should be noted that several metrics that make up the total suite used in this report are based on similar sets of invertebrate taxa, meaning that they could all be driven by an abundance or count of a few of the same taxa. For instance, the family Chironomidae (non-biting midges) is within the order Diptera. Since this family dominated the Diptera, metrics calculated using either the Diptera or the Chironomidae will generate similar values and similar differences among sites.

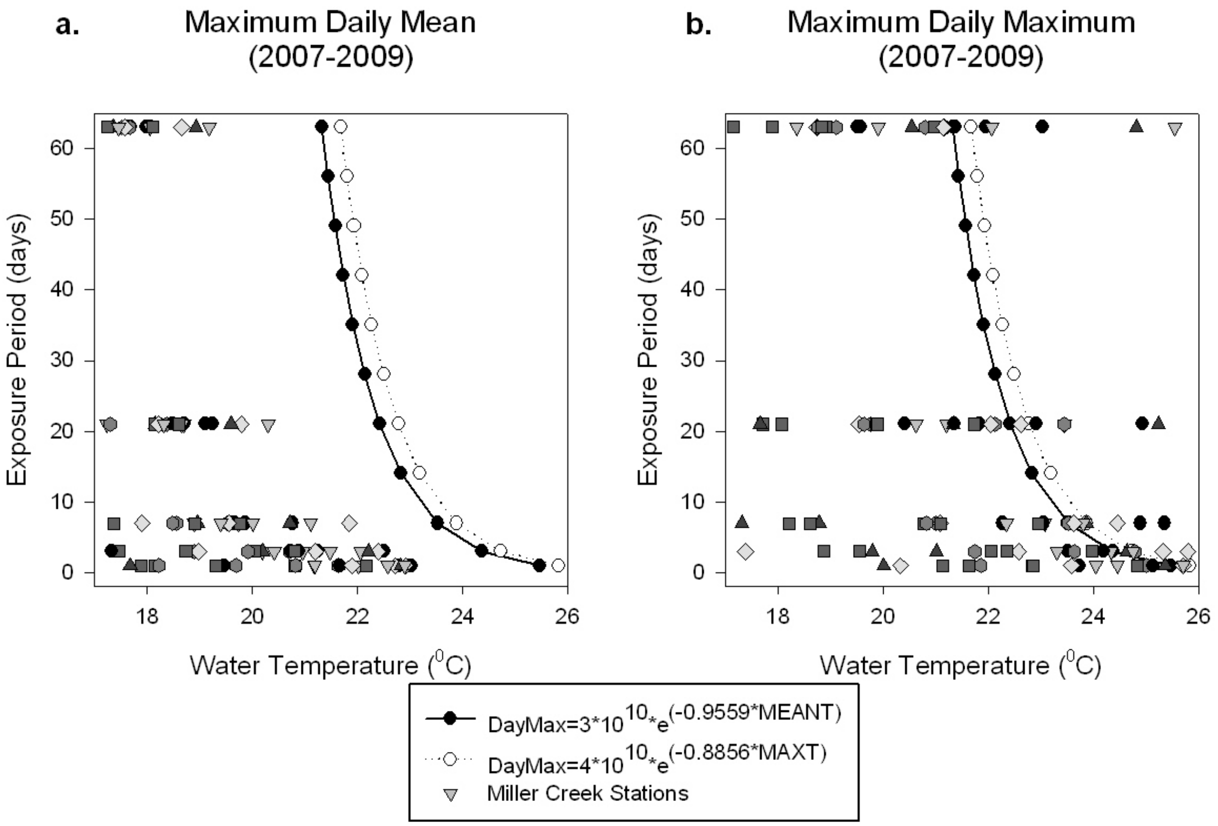

Figure 8. Maximum daily mean (a) and maximum daily maximum (b) temperatures from all 25-27 Miller Creek stations used to calculate 1, 3, 7, 21, and 63 day moving averages for of the open-water season from 2007-2009. Reference temperature tolerance estimates of MEANT (mean daily maximum) and MAXT (maximum daily maximum) are based on methods from Werhly et al. (2007) and plotted for 1, 3, 7, 14, 21, 28, 35, 42, 48, 54, and 63 days.

The mean abundance of macroinvertebrates per square meter was not significantly different among the five Miller Creek sampling locations (Fig. 9). However, the Mall site had significantly fewer macroinvertebrate taxa per sample than the other sites (Fig. 6). Other metrics indicate that the Mall and LP sites were subtly different from the other sites. This difference may be due to differences in substrate, and the invertebrate habitat preferences of those assemblages. Chironomidae (Diptera) are considered to be generally tolerant of stressful conditions, highly adaptable, and are common in depositional substrates, among other habitats (Rosenberg and Resh 1993). The Mall site contained a much larger proportion of Chironomidae than the other Miller sites (Table 8).

Burrowers at the LP site were significantly higher than at other sampling locations; this difference is largely driven by the abundance of Chironomidae and Oligochaeta (aquatic worms; Table 8). Oligochaete abundances in turn influenced the ‘non-insect’ and ‘tolerance’ metrics that responded similarly (Table 7). Swimming taxa were observed in greater abundances at the Chambersburg site, and were significantly more abundant than at the Kohls, LSC, and LP sites. Additional invertebrate traits that were significantly different among sampling sites responded similarly and include other behavioral attributes such as climbers and sprawlers, with the downstream LP location containing fewer numbers than any other location (Table 8).

Table 8. Miller Creek macroinvertebrate metrics calculated for the TMDL sampling sites. Values for each trait are expressed as the mean % of total abundance for all individuals (insects and non-insects) per sample. Chirond% = Chironomidae (Diptera); Burrow% = burrowing behavior; Tol% = tolerant of disturbance; EPT% = Ephemeroptera, Plecoptera, and Trichoptera; Col-Filt% = collector-filterers; and Pred% = predators. Classifications are based on information from several sources (c.f. Merritt and Cummins 1996). Values represent means ± one standard error.

Sites	Chirond%	Burrow%	Tol%	Swim%	EPT%	Col-Filt%	Pred%
Kohls	^{b} 25.6±2.5	^{b} 34.1±5.1	^{b} 18.2±2.9	^{bc} 2.8±0.6	^{bc} 10.1±2.5	^{abc} 20.9±7.3	^{bc} 6.1±0.8
Mall	^{a} 54.2±9.0	^{b} 31.8±8.2	^{a} 16.2±5.4	^{ab} 4.3±1.3	^{ab} 5.9±1.6	^{ab} 11.6±2.3	^{ab} 7.3±1.4
Chambers	^{a} 46.4±3.8	^{b} 10.4±2.3	^{b} 5.6±1.2	^{a} 26.5±4.7	^{a} 31.0±5.4	^{a} 13.2±1.4	^{a} 8.9±2.2
LSC	^{a} 46.8±6.6	^{b} 24.0±4.7	^{b} 8.8±1.7	^{cd} 0.7±0.3	^{dc} 9.2±3.8	^{bc} 9.5±1.9	^{cd} 3.9±0.3
LP	^{b} 22.2±2.8	^{a} 49.8±7.5	^{a} 44.3±8.0	^{d} 0.6±0.2	^{d} 6.4±2.2	^{c} 5.6±1.7	^{d} 2.2±0.3

^{x}Denotes a significant difference based on a one-way ANOVA. Value $p \leq 0.05$. Mean values per metric with the same letter, or no letter, were not different from one another based on Duncan's mean comparisons.

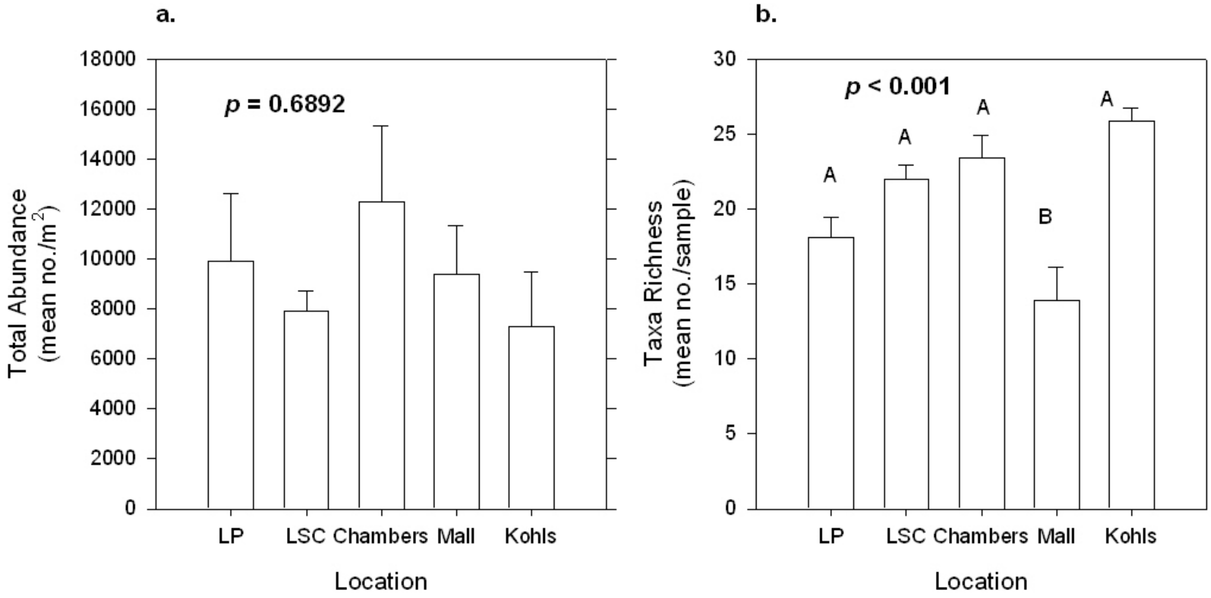

Figure 9. Mean total abundance per square meter of macroinvertebrates at Miller Creek TMDL sampling locations (a). Mean taxa richness per macroinvertebrate sample (b). Values represent means + 1 standard error. Data were analyzed with a 1-way ANOVA (SAS, 1988), followed by Duncan's means comparison procedure for the separation of means. Bars with the same letter are not significantly different. Value p is from the overall ANOVA.

Ephemeroptera (mayflies) are a sensitive and a reliable biological indicator, and commonly combined with Plecoptera (stoneflies) and Trichoptera (caddisflies) into the EPT metric to clarify the response of just one component, making the metric more robust. Ephemeroptera, Trichoptera, and EPT all showed a significant difference between locations (Table 8), with the Chambersburg site having higher mean numbers than the other sites, and were generally significantly different than LP and LSC.

The mechanisms that invertebrates use to feed themselves can also provide insights into the condition of stream sites. For example, collector-filterers (invertebrates that filter food particles out of the current) had higher mean abundances at the Chambersburg site, but were not significantly higher than the upstream Mall and Kohls locations (Table 7). The Chambersburg site did contain significantly more collector-filterers than the LSC and LP sites downstream. Predator abundance (notably a high occurrence within the family Chironomidae) was highest at the Mall site, and although not significantly different than the Kohls location, the Mall did contain numbers significantly higher than those found at Chambersburg, LSC, and LP. Predators at the Kohls and Chambersburg sites were also significantly different than LSC and LP sites downstream (Table 8).

Comparisons among sites - Use of the macroinvertebrate community to assess stream ecosystem condition relies on the varying sensitivities of the different taxa to the many different stressors to which they may be exposed (Rosenberg and Resh 1993). Most of the early summer samples in our comparison dataset do not have high resolution taxonomy. These datasets (the Hershey data) do not have the Chironomidae (non-biting midges) identified to genus, and the researchers limited their investigation primarily to insect taxa instead of the full suite of macroinvertebrates. Thus, when using these samples in the analyses, we limited ourselves to just working with aquatic insects, with the Chironomidae at the family level. The full suite of macroinvertebrates collected from Miller Creek is listed in Appendices 1 and 2. However, comparisons with stream invertebrate datasets collected in late summer should be done with great caution due to the seasonal difference in invertebrate maturation.

We evaluated the macroinvertebrates from Miller Creek samples in several different ways to assess what they can tell us about the creek's condition. These included enumerating the number and types of invertebrate taxa present, the % composition of the entire community, and evaluating the sensitivity of these taxa to various types of stress and to taxa metrics we created based on published and unpublished data on aquatic insect temperature preferences (D. Huff, personal communication). A second set of evaluations included invertebrate feeding and behavioral traits. Finally, we used published numerical sensitivity values to quantify human-caused stress on invertebrate taxa. Most of the 'indicator metrics' generated from these analyses are commonly used in the evaluation of wadeable stream condition (c.f. Gerritsen 1995, Richards et al. 1997, Breneman et al. 2000).

Macroinvertebrates that are particularly sensitive to stress often inhabit riffle habitats of streams because these areas typically contain substantial amounts of interstitial space, high dissolved oxygen levels, and good water flow which carries food particles to the invertebrates. Thus the following comparisons will focus primarily on macroinvertebrates collected quantitatively (i.e., using the Hess sampler) from riffle or run habitats.

Taxa richness is often considered a good indicator of stream condition. We collected a total of 116 taxa from Miller Creek, with 51 to 62 taxa per site (Table 9). The LP site had about 10 fewer taxa (51) than the other sites, which had 60-62 taxa. Although the Mall and LP sites were in the lowest quartile in the dataset for insect taxa richness, the numbers of taxa found were all within the range of the comparison sites. The Chambersburg, Kohls, and LSC sites all had relatively high numbers of insect taxa.

Table 9. Metrics calculated on aquatic insects from quantitative riffle samples collected from Duluth and North Shore streams. Current study sites in blue. 'Insect taxa' indicates mean aquatic insect taxa richness per site. 'Insect Tol score' is the mean site tolerance score calculated only using insect taxa, while 'Invert Tol score' is the mean site tolerance score calculated using the full suite of invertebrates. 'Sensit' is mean number of sensitive insect taxa (tolerance values ≤3); '% Chiron' is % of Chironomidae (Diptera) at sites. 'Hydropsych' is mean % of Trichoptera from the family Hydropsychidae. Sites are sorted by increasing tolerance score.

Stream-site	Insect taxa	EPT taxa	% EPT	Insect Tol score	Invert Tol score	Sensit	% Chiron	% Hydropsych
Knife-Hershey1996	12	9	77	2.64		7	19	0
McCarthy-Hershey1996	18	13	59	3.63		9	27	5
West Knife-Hershey1996	17	13	33	4.11		9	44	40
E Split Rock-Hershey1996	16	11	38	4.17		8	45	36
Skunk-Hershey1996	20	13	43	4.18		10	45	50
Chester-Hershey1996	12	8	45	4.62		4	51	2
Little Knife-Hershey1996	17	14	27	4.92		11	71	17
Miller-Hershey1996	9	5	20	5.18		2	75	9
Tischer-Hershey1996	10	6	20	5.29		2	71	14
Miller-Chambers2008	25	14	28	5.32	5.87	7	62	74
AmityA-SWANS2008	35	23	28	5.36	5.96	14	37	74
Mission-SWANS2008	26	17	21	5.56	5.35	6	67	26
Miller-Kohls2008	22	8	14	5.69	6.65	3	62	6
Miller-LP2008	13	5	8	5.71	7.41	3	77	95
Miller-LSC2008	20	10	4	5.80	6.42	5	90	57
Miller-Mall2008	10	6	10	5.83	6.43	3	80	76
AmityB-SWANS2008	36	26	22	5.85	6.10	14	44	59

Macroinvertebrates that are considered among the most sensitive to stress are found in the insect orders Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies). We found 5 (LP site) to 14 (Chambersburg site) EPT genera in Miller Creek riffles, which is within the range of the other sites in the dataset, although sites with < 10 EPT genera tend to be urban sites (Table 9). The proportion of individuals in these three orders comprising all the macroinvertebrates collected in quantitative riffle samples (% EPT, Fig. 10) or all the insects in riffle samples (Table 9, Fig. 11) was low for all but the Chambersburg site. For the rest of the Miller Creek sites, only 4-14% of the aquatic insect community was comprised of mayflies, stoneflies, and caddisflies, with the LP and LSC sites being particularly low. In this comparison, the Hershey sites appear to have quite high abundances of EPT insects. However, the under-representation of Chironomidae due to their sampling methods increases the apparent relative abundance of EPT insects in comparison with the other sites (Table 9, Fig. 11). It is noteworthy that the Amity Creek and Mission Creek sites, which were sampled the same year at the same time using the exact same methods, have higher proportions of EPT insects than all but the Chambersburg site (Fig. 11).

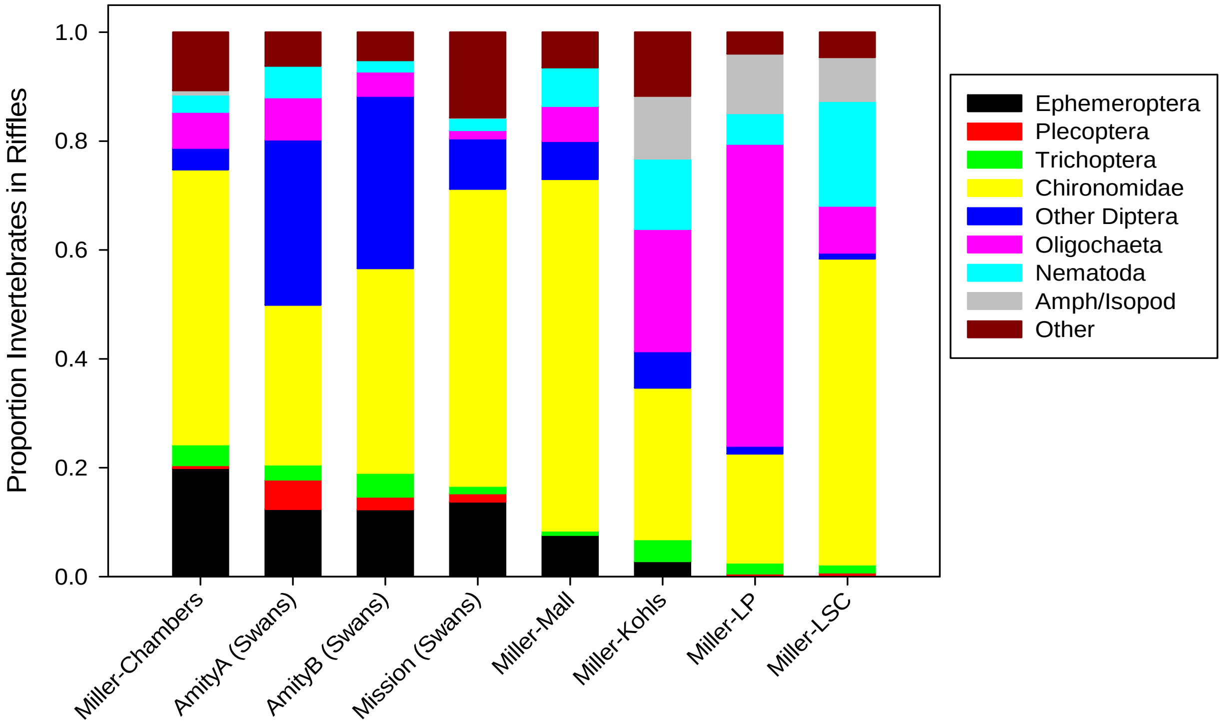

Figure 10. Proportional abundance of invertebrate taxa collected from Duluth-area streams. Sites are sorted from most to least EPT taxa.

The LSC, LP, and Mall sites were dominated by the Diptera family Chironomidae, with a greater percentage of the aquatic insect assemblage comprised of this group than any other sites in the comparison dataset (Fig. 11). Sites highly dominated by Chironomidae are typically considered to be stressed in some manner, although the source of that stress is often not clearly indicated by the taxonomic composition.

Using the full suite of macroinvertebrates (with only a few comparison sites due to the taxonomy issues previously mentioned) shows that the Kohls and Mall sites had 50% or more of their riffle communities comprised of other macroinvertebrates such as oligochaetes, nematodes, and amphipods and isopods (Fig. 10). The LSC site is dominated by small, reasonably-hardy taxa: chironomids, oligochaetes, and nematodes.

Comparing the number of EPT taxa among sites is also informative and can help reduce the influence of methods differences among studies. This comparison spreads out the Miller Creek sites more among the comparison sites, with the Chambersburg site having the most EPT taxa of the Miller Creek sites, and just outside the top quartile of comparison sites, and the LP site having the fewest EPT taxa (Fig. 12). Note that the Mall site had the lowest insect taxa count, and had no Plecoptera (stoneflies) in quantitative riffle samples. Many stoneflies are active predators requiring relatively good habitat conditions with plenty of interstitial spaces among rocky substrates and relatively high levels of dissolved oxygen.

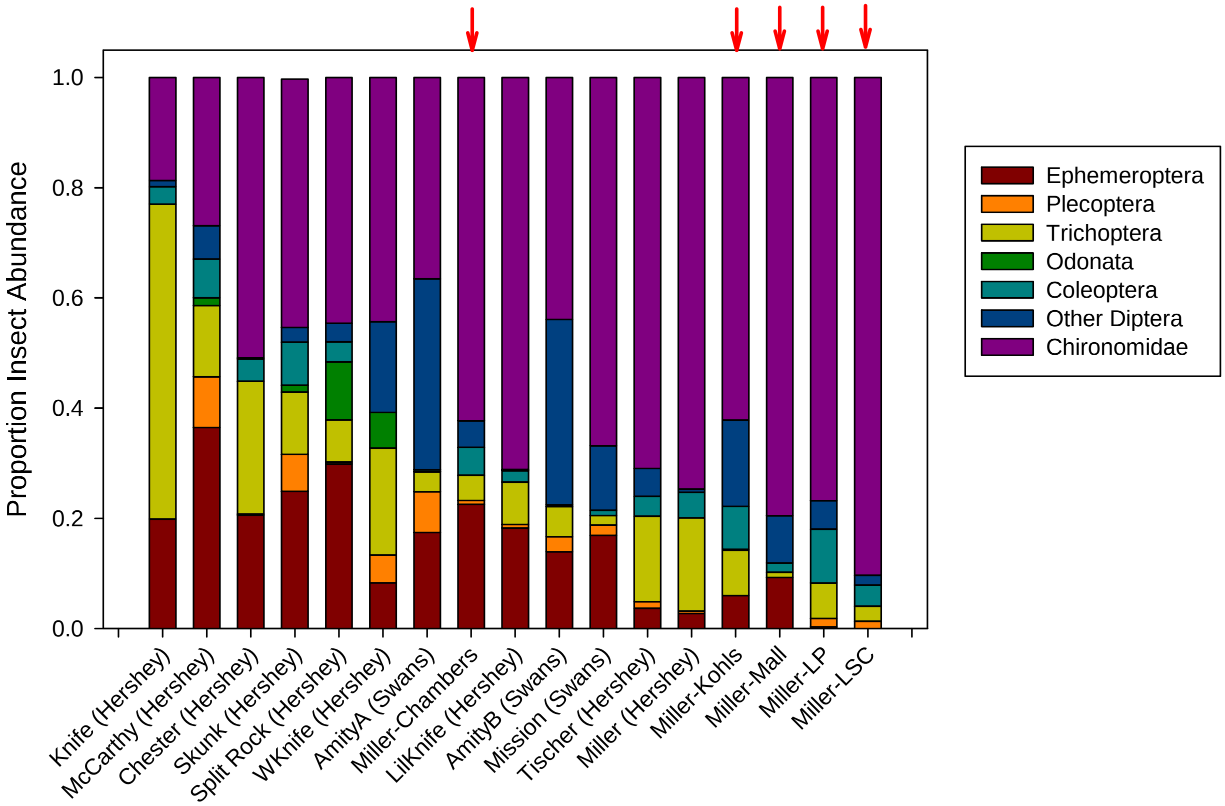

Figure 11. Proportional abundance of insect orders collected from Duluth and North Shore streams. Sites are sorted from most Ephemeroptera, Plecoptera, and Trichoptera (left) to least (right). Sites from the current study are marked with arrows

Exploring the make-up of the macroinvertebrate community by functional feeding group proportions can also be informative. Functional feeding group categories describe how, and, to some extent, on what the invertebrates feed. Categories include collector-gatherers, which collect fine particles to feed on, collector-filterers that filter fine particles out of the water column, scraper-grazers that scrape algae and detritus off of rock and plants, shredders that shred up fallen leaves and sometimes wood, and predators that feed on other animals. The Diptera family Chironomidae contains genera that feed in each of these ways, but when these genera are lumped at the family level, chironomids are considered collector-gatherers. The high percentage of Chironomidae at Miller Creek sites translates to a high percentage of gatherers compared to most other sites (Fig. 13). Gatherers are considered to be more tolerant of stressful situations because they can feed on a wide variety of food types, scavenging whatever is available floating downstream. Streams with communities comprised largely of gatherers are often suspected of having nutrient enrichment problems.

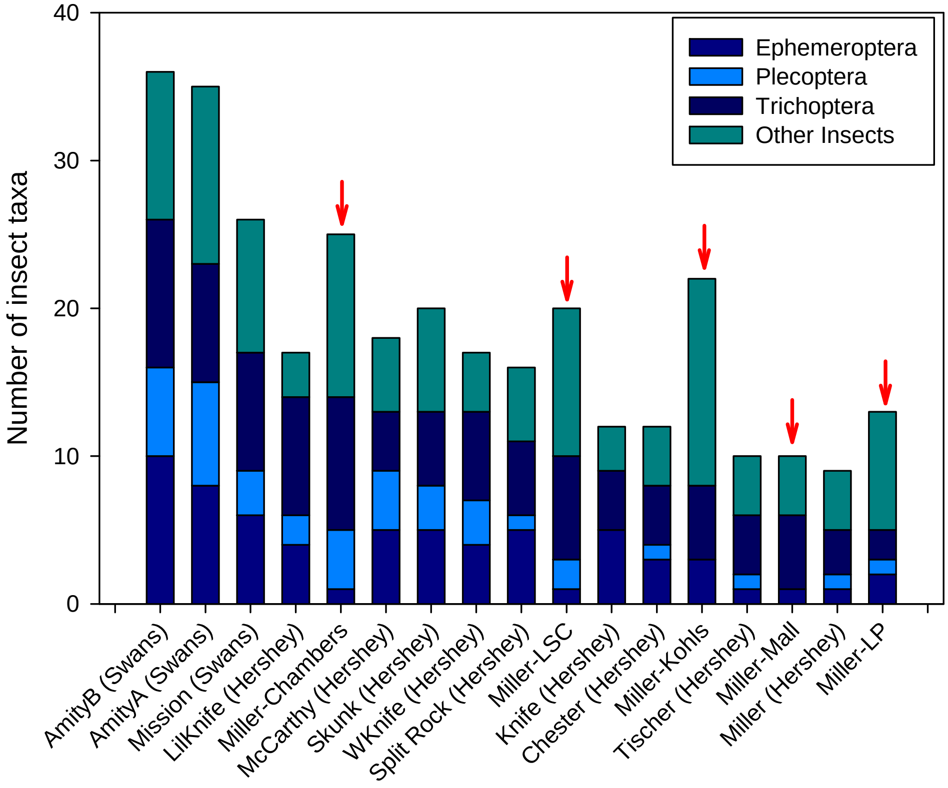

Figure 12. Number of EPT and total insect taxa collected from Duluth and North Shore streams. Sites are sorted by decreasing number of EPT taxa. Sites from the current study are marked with arrows.

We typically assume that predators are more sensitive to stressors than are some other feeding groups because they feed higher up on the food chain. Miller Creek sites had a relatively small proportion of the community represented by predatory insects, with the exception of the Kohls site, which approached 10% (Fig. 13).

Scraper-grazer invertebrates make their living scraping algae and detritus off rocks, wood, and other structures; these include Gastropoda (snails) and several families of Trichoptera (caddisflies), among others. Grazers are affected by anything that influences the amount of algae on rocks (including stream shading) and can become very abundant in sunny, nutrient-rich situations. Because algae grow on the tops of rocks where there is sunlight, grazers may also be affected by high flows and physical abrasion. Grazers were almost non-existent at all Miller Creek sites except for a small number of grazing insects at LSC (Fig. 13). In contrast, most of the comparison sites had at least some insect grazers comprising their communities. While it is tempting to blame this lack of grazers on high stream shading, sites with comparable amounts of shading (Hershey sites Skunk, Tischer, and Miller in 1996) had higher proportions of grazers. Among the comparison sites, only Amity A and B had such low grazer proportions, and these sites are suspected of having problems with excess sediment.

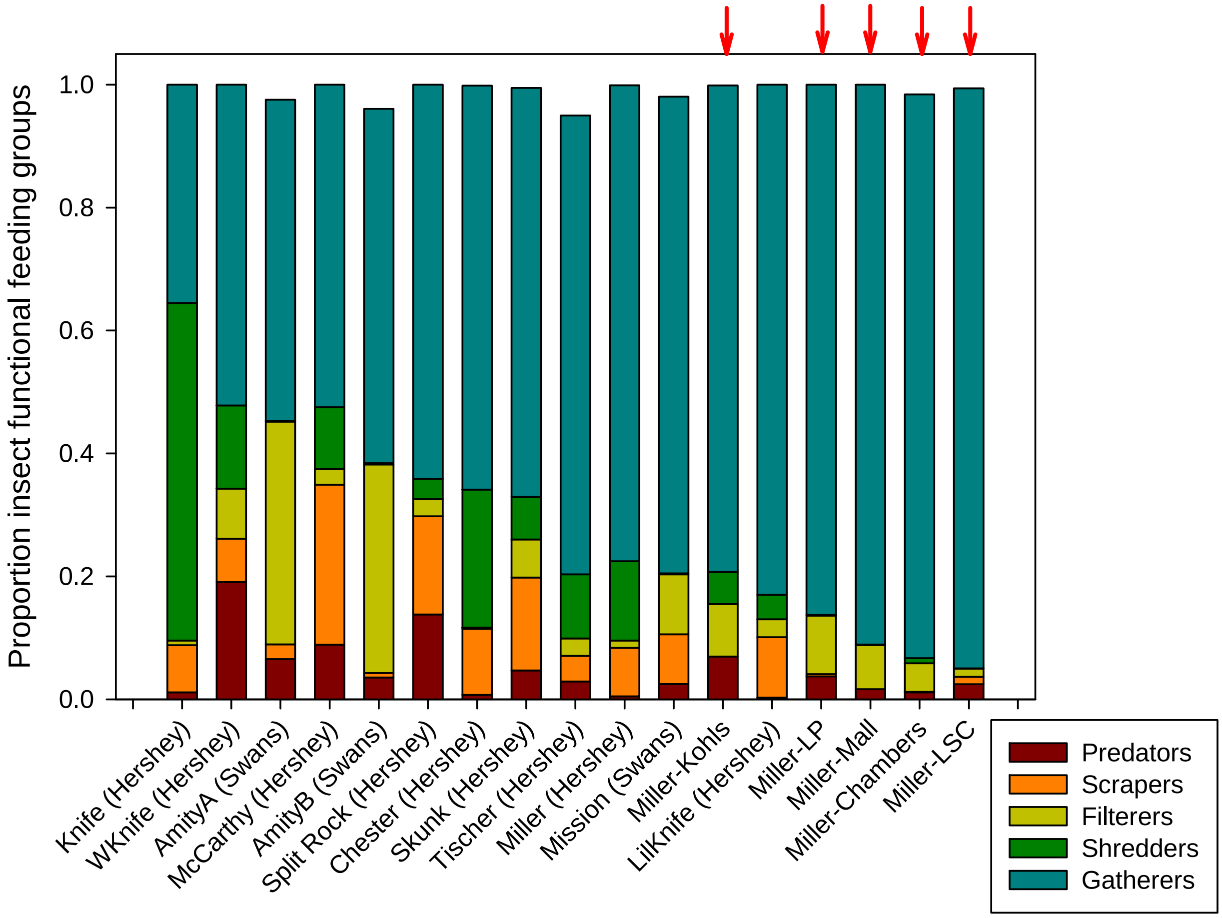

Figure 13. Functional feeding groups of insects in Duluth and North Shore stream riffles. Proportions do not always add up to 1 because of a lack of information about some taxa or due to lumping of taxa. Sites are ordered by increasing proportions of collector-gatherers. Miller Creek TMDL sites are marked with red arrows.

Shredder proportions in Miller Creek were also low compared to most other sites in the dataset. This is somewhat unexpected because of the high amounts of shading by deciduous trees and shrubs; leaves from riparian deciduous vegetation are a primary food source for stream shredding insects. Because decaying leaves are a rather low-energy food resource, some stream shredders have longer life-cycles than insects eating a more energy-rich food. For example, the shredding stonefly *Pteronarcys* may take three years to reach maturity in North Shore streams (V. Brady personal observation). No *Pteronarcys* were found at any Miller site, and few were present at comparison sites (found only at Amity A and B and McCarthy Creek, data not shown).

Invertebrates that filter their food from the water column are often also abundant when there is nutrient enrichment, and typically make up a greater proportion of the community as they move downstream from the headwaters to the mouth of a river. However, because these invertebrates must approach or even enter the current in order to capture food particles with their nets (most taxa, e.g. Hydropsychidae caddisflies), fans (Simuliidae), or gills (Sphaeriidae), they may be particularly vulnerable to sediment in the water. They may either be physically abraded by the larger particles such as sand, or may have their nets, fans, or gills clogged by silts and clays, making it difficult for them to feed. Filtering invertebrates comprised a relatively small proportion of the community at the Miller Creek sites, which is comparable to many of the comparison sites (Fig. 13). Hydropsychid (net-spinning) caddisflies made up the majority of caddisflies at all of the Miller Creek sites except Kohls (Table 9), where the slower flow and habitat may not be conducive to filter-feeding using spun nets.

Behavioral traits of stream invertebrates can also provide insight into stream habitat condition and water quality. Chironomid genera do not cover as many behavioral trait categories as they do feeding group categories. Most chironomids fall into the behavior groups of burrowers, clingers, and climbers (to some extent). Because the Chironomidae are lumped at the family level for comparison with the other sites, they are all classified as burrowers in this analysis. When assessing stream condition, we typically contrast the proportions of clingers and burrowers. Clingers cling to rocks in riffles in the current and use the interstitial spaces between and beneath rocks to escape from predators or find refuge from the flow, and to collect food particles. Thus, proportions of clingers tend to be reduced by anything that reduces interstitial space around larger substrates (boulder, cobble, pebble). This can be natural, as when a stream has large amounts of bedrock or is naturally sandy, or can be related to human-caused erosion and sedimentation issues. When there are abundant fine substrates, particularly silts, in streams, the proportion of burrowers usually increases. Miller Creek sites have high proportions of burrowers due to the high proportions of Chironomidae comprising the insect communities (Fig. 14). This is partially an artifact of the chironomid identification being lumped at the family level and also due to the fact that many chironomids can exist as functional clingers when necessary. Note that the only site with large amounts of fine sediments is the Mall site. Insects classified as true ‘clingers’ make up a relatively low proportion at Miller Creek sites. However, these proportions are close to the range represented by the comparison sites. The LP site had the highest proportion of clingers.

Another behavioral group important to a discussion of stream condition is the sprawlers, which sprawl on top of substrates that would tend to bury them, and are often found in areas with excess sediment. Sprawlers are mostly absent at Miller Creek sites with the exception of the Kohls site (Fig. 14), which makes sense given the low amounts of fine substrates present. Swimmers, as the name implies, move around by swimming. Although they are typically not a large component of most North Shore stream insect communities, they do make up fairly large proportions of the aquatic insect community at McCarthy, Skunk, and Chester Creeks, and at the Chambersburg site (Fig. 14).

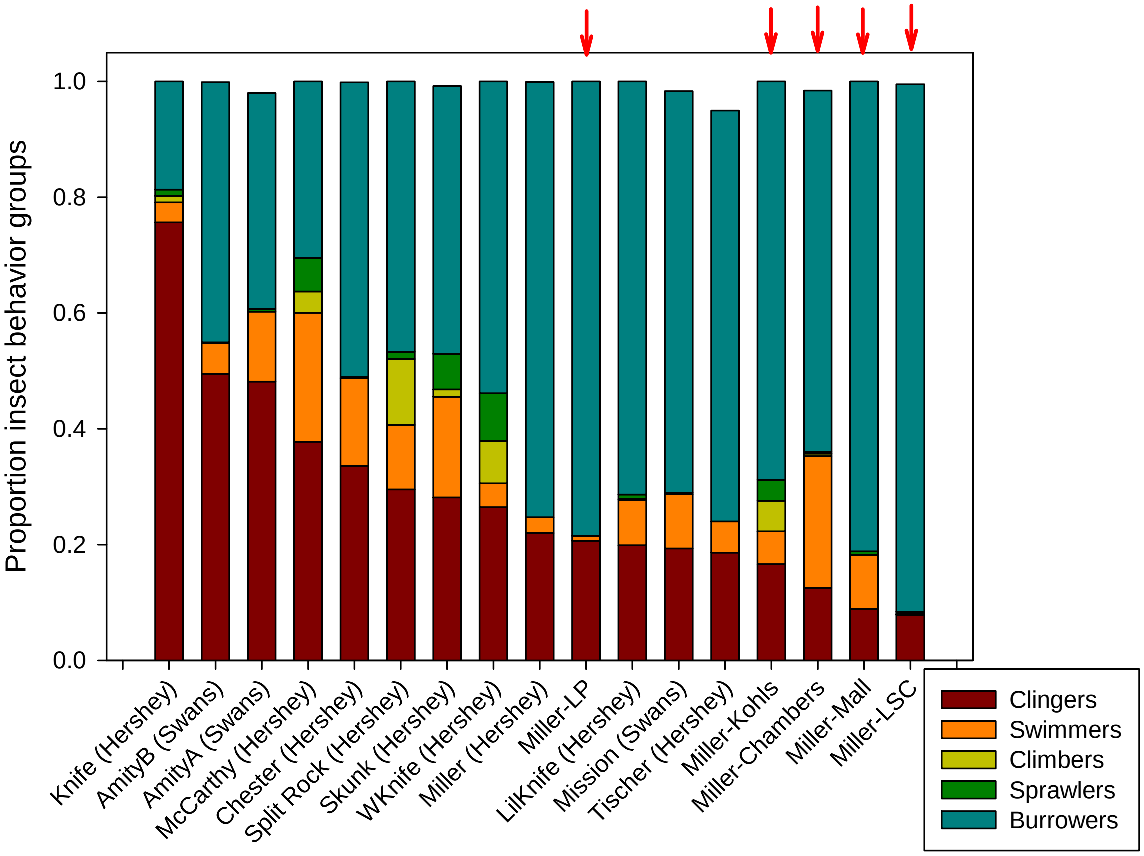

Figure 14. Behavioral groups of macroinvertebrates in North Shore stream riffles. Proportions do not always add up to 1 because of a lack of trait information on some groups, or due to lumping of taxa. Sites are sorted by decreasing proportions of clingers. Sites in the current study are indicated by arrows.

Tolerance values are numeric values assigned to aquatic biota that indicate their tolerance of stress. These numbers are based on laboratory tests and large-scale biotic surveys across a variety of aquatic conditions. They are often used as a general measure of tolerance to anthropogenic stress, but tend to be more indicative of tolerance of nutrient enrichment and low dissolved oxygen (c.f., Barbour et al. 1999). We combined several sources to obtain the most appropriate tolerance values for the stream invertebrates found in northern Minnesota; these values range from 0 (least tolerant) to 10 (most tolerant) (see Methods). From these values, several indicators of stream condition can be created. One such indicator is the proportion of sensitive taxa (Table 9, Fig.15); we have defined sensitive taxa as those with a tolerance value less than or equal to three. Miller Creek sites fall in the lower range of the proportion of sensitive taxa, and in the lower range of overall numbers of taxa among comparison sites. Again, the Chambersburg site had both the highest proportion of sensitive taxa and the highest number of insect taxa of the Miller TMDL sites.

Tolerance values are also used to calculate an overall ‘tolerance score’ for each site. Tolerance scores cannot be lower than zero, but can be quite large for sites that have high abundances of very tolerant organisms. Calculating these scores based just on the aquatic insects (so that the Hershey sites can be included for comparison) typically causes the scores to be lower (less tolerant) than they would be if the scores were calculated using all the macroinvertebrates found in samples (compare columns in Table 9). Miller Creek site scores are all in the higher (more tolerant) end of the range covered by the comparison sites (Table 9). The Chambersburg site had the lowest score at 5.32, with the Mall and LSC sites at about 5.8, among the highest in the comparison dataset. When all macroinvertebrates are included in the tolerance score calculations (and using the full taxonomy of the chironomids), all of the Miller Creek sites move even higher on the tolerance scale, with the LP site moving into the 'most tolerant' position. Of the 50 sites in our North Shore streams database, the LP site holds the dubious distinction of having the highest tolerance score, with the Kohls, Mall, and LSC sites having the next highest scores (V. Brady, unpublished data).

The TMDL for Miller Creek is for warm temperatures for a trout stream, rather than for turbidity, making this TMDL different from many for North Shore streams. We calculated temperature metrics for the aquatic macroinvertebrates using data from a recent study by D. Huff. While the median temperature 'preferences' in his study were calculated based on grab samples, the large number of sites in his database (n=764) provides a start at work on this topic for upper Midwestern streams. Based on these data, we created warm water and cool/cold water preference metrics, with warm water defined rather arbitrarily as median temperature preference greater than 21° C, and cool/cold water preference as median temperature preference less than 18° C. The Hershey sites were excluded from this analysis because we needed to include the full range of insect identifications (primarily Chironomidae at the genus level) for the indicators to show differences among sites.

The LSC and LP sites had the most cold-preferring invertebrate taxa, with the Mall and Kohl sites having the fewest (Fig. 16). The Kohls site had the most warm-preferring invertebrate taxa. Note that the Mall (especially) and Kohls had fewer taxa that exhibited a strong temperature preference. This analysis leaves out invertebrates that have a median temperature preference between 18 and 21° C, or that did not exhibit a strong preference in the original study. It also leaves out invertebrates for which we have no temperature preference data. This resulted in a relatively low number of taxa showing warm and cold preferences with which we could work. However, at some sites theses taxa comprised nearly 20 % of the mean invertebrate abundance in riffles (Fig. 17). For example, in LSC and LP samples, cold-preferring invertebrates comprised 18% and 13% of the total abundance, respectively. Sites at Kohls and the Mall again had low percentages of invertebrates that showed strong warm or cold water temperature preferences.

Conclusions

Most Miller Creek sites seem to have reasonably good habitat conditions for macroinvertebrates, although some of the sites are a bit shallow for fish. With the exception of the Mall site, most Miller sites have substrate of an appropriate size to create interstitial space for macroinvertebrates, with low amounts of embeddedness and fine sediments. The LP site is a bit harsher because it has higher velocity water flowing partially over bedrock, which limits living space for macroinvertebrates. Stream shading is high at all sites except the Mall, with some sites being almost completely shaded.

A series of in-stream temperature loggers (25 to 27) were deployed by SSL SWCD staff for the ice-free seasons of 2007-2009. Data were summarized by day and night categorical mean temperatures, daily maximum means, and daily maximum moving averages for all stations by year. During peak stream temperatures, several stations remained below the critical 20° C threshold for salmonids, while others had many days of maximum temperatures above this threshold. Based on presence/absence of salmonids and temperature records used to establish tolerance estimates (Wehrly et al. 2007), maximum daily moving averages for every Miller Creek stations, from 1 day to 63 days, did not exceed those values at any time over the period of record. However, maximum daily maximums and duration of peak temperatures seen in the data set leave no doubt that areas along Miller Creek become uninhabitable to trout. Correlating this information to stress and/or lethal conditions for trout is quite problematic due to the artificial settings and conditions under which most salmonid temperature preference studies have been conducted. Applying set thresholds to a habitat that fluctuates both spatially and temporally is difficult, but the temperature logger data indicate that locations within Miller Creek can serve as refugia for trout.

The macroinvertebrate community in Miller Creek does not compare particularly favorably to streams in less urban watersheds, with the exception of the Chambersburg site. The other four sites have low taxa counts and abundances of taxa considered sensitive to stress, particularly the EPT taxa. Instead, these sites have high proportions of more tolerant taxa such as Chironomidae (Diptera) and oligochaete and nematode worms.

Macroinvertebrate trait metrics also indicate that Miller Creek sites are experiencing stress. Several sites have very large proportions of collector-gathering insects that are able to survive by eating a variety of detritus particles that wash downstream. These invertebrates are considered more tolerant of stress because they make use of an easily-available food resource that often increases with increasing amounts of nutrients added to streams. Conversely, there are few predatory insects in Miller Creek. Predators are considered more susceptible to stress because many of them are larger, more active invertebrates who use a more specialized food resource. The lack of leaf-shredding insects is surprising given the high amounts of stream shading at most sites. Most of the comparison sites had a higher proportion of shredding insects.

There have been fewer studies of temperature preferences and/or requirements of macroinvertebrates than there have been for fish. However, using the data available to us, we found that the LSC and LP sites both had higher numbers and proportions of cool/cold preference taxa than any of the other Miller Creek sites or the 2008 comparison sites (Amity and Mission Creeks). At LSC, nearly 20% of the invertebrate community was comprised of cold-preference taxa. There were few taxa at Kohls or the Mall sites that exhibited strong temperature preferences, based on the limited information available to us.

Our results suggest that the Mall site has some habitat problems, particularly with sand in the substrate, while the LP site is a harsher environment both naturally and likely due to development. The Kohls site is more open (less shaded) than the other sites and has more taxa that prefer warm water than any of the other sites. However, these taxa make up a very small component of the community. The information on temperature and invertebrates that we have does not suggest that warm temperatures are driving invertebrate differences among sites. Our metrics do suggest that two of the sites (LSC and LP) supported more cool-water preferring invertebrates than did the other sites, including the comparison sites. But the converse does not seem to be true. Instead, the Mall and Kohls site samples were comprised largely of invertebrates that either do not have strong temperature preferences, prefer temperatures in the mid-range (between 18 and 21° C), or for which temperature preferences are not known.

Although we do not have the data to identify what specifically is causing the macroinvertebrate community to appear in poorer condition than sites with less urban watersheds, we feel it safe to say that the amount of development in the Miller Creek watershed is the ultimate cause. Best management practices within the watershed and in the riparian zone that have been shown to reduce stream impacts are encouraged.

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Appendix 1. Mean number of taxa per square meter occurring in habitats at each sampling location. If Standard Error is blank, taxon was collected in only one sample at that site. If blank for all taxa, there was only one sample of this type collected at the sampling station. Chambers = Chambersburg Rd; Kohls = Kohls store; LP = Lincoln Park; LSC = Lake Superior College; Mall = Miller Hill Mall.

Miller Site	Habitat	Gear	Taxa	Mean # per m^2	Standard Error
Chambers	Riffle	Hess	Acari	368.22	118.04
Chambers	Riffle	Hess	Agnetina	23.26	
Chambers	Riffle	Hess	Antocha	197.67	106.31
Chambers	Riffle	Hess	Baetidae	3356.59	1655.05
Chambers	Riffle	Hess	Brachycentridae	62.02	24.36
Chambers	Riffle	Hess	Caecidotea	88.37	19.17
Chambers	Riffle	Hess	Chelifera	106.98	18.51
Chambers	Riffle	Hess	Cheumatopsyche	11.63	0.00
Chambers	Riffle	Hess	Clinocera	79.07	20.80
Chambers	Riffle	Hess	Collembola	46.51	
Chambers	Riffle	Hess	Cricotopus	3070.33	908.46
Chambers	Riffle	Hess	Dicrotendipes	101.02	
Chambers	Riffle	Hess	Dubiraphia	11.63	
Chambers	Riffle	Hess	Elmidae	46.51	
Chambers	Riffle	Hess	Endochironomus	217.96	58.73
Chambers	Riffle	Hess	Ephemeroptera	476.74	260.31
Chambers	Riffle	Hess	Eukiefferiella	498.24	264.45
Chambers	Riffle	Hess	Hemerodromia	46.51	
Chambers	Riffle	Hess	Hesperophylax	11.63	
Chambers	Riffle	Hess	Hydropsyche	367.44	92.57
Chambers	Riffle	Hess	Hydropsychidae	110.47	37.28
Chambers	Riffle	Hess	Ilybius	46.51	
Chambers	Riffle	Hess	Isoperla	44.57	17.61
Chambers	Riffle	Hess	Lepidostoma	23.26	4.75
Chambers	Riffle	Hess	Leptoceridae	46.51	
Chambers	Riffle	Hess	Nematoda	277.13	107.47
Chambers	Riffle	Hess	Nilotanypus	492.01	180.04
Chambers	Riffle	Hess	Oecetis	11.63	
Chambers	Riffle	Hess	Oligochaeta	726.74	151.04
Chambers	Riffle	Hess	Optioservus	656.98	242.94
Chambers	Riffle	Hess	Orthocladius	618.46	
Chambers	Riffle	Hess	Parametriocnemus	300.53	84.91
Chambers	Riffle	Hess	Paratendipes	249.43	68.93
Chambers	Riffle	Hess	Perlidae	11.63	
Chambers	Riffle	Hess	Perlodidae	46.51	
Chambers	Riffle	Hess	Phaenopsectra	53.54	
Chambers	Riffle	Hess	Physella	23.26	
Chambers	Riffle	Hess	Plecoptera	78.49	19.52
Chambers	Riffle	Hess	Polypedilum	324.76	95.87
Chambers	Riffle	Hess	Probezzia	29.07	10.07

Appendix 1. Continued.

Chambers	Riffle	Hess	Pycnopsyche	34.88	
Chambers	Riffle	Hess	Simulium	305.23	160.30
Chambers	Riffle	Hess	Sphaeriidae	23.26	
Chambers	Riffle	Hess	Stenelmis	23.26	
Chambers	Riffle	Hess	Tanytarsus	802.12	269.19
Chambers	Riffle	Hess	Thienemannimyia	214.11	51.65
Chambers	Riffle	Hess	Turbellaria	34.88	6.71
Kohls	Riffle	Hess	Ablabesmyia	40.21	
Kohls	Riffle	Hess	Acari	127.91	52.65
Kohls	Riffle	Hess	Antocha	11.63	
Kohls	Riffle	Hess	Baetidae	186.05	69.96
Kohls	Riffle	Hess	Bezzia	174.42	87.27
Kohls	Riffle	Hess	Brillia	50.39	
Kohls	Riffle	Hess	Caecidotea	1436.05	993.72
Kohls	Riffle	Hess	Caenis	15.50	2.74
Kohls	Riffle	Hess	Ceraclea	119.19	31.58
Kohls	Riffle	Hess	Ceratopogon	17.44	3.36
Kohls	Riffle	Hess	Ceratopogonidae	23.26	
Kohls	Riffle	Hess	Chrysops	17.44	3.36
Kohls	Riffle	Hess	Cladotanytarsus	91.73	32.93
Kohls	Riffle	Hess	Clinocera	167.44	42.80
Kohls	Riffle	Hess	Coenagrionidae	11.63	
Kohls	Riffle	Hess	Collembola	11.63	
Kohls	Riffle	Hess	Corduliidae	11.63	
Kohls	Riffle	Hess	Cricotopus	1170.66	341.57
Kohls	Riffle	Hess	Dasyhelea	50.39	
Kohls	Riffle	Hess	Dicrotendipes	52.99	19.31
Kohls	Riffle	Hess	Dubiraphia	40.70	9.84
Kohls	Riffle	Hess	Eukiefferiella	75.74	26.51
Kohls	Riffle	Hess	Ferrissia	17.44	2.74
Kohls	Riffle	Hess	Hirudinea	23.26	0.00
Kohls	Riffle	Hess	Hydra	11.63	
Kohls	Riffle	Hess	Hydropsychidae	11.63	
Kohls	Riffle	Hess	Hydroptilidae	11.63	
Kohls	Riffle	Hess	Lauterborniella	50.39	
Kohls	Riffle	Hess	Leptophlebiidae	11.63	
Kohls	Riffle	Hess	Limnephilidae	85.27	15.26
Kohls	Riffle	Hess	Limnephilus	65.12	14.08
Kohls	Riffle	Hess	Nanocladius	35.49	8.60
Kohls	Riffle	Hess	Nematoda	968.99	298.89
Kohls	Riffle	Hess	Oligochaeta	1335.27	253.09
Kohls	Riffle	Hess	Optioservus	228.68	141.23
Kohls	Riffle	Hess	Orthocladius	40.21	
Kohls	Riffle	Hess	Parametriocnemus	170.18	75.71
Kohls	Riffle	Hess	Paratendipes	19.38	0.70
Kohls	Riffle	Hess	Physella	90.12	48.47
Kohls	Riffle	Hess	Planorbidae	15.50	2.74

Appendix 1. Continued.

Kohls	Riffle	Hess	Plecoptera	93.02	16.89
Kohls	Riffle	Hess	Polypedilum	60.68	23.15
Kohls	Riffle	Hess	Probezzia	145.35	62.31
Kohls	Riffle	Hess	Psectrocladius	31.49	5.04
Kohls	Riffle	Hess	Rheocricotopus	40.21	
Kohls	Riffle	Hess	Simulium	412.79	296.71
Kohls	Riffle	Hess	Somatochlora	11.63	
Kohls	Riffle	Hess	Sphaeriidae	48.84	19.40
Kohls	Riffle	Hess	Tanytarsus	200.30	66.72
Kohls	Riffle	Hess	Thienemanniella	18.17	
Kohls	Riffle	Hess	Thienemannimyia	49.06	15.18
Kohls	Riffle	Hess	Turbellaria	11.63	
LP	Riffle	Hess	Acari	31.01	5.48
LP	Riffle	Hess	Antocha	11.63	
LP	Riffle	Hess	Baetidae	46.51	
LP	Riffle	Hess	Baetis	11.63	
LP	Riffle	Hess	Caecidotea	11.63	
LP	Riffle	Hess	Cardiocladius	109.50	
LP	Riffle	Hess	Collembola	11.63	
LP	Riffle	Hess	Cricotopus	1149.06	146.02
LP	Riffle	Hess	Curculionidae	11.63	
LP	Riffle	Hess	Diamesa	121.13	48.08
LP	Riffle	Hess	Einfeldia	93.75	40.70
LP	Riffle	Hess	Endochironomus	66.86	24.62
LP	Riffle	Hess	Erpobdellidae	11.63	0.00
LP	Riffle	Hess	Eukiefferiella	207.03	53.61
LP	Riffle	Hess	Gammarus	1036.82	486.04
LP	Riffle	Hess	Glossosomatidae	34.88	
LP	Riffle	Hess	Hydropsyche	169.77	57.32
LP	Riffle	Hess	Ilybius	29.07	10.07
LP	Riffle	Hess	Isoperla	37.21	3.97
LP	Riffle	Hess	Lepidoptera	11.63	
LP	Riffle	Hess	Nematoda	434.11	205.84
LP	Riffle	Hess	Nilotanypus	98.84	
LP	Riffle	Hess	Oligochaeta	6125.97	2306.07
LP	Riffle	Hess	Optioservus	262.79	117.18
LP	Riffle	Hess	Orthocladius	23.26	
LP	Riffle	Hess	Parametriocnemus	41.57	8.55
LP	Riffle	Hess	Phaenopsectra	28.34	
LP	Riffle	Hess	Plecoptera	11.63	
LP	Riffle	Hess	Polypedilum	83.30	25.09
LP	Riffle	Hess	Probezzia	52.33	11.95
LP	Riffle	Hess	Simulium	302.33	93.99
LP	Riffle	Hess	Sphaeriidae	11.63	
LP	Riffle	Hess	Stempellinella	28.34	
LP	Riffle	Hess	Stilobezzia	11.63	
LP	Riffle	Hess	Tanytarsus	53.07	16.20

Appendix 1. Continued.

LP	Riffle	Hess	Thienemanniella	47.97	0.84
LP	Riffle	Hess	Thienemannimyia	120.47	13.19
LSC	Riffle	Hess	Acari	67.83	12.53
LSC	Riffle	Hess	Antocha	17.44	3.36
LSC	Riffle	Hess	Baetidae	11.63	
LSC	Riffle	Hess	Bezzia	11.63	
LSC	Riffle	Hess	Caecidotea	151.16	64.22
LSC	Riffle	Hess	Ceraclea	23.26	
LSC	Riffle	Hess	Ceratopogonidae	29.07	10.07
LSC	Riffle	Hess	Chelifera	38.76	5.48
LSC	Riffle	Hess	Cheumatopsyche	11.63	0.00
LSC	Riffle	Hess	Clinocera	34.88	9.49
LSC	Riffle	Hess	Collembola	52.33	16.78
LSC	Riffle	Hess	Corynoneura	176.84	
LSC	Riffle	Hess	Cricotopus	2451.37	909.18
LSC	Riffle	Hess	Culicoides	11.63	
LSC	Riffle	Hess	Diamesa	79.70	
LSC	Riffle	Hess	Einfeldia	38.28	
LSC	Riffle	Hess	Endochironomus	174.27	84.37
LSC	Riffle	Hess	Erpobdellidae	11.63	
LSC	Riffle	Hess	Eukiefferiella	902.28	238.61
LSC	Riffle	Hess	Gammarus	478.68	142.52
LSC	Riffle	Hess	Glossiphoniidae	11.63	
LSC	Riffle	Hess	Glossosomatidae	52.33	13.70
LSC	Riffle	Hess	Helobdella	162.79	
LSC	Riffle	Hess	Hemerodromia	11.63	
LSC	Riffle	Hess	Hydrophilidae	11.63	
LSC	Riffle	Hess	Hydropsyche	42.64	4.90
LSC	Riffle	Hess	Hydroptila	11.63	
LSC	Riffle	Hess	Isoperla	50.39	25.06
LSC	Riffle	Hess	Limnephilus	23.26	
LSC	Riffle	Hess	Nematoda	1220.93	274.48
LSC	Riffle	Hess	Nilotanypus	107.56	40.00
LSC	Riffle	Hess	Oligochaeta	596.90	203.66
LSC	Riffle	Hess	Optioservus	130.23	62.20
LSC	Riffle	Hess	Orthocladius	209.41	58.20
LSC	Riffle	Hess	Parametriocnemus	163.43	51.43
LSC	Riffle	Hess	Paratanytarsus	176.84	
LSC	Riffle	Hess	Perlidae	11.63	
LSC	Riffle	Hess	Plecoptera	27.13	10.96
LSC	Riffle	Hess	Polycentropus	11.63	
LSC	Riffle	Hess	Polypedilum	180.99	31.49
LSC	Riffle	Hess	Probezzia	49.42	8.11
LSC	Riffle	Hess	Rheotanytarsus	96.73	
LSC	Riffle	Hess	Sphaeriidae	17.44	3.36
LSC	Riffle	Hess	Tanytarsus	392.39	121.97
LSC	Riffle	Hess	Thienemannimyia	38.28	

Appendix 1. Continued.

LSC	Riffle	Hess	Trichoptera	11.63	
LSC	Riffle	Hess	Turbellaria	11.63	
Mall	Riffle	Hess	Acari	124.03	25.24
Mall	Riffle	Hess	Baetidae	934.88	215.18
Mall	Riffle	Hess	Ceraclea	46.51	11.23
Mall	Riffle	Hess	Cheumatopsyche	58.14	
Mall	Riffle	Hess	Clinocera	279.07	77.94
Mall	Riffle	Hess	Cricotopus	5436.35	554.72
Mall	Riffle	Hess	Dicrotendipes	341.51	131.11
Mall	Riffle	Hess	Einfeldia	145.83	
Mall	Riffle	Hess	Ephemeroptera	46.51	
Mall	Riffle	Hess	Erpobdellidae	19.38	2.74
Mall	Riffle	Hess	Eukiefferiella	122.34	13.57
Mall	Riffle	Hess	Ferrissia	46.51	
Mall	Riffle	Hess	Glyptotendipes	167.39	
Mall	Riffle	Hess	Hirudinea	11.63	
Mall	Riffle	Hess	Hydropsyche	93.02	
Mall	Riffle	Hess	Lepidostoma	11.63	
Mall	Riffle	Hess	Limnephilus	11.63	
Mall	Riffle	Hess	Nematoda	771.32	287.03
Mall	Riffle	Hess	Nilotanypus	149.35	27.90
Mall	Riffle	Hess	Oligochaeta	616.28	180.04
Mall	Riffle	Hess	Optioservus	176.74	45.83
Mall	Riffle	Hess	Orthocladius	145.83	
Mall	Riffle	Hess	Parametriocnemus	126.21	
Mall	Riffle	Hess	Paratendipes	126.21	
Mall	Riffle	Hess	Physella	63.95	30.21
Mall	Riffle	Hess	Plecoptera	55.81	10.29
Mall	Riffle	Hess	Polypedilum	121.09	11.59
Mall	Riffle	Hess	Probezzia	188.37	89.15
Mall	Riffle	Hess	Simulium	797.67	267.10
Mall	Riffle	Hess	Sphaeriidae	58.14	26.85
Mall	Riffle	Hess	Tanytarsus	457.06	129.43
Mall	Riffle	Hess	Thienemannimyia	144.92	8.51
Mall	pool	Core	Acari	666.67	
Mall	pool	Core	Acari	666.67	
Mall	pool	Core	Baetidae	222.22	
Mall	pool	Core	Baetidae	222.22	
Mall	pool	Core	Ceratopogon	222.22	
Mall	pool	Core	Ceratopogon	222.22	
Mall	pool	Core	Chironomus	861.11	
Mall	pool	Core	Chironomus	861.11	
Mall	pool	Core	Cladopelma	861.11	
Mall	pool	Core	Cladopelma	861.11	
Mall	pool	Core	Cricotopus	800.93	381.92
Mall	pool	Core	Cricotopus	800.93	540.12
Mall	pool	Core	Cryptochironomus	430.56	

Appendix 1. Continued.

Mall	pool	Core	Cryptochironomus	430.56	
Mall	pool	Core	Cryptotendipes	430.56	
Mall	pool	Core	Cryptotendipes	430.56	
Mall	pool	Core	Culicoides	333.33	111.11
Mall	pool	Core	Culicoides	333.33	157.13
Mall	pool	Core	Dicrotendipes	430.56	
Mall	pool	Core	Dicrotendipes	430.56	
Mall	pool	Core	Dubiraphia	222.22	
Mall	pool	Core	Dubiraphia	222.22	
Mall	pool	Core	Erpobdellidae	222.22	
Mall	pool	Core	Erpobdellidae	222.22	
Mall	pool	Core	Macropelopia	430.56	
Mall	pool	Core	Macropelopia	430.56	
Mall	pool	Core	Nematoda	1259.26	339.45
Mall	pool	Core	Nematoda	1259.26	240.03
Mall	pool	Core	Oligochaeta	2370.37	462.59
Mall	pool	Core	Oligochaeta	2370.37	327.10
Mall	pool	Core	Parametriocnemus	430.56	
Mall	pool	Core	Parametriocnemus	430.56	
Mall	pool	Core	Paratendipes	3013.89	
Mall	pool	Core	Paratendipes	3013.89	
Mall	pool	Core	Polypedilum	4398.15	4198.05
Mall	pool	Core	Polypedilum	4398.15	5936.93
Mall	pool	Core	Simulium	444.44	
Mall	pool	Core	Simulium	444.44	
Mall	pool	Core	Sphaeriidae	333.33	157.13
Mall	pool	Core	Sphaeriidae	333.33	111.11
Mall	pool	Core	Tanytarsus	652.78	564.34
Mall	pool	Core	Tanytarsus	652.78	399.05

Appendix 2. Mean number of taxa per sample occurring in habitats at each sampling location. If Standard Error is blank, taxon was collected in only one sample at that site. If blank for all taxa, there was only one sample of this type collected at the sampling station. Chambers = Chambersburg Rd; Kohls = Kohls store; LP = Lincoln Park; LSC = Lake Superior College; Mall = Miller Hill Mall.

Miller Site	Habitat	Gear	Taxa	Mean Count	Standard Error
Chambers	Riffle/Bank	Dnet	Aeshna	1.00	
Chambers	Riffle/Bank	Dnet	Antocha	2.50	1.22
Chambers	Riffle/Bank	Dnet	Baetidae	71.00	24.27
Chambers	Riffle/Bank	Dnet	Brillia	2.67	
Chambers	Riffle/Bank	Dnet	Caecidotea	5.00	2.31
Chambers	Riffle/Bank	Dnet	Cardiocladius	1.48	
Chambers	Riffle/Bank	Dnet	Collembola	7.50	0.41
Chambers	Riffle/Bank	Dnet	Cricotopus	44.49	17.76
Chambers	Riffle/Bank	Dnet	Culicoides	2.00	
Chambers	Riffle/Bank	Dnet	Curculionidae	2.00	
Chambers	Riffle/Bank	Dnet	Endochironomus	3.83	
Chambers	Riffle/Bank	Dnet	Eukiefferiella	7.10	2.24
Chambers	Riffle/Bank	Dnet	Glyptotendipes	1.48	
Chambers	Riffle/Bank	Dnet	Hydrophilidae	5.00	
Chambers	Riffle/Bank	Dnet	Hydropsyche	1.50	0.41
Chambers	Riffle/Bank	Dnet	Ilybius	6.67	5.17
Chambers	Riffle/Bank	Dnet	Ironoquia	1.50	0.41
Chambers	Riffle/Bank	Dnet	Larsia	1.48	
Chambers	Riffle/Bank	Dnet	Limnephilus	16.33	1.67
Chambers	Riffle/Bank	Dnet	Mystacides	5.00	
Chambers	Riffle/Bank	Dnet	Nematoda	4.00	0.00
Chambers	Riffle/Bank	Dnet	Nilotanypus	2.67	
Chambers	Riffle/Bank	Dnet	Odontomyia	1.00	
Chambers	Riffle/Bank	Dnet	Oecetis	4.00	
Chambers	Riffle/Bank	Dnet	Oligochaeta	6.00	1.15
Chambers	Riffle/Bank	Dnet	Optioservus	4.00	
Chambers	Riffle/Bank	Dnet	Parametriocnemus	4.15	0.97
Chambers	Riffle/Bank	Dnet	Paratanytarsus	1.48	
Chambers	Riffle/Bank	Dnet	Phaenopsectra	2.96	
Chambers	Riffle/Bank	Dnet	Physella	2.00	
Chambers	Riffle/Bank	Dnet	Plecoptera	2.00	
Chambers	Riffle/Bank	Dnet	Polypedilum	10.24	2.55
Chambers	Riffle/Bank	Dnet	Simulium	12.33	6.01
Chambers	Riffle/Bank	Dnet	Sphaeriidae	4.00	0.00
Chambers	Riffle/Bank	Dnet	Tanytarsus	17.74	1.22
Chambers	Riffle/Bank	Dnet	Thienemannimyia	2.96	
Chambers	Riffle/Bank	Dnet	Turbellaria	2.00	
Kohls	Riffle/Bank	Dnet	Acari	6.00	2.52
Kohls	Riffle/Bank	Dnet	Baetidae	8.00	3.27

Kohls	Riffle/Bank	Dnet	Brillia	4.04	
Kohls	Riffle/Bank	Dnet	Caecidotea	3.67	1.45
Kohls	Riffle/Bank	Dnet	Caenis	2.00	
Kohls	Riffle/Bank	Dnet	Ceraclea	1.50	0.41
Kohls	Riffle/Bank	Dnet	Cladotanytarsus	2.61	0.25
Kohls	Riffle/Bank	Dnet	Clinocera	9.33	6.89
Kohls	Riffle/Bank	Dnet	Cricotopus	49.93	19.55
Kohls	Riffle/Bank	Dnet	Dicrotendipes	3.68	1.36
Kohls	Riffle/Bank	Dnet	Dubiraphia	1.00	
Kohls	Riffle/Bank	Dnet	Dytiscidae	1.00	
Kohls	Riffle/Bank	Dnet	Endochironomus	2.03	0.72
Kohls	Riffle/Bank	Dnet	Ephemeroptera	4.50	2.86
Kohls	Riffle/Bank	Dnet	Eukiefferiella	4.61	2.83
Kohls	Riffle/Bank	Dnet	Hyalella	4.00	
Kohls	Riffle/Bank	Dnet	Hydrophilidae	2.50	1.22
Kohls	Riffle/Bank	Dnet	Ilybius	1.00	
Kohls	Riffle/Bank	Dnet	Limnephilus	37.00	18.36
Kohls	Riffle/Bank	Dnet	Nematoda	42.33	26.26
Kohls	Riffle/Bank	Dnet	Oligochaeta	46.33	17.07
Kohls	Riffle/Bank	Dnet	Optioservus	7.00	4.08
Kohls	Riffle/Bank	Dnet	Parametriocnemus	9.43	7.41
Kohls	Riffle/Bank	Dnet	Phaenopsectra	3.49	1.91
Kohls	Riffle/Bank	Dnet	Physella	5.00	3.27
Kohls	Riffle/Bank	Dnet	Plecoptera	4.00	
Kohls	Riffle/Bank	Dnet	Polypedilum	5.84	
Kohls	Riffle/Bank	Dnet	Probezzia	6.00	1.63
Kohls	Riffle/Bank	Dnet	Psectrocladius	4.04	
Kohls	Riffle/Bank	Dnet	Rheotanytarsus	4.04	
Kohls	Riffle/Bank	Dnet	Simulium	332.33	231.21
Kohls	Riffle/Bank	Dnet	Somatochlora	1.00	
Kohls	Riffle/Bank	Dnet	Sphaeriidae	1.50	0.41
Kohls	Riffle/Bank	Dnet	Tanytarsus	13.16	5.09
Kohls	Riffle/Bank	Dnet	Thienemanniella	2.92	
Kohls	Riffle/Bank	Dnet	Thienemannimyia	7.51	3.75
Kohls	Riffle/Bank	Dnet	Trichoptera	1.00	
LP	CWD/Bank	Dnet	Baetis	1.00	
LP	CWD/Bank	Dnet	Collembola	3.00	
LP	CWD/Bank	Dnet	Cricotopus	5.00	
LP	CWD/Bank	Dnet	Diamesa	1.00	
LP	CWD/Bank	Dnet	Gammarus	20.00	
LP	CWD/Bank	Dnet	Hesperophylax	1.00	
LP	CWD/Bank	Dnet	Hydropsyche	1.00	
LP	CWD/Bank	Dnet	Limnephilus	2.00	
LP	CWD/Bank	Dnet	Nematoda	2.00	
LP	CWD/Bank	Dnet	Nemoura	1.00	
LP	CWD/Bank	Dnet	Oligochaeta	5.00	
LP	CWD/Bank	Dnet	Optioservus	1.00	

Appendix 2. Continued.

LP	CWD/Bank	Dnet	Physella	2.00	
LP	CWD/Bank	Dnet	Polypedilum	1.00	
LP	CWD/Bank	Dnet	Simulium	1.00	
LP	CWD/Bank	Dnet	Thienemannimyia	1.00	
LP	Riffle/Bank	Dnet	Acari	2.00	1.00
LP	Riffle/Bank	Dnet	Agnetina	1.00	
LP	Riffle/Bank	Dnet	Baetis	2.00	
LP	Riffle/Bank	Dnet	Brillia	1.20	
LP	Riffle/Bank	Dnet	Caecidotea	1.00	
LP	Riffle/Bank	Dnet	Ceraclea	1.00	
LP	Riffle/Bank	Dnet	Cheumatopsyche	2.00	
LP	Riffle/Bank	Dnet	Collembola	1.00	
LP	Riffle/Bank	Dnet	Cricotopus	12.56	7.76
LP	Riffle/Bank	Dnet	Diamesa	2.99	0.59
LP	Riffle/Bank	Dnet	Dolichopodidae	1.00	
LP	Riffle/Bank	Dnet	Einfeldia	3.59	
LP	Riffle/Bank	Dnet	Endochironomus	1.20	
LP	Riffle/Bank	Dnet	Erpobdellidae	1.00	
LP	Riffle/Bank	Dnet	Eukiefferiella	2.40	1.20
LP	Riffle/Bank	Dnet	Gammarus	20.50	4.50
LP	Riffle/Bank	Dnet	Glossosomatidae	1.00	
LP	Riffle/Bank	Dnet	Hydropsyche	19.00	
LP	Riffle/Bank	Dnet	Ironoquia	2.00	
LP	Riffle/Bank	Dnet	Lepidoptera	1.00	
LP	Riffle/Bank	Dnet	Lepidostoma	1.00	
LP	Riffle/Bank	Dnet	Limnephilus	9.00	
LP	Riffle/Bank	Dnet	Mystacides	1.00	
LP	Riffle/Bank	Dnet	Nematoda	2.50	0.50
LP	Riffle/Bank	Dnet	Oecetis	1.00	
LP	Riffle/Bank	Dnet	Oligochaeta	62.50	56.50
LP	Riffle/Bank	Dnet	Optioservus	5.50	4.50
LP	Riffle/Bank	Dnet	Orthocladius	7.17	
LP	Riffle/Bank	Dnet	Parametriocnemus	2.40	
LP	Riffle/Bank	Dnet	Phaenopsectra	1.20	
LP	Riffle/Bank	Dnet	Physella	1.00	0.00
LP	Riffle/Bank	Dnet	Polypedilum	4.78	3.58
LP	Riffle/Bank	Dnet	Rheotanytarsus	1.20	
LP	Riffle/Bank	Dnet	Simulium	20.00	
LP	Riffle/Bank	Dnet	Tanytarsus	7.20	
LP	Riffle/Bank	Dnet	Thienemanniella	1.20	
LP	Riffle/Bank	Dnet	Thienemannimyia	1.20	
LSC	Riffle/Bank	Dnet	Acari	2.33	0.67
LSC	Riffle/Bank	Dnet	Caecidotea	18.67	11.41
LSC	Riffle/Bank	Dnet	Ceraclea	3.00	0.82
LSC	Riffle/Bank	Dnet	Chrysops	1.00	0.00
LSC	Riffle/Bank	Dnet	Collembola	1.00	0.00
LSC	Riffle/Bank	Dnet	Cricotopus	10.28	3.29

Appendix 2. Continued.

LSC	Riffle/Bank	Dnet	Curculionidae	1.00	
LSC	Riffle/Bank	Dnet	Endochironomus	1.10	
LSC	Riffle/Bank	Dnet	Eukiefferiella	2.76	1.36
LSC	Riffle/Bank	Dnet	Gammarus	24.00	12.00
LSC	Riffle/Bank	Dnet	Gerris	1.50	0.41
LSC	Riffle/Bank	Dnet	Hydrophilidae	1.00	
LSC	Riffle/Bank	Dnet	Hydropsyche	1.00	
LSC	Riffle/Bank	Dnet	Ilybius	1.50	0.41
LSC	Riffle/Bank	Dnet	Isoperla	1.00	0.00
LSC	Riffle/Bank	Dnet	Larsia	1.10	
LSC	Riffle/Bank	Dnet	Lepidoptera	1.00	
LSC	Riffle/Bank	Dnet	Leptoceridae	1.00	
LSC	Riffle/Bank	Dnet	Limnephilus	33.33	8.25
LSC	Riffle/Bank	Dnet	Microtendipes	1.09	
LSC	Riffle/Bank	Dnet	Nematoda	4.33	2.40
LSC	Riffle/Bank	Dnet	Nilotanypus	1.09	
LSC	Riffle/Bank	Dnet	Oligochaeta	14.67	4.63
LSC	Riffle/Bank	Dnet	Optioservus	2.67	1.20
LSC	Riffle/Bank	Dnet	Orthocladius	1.09	
LSC	Riffle/Bank	Dnet	Parachironomus	1.09	
LSC	Riffle/Bank	Dnet	Parametriocnemus	1.09	
LSC	Riffle/Bank	Dnet	Paratanytarsus	2.19	
LSC	Riffle/Bank	Dnet	Paratendipes	3.66	0.73
LSC	Riffle/Bank	Dnet	Phaenopsectra	1.10	0.00
LSC	Riffle/Bank	Dnet	Physella	6.50	0.41
LSC	Riffle/Bank	Dnet	Planorbidae	1.00	
LSC	Riffle/Bank	Dnet	Polypedilum	2.20	
LSC	Riffle/Bank	Dnet	Probezzia	1.00	
LSC	Riffle/Bank	Dnet	Rheotanytarsus	1.09	
LSC	Riffle/Bank	Dnet	Simulium	2.50	0.41
LSC	Riffle/Bank	Dnet	Sphaeriidae	1.50	0.41
LSC	Riffle/Bank	Dnet	Tanytarsus	22.74	4.36
LSC	Riffle/Bank	Dnet	Thienemannimyia	1.09	
Mall	Riffle/Bank	Dnet	Ablabesmyia	7.71	
Mall	Riffle/Bank	Dnet	Ablabesmyia	7.71	
Mall	Riffle/Bank	Dnet	Acari	7.50	5.50
Mall	Riffle/Bank	Dnet	Acari	7.50	7.78
Mall	Riffle/Bank	Dnet	Aeshna	1.50	0.71
Mall	Riffle/Bank	Dnet	Aeshna	1.50	0.50
Mall	Riffle/Bank	Dnet	Aeshnidae	1.00	
Mall	Riffle/Bank	Dnet	Aeshnidae	1.00	
Mall	Riffle/Bank	Dnet	Baetidae	5.00	2.55
Mall	Riffle/Bank	Dnet	Baetidae	5.00	3.61
Mall	Riffle/Bank	Dnet	Cardiocladius	2.54	
Mall	Riffle/Bank	Dnet	Cardiocladius	2.54	
Mall	Riffle/Bank	Dnet	Ceraclea	2.33	1.15
Mall	Riffle/Bank	Dnet	Ceraclea	2.33	0.82

Appendix 2. Continued.

Mall	Riffle/Bank	Dnet	Ceratopogonidae	2.00	
Mall	Riffle/Bank	Dnet	Ceratopogonidae	2.00	
Mall	Riffle/Bank	Dnet	Chelifera	2.00	
Mall	Riffle/Bank	Dnet	Chelifera	2.00	
Mall	Riffle/Bank	Dnet	Coenagrionidae	1.00	0.00
Mall	Riffle/Bank	Dnet	Coenagrionidae	1.00	0.00
Mall	Riffle/Bank	Dnet	Collembola	2.50	1.50
Mall	Riffle/Bank	Dnet	Collembola	2.50	2.12
Mall	Riffle/Bank	Dnet	Corduliidae	4.00	
Mall	Riffle/Bank	Dnet	Corduliidae	4.00	
Mall	Riffle/Bank	Dnet	Cricotopus	51.42	31.89
Mall	Riffle/Bank	Dnet	Cricotopus	51.42	45.09
Mall	Riffle/Bank	Dnet	Curculionidae	2.00	
Mall	Riffle/Bank	Dnet	Curculionidae	2.00	
Mall	Riffle/Bank	Dnet	Dicrotendipes	5.76	3.56
Mall	Riffle/Bank	Dnet	Dicrotendipes	5.76	5.03
Mall	Riffle/Bank	Dnet	Dolichopodidae	1.00	
Mall	Riffle/Bank	Dnet	Dolichopodidae	1.00	
Mall	Riffle/Bank	Dnet	Dubiraphia	1.50	0.71
Mall	Riffle/Bank	Dnet	Dubiraphia	1.50	0.50
Mall	Riffle/Bank	Dnet	Erpobdellidae	1.00	
Mall	Riffle/Bank	Dnet	Erpobdellidae	1.00	
Mall	Riffle/Bank	Dnet	Gerris	1.00	
Mall	Riffle/Bank	Dnet	Gerris	1.00	
Mall	Riffle/Bank	Dnet	Gyraulus	2.00	
Mall	Riffle/Bank	Dnet	Gyraulus	2.00	
Mall	Riffle/Bank	Dnet	Hydrophilidae	2.00	0.00
Mall	Riffle/Bank	Dnet	Hydrophilidae	2.00	0.00
Mall	Riffle/Bank	Dnet	Hydropsyche	1.00	
Mall	Riffle/Bank	Dnet	Hydropsyche	1.00	
Mall	Riffle/Bank	Dnet	Ilybius	2.00	
Mall	Riffle/Bank	Dnet	Ilybius	2.00	
Mall	Riffle/Bank	Dnet	Larsia	7.71	
Mall	Riffle/Bank	Dnet	Larsia	7.71	
Mall	Riffle/Bank	Dnet	Limnephilus	16.00	6.75
Mall	Riffle/Bank	Dnet	Limnephilus	16.00	9.54
Mall	Riffle/Bank	Dnet	Lymnaeidae	1.00	
Mall	Riffle/Bank	Dnet	Lymnaeidae	1.00	
Mall	Riffle/Bank	Dnet	Nectopsyche	1.00	
Mall	Riffle/Bank	Dnet	Nectopsyche	1.00	
Mall	Riffle/Bank	Dnet	Nematoda	6.00	1.22
Mall	Riffle/Bank	Dnet	Nematoda	6.00	1.73
Mall	Riffle/Bank	Dnet	Oligochaeta	46.00	38.20
Mall	Riffle/Bank	Dnet	Oligochaeta	46.00	54.03
Mall	Riffle/Bank	Dnet	Optioservus	1.00	
Mall	Riffle/Bank	Dnet	Optioservus	1.00	
Mall	Riffle/Bank	Dnet	Paratanytarsus	4.49	4.55

Appendix 2. Continued.

Mall	Riffle/Bank	Dnet	Paratanytarsus	4.49	3.22
Mall	Riffle/Bank	Dnet	Paratendipes	53.96	
Mall	Riffle/Bank	Dnet	Paratendipes	53.96	
Mall	Riffle/Bank	Dnet	Phaenopsectra	13.16	9.97
Mall	Riffle/Bank	Dnet	Phaenopsectra	13.16	14.10
Mall	Riffle/Bank	Dnet	Physella	45.67	22.05
Mall	Riffle/Bank	Dnet	Physella	45.67	31.18
Mall	Riffle/Bank	Dnet	Planorbidae	2.50	1.50
Mall	Riffle/Bank	Dnet	Planorbidae	2.50	2.12
Mall	Riffle/Bank	Dnet	Plecoptera	1.00	
Mall	Riffle/Bank	Dnet	Plecoptera	1.00	
Mall	Riffle/Bank	Dnet	Polypedilum	4.90	3.00
Mall	Riffle/Bank	Dnet	Polypedilum	4.90	4.24
Mall	Riffle/Bank	Dnet	Probezzia	2.00	1.00
Mall	Riffle/Bank	Dnet	Probezzia	2.00	0.71
Mall	Riffle/Bank	Dnet	Psectrocladius	11.56	
Mall	Riffle/Bank	Dnet	Psectrocladius	11.56	
Mall	Riffle/Bank	Dnet	Simulium	15.00	15.92
Mall	Riffle/Bank	Dnet	Simulium	15.00	22.52
Mall	Riffle/Bank	Dnet	Sphaeriidae	25.50	23.50
Mall	Riffle/Bank	Dnet	Sphaeriidae	25.50	33.23
Mall	Riffle/Bank	Dnet	Tanytarsus	15.16	9.73
Mall	Riffle/Bank	Dnet	Tanytarsus	15.16	13.76
Mall	Riffle/Bank	Dnet	Thienemannimyia	16.17	5.72
Mall	Riffle/Bank	Dnet	Thienemannimyia	16.17	8.08

Appendix 3. Average number of hours by logger station on Miller Creek at which water temperatures rose above 20 C. Data are presented as weeks within each month.

2007	May	May	May	June	June	June	June	July	July	July	July	Aug	Aug	Aug	Aug	Sept	Sept
Station	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2
2	0.0	7.5	5.0	28.0	28.0	42.5	5.0	0.0	170.8	10.5	20.0	0.0	0.0	0.0	0.0	0.0	0.0
4	0.0	0.0	0.0	0.0	0.7	0.0	2.2	22.9	30.0	19.6	3.5	0.0	0.0	0.0	0.0	0.0	0.0
6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9	0.0	28.8	2.1	32.3	23.4	36.3	22.6	98.3	40.0	22.1	26.9	1.2	0.0	13.7	0.0	0.0	0.0
10	0.0	12.0	0.0	24.0	0.0	12.0	0.0	72.0	30.0	0.0	12.0	0.0	0.0	0.0	0.0	0.0	0.0
11	0.0	50.7	5.5	44.7	25.0	44.5	0.0	59.7	9.2	6.0	0.0	0.0	0.0	6.8	0.0	0.0	0.0
12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
13	0.0	58.0	6.5	60.5	31.5	51.0	32.0	106.5	50.5	18.5	17.0	0.0	0.0	0.0	0.0	0.0	0.0
14	0.0	12.0	0.0	0.0	0.0	0.0	0.0	60.0	18.0	0.0	12.0	0.0	0.0	12.0	0.0	0.0	0.0
16	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.0	0.0	0.0	0.0	0.0	0.0	12.0	0.0	0.0	0.0
17	0.0	70.5	14.8	49.3	29.0	51.3	35.6	110.4	50.9	31.2	25.0	0.0	0.6	16.4	0.0	0.0	0.0
18	0.0	77.0	11.5	80.0	40.5	57.0	51.5	50.0	72.8	51.5	53.5	6.0	2.3	28.5	0.0	0.0	0.0
19	0.0	17.5	0.0	5.9	1.8	0.0	0.0	55.6	1.2	0.0	0.0	0.0	0.0	6.1	0.0	0.0	0.0
20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	25.3	5.3	33.4	4.1	5.0	3.6	19.8	0.0	0.0	0.0
21	0.0	0.0	0.0	0.0	0.0	0.0	78.4	89.7	163.3	56.0	29.9	7.3	5.8	34.1	0.0	0.0	0.0
23	0.0	57.3	7.6	65.3	32.6	60.3	44.3	104.0	72.5	36.3	34.2	0.0	0.0	2.3	0.0	0.0	0.0
24	0.0	55.3	7.6	67.7	34.3	56.2	56.8	110.2	43.8	44.5	30.8	15.9	8.7	26.8	0.0	0.8	0.0
25	0.0	40.8	2.5	48.8	28.8	55.2	29.5	104.8	65.2	62.0	55.5	0.0	2.8	0.0	0.0	0.0	0.0
26	0.0	37.4	0.0	47.9	21.9	51.2	38.3	109.8	51.4	0.0	14.5	0.0	0.0	5.2	0.0	0.0	0.0
28	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
29	0.0	8.9	0.0	27.7	12.2	13.2	0.0	80.3	21.1	6.0	11.3	0.0	0.0	11.1	0.0	0.0	0.0
31	0.0	63.3	6.6	49.1	20.3	25.7	33.1	80.6	38.3	59.6	32.8	7.1	10.4	34.7	1.9	1.9	0.0
32	0.0	5.1	0.0	8.7	6.8	6.4	0.0	52.8	23.4	13.7	0.0	0.0	0.0	8.3	0.0	0.0	0.0

2008	May	May	May	June	June	June	June	July	July	July	July	Aug	Aug	Aug	Aug	Sept	Sept
Station	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2
6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.0	0.0	0.0
8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9	0.0	0.0	0.0	19.4	6.1	11.1	0.0	10.3	19.6	14.7	3.9	16.3	0.0	6.5	0.0	0.0	0.0
10	0.0	0.0	0.0	22.9	7.1	11.9	0.0	8.6	18.2	15.5	1.2	23.5	0.0	5.8	0.0	0.0	0.0
11	0.0	0.0	0.0	17.5	4.0	10.2	0.0	7.7	16.3	8.9	0.0	2.3	0.0	2.5	0.0	0.0	0.0
12	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14	0.0	0.0	0.0	0.2	0.0	4.3	0.0	8.5	0.1	11.0	10.2	37.3	4.6	3.2	0.0	0.0	0.0
16	0.0	0.0	0.6	0.6	0.0	0.0	0.0	5.6	0.3	2.2	0.8	0.6	0.0	3.3	0.0	0.0	0.0
17	0.0	0.0	27.5	49.4	18.5	38.7	11.1	11.8	30.1	32.8	10.8	35.2	0.0	13.7	0.0	0.0	0.0
19	0.0	0.0	0.7	0.9	0.0	0.0	0.0	2.6	5.8	4.5	0.0	1.8	0.0	2.6	0.0	0.0	0.0
20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	14.2	0.0	0.5	0.0	0.0	0.0
21	0.0	0.0	12.6	73.1	32.3	92.3	10.3	8.1	29.6	78.0	31.5	85.4	8.7	9.9	0.0	0.0	0.0
22	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	13.5	39.2	11.3	0.1	0.0	0.0	0.0
23	0.0	0.0	0.0	37.3	15.9	26.0	0.0	8.1	10.7	15.3	0.0	0.0	0.0	1.5	0.0	0.0	0.0

Appendix 3. Continued.

Station	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2
24	0.0	0.0	0.0	42.1	20.4	42.2	0.0	5.3	16.8	23.7	6.7	16.4	0.0	1.6	0.0	0.0	0.0
25	0.0	0.0	0.0	32.8	8.8	22.3	0.0	0.0	14.2	13.7	0.0	7.2	0.0	0.5	0.0	0.0	0.0
26	0.0	0.0	0.0	35.3	10.0	38.9	0.0	0.0	16.4	15.2	0.9	36.2	0.0	4.7	0.0	0.0	0.0
28	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
29	0.0	0.0	0.0	10.6	0.6	9.3	0.0	0.0	1.6	0.0	0.0	0.0	0.0	1.3	0.0	0.0	0.0
30	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
31	0.0	0.0	2.1	26.5	14.8	35.6	0.0	0.2	8.9	14.2	0.4	40.4	15.5	2.7	0.0	0.0	0.0
32	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0

2009	May	May	May	June	June	June	June	July	July	July	July	Aug	Aug	Aug	Aug	Sept	Sept
Station	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2
6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0
8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9	0.0	0.0	5.3	31.0	0.6	5.4	0.0	0.0	5.4	0.0	47.5	5.3	0.0	0.0	2.2	0.0	0.0
10	10.7	0.0	5.8	35.9	0.0	36.9	19.5	0.0	5.8	0.0	46.5	4.4	0.0	0.0	0.0	0.0	0.0
11	0.0	0.0	2.7	30.7	0.0	0.0	0.0	0.0	0.8	0.0	22.1	8.5	0.0	0.0	0.0	0.0	0.0
12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0
14	10.2	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	8.3	0.0	0.0	0.0	0.0	0.0
17	10.2	0.0	16.7	67.3	2.8	49.5	15.8	0.0	7.3	0.0	39.6	58.0	0.0	0.0	0.0	0.0	0.0
19	0.0	0.0	0.0	2.5	0.0	0.0	0.0	0.4	0.0	0.0	0.0	12.3	0.0	0.0	0.0	0.0	0.0
20	10.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
21	0.0	0.0	26.2	128.7	9.5	74.5	10.6	11.4	12.2	0.0	42.8	53.8	2.7	0.0	0.0	0.0	0.0
22	0.0	0.0	0.0	0.0	0.0	25.8	8.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23	0.0	0.0	9.7	56.1	0.0	12.6	3.8	0.0	2.4	0.0	22.8	1.1	0.0	0.0	0.0	0.0	0.0
24	0.0	0.0	9.3	66.8	4.0	32.0	0.0	0.0	1.2	0.0	37.0	2.3	0.0	0.0	0.0	0.0	0.0
25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
26	0.0	0.0	18.7	55.9	4.6	0.0	0.0	0.0	0.4	0.0	25.7	4.9	0.0	0.0	0.0	0.0	0.0
28	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
29	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.6	4.5	0.0	0.0	0.0	0.0	0.0
30	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	51.7	14.6	10.8	1.1	22.8	22.0	1.3
31	0.0	0.0	4.4	30.2	7.9	40.8	11.8	11.0	11.7	18.0	40.2	3.3	0.0	0.0	0.0	0.0	0.0
32	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0