RESPONSE OF CHIRONOMIDAE ASSEMBLAGES TO LAND USE IN AN URBAN STREAM

A THESIS
SUBMITTED TO THE FACULTY OF
UNIVERSITY OF MINNESOTA
BY

JESSICA WYN MILLER

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

ADVISOR
DR. LEONARD C. FERRINGTON, JR.

MARCH 2014

ACKNOWLEDGEMENTS

Thank you to everyone that provided help and support for this thesis project. First I must thank my advisor Len Ferrington for the time spent with help, guidance, support, and advice that began before I started this program. In addition, I thank my committee, Susan Gresens, and Roger Moon for their help and useful guidance. Thank you to Metropolitan Mosquito Control District and Capitol Regions Watershed District for financial support during this thesis work. Big thanks to Susan, and Len for their collection and data of Chironomidae in Minnehaha Creek. Thanks to Minnehaha Creek Watershed District for their data contribution.

I would like to specially thank members of the Chironomidae Research Group and lab/office mates, Alex Egan, Petra Kranzfelder, Jane Mazack, Alyssa Anderson, Will French, and Lori Krider, for field work opportunities, friendship, support, feedback, and the push to challenge myself.

Finally and importantly a very heartfelt thanks to my family. My parents, Mark and Sandy with their support, teachings, travel and love has given me the passion and skills to set my goals and achieve them. The Arendt family, especially the time we spent growing up outdoors in Minnesota and traveling. The Miller Clan, also for family travels and some that showed the differences and similarities to Minnesota. I have a special thanks to Uncle Denny who helped me choose how big a mark I want to leave on this world.

Dedication

This thesis is dedicated to my family especially my little brother David Justice Miller. Thanks for loving all of those creepy crawlies growing up.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

Stream management in urban settings faces many challenges, because urban development impacts aquatic systems and hydrologic dynamics. Wetlands are drained, stream channels are straightened, and surrounding land is developed and may be built up to the stream edge. Urban development represents a combination of human alterations, however increases in percent impervious surface is a surrogate metric that has been used to represent the intensity of urban development. Impervious surface (IS) is defined as any constructed surface such as, but not limited to, rooftops, roads, asphalt, and concrete, that restricts water infiltration to the soils beneath (Standfield 2006).

Urbanization is considered to be one of the most severe threats to biodiversity on regional scales (McKinney 2006), with increased IS identified as a primary driver of species losses. Impervious surface (Gresens et al. 2007) combined with riparian encroachment, degradation and excessive loss of riparian habitat (Yoder and Miltner 1999) have been shown to cause significant changes to the species richness and composition of aquatic life in urban streams.

Percent IS is recognized as a reliable variable for quantifying both physical and biological stressors in streams (Standfield and Kilgour2006). Changes in hydrology affecting metropolitan streams can be primarily caused by both the total amount and percentage of IS area within the watershed. Common inputs or stressors associated with rainwater run off include: NaCl, heavy metals (Blasius et al. 2002, Blakely et al. 2005, Paul and Meyer 2001), thermal changes (Herb et al. 2008, LeBlanc et al. 1996), street litter, chemicals, debris from storm drains, rapid discharge fluctuations, increases in velocity, and increased flashiness (Cobb et al. 1992, Violin et al. 2011). Collectively these stressors derived from urban landscapes cause in-stream ecological degradation, referred to as the urban stream syndrome (Meyer et al. 2005, Walsh et al. 2005), which include reductions in species richness, homogenization of aquatic insect communities, and transitions to assemblages comprised of more-tolerant taxa. The intensity and patterns of changes are encapsulated within the Biotic Homogenization Hypothesis (McKinney and Lockwood 1999), and provide the framework for quantifying responses.

The urban gradient concept was developed by Purcell et al. (2009) to amalgamate population density, road density and percent urban land use/land cover into a single metric. In that study the index showed a consistent inverse relationship between biological indicators and urban conditions. Stanfield and Kilgour (2006) listed many studies with impairment evident when catchment area IS is over 10% and other studies showing impairment even at 3-5%.

Biomonitoring programs use living organisms for measuring water quality impacts of urbanization on stream ecosystems. Benthic macroinvertebrates are widely used and effective as biological indicators (Purcell et al. 2009). The ability of a macroinvertebrate to tolerate pollution or contaminated water is indicated by the tolerance values assigned to a taxon. By analyzing the variations of tolerances it is possible to demonstrate changes in community structure.

Insects in the order Diptera are very useful for biomonitoring aquatic systems and are particularly suited for assessments of urban stream syndrome responses because they can be very species rich and have a wide range of tolerance values, especially within the family Chironomidae (Ferrington et al. 1991, Ferrington et al. 2008). Chironomids are found throughout the world and have a relatively short life cycle that facilitates efficient monitoring. These invertebrates respond to short bursts of stress input characteristic of high run off events after rainfalls (Ferrington 2008, Ferrington et al. 2008). In addition the pupal exuviae collection protocol developed by Ferrington et al. (1991) has been shown to be an efficient, effective, and economical method for surveying Chironomidae composition, and has been successfully employed to measure enrichment responses in urban streams (Ferrington and Crisp 1989; Wright et al. 1996).

Chironomidae are often identified only to family or tribe-levels in routine biological monitoring and impact assessment studies. This decreases their efficacy as a metric on which management decisions can be based. Information content derived from Chironomidae is highest, of course, when species-level identifications are possible, but this level of taxonomic precision is difficult to consistently attain, and many regulatory agencies do not have this capability within their monitoring and assessment units. Consequently, genus-level identifications are often considered as an effective compromise between tribe- and species-level approaches and Miloševićet al. (2014) demonstrated using the self-organizing map method, classification strength analysis and Spearman's rank correlation, that the genus-level data accurately approximated species-level community patterns in impact assessments.

In aquatic systems with good water quality Chironomidae typically increase in species richness from small streams to larger, intermediate-sized streams (Coffman, 1989). The increases typically occur gradually over spatial scales of kilometers of stream length, and sites separated by 2-4 kilometers in unpolluted streams can differ by 30% to 40% of taxa (Ferrington, unpublished data for streams in Bear Run Nature Preserve, western PA). By contrast, stresses associated with organic enrichment in urban streams in Kansas resulted in decreases in richness at sites downstream of inputs and increased similarities among sites due to predominance of tolerant taxa (Ferrington and Crisp 1989). Similar patterns of generic richness are also observable in both of these studies.

Biotic homogenization refers to an increase in species similarity in space and/or over time and can arise through several ecological mechanisms (Olden 2004). Biotic homogenization or loss of landscape-level diversity caused by human activities can increase the incidence of non-native species or cause shifts to genera with higher tolerance values, and result in extirpation of native species or genera with lower tolerance values (Stranko 2010). The changes in species richness and tolerance found by Ferrington and Crisp (1989) conformed to patterns predicted by the Biotic Homogenization Hypothesis.

Minnehaha Creek is a valuable esthetic and recreational resource in Minneapolis, MN. It is managed as an urban canoe route, and at small spatial scale has relatively well buffered riparian areas spaced intermittently along the stream course. Aquatic insect communities in the stream provide food for many other organisms such as fish, birds, mammals, and amphibians. For instance, Nakano and Murakami (2001) estimated that

25.6% of riparian bird's diet comes from aquatic insects, due to reduction of terrestrial insects during leafless time periods in temperate climates.

Although protected by high-quality riparian buffers in some areas and free of obvious point sources of organic enrichment, Minnehaha Creek traverses a landscape that at larger spatial scales is highly urbanized, with associated extremely high %IS. Prior to this study, no comprehensive survey of Chironomidae existed for the stream. However, based on the extensive urbanization and resultant high %IS, it could be expected that longitudinal patterns of aquatic insect composition would conform to patterns predicted by the Biotic Homogenization Hypothesis and, consequently, the Chironomidae communities furthest downstream in the catchment would be highly reduced in generic richness and homogenized compared to sites in the upper portions of the catchment. It could also be expected that community composition would transition to more highly tolerant taxa in the lower part of the catchment relative to the upper portions.

Impervious surfaces upstream of sample sites contribute run-off and associated pollutants. Prior to this study it was expected that the total amount of IS upstream of sample sites would increase progressively from upstream to downstream, producing successively greater degrees of stress on chironomids at sites from upstream to downstream. It was also expected that %IS would increase substantially between sample sites from upstream to downstream. A conceptual model to illustrate predicted reductions in generic richness is shown in Figure 1.

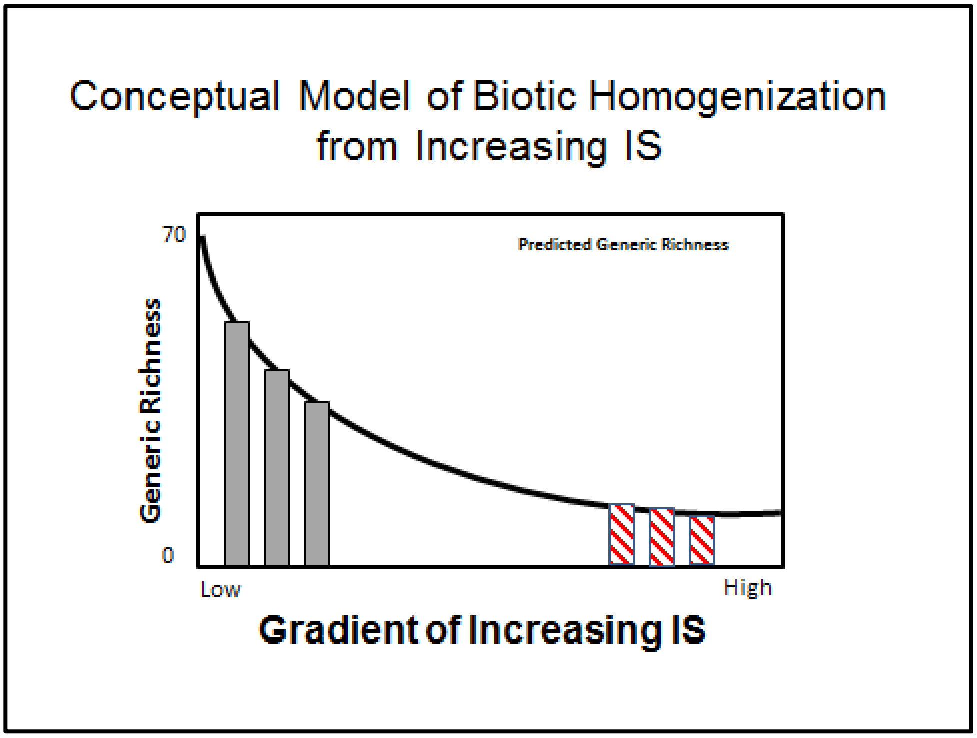


Figure 1.Conceptual model illustrating predicted reductions in generic richness as a function of increasing impervious surface at sample sites from upstream to downstream in Minnehaha Creek.

In addition to changes in generic richnesses, it is also possible to predict how biotic homogenization will influence similarity of Chironomidae across sample sites. With three downstream sites and three upstream sites there are three comparisons of downstream with downstream sites (within downstream classification), three comparisons of upstream with upstream sites (within upstream classification) and nine comparisons of upstream sites with downstream sites (cross-classification). The Biotic Homogenization theory predicts that sites furthest downstream will be the most similar to each other and on average more similar than the three sites upstream will be to each other. The similarity of upstream sites to downstream sites will be the lowest.

Furthermore, sites that are adjacent to each other within a classification will be most similar (e.g., downstream sites six and five and five and four should be more similar to each other than sites six and four). To investigate the magnitude of changes in Chironomidae the following hypotheses were formulated and assessed regarding Chironomidae community responses to land use conditions in the watershed of Minnehaha Creek:

H_1: Cumulative stresses associated with increasing IS at catchment-scale levels will reduce Chironomidae generic richness from upstream to downstream;

H_2: Cumulative stressor input will act longitudinally at large spatial scale to homogenize the Chironomidae community with increasing IS upstream of sample sites;

H_3: Riparian buffers may operate at local landscape scales to ameliorate cumulative impacts expected based on large-scale patterns of IS.

METHODS AND MATERIALS

Study area

The Minnehaha Creek watershed is shown in Figure 2. The watershed can be divided into two distinct regions with differing landscape features, with Lake Minnetonka serving as a natural dividing point. Streams feeding into Lake Minnetonka are all small, with some becoming predictably intermittent in dry years, and draining a mosaic of land uses ranging from primarily agricultural fields through low level urban areas. By contrast, the lower portion of the watershed has more intensive urban and industrial development.

Minnehaha Creek Watershed District is the local agency tasked with managing water quality in the catchment. Minnehaha Creek occurs in the lower portion of the watershed and originates at the outflow of Lake Minnetonka at Gray's Bay, then flows within the cities of Plymouth, Wayzata, Minnetonka, St. Louis Park, Hopkins, Edina, Minneapolis, and Richfield. Minnehaha Creek is a class 2B urban stream as categorized by Rosgen stream analysis, drains an area of 31,258 acres (126.5km^2) including at least portions of 27 cities and drops 68 meters in elevation along its flow length of 35 kilometers (MCWD 2013).

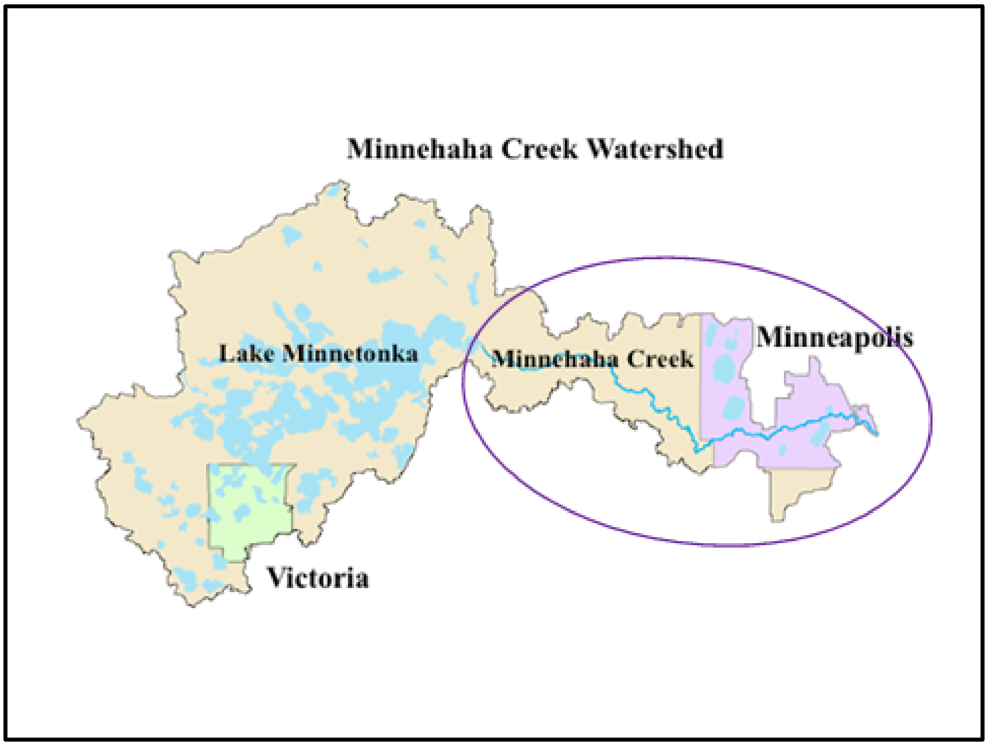


Figure 2. Minnehaha Creek Watershed, Minnesota, USA.

Samples of Chironomidae pupal exuviae were collected from six sites along Minnehaha Creek, near Minneapolis, Minnesota (Figure 3). Three of the sample sites are located in the upper half of the catchment where urbanization adjacent to the stream is less dense (sites 1, 2 and 3). Three sample sites are located in the lower portion of the catchment where urban development is denser. Each sample site consisted of a one hundred meter stretch of stream, with the downstream edge located at least 100 meters downstream of any road crossings. The latitudes and longitudes of the downstream edges of sample sites are included in Appendix table A.

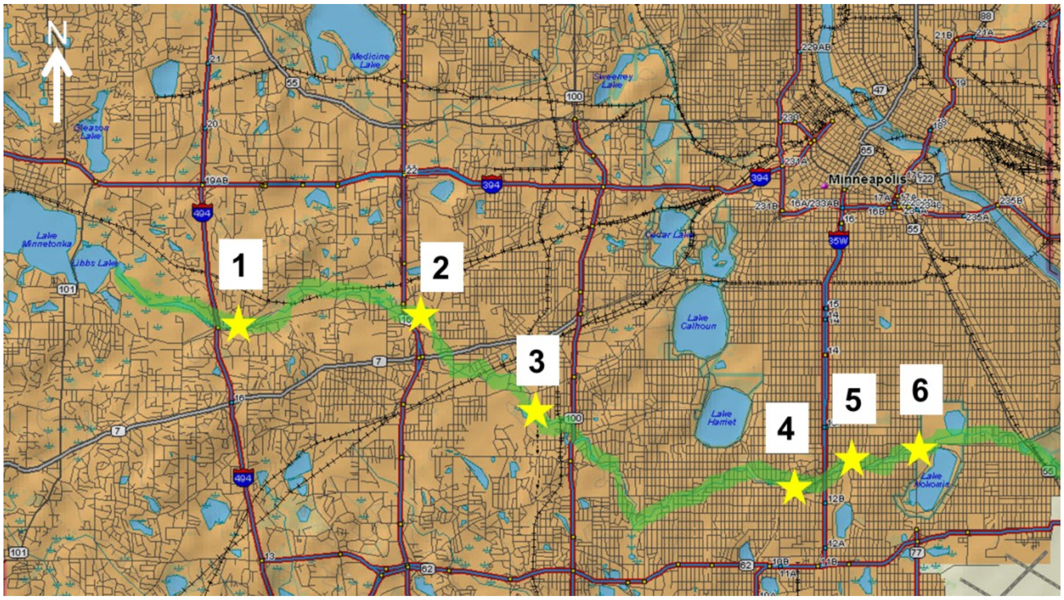


Figure 3. Map of Minnehaha Creek showing locations of sample sites.

Substrate Composition

Substrate heterogeneity can influence taxonomic richness of aquatic insects, (Gresens and Ferrington 2008). It was necessary to assess the characteristics of substrates across sample sites. Pebble count data was collected in 2003 by Susan Gresens using methods in Kondolf (1997). Results were graphed with pebble size against the percent total represented at that size (Figure 4). Raw data for pebble counts are provided in Appendix (Table B).

Sinuosity

Sinuosity can potentially influence taxonomic richness of aquatic insects. Sinuosity measurements of Minnehaha Creek were categorized by the sinuosity index in Stejskalová (2013) referring to Gordon and Finlayson. Sinuosity was calculated as the length of a stretch of Minnehaha Creek divided by the length of a straight line from beginning to end of that stretch. Sinuosity was measured for site 1 starting at the outflow of Gray's Bay downstream to the upper edge of site 1. For each of the sites further downstream, calculations were based on measurements taken from the downstream edge the site upstream to the upstream edge of the site being measured.

Catchment-Scale IS

ArcMap was used to measure both cumulative upstream IS and %IS for the drainage area of each of the six sample sites on Minnehaha Creek. Land use and drainage area measurements were calculated specifically from the headwaters of Minnehaha Creek at Gray's Bay downstream to each sample site, and also from the head waters to the Mississippi River. However, for total catchment area all of Minnehaha Creek Watershed was measured, specifically including small streams draining into Lake Minnetonka upstream of Minnehaha Creek.

Riparian-Scale IS

Smaller-scale riparian conditions were quantified using Google Earth for each of the six 100-meter sample sites at three different spatial scales. Land cover was analyzed within three quadrilateral for each site (10m wide x 100m long ,100m wide x 100m long, and 200m wide x 100m long); Minnehaha Creek was located at the center width of each of these quadrilaterals. Percent IS was calculated by measuring polygons (Clark 2014) (Appendix, Figure C-H) of all IS land uses (houses, streets, walking paths, parking lots, etc) divided by total area (open water was not included in this calculation).

Sample Collection and Specimen Processing

Surface floating pupal exuviae (SFPE) were collected by L. Ferrington and S. Gresens every 3 weeks in 2003 from just after ice-out in April to November according to methods of Ferrington et al. (1991). Samples were collected for 10 minutes at each sample site on each sample date. Areas in which SFPE are likely to accumulate, by water movement or air currents, along a 100-meter stretch were repeatedly dipped into with a pan and material then poured through a 125µ sieve to retain SFPE and other floating material. The contents remaining on the sieve were transferred to a sample jar with 80% ethanol solution as preservative for lab processing. Exuviae were removed from the sample by sorting under 10X magnification and identified to genus. Selected specimens were slide mounted for verification and a voucher collection of slide-mounted specimens was prepared. The slide mounted exuviae were identified to genus by J. Miller using

Ferrington et al. (2008) and Wiederholm (1989) and all generic identifications were confirmed by L. Ferrington and/or S. Gresens.

Analysis of Data

Similarity of chironomid communities for all combinations of sites was calculated using both Jaccard's and Whittaker's similarity indices. With six sample sites the number of two-sample comparisons is fifteen.

Jaccard's Coefficient of Similarity is calculated as follows:

$$JCS = A / (A+B+C)$$

where A is equal to the number of genera shared among two samplesites being compared, B is equal to the number of genera unique to the first of the two sample sites, and C is equal to the number of genera unique to the second of the two sample sites. The range of values for this coefficient is between 0 and 1, and when multiplied by 100 is the percent of similarity between the two sample sites.

Whittaker's Percent Similarity (WPS) is calculated as follows:

$$WPS = \Sigma \min (p_{ij} \text{ or } p_{ik})$$

Where p_{ij} is the frequency of genus i at site j and p_{ik} is the frequency of genus i at site k (when sites j and k are being compared).

Biotic Index

Tolerance values were assigned for all chironomid genera based on Ferrington et al. (2008). However, some genera collected from Minnehaha Creek are not included in Ferrington et al. (2008). Tolerance values for these genera were assigned based on best professional judgment derived from other studies on Chironomidae in Minnesota since 2001.

Tolerance values range from 1 to 10, with 1 as the least tolerant (most sensitive to pollutants or stressors) and 10 as the most tolerant. Two standard versions of the Biotic Index (BI) were calculated, a qualitative version and quantitative version. The qualitative version is equal to the sum of the tolerance values of all genera present at the site divided by the total number of genera. The quantitative form of the BI is calculated as defined by Hilsenhoff (1977).

The equation for qualitative tolerance value is calculated as follows:

$$T_t = \sum T_{gn} / N_t$$

T_t is equal to the tolerance value calculated for site t. T_{gn} is equal to the Tolerance value (g) of a specific genus present at site t (n). N_t is equal to the number of genera present at site t. All values are summed for a given sample site.

The equation for quantitative tolerance value is calculated as follows:

$$T_t = \sum (T_{gn} * n_{gn}) / n_t$$

In this equation, n_{gn} is the total number of specimens of genus n and n_t is the total number of specimens collected at site t.

Results

Substrate Composition

The substrate compositions between sites are shown graphically in Figure 4. Small substrates dominated all sample sites. However sample sites 3 and 6 had more similar substrate compositions, with a high proportion of fine and coarse sands and small pebbles. The remaining sample sites (sites 1, 2, 4 and 5) were also somewhat similar to each other but had slightly larger substrates than sites 3 and 6 (Figure 4).

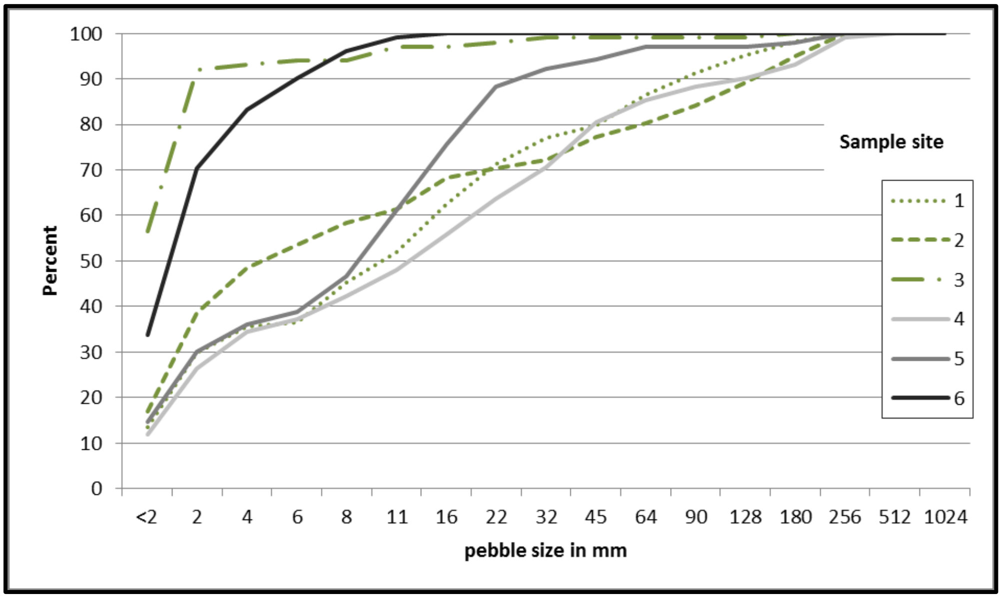


Figure 4. Percent composition across substrate categories for all sample sites.

Sinuosity

Sinuosity ranged from 1.08-1.75. The least sinuous segment of stream was upstream of site 1 and the most sinuous segment was upstream of site 4. Sinuosity of segments upstream of sites 1, 2, and 3 were 1.08, 1.49, and 1.36, and the corresponding segments of downstream sites 4, 5, and 6 were 1.75, 1.51, and 1.15 (Table 1). In Stejskalová (2013) a reference was made to Gordon and Finlayson for a sinuosity index that categorizes a straight watercourse as varying between 1-1.5 and meandering streams as ranging from 1.5-4. Using these cut-off points, sites 4 and 5 would be considered meandering and the rest of the stream segments upstream of sample sites as straight. However, with a simple T-test the segments of upstream and downstream sites are not statistically different (p value =0.51). Considered as a group, neither the upstream nor the downstream sites had a sinuosity that deviated substantially from the sinuosity calculation for the entire stream (Table 1).

Sample site	Sinuosity
1	1.08
2	1.49
3	1.36
4	1.75
5	1.51
6	1.15
Minnehaha Creek	1.53

Table 1. Sinuosity of Minnehaha Creek upstream of each sample site, and total sinuosity for Minnehaha Creek.

Catchment-Scale IS

Expectations for IS at catchment scale in H_1 were that both the total amount and %IS would increase with increased drainage area as the sites were located further downstream, and that chironomid communities would reflect that increase. However upstream sample sites began with a high %IS and downstream sites only slightly increased (5%). At sample site 1 the IS was 6.35km^2 which represented 42% of the total drainage area (table 2). Sample site 4 added the most IS area because of the long distance between site 3 and site 4.

site	Cumulative Drainage area in km^2	Site specific area of drainage in km^2	Cumulative IS area km^2	Site specific area of Drainage km^2	% IS	Site specific % IS
1	15.11	15.11	6.35	6.35	42.06%	42.05%
2	31.34	16.23	13.71	7.36	43.76%	45.32%
3	39.43	8.09	18.27	4.56	46.36%	56.45%
4	94.32	54.89	44.68	26.41	47.39%	48.11%
5	100.39	6.07	47.41	2.73	47.25%	44.96%
6	101.85	1.46	47.9	0.49	47.05%	33.41%

Table 2. Impervious surface area for each sample site and how many km^2 were added at each sample site.

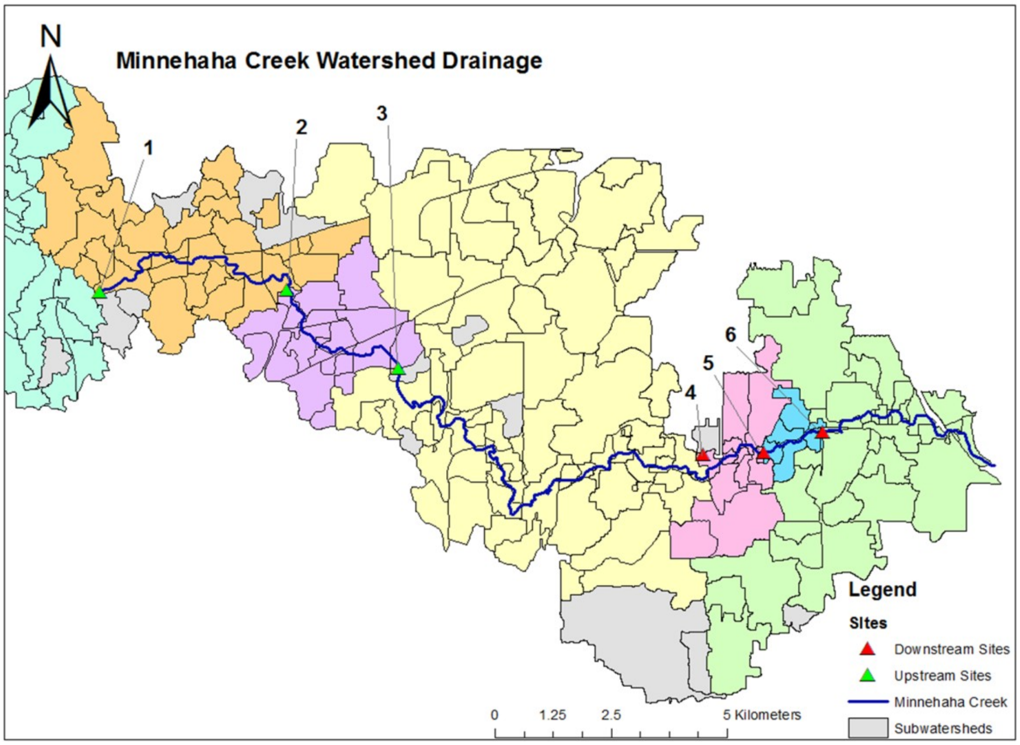


Figure 5. Drainage area upstream of sample sites.

The percent IS of the drainage area of the six sample sites (Figure 5) were very similar with a range of 42.1% to 47.4%. The IS of the upstream sites 1, 2, and 3 were 42.06%, 43.76%, and 46.36%. The IS of the downstream sites 4, 5, and 6 were 47.39%, 47.25%, and 47.05%. The lowest percent IS at 42% was at the most upstream site (1), and the highest at 47.4% at site 4. At the watershed scale the 3 upstream sites had a lower percentage of IS than the 3 downstream sites.

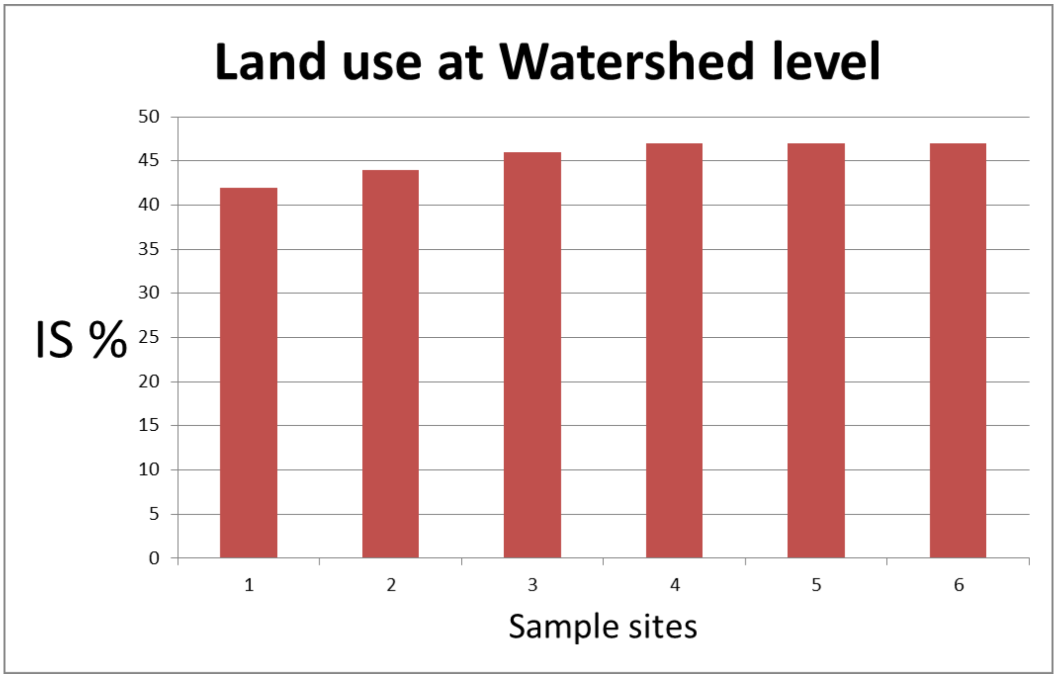


Figure 6. Percent impervious surface for each sample site at the watershed drainage scale.

Riparian-Scale IS

Figure 7 shows the %IS increases as the area being measured increases. Measurements of the %IS at the 200m x 100m area ranged from 10-52%. Upstream sites 1, 2, and 3 were 46%, 36%, and 52%IS. The downstream sites 4, 5, and 6 were 44%, 51% and 10%IS. The lowest, at 10%IS, was at downstream site 6, and highest IS was at upstream site 3 with 52%IS. At all of the 6 sites this is the highest %IS at the local three scales.

Measurements of the IS at the 100m x 100m area ranged from 8-39%. Upstream sites 1, 2, and 3 were 36%, 17%, and 10%IS. The downstream sites 4, 5, and 6 were 36%, 39%, and 8%IS. At the 100m x 100m scale the lowest IS at 8% was downstream site 6, and highest at 39% was downstream site 5. At 5 of the 6 sites this value is between the 10m x 100m and the 200m x 100m %IS.

Percent IS at the 10m x 100m buffer scale ranged from 0-28%. Upstream sites 1, 2, and 3 were 13%, 28%, and 0%. Downstream sites 4, 5, and 6 were 20%, 21%, and 6% IS respectively. The lowest percent IS at 0% was upstream at site 3, and the highest at 28% was upstream at site 2. At five of the six sites the riparian area has the lowest %IS.

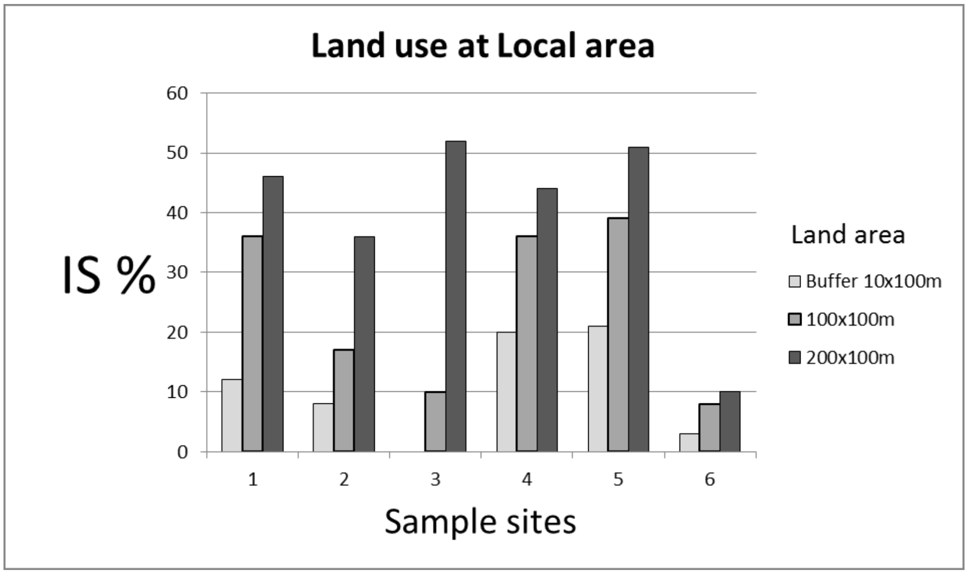


Figure 7. Percent impervious surface for each sample site at the 3 local spatial scales.

	IS % for land area				
Site	Buffer 10x100m	100x100m	200x100m	% IS in total drainage area	differecne in total % and buffer %
1	12	36	46	42	30
2	8	17	36	44	36
3	0	10	52	46	46
4	20	36	44	47	27
5	21	39	51	47	26
6	3	8	10	47	44

Table 3. Percent impervious surface by site and land area.

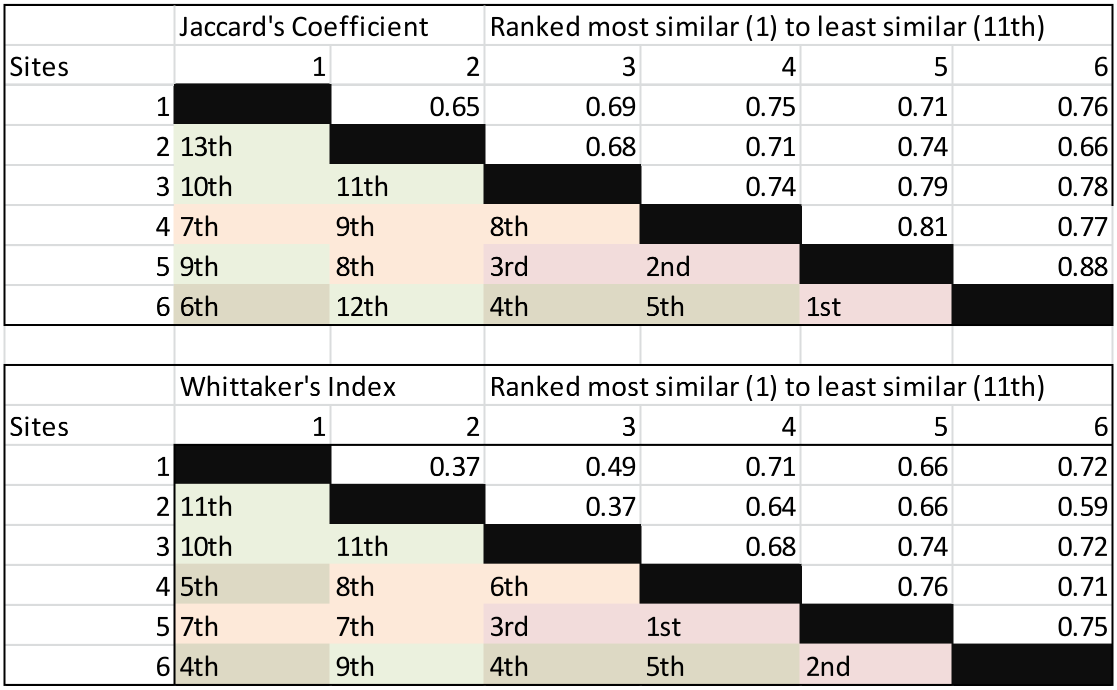
Chironomid composition

A total of 61 genera were collected across all six sample sites. Specimens of SFPE collected in at each of the six sites ranged from 2,262-19,047, with a total collection of 38,358 SFPE. Site 5 had the fewest and site 2 had the most of the total specimens collected (see Appendix C). Composition of Chironomidae genera at each of the six sample sites ranged from 39-47. Site 2 had the fewest at 39 genera and site 4 had the most at 47 genera.

Chironomid Assemblage Similarity

Jaccard's coefficient of similarity, among pairs of upstream sites, the similarity between; site one and two was 64.8%; one and three was 69.1%, site two and three was 68.0%. Looking at the downstream sites the similarity between; four and five was 81.5%, four and six was 76.8%; five and six was 82.2%. The average of upstream versus downstream was 68.3%.

The similarity between pairs of upstream sites usingWhittaker's index, site one and two was 36.6%; site one and three 49.0%; site two and three 37.4%. The average similarity was 41.0% for upstream versus upstream sites. Looking at the downstream sites, the similarity between; four and five was 75.9%; site four and six was 70.9%, site five and six was 75.4%. The average similarity was 74.1% for downstream versus downstream sites. The average was 53.1% of cross classification upstream versus downstream.



	Jaccard's Coefficient		Ranked most similar (1) to least similar (11th)			
Sites	1	2	3	4	5	6
1		0.65	0.69	0.75	0.71	0.76
2	13th		0.68	0.71	0.74	0.66
3	10th	11th		0.74	0.79	0.78
4	7th	9th	8th		0.81	0.77
5	9th	8th	3rd	2nd		0.88
6	6th	12th	4th	5th	1st	

	Whittaker's Index		Ranked most similar (1) to least similar (11th)			
Sites	1	2	3	4	5	6
1		0.37	0.49	0.71	0.66	0.72
2	11th		0.37	0.64	0.66	0.59
3	10th	11th		0.68	0.74	0.72
4	5th	8th	6th		0.76	0.71
5	7th	7th	3rd	1st		0.75
6	4th	9th	4th	5th	2nd	

Table 4. Jaccard's and Whittaker's similarity of sample sites and rank of similarity

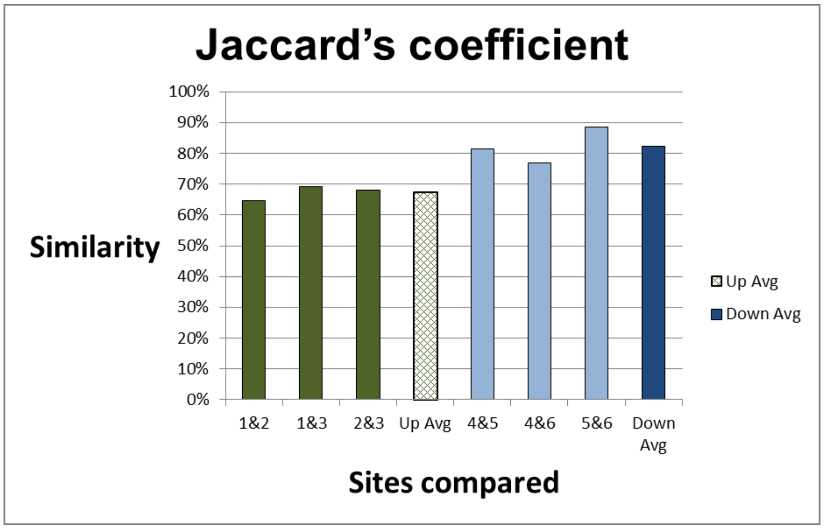


Figure 8. Jaccard's coefficient shows increasing similarity at downstream sites compared to upstream sites.

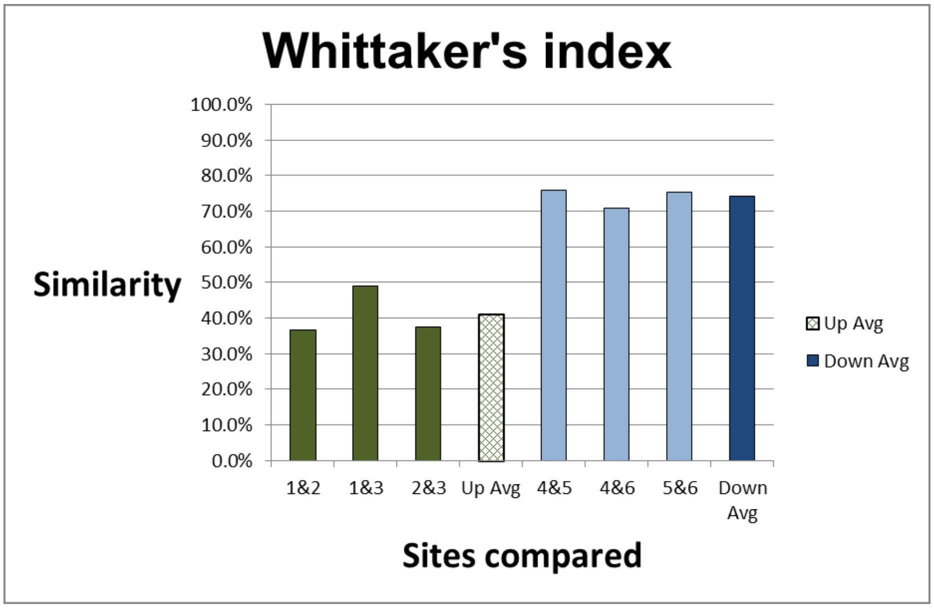


Figure 9. Whittaker's index shows increasing similarity at downstream sites compared to upstream sites.

Biotic Index

Tolerance value averages ranged from 6.17-6.57 qualitatively, and from 5.86-6.39 quantitatively. Upstream sites 1, 2, and 3 were 6.17, 6.33, and 6.26 qualitatively. Downstream sites 4, 5, and 6 were 6.19, 6.44, and 6.57 qualitatively. Quantitative tolerance values for sites 1, 2, and 3 were 6.19, 5.86, and 6.38. Quantitative tolerance values downstream for sites 4, 5, and 6 were 6.39, 6.21, 6.16.

Biotic Index		
	quantitative	qualitative
Site 1	6.19	6.17
Site 2	5.86	6.33
Site 3	6.38	6.26
Site 4	6.39	6.19
Site 5	6.21	6.44
Site 6	6.16	6.57
Mhaha Creek	6.07	6

Table 5. Biotic Index values for each sample site for qualitative and quantitative measurements.

DISCUSSION

Substrate Composition

The inspection of pebble counts indicates all six sample sites have comparable substrate heterogeneity that is dominated by smaller-sized particles. These data suggest that in-stream substrate conditions are not likely to be sufficiently different enough to cause changes in the chironomid community. Consequently, it can be assumed that substrate heterogeneity is not likely to have a complicating effect on community diversity for site to site comparisons.

Sinuosity

In Iwata (2003) a positive correlation between increasing sinuosity and greater aquatic insect abundance was seen. From the perspective of individual sites, Minnehaha Creek data shows that the most sinuous segment was upstream of the sample site with the most abundant genera (though the other sites did show a consistent relationship of species richness with sinuosity). Consequently, this may just represent a spurious result since no statistically significant difference in average sinuosity was observed for upstream sites versus downstream sites. Consequently, sinuosity is not considered to be substantively influencing patterns of generic richness and sample site similarities across all six sites. However, the high generic richness seen for all sites suggest that the degree of sinuosity present at both areas, and along Minnehaha Creek in general, could be a part of the buffering for stressors coming from IS within the watershed drainage which allows the unexpectedly high generic richness at all sample sites.

Catchment-Scale IS

Results for total IS upstream of sample site was consistent with assumption made at the start of the research project. The amount of IS upstream of site 1, however, was much higher than anticipated based on lower road density and wetland habitats that are situated near the outflow of Grey's Bay.

The %IS in the catchment draining into Minnehaha Creek upstream of site 1 was also much higher (at 42%) than anticipated before the land use patterns were quantified. It was expected that the values could vary from about 20-30%IS based on development goals for local municipalities. In addition to the higher amount of %IS upstream of site 1, there was not a substantive and continuous increase in %IS from this site to the other five sites further downstream. Expectations that %IS would increase as the creek flows downstream due to higher street density in a more populated areas such as the southwest and Nokomis communities in South Minneapolis (Figure 10 and 11) were not confirmed by land-use data.

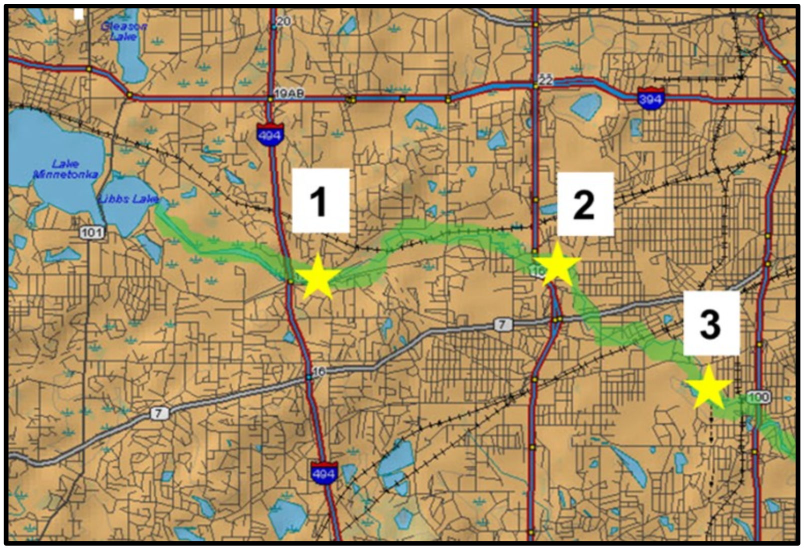


Figure 10. Upstream street density

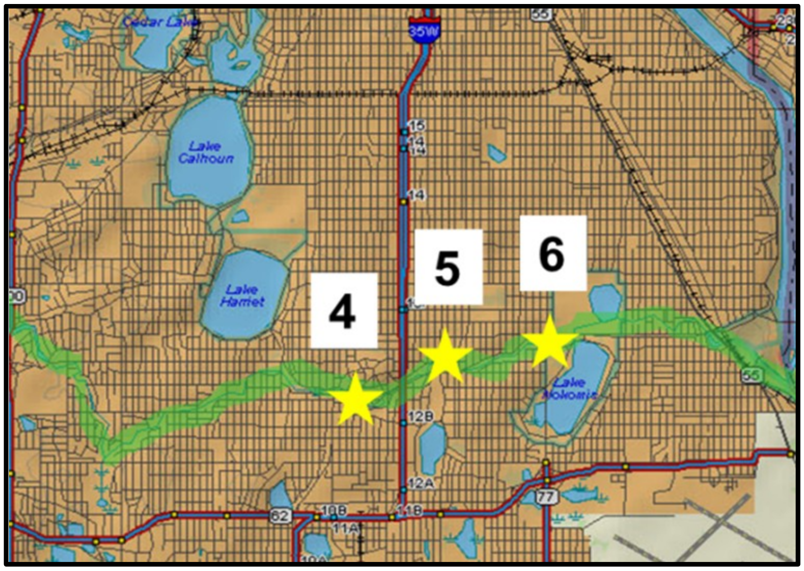


Figure 11. Downstream street density.

Riparian-Scale IS

The data shows all of the six sample sites increasing in %IS as increasing area is measured at the 3 local levels.

Because IS surface at the watershed area measurement at every site is quite high, how can there be such rich generic diversity? It could be from areas that buffer potential inputs from the IS draining into Minnehaha Creek. Specifically from the 10m area along Minnehaha Creek with the lowest %IS.

Chironomid composition

The generic richness in Minnehaha Creek is unexpectedly high considering watershed level IS ranges between 42-47%. The richness values are similar to Bouchard (2007) who investigated six local streams draining catchments with less urbanization but near the Minneapolis/Saint Paul metro area. Values in the Bouchard study ranged from 44-55 total genera in the surface water streams. There is not much difference in the cumulative number of genera present at Minnehaha Creek's upstream sites (55 genera) versus at downstream sites (52 genera).

Schiff and Gaboury (2007) identified 5% as the critical level for protecting natural communities of aquatic biota, and predicted that over 10-20%IS can alter hydrology and in-stream habitats of macroinvertebrates. They show responses suggesting increasing levels of %IS will increasingly have negative effects within a stream's aquatic biota.

Based on their predictions, Minnehaha Creek is clearly beyond the critical lower level of %IS needed to support a diverse Chironomidae assemblage at each of the six sites. Accordingly the community structure should reflect impacts related to generic reduction and transition to a community consisting of mostly tolerant or highly tolerant taxa. Neither of these responses was observed and the sinuosity of the stream channel combined with riparian buffering are likely to be implicated in reducing the impact of high %IS and facilitating the high generic richness.

Figure 1 in the Introduction showed a conceptual model of species richness responses to biotic homogenization as a predictive exponential decline model to how chironomid communities would respond to increasing inputs from urbanization in the Minnehaha Creek watershed. By contrast, Figure 12 (below) shows the actual patterns of generic richness for the sites in the upstream and downstream areas of Minnehaha Creek. In this conceptual model the results for the upstream site are shifted to the right to better correspond with the total IS upstream of each site and corresponding %IS.

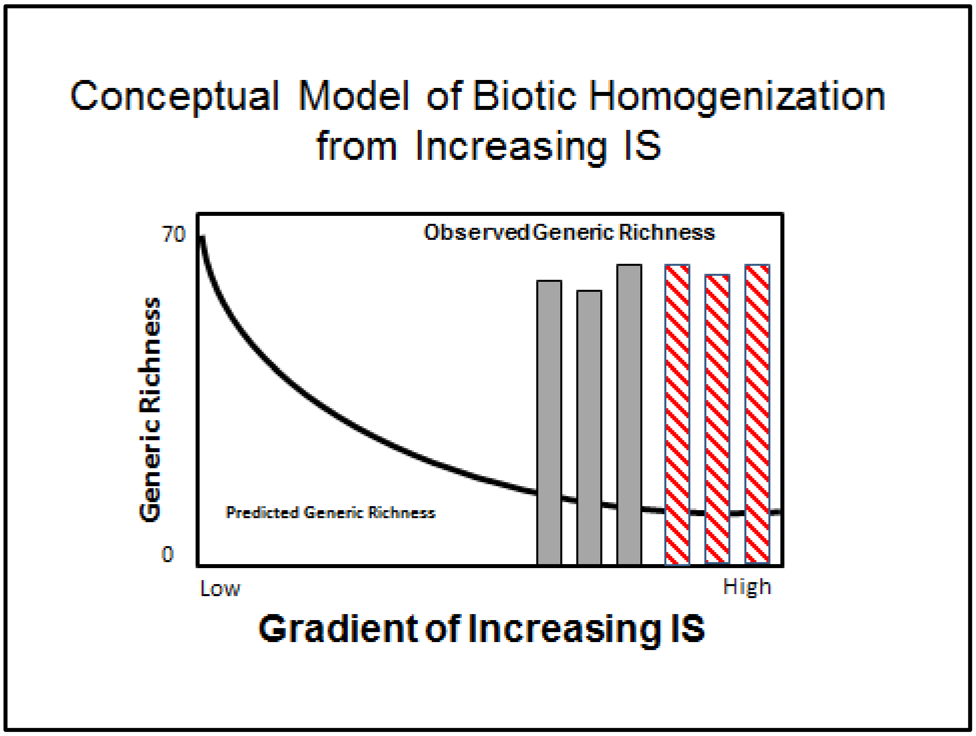


Figure 12. Conceptual model showing observed generic richness of Chironomidae at sample sites successively downstream of Grey's Bay.

Site 2 has the least number of genera and the largest total number of specimens collected. These two metrics could suggest that there is some type of pollutant, such as excessive nutrient loading, which reduces the generic composition but supports a large population of tolerant species. However, on close inspection of the taxonomic composition this does not appear to be the case. Most of the increase in numbers of specimens collected at this site relative to other sites is attributable to a single genus, *Thienemanniella*, which is not tolerant of excessive organic loading. Yet, this genus is one of the smaller-sized genera (less than 4 mm length when larvae are mature) and often is among the most-abundant genera in healthy stream systems, along with the genera *Corynoneura* and *Nanocladius*. This genus may be highly synchronous in emergence during early spring months after ice-out. It is possible that the sampling dates occurred during a synchronous emergence, yielding the large number of specimens at this site.

Biotic Index

Minnehaha Creek being an urban stream with a high %IS shows an unexpectedly high generic composition. Comparing Minnehaha Creek sample sites (39-47 genera) to six surface water dominated streams with less-urbanized watershed near Minneapolis (Cedar Creek, Chub Creek, Credit Creek, Rock Creek, Rush Creek, and Sunrise River) had a range from 44-55 genera (Bouchard 2007). Minnehaha Creek with a qualitative BI value of 6.00 was lower than the value of 6.5 found in Bouchard (2007).

Although the qualitative BI values based on cumulative taxonomic composition at each to the sample sites are a little higher, no strong pattern of increasing qualitative BI is observed from upstream to downstream (Table 5). However, the two highest BI values are for sites 5 and 6, which have the most IS upstream of them. The average values for upstream sites (6.25) and (6.40) are not statistically significantly different.

The quantitative BI values support the interpretation that the communities are not structurally composed of highly tolerant individuals. Averaged across all specimens collected during this study, the quantitative BI is 6.07, and the average of upstream sites (6.14) slightly exceeds the average of downstream site (6.25). Hilsenhoff (1987) provides the following scale for interpreting the quantitative BI values:

0.00-3.50	Excellent water quality
3.51-4.50	Very good water quality, w/ possible slight organic enrichment
4.51-5.50	Good water quality, w/ some organic enrichment
5.51-6.50	Fair water quality, w/ fairly significant organic enrichment
6.51-7.50	Fairly poor water quality, w/ significant organic enrichment
7.51-8.50	Poor water quality, w/ very significant organic enrichment
> 8.51	Very poor water quality, w/ severe organic enrichment

Using this scale, the BI suggests Fair water quality in Minnehaha Creek. Human impacts have homogenized the landscape of Minnehaha Creek Watershed. Percent IS is high throughout the watershed at 42-47%. This means that nearly half of all the land in this area does not allow water to infiltrate soils. This landscape drains into Minnehaha Creek. The habitats in the creek are affected by water inputs draining from the urban landscape they become homogenized and specialty niches disappear. Diversity in chironomids is due to an ability to adapt to unique ecosystems. Homogenized habitats may not be able to support sensitive genera of chironomids and only those that have a high tolerance value can be supported by that habitat. This will lead to specific genera that area able to inhabit that stressed locations and will out compete the sensitive genera (if even able to tolerate the stress levels) to be the strong type. In H_1 it was expected that with increased downstream distance in Minnehaha Creek the increased homogenization would be evident in chironomid assemblages reflecting the increased stress inputs in the water. To indicate a response to the stress inputs from IS, chironomid assemblages could be expected to have higher biotic indices. The homogenization of chironomid would be because the communities would be made up of more tolerant taxa. This effect is seen by increasing urbanization of land, this means an increase of impervious surfaces. The urban stream syndrome indicates that impervious surfaces accumulate many types of pollutants and high % of IS will impact urban waters negatively.

When analyzing the 10m x 100m buffer on Minnehaha Creek at these 6 sample sites there was a significant reduction in the %IS compared to the watershed %IS. The riparian (10m x 100m) buffer area could be ameliorating the effects of high %IS drainage area may be occurring.

Chironomid Community Similarity and Biotic Homogenization

Figure 1 shows the conceptual model of biotic homogenizations as a predictive model to how assemblages would respond to increasing inputs from urbanization Minnehaha Creek. As shown earlier, Figure 12 represents a concept of the generic richness as a function of IS gradients in Minnehaha Creek. This model is based on an exponential decline of taxa that is greatest at low levels of IS. A conceptual model that more accurately fits the data generated in this study is presented in Figure 13, where generic level responses are not predicted until extremely high-levels of IS encountered.

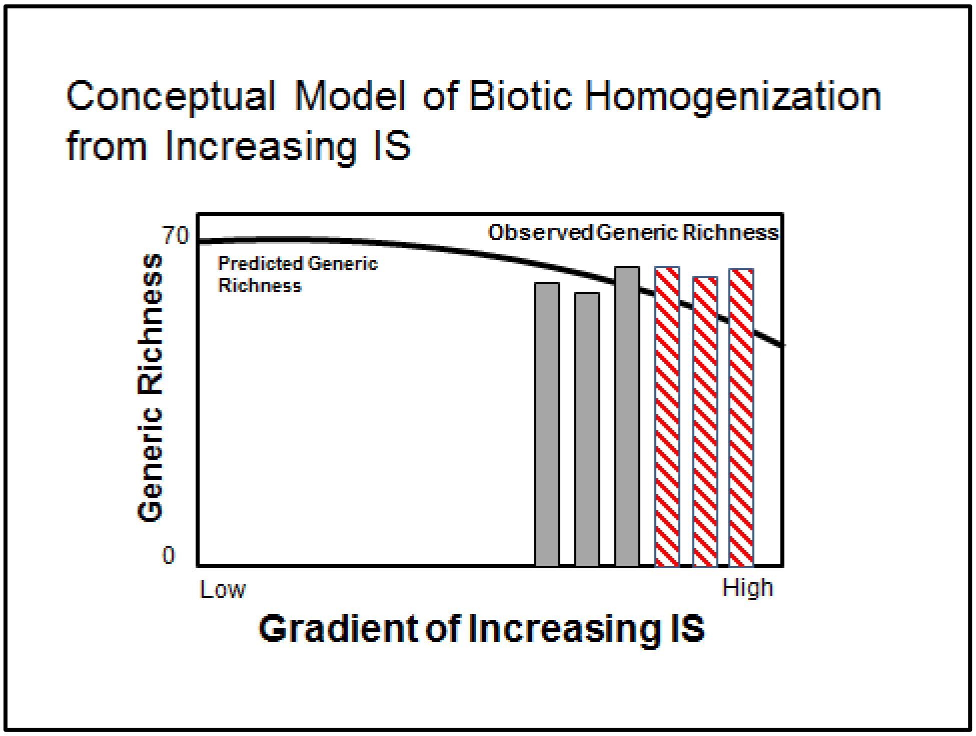


Figure 13. An alternative concept of Biotic Homogenization in Minnehaha Creek.

The difference between the two models relates to the shape of the expected response curve, and the underlying mechanism(s) that are responsible for the generic patterns. Two potential mechanisms could account for the response curve observed in the study. One potential way to interpret the richness patterns is to propose that chironomids as a group are much more tolerant than other groups of macroinvertebrates and that they can resist the cumulative input of stressors to the stream from the higher levels of IS in the catchment. If this mechanism is correct, then it could be expected that the BI analysis would show consistently higher levels of tolerant taxa or individuals from upstream to downstream. The data, however, do not support this mechanism.

An alternative explanation for the departure of observed richnesses from the pattern of expected richnesses, especially at downstream sites relative to upstream sites, could be that the physical setting of Minnehaha Creek, with wetlands and buffers in riparian zone interspersed along its length could allow the higher generic richness by intercepting some of the stressors derived from the IS before they reach the stream channel. In addition, the moderate level of sinuosity of the stream channel could also provide additional microhabitat heterogeneity that contributes to generic richness. The observed BI values would be consistent under the assumptions of this mechanism.

In addition to changes in generic richnesses, it is also possible to predict how biotic homogenization will influence similarity of Chironomidae across sample sites. With three downstream sites and three upstream sites there are three comparisons of downstream with downstream sites (within downstream classification), three comparisons of upstream with upstream sites (within upstream classification) and nine comparisons of upstream sites with downstream sites (cross-classification). The Biotic Homogenization theory predicts that sites furthest downstream will be the most similar to each other and on average more similar than the three sites upstream will be to each other. The similarity of upstream sites to downstream sites will be the lowest. Furthermore, sites that are adjacent to each other within a classification will be most similar (e.g., downstream sites six and five and five and four should be more similar to each other than sites six and four).

Although it is theoretically possible that substrate variability and differences in sinuosity could strongly influences generic composition, a graphical analysis of these parameters versus richness did not reveal strong relationships. The results of the graphical analyses are included as figures H though Q in the Appendix rather than included in text because no apparent relationships were suggested.

FUTURE WORK

Even though Minnehaha Creek is listed as impaired (Minnehaha Creek Watershed District 2004) and has high levels of impervious surface the assemblages of chironomids in Minnehaha Creek seem robust. As management strategies are designed to address the impairment, care needs to be taken to not create conditions that reduce the robustness of the Chironomidae, and assessments should be performed to insure that robust communities of aquatic insects exist after management plans are implemented.

These insects were collected in 2003. Since that time two re-meanders have been installed (2009 and 2013) in the upstream portion of Minnehaha Creek just upstream of the excelsior site (site 3), and subsequently increased the sinuosity of this site. There are other changes that have taken place within this watershed including an increase of rain garden installations. Rain garden workshops and public outreach has been raising awareness of stormwater management for many years. Another program which is likely to continue increasing physical ways to manage storm water is the master water steward program which is now in its second year (2014) of a three year pilot program.

This work will be valuable as a reference to compare assemblages collected after the watershed improvements. It will be important in understanding changes in chironomid assemblages and their response to “improvements” on Minnehaha Creek. It can be expected that the improvements made are reflected slowly in fish and other wildlife, but because of the rapid lifecycle dynamics of Chironomidae they may be the first to show responses to these changes.

REFERENCES CITED

Blakely, T.J., & J.S. Harding. 2005. Longitudinal patterns in benthic communities in an urban stream under restoration. New Zealand Journal of Marine and Freshwater Research. 39:17-28.

Blasius, B.J., & R.W. Merritt. 2002. Field and laboratory investigations on the effects of road salt (NaCl) on stream macroinvertebrate communities. Environmental Pollution 120:219-231.

Bouchard, R.W. Jr. 2007. Phenology and taxonomic composition of lotic Chironomidae (Diptera) communities in contrasting thermal regimes. Ph.D. Dissertation University of Minnesota, St Paul, MN.

Cobb, D. G., T.D. Galloway, and J.F. Flannagan. 1992. Effects of discharge and substrate stability on density and species composition of stream insects. Canadian Journal of Fisheries and Aquatic Sciences 49:1788-1795.

Collwell, R. K. 2006. EstimateS: Statistical estimation of species richness and shared species from samples. Version 9. Persistent URL <purl.oclc.org/estimates>.

Clark, Bill. 2014. Earth Point Polygon Area. http://www.earthpoint.us

Ferrington Jr, L.C., M.A. Blackwood, C.A. Wright, N.H. Crisp, J.L. Kavanaugh, and F.J. Schmidt.1991. A protocol for using surface-floating pupal exuviae of Chironomidae for rapid bioassessment of changing water quality. Sediment and Stream Water Quality in a Changing Environment: Trends and explanation. Proceedings of the Vienna symposium. IAHS publication number 203:181-190.

Ferrington Jr, L.C., and N.H. Crisp. 1996. Water chemistry characteristics of receiving streams and the occurrence of *Chironomusriparius* and other Chironomidae in Kansas. Acta Biologica Debrecen Oecologica Hungarica 3:115-126.

Ferrington Jr, L.C. 2008. Global diversity of non-biting midges (Chironomidae; Insecta-Diptera) in freshwater. Hydrobiologia 595:447-455.

Ferrington Jr, L.C., M.B. Berg and W.P. Coffman. 2008. Chironomidae. Chapter 26 (p847- 989) In: R. W. Merritt, K. W. Cummins and M. B. Berg, eds. An introduction to the aquatic insects of North America.4th Ed., Kendall/Hunt Publishing Company, Dubuque, Iowa.

Gresens, S.E., K.T. Belt, J.A. Tang, D.C. Gwinn, and P.A. Banks. 2007. Temporal and spatial responses of Chironomidae (Diptera) and other benthic invertebrates to urban stormwater runoff. Hydrobiologia 575:173-190.

Gresens, S.E., & L.C. Ferrington Jr. 2008. Taxonomic distinctness provides an alternative view of the diversity of Chironomidae (Diptera) assemblages. Proceeding of the 16th International Chironomid Symposium. 13:101-108

Herb, W.R., B. Janke, O. Mohseni, and H.G. Stefan. 2008. Thermal pollution of streams by runoff from paved surfaces. Hydrological Processes 22: 987-999.

Hilsenhoff, W.L. 1977. Use of arthropods to evaluate water quality of streams. Technical bulletin. (Wisconsin Dept. of Natural Resources), No. 100 Wisconsin Department of Natural Resources.

Iwata, T., S. Nakano, and M. Murakami. 2003. Stream meanders increase insectivorous bird abundance in riparian deciduous forests. Ecography 26: 325-337.

Kondolf, G.M. 1997. Application of the pebble count: notes on purpose, method and variants. Journal of the American Water Resources Association. 33:79-87.

LeBlanc, R.T., R.D. Brown, and J.E. FitzGibbon. 1997. Modeling the effects of land use change on the water temperature in unregulated urban streams. Journal of Environmental Management. 49:445-469.

McKinney, R.L. 2006. Urbanization as a major cause of biotic homogenization. Biological Conservation. 127: 247-260.

McKinney, R. L. & J.L. Lockwood. 1999. Biotic homogenization: a few winners replacing many losers in the next mass extinction. Trends in Ecology & Evolution 14:450-453.

Meyer, J.L., M.J.Paul, and W.K.Taulbee. 2005. Stream ecosystem function in urbanizing landscapes. Journal of the North American Benthological Society. 24:602-612.

Minnehaha Creek Watershed District (MCWD). http://minnehahacreek.org/.

Milošević, D.,M.Stojković, D. Čerba, A. Petrović, M. Paunović&V.Simić. 2014. Different aggregation approaches in the chironomid community and the threshold of acceptable information loss. Hydrobiologia. 724 (in press)

Nakano, L. and M. Murakami. 2001. Reciprocal subsidies: dynamic interdependence between terrestrial and aquatic food webs. Proceedings of the National Academy of Sciences, USA. 98:166-170.

Olden J. D., and N.L. Poff. 2004. Clarifying biotic homogenization. Trends in Ecology and Evolution. 19: 283-284.

Purcell, A.H., D.W. Bressler, M.J. Paul, M.T. Barbour, E.T. Rankin, J.L. Carter, and V.H. Resh. 2009. Assessment tools for urban catchments: Developing biological indicators based on benthic macroinvertebrates. Journal of the American Water Resources Association. 45:306-319

Rooney, T.P., J.D. Olden, M.K. Leach, and D.A. Rogers.2007. Biotic homogenization and conservation prioritization. BiologicalConservation 134:447-450.

Schiff, R., & G. Benoit. 2007. Effects of impervious cover at multiple spatial scales on coastal watershed streams. Journal of the American Water Resources Association. 43(3):712-730

Stanfield, L.W., & B.W. Kilgour. 2006. Effects of percent impervious cover on fish and benthos assemblages and instream habitats in Lake Ontario tributaries. American Fisheries Society Symposium. 48:577-599.

Stranko, S.A., S.E.Gresens, R.J. Klauda,J.V.Kilian, P.J. Ciccotto, M.J. Ashton, and A.J. Becker. 2010. Differential effects of urbanization and non-natives on imperiled stream species. Northeastern Naturalist. 17:593-614.

Violin, C.R., R. Cada, E.B. Sudduth, B.A. Hassett, D.L. Penrose, and E.S. Bernhardt. 2011. Effects of urbanization and urban stream restoration on the physical and biological structure of stream ecosystems. Ecological Applications. 21: 1932-1949.

Walsh, J., A.H. Roy, J.W. Feminella, P.D. Cottinghom, P.M. Groffman, and R.P. Morgan. 2005. The urban stream syndrome: current knowledge and the search for a cure. Journal of the North American Benthological Society. 24:706-723.

Wiederholm, T. 1989. Chironomidae of the Holarctic Region: Keys and diagnoses. Part 2. Pupae. EntomologicaScandanavica Supplement. 28:1-482.

Wright, C. A., L.C. Ferrington Jr, and N.H. Crisp.1996. Analysis of chlordane-impacted streams using chironomid pupal exuviae (Diptera: Chironomidae). Hydrobiologia 318:69-77.

Yoder, C. O., R.J. Miltner, and D. White. 1999. Assessing the status of aquatic life designated uses in urban and suburban watersheds. National Conference of Retrofit Opportunities for Water Resource Protection in Urban Environments. EPA Chicago, IL.

APPENDIX

Figure A. Substrate measurements showing percentage in each size class.

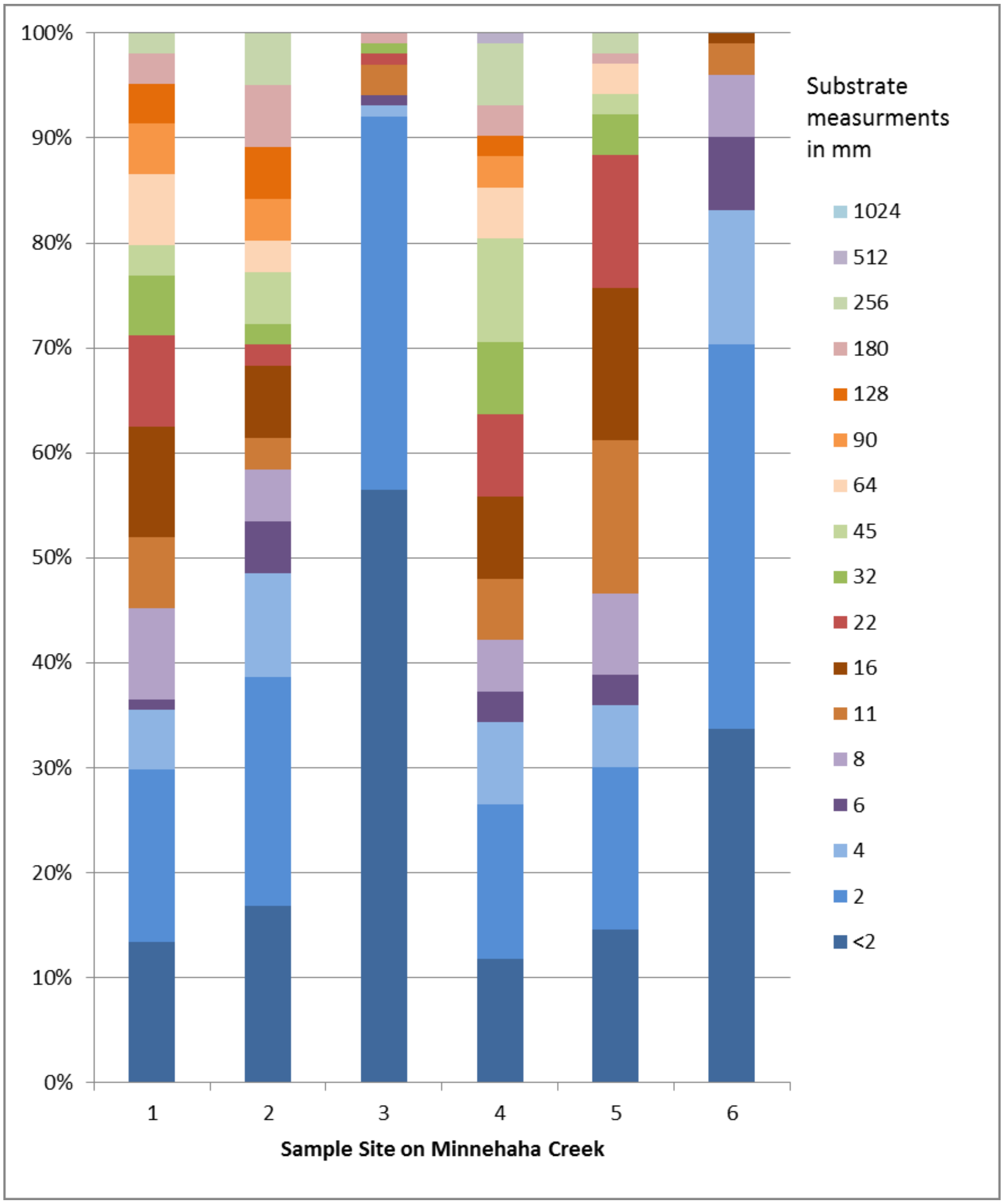


Table A. GPS coordinates and elevation at the six sample sites.

Site #	Site name	Decimal Latitude	Degres Longitude	Elevation at Site (Meters)
1	Bridge street	44.94178	-93.44502	279
2	W 34th St	44.94202	-93.39258	277
3	Excelsior	44.92719	-93.36239	271
4	Near Pratt Ave	44.90596	-93.27945	255
5	Chicago Ave	44.91112	-93.26290	252
6	Upstream L Nakomis	44.91542	-93.24487	250

Table B. Sites with instream substrate composition by particle size.

Sites	1	2	3	4	5	6
Size Class						
<2	13.46	16.83	56.44	11.76	14.56	33.66
2	29.81	38.61	92.08	26.47	30.10	70.30
4	35.58	48.51	93.07	34.31	35.92	83.17
6	36.54	53.47	94.06	37.25	38.83	90.10
8	45.19	58.42	94.06	42.16	46.60	96.04
11	51.92	61.39	97.03	48.04	61.17	99.01
16	62.50	68.32	97.03	55.88	75.73	100.00
22	71.15	70.30	98.02	63.73	88.35	100.00
32	76.92	72.28	99.01	70.59	92.23	100.00
45	79.81	77.23	99.01	80.39	94.17	100.00
64	86.54	80.20	99.01	85.29	97.09	100.00
90	91.35	84.16	99.01	88.24	97.09	100.00
128	95.19	89.11	99.01	90.20	97.09	100.00
180	98.08	95.05	100.00	93.14	98.06	100.00
256	100.00	100.00	100.00	99.02	100.00	100.00
512	100.00	100.00	100.00	100.00	100.00	100.00
1024	100.00	100	100	100	100	100

Figure B. Sample site 1 aerial view from Google earth.

Figure C. Sample site 2 aerial view from Google earth

Figure D. Sample site 3 aerial view from Google earth

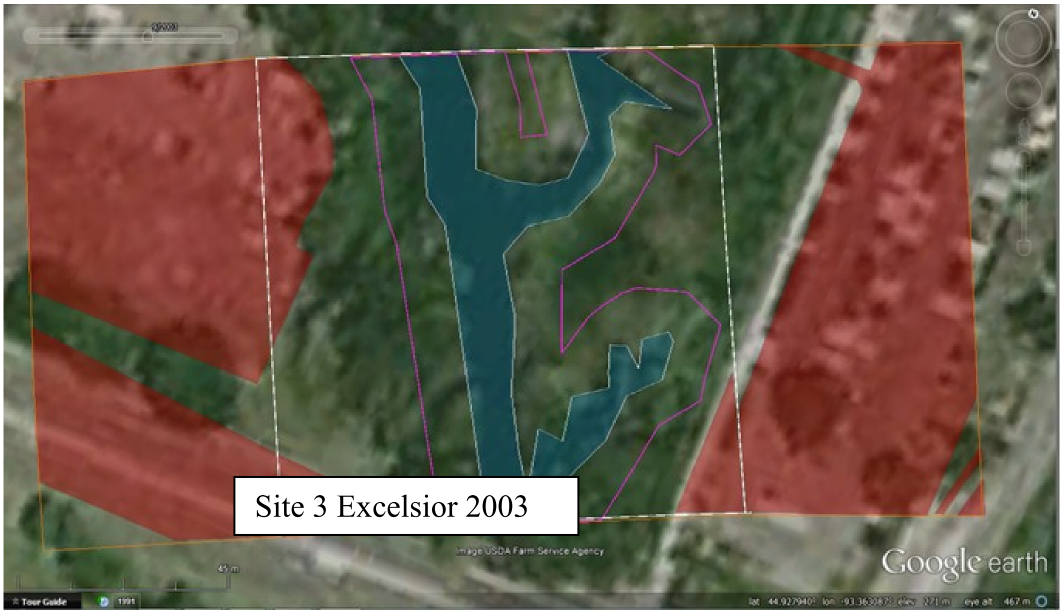


Figure E. Sample site 4 aerial view from Google earth

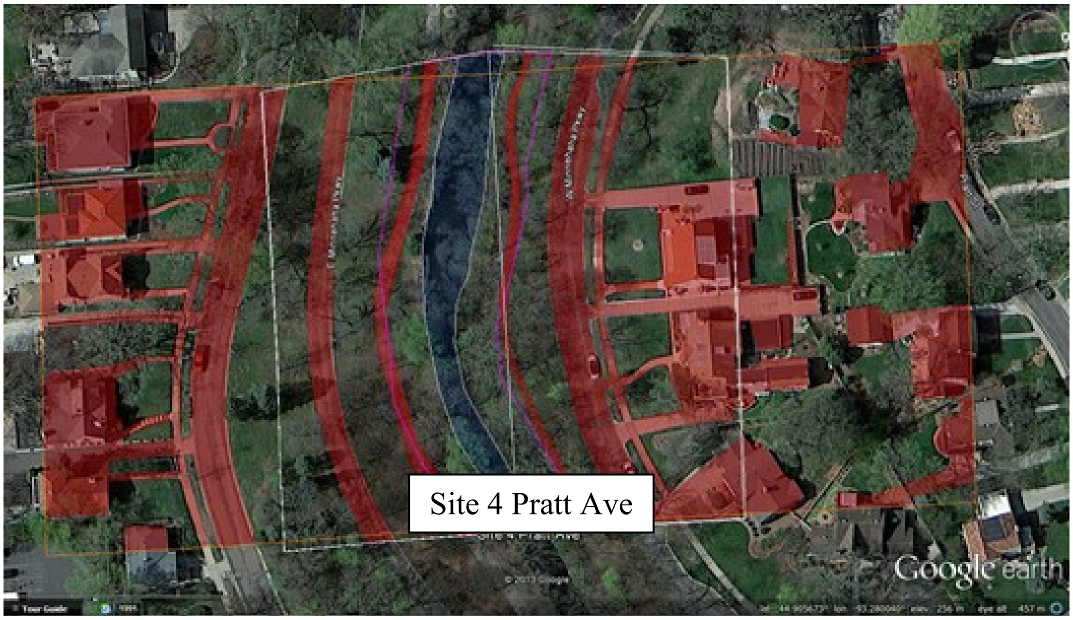


Figure F. Sample site 5 aerial view from Google earth

Figure G. Sample site 6 aerial view from Google earth

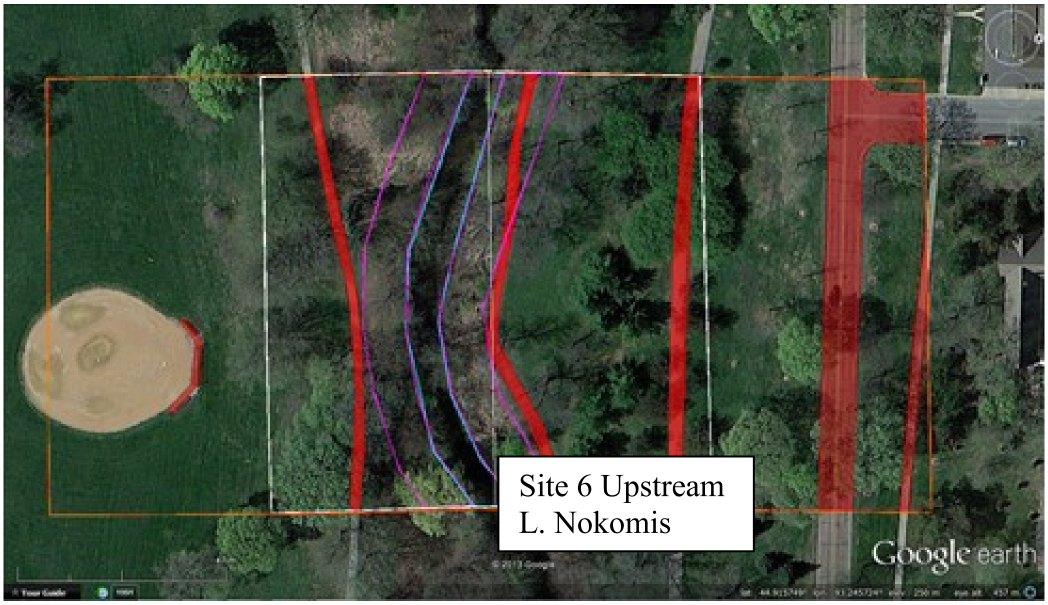


Table C. List of genera and Tolerance values.

Totals by Sample Site		Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Total
Summed at Genus Level	Tolerance	Bridge	34th	Excelsior	Near Pratt	Chicago	Lake	
TAXON	Value	Street	Street	Blvd	Avenue	Avenue	Nokomis	collected
Ablabesmyia sp.	8	13	1	22	8	2	1	47
Clinotanypus	5	3	0	0	0	0	0	3
Conchapelopia spp.	6	81	5	9	17	5	10	127
Guttipelopia	5	11	0	0	0	0	0	11
Hayesomyia senata	6	0	0	0	1	0	1	2
Helopelopia sp.	3	0	0	0	0	1	1	2
Labrundinia sp.	7	5	1	3	5	6	2	22
Larsia sp.	6	0	0	0	4	1	3	8
Meropelopia sp.	5	0	0	0	2	1	0	3
Nilotanypus sp.	6	3	0	3	5	6	3	20
Pentaneura sp.	6	2	2	5	1	1	4	15
Procladius spp.	9	29	5	10	9	7	6	66
Acricotopus sp.	4	9	4	0	0	0	0	13
Brillia sp.	5	0	0	0	0	1	4	5
Cardiocladius sp.	5	22	7	0	3	4	0	36
Corynoneura spp.	7	86	1628	1430	777	429	223	4573
Cricotopus spp.	7	516	237	122	116	130	104	1225
Eukiefferiella spp.	8	260	5	0	8	1	4	278
Hydrobaenus spp.	8	55	130	341	218	199	176	1119
Limnophyes sp.	5	0	1	2	1	2	3	9
Lopescladius sp.	4	1	0	10	9	2	4	26
Nanocladius spp.	3	619	1797	107	188	123	192	3026
Orthocladius (O.)	6	54	100	807	385	130	104	1580
Parakiefferiella spp.	2	39	25	196	26	116	165	567
Parametriocnemus spp.	5	7	58	3	18	13	23	122
Paraphaenocladius sp.	3	0	1	0	1	0	0	2
Psectrocladius spp.	8	24	13	2	2	1	4	46
Pseudosmittia	2	0	2	0	0	0	0	2
Rheocricotopus sp.	6	3	12	35	49	44	51	194
Thienemanniella spp.	6	573	13466	1227	283	507	431	16487
Tvetenia sp.	5	77	35	70	118	56	71	427
Gymnometriocnemus sp.	3	2	0	1	0	0	0	3
Chironomus spp.	10	2	6	126	7	17	88	246
Cladopelma sp.	9	0	0	1	0	0	0	1
Cryptochironomus spp.	8	36	3	60	17	4	24	144
Cryptotendipes sp.	6	0	0	7	0	0	0	7
Dicrotendipes spp.	5	21	7	63	19	9	11	130
Einfeldia sp.	7	290	6	27	0	0	0	323
Endochironomus spp.	8	78	11	3	0	3	8	103

Table C. List of genera and Tolerance values. (continued)

Glyptotendipes spp.	10	2	0	0	2	0	1	5
Harnischia sp.	8	0	0	5	0	1	4	10
Lauterborniella sp.	6	1	0	0	0	0	1	2
Microtendipes sp.	7	40	0	1	10	2	13	66
Parachironomus spp.	10	133	33	109	9	7	5	296
Paracladopelma sp.	7	1	0	4	20	13	31	69
Paralauterborniella sp.	4	0	5	4	2	1	1	13
Paratendipes sp.	8	2	63	2	5	3	18	93
Phaenopsectra	7	4	4	18	3	6	16	51
Polypedilum spp.	7	294	120	688	463	210	474	2249
Pseudochironomus sp.	5	1	0	0	3	0	0	4
Saetheria sp.	4	9	0	172	2	1	4	188
Stenochironomus sp.	5	2	1	9	8	3	8	31
Stictochironomus sp.	9	0	0	0	15	9	9	33
Xenochironomus xenolabius	1	4	0	0	1	0	0	5
Zavreliella	5	0	1	0	0	0	0	1
Cladotanytarsus spp.	7	12	7	21	13	6	12	71
Micropsectra spp.	7	153	271	200	25	25	50	724
Paratanytarsus spp.	6	263	446	869	51	33	114	1776
Rheotanytarsus spp.	6	124	346	106	69	58	118	821
Stempellinella sp	4	0	0	2	1	0	0	3
Tanytarsus spp.	6	77	182	272	108	63	125	827
Total Genera		46	39	43	47	45	46	61
Total Specimens		4043	19047	7174	3107	2262	2725	38358

Table D. Collect site information: GPS coordinates and elevation.

Orig site #	Site #	Site name	Decimal Latitude	Degres Longitude	Elevation at Site (Meters)
14	1	Bridge street	44.94178	-93.44502	279
13	2	W 34th St	44.94202	-93.39258	277
12	3	Excelsior	44.92719	-93.36239	271
7	4	Near Pratt Ave	44.90596	-93.27945	255
6	5	Chicago Ave	44.91112	-93.26290	252
5	6	Upstream L Nakomis	44.91542	-93.24487	250

Table E. Raw data for IS of all sites at the 10m x 100m buffer area.

Site and area size	10x100m area in m^2	10x100m % of land
10x100m Site 1 area	2987.73	
10x100m Site 1 Impermeable	266.58	12%
10x100m Site 1 Water	790.87	
10x100m Site 2 area	2087.25	
10x100m Site 2 Impermeable	159.23	8%
10x100m Site 2 Water	1523.16	
10x100m Site 3 area	5428.53	
10x100m Site 3 Impermeable	0.00	0%
10x100m Site 3 Water	1946.00	
10x100m Site 4 area	2903.16	
10x100m Site 4 impermeable	374.88	20%
10x100m Site 4 Water	989.00	
10x100m Site 5 area	2810.00	
10x100m Site 5 Impermeable	410.52	21%
10x100m Site 5 Water	824.35	
10x100m Site 6 area	2162.10	
10x100m Site 6 Impermeable	74.10	3%
10x100m Site 6 Water	862.77	

Table F. Raw data for IS of all sites at the 100m x 100m area.

Site and area size	100x100m area in m^2	100x100m % of land
100x100m Site 1 area	10091.78	
100x100m Site 1 Impermeable	3348.96	36%
100x100m Site 1 Water	790.87	
100x100m Site 2 total	10010.63	
100x100m Site 2 Impermeable	1452.97	17%
100x100m Site 2 Water	1523.16	
100x100m Site 3 Total	9731.00	
100x100m Site 3 Impermeable	744.00	10%
100x100m Site 3 Water	1946.00	
100x100m Site 4 area	10147.00	
100x100m Site 4 impermeable	3328.00	36%
100x100m Site 4 Water	989.00	
100x100m Site 5 area	9857.99	
100x100m Site 5 Impermeable	3495.75	39%
100x100m Site 5 Water	824.35	
100x100m Site 6 area	9988.91	
100x100m Site 6 Impermeable	751.51	8%
100x100m Site 6 Water	862.77	

Table G. Raw data for IS of all sites at the 200m x 100m area.

Site and area size	200x100m area in m^2	200x100m % of land
200x100m Site 1 area	19968.19	
200x100m Site 1 Impermeable	8837.40	46%
200x100m Site 1 Water	790.87	
200x100m Site 2 total	19838.06	
200x100m Site 2 Impermeable	6556.70	36%
200x100m Site 2 Water	1523.16	
200x100m Site 3 Total	18624.99	
200x100m Site 3 Impermeable	8706.82	52%
200x100m Site 3 Water	1946.00	
200x100m Site 4 area	19641.65	
200x100m Site 4 impermeable	8241.51	44%
200x100m Site 4 Water	989.00	
200x100m Site 5 area	19387.46	
200x100m Site 5 Impermeable	9522.81	51%
200x100m Site 5 Water	824.35	
200x100m Site 6 area	19957.77	
200x100m Site 6 Impermeable	1814.44	10%
200x100m Site 6 Water	862.77	

Table H. Raw data for IS of all sites at the total drainage area.

Site and area size	Drainage area in km^2	Total drainage % of land	cumulative % total drainage
Total drainage Site 1	15.11	42.03%	42.03%
total draingae IS Site 1	6.35		
Total drainage Site 2	16.23	45.35%	43.75%
total draingae IS Site 2	7.36		
Total drainage Site 3	8.09	56.37%	46.34%
total draingae IS Site 3	4.56		
Total drainage Site 4	54.89	48.11%	47.37%
total draingae IS Site 4	26.41		
Total drainage Site 5	6.07	44.98%	47.23%
total draingae IS Site 5	2.73		
Total drainage Site 6	1.46	33.56%	47.03%
total draingae IS Site 6	0.49		

Figure H. Jaccard's coefficient of similarity between two sites plotted with absolute difference in % substrate <2mm between those sites.

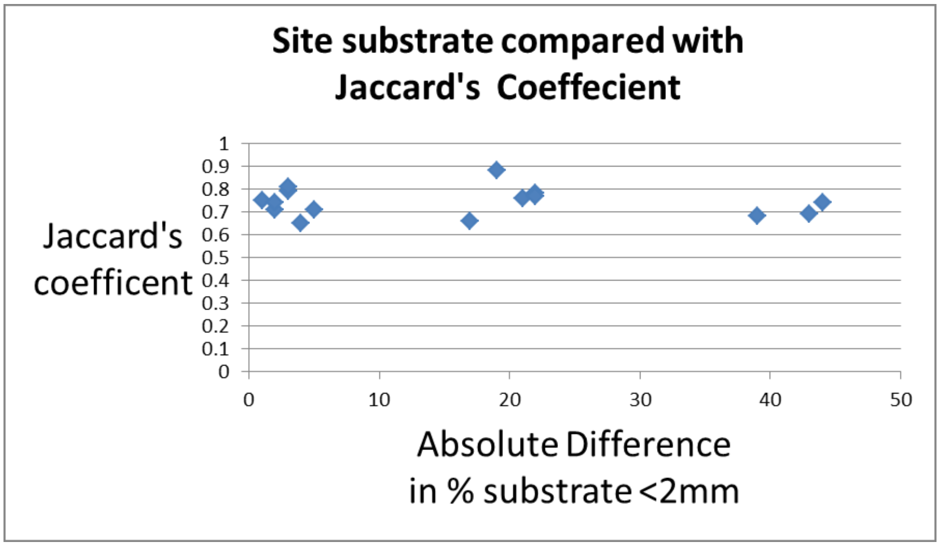


Figure I. Whittaker's Index of similarity between two sites plotted with absolute difference in % substrate <2mm between those sites.

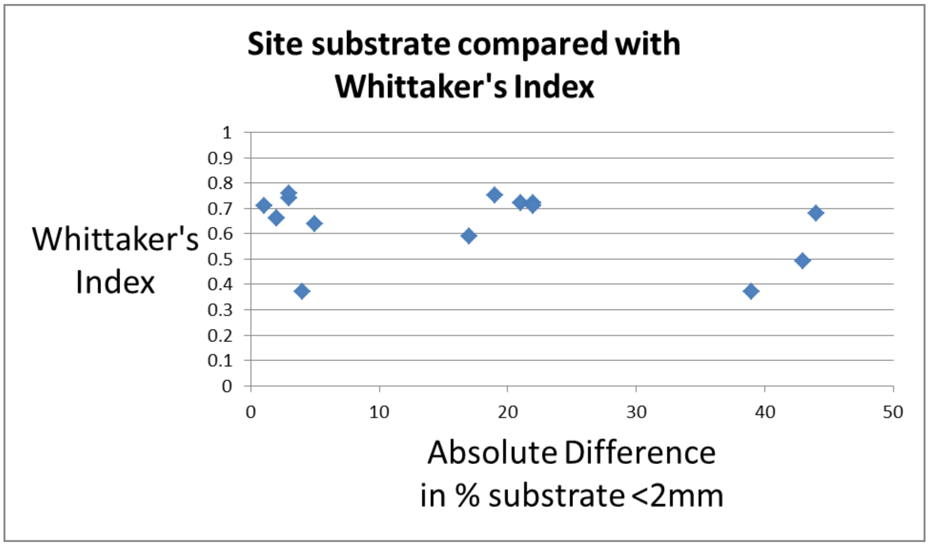


Figure J. Number of genera plotted with sinuosity.

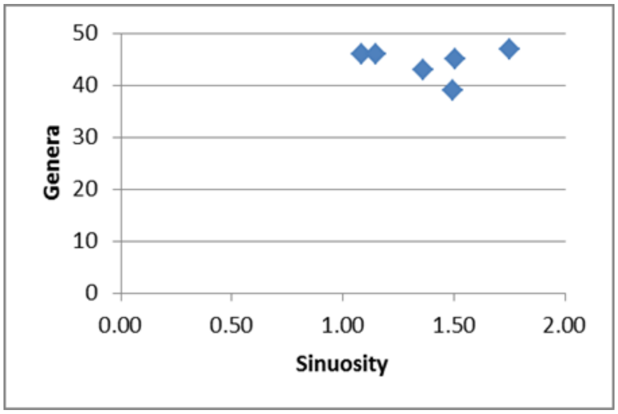


Figure K. Number of genera plotted with elevation.

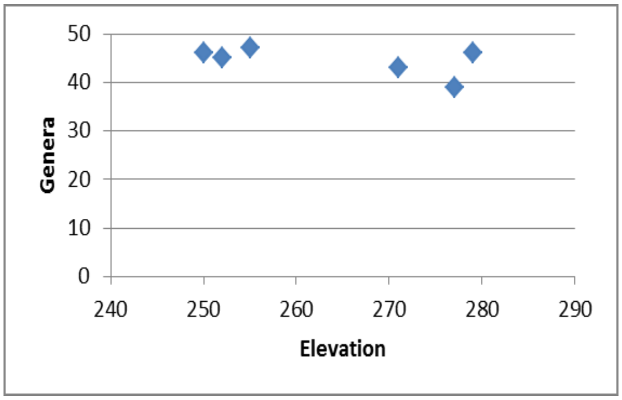


Figure L. Number of genera plotted with % <2mm pebbles

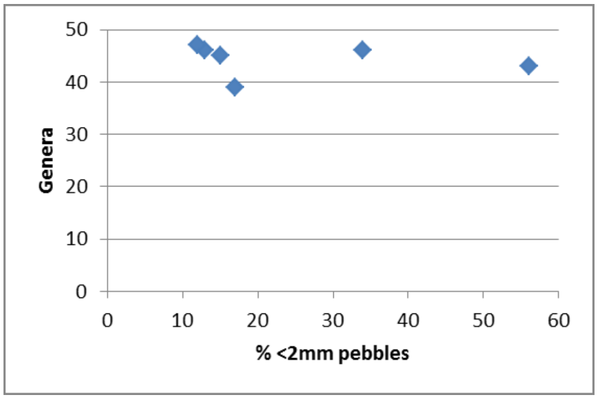


Figure M. Number of genera with increasing % IS at the watershed level.

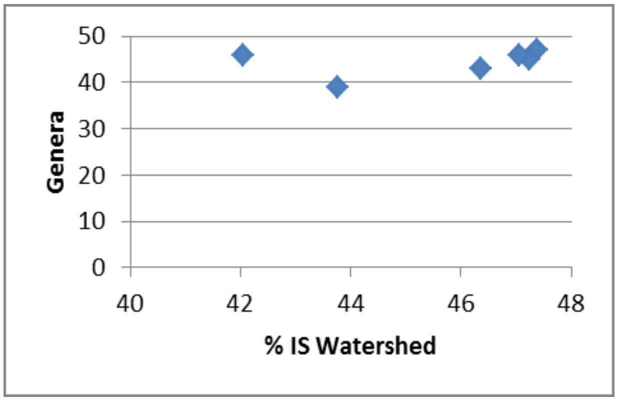


Figure N. Number of genera plotted with impervious surface area within the Minnehaha Creek watershed.

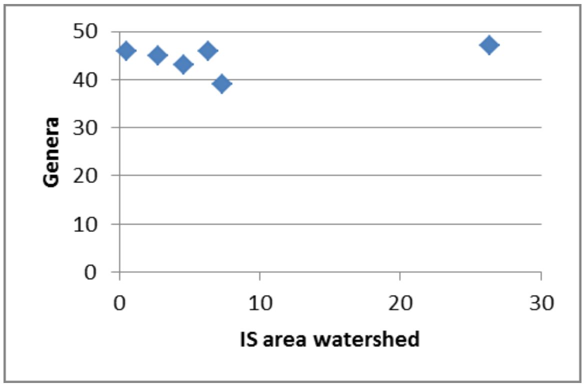


Figure O. Number of genera plotted with buffer area %IS.

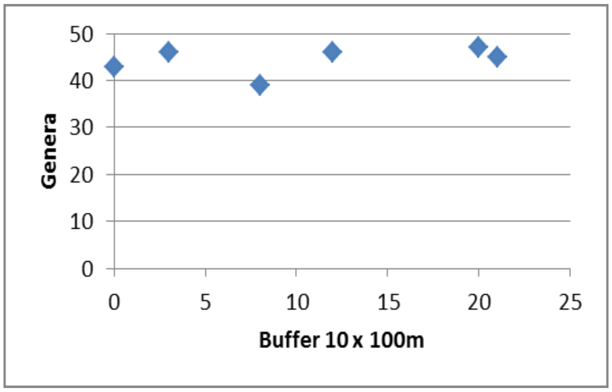


Figure P. Number of genera plotted with 100 x 100m area %IS.

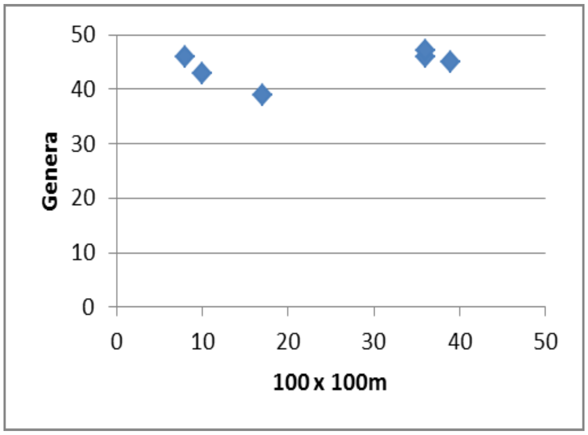


Figure Q. Number of genera plotted with 200 x 100m area %IS.