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# Aquatic Ecosystem Response to Storm Water Abatement Measures in the Ravines of the GVSU Allendale Campus: Establishment of Base-line Biological Condition

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**Abstract:**

The ravine tributary streams surrounding Grand Valley State Universities Allendale campus represent unique and understudied ecosystems, worthy of significant restoration efforts and of long-lasting protection. They are variously affected by storm water runoff, representing a spectrum from severely impacted to relatively pristine. Quantitative macroinvertebrate samples taken from six streams in late June 2007, indicated that insect diversity was positively correlated to ammonium (p=0.057), while total abundance was negatively correlated to phosphate and chlorophyll-*a* concentration (n.s.). In addition, phosphate, nitrate, sulfate and iron concentrations were elevated in streams that experience significant storm-water runoff and these streams also tended to have lower macroinvertebrate abundance, diversity and richness. These elevated nutrients, phosphorus in particular, were rapidly taken up by the benthic algae as evidenced by declining nutrients, and increased algal pigment and organic matter concentration from up to down-stream (n.s.). Biological uptake did not translate into increased macroinvertebrate abundance, likely because of the flashy discharge regime. Combination of non EPT (Ephemeroptera, Plecoptera, and Trichoptera) metrics indicated that the Shire and Junkyard ravines were in better condition than sites at Isengard and Fangorn—patterns which strongly suggest that extent of storm-water runoff has negatively impacted the macroinvertebrate communities. The fish community assessment indicated that blacknose dace (*Rhinichthys atratulus*), a species known to prefer cold, clean water, was most abundant in the Shire—the most pristine ravine stream sampled. Comparing length/weight data in the sampled streams to state standards indicated that these dace are not as fit as typically found in other water bodies whereas other taxa, namely the white sucker (*Catostomus commersonii*) and creek chub (*Somotillus atromaculatus*) are indistinguishable from state fitness standards. We were successful establishing biological base-line conditions prior to the initiation of a campus wide storm-water abatement program and can use these benchmarks to gage the long-term efficacy of restoration using physicochemical, population, community and ecosystem functional attributes measured in these unique ecosystems.

## Introduction:

Biological monitoring to establish the relative health or ecological integrity of aquatic ecosystems represents a cornerstone for management and restoration (Karr 1991, Bernhardt et al. 2005, Snyder et al. 2002, Snyder et al. 2007, Salas and Snyder *submitted*). The advantages of using living organisms, be they fish, insects, or algae, to assess ecosystem integrity include (i) the integration of chemical and physical conditions over the life-spans of the organisms studied (days to weeks for algae, weeks to months for insects, and months to years for fish); (ii) the ability to use indicator species (in all taxonomic groups) for both pollution tolerance and intolerance to characterize biological condition; and (iii) using basic community metrics such as diversity and richness to understand the relative uniqueness of any given system. The later has implications in unique aquatic ecosystems like the Allendale campus ravines streams because these types of systems are poorly understood and understudied.

Specifically, the ravine streams on the Allendale campus can be characterized as small, 1$^{st}$ order tributary systems. Historically they would likely have been intermittent, reaching low or no flow in the mid to late summer, similar to streams found in Austrialia (Boulton and Suter 1986, Boulton and Lake 1988, Boulton and Lake 1992). The actual historical extent to which these systems would experience low or no flow would have been determined by the relative contribution of ground water and surface water inflow.

A recent GVSU report documents the increase in both volume and intensity of discharge in these streams as the various watersheds were cleared, first for agriculture, and then for development of the GVSU Allendale campus and associated infrastructure including buildings, parking lots, roads, open grassy areas, etc (Womble and Wampler 2006). As a result of these land-use changes, the amount and intensity of storm water entering the ravine streams has increased dramatically leading to an increase in rates of erosion. As a result, Facilities Management at GVSU has embarked on an ambitious project to curtail the amount of storm water runoff entering the GVSU ravine ecosystems. This is important because the increase in volume and velocity of water as the Allendale campus has grown has steadily eroded these systems at an alarming rate, well beyond that which occurred historically (Womble and Wampler 2006). Geology Professor Peter Wampler and colleagues have undertaken a detailed monitoring and evaluation of the ravine ecosystems from a hydrology and geomorphology perspective. Our biological objectives meshed with the geomorphic analyses by (i) provide a detailed assessment of the biological conditions of the ravines, specifically in regards to the algal, macroinvertebrate, and fish communities; and (ii) establishing base-line conditions prior to infrastructure stormwater modification by facilities management. Our goal is to publish our results both internally and externally in order to facilitate better management of storm water on the Allendale campus.

## Methods:

In coordination with Dr. Wampler (Geology) and his students, we surveyed the biological community of four ravine streams and as well as a stream flowing through the Meadows golf course and Ottawa Creek. Specific sites corresponded to sites already established by Dr. Wampler that contain stage-discharge gages (Womble and Wampler 2006). Three of the ravines are considered degraded and experience significantly increased discharge and erosion. These ravines were contrasted to a single control ravine that has experience minimal alteration, with the exception of some agricultural activity and to the smaller Golf Course stream—a tributary of

Ottawa Creek, which was the final site (Figure 1). In this first year of study, our experimental design was simply to contrast the degraded sites with the control ravine stream as well as the more permanent Golf Course and Ottawa Creek sites to establish base-line biological conditions. In future years, we hope to establish a before-after, control-impacted (or BACI) experimental design that better allows us to quantify the spatial and temporal extent of restoration (Underwood 1994).

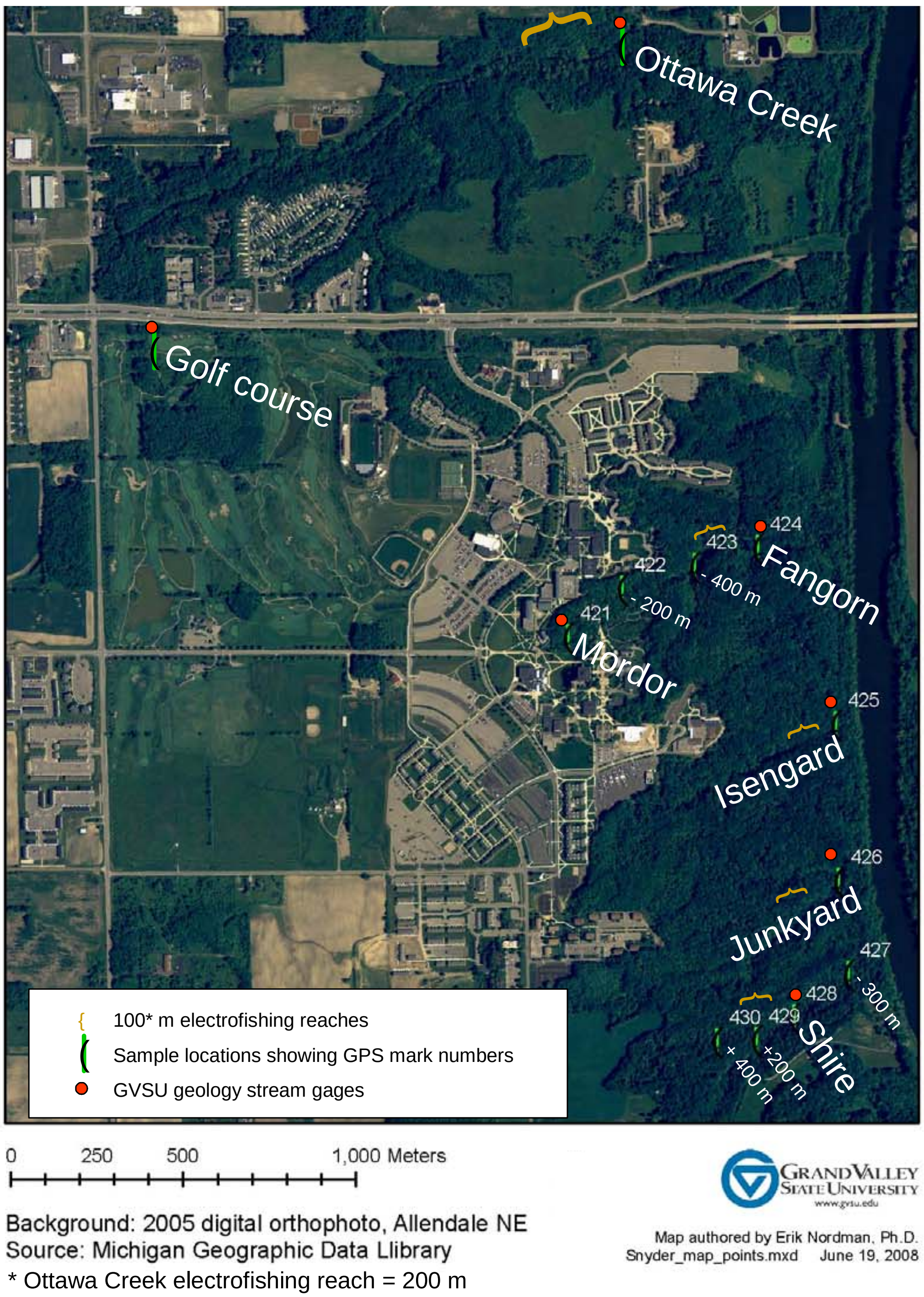



Figure 1. Base map showing sample points and electrofishing reaches, GVSU Allendale Campus, Michigan.

*Algae:*

The algal community was sampled quantitatively following standard methods (Barbor et al. 1999), using unglazed, 4x4 cm tiles, clamped in a 2x6 rectangular array and mounted on bricks. Velocity was measured at all tile locations. Three tiles were randomly removed weekly for 4 weeks after a 1 week starting incubation. One half of each tile was scraped and filtered (0.26 um pre-ashed GFF filter) for chlorophyll-*a* (ethanol extraction and measurement using spectrophotometry) (APHA 2005) and organic matter content (as ash-free dry mass or AFDM), while the other half was preserved in 30% formalin for diatom enumeration. The three diatom scrapes were each pooled, have been permanently mounted, and are in the process of being enumerated using available taxonomic keys (Patrick and Reimer 1966, 1975, Krammer and Lange-Bertalot 1986, 1988, 1991a, 1991b).

*Macroinvertebrates:*

An analysis of macroinvertebrates is important because they represent a fundamental link in the food web between the algae and detritus and fish. In addition, like the algae, macroinvertebrates provide an excellent indication of aquatic ecosystem health or integrity because they integrate ecological conditions over time (Hynes 1970, Allen 1995). As such, they provide potentially much more information on recent past habitat quality than, for example, synoptic samples of water chemistry alone. In addition, they are ubiquitous, exhibiting a wide variety of behavioral and life-history variations (Wiley and Kohler 1984) and specific indicator taxa can be found in systems that range from pristine to highly degraded. Pollution tolerance indices for these various taxa can be found in the rapid bioassessment protocols of the EPA (Barbour et al. 1999).

Quantitative macroinvertebrate samples were taken in triplicate with a Surber sampler (0.25 $m^2$, mesh size = 0.26 mm). In addition, a kick net was used to collect a single qualitative sample from a variety of habitat types (pools, overhanging banks, macrophyte beds, large woody debris, etc.). The samples were fixed in 95% ethanol and a total of 18 Surber samples and 6 kick samples were taken. Invertebrates were picked from samples, preserved in 95% ethanol, and later counted and sorted into taxonomic categories. Ephemeroptera, Plecoptera, and Trichoptera were keyed to genus using Merrit and Cummins (1996), Stewart and Stark (2002), and Wiggins (1996) respectively. The rest of the insects were keyed to family using Merrit and Cummins (1996) and Borror, Triplehorn, and Johnson (1989). The rest of the non-insects were keyed to either to class, order, or family.

*Fish:*

Backback electrofishing techniques were used following standard procedures as outlined in Reynolds (1983) and Nickum (1988). Using blocker nets and sampling 100 m reaches in each stream, three-pass depletion methods were performed at an approximate voltage of 250, duty cycle of 35%, and frequency of 90 Hz. All captured fish were measured (weight and length), identified and released to the appropriate stream reach.

Data collected was analyzed using both fish presence/absence and abundance. In addition, catch per unit effort (or CPUE) was quantified for each electrofishing reach. The Zippin (1958) method was used to conduct fish population estimates, although the entire fish community was combined for this analysis, thus estimates represent the entire fish community density per 100 m sample reach. Although a three-pass depletion method was employed, data were analyzed using only the first two passes following standard techniques described by Lockwood and Schneider (2000). Fitness was assessed using length/weight data (Appendix; Table 1) following standard methods and was compared to standards published for the State of Michigan (Schneider et al. 2000).

Additional data collected included basic chemical and physical properties of the reaches. Measurements of velocity, depth, pH, temperature, total dissolved solids, dissolved oxygen, turbidity, and underwater and surface light (photosynthetically active radiation or PAR) were collected as well as macronutrients (Table 1, Appendix; Tables 2 & 3).

Table 1. Characterization of GVSU Allendale study sites using average water quality and quantity measurements tabulated throughout the summer sampling period, 2007. See appendix (Tables 2 & 3) for dates and n-size samples. $NH_4$ = ammonium, $NO_3$ = nitrate, $NO_2$ = nitrite, $PO_4$ = phosphate, $SO_4$ = sulfate, TDS = total dissolved solids, D.O. = dissolved oxygen, % Sat. = percent saturation of D.O., CV=coefficient of variation, NTU = nephelometric turbidity units, Chl.*a* = chlorophyll *a*, AFDM = ash-free dry mass (organic matter content).

| | Concentration (mg/L) | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Site | $NH_4$ | $NO_3$ | $NO_2$ | $PO_4$ | SO4 | Fe | TDS | D.O. | % Sat | Specific Conductivity ($mS/cm^2$) | pH | Turbidity (NTU) | Discharge ($m^3/s$) | Discharge (CV) | Chl a ($ug/cm^2$) | n-size (chl) | AFDM ($mg/cm^2$) |
| Fangorn | 0.18 | 0.81 | 0.03 | 0.16 | 54.1 | 0.44 | 0.90 | 10.05 | 101.03 | 1.65 | 8.29 | 10.07 | 0.04 | 81.97 | 1.76 | 10 | 0.78 [a] |
| Isengard | 0.19 | 0.81 | 0.02 | 0.07 | 33.6 | 0.08 | 0.67 | 9.56 | 96.32 | 1.14 | 7.88 | 2.84 | 0.07 | 113.79 | 0.04 | 3 | 0.58 [b] |
| Junkyard | 0.43 | 0.43 | 0.03 | 0.06 | 42.0 | 0.10 | 0.44 | 9.50 | 97.63 | 0.66 | 8.03 | 31.90 | 0.02 | -- | 0.05 | 9 | 0.51 [c] |
| Shire | 0.13 | 0.28 | 0.02 | 0.06 | 17.0 | -- | 0.41 | 9.65 | 97.38 | 0.68 | 8.13 | 8.13 | 0.01 | 64.06 | 0.32 | 8 | 1.42 [d] |
| Golf Course | 0.76 | 0.53 | 0.03 | 0.14 | 39.7 | 0.06 | 0.72 | 8.62 | 91.96 | 1.10 | 7.95 | 16.66 | 0.75 | 136.38 | 0.66 | 4 | 0.81 [e] |
| Ottawa Creek | -- | 3.33 | -- | 0.17 | 74.0 | -- | 0.52 | 7.55 | 80.78 | 0.78 | 7.78 | -- | 3.96 | 55.72 | 0.16 | 3 | 0.78 [f] |

[a] Mean of 10 natural substrate samples; 4 from Mordor collected on 5/24, 6/4, 6/14 & 7/16, 4 from Mordor-200 (ditto), and 2 from Mordor-400 collected on 5/24 & 7/16.
[b] Mean of 3 natural substrate samples collected on 6/4, 6/14, & 7/16.
[c] Mean of 9 tile samples collected (3 each) on 6/4, 6/27, and 7/3.
[d] Mean of 8 natural substrate samples collected (4 each) at Shire+200 and Shire+400 on 5/24, 6/4, 6/12, & 7/16.
[e] Mean of 4 natural substrate samples collected on 5/24, 6/4, 6/12, & 7/17.
[f] Mean of 3 natural substrate samples collected on 5/24, 6/4 & 7/17).

## Results:

### *Macroinvertebrates and algae:*

A variety of metrics were calculated from quantitative macroinvertebrate samples (Table 2). Each metric was then ranked with 1 being the best and 6 the worst. The mean score for all 14 metrics ranked the golf course stream and Ottawa creek as the two best, respectively (Table 3). However, when the mayflies, stoneflies, and caddisflies (or EPT; Ephemeroptera, Plecoptera, and Trichoptera) were excluded from the analysis given the likelihood that the EPT were *never* very prevalent in the transient ravine streams, the sites showed a different pattern, with Modor and Isengard being the worst and Junkyard and Shire being the best (Table 3).

Table 2. Summary of mean macroinvertebrate metrics calculated from three synoptic Surber samples collected on May 30th, 2007. See text for details on the various metric calculations.

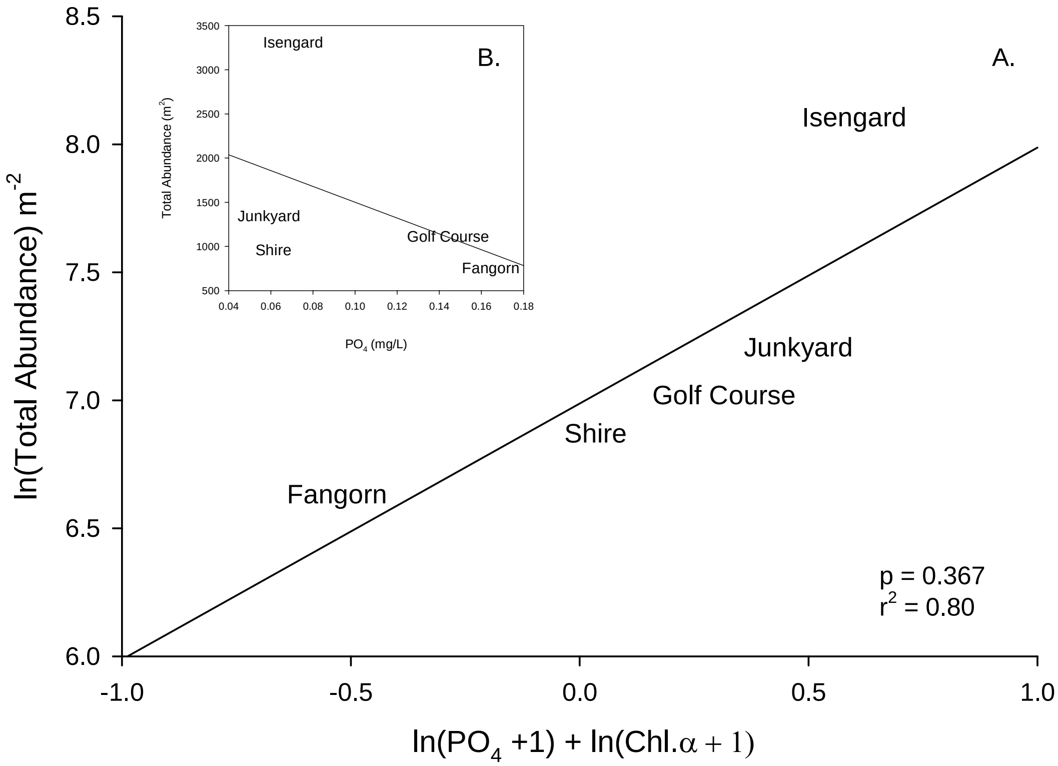
| Site | Richness | Shannon's Diversity | Simpson's Dominance | EPT Richness | Abundance ($m^2$) EPT | E | P | T | Chironomidae | Total Abund. | % Chironomidae | %EPT | Family Biotic Index |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Fangorn | 3 | 0.70 | 0.54 | 0.33 | 3.7 | 0.0 | 0.0 | 3.7 | 64.2 | 759 | 0.61 | 0.61 | 6.67 |
| Isengard | 6 | 0.97 | 0.54 | 2.00 | 118.5 | 103.7 | 3.7 | 11.1 | 74.2 | 3311 | 4.20 | 4.20 | 6.76 |
| Junkyard | 6 | 1.07 | 0.42 | 0.00 | 0.0 | 0.0 | 0.0 | 0.0 | 49.3 | 1348 | 0.00 | 0.00 | 6.59 |
| Shire | 3 | 0.82 | 0.52 | 0.00 | 0.0 | 0.0 | 0.0 | 0.0 | 38.4 | 963 | 0.00 | 0.00 | 6.50 |
| Golf Course | 6 | 1.22 | 0.36 | 1.33 | 51.9 | 7.4 | 0.0 | 44.4 | 50.3 | 1119 | 11.44 | 11.44 | 6.37 |
| Ottawa Creek | 5 | 0.79 | 0.61 | 1.33 | 133.3 | 66.7 | 0.0 | 66.7 | 66.2 | 9733 | 0.90 | 0.90 | 6.60 |

Table 3. Rank order of various macroinvertebrate metrics in the sampled streams. The colors of the ravine sample locations indicate impacted (red) and control or unimpacted (green). The color highlights for the metrics indicate rank order with green (1) being best vs. grey (6 and/or 5.5) being the worst. See the text for details on the calculation of the various metrics.

| Metrics | **Sample locations** **Mordor** | **Isengard** | **Junkyard** | **Shire** | **Golf Course** | **Ottawa Creek** |
|---|---|---|---|---|---|---|
| Abundance ($m^2$) | 6 | 2 | 3 | 5 | 4 | 1 |
| Diversity (H') | 6 | 5 | 2 | 4 | 1 | 3 |
| Richness | 6 | 1 | 4 | 5 | 3 | 2 |
| Dominance | 5 | 6 | 1 | 3 | 2 | 4 |
| %EPT | 5 | 2 | 5 | 5 | 1 | 3 |
| EPT Richness | 4 | 1 | 5.5 | 5.5 | 2.5 | 2.5 |
| EPT Abundance | 4 | 3 | 5.5 | 5.5 | 2 | 1 |
| E Abundance | 5 | 1 | 5 | 5 | 3 | 2 |
| P Abundance | 4.5 | 1 | 4.5 | 4.5 | 4.5 | 4.5 |
| T Abundance | 3 | 4 | 5.5 | 5.5 | 2 | 1 |
| %Chironomidae | 5 | 6 | 2 | 1 | 3 | 4 |
| Chironomidae Abundance | 2 | 5 | 4 | 1 | 3 | 6 |
| FBI | 4 | 5 | 3 | 1 | 2 | 6 |
| overall mean | 4.6 | 3.2 | 3.8 | 3.9 | 2.5 | 3.1 |
| mean without EPT metrics | 4.9 | 4.3 | 2.7 | 2.9 | 2.6 | 3.7 |

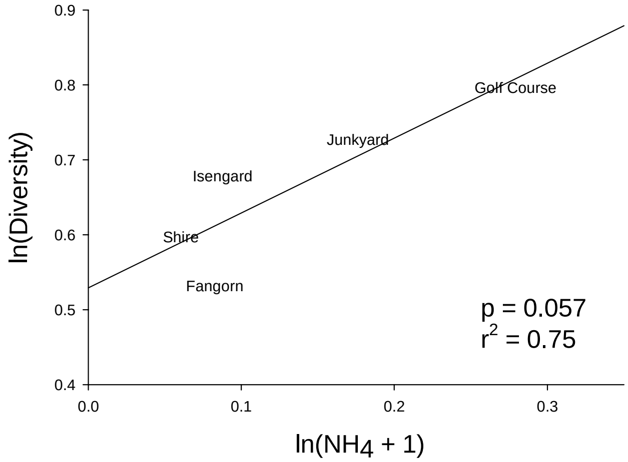
*Correlations (Multiple Linear Regression modeling):*

Ottawa Creek was excluded from MLR modeling given that it was a much larger stream system. Results indicated that total abundance in the remaining five sites was partially explained by a combination of phosphorus concentration and chlorophyll, although this relationship was not significant (Figure 2, Table 4). The trend suggests that as phosphorus increases, total abundance declines. Similar patterns were observed with chlorophyll *a* concentration. The difference in slopes in Figure A and B below is simply due to the data transformation and also the inclusion of both phosphorus and chlorophyll as the combined independent variable on the x-axis. Diversity was significantly positively correlated to ammonium concentrations, which were highest in the golf course and junk yard sites (Figure 3, Table 4).




$\ln(\text{total abund.}) = [9.915*\ln(PO_4 + 1) - 2.010*\ln(\text{Chl.a} + 1)] + 6.987$

Figure 2. Macroinvertebrate multiple linear regression model examining (A) the relationship between total abundance (transformed) and independent variables (phosphorus and chlorophyll, both transformed) and (B) the relationship between untransformed total abundance and phosphorus. Results presented in the embedded graph (B) show that as phosphorus increases, total abundance declines. Ln = natural log, $PO_4$ = phosphate phosphorus concentration (mg/L), Chl. a = chlorophyll concentration ($ug/cm^2$), $r^2$ = amount of variation in the dependent variable (abundance) explained by the suite of independent variables ($PO_4$ and Chl *a*), p = significance of the overall interaction.




ln(diversity) = [0.495*ln(NH4 + 1)] + 0.529

Figure 3. Macroinvertebrate multiple linear regression model examining the relationship between Shannon's diversity and the independent variable ammonium ($NH_4$, mg/L). $r^2$ = amount of variation in the dependent variable (diversity) explained by the ammonium concentration, p = significance of the overall interaction.

Table 4. Summary of step-wise multiple linear regression modeling. $NH_4$ = ammonium concentration (mg/L), Q = discharge ($m^3/s$), $NO_3$ = nitrate concentration (mg/L), Chl. *a* = chlorophyll concentration ($ug/cm^2$), and $PO_4$ = phosphate concentration (mg/L). S.E. = standard error, Sum Sq. = sum of squares, Mean Sq. = mean square, F = f statistic, p = probability, ln = natural log. The yellow box highlights the only statistically significant interaction.

| Dependent Variable | Independent Variable | df | r | $r^2$ | S.E. | Sum Sq. | Mean Sq. | F | p | regression equation |
|---|---|---|---|---|---|---|---|---|---|---|
| diversity | $NH_4$ | 4 | 0.866 | 0.751 | 0.06 | 0.044 | 0.033 | 9.038 | 0.057 | ln(**diversity**) = [0.495*ln(**$NH_4$** + 1)] + 0.529 |
| dominance | Q & $NO_3$ | 4 | 0.845 | 0.715 | 0.042 | 0.009 | 0.004 | 2.506 | 0.285 | ln(**dominance** + 1) = [0.122*ln(**$NO_3$** + 1) - 0.186*ln(**Q**)] + 0.361 |
| total abundance | $PO_4$ & Chl *a* | 4 | 0.795 | 0.633 | 0.484 | 0.808 | 0.404 | 1.723 | 0.367 | ln(**total abund.**) = [9.915*ln(**$PO_4$** + 1) - 2.010*ln(**Chl.*a*** + 1)] + 6.987 |
| total abundance | $PO_4$ | 4 | 0.511 | 0.262 | 0.561 | 1.277 | 0.334 | 1.063 | 0.378 | ln(**total abund.**) = [-6.371*ln(**$PO_4$** + 1)] + 7.768 |

The negative correlation between nitrate-nitrogen (ppm) and insect diversity was significantly different only between Mordor and the Golf Course stream (other pair-wise comparisons were not significant) (one-way post-hoc ANOVA). In other words, Mordor had high $NO_3$-N and low diversity relative to the Golf Course. The same pattern was found for insect diversity and sulfate concentrations. Three of the other streams (Junkyard, Isengard, and Shire) showed no significant differences. The negative correlation between iron concentrations and macroinvertebrate richness was significant with the Shire (non-impacted) and Mordor (impacted) sites paired against Isengard, Junkyard, and Golf Course. The former two sites had higher iron and lower richness vs. the latter three sites.

Higher discharge was positively correlated with total macroinvertebrate abundances and this relationship was significantly different between all 6 streams with Ottawa Creek being highest and Mordor being the lowest (one-way post-hoc ANOVA).

There were no significant differences in algal pigment concentration between sites, although through time there were significant increases (ANOVA, $p<0.05$) in chlorophyll-*a* at Fangorn, Isengard, Shire, and Shire -300, respectively, and in organic matter content (AFDM) at Isengard and Ottawa Creek, respectively (Appendix; Table 2). Longitudinal comparisons in chlorophyll pigment, organic matter content, and nutrient concentrations in the Little Mac and Shire ravines indicated that the former had much higher concentrations of both chlorophyll and nutrients. In addition, biological uptake of phosphorus was evident in this system. Similar patterns were *not* observed in the Shire (Figure 4). There was much less organic matter in Little Mac vs. the Shire, perhaps due to the flashy flow regime in the former system, driven by excessive storm-water runoff.

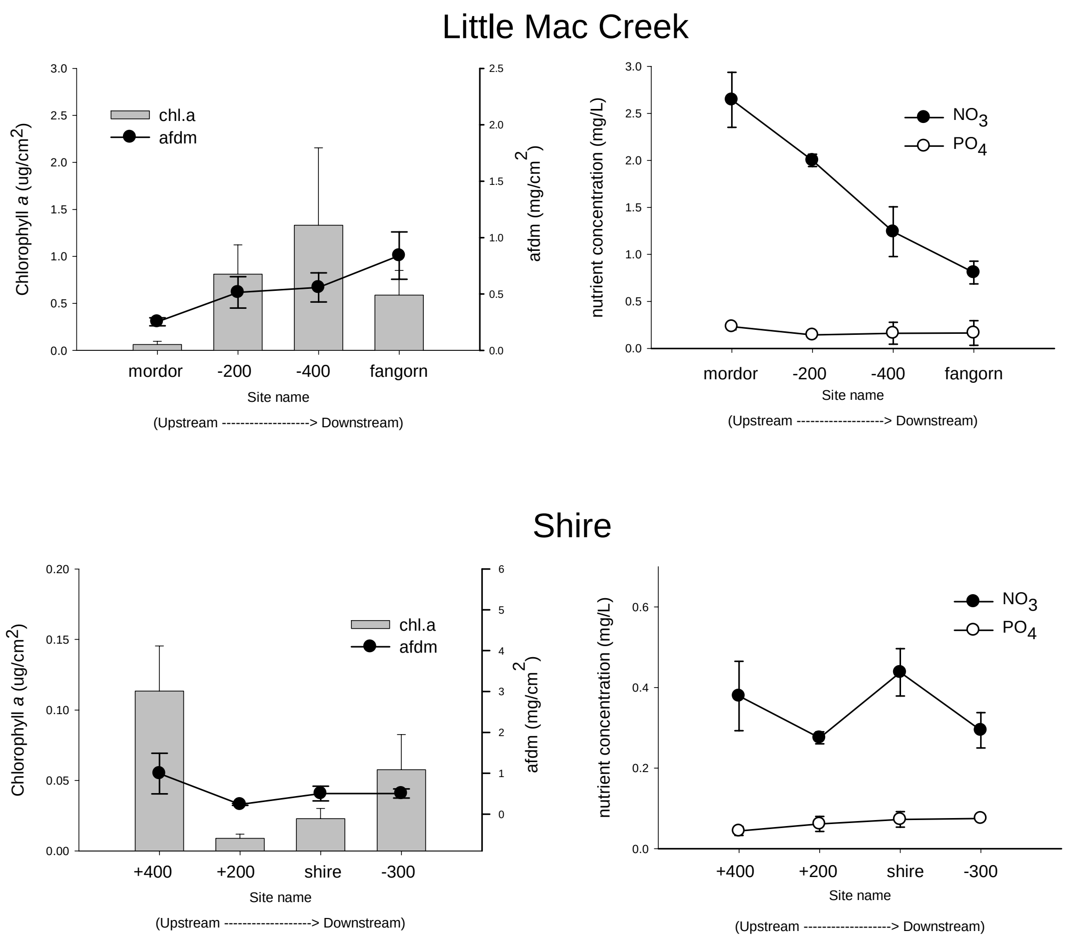



Figure 4. Longitudinal patterns (+/-1 S.E.) in chlorophyll-*a* concentration (ug/cm$^2$) and nitrate and phosphate concentrations (mg/L) from up to down-stream in the Little Mac and Shire ravines. Note that y-axes scales are different between the two ravine streams.

*Fish:*

Of the four streams sampled, Ottawa Creek had the highest fish species diversity (9), which is not surprising given its larger size. Of the four ravine streams, Fangorn was ranked first with 5 taxa, followed by Isengard (3), the Shire (1), while no fish were found in the Junkyard ravine stream (Tables 5 & 6). Again, we think stream size and permanence largely explains this pattern. Shannon's diversity index (H') combines equitability (or evenness) and taxa richness and the higher the value the better and more balanced the fish community. Of note was the exceptionally low diversity at the Fangorn site caused by the very high abundance of creek chub (Table 4). Population estimates per 100 m of each ravine stream (excluding Ottawa Creek) were 345, 62, and 11 individuals at the Fangorn, Shire, and Isengard sites, respectively. Within the three ravine streams containing fish, the community was composed of various combinations of creek chub, blacknose dace, central mud minnow, pumpkinseed and longnose dace (Table 6).

Table 5. The fish community size estimates were conducted using a two-pass depletion model (Zippin 1958, Lockwood and Schneider 2000). If p, the probability of capture falls below 0.20 then the community estimates are quite biased. If p is greater than 0.80 then the estimates are unbiased. Shannon's diversity index measures both community evenness and number of species. The higher the value, the more ecologically robust the system, in terms of biodiversity and resilience and resistence to disturbances, both anthropogenic and natural. The maximum H' is dependent on taxa richness. Shannon's equitability index ranges from 0 to 1, with higher values representing a more even community--e.g. one that is not dominated by one or two taxa. The fish communities were sampled between July 23rd and August 2nd, 2007.

| Community metrics | Ottawa Creek | Shire | Isengard | Fangorn | Junkyard |
|---|---|---|---|---|---|
| Species Richness | 9 | 1 | 3 | 5 | 0 |
| Shannon's Diversity (H') | 1.16 | -- | 0.60 | 0.19 | -- |
| maximum possible H' | 2.2 | -- | 1.10 | 1.61 | -- |
| Shannon's Equitability (EH) | 0.53 | -- | 0.55 | 0.17 | -- |
| | | | | | |
| total fish caught in first pass | 169 | 37 | 10 | 116 | -- |
| total fish caught in second pass | 99 | 15 | 1 | 77 | -- |
| total fish caught in third pass | 56 | 2 | -- | 32 | -- |
| | | | | | |
| p = probability of capture | 0.41 | 0.59 | 0.90 | 0.34 | -- |
| Variance of N | 3124.5 | 68.4 | 0.2 | 6655.7 | -- |
| Standard error of N | 55.9 | 8.3 | 0.4 | 81.6 | -- |
| Community size (N) per 100 m | 408 | 62 | 11 | 345 | -- |
| N low (approx. 95% CI) | 352 | 54 | 11 | 263 | -- |
| N high (approx. 95% CI) | 464 | 70 | 12 | 427 | -- |

Table 6. Comparison of fish population metrics in all six study streams on the Allendale, GVSU campus. CPUE = catch per minute effort. Data represent the total catch in a three-pass depletion sample using a backpack electrofishing unit. Reach length was 100 m.

| Site | Common Name<br>*Genera species* | Creek Chub<br>*Semotilus atromaculatus* | White Sucker<br>*Catostomus commersonii* | Blacknose Dace<br>*Rhinichthys atratulus* | Johnny Darter<br>*Ethostoma nigrum* | Blue Gill<br>*Lepomis macrochirus* | Mud Minnow<br>*Umbra limi* | Rainbow Darter<br>*Etheostoma caeruleum* | Brook Stickleback<br>*Culaea inconstans* | Goldfish<br>*Carassius auratus* | Pumkin-seed<br>*Lepomis gibbosus* | Longnose Dace<br>*Rhinichthys cataractae* | total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ottawa Creek | total catch | 203 | 54 | 47 | 12 | 5 | 2 | 2 | 1 | 1 | -- | -- | 327 |
| | CPUE (min) | 3.150 | 0.838 | 0.729 | 0.186 | 0.078 | 0.031 | 0.031 | 0.016 | 0.016 | -- | -- | 5.07 |
| | relative abundance | 0.621 | 0.165 | 0.144 | 0.037 | 0.015 | 0.006 | 0.006 | 0.003 | 0.003 | -- | -- | 1 |
| Shire | total catch | -- | -- | 54 | -- | -- | -- | -- | -- | -- | -- | -- | 54 |
| | CPUE (min) | -- | -- | 3.240 | -- | -- | -- | -- | -- | -- | -- | -- | 3.24 |
| | relative abundance | -- | -- | 1.000 | -- | -- | -- | -- | -- | -- | -- | -- | 1 |
| Junkyard | no fish | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Fangorn | total catch | 213 | -- | 8 | -- | -- | 1 | -- | -- | -- | 1 | 1 | 224 |
| | CPUE (min) | 6.594 | -- | 0.248 | -- | -- | 0.031 | -- | -- | -- | 0.031 | 0.031 | 6.93 |
| | relative abundance | 0.951 | -- | 0.036 | -- | -- | 0.004 | -- | -- | -- | 0.004 | 0.004 | 1 |
| Isengard | total catch | 9 | -- | 1 | -- | -- | 1 | -- | -- | -- | -- | -- | 11 |
| | CPUE (min) | 0.430 | -- | 0.048 | -- | -- | 0.048 | -- | -- | -- | -- | -- | 0.53 |
| | relative abundance | 0.818 | -- | 0.091 | -- | -- | 0.091 | -- | -- | -- | -- | -- | 1 |

The relationship between fish length and weight was examined using standard methods in which log base-10 weight (grams)—the dependent variable, is plotted against log base-10 length (mm)—the independent variable, to assess fish population fitness or health (Schneider et al. 2000). By comparing both the slope and location above or below the State of Michigan standards, we can assess whether the ravine populations are similar or different. Results indicated that in Ottawa Creek, white sucker and creek chub are indistinguishable from the state-wide standards, whereas the population of blacknose dace and johnny darter fall slightly below the state standards. Similarly, blacknose dace at the Shire and Fangorn sites also fall below state standards, versus Creek Chub which are indistinguishable from the State standard (Figure 5).

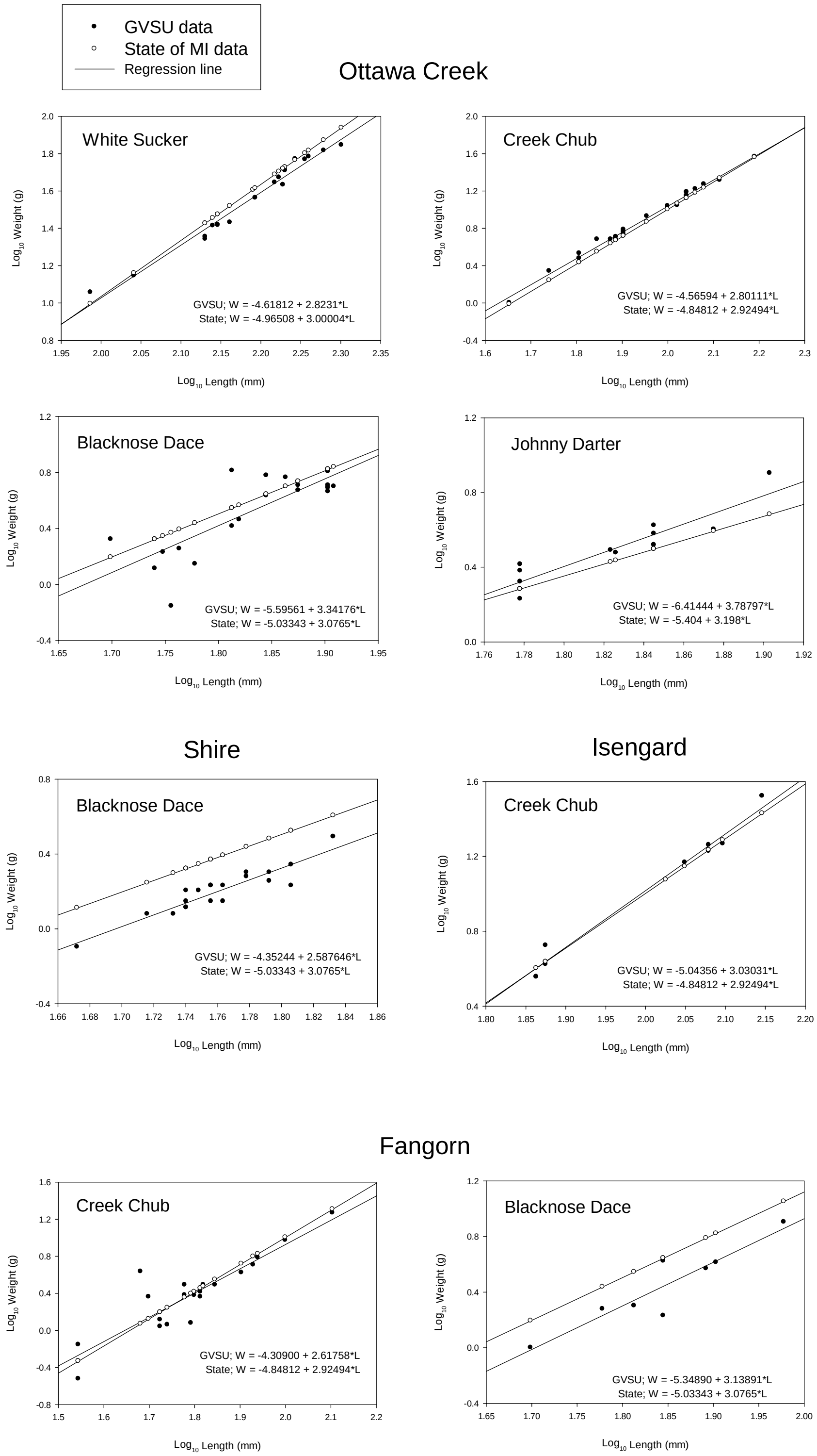



Figure 5. Comparison of length-weight data from the ravine streams and Ottawa Creek, GVSU Allendale campus, Michigan. State of Michigan standards are indicated by the open circles whereas ravine systems are

denoted with the closed circles. All length/weight data have log base-10 transformed.

## Discussion:

*Macroinvertebrates and longitudinal patterns in nutrients and algae:*

Across all streams with the exception of Ottawa Creek, we found that both phosphorus and chlorophyll were negatively correlated to total macroinvertebrate abundance, although this relationship was not statistically significant. That is, as concentrations of phosphorus and chlorophyll increased, the density or abundance of the insects declined. We theorize that the streams experiencing elevated P and chlorophyll levels were more impacted by storm water runoff and thus had elevated nutrient levels due mainly to fertilizer applications on the GVSU campus grounds. For example, there is evidence of this in the Little Mac ravine where longitudinal sampling indicated an interesting link between high phosphate concentrations and algal pigment concentrations. Stormwater runoff into the upstream end of this ravine likely contains elevated nutrients, including phosphorus, which then declines downstream even as chlorophyll-*a* and organic matter concentrations increase—a pattern indicative of nutrient uptake by the algae. We would have expected that the increase in algal pigment concentration and organic matter content would contribute to higher macroinvertebrate abundance—a pattern which was not observed, possibly due to the flashy discharge regime in the Little Mac system. Alternatively, because we sampled only one time, we may have missed the expected positive response in the insects to elevated nutrients. Additional monthly sampling could better elucidate this pattern.

Diversity is a measure of a biological community health. The higher the diversity, the healthier the community and the more able to withstand and recover from disturbance events—both natural and anthropogenic. When the largest site on Ottawa Creek was excluded from the analysis, we found that macroinvertebrate diversity was highest in the golf course and junkyard streams—an unexpected finding that we initially attributed to stream size and persistence of flow, especially in the golf course stream. However, statistical analyses in the form of a step-wise multiple linear regression indicated that ammonium concentration was the only variable significantly correlated to diversity in the five streams, vs. discharge. In other words, as ammonia concentrations increased, diversity also increased. Thus the golf course and junkyard sites had both highest diversity and highest ammonium concentration. Although the relationship between ammonium and diversity appears positive and linear, it is important to note that it is very possible to increase concentrations of the nutrient to the point of detriment to the community. For example, the State of Michigan sets ammonium water quality standards at 0.029 mg/L FCV and 0.160 mg/L FAV, respectively, for biological communities. The level above which long-term exposure is detrimental is called the final chronic value, or FCV, and the level above which exposure is imminently lethal is called the final acute value, or FAV (Michigan DEQ 2008). All the concentrations recorded in our study streams were *above* the FCV level and all but the Shire were above the FAV level (see Table 1 for ambient nutrient concentrations). However it is important to keep in mind the laboratory methodology used for these analyses—a HACH Smart 2 Colorimeter—does not have the resolution or sensitivity used by the Michigan DEQ methodology. Thus $NH_4$ concentrations are a concern, but additional samples and laboratory methods should be applied before final conclusions are drawn. We think the positive relationship between $NH_4$ concentration and diversity warrants further study.

Hydropyschidae and Baetidae species, members of Trichoptera and Ephemeroptera orders, respectively and thought to indicate good water quality, were found in both impacted and non-impacted sites, but were considerably less abundant in the sites influenced by storm-water runoff, similar to findings in the Provo River, Utah (Gray 2004). However, our streams were quite small and even fall into a grey area between intermittent and permanent. Thus the natural abundance of EPT taxa was likely never very high.

In summary, we found the following:

- Nitrate-nitrogen, sulfate and iron concentrations were elevated in streams that experience significant storm-water runoff.
- These streams also tended to have lower macroinvertebrate abundance, diversity and richness.
- Discharge was positively correlated to macroinvertebrate abundance, but was largely driven by the single large site on Ottawa Creek.
- Both phosphorus and chlorophyll were negatively correlated to total abundance in all streams excluding Ottawa Creek. This relationship was not statistically significant.
- Elevated phosphorus and subsequent downstream uptake by algae were evident in the Little Mac ravine, but not in the Shire. This did not translate into higher macroinvertebrate biomass, implicating some other variable, such as flashy discharge, as a limiting factor.
- Ammonium concentrations were positively correlated to insect diversity. We have no good explanation at this time and recommend further analysis.
- Combining all non-EPT community metrics indicated that the Shire and Junkyard ravines were in better condition than Isengard and Fangorn—patterns which strongly suggest that extent of storm-water runoff has negatively impacted the macroinvertebrate communities.

*Fish:*

The fish community was structured mainly by stream size with the most diverse and species rich assemblage occurring in Ottawa Creek. This is not a surprising finding and, as with the macroinvertebrates, we think this system represents a useful comparison to place the ravine streams in perspective. When examining just the ravine streams (sites at Shire, Isengard, Fangorn, and Junkyard) we found no fish in the Junkyard indicating that too little water is present in this system to maintain a fish community, at least during our sampling period. In the other three ravine systems, the site at Fangorn on Little Mac Creek was the lowest in diversity suggesting that the impact of storm water runoff has had a significant impact on the fish community in this system. However this is speculative given the lack of information on the fish community before the Allendale campus was present. Even so, we predict that diversity should improve as conditions in this highly disturbed stream improve.

Excluding the Ottawa Creek site leaves the Shire as the singular control for the fish community assessment. We only found blacknose dace in this system—thus community-level analysis indicates an extremely depauperate system. However, it is important to keep in mind the intermittent nature of these streams. Also, blacknose dace are considered to be indicators of good water quality preferring small, cool headwater streams and fast water

(Becker 1983) and their dominance and abundance in the Shire suggests that although discharge may be minimal, the quality of water is quite high. This is in direct contrast to the sites at Fangorn and Isengard where blacknose dace numbers were very low.

As restoration commences we predict that fish diversity at the Fangorn site on Little Mac Creek should improve as storm water abatement progresses. Also, we predict that presence of pollution intolerant taxa such as the blacknose dace should increase at the more disturbed sites of Fangorn (Little Mac Creek) and Isengard (behind the Calder art building).

Fish population fitness was assessed using length/weight data. We found that in all sites where present, blacknose dace were not as fit as the state standard. We infer this to mean that some necessary life-history requirements such food, habitat, density, predation pressure, disturbance regime, etc, are not being met. If we assume, as is likely, that excess storm-water runoff and the pollution associated with this runoff is linked to this limiting factor(s), then it follows that as restoration commences, the length/weight relationships in the dace populations should also improve. However, it is important to note that even in the Shire, the system least disturbed and considered to be a reference, the dace population was below the state standards. Thus it is also possible that the ravines, given their emphemeral flow regime, have never had robust dace populations. Measuring the dace populations through time as restoration commences should yield some insight.

*Conclusions:*

The problem of storm-water runoff in the ravines has likely shifted these systems from fairly stable to highly unstable, as evidenced by the significant erosion problems previously discussed and quantified elsewhere (Womble and Wampler 2006). In addition, we found that those systems receiving more storm-water had elevated nutrients—likely as a result of runoff from the GVSU grounds. Generally we found that the more disturbed the ravine systems had lower overall community health. From an ecological standpoint then, the interesting question becomes one of how the systems will respond to a reduction in storm-water runoff. To aid us, we can assemble a theoretical construct examining the relationship between stability, ecosystem health, and storm water runoff (Figure 6).

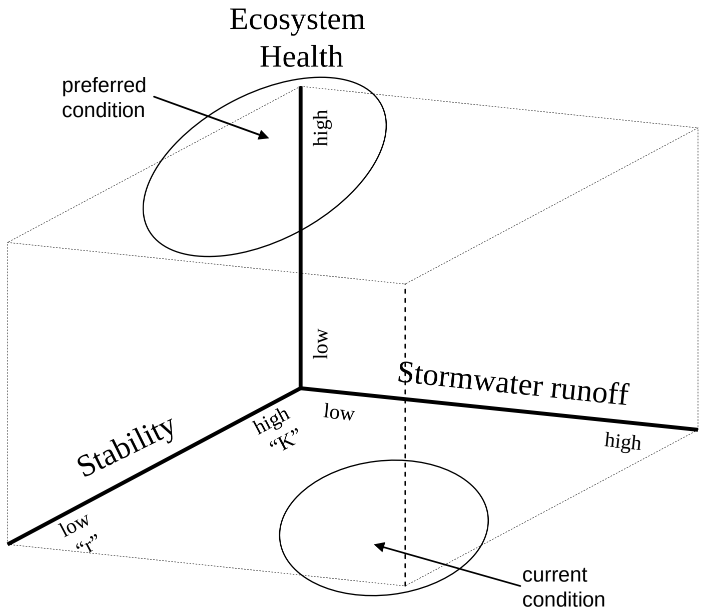



Figure 6. Theoretical model examining the relationships between stability, stormwater runoff, and ecosystem health. Health could include such metrics as community diversity, richness, and abundance, as well as functional metrics such as nutrient spiraling, decomposition, primary & secondary productivity, etc. The circles represent approximate current condition and preferred future condition.

It is important to note that stream ecosystems have long been envisioned as existing along a disturbance continuum and that different processes are likely to operate along this continuum with respect to the variables that influence community structure and function. For example, in a disturbance driven system, we would expect organisms to be disturbance-adapted (sometimes called ‘r-strategists). Whereas in a stable system, we would expect community structure to be determined by biological interactions involving competition and predation—also called density dependent interactions and more typically characterized by long-lived organisms (sometimes called ‘K-strategists) (Resh et al. 1988, Lake 2000). If we assume that the ravine streams historically would have been intermittent, reaching low to no-flow in mid to late summer, then they would have represented a fairly disturbance-driven type of system with the disturbance being characterized as drought. Our results using the Shire as a control seem to support this premise. The Shire had low diversity and richness, although the taxa found there were indicative of generally good water quality. The point is that the ravine streams must be placed in the proper context—being originally areas of potential refuge from flooding in the Grand River, but being naturally disturbance-driven with respect to low flow and potential drying.

The trick to using a system like the Shire as a control is understanding the interaction between percent paved and covered surfaces vs. irrigation. The driver of *historical* base-flow patterns would have been determined by ground water inflow into the receiving ravine streams—rates determined by groundwater infiltration and subsequent shallow aquifer recharge. In the past, the absence of paved surfaces would have resulted in higher groundwater recharge rates which would have declined through time as impervious surface area increased. For example, Womble and Wampler (2007) found a 189% increase in impervious surface area on the GVSU Allendale campus from 1973 to 2004. Complicating matter is the extensive amount of irrigation likely used during the agricultural era and currently being used on the GVSU campus, which would do the opposite and increase infiltration. Thus estimating historic inflow into the ravines becomes very problematic.

The current restoration plan to redirect storm water away from the ravines into a constructed wetland behind Laker Village Apartments should increase infiltration into the shallow aquifer system and largely solve the problem of peak discharge events. The remaining riddle of how much ground water historically sustained the ravine streams relative to present conditions that include GVSU irrigation practices can only be guessed. However, we believe that the Shire likely represents a reasonable template. This stream experiences no excess discharge from storm-water runoff and the uplands are farmed but are rarely irrigated (personal observation).

The results presented herein represent a pre-restoration data base from which future restoration efforts can be assessed from a biological standpoint. Storm-water abatement on the intermittent streams of the GVSU campus should have a long-term positive impact on the macroinvertebrate and fish assemblages, assuming there is adequate groundwater recharge and subsequent natural discharge into these streams. This should occur as the systems become more stable both in terms of flow regime and sediment transport and mass-wasting. The exact recovery trajectories of the individual streams depend on amount of storm-water reduction, natural aquifer recharge and inflow, irrigation recharge, and the amount of time required for the establishment of a new dynamic equilibrium with respect to sediment transport and discharge.

Potential future research directions:

- In a truly intermittent stream, we would hypothesize that the macroinvertebrate and fish community would be adapted to conditions that would dictate a life-history strategy that made use of intermittent resources. Insects would tend to have either (i) rapid emergence and subsequent oviposition prior to stream drying, or (ii) would exhibit resiliency in the face of stream drying, perhaps surviving through utilization of pools or use of the hyporheic zone as an area of refugia (Delucchi and Peckarsky 1986, Miller and Golladay 1996). Fish would either migrate to the Grand River to escape drying or, like the macroinvertebrate community, would make use of areas of refuge, such as pools.
- Migration or dispersal of fish and aquatic insects between streams and/or the main channel has not been measured. A genetic analysis would provide insight into the dispersal capabilities and also the degree of connectedness between different ravines and between the main channel and ravines. This could be important given the unique nature of these ecosystems.
- Use of the ravines by the fish and macroinvertebrate community could be examined through time and at different life-history stages. In other words, the ecological importance of systems may change seasonally.
- Taking an indicator population, for example the blacknose dace, and measuring their fitness, productivity, fecundity, etc, through time, would provide a quantifiable metric by which to assess the efficacy of the restoration effort.

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Appendix

Table 1. Lenth/weight relationships for fish. Contact Eric Snyder for electronic data base containing triple pass electrofishing data.

| SITE: Common Name | Length (mm) | Weight (g) | log10 length (mm) | log10 weight (g) | state data log10 weight (g) |
|---|---|---|---|---|---|
| **OTTAWA CREEK:** | | | | | |
| White Sucker | 135 | 22.6 | 2.13 | 1.35 | 1.43 |
| White Sucker | 170 | 51.6 | 2.23 | 1.71 | 1.73 |
| White Sucker | 180 | 58.7 | 2.26 | 1.77 | 1.80 |
| White Sucker | 140 | 26.2 | 2.15 | 1.42 | 1.47 |
| White Sucker | 110 | 14.0 | 2.04 | 1.15 | 1.16 |
| White Sucker | 97 | 11.4 | 1.99 | 1.06 | 1.00 |
| White Sucker | 140 | 26.1 | 2.15 | 1.42 | 1.47 |
| White Sucker | 155 | 40.3 | 2.19 | 1.61 | 1.61 |
| White Sucker | 165 | 44.1 | 2.22 | 1.64 | 1.69 |
| White Sucker | 170 | 51.2 | 2.23 | 1.71 | 1.73 |
| White Sucker | 200 | 70.0 | 2.30 | 1.85 | 1.94 |
| White Sucker | 182 | 60.7 | 2.26 | 1.78 | 1.82 |
| White Sucker | 145 | 27.0 | 2.16 | 1.43 | 1.52 |
| White Sucker | 175 | 59.0 | 2.24 | 1.77 | 1.76 |
| White Sucker | 190 | 65.5 | 2.28 | 1.82 | 1.87 |
| White Sucker | 138 | 25.9 | 2.14 | 1.41 | 1.45 |
| White Sucker | 169 | 42.9 | 2.23 | 1.63 | 1.72 |
| White Sucker | 167 | 47.0 | 2.22 | 1.67 | 1.70 |
| White Sucker | 135 | 22.0 | 2.13 | 1.34 | 1.43 |
| White Sucker | 156 | 36.5 | 2.19 | 1.56 | 1.61 |
| Creek Chub | 100 | 10.9 | 2.00 | 1.04 | 1.00 |
| Creek Chub | 90 | 8.5 | 1.95 | 0.93 | 0.87 |
| Creek Chub | 64 | 3.4 | 1.81 | 0.53 | 0.43 |
| Creek Chub | 110 | 15.4 | 2.04 | 1.19 | 1.12 |
| Creek Chub | 70 | 4.8 | 1.85 | 0.68 | 0.55 |
| Creek Chub | 45 | 1.0 | 1.65 | 0.00 | -0.01 |
| Creek Chub | 64 | 3.0 | 1.81 | 0.48 | 0.43 |
| Creek Chub | 55 | 2.2 | 1.74 | 0.34 | 0.24 |
| Creek Chub | 130 | 20.7 | 2.11 | 1.32 | 1.34 |
| Creek Chub | 75 | 4.8 | 1.88 | 0.68 | 0.64 |
| Creek Chub | 110 | 14.1 | 2.04 | 1.15 | 1.12 |
| Creek Chub | 80 | 5.5 | 1.90 | 0.74 | 0.72 |
| Creek Chub | 80 | 5.8 | 1.90 | 0.76 | 0.72 |
| Creek Chub | 155 | 36.8 | 2.19 | 1.57 | 1.56 |
| Creek Chub | 115 | 16.6 | 2.06 | 1.22 | 1.18 |
| Creek Chub | 120 | 18.7 | 2.08 | 1.27 | 1.23 |
| Creek Chub | 77 | 5.1 | 1.89 | 0.71 | 0.67 |
| Creek Chub | 80 | 6.1 | 1.90 | 0.79 | 0.72 |
| Creek Chub | 77 | 4.8 | 1.89 | 0.68 | 0.67 |
| Creek Chub | 105 | 11.1 | 2.02 | 1.05 | 1.06 |
| Blacknose Dace | 70 | 6.0 | 1.85 | 0.78 | 0.64 |
| Blacknose Dace | 73 | 5.8 | 1.86 | 0.76 | 0.70 |
| Blacknose Dace | 80 | 4.6 | 1.90 | 0.66 | 0.82 |
| Blacknose Dace | 80 | 6.4 | 1.90 | 0.81 | 0.82 |
| Blacknose Dace | 66 | 2.9 | 1.82 | 0.46 | 0.56 |
| Blacknose Dace | 58 | 1.8 | 1.76 | 0.26 | 0.39 |
| Blacknose Dace | 81 | 5.0 | 1.91 | 0.70 | 0.84 |
| Blacknose Dace | 70 | 4.3 | 1.85 | 0.63 | 0.64 |
| Blacknose Dace | 55 | 1.3 | 1.74 | 0.11 | 0.32 |
| Blacknose Dace | 50 | 2.1 | 1.70 | 0.32 | 0.19 |
| Blacknose Dace | 55 | 2.1 | 1.74 | 0.32 | 0.32 |
| Blacknose Dace | 65 | 6.5 | 1.81 | 0.81 | 0.54 |
| Blacknose Dace | 75 | 5.1 | 1.88 | 0.71 | 0.74 |
| Blacknose Dace | 56 | 1.7 | 1.75 | 0.23 | 0.34 |
| Blacknose Dace | 65 | 2.6 | 1.81 | 0.41 | 0.54 |
| Blacknose Dace | 60 | 1.4 | 1.78 | 0.15 | 0.44 |
| Blacknose Dace | 57 | 0.7 | 1.76 | -0.15 | 0.37 |
| Blacknose Dace | 80 | 4.9 | 1.90 | 0.69 | 0.82 |
| Blacknose Dace | 80 | 5.1 | 1.90 | 0.71 | 0.82 |
| Blacknose Dace | 75 | 4.7 | 1.88 | 0.67 | 0.74 |
| Johnny Darter | 70 | 3.3 | 1.85 | 0.52 | 0.50 |
| Johnny Darter | 70 | 3.8 | 1.85 | 0.58 | 0.50 |
| Johnny Darter | 60 | 2.4 | 1.78 | 0.38 | 0.28 |
| Johnny Darter | 60 | 2.6 | 1.78 | 0.41 | 0.28 |
| Johnny Darter | 67 | 3.1 | 1.82 | 0.49 | 0.43 |
| Johnny Darter | 60 | 2.1 | 1.78 | 0.32 | 0.28 |
| Johnny Darter | 70 | 4.2 | 1.85 | 0.62 | 0.50 |
| Johnny Darter | 70 | 3.3 | 1.85 | 0.52 | 0.50 |
| Johnny Darter | 80 | 8.0 | 1.90 | 0.90 | 0.68 |
| Johnny Darter | 60 | 1.7 | 1.78 | 0.23 | 0.28 |
| Johnny Darter | 67 | 3.0 | 1.83 | 0.48 | 0.44 |
| Johnny Darter | 75 | 4.0 | 1.88 | 0.60 | 0.59 |
| Blue Gill | 70 | 5.9 | | | |
| Blue Gill | 100 | 20.0 | | | |
| Blue Gill | 110 | 28.8 | | | |
| Blue Gill | 102 | 19.8 | | | |
| Blue Gill | 110 | 26.5 | | | |
| Brook Stickleback | 50 | 1.0 | | | |
| Goldfish | 142 | 54.2 | | | |
| Mud Minnow | 106 | 5.3 | | | |
| Mud Minnow | 78 | 6.1 | | | |
| Rainbow Darter | 60 | 1.9 | | | |

| SITE: Common Name | Length (mm) | Weight (g) | log10 length (mm) | log10 weight (g) | state data log10 weight (g) |
|---|---|---|---|---|---|
| **SHIRE:** | | | | | |
| Blacknose Dace | 64 | 1.7 | 1.81 | 0.23 | 0.52 |
| Blacknose Dace | 52 | 1.2 | 1.72 | 0.08 | 0.25 |
| Blacknose Dace | 58 | 1.4 | 1.76 | 0.15 | 0.39 |
| Blacknose Dace | 57 | 1.4 | 1.76 | 0.15 | 0.37 |
| Blacknose Dace | 55 | 1.3 | 1.74 | 0.11 | 0.32 |
| Blacknose Dace | 64 | 2.2 | 1.81 | 0.34 | 0.52 |
| Blacknose Dace | 68 | 3.1 | 1.83 | 0.49 | 0.60 |
| Blacknose Dace | 58 | 1.7 | 1.76 | 0.23 | 0.39 |
| Blacknose Dace | 54 | 1.2 | 1.73 | 0.08 | 0.30 |
| Blacknose Dace | 55 | 1.3 | 1.74 | 0.11 | 0.32 |
| Blacknose Dace | 62 | 1.8 | 1.79 | 0.26 | 0.48 |
| Blacknose Dace | 47 | 0.8 | 1.67 | -0.10 | 0.11 |
| Blacknose Dace | 60 | 1.9 | 1.78 | 0.28 | 0.44 |
| Blacknose Dace | 62 | 2.0 | 1.79 | 0.30 | 0.48 |
| Blacknose Dace | 55 | 1.6 | 1.74 | 0.20 | 0.32 |
| Blacknose Dace | 57 | 1.7 | 1.76 | 0.23 | 0.37 |
| Blacknose Dace | 56 | 1.6 | 1.75 | 0.20 | 0.34 |
| Blacknose Dace | 60 | 2.0 | 1.78 | 0.30 | 0.44 |
| Blacknose Dace | 57 | 1.7 | 1.76 | 0.23 | 0.37 |
| Blacknose Dace | 55 | 1.4 | 1.74 | 0.15 | 0.32 |
| Blacknose Dace | 25 | 0.2 | 1.40 | -0.70 | -0.73 |
| **ISENGARD:** | | | | | |
| Creek Chub | 73 | 3.6 | 1.86 | 0.56 | 0.60 |
| Creek Chub | 75 | 4.2 | 1.88 | 0.62 | 0.64 |
| Creek Chub | 106 | 11.9 | 2.03 | 1.08 | 1.08 |
| Creek Chub | 75 | 5.3 | 1.88 | 0.72 | 0.64 |
| Creek Chub | 120 | 16.9 | 2.08 | 1.23 | 1.23 |
| Creek Chub | 112 | 14.7 | 2.05 | 1.17 | 1.15 |
| Creek Chub | 120 | 18.2 | 2.08 | 1.26 | 1.23 |
| Creek Chub | 125 | 18.5 | 2.10 | 1.27 | 1.29 |
| Creek Chub | 140 | 33.3 | 2.15 | 1.52 | 1.43 |
| Mud Minnow | 63 | 2.7 | | | |
| Blacknose Dace | 70 | 3.3 | | | |
| **FANGORN:** | | | | | |
| Creek Chub | 63 | 2.4 | 1.80 | 0.38 | 0.41 |
| Creek Chub | 55 | 1.2 | 1.74 | 0.06 | 0.24 |
| Creek Chub | 65 | 2.6 | 1.81 | 0.41 | 0.45 |
| Creek Chub | 65 | 2.3 | 1.81 | 0.36 | 0.45 |
| Creek Chub | 80 | 4.2 | 1.90 | 0.62 | 0.72 |
| Creek Chub | 50 | 2.3 | 1.70 | 0.36 | 0.12 |
| Creek Chub | 127 | 18.5 | 2.10 | 1.27 | 1.31 |
| Creek Chub | 62 | 1.2 | 1.79 | 0.08 | 0.39 |
| Creek Chub | 70 | 3.1 | 1.85 | 0.49 | 0.55 |
| Creek Chub | 87 | 6.1 | 1.94 | 0.79 | 0.82 |
| Creek Chub | 35 | 0.7 | 1.54 | -0.15 | -0.33 |
| Creek Chub | 85 | 5.1 | 1.93 | 0.71 | 0.80 |
| Creek Chub | 53 | 1.3 | 1.72 | 0.11 | 0.20 |
| Creek Chub | 60 | 3.1 | 1.78 | 0.49 | 0.35 |
| Creek Chub | 60 | 2.4 | 1.78 | 0.38 | 0.35 |
| Creek Chub | 48 | 4.3 | 1.68 | 0.63 | 0.07 |
| Creek Chub | 66 | 3.1 | 1.82 | 0.49 | 0.47 |
| Creek Chub | 35 | 0.3 | 1.54 | -0.52 | -0.33 |
| Creek Chub | 100 | 9.4 | 2.00 | 0.97 | 1.00 |
| Creek Chub | 53 | 1.1 | 1.72 | 0.04 | 0.20 |
| Blacknose Dace | 70 | 1.7 | 1.85 | 0.23 | 0.64 |
| Blacknose Dace | 70 | 4.2 | 1.85 | 0.62 | 0.64 |
| Blacknose Dace | 78 | 3.7 | 1.89 | 0.57 | 0.79 |
| Blacknose Dace | 80 | 4.1 | 1.90 | 0.61 | 0.82 |
| Blacknose Dace | 95 | 8.0 | 1.98 | 0.90 | 1.05 |
| Blacknose Dace | 60 | 1.9 | 1.78 | 0.28 | 0.44 |
| Blacknose Dace | 50 | 1.0 | 1.70 | 0.00 | 0.19 |
| Blacknose Dace | 65 | 2.0 | 1.81 | 0.30 | 0.54 |
| Pumkinseed Sunfish | 70 | 5.6 | | | |
| Longnose Dace | 74 | 3.2 | | | |
| Longnose Dace | 70 | 2.8 | | | |
| Central Minnow | 68 | 3.4 | | | |

Table 2. Dates, concentrations, and locations of nutrient sampling conducted in areas overlapping with the biological survey conducted summer 2007. Nutrient analyses were generously conducted by the Geology Department, GVSU. Sample times ranged between 10:00 & 15:00.

| | | Concentration (mg/L) | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Date/time | Description | $NH_4$ | $NO_3$ | $NO_2$ | $PO_4$ | SO4 | Fe | Turbidity (NTU) |
| 5/2/07 | Mordor | -- | 1.48 | -- | 0.34 | 35.8 | 0.16 | -- |
| 5/14/07 | Mordor | -- | 3.00 | -- | 0.22 | 50.5 | -- | -- |
| 5/24/07 | Mordor | 0.19 | 2.94 | 0.03 | 0.25 | 70.3 | -- | -- |
| 7/1/07 | Mordor | 0.20 | 2.84 | 0.03 | 0.21 | 42.3 | 0.01 | 1.26 |
| 7/16/07 | Mordor | 0.12 | 2.97 | 0.03 | 0.14 | 29.5 | -- | 1.05 |
| 8/16/07 | Mordor | 0.24 | -- | -- | -- | -- | -- | -- |
| 5/14/07 | Mordor -200 | -- | 1.94 | -- | 0.15 | 38.0 | -- | -- |
| 7/16/07 | Mordor -200 | 0.24 | 2.07 | 0.02 | 0.13 | 27.0 | -- | 0.66 |
| 5/14/07 | Mordor -400 | -- | 0.98 | -- | 0.05 | 47.3 | -- | -- |
| 7/16/07 | Mordor -400 | 0.11 | 1.51 | 0.01 | 0.28 | 25.3 | -- | 4.03 |
| 5/2/07 | Fangorn | -- | 0.48 | -- | 0.05 | 42.3 | 0.62 | -- |
| 5/14/07 | Fangorn | -- | 0.90 | -- | 0.04 | 40.5 | -- | -- |
| 5/24/07 | Fangorn | 0.14 | 0.79 | 0.02 | 0.56 | 70.8 | -- | -- |
| 7/1/07 | Fangorn | 0.29 | 1.06 | 0.04 | 0.02 | 62.8 | 0.26 | 10.07 |
| 8/16/07 | Fangorn | 0.12 | -- | -- | -- | -- | -- | -- |
| | Overall average | 0.18 | 1.76 | 0.02 | 0.19 | 44.8 | 0.26 | 3.41 |
| | Fangorn average | 0.18 | 0.81 | 0.03 | 0.16 | 54.1 | 0.44 | 10.07 |
| 5/14/07 | Isengard | -- | 0.44 | -- | 0.06 | 23.3 | -- | -- |
| 5/24/07 | Isengard | 0.21 | 0.55 | 0.02 | 0.13 | 35.3 | -- | -- |
| 7/1/07 | Isengard | 0.22 | 1.07 | 0.01 | 0.03 | 40.3 | 0.08 | 3.01 |
| 7/16/07 | Isengard | 0.16 | 1.17 | 0.02 | 0.06 | 35.8 | -- | 2.67 |
| | Isengard average | 0.19 | 0.81 | 0.02 | 0.07 | 33.6 | 0.08 | 2.84 |
| 5/14/07 | Junk yard | -- | 0.42 | -- | 0.06 | 47.0 | -- | -- |
| 5/24/07 | Junk yard | 0.19 | 0.39 | 0.03 | 0.09 | 50.8 | -- | -- |
| 7/1/07 | Junk yard | 0.67 | 0.49 | 0.02 | 0.03 | 28.3 | 0.10 | 31.90 |
| | Junkyard average | 0.43 | 0.43 | 0.03 | 0.06 | 42.0 | 0.10 | 31.90 |
| 5/14/07 | Shire | -- | 0.41 | -- | 0.07 | 17.5 | -- | -- |
| 5/24/07 | Shire | 0.14 | 0.33 | 0.02 | 0.13 | 28.5 | -- | -- |
| 7/1/07 | Shire | 0.57 | 0.61 | 0.01 | 0.05 | 32.8 | 0.15 | 5.55 |
| 7/16/07 | Shire | 0.16 | 0.41 | 0.03 | 0.04 | 19.8 | -- | 11.20 |
| 5/14/07 | Shire +200 | -- | 0.29 | -- | 0.08 | 12.5 | -- | -- |
| 7/16/07 | Shire +200 | 0.13 | 0.26 | 0.02 | 0.04 | 21.5 | -- | 8.13 |
| 5/14/07 | Shire +400 | -- | 0.47 | -- | 0.06 | 27.0 | -- | -- |
| 7/16/07 | Shire +400 | 0.16 | 0.29 | 0.03 | 0.03 | 33.5 | -- | 18.60 |
| 5/14/07 | Shire -300 | -- | 0.25 | -- | 0.08 | 16.5 | -- | -- |
| 7/16/07 | Shire -300 | 0.07 | 0.34 | 0.02 | 0.07 | 18.5 | -- | 35.60 |
| | Shire overall average | 0.20 | 0.36 | 0.02 | 0.07 | 22.8 | 0.15 | 15.82 |
| | Shire +200 average | 0.13 | 0.28 | 0.02 | 0.06 | 17.0 | -- | 8.13 |
| n.a. | Golf Course | -- | -- | -- | -- | -- | -- | 23.70 |
| 5/17/07 | Golf Course | -- | 0.42 | -- | 0.13 | 38.5 | -- | -- |
| 6/14/07 | Golf Course | 0.24 | 0.67 | 0.05 | 0.08 | 59.5 | -- | 9.61 |
| 7/12/07 | Golf Course | 1.27 | 0.51 | 0.02 | 0.23 | 21.0 | 0.06 | -- |
| | Golf Course average | 0.76 | 0.53 | 0.03 | 0.14 | 39.7 | 0.06 | 16.66 |

Table 3. Physcial/chemical measurements. PAR = photosynthetically active radiation and LB/RB correspond to left and right bank, respectively, looking upstream.

| Site | Date and time | Dissolved oxygen % Sat | D.O. (mg/L) | Temp. © | pH | Specific Conductance (mS/cm²) | Total Dissolved Solids TDS (g/L) | PAR underwater (uE/cm²/s) | PAR surface (uE/cm²/s) |
|---|---|---|---|---|---|---|---|---|---|
| **Mordor** | 5/14/2007 11:00 a.m. | 92.8 | 10.14 | 11.4 | 8.3 | 3.05 | | 8.3 | 21.6 |
| | 5/29/07 9:50 a.m. | 99.1 | 10.39 | 13.0 | 8.2 | 2.18 | 1.44 | 10.9 | |
| | 6/4/2007 1:15 p.m. | 99.8 | 9.90 | 15.6 | 8.1 | 1.12 | 0.73 | | |
| | 6/14/07 11:45 a.m. | 92.1 | 9.28 | 14.8 | 8.0 | 2.07 | 1.34 | | |
| | 7/16/07 12:55 p.m. | 102.1 | 10.03 | 16.0 | 8.1 | 1.23 | 0.80 | 2.8 | |
| **Mordor - 200** | 5/14/2007 | 107.6 | 11.56 | 12.0 | 8.3 | 2.78 | | 35.6 | 279.0 |
| | 5/29/07 9:50 a.m. | 98.3 | 9.91 | 14.7 | 8.1 | 2.05 | 1.33 | 90.4 | |
| | 6/4/2007 1:15 p.m. | 94.5 | 8.92 | 18.0 | 7.9 | 0.77 | 0.50 | | |
| | 6/14/07 11:45 a.m. | 94.7 | 8.98 | 17.7 | 8.0 | 1.92 | 1.25 | | |
| | 7/16/07 12:55 p.m. | 100.1 | 9.62 | 17.0 | 8.1 | 1.81 | 1.18 | 23.8 | |
| **Mordor - 400** | 5/14/2007 DS Confluence | 123.1 | 12.84 | 13.4 | 8.4 | 2.27 | | 107.6 | 7.8 |
| | 5/14/2007 US Confluence | 123.0 | 12.74 | 13.8 | 8.7 | 2.63 | | | |
| | 5/14/2007 Sidestream | 103.5 | 10.98 | 12.7 | 8.4 | 1.28 | | | |
| | 5/29/07 9:50 a.m. | 119.5 | 11.70 | 16.2 | 8.1 | 1.08 | 0.70 | 57.0 | |
| | 6/4/2007 1:15 p.m. | 94.5 | 8.92 | 18.0 | 7.9 | 0.77 | 0.50 | | |
| | 6/14/07 11:00 a.m. | 99.2 | 9.16 | 19.1 | 8.0 | 1.02 | 0.66 | | |
| | 7/16/07 12:15 p.m. | 110.1 | 10.17 | 19.0 | 8.1 | 1.02 | 0.77 | 78.0 | |
| **Fangorn** | 5/14/2007 | 103.7 | 10.59 | 13.7 | 8.2 | 1.99 | | 96.4 | 84.9 |
| | 5/29/07 11:45 a.m. | 99.7 | 9.73 | 16.3 | 7.8 | 1.36 | 0.89 | 24.0 | |
| | 6/04/07 12:15 p.m. | 92.8 | 88.70 | 17.3 | 7.8 | 1.11 | 0.72 | | |
| | 6/14/2007 10:45 a.m. | 92.4 | 8.71 | 18.0 | 7.8 | 1.46 | 0.95 | | |
| | 6/22/2007 | 91.6 | 8.98 | 16.1 | 7.8 | 1.08 | 0.70 | | |
| | 7/23/07 9:40 a.m. | 104.7 | 10.14 | 16.7 | 8.1 | 1.17 | 0.76 | | |
| **Isengard** | 5/14/2007 | 103.0 | 10.90 | 12.7 | 8.1 | 1.56 | | 73.1 | 64.9 |
| | 5/29/07 12:30 p.m. | 97.6 | 9.80 | 15.1 | 7.8 | 0.73 | 0.47 | 16.0 | |
| | 6/04/07 11:45 a.m. | 92.7 | 9.07 | 16.3 | 7.8 | 0.95 | 0.62 | | |
| | 6/14/07 10:15 a.m. | 91.4 | 8.73 | 17.4 | 7.8 | 1.28 | 0.83 | | |
| | 7/16/07 11:45 a.m. | 96.9 | 9.31 | 17.0 | 8.0 | 1.18 | 0.77 | 8.4 | |
| **Junkyard** | 5/14/2007 | 96.9 | 10.07 | 14.7 | 8.4 | 1.08 | | 56.8 | 58.1 |
| | 5/29/07 1:00 p.m. | 95.6 | 9.12 | 17.5 | 7.9 | 0.70 | 0.46 | 20.0 | |
| | 6/04/07 11:15 a.m. | 95.5 | 9.30 | 16.6 | 7.8 | 0.67 | 0.43 | | |
| | 6/12/07 11:00 a.m. | 94.7 | 9.18 | 16.5 | 7.9 | 0.70 | 0.45 | | |
| | 6/27/07 10:30 a.m. | 99.4 | 9.35 | 15.2 | 8.0 | 0.66 | 0.43 | | |
| | 7/03/07 11:00 a.m. | 103.7 | 9.97 | 16.9 | 8.1 | 0.66 | 0.43 | | |
| **Shire - 300** | 5/14/2007 | 100.3 | 10.11 | 14.9 | 8.4 | 0.87 | | 34.5 | 33.7 |
| | 5/29/07 1:40 p.m. | 93.1 | 8.96 | 17.1 | 8.0 | 0.64 | 0.41 | 16.4 | |
| | 6/04/07 10:40 a.m. | 95.6 | 9.39 | 16.1 | 8.0 | 0.63 | 0.40 | | |
| | 6/12/07 10:45 a.m. | 94.9 | 9.28 | 16.3 | 8.1 | 0.65 | 0.42 | | |
| | 7/16/07 10:55 a.m. | 97.6 | 9.51 | 16.5 | 8.2 | 0.42 | 0.27 | | |
| | | in front @ 2 cm. | behind @ 2 cm. | r. side @ 2 cm | l. side @ 2 cm. | | | | |
| | Velocity at tiles | 0.8 | 0.15 | 0.1 | 0.2 | | | | |
| **Shire** | 5/14/2007 | 94.6 | 9.51 | 15.0 | 8.4 | 0.84 | | 14.1 | 14.2 |
| | 5/29/07 2:00 p.m. | 94.9 | 9.13 | 17.1 | 8.0 | 0.64 | 0.41 | 2.5 | |
| | 6/04/07 10:25 a.m. | 96.8 | 9.56 | 15.7 | 8.0 | 0.63 | 0.41 | | |
| | 6/12/07 10:25 a.m. | 95.9 | 9.50 | 15.8 | 8.1 | 0.65 | 0.42 | | |
| | 7/16/2007 10:30 a.m. | 101.0 | 9.88 | 16.3 | 8.2 | 0.64 | 0.42 | 1.6 | |
| **Shire + 200** | 5/14/2007 | 96.2 | 9.85 | 14.5 | 8.4 | 0.86 | | 55.8 | 42.6 |
| | 5/29/07 2:00 p.m. | 95.2 | 9.28 | 16.6 | 8.0 | 0.37 | 0.24 | 6.8 | |
| | 6/4/07 10:05 a.m. | 97.9 | 9.75 | 15.6 | 8.1 | 0.64 | 0.42 | | |
| | 6/12/07 10:15 a.m. | 97.1 | 9.66 | 15.6 | 8.2 | 0.65 | 0.43 | | |
| | 7/16/07 10:15 a.m. | 100.4 | 9.86 | 16.1 | 8.2 | 0.66 | 0.43 | 8.0 | |
| **Shire + 400** | 5/14/2007 | 100.4 | 10.26 | 14.2 | 8.4 | 0.90 | | 88.3 | 71.9 |
| | 5/29/07 2:40 p.m. | 100.1 | 9.84 | 16.1 | 8.1 | 0.68 | 0.44 | 63.0 | |
| | 6/04/07 9:50 a.m. | 100.0 | 10.11 | 14.8 | 8.0 | 0.68 | 0.44 | | |
| | 6/12/07 9:50 a.m. | 94.3 | 9.50 | 14.9 | 8.1 | 0.70 | 0.46 | | |
| | 7/16/07 9:50 a.m. | 101.3 | 10.03 | 15.5 | 8.0 | 0.72 | 0.47 | 19.8 | |
| **Golf Course** | 5/15/2007 | 104.4 | 9.85 | 18.9 | 8.4 | 1.07 | | 54.2 | 114.5 |
| | 5/29/2007 | 84.3 | 8.04 | 17.5 | 7.8 | 1.42 | 0.92 | | |
| | 6/04/07 1:50 p.m. | 91.6 | 8.64 | 18.0 | 8.0 | 1.12 | 0.73 | | |
| | 6/12/2007 | 89.3 | 8.38 | 18.2 | 7.9 | 1.51 | 0.98 | | |
| | 7/17/07 10:50 a.m. | 90.2 | 8.19 | 20.0 | 7.7 | 0.36 | 0.24 | | |
| **Ottawa Creek** | 5/15/07 1:30 p.m. | 97.1 | 9.30 | 17.0 | 8.3 | 0.71 | | 212.9 | 208.1 |
| | 5/30/2007 | 73.7 | 6.98 | 17.9 | 7.7 | 0.79 | 0.51 | 43.5 | |
| | 06/04/07 2:25 p.m. | 72.3 | 6.37 | 18.4 | 7.6 | 0.68 | 0.44 | | |
| | 6/12/2007 | 77.4 | 7.35 | 17.7 | 7.6 | 0.76 | 0.49 | | |
| | 7/17/07 11:20 a.m. | 83.4 | 7.75 | 18.8 | 7.7 | 0.98 | 0.64 | | |

| Site | Date/parameter | Cross-sectional data for discharge (LB & RB = left and right bank) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Mordor** | 5/14/2007 | LB | | | | | | | | | | RB |
| | Distance (cm) | 100 | 90 | 80 | 70 | 60 | 50 | 40 | 30 | 20 | 10 | 0 |
| | Depth (cm) | 0 | 0 | 1 | 1 | 3 | 2 | 2 | 2 | 2 | 2 | 0 |
| | Velocity (ft/s) | 0 | 0 | 0 | 0.09 | 0.04 | 0.03 | 0.03 | 0.02 | 0.06 | 0.02 | 0 |
| | Vel. at tiles @ 2 cm. | 0.23 | | | | | | | | | | |
| | 7/16/2007 | LB | | | | | | | | | | RB |
| | Distance (cm) | 110 | 99 | 88 | 77 | 66 | 55 | 44 | 33 | 22 | 11 | 0 |
| | Depth (cm) | 0 | 1 | 1 | 1 | 3 | 2 | 2 | 2 | 2 | 2 | 0 |
| | Velocity (ft/s) | 0 | 0.01 | 0.01 | 0.03 | 0.04 | 0.05 | 0.12 | 0.25 | 0.18 | 0.05 | 0 |
| **Mordor - 200** | 5/14/2007 | LB | | | | | | | | | | RB |
| | Distance (cm) | 150 | 135 | 120 | 105 | 90 | 75 | 60 | 45 | 30 | 15 | 0 |
| | Depth (cm) | 0 | 4 | 2 | 6 | 6 | 5 | 4 | 4 | 3 | 2 | 0 |
| | Velocity (ft/s) | 0 | 0.09 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Vel. at tiles @ 2 cm. | 0.23 | | | | | | | | | | |
| | 7/16/2007 | LB | | | | | | | | | | RB |
| | Distance (cm) | 140 | 126 | 112 | 98 | 84 | 70 | 56 | 42 | 28 | 14 | 0 |
| | Depth (cm) | 0 | 4 | 2 | 6 | 6 | 5 | 4 | 4 | 3 | 2 | 0 |
| | Velocity (ft/s) | 0 | 0.05 | 0.02 | 0.08 | 0.08 | 0.09 | 0.11 | 0.09 | 0.09 | 0.09 | 0 |
| **Mordor - 400** | 5/14/2007 | LB | | | | | | | | | | RB |
| | Distance (cm) | 50 | 45 | 40 | 35 | 30 | 25 | 20 | 15 | 10 | 5 | 0 |
| | Depth (cm) | 0 | 0 | 1 | 1 | 1 | 1 | 2 | 2 | 2 | 1 | 0 |
| | Velocity (ft/s) | 0 | 0 | 0.07 | 0.08 | 0.15 | 0.26 | 0.3 | 0.2 | 0.08 | 0.05 | 0 |
| | Vel. at tiles @ 2 cm. | 0.23 | | | | | | | | | | |
| | 7/16/2007 | LB | | | | | | | | | | RB |
| | Distance (cm) | 55 | 49.5 | 44 | 38.5 | 33 | 27.5 | 22 | 16.5 | 11 | 5.5 | 0 |
| | Depth (cm) | 0 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 2 | 1 | 0 |
| | Velocity (ft/s) | 0 | 0.35 | 0.57 | 1.03 | 1.18 | 1.33 | 1.03 | 0.63 | 0.52 | 0 | 0 |
| **Fangorn** | 5/14/2007 | LB | | | | | | | | | | RB |
| | Distance (cm) | 150 | 125 | 120 | 105 | 90 | 75 | 60 | 45 | 30 | 15 | 0 |
| | Depth (cm) | 0 | 1 | 5 | 8 | 4 | 18 | 18 | 18 | 8 | 3 | 0 |
| | Velocity (ft/s) | 0 | 0 | 0 | 0.04 | 0.03 | 0.03 | 0.02 | 0 | 0.04 | 0 | 0 |
| | Vel. at tiles @ 7cm | 0.04 | | | | | | | | | | |
| | 7/23/2007 | LB | | | | | | | | | | RB |
| | Distance (cm) | 150 | 125 | 120 | 105 | 90 | 75 | 60 | 45 | 30 | 15 | 0 |
| | Depth (cm) | 0 | 1 | 5 | 8 | 4 | 18 | 18 | 18 | 8 | 3 | 0 |
| | Velocity (ft/s) | 0 | 0.07 | 0.07 | 0.08 | 0.04 | 0.03 | 0.06 | 0.02 | 0.02 | 0.02 | 0 |
| **Isengard** | 5/14/2007 | LB | | | | | | | | | | RB |
| | Distance (cm) | 60 | 54 | 48 | 42 | 36 | 30 | 24 | 18 | 12 | 6 | 0 |
| | Depth (cm) | 0 | 2 | 2 | 4 | 4 | 4 | 4 | 2 | 2 | 2 | 0 |
| | Velocity (ft/s) | 0 | 0 | 0.06 | 0.17 | 0.25 | 0.28 | 0.27 | 0.33 | 0.25 | 0.07 | 0 |
| | Vel. at tiles @ 4 cm | 0.12 | | | | | | | | | | |
| | 7/16/2007 | LB | | | | | | | | | | RB |
| | Distance (cm) | 60 | 54 | 48 | 42 | 36 | 30 | 24 | 18 | 12 | 6 | 0 |
| | Depth (cm) | 0 | 2 | 2 | 4 | 4 | 4 | 4 | 2 | 2 | 2 | 0 |
| | Velocity (ft/s) | 0 | 0.06 | 0.07 | 0.07 | 0.09 | 0.1 | 0.01 | 0.13 | 0.12 | 0.07 | 0 |
| **Junkyard** | Discharge 5/14/07 | LB | | | | | RB | | | | | |
| | Distance (cm) | 30 | 24 | 18 | 12 | 6 | 0 | | | | | |
| | Depth (cm) | 0 | 4 | 6 | 6 | 2 | 0 | | | | | |
| | Velocity (ft/s) | 0 | 0.15 | 0.3 | 0.24 | 0.11 | 0 | | | | | |
| | Vel. at tiles@ 4 cm | 0.18 | | | | | | | | | | |
| **Shire - 300** | 5/14/2007 | LB | | | | | | RB | | | | |
| | Distance (cm) | 40 | 33.3 | 26.6 | 19.9 | 13.2 | 6.5 | 0 | | | | |
| | Depth (cm) | 0 | 2 | 3 | 3 | 3 | 2 | 0 | | | | |
| | Velocity (ft/s) | 0 | 0.29 | 0.39 | 0.38 | 0.42 | 0.36 | 0 | | | | |
| | 7/16/2007 | LB | | | | | | | | | | RB |
| | Distance (cm) | 55 | 49.5 | 44 | 38.5 | 33 | 27.5 | 22 | 16.5 | 11 | 5.5 | 0 |
| | Depth (cm) | 0 | 2 | 2 | 2 | 4 | 2 | 1 | 1 | 1 | 2 | 0 |
| | Velocity (ft/s) | 0 | 0.21 | 0.25 | 0.24 | 0.24 | 0.23 | 0.27 | 0.15 | 0.13 | 0.2 | 0 |
| **Shire** | 5/14/2007 | LB | | | | | RB | | | | | |
| | Distance (cm) | 30 | 24 | 18 | 12 | 6 | 0 | | | | | |
| | Depth (cm) | 0 | 1 | 5 | 4 | 2 | 0 | | | | | |
| | Velocity (ft/s) | 0 | 0.28 | 0.21 | 0.29 | 0.07 | 0 | | | | | |
| | Vel. at tiles @ 2 cm. | 0.17 | | | | | | | | | | |
| | 7/16/2007 | LB | | | | | | | | | | RB |
| | Distance (cm) | 50 | 45 | 40 | 35 | 30 | 25 | 20 | 15 | 10 | 5 | 0 |
| | Depth (cm) | 0 | 1 | 1 | 1 | 5 | 5 | 4 | 4 | 2 | 2 | 0 |
| | Velocity (ft/s) | 0 | 0.07 | 0.11 | 0.31 | 0.03 | 0.28 | 0.24 | 0.22 | 0.24 | 0.06 | 0 |
| **Shire + 200** | 5/14/2007 | LB | | | | | | RB | | | | |
| | Distance (cm) | 50 | 41.7 | 33.4 | 25.1 | 16.8 | 8.5 | 0 | | | | |
| | Depth (cm) | 0 | 2 | 4 | 5 | 6 | 2 | 0 | | | | |
| | Velocity (ft/s) | 0 | 0 | 0.14 | 0.12 | 0.12 | 0 | 0 | | | | |
| | Velocity at tiles @ 4 cr | 0.03 | | | | | | | | | | |
| | 7/16/2007 | LB | | | | | | | | | | RB |
| | Distance (cm) | 1 | 0.9 | 0.8 | 0.7 | 0.6 | 0.5 | 0.4 | 0.3 | 0.2 | 0.1 | 0 |
| | Depth (cm) | 0 | 2 | 2 | 2 | 4 | 4 | 5 | 5 | 5 | 2 | 0 |
| | Velocity (ft/s) | 0 | 0.07 | 0.09 | 0.03 | 0.08 | 0.08 | 0.09 | 0.1 | 0.11 | 0.04 | 0 |
| **Shire + 400** | 5/14/2007 | LB | | | | | | RB | | | | |
| | Distance (cm) | 30 | 25 | 20 | 15 | 10 | 5 | 0 | | | | |
| | Depth (cm) | 0 | 2 | 4 | 5 | 4 | 4 | 0 | | | | |
| | Velocity (ft/s) | 0 | 0.1 | 0.12 | 0.13 | 0.11 | 0.08 | 0 | | | | |
| | Vel. at tiles @ 2 cm | 0.05 | | | | | | | | | | |
| | 7/16/2007 | LB | | | | | | | | | | RB |
| | Distance (cm) | 80 | 72 | 64 | 56 | 48 | 40 | 32 | 24 | 16 | 8 | 0 |
| | Depth (cm) | 0 | 2 | 2 | 4 | 4 | 4 | 5 | 4 | 4 | 4 | 0 |
| | Velocity (ft/s) | 0 | 0.14 | 0.16 | 0.14 | 0.1 | 0.04 | 0.04 | 0.12 | 0.09 | 0.09 | 0 |
| **Golf Course** | 5/15/2007 | LB | | | | | | | | | RB | |
| | Distance (cm) | 90 | 80 | 70 | 60 | 50 | 40 | 30 | 20 | 10 | 0 | |
| | Depth (cm) | 0 | 2 | 3 | 4 | 4 | 4 | 4 | 1 | 1 | 0 | |
| | Velocity (ft/s) | 0 | 0.1 | 0.13 | 0.15 | 0.13 | 0.09 | 0.09 | 0.08 | 0.03 | 0 | |
| | Vel. at tiles @ 5 cm | 0.13 | | | | | | | | | | |
| | 7/17/2007 | LB | | | | | | | | | | RB |
| | Distance (cm) | 120 | 108 | 96 | 84 | 72 | 60 | 48 | 36 | 24 | 12 | 0 |
| | Depth (cm) | 0 | 2 | 3 | 4 | 4 | 4 | 4 | 2 | 1 | 1 | 0 |
| | Velocity (ft/s) | 0 | 0.59 | 0.69 | 0.57 | 0.53 | 0.49 | 0.34 | 0.1 | 0.32 | 0.32 | 0 |
| **Ottawa Creek** | 5/15/2007 | LB | | | | | | | | | | RB |
| | Distance (cm) | 250 | 225 | 200 | 175 | 150 | 125 | 100 | 75 | 50 | 25 | 0 |
| | Depth (cm) | 0 | 12 | 20 | 23 | 25 | 20 | 25 | 26 | 22 | 10 | 0 |
| | Velocity (ft/s) | 0 | 0.63 | 0.59 | 0.6 | 0.65 | 0.67 | 0.49 | 0.36 | 0.29 | 0.08 | 0 |
| | Velocity at tiles @ 5 cr | 1.06 | | | | | | | | | | |
| | 7/17/2007 | LB | | | | | | | | | | RB |
| | Distance (cm) | 220 | 198 | 176 | 154 | 132 | 110 | 88 | 66 | 44 | 22 | 0 |
| | Depth (cm) | 0 | 12 | 20 | 23 | 25 | 20 | 25 | 26 | 22 | 20 | 0 |
| | Velocity (ft/s) | 0 | 0.27 | 1.45 | 1.45 | 1.71 | 1.6 | 1.46 | 1.3 | 0.97 | 0.36 | 0 |

# Table 4. Summary of macroinvertebrate community data from both quantitative and qualitative samples.

**5/30/2007** 1 suber : 900 cm2 conversion factor (900/10000) = 11.111
**Ravines** 1 meter 10000 cm2

| | Mordor | | | | | | | Isengard | | | | | | | Junkyard | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Taxa** | surber 1 | abund (m2) | surber 2 | abund (m2) | surber 3 | abund (m2) | qual | surber 1 | abund (m2) | surber 2 | abund (m2) | surber 3 | abund (m2) | qual | surbur 1 | abund (m2) | surber 2 | abund (m2) | surbur 3 | abund (m2) | qual |
| Amphipoda | 16 | 177.8 | 13 | 144.4 | 40 | 444.4 | 6 | 3 | 33.3 | 6 | 66.7 | 9 | 100.0 | 3 | 31 | 344.4 | 25 | 277.8 | 52 | 577.8 | 0 |
| Diptera Chironomidae | 34 | 377.8 | 35 | 388.9 | 60 | 666.7 | 0 | 143 | 1588.9 | 200 | 2222.2 | 115 | 1277.8 | 0 | 18 | 200.0 | 95 | 1055.6 | 78 | 866.7 | 0 |
| Diptera adult | 2 | 22.2 | 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 |
| Diptera Simuliidae | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 22 | 244.4 | 36 | 400.0 | 42 | 466.7 | 0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 |
| Diptera Tipulidae | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0 | 0.0 | 0 | 0.0 | 1 | 11.1 | 1 | 1 | 11.1 | 1 | 11.1 | 0 | 0.0 | 0 |
| Diptera Tabanidae | 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 |
| Trichoptera Hydropsychidae Diplectrona | 1 | 11.1 | 0 | 0.0 | 0 | 0.0 | 0 | 1 | 11.1 | 1 | 11.1 | 0 | 0.0 | 0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 |
| Trichoptera Hydropsychidae | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 1 | 11.1 | 0 | 0.0 | 0 | 0.0 | 0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 |
| Coleoptera Staphylinidae | 2 | 22.2 | 0 | 0.0 | 0 | 0.0 | 0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0 | 0.0 | 1 | 11.1 | 0 | 0.0 | 0 |
| Coleoptera Dytiscidae | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 2 | 22.2 | 0 | 0.0 | 3 | 33.3 | 1 |
| Coleoptera Curculionidae | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 2 | 22.2 | 0 | 0.0 | 1 | 11.1 | 0 |
| Isopoda Asellidae | 0 | 0.0 | 1 | 11.1 | 1 | 11.1 | 0 | 10 | 111.1 | 14 | 155.6 | 9 | 100.0 | 0 | 21 | 233.3 | 5 | 55.6 | 23 | 255.6 | 0 |
| Ephemeroptera Baetidae Baetis | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 16 | 177.8 | 10 | 111.1 | 0 | 0.0 | 0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 |
| Ephemeroptera Baetidae Pseudocloeon | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0 | 0.0 | 0 | 0.0 | 2 | 22.2 | 0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 |
| Hymenoptera Formicidae | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0 | 0.0 | 1 | 11.1 | 0 | 0.0 | 0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 |
| Oligochaeta | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0 | 0.0 | 0 | 0.0 | 5 | 55.6 | 0 | 0 | 0.0 | 0 | 0.0 | 2 | 22.2 | 0 |
| Hemiptera Veliidae | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 1 | 11.1 | 0 | 0.0 | 0 | 0.0 | 0 |
| Hemiptera Gerridae | 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 | 1 | 11.1 | 2 |
| Gastropoda | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0 | 0.0 | 1 | 11.1 | 0 | 0.0 | 0 |
| Bivalve | 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 |
| Arachnida | 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 | 1 |
| Odonata Calopterygidae | 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 |
| total abundance (m2) | | 611.1 | | 544.4 | | 1122.2 | | | 2177.8 | | 2977.8 | | 2033.3 | | | 844.4 | | 1422.2 | | 1777.8 | |
| taxa richness | | 5 | | 3 | | 3 | | | 7 | | 7 | | 7 | | | 7 | | 6 | | 7 | |
| diversity | | | | | | | | | | | | | | | | | | | | | |
| average abundance (m2) | | 759.3 | | | | | | | 2396.3 | | | | | | | 1348.1 | | | | | |
| standard deviation | | 316.1 | | | | | | | 508.7 | | | | | | | 471.1 | | | | | |
| average richness | | 3.7 | | | | | | | 7.0 | | | | | | | 6.7 | | | | | |

| | Shire | | | | | | | Golf Course | | | | | | | Ottawa | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Taxa** | surbur 1 | abund (m2) | surbur 2 | abund (m2) | surbur 3 | abund (m2) | qual | surbur 1 | abund (m2) | surber 2 | abund (m2) | surbur 3 | abund (m2) | qual | surbur 1 | abund (m2) | surber 2 | abund (m2) | surbur 3 | abund (m2) | qual |
| Amphipoda | 112 | 1244.4 | 30 | 333.3 | 6 | 66.7 | 18 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 7 | 77.8 | 150 | 1666.7 | 200 | 2222.2 | 16 |
| Diptera Chironomidae | 52 | 577.8 | 8 | 88.9 | 20 | 222.2 | 0 | 33 | 366.7 | 132 | 1466.7 | 8 | 88.9 | 0 | 128 | 1422.2 | 140 | 1555.6 | 200 | 2222.2 | 16 |
| Diptera adult | 1 | 11.1 | 0 | 0.0 | 0 | 0.0 | 0 | 10 | 111.1 | 0 | 0.0 | 0 | 0.0 | 0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 |
| Diptera Simuliidae | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 14 | 155.6 | 62 | 688.9 | 2 | 22.2 | 1 | 0 | 0.0 | 33 | 366.7 | 5 | 55.6 | 4 |
| Diptera Tipulidae | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0 | 0.0 | 1 | 11.1 | 0 | 0.0 | 0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 |
| Diptera Tabanidae | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0 | 0.0 | 1 | 11.1 | 0 | 0.0 | 0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 |
| Trichoptera Hydropsychidae Diplectrona | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 3 | 33.3 | 1 | 11.1 | 8 | 88.9 | 0 | 0 | 0.0 | 1 | 11.1 | 10 | 111.1 | 1 |
| Trichoptera Hydropsychidae | 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 |
| Coleoptera Staphylinidae | 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 |
| Coleoptera Dytiscidae | 5 | 55.6 | 0 | 0.0 | 1 | 11.1 | 0 | 4 | 44.4 | 3 | 33.3 | 2 | 22.2 | 2 | 0 | 0.0 | 0 | 0.0 | 2 | 22.2 | 0 |
| Coleoptera Curculionidae | 0 | 0.0 | 0 | 0.0 | 2 | 22.2 | 0 | 0 | 0.0 | 1 | 11.1 | 0 | 0.0 | 1 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 |
| Isopoda Asellidae | 20 | 222.2 | 0 | 0.0 | 3 | 33.3 | 4 | 1 | 11.1 | 0 | 0.0 | 3 | 33.3 | 3 | 1 | 11.1 | 5 | 55.6 | 19 | 211.1 | 7 |
| Ephemeroptera Baetidae Baetis | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0 | 0.0 | 2 | 22.2 | 0 | 0.0 | 1 | 0 | 0.0 | 5 | 55.6 | 13 | 144.4 | 3 |
| Ephemeroptera Baetidae Pseudocloeon | 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 |
| Hymenoptera Formicidae | 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 |
| Oligochaeta | 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 |
| Hemiptera Veliidae | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 1 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 |
| Hemiptera Gerridae | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 1 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 2 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 |
| Gastropoda | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0 | 0.0 | 3 | 33.3 | 6 | 66.7 | 0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 |
| Bivalve | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 1 | 11.1 | 0 | 0.0 | 0 | 0.0 | 0 |
| Arachnida | 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 |
| Odonata Calopterygidae | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 2 | 22.2 | 0 | 0.0 | 0 | 0.0 | 1 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 3 |
| total abundance (m2) | | 2111.1 | | 422.2 | | 355.6 | | | 744.4 | | 2288.9 | | 322.2 | | | 1522.2 | | 3711.1 | | 4988.9 | |
| taxa richness | | 5.0 | | 2 | | 5 | | | 7 | | 9 | | 5 | | | 4 | | 6 | | 7 | |
| diversity | | | | | | | | | | | | | | | | | | | | | |
| average abundance (m2) | | 963.0 | | | | | | | 1118.5 | | | | | | | 3407.4 | | | | | |
| standard deviation | | 994.9 | | | | | | | 1035.3 | | | | | | | 1753.2 | | | | | |
| average richness | | 4.0 | | | | | | | 7.0 | | | | | | | 5.7 | | | | | |

A.

B.

C.

D.

KEY

A. Fangorn gage (Little Mac ravine)
B. Fangorn (Little Mac ravine)
C. Female snapping turtle, Grand River floodplain
D. Upstream of Isengard in the Calder Art ravine.
E. Male blacknose dace with mating colors.
F. Electrofishing at Fangorn
G. Fish processing at Fangorn

F.

E.

G.