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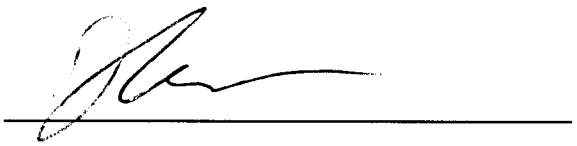

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THE EFFECTS OF HABITAT QUALITY ON ABIOTIC FACTORS AND HETEROTROPHIC MICROBIAL ACTIVITY IN A FRESHWATER STREAM SYSTEM.

BY

DAPHNE KAMPINGA

THESIS

SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF

MASTER OF SCIENCE IN BIOLOGICAL SCIENCES

IN THE GRADUATE SCHOOL, EASTERN ILLINOIS UNIVERSITY
CHARLESTON, ILLINOIS

2005

I HEREBY RECOMMEND THAT THIS THESIS BE ACCEPTED AS FULFILLING
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28 Nov '05 — DATE
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28 November 2005 — DATE
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ABSTRACT:

Much of the Midwest, as well as Illinois' landscape, has largely been transformed from its original habitat of prairie, savanna, wetlands, and forest into corn and soybean fields and urban areas. As a result, less than 1% of the original habitat in Illinois remains intact today. These modifications can lead to habitat fragmentation and affect riparian zone vegetation, which is an important link between the land-water interface and influences processes such as organic matter inputs and water temperature regimes. As a result of fragmentation, riparian zone loss has occurred and catchment vegetation associated with streams can vary from agricultural fields, to forest patches, to residential areas. Thus, the objectives of this study were to: 1. determine whether habitat quality has an affect on abiotic stream variables, 2. establish if a relationship exists between habitat quality and heterotrophic density and metabolism, and 3. ascertain which abiotic stream variables can be used to predict heterotrophic density and metabolism. Through the use of The Stream Habitat Assessment Procedure we found that although varying habitat quality exists within the Embarras River watershed; no such effects can be seen in the water quality data. A multiple regression model reveals that there are several SHAP metrics (substrate stability, instream cover and deposition) important in predicting the oxygen consumption of benthic heterotrophic microbes only, while no useable models exist for predicting bacterial/fungal densities. Further analysis revealed a list of variables that are useful in predicting the density and metabolism of

heterotrophic microbes, but were different for each class of microbes (benthic/suspended and fungal/bacterial), indicating that no one set of water quality variables can be used to predict the activity or metabolisms of heterotrophic microbes as a unit.

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When I first started my graduate work at EIU Graduate School, specifically the Department of Biological Sciences, I had no idea exactly how great an impact this would have on my life. It is now a few years later and with finished product in hand, I can say with 110% confidence that making the decision to go to grad school at EIU was the best decision I have ever made. This has been confirmed by the fact that I love going to work every day. Although I continue to learn new things on the job on an almost daily basis, the Department of Biological Sciences at EIU prepared me exceptionally well for my job and hopefully long lived career. I want to thank every professor, staff member, and fellow student in the Biology Department because there isn't a single person who didn't have a positive affect on the outcome of my education. With that said, there are a few individuals who played a key role in my project and education.

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and methods. He also provided a fantastic opportunity to do a research project in Mobile Bay, Alabama, which stands out in my mind as one of the best experiences from grad school. Dr. Nelson was essential in providing me with knowledge of overall conservation issues. He taught me to look at how everything is connected and to take a look at the complete picture, from the smallest to the largest occupant of an ecosystem. Each has shared their extensive knowledge with me and I greatly appreciate all their suggestions and assistance.

Lastly, my project could not have been completed with out the help of my friends and fellow scholars. Their assistance in keeping me sane was imperative and their help with this project as well as my academics was indispensable. In particular I want to thank Shari Fanta, Nathan Badgett and Brian Towey who each gave up early mornings for field work and late evenings for assistance in the lab and fished me out of the streams time and time again.

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INTRODUCTION

Much of the Midwest, as well as Illinois' landscape, has largely been transformed from its original habitat of prairie, savanna, wetlands, and forest into corn and soybean fields and urban areas. As a result of these landscape changes, less than 1% of the original habitat in Illinois remains intact today (Page et al., 1997). Modifications made to the original habitat have lead to terrestrial habitat fragmentation, which typically results in a landscape consisting of small isolated patches of native vegetation surrounded by matrices of urban development and agricultural fields (Saunders et al., 1991).

The creation of these small remnant patches may lead to a shortage of resources, increased predation, and lack of dispersal within and between patches ultimately leading to major declines in species diversity and adverse effects on species richness (Page et al., 1997). These changes to species diversity and richness can occur through the exclusion of species that prefer interior habitat over edge habitat and/or by bringing species together that would otherwise not encounter each other by habitat modification. Modification made to the habitat due to fragmentation may lead to changes in the type and quality of both food and cover available to an organism through alterations made to the microclimate (Saunders et al., 1991). Occurrence of these modifications may cause the native communities to become more susceptible to the establishment of invasive species (Hobbs, 1989). Establishment of nonnative vegetation seems to be amplified after some form of disturbance. Therefore not only changing the availability of food and cover but also increasing contact between unfamiliar species and with humans (Yahner et al., 1989). These are all well documented

cases of the effects of terrestrial habitat fragmentation; however, much less empirical data has been documented on the effects of fragmentation associated with lotic ecosystems.

Modifications made to the terrestrial vegetation can not only cause terrestrial habitat fragmentation but can also lead to aquatic habitat fragmentation when associated with changes in riparian zones vegetation. Aquatic habitat fragmentation occurs when modifications made to the surrounding terrestrial habitat creates unsuitable habitat for aquatic organisms in the adjoining stream (Wissman and Beschta, 1998). Stream habitat fragmentation can be defined as a loss of connectivity and decreased complexity between the upstream and downstream reaches of an aquatic community caused by the loss of lateral connectivity between the channel and its adjacent riparian zone (Page et al.., 1997). Thus, terrestrial vegetation is an important link between the land-water interface, specifically; the riparian zone has been shown to directly influence important stream processes such as temperature regimes, nutrient dynamics associated with water quality and organic matter inputs, as well as sedimentation (Allen and Johnson, 1997).

Riparian zone vegetation can help mediate water temperature especially in small to mid sized streams by reducing the amount of solar radiation that reaches the water, therefore minimizing temperature fluctuations (Osborne and Kovacic, 1993; Karr and Schlosser, 1978). Increasing temperatures in a stream can effect the fundamental aspects of the aquatic environment thereby influencing every heterotrophic organism that inhabits the stream. Higher water

temperatures can result in oxygen depletion by decreasing the water's oxygen solubility. Additionally, higher stream temperatures, will reduce the streams ability to assimilate waste, further decreasing the stream's oxygen holding capacity, ultimately lowering the amount of oxygen present in the water column to even lower levels (Karr and Schlosser, 1978). The increased water temperatures and decreased oxygen availability associated with the loss of riparian vegetation may displace native species that require lower temperature, high oxygen environments and replace them with tolerant species better suited for high temperature environments (Brown and Brazier, 1972). The displacement of a species due to temperature changes in a stream can be seen in Missouri where smallmouth bass are effectively being replaced by largemouth bass due to increasing water temperature associated with the loss of riparian zone vegetation (Sowa and Rabeni, 1995).

Stream ecologists have also recognized the importance of the association between riparian zone vegetation and water quality. Riparian zone vegetation acting as a denitrification mechanism seems to be the primary means of reducing nitrate concentrations from groundwater before they reach the stream. Riparian zones vegetated with forest or grass vegetation effectively reduced the nitrate N concentrations in groundwater up to 90%, while a riparian zone made up of row crops had significantly higher concentrations of nitrates in the groundwater, which feed the streams (Osborne and Kovacic, 1993). Additionally, the same study revealed that when comparing the three types of vegetated riparian zones, only a forested buffer was shown to be superior in the retention of phosphorus.

Thus, a forested stream buffer zone works the best at filtering nutrients from the groundwater and illustrates the important role that riparian zones with native vegetation play in the elimination of excess nutrients in groundwater before they reach the stream.

Not only is riparian vegetation important in nutrient transport, it also plays an important role in sediment transport. Sediment load is a function of both the amount of vegetation in the buffer zone as well as buffer zone width. Both of these factors can play a role in reducing the overall sediment load as well as decreasing the particle size of sediment deposited within the stream (Karr and Schlosser, 1978). Riparian vegetation has the ability to reduce the velocity of surface runoff by increasing the amount of friction runoff encounters with the soil surface. The amount of increase in friction is dependent upon the type of vegetation as well as the amount of litter the vegetation places on the ground. Thus, the type and amount of vegetation can have an effect on the rate of deposition and consequently reduce the potential for stream erosion and sedimentation (Tabacchi et al., 1998). When riparian zone vegetation is removed or modified, high levels of sedimentation can enter a stream and modify stable streambeds into sandy unstable stream bottoms, which can lead to reduced productivity in streams across all trophic levels. The harmful effects of sedimentation on fish communities can be seen in their reproductive success, which dramatically decreases in areas with high sediment loads due to the covering of spawning areas and eggs, and the inhibition of further development of fertilized eggs and the hatching of fry (Berkman and Rabeni, 1987).

Since organic matter (OM) is primarily derived from allochthonous inputs originating from terrestrial sources such as leaf litter, soil and groundwater and is then transferred from the riparian zone into the stream, the OM present in the water is highly dependent on the surrounding terrestrial vegetation (Tranvik, 1992). Grasslands typically offer the greatest amount of OM; forested land contributes a lesser amount, while desert provides the least (Allen, 1995). Carbon is the most abundant element, comprising almost half of the OM present in a stream system (Pusch et al., 1998). Some factors that impact the carbon content of OM in the stream include the amount and type of vegetation present in the watershed, how much contact water entering the stream has with the vegetation, as well as how deep into the soil the water penetrates. Specifically, contact with vegetation and shallow penetration into the soil has been shown to increase the carbon content of OM in the water entering the stream. A study in North Carolina showed that carbon concentrations were 2-12 mg/l in surface ground water and as little as 0.2-0.7 mg/l in sub-surface samples (Meyer and Tate, 1983). Another study found that the carbon content of rainwater entering the stream could double after passing through the canopy of a forest due to leaching of carbon from the leaves (Thurman, 1985).

The two main types of microbes found in a stream ecosystem are benthic and suspended microbes. Typically, benthic microbes are associated with biofilm and are much more active than suspended microbes, except in larger rivers, where suspended microbes play a greater role in community respiration (Pusch et al., 1998; Meyer, 1990). Biofilm occurs in association with the sediment on the

bottom of the streambed and is made up of a polysaccharide matrix, which consists of an assemblage of microbes such as bacteria, fungi, and algae (Pusch et al., 1998; Fischer and Pusch, 2001). In small streams, suspended microbes are thought to originate from benthic populations and occur through the sloughing of material from biofilm, once in suspension in the water column, these microbes are very susceptible to being washed downstream (Edwards et al., 1990).

Aquatic heterotrophic microbes are the foremost consumers of OM, and use carbon as an energy source to produce biomass (Brugger et al., 2001). Microbial colonization enhances the uptake and holding of OM, which allows other aquatic stream species to extract more nutrition from the organic matter supplied to the stream from the surrounding vegetation. As a food source, aquatic microbes are a very important nutritional source for invertebrates that inhabit streams. Stream invertebrates fall into four main functional groups, shredders such as the crane fly larvae (*Tipulidae*), collectors such as black fly larvae (*Simuliidae*), predators such as megalopterans, and scrapers such as certain caddis larvae (*Neophylax*) and each is highly dependent on microbial populations, as the link to higher trophic levels (Meyer, 1994; Cummins et al., 1989).

Shredders feed on vascular plant tissue but only after sufficient microbial colonization. Microbes facilitate feeding on vascular plants by producing the biochemical and structural changes necessary to convert plant litter into a nutritional food source for invertebrates (Cummins and Klug, 1979). The role of

shredders is to convert large pieces of plant litter, course particulate organic matter (CPOM), into finer, more useable pieces (fine particulate organic matter, FPOM), which can then be utilized by the other functional invertebrate groups (Short and Maslin, 1977). Collectors are a group that feeds on FPOM made available by the shredders using morphological and behavioral modifications that allow them to filter FPOM from the water column or gather it from the substrate. Scrapers are direct consumers of microbes feeding on benthic microbes and algae associated with the biofilm attached to the streambed. Lastly, the predator group is tied to microbial colonization through their dependence on other invertebrates as food sources (Cummins, 1973).

In addition to serving as a link between trophic levels, vigorous microbial activity have also been shown to offer beneficial activities such as increased retention and storage of nutrients as well as detoxification of pollutants in streams (Pusch et al., 1998). Aquatic microbes can have a drastic effect on the availability of nutrients in streams. Rapid uptake and short transport distances of nutrients such as nitrates and phosphates can be seen in areas of a stream with abundant microbial populations that are metabolically active (Fenchel and Harrison, 1976). Cropping microbial populations by invertebrate consumers such as scrapers can stimulate the release of these nutrients increasing their spiraling length and making them available to other organisms downstream (Allen, 1995).

Many in-stream abiotic factors are in some way affected by catchment vegetation and habitat quality. However, as a result of fragmentation which leads to riparian zone loss, catchment vegetation associated with streams can vary

ranging from agricultural fields, to forest patches, to residential areas. Thus, the objective of this study was to determine:

1. Determine whether habitat quality has an effect on abiotic stream variables,
2. Establish if a relationship exists between habitat quality and heterotrophic density and metabolism.
3. Ascertain which abiotic stream variables can be used to predict heterotrophic density and metabolism.

METHODS:

Sampling locations and habitat quality:

Six sampling sites were selected along the Embarras River and its tributaries located throughout Cumberland, Coles, Douglas, and Champaign counties in Illinois (Figures 1 and 2). The sampling sites varied in stream order from three to four and were in varying degrees of riparian zone fragmentation. The sites ranged in % canopy cover from 3.54% to 87.52% (Table 1). Overall average canopy cover for each stream was identified through the use of Illinois Stream Information System/Geographical Information System (ISIS/GIS) and a representative sample site (stream reach) with the appropriate canopy cover was located for each stream using a densiometer. The terrestrial and aquatic habitat structure of each sample site was also evaluated using the Stream Habitat Assessment Procedure (SHAP; IEPA, 1994). At each site a team of four people independently performed a SHAP analysis and a mean SHAP score was determined for each site. The procedure provided a qualitative method for the consideration of aquatic as well as terrestrial features of a stream. Each person performing the SHAP analysis rated fifteen stream metrics that fall into three main categories 1) substrate and in stream quality, 2) channel morphology and hydrology, and 3) riparian and bank features. Scores given to each of the fifteen metrics in the three categories were added up to place each sample site into one of four habitat quality categories (excellent being ≥142, good ≥100<142, fair ≥59<100, and poor <59) (Table 2).

Sampling regime:

Sampling occurred approximately every 5 weeks during base flow conditions starting June 24, 2002 through June 2, 2003. Both water and sediment samples were taken for laboratory analysis while some water quality parameters were determined in the field. Each variable was measured in triplicate at every sample location and reported as an average with standard deviations.

Water quality variables:

Dissolved oxygen (DO), temperature (Temp °C), pH, and conductivity (Cond) of the water were measured in the field through the use of a YSI 556 Multi-probe System. Depth was measured at each sample site by a meter stick, while flow was measured with the Global Water Flow Probe (FP101). Turbidity (Turb) was measured in the lab using a LaMotte 2020 turbidimeter. Alkalinity (T Alk) and hardness (Hardn) of water samples were measured by titration while organic matter was measured by performing solids determinations according to Standard Methods (APHA 1995).

Water samples were analyzed for total solids (TS) and suspended solids (SS) by drying a 75 ml sub sample for TS and filtering up to a 600 ml sub samples for SS overnight at 103-105 °C. Dried residues were cooled in a desiccator, weighed and placed in a muffle furnace at 550 °C for twenty minutes to determine the volatile total solids fractions (VTS - w) as well as the volatile suspended solids fraction (VSS). Lastly, volatile dissolved solids (VDS) were

determined through subtraction (VTS-w – VSS) and are a measure of dissolved organic matter content of the water.

Heterotrophic metabolism of suspended microbes was measured as O_2 consumption (O_2 Cons-w) by incubating 300 ml BOD bottles *in situ* according to procedures outlined in Methods in Stream Ecology (Ward and Johnson, 1996). The technique consists of measuring dissolved oxygen (DO) through Winkler titrations on an initial sample as well as an incubated sample. The oxygen content of the initial sample was collected in clear 300 ml BOD bottles and fixed immediately while in the field and titrated upon arrival in the lab, serving as the baseline oxygen level for that site. Incubated water samples were kept under water at the sampling site (in blackened BOD bottles to eliminate oxygen production by autotrophs) and removed from the stream after a period of at least 48 hours but no more than 55 hours. The incubated samples were then fixed in the field and titrated upon arrival at the lab and served as an index to O_2 consumption (heterotrophic metabolism) by subtracting the amount of DO in the incubated sample from the amount of DO in the initial sample.

Heterotrophic density of suspended microbes (bact – w & fungi – w) was analyzed by performing a dilution scheme by preparing dilutions of 0.1, 0.01, and 0.001 ml of sample water, followed by heterotrophic spread plate counts (APHA 1995). Heterotrophic plate count agar® was used to determine bacterial density and Czapek agar® with Streptomycin Sulfate® and Terramycin® to eliminate bacterial contamination was used to determine fungal density. Bacterial spread plates were incubated for a period of 48 hours at 35 °C while the fungal plates

were incubated for 5 days at 20 °C. After the appropriate incubation time, growth was manually counted on both types of plates, using a Quebec colony counter. Plates containing the dilution that produced 30-300 colony-forming units (CFU) were selected for the bacterial plate count, while plates containing the dilution that produced 100-150 CFU's were selected for the fungal plate counts. The average number of CFU for the triplicate plates of the determined dilution was then divided by the actual volume of the sample on the plate to calculate CFU/ml (APHA, 1995).

Sediment samples:

Sediment samples were analyzed for organic matter content by placing a 25- 50 g sub sample in the drying oven overnight at 103-105 °C. These dried sub samples were cooled in a desiccator, weighed and transferred into the muffle furnace at 550 °C for thirty minutes to determine its volatile total solids fraction (VTS - s) according to Standard Methods (APHA 1995).

Heterotrophic metabolism of benthic microbes was measured as O_2 consumption (O_2 Cons-s) by incubating 300 ml BOD bottles *in situ* according to a procedure outlined by Ward and Johnson, (1996). The technique is similar to the one used for measuring the metabolism of suspended microbes (as described previously) with a few alterations to account for the use of sediment. The oxygen content of the initial sample was collected in clear 300 ml BOD bottles and fixed immediately while in the field and titrated (Winkler titration) upon arrival in the lab, serving as the baseline oxygen level for that site. In order to measure the rate of O_2 consumption of benthic microbes, 10 cm^3 of sediment was added to the

incubated BOD bottle, which was again kept under water at the sample site (in blackened BOD bottles) and removed from the stream after a period of at least 48 hours but no more than 55 hours. Upon arrival at the lab, the incubated sample was fixed and treated with an Aluminum flocculation to allow the sediment to settle to the bottom, followed by a Winkler titration which was performed on the clear supernatant in 60ml BOD bottles, to determine DO (APHA, 1995). O_2 consumption (heterotrophic metabolism) was calculated by subtracting the amount of DO in the incubated sample from the amount of DO in the initial sample. The resulting number was then multiplied by 29 as a correction factor to account for the displacement of water by the 10 cm^3 of sediment (300 ml – 10 ml sediment volume = 290 ml; 290ml streamwater / 10 ml sediment = 29 ml streamwater / cm^3 sediment).

Heterotrophic density of benthic microbes (bact- s & fungi – s) was analyzed by performing a dilution scheme by preparing dilutions of 0.01, 0.001, and 0.0001 ml of sediment sample, followed by heterotrophic spread plate counts (APHA 1995). Heterotrophic plate count agar® was again used to determine bacterial density and Yeast extract-malt extract-glucose agar with Streptomycin Sulfate® and Terramycin® to eliminate bacterial contamination was used to determine fungal density. Incubation times for benthic plates were the same as incubation times for suspended microbe plates, bacterial plates were incubated at 35 °C for a period of 48 hours, while the fungal plates were incubated at 20 °C for 5 days. After the appropriate incubation time, growth was manually counted on both types of plates, using a Quebec colony counter. Plates containing the

dilution that produced 30-300 CFU's were selected for the bacterial plate count, while plates containing the dilution that produced 100-150 CFU's were selected for the fungal plate counts. The average number of CFU for the triplicate plates of the determined dilution were then divided by the actual volume of the sample on the plate to calculate CFU/ml (APHA, 1995).

Statistical analyses:

To address the first objective of this study (whether habitat quality has an effect on abiotic variables), an analysis of variance was used to determine if SHAP scores at each site were significantly different for habitat quality. This was followed by a Tukey test to establish where differences in habitat quality occurred among sites. To reduce the possibility of multicollinearity between data points, a correlation matrix was run which allowed the elimination of variables that were closely correlated with more than one additional variable in the data set ($P < 0.0036$). These variables were eliminated from any further analysis. Principle component analysis (PCA) was run to help condense the large data set of abiotic variables into new, easier to interpret variables. These new variables take every sampling date into account to create a newly derived abiotic variable for each site. The new variables were then used in an MANOVA to determine if differences in habitat quality (SHAP scores) have an effect on the composite abiotic variables.

In order to address the second objective (if a relationship exists between habitat quality and heterotrophic density and metabolism), a multiple regression

was performed to determine if SHAP metrics can be used to predict bacterial/fungal density and heterotrophic metabolism.

The third objective (which abiotic variables can be used to predict heterotrophic density and metabolism) was partially addressed by performing a regression analysis between VTS – s and benthic bacterial/fungal densities as well as heterotrophic metabolism to determine if a significant relationship exists. In addition, multiple regression analysis for water quality and sediment samples were ultilized to investigate the relationship between suspended heterotrophic density and metabolism against abiotic variables. All analyses were completed using SPSS version 11.0 for Windows statistical computer software.

Figure 1: Location of Embarras River watershed in Illinois.

Embarras River
Watershed

Figure 2: Location of six sample sites along the Embarras River and tributaries.

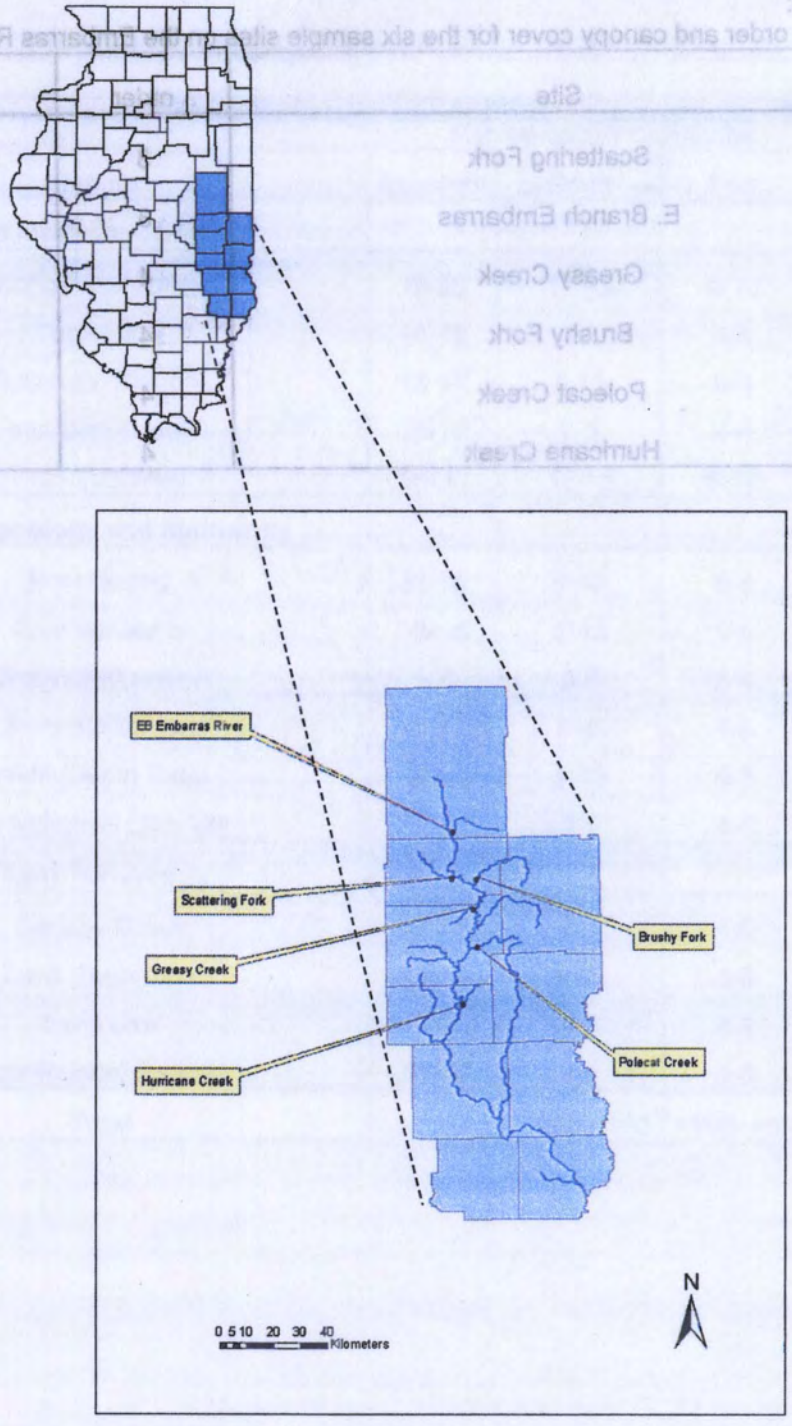
EB Embarras River
Scattering Fork
Greasy Creek
Hurricane Creek
Brushy Fork
Polecat Creek
N
0 5 10 20 30 40
Kilometers

Table 1:
Stream order and canopy cover for the six sample sites on the Embarras River Watershed

Site	order	% canopy
Scattering Fork	3	3.54
E. Branch Embarras	3	25.3
Greasy Creek	4	45.25
Brushy Fork	4	53.2
Polecat Creek	4	69.58
Hurricane Creek	4	87.52

Table 2:
SHAP Metrics and Habitat quality categories.

	Habitat quality categories			
Metric	Excellent	Good	Fair	Poor
Substrate and instream cover				
Bottom Substrate	16-20	11-15	6-10	1-5
Deposition	10-12	7-9	4-6	1-3
Substrate Stability	13-16	9-12	5-8	1-4
Instream Cover	10-12	7-9	4-6	1-3
Pool Substrate	16-20	11-15	6-10	1-5
Channel morphology and hydrology				
Pool Quality	13-16	9-12	5-8	1-4
Pool Variability	13-16	9-12	5-8	1-4
Channel Alteration	7-8	5-6	3-4	1-2
Channel Sinuosity	10-12	7-9	4-6	1-3
Width/Depth Ratio	13-16	9-12	5-8	1-4
Hydrological Diversity	10-12	7-9	4-6	1-3
Riparian and bank features				
Canopy Cover	10-12	7-9	4-6	1-3
Bank Vegetation	13-16	9-12	5-8	1-4
Land Use	7-8	5-6	3-4	1-2
Flow Related Refugia	10-12	7-9	4-6	1-3
Total	>=142	<142>=100	<100>=59	<59

RESULTS:

Habitat Quality:

When comparing overall habitat quality using SHAP (fifteen metrics) among our six sampling sites, an ANOVA determined that there was a significant difference in habitat quality among sites with some sites consisting of more favorable habitat while other sites consisted of less favorable habitat along the Embarras River and its tributaries. Three distinct habitat categories were established through a Tukey's post hoc test placing sites into poor, good, and excellent categories based on overall habitat quality (Figure 3, Table 3 & 4). Hurricane Creek, Scattering Fork, and the East Branch of the Embarras River were placed into the poor habitat category. Greasy Creek and Brushy Fork were both placed in the good category, while mean SHAP scores for Polecat Creek placed it in the excellent category.

Water quality variables:

Water quality parameters for the entire sampling year reveal that mean annual Temp ranged from 15.3 to 17.3 °C, Cond ranged from 502.11 to 636.85 mS, pH from 8.04 to 8.44, and Turb from 9.38 to 39.74 NTU. Temp, Cond, pH, and Turb were highest at the Scattering Fork sampling site while DO was highest in Polecat Creek with annual averages ranging from 5.24 to 15.82 mg/L across sites. Depth and flow were highest at the Brushy Fork sampling site, ranging from 0.3 to 0.48 m and 0 to 0.48 km/hr respectively. T Alk ranged from 241.05 to 249.89 mg $CaCO_3$/L across all sites, with Hurricane Creek having the highest T Alk measurements. Water Hardness was highest in the E.B. Embarras river site ranging from a low of 262.91 to a high of 324.63 mg $CaCO_3$/L (Table 5).

The mean annual TS ranged from a low of 390.67 at Greasy Creek to a high of 476.49 mg/L at Scattering Fork. VTS-w ranged from 135.85 to 172.20 mg/L at Hurricane Creek and Polecat Creek, respectively. SS rendered the opposite results with the lowest value of 36.00 mg/L obtained at Polecat Creek while the highest value was obtained at Hurricane Creek (69.47 mg/L). VSS ranged from a low of 6.79 at Polecat creek to a high of 18.10 mg/L at the E. Branch Embarras River. VDS ranged from 123.41 at Scattering Fork to 165.41 mg/L in Polecat creek (Table 5). The mean annual VTS-s for all sites ranged from 12.70 to 60.61 mg/g (Table 6).

The correlation matrix, which allowed us to identify variables that were closely correlated with the other variables measured, identified TS-w and VTS-w to be variables that were correlated to each other as well as T Alk, Temp, and VDS (Table 7). TS-w and VTS-w were removed from the total list of variables and were no longer considered in further analysis. Next a PCA was run, which produced newly created, easier to interpret variables called a regression factor. The regression factors represent all the measured abiotic variables for the entire sampling year for each sample site. Four regression factors were found to be significant with eigenvalues above 1, which were used in an MANOVA to look for overall differences in abiotic variables between sample sites. The analysis revealed that even though 3 separate SHAP categories were found, water quality variables were not statistically different across the sampling year between sites (Table 8 & 9).

Microbes and Habitat:

Bacterial density is the highest at Scattering Fork with 2,540 CFU/ml in the water column while E. Branch Embarras River has the lowest density with 1,256 CFU/ml. Suspended fungal densities were always drastically lower than bacterial densities with Brushy Fork having the highest count at 81 CFU/ml and Greasy Creek having the lowest with 14 CFU/ml. Oxygen consumption of suspended heterotrophic microbes was highest at the Scattering Fork sampling site (0.05 mg/L/hr) and lowest at Brushy Fork (0.02 mg/L/hr) (Table 5).

Benthic bacterial density ranged from 65,200 to 263,450 CFU/ml while fungal densities were again much lower, ranging from 2,288 to 8,029 CFU/ml. Oxygen consumption of benthic heterotrophic microbes ranged from 0.99 to 3.13 $mg/cm^3/hr$. The highest values for VTS-s, fungi-s and O_2 Cons-s were observed in the E. Branch Embarras River while the lowest values for these variables occurred in Polecat Creek. Bacterial density peaks occurred in Hurricane Creek and bacterial density was lowest at Scattering Fork (Table 6).

The multiple regressions for habitat quality using % canopy cover and each SHAP metric as well as the total score as independent variables determined that there were no usable models for predicting suspended bacterial/fungal density or heterotrophic metabolism. The multiple regression for habitat quality and benthic microbes showed that there is only one usable model for predicting benthic heterotrophic metabolism. Using substrate stability (SS), deposition (D) and in stream cover (IC), the model for heterotrophic metabolism explains approximately 36% of the variation ($P < 0.001$) and produced the

following equation for O_2 consumption = -0.693 (SS) + 1.234 (D) – 0.451 (IC) + 2.497 (Table 10).

Microbes and Water Quality:

Since suspended bacterial and fungal density are not correlated to each other (R = 0.259, P >0.05) or to heterotrophic metabolism (bacterial R = -0.193, fungal R = 0.022, P > 0.05), each variable was placed in the multiple regression model as three separate dependent variables while keeping all independent variables (water quality variables) the same, therefore creating three separate models for each variable. A significant multiple regression (R^2 =0.60) revealed that several abiotic factors were found to be significantly related to bacterial/fungal density and heterotrophic metabolism. The model for bacterial density indicated that VSS and DO were the two abiotic variables important to predicting bacterial density (Table 11) with the equation for calculating bacterial density = 14.621 (VSS) – 130.670 (DO) + 1918.67. The model for fungal density determined that VSS, VDS and DO helped explain almost 52% of the variation (P < 0.001) and has an equation for predicting Fungal density = 0.468 (VSS) – 1.058 (VDS) – 7.508 (DO) + 205.135 (Table 11). Using Temp and Cond, the regression for heterotrophic metabolism explains approximately 38% of the variation (P < 0.001) (Table 11). The equation for O_2 consumption = 1.393E –03 (Temp) + 6.931E –05 (Cond) – 9.94E-03.

Here, we again see that benthic bacterial and fungal density were not correlated to each other (R = 0.037, P >0.05) or to heterotrophic metabolism (bacterial R = -0.103, fungal R = 0.142, P > 0.05), therefore each variable was

analyzed individually in a linear regression analysis with VTS-s as the independent variable. The only dependent variable that had a significant relationship with VTS-s was O_2 Cons – s ($P < 0.05$). The linear equation is O_2 Cons – s = 3.775E-02 X + 0.631 which helps explain just over 40% of the variation in the data (Figure 4).

Figure 3: Average total SHAP Score for each sampling site

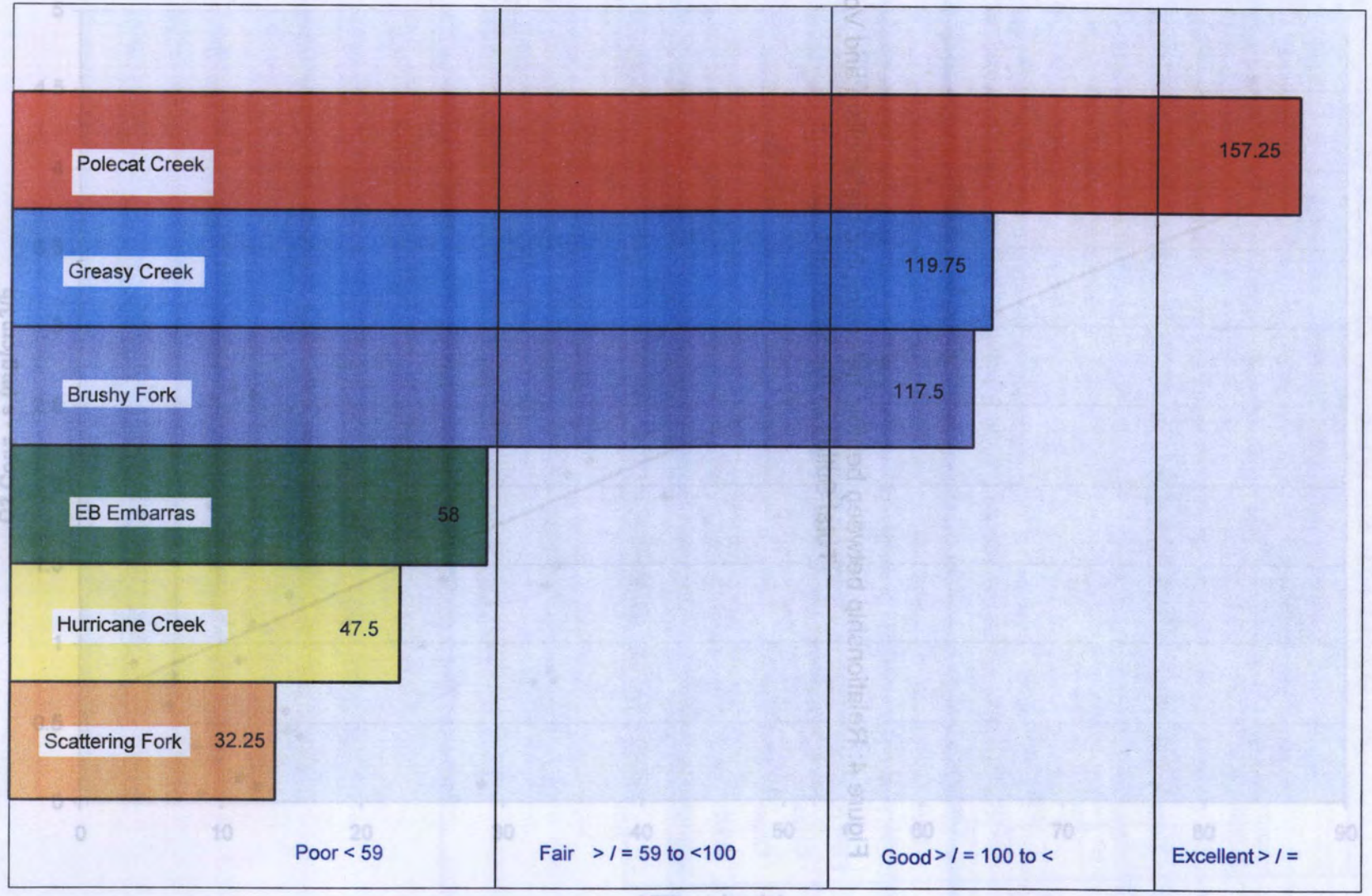
Polecat Creek
157.25
Greasy Creek
119.75
Brushy Fork
117.5
EB Embarras
58
Hurricane Creek
47.5
Scattering Fork
32.25
Poor < 59
Fair > / = 59 to <100
Good > / = 100 to <
Excellent > / =

Figure 4: Relationship between benthic heterotrophic metabolism and Volatile Total Solids in the sediment

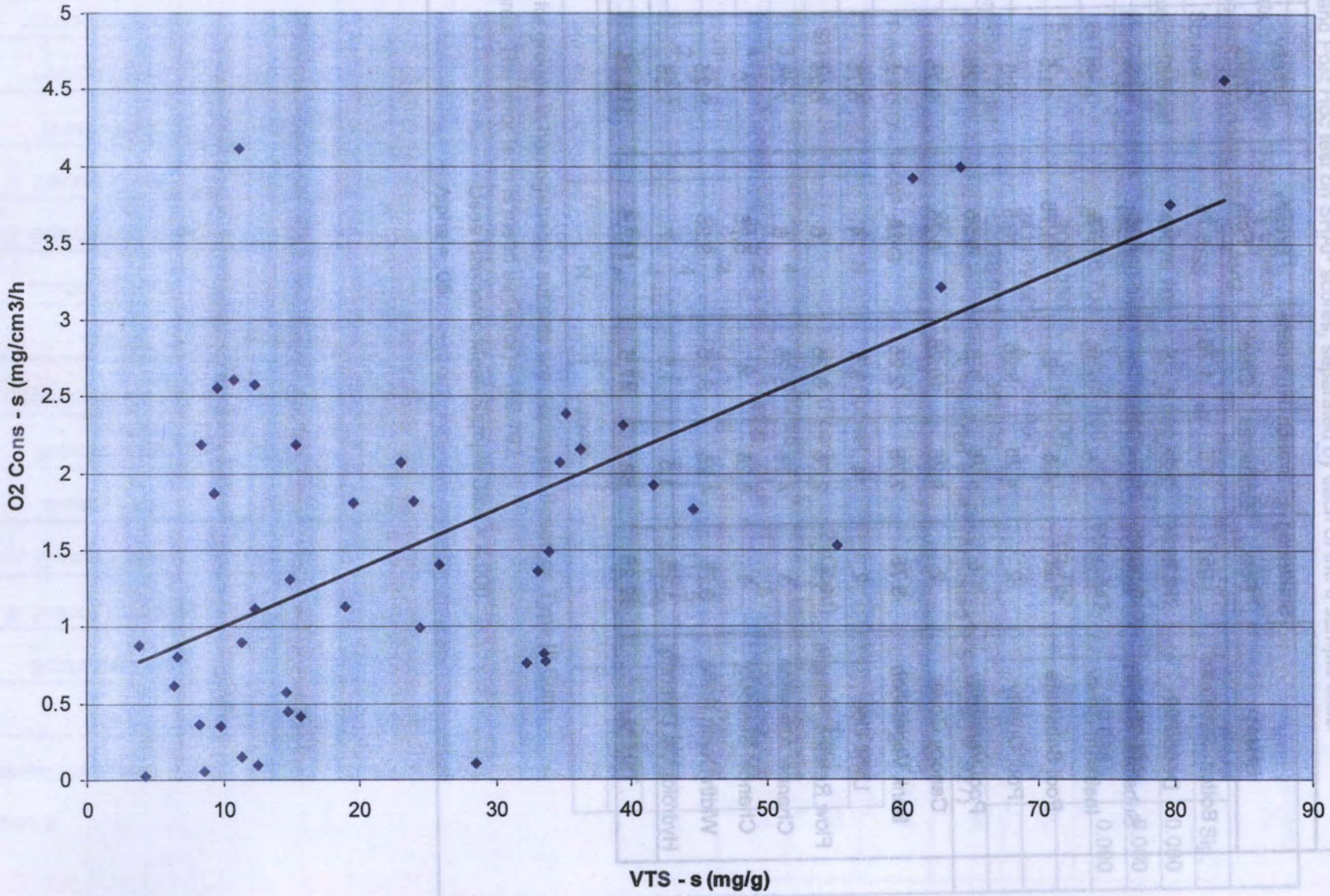
O2 Cons - s (mg/cm3/h
VTS - s (mg/g)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
0
10
20
30
40
50
60
70
80
90

Table 3:
Average SHAP scores for all 15 metrics at each of the six sample sites.

SHAP	Scattering Fork	E. Branch Embarras	Hurricane Creek	Brushy Fork	Greasy Creek	Polecat Creek
Bottom Substrate	1.5	1.5	1.75	8.75	8	15.5
Deposition	1.25	2.25	2	6	6.5	10.25
Substrate Stability	3.25	1.75	2	7.25	9.75	14.75
Instream Cover	1.25	2.5	3.25	7.75	6.25	8.5
Pool Substrate	1.25	4.5	2	11.75	11.5	15.5
Pool Quality	2	4.25	3.25	10.5	6.5	11.5
Pool Variability	1.5	1.75	1.5	9.25	4.25	11.75
Canopy Cover	2	9.25	10.25	8.25	9.75	11.75
Bank Vegetation	3.75	7.75	2.25	10	11.5	7.75
Land Use	2	4	3.5	4	5.75	6
Flow Related Refugia	1.5	2.75	3.25	6	6.25	7.5
Channel Alteration	3	4.75	3.25	6	7.25	7.5
Channel Sinuosity	3	5.25	4	5.75	10	7
Width/Depth Ratio	3.75	4.25	3.75	9.25	9.25	12
Hydrological Diversity	1.25	1.5	1.5	7	7.25	10
TOTAL	32.25	58	47.5	117.5	119.75	157.25

Table 4:
ANOVA and Post Hoc test on SHAP scores, separated by each of the 6 sample sites.

Tests of Between-Subjects Effects

Dependent Variable: SHAP_AVG

Source	SS	df	MS	F	Sig.
Corrected Model	49276.708	5.000	9855.342	59.088	0.000
Intercept	188860.042	1.000	188860.042	1132.311	0.000
SITE	49276.708	5.000	9855.342	59.088	0.000
Error	3002.250	18.000	166.792		
Total	241139.000	24.000			
Corrected Total	52278.958	23.000			

a R Squared = .943 (Adjusted R Squared = .927)

Tukey HSD - SHAP_AVG

	N	Subset		
SITE		1 (Poor)	2 (Good)	3 (Exc)
3	4	32.25		
4	4	47.5		
1	4	58		
2	4		117.5	
6	4		119.75	
5	4			157.25
	N	Subset		

Means for groups in homogeneous subsets are displayed. Based on Type III Sum of squares. The error term is mean sqr(error)= 166.792.

a Uses Harmonic Mean Sample Size = 4.000.

b Alpha = .05.

Table 5:

Annual averages for water quality variables collected at each of the six sample sites (Standard Deviation is noted underneath number).

Site	% canopy	temp (°C)	DO (mg/L)	pH	turb (NTU)	cond (mS)	depth (m)	flow (km/h)	hardn ($Mg/CaCO_3/L$)	T Alk ($Mg/CaCO_3/L$)
Scattering Fork	3.54	17.26	5.73	8.44	39.57	636.85	0.4	0.1	262.91	248.86
		9.71	3.24	0.28	30.24	104.32	0.09	0.25	47.42	34.96
E. Branch Embarras	25.3	15.6	7.34	8.21	20.24	597.48	0.3	0.27	324.63	253.68
		9.03	3.27	0.28	8.72	86.67	0.11	0.35	39.33	19.63
Greasy Creek	45.25	15.3	6.55	8.22	16.21	517.01	0.24	0	278.2	262.42
		8.62	4.16	0.34	28.19	119.96	0.19	0	34.84	71.47
Brushy Fork	53.2	15.83	5.24	8.04	15.07	568.67	0.48	0.28	296.43	241.05
		8.66	2.8	0.49	10.38	84.41	0.10	0.34	41.39	16.08
Polecat Creek	69.58	15.82	8.08	8.23	9.38	534.61	0.46	0	315.84	272.9
		8.48	3.67	0.31	6.03	121.82	0.18	0	27.84	45.59
Hurricane Creek	87.52	16.82	6.76	8.24	22.99	502.11	0.34	0.05	294.54	273.33
		8.14	2.79	0.30	20.35	144.91	0.16	0.12	46.31	33.47

Site	% canopy	TS (mg/L)	VTS-w (mg/L)	SS (mg/L)	VSS (mg/L)	VDS (mg/L)	bact-w (cfu/ml)	fungi-w (cfu/ml)	O_2 Cons-w (mg/L/hr)
Scattering Fork	3.54	476.4942	140.6906	59.5317	17.4272	123.4112	2540	66	0.0500
		56.5	44.79	40.59	14.39	43.44	2330	93	0.03
E. Branch Embarras	25.3	490.0495	167.7338	52.0635	18.1012	157.077	1256	39	0.0262
		106.91	77.82	38.08	23.40	80.42	723	50	0.02
Greasy Creek	45.25	390.6668	153.7224	31.3987	9.7627	143.9598	2043	14	0.033
		115.77	103.34	41.70	6.83	98.39	2717	14	0.03
Brushy Fork	53.2	451.3089	170.9137	47.7352	12.1397	158.5516	2206	81	0.0199
		104.56	100.00	27.38	7.15	101.60	2171	99	0.01
Polecat Creek	69.58	447.3086	172.1972	36.0019	6.786	165.4112	2196	59	0.0313
		122.32	108.44	27.18	6.73	109.18	2767	105	0.03
Hurricane Creek	87.52	436.1484	135.8522	69.4732	9.0484	125.0787	1463	70	0.0350
		99.01	75.76	68.08	8.25	76.71	1158	133	0.02

Table 6:
Annual averages for the sediment variables measured at each of the six sample sites (Standard deviation is noted underneath number).

Site	% canopy	VTS-s (mg/L)	bact-s (cfu/ml)	fungi-s (cfu/ml)	O_2 Cons–s ($mg/Cm^3/hr$)
Scattering Fork	3.54	30.7133 7.24	65200 84354	4317 7357	1.3352 0.72
E. Branch Embarras	25.3	60.6141 14.38	148813 132469	8029 15904	3.1330 1.13
Greasy Creek	45.25	13.4301 4.13	108238 76190	2748 1478	0.9724 0.84
Brushy Fork	53.2	16.4363 8.25	147517 205211	6102 8085	1.5594 0.99
Polecat Creek	69.58	12.6976 8.26	84108 43456	2288 1323	0.9882 0.74
Hurricane Creek	87.52	18.9623 13.36	263450 478756	3297 2565	1.6298 1.33

Table 7: Correlations for abiotic variables.

		Temp	DO	pH	Turb	Cond	Depth	Flow	Hardn	T_Alk	TS-w	VTS-w	SS-w	VSS-w	VDS
Temp	R	1.000	0.206	-0.261	0.210	0.176	0.056	0.252	-0.085	-0.195	0.233	0.450*	-0.035	-0.152	-0.135
	Sig.	.	0.140	0.059	0.131	0.208	0.710	0.144	0.571	0.161	0.093	0.001	0.805	0.276	.
	N	53	53	53	53	53	47	35	47	53	53	53	53	53	51
DO	R	0.206	1.000	0.264	-0.265	-0.247	-0.047	0.074	0.158	0.014	-0.131	-0.050	-0.257	-0.073	-0.261
	Sig.	0.140	.	0.056	0.055	0.075	0.755	0.674	0.288	0.921	0.348	0.723	0.063	0.601	0.140
	N	53	53	53	53	53	47	35	47	53	53	53	53	53	51
pH	R	-0.261	0.264	1.000	0.008	0.044	-0.198	-0.076	-0.108	0.119	-0.093	-0.284	-0.054	-0.013	-0.177
	Sig.	0.059	0.056	.	0.955	0.754	0.182	0.665	0.469	0.395	0.506	0.039	0.701	0.927	0.053
	N	53	53	53	53	53	47	35	47	53	53	53	53	53	51
Turb	R	0.210	-0.265	0.008	1.000	0.047	-0.037	0.130	-0.335	-0.152	0.346	0.155	0.779	-0.016	0.213
	Sig.	0.131	0.055	0.955	.	0.737	0.803	0.456	0.021	0.276	0.011	0.269	0.004	0.911	1.204
	N	53	53	53	53	53	47	35	47	53	53	53	53	53	51
Cond	R	0.176	-0.247	0.044	0.047	1.000	0.073	0.118	0.027	-0.028	0.205	0.175	-0.143	0.032	0.058
	Sig.	0.208	0.075	0.754	0.737	.	0.624	0.498	0.855	0.844	0.141	0.209	0.309	0.818	1.010
	N	53	53	53	53	53	47	35	47	53	53	53	53	53	51
Depth	R	0.056	-0.047	-0.198	-0.037	0.073	1.000	-0.108	-0.145	-0.194	-0.145	-0.005	-0.117	0.025	-0.056
	Sig.	0.710	0.755	0.182	0.803	0.624	.	0.538	0.364	0.191	0.329	0.975	0.435	0.869	0.578
	N	47	47	47	47	47	47	35	41	47	47	47	47	47	45
Flow	R	0.252	0.074	-0.076	0.130	0.118	-0.108	1.000	0.169	-0.003	0.238	0.352	0.059	-0.067	0.168
	Sig.	0.144	0.674	0.665	0.456	0.498	0.538	.	0.331	0.988	0.169	0.038	0.738	0.704	0.619
	N	35	35	35	35	35	35	35	35	35	35	35	35	35	35
Hardn	R	-0.085	0.158	-0.108	-0.335	0.027	-0.145	0.169	1.000	0.001	0.306	0.223	-0.139	-0.047	0.198
	Sig.	0.571	0.288	0.469	0.021	0.855	0.364	0.331	.	0.995	0.036	0.131	0.351	0.755	0.388
	N	47	47	47	47	47	41	35	47	47	47	47	47	47	46
T_Alk	R	-0.195	0.014	0.119	-0.152	-0.028	-0.194	-0.003	0.001	1.000	-0.675*	-0.807*	0.024	0.021	0.434
	Sig.	0.161	0.921	0.395	0.276	0.844	0.191	0.988	0.995	.	0.000	0.000	0.862	0.882	0.924
	N	53	53	53	53	53	47	35	47	53	53	53	53	53	51

TS-w	R	0.233	-0.131	-0.093	0.346	0.205	-0.145	0.238	0.306	-0.675*	1.000	0.776*	0.197	-0.149	-0.324
	Sig.	0.093	0.348	0.506	0.011	0.141	0.329	0.169	0.036	0.000	.	0.000	0.158	0.288	0.043
	N	53	53	53	53	53	47	35	47	53	53	53	53	53	51
VTS-w	R	0.450*	-0.050	-0.284	0.155	0.175	-0.005	0.352	0.223	-0.807*	0.776*	1.000	-0.053	-0.098	0.450
	Sig.	0.001	0.723	0.039	0.269	0.209	0.975	0.038	0.131	0.000	0.000	.	0.708	0.484	0.087
	N	53	53	53	53	53	47	35	47	53	53	53	53	53	51
SS-w	R	-0.035	-0.257	-0.054	0.779	-0.143	-0.117	0.059	-0.139	0.024	0.197	-0.053	1.000	-0.017	-0.135
	Sig.	0.805	0.063	0.701	0.004	0.309	0.435	0.738	0.351	0.862	0.158	0.708	.	0.903	0.549
	N	53	53	53	53	53	47	35	47	53	53	53	53	53	51
VSS-w	R	-0.152	-0.073	-0.013	-0.016	0.032	0.025	-0.067	-0.047	0.021	-0.149	-0.098	-0.017	1.000	0.279
	Sig.	0.276	0.601	0.927	0.911	0.818	0.869	0.704	0.755	0.882	0.288	0.484	0.903	.	0.721
	N	53	53	53	53	53	47	35	47	53	53	53	53	53	51
VDS	R	0.442	-0.011	-0.279	0.084	0.162	0.026	0.286	0.250	-0.798	0.753*	0.995*	-0.122	-0.101	-0.241
	Sig.	0.016	0.940	0.043	0.551	0.245	0.865	0.096	0.090	0.008	0.000	0.000	0.385	0.471	0.165
	N	53	53	53	53	53	47	35	47	53	53	53	53	53	51

* indicates Correlation is significant at the 0.05 level (2-tailed).

P Value is adjusted for multiple comparisons to P < 0.0036.

Table 8:
Total variance explained by each regression factor.

Total Variance Explained			
Component	Initial Eigenvalues		
	Total	Variance	Cumulative
1	2.2743	18.9522	18.9522
2	2.1159	17.6326	36.5848
3	1.7246	14.3718	50.9567
4	1.4838	12.3648	63.3214
Extraction Method: Principal Component Analysis.			

Table 9:

Multivariate analysis of variance for each regression factor separated by each of the 6 sample sites.

Tests of Between-Subjects Effects Dependent Variable: Regressions Factors (RF)						
Source	RF	SS	df	MS	F	Sig.
Model	RF 1	5.07	6	.84	.84	.54
	RF 2	7.14	6	1.19	1.28	.29
	RF 3	6.64	6	1.10	1.17	.34
	RF 4	7.24	6	1.20	1.30	.28
SITE	RF 1	5.07	6	.84	.84	.54
	RF 2	7.14	6	1.19	1.28	.29
	RF 3	6.64	6	1.10	1.17	.34
	RF 4	7.24	6	1.20	1.30	.28
Error	RF 1	28.92	29	.99		
	RF 2	26.85	29	.92		
	RF 3	27.35	29	.94		
	RF 4	26.75	29	.92		
Total	RF 1	34	35			
	RF 2	34	35			
	RF 3	34	35			
	RF 4	34	35			

a	R Squared = .100 (Adjusted R Squared = -.087)
b	R Squared = .212 (Adjusted R Squared = .049)
c	R Squared = .120 (Adjusted R Squared = -.062)
d	R Squared = .102 (Adjusted R Squared = -.083)

Table 10:

Multiple Regression Models for benthic microbes and SHAP metrics with correlations for each chosen variable, overall model significance and overall model R^2

SHAP	bacteria	fungi	O_2Cons
Bottom Substrate			
Deposition			+ 0.525
Substrate Stability			+ 0.420
Instream Cover			+ 0.599
Pool Substrate			
Pool Quality			
Pool Variability			
Canopy Cover			
Bank Vegetation			
Land Use			
Flow Related Refugia			
Channel Alteration			
Channel Sinuosity			
Width/Depth Ratio			
Hydrological Diversity			
Total SHAP score			
% CC (densiometer)			
Model P=			0.000
Model R^2			0.359

Table 11:

Multiple Regression Models for suspended microbes and water quality variables with correlations for each chosen variable, overall model significance and overall model R^2.

	bacteria	fungi	O_2 Cons
Temp			+ 0.537
DO	+ 0.776	+ 0.719	
pH			
Turb			
Cond			+ 0.620
Depth			
Flow			
Hardn			
T Alk			
SS			
VSS	+ 0.723	+ 0.494	
VDS		+ 0.644	
Model P=	0.000	0.000	0.001
Model R^2	0.602	0.517	0.384

DISCUSSION:

Habitat Quality:

An ANOVA on the SHAP results from our six sample sites separated the sites into three specific habitat quality categories. Hurricane Creek, Scattering Fork, and the East Branch of the Embarras River were categorized as having poor habitat quality. Greasy Creek and Brushy Fork are both good quality habitats, while only Polecat Creek was considered a site with excellent quality habitat. The separation of sites into habitat categories was not due to one particular habitat metric, or a specific grouping of metrics differing between sampling sites. What was observed was that if the final score for a sampling site was good, then most of the 15 metrics measured for that site were also rated in the same category as the overall score, thus revealing no specific metric differences between sites but illustrating an overall decline in all habitat parameters as the area degradates. The sample sites that were found to have poor habitat quality are described by their SHAP scores in ways that are consistent with what researchers would expect to find in agriculture watersheds. An example of this can be seen at the Scattering Fork sample site (poor quality) which has minimal to no canopy cover, sandy bottom substrate and minimal to no bank vegetation (Table 3) (Osborne and Kovacic, 1993; Tabacchi et al., 1998; Kaplan and Bott, 1989; Omernik et al., 1981). Roth et al. also observed this overall stream habitat degradation, in a study of a Michigan watershed where a significant negative relationship between habitat quality and extent of agriculture was found (1996).

Water quality variables

There seem to be some seasonal trends apparent in the data collected at the six sample sites that can help explain what was observed in the water quality data. In agricultural watersheds, spring brings with it the tilling and fertilization of fields, in preparation for the planting of crops. This process eliminates all ground cover causing field runoff to deliver increased amounts of nutrients, sediment and organic matter to a stream, initiating a peak in conductivity as well as VSS in the spring months (Osborne and Wiley, 1988)(Table 12).

Many variables are at their lowest during the winter months. Variables such as temperature, turbidity, volatile suspended solids, and volatile dissolved solids. This is a time when there are no leaves on the trees and they are no longer on the ground either, so organic matter input (VSS and VDS) is low which can also relate to low turbidity. Air temperatures are typically low in winter, which translates into low water temperatures (Table 13).

Since the six sample sites could be placed in three statistically different habitat categories, one would expect that these measured habitat differences would initiate differences in the aquatic abiotic factors measured at the specific study sites. However, this was not the case, no statistical difference was found for any of the measured abiotic factors among sites over the annual sampling period. The inability to observe the association between habitat quality and abiotic factors may be due to scale. The differences observed in habitat quality were measured at the local scale (reach), while the water collected at each site used to determine abiotic factors may have been affected by processes occurring

over a larger, regional area, The Embarras River basin. Thus the small sections of stream and riparian zone that were rated as good and excellent habitat quality by SHAP were not large enough areas to have a positive effect on the water quality of the basin, a concept also considered by other researchers (Allen et al., 1997; Johnson and Gage, 1997). These researchers looked at the importance of scale and found regional spatial scales to be more reflective of in stream habitat quality and biotic integrity compared to local spatial scales. Thus, because Illinois, and in this case specifically the Embarras River Basin, is made up of mostly agricultural habitat, the small patches of riparian zone and adjoining stream deemed as quality habitat are not influential enough to have a significant effect on the water quality and microbial density / activity of the system. This is not to say that local habitat quality improvements should not be made. Streamside vegetation does affect local temperature regimes, thus preventing excessive summer warming, as well as overland flow and organic matter input, and mediates terrestrial input of nutrients to downstream reaches (Roth et al., 1996; Gregory et al., 1991; Allen and Johnson, 1997; Karr and Schlosser, 1978). However, in our case, as well as others, it appears that numerous water quality factors are more significantly influenced by regional rather than local terrestrial habitat quality (Roth et al., 1996). Therefore, the differences we expected to see in the abiotic factors observed during this study did not correspond to the differences seen in habitat quality determined by SHAP scores determined at the reach scale.

Microbes and Habitat

We found no relationship between habitat quality and suspended microbes. In low order streams, the production of suspended microbes is thought to be small and seem to originate as benthic microbes. Benthic microbes are consequently sloughed off and placed in suspension and often washed downstream (Edwards et al., 1990). The lack of a relationship between suspended microbes and the surrounding habitat can therefore be explained because suspended microbes originate upstream and are not directly associated with the local habitat parameters where they were collected. However, possibly knowing exactly were these suspended microbes originated could reveal a significant relationship with the habitat variables of that particular area.

Benthic microbes do seem to be more dependent on habitat quality but only when related to metabolism. Microbial densities were not driven by any of the measured habitat parameters. However, microbial metabolism, measured as oxygen consumption, was driven by a positive relationship with substrate stability, deposition, and instream cover. Substrate stability is important because it leads to a more stable living environment with an abundance of surface area and habitat for numerical growth. A positive relationship with deposition also exists, which reveals a need by the microbes for a constant source of nutrients for metabolic processes. Lastly, instream cover shades the streams and maintains water at a cooler temperature allowing for the water to hold a higher level of dissolved oxygen and is therefore more likely to support increased heterotrophic activity. Thus, the positive relationships observed between

microbial metabolism and substrate stability, instream cover and deposition exists to influence oxygen consumption and ultimately lead to an increase in metabolism.

Microbes and Water Quality

The water quality model for suspended microbes reveals that VSS and DO are two factors important to both bacteria and fungi, whereas VDS is useful only to fungi. Bacterial and fungal densities both show a positive relationship with VSS and DO. Oxygen drives all heterotrophic systems while volatile suspended solids are important because they are made up of fractions such as course and fine particulate organic matter (CPOM and FPOM) which can serve as an energy source for microbes. Both bacteria and fungi use VSS as a source of nutrients, but it appears that bacteria ultimately out compete fungi for this energy source, therefore with time, eliminating VSS as an available food source for fungal densities. Suberkropp and Klug (1976) found that only in the initial stages of leaf breakdown by microbial colonization did fungi dominate in numbers over bacteria. After approximately 12-18 weeks of leaf processing, a switch occurs and bacteria dominate the breakdown process until completion. This would suggest that both types of microbes initially use VSS as a food source, but eventually, high densities of bacteria force fungi to switch to other available food sources. As seen by the statistical model, VDS was determined to be significant only to the fungal density model. Subsequently, in this study, the other energy source helping to determine fungal density appears to be volatile dissolved solids

(VDS), which is made up of components such as carbohydrates and glucose (APHA).

The water quality model for suspended heterotrophic metabolism is driven by temperature and conductivity. A positive relationship was seen between both of these water quality variables (temperature/conductivity) and metabolism. Like most heterotrophic organisms, as temperature increases metabolism also increases, while the importance of conductivity to microbial metabolism is still undetermined

Conductivity is routinely used as an index of dissolved ions and includes both negatively charged particles (nitrates, phosphates etc.) and positively charged particles (magnesium and sodium), which make up the inorganic portion of conductivity. The smaller, organic fraction of conductivity could act as a source of nutrients for heterotrophic metabolism (APHA). Conductivity is also temperature sensitive and increases with increasing water temperatures making it possible that conductivity may have no direct relationship with metabolism but was chosen for the regressions simply because of its close relationship with temperature (Cole, 1979). I do not believe this to be true in this study because the variables showed no collinearity in our statistical analyses. The last possibility is that the overall charge of these particles could be leading to the stimulation of heterotrophic microbial metabolism. Despite the undetermined nature of the relationship between microbial metabolism and conductivity, together with temperature, they both seem to influence oxygen consumption and ultimately lead to an increase in metabolism.

Benthic microbial densities did not have a statistically significant relationship with the volatile total solids in the substrate, however, their metabolism did. Studies have found that organic matter content of sandy substrates is higher than that of other substrates, and microbial production follows a similar trend (Kaplan and Bott, 1989, Crocker and Meyer, 1987). The relationships observed were probably due to the fact that there is plenty of surface area for microbes to grow on in the sandy substrate of the stream reaches sampled, making VTS irrelevant to their numerical growth. However, VTS present in the substrate represents the organic matter available as an energy source for microbes and consequently plays an important role in determining the metabolic rate of benthic microbes

Table 12: Seasonal averages for water quality variables collected during the spring at each of the six sample sites (4/30/03, 6/2/03). (Standard Deviation is noted underneath number when available)

Site	% canopy	temp (°C)	DO (mg/L)	pH	turb (NTU)	cond (mS)	depth (m)	flow (km/h)	hardn ($Mg/CaCO_3/L$)	T Alk ($mg/CaCO_3/L$)
Scattering Fork	3.54	19.84	5.95	8.42	48.19	665.50	0.32	0.61	282.62	241.19
		4.57	0.51	0.18	13.41	28.99	0.12	(n/a)	1.29	1.50
E. Branch Embarras	25.3	16.47	7.24	8.45	22.94	650.50	0.25	0.00	321.43	247.61
		2.88	1.82	0.25	0.23	17.68	0.01	(n/a)	1.39	1.56
Greasy Creek	45.25	19.07	8.02	8.20	4.63	564.00	0.23	0.00	265.71	227.38
		5.99	0.45	0.21	1.78	74.95	0.07	(n/a)	19.16	24.04
Brushy Fork	53.2	17.02	6.40	8.20	30.77	623.50	0.40	0.76	300.86	244.38
		1.58	0.83	0.04	1.98	19.09	0.11	(n/a)	5.42	3.01
Polecat Creek	69.58	18.20	10.68	8.29	10.30	596.50	0.41	0.00	297.75	246.50
		4.48	0.91	0.40	10.06	41.72	0.09	(n/a)	12.47	12.02
Hurricane Creek	87.52	18.85	6.75	8.28	6.40	583.00	0.19	0.29	338.79	260.32
		5.69	0.62	0.26	0.24	24.04	0.08	(n/a)	65.34	13.53

Site	% canopy	TS (mg/L)	VTS-w (mg/L)	SS (mg/L)	VSS (mg/L)	VDS (mg/L)	bact-w (cfu/ml)	fungi-w (cfu/ml)	O_2 Cons-w (mg/L/hr)
Scattering Fork	3.54	501.5556	187.3333	86.3452	27.8129	159.5204	4138	0	0.0390
		39.28	43.68	37.63	26.51	70.19	4518	0	0.04
E. Branch Embarras	25.3	422.8889	175.7778	57.5223	46.4667	162.8112	1549	0	0.0395
		62.54	0.31	1.05	46.20	1.49	1341	0	0.01
Greasy Creek	45.25	348.8889	150.6667	5.7143	10.8373	139.8294	4340	0	0.0370
		27.66	3.77	0.54	10.53	14.30	6025	0	0.05
Brushy Fork	53.2	435.7778	155.5556	82.7881	17.2206	138.3349	3812	35	0.0295
		40.54	1.89	8.93	5.96	4.07	4839	49	0.01
Polecat Creek	69.58	449.1111	199.3334	35.5608	12.6845	186.6488	747	0	0.0515
		11.63	12.26	40.65	14.33	26.59	674	0	0.07
Hurricane Creek	87.52	419.1111	153.1111	36.1760	7.1204	145.0741	762	0	0.0365
		72.28	51.23	19.64	0.36	50.29	125	0	0.00

Table 13:
Seasonal averages for water quality variables collected during the winter at each of the six sample sites (1/803, 3/12/03).
(Standard Deviation is noted underneath number when available)

Site	% canopy	temp (°C)	DO (mg/L)	pH	turb (NTU)	cond (mS)	depth (m)	flow (km/h)	hardn ($Mg/CaCO_3/L$)	T Alk ($mg/CaCO_3/L$)
Scattering Fork	3.54	5.09	9.25	8.63	9.54	585.00	0.40	0.00	288.66	245.44
		4.36	3.13	0.43	0.78	271.53	0.07	0.00	10.09	19.53
E. Branch Embarras	25.3	3.42	7.21	8.43	17.63	507.50	0.28	0.00	358.71	240.13
		3.18	1.87	0.01	16.04	184.55	0.24	0.00	12.84	21.04
Greasy Creek	45.25	4.65	10.69	8.66	3.64	424.50	0.17	0.00	266.28	227.38
		3.14	5.54	0.30	2.18	132.23	0.13	0.00	16.97	27.05
Brushy Fork	53.2	4.10	5.35	8.43	6.72	481.00	0.41	0.30	319.79	241.19
		3.07	0.32	0.07	6.00	168.29	0.02	0.42	26.60	22.54
Polecat Creek	69.58	5.78	11.19	8.59	12.83	484.00	0.69	0.00	318.82	243.32
		3.75	3.49	0.25	11.21	137.18	0.25	0.00	30.73	25.55
Hurricane Creek	87.52	8.04	8.15	8.50	26.94	414.00	0.20	0.00	251.44	246.50
		6.70	1.15	0.25	31.02	195.16	0.12	0.00	47.14	21.03

Site	% canopy	TS (mg/L)	VTS-w (mg/L)	SS (mg/L)	VSS (mg/L)	VDS (mg/L)	bact-w (cfu/ml)	fungi-w (cfu/ml)	O_2 Cons-w (mg/L/hr)
Scattering Fork	3.54	503.1112	103.1111	12.9143	5.1238	98.6540	1242	48	0.0351
		15.08	15.71	6.38	0.11	14.88	568	35	0.05
E. Branch Embarras	25.3	501.1111	123.3333	83.0953	12.9619	110.3714	1097	77	0.0033
		96.48	5.34	88.02	10.52	15.86	292	57	0.00
Greasy Creek	45.25	324.2223	84.6667	11.3096	5.9842	78.6826	970	9	0.0100
		24.83	11.63	6.16	2.54	9.09	52	12	0.00
Brushy Fork	53.2	409.1112	114.2223	28.4286	9.5238	104.6984	639	49	0.0117
		34.26	0.63	33.34	7.27	7.90	158	69	0.00
Polecat Creek	69.58	406.8889	93.3334	55.1000	8.3381	84.9952	618	9	0.0141
		14.77	3.77	34.27	1.14	2.63	148	2	0.01
Hurricane Creek	87.52	418.2223	86.6667	94.9334	7.7715	76.8286	587	15	0.0047
		40.86	30.80	111.09	5.06	38.79	151	11	(n/a)

CONCLUSIONS:

In conclusion, to answer the first question I set out to answer in my objectives, whether habitat quality has an effect on abiotic stream variables, we found that even though differences in local habitat quality could be seen amongst our sample sites across the Emberras River watershed, no differences in water quality variables could be found among sites. When investigating if a relationship existed between habitat quality and heterotrophic density and metabolism, I was only able to find one between benthic microbes and habitat quality. Lastly, I wanted to find the water quality variable and/or set of water quality variables that could be used to predict heterotrophic microbial density and metabolism. What I found was a list of variables that are useful in predicting the density and metabolism of heterotrophic microbes, but were different for each class of microbes (benthic/suspended and fungal/bacterial), indicating that no one set of water quality variables can be used to predict the activity or metabolisms of heterotrophic microbes as a unit.

The habitat assessment procedure used in this study (SHAP) is a protocol used to measure the local habitat quality of a particular reach of stream. It does not measure regional habitat quality and is limited to approximately 28 meters inland on both sides of the stream. Since the Embarras River watershed drains water from a largely agricultural land use area, SHAP is precise enough to detect the minute variations between each sample sites but is not broad enough to take the one analogous factor into account (similar landscape on a regional scale). In order to detect the variations that are most important in homogeneous landscapes such as that found in the Embarras River watershed, I think it would

be beneficial to come up with a broader, more regional approach to habitat assessment. No such protocol exists as of yet, but coming up with one could be helpful in future land use and stream management decisions. Since the desired positive effects of the small patches of quality habitat that currently exist don't have far reaching effects on water quality and overall habitat quality, inter-agency cooperation across regions with similar landscapes might be necessary. Regional habitat assessment could lead to better management plans for areas with similar landscape, land-use or watershed types. Setting regional standards for the conservation of watersheds in similar ecoregions may leave local biologists with the capacity to concentrate on the specific needs of their areas and might also encourage the transformation of currently existing small, remnant patches of high quality native habitat into larger more encompassing areas of higher quality habitat.

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APPENDICES

Appendix A: Water quality & microbial data for all collection dates & sample sites

site	sample	date	temp (°C)	DO (mg/L)	pH	turb (NTU)	cond (mS)	depth (m)	flow (km/h)	T Alk mg $CaCO_3$/L
1	a	6/24/02	23.70	8.43	8.07	28.00	615.00			0.00
	b	6/24/02	23.50	8.13	7.98	27.00	619.00			0.00
	c	6/24/02	23.50	7.99	7.93	28.00	621.00			0.00
avg		6/24/02	23.57	8.18	7.99	27.67	618.33	n/a	n/a	0.00
2	a	6/24/02	23.30	8.19	8.05	17.00	612.00			0.00
	b	6/24/02	23.20	7.95	7.94	19.00	612.00			0.00
	c	6/24/02	23.20	8.10	7.92	17.00	613.00			0.00
avg		6/24/02	23.23	8.08	7.97	17.67	612.33	n/a	n/a	0.00
3	a	6/24/02	23.00	7.28	7.91	37.00	640.00			363.00
	b	6/24/02	23.10	6.93	7.90	38.00	639.00			341.00
	c	6/24/02	23.10	10.98	7.90	50.00	639.00			286.00
avg		6/24/02	23.07	8.40	7.90	41.67	639.33	n/a	n/a	330.00
4	a	6/24/02	23.40	6.05	8.09	6.70	565.00			143.00
	b	6/24/02	23.20	6.15	7.99	8.90	572.00			44.00
	c	6/24/02	23.70	5.97	7.95	10.00	570.00			0.00
avg		6/24/02	23.43	6.06	8.01	8.53	569.00	n/a	n/a	62.33
5	a	6/24/02	24.60	8.79	8.13	11.00	624.00			0.00
	b	6/24/02	24.40	9.13	8.16	10.00	629.00			44.00
	c	6/24/02	24.40	9.12	8.17	8.50	629.00			70.00
avg		6/24/02	24.47	9.01	8.15	9.83	627.33	n/a	n/a	38.00
6	a	6/24/02	21.60	7.34	7.87	90.00	419.40			0.00
	b	6/24/02	21.50	7.30	7.72	80.00	520.20			0.00
	c	6/24/02	21.40	7.28	7.66	85.00	419.60			0.00
avg		6/24/02	21.50	7.31	7.75	85.00	453.07	n/a	n/a	0.00
1	a	7/30/02	26.60	12.42	8.09	6.9	594.0	0.35	1.15	268.13
	b	7/30/02	26.50	12.40	8.07	6.2	593.0	0.31	0.57	254.38
	c	7/30/02	26.80	12.37	8.05	6.2	586.0	0.37	0.57	316.25
avg		7/30/02	26.63	12.40	8.07	6.4	591.0	0.34	0.76	279.59
2	a	7/30/02	27.00	9.12	8.01	12.0	623.0	0.54	0.38	206.25
	b	7/30/02	26.90	9.10	8.02	9.1	625.0	0.60	0.22	295.63
	c	7/30/02	26.80	9.12	8.02	11.0	626.0	0.55	0.32	288.75
avg		7/30/02	26.90	9.11	8.02	10.7	624.7	0.56	0.31	263.54
3	a	7/30/02	31.50	5.64	8.44	30.0	613.0	0.44	0.00	226.88
	b	7/30/02	30.50	5.31	8.46	40.0	612.0	0.32	0.00	226.88
	c	7/30/02	31.30	5.25	8.47	34.0	612.0	0.55	0.00	226.88
avg		7/30/02	31.10	5.40	8.46	34.7	612.3	0.44	0.00	226.88
4	a	7/30/02	28.50	4.97	7.61	55.0	552.0	0.46	0.00	268.13
	b	7/30/02	28.80	4.94	7.62	12.0	551.0	0.57	0.00	261.25
	c	7/30/02	28.50	5.04	7.63	50.0	549.0	0.53	0.00	268.13
avg		7/30/02	28.60	4.98	7.62	39.0	550.7	0.52	0.00	265.84
5	a	7/30/02	28.20	7.31	8.02	5.7	274.5	0.50	0.00	268.13
	b	7/30/02	28.10	6.18	8.06	5.7	276.0	0.44	0.00	288.75
	c	7/30/02	27.70	6.48	8.08	5.6	272.1	0.16	0.00	275.00
avg		7/30/02	28.00	6.66	8.05	5.7	274.2	0.37	0.00	277.29
6	a	7/30/02	24.90	3.88	8.07	6.1	479.0	0.66	0.00	233.75
	b	7/30/02	25.00	3.96	8.06	5.8	479.0	0.68	0.00	233.75
	c	7/30/02	25.00	3.91	8.05	6.6	482.0	0.61	0.00	247.50
avg		7/30/02	24.97	3.92	8.06	6.2	480.0	0.65	0.00	238.33
1	a	9/2/02	25.90	10.80	8.40	17.00	591	0.155	0.00	281.88
	b	9/2/02	24.70	10.72	8.33	22.00	603	0.265	0.00	281.88
	c	9/2/02	26.10	11.05	8.39	15.00	580	0.300	0.00	261.25
avg		9/2/02	25.57	10.86	8.37	18.00	591	0.240	0.00	275.00

site	sample	hardn	TS-w	VTS-w
		mg $CaCO_3$/L	(mg/L)	(mg/L)
1	a	354.32	713.333	360.000
	b	329.6	704.000	349.333
	c	364.62	753.333	370.667
avg		349.513	723.555	360.000
2	a	350.2	744.000	426.667
	b	352.26	700.000	412.000
	c	368.74	704.000	453.333
avg		357.067	716.000	430.667
3	a	335.78	381.333	130.667
	b	350.2	386.667	145.333
	c	352.26	538.667	278.667
avg		346.080	435.556	184.889
4	a	298.7	586.667	230.667
	b	319.3	713.333	360.000
	c	311.06	716.000	353.333
avg		309.687	672.000	314.667
5	a	344.02	768.000	409.333
	b	346.08	769.333	454.667
	c	362.56	718.667	445.333
avg		350.887	752.000	436.444
6	a	259.56	664.000	374.667
	b	298.7	676.000	392.000
	c	269.86	640.000	428.000
avg		276.040	660.000	398.222
1	a	309.29	429.333	165.333
	b	321.11	409.333	169.333
	c	338.84	401.333	156.000
avg		323.08	413.333	163.556
2	a	311.26	466.667	174.667
	b	334.90	430.667	161.333
	c	319.14	464.000	174.667
avg		321.77	453.778	170.222
3	a	246.25	376.000	128.000
	b	222.61	429.333	149.333
	c	212.76	408.000	146.667
avg		227.21	404.444	141.333
4	a	263.98	466.667	142.667
	b	263.98	374.667	138.667
	c	281.71	460.000	138.667
avg		269.89	433.778	140.000
5	a	307.32	384.000	184.000
	b	267.92	381.333	168.000
	c	279.74	372.000	190.667
avg		284.99	379.111	180.889
6	a	234.43	321.333	152.000
	b	242.31	334.667	157.333
	c	232.46	330.667	154.667
avg		236.40	328.889	154.667
1	a	321.36	550.667	126.667
	b	350.20	549.333	100.000
	c	344.02	536.000	104.000
avg		338.53	545.333	110.222

site	sample	SS-w (mg/L)	VSS-w (mg/L)	VDS (mg/L)	bact-w (cfu/ml)	fungi-w (cfu/ml)	O2 C-w (mg/L/hr)	VTS-s (mg/g)	bact-s (cfu/ml)
1	a	35.082	6.557	353.443	400			32.495	
	b	36.250	5.000	344.333	1000			88.120	
	c	33.851	1.242	369.424	600			47.419	
avg		35.061	4.266	355.733	667	n/a	0.013	56.011	n/a
2	a	32.333	9.333	417.333	1600			9.832	
	b	43.488	10.000	402.000	2300			36.121	
	c	31.400	4.200	449.133	1800			7.828	
avg		35.740	7.844	422.822	1900	n/a	0.018	17.927	n/a
3	a	50.333	9.333	121.333	500			39.054	
	b	50.303	9.697	135.636	1700			35.306	
	c	54.400	12.000	266.667	2200			34.481	
avg		51.679	10.343	174.545	1467	n/a	0.039	36.280	n/a
4	a	3.400	3.400	227.267	2800			7.379	
	b	8.333	2.500	322.833	850			7.633	
	c	6.600	0.800	352.533	350			6.764	
avg		6.111	4.167	300.878	1333	n/a	0.061	7.259	n/a
5	a	15.400	5.000	404.333	300			5.796	
	b	16.600	4.800	449.867	500			9.748	
	c	15.400	3.200	442.133	600			7.516	
avg		15.800	4.333	432.111	467	n/a	0.052	7.687	n/a
6	a	130.263	23.026	351.640	400			18.269	
	b	136.250	21.875	370.125	400			23.771	
	c	111.333	21.333	406.667	1200			23.701	
avg		125.949	22.078	376.144	667	n/a	0.080	21.914	n/a
1	a	16.000	5.800	159.533	200	0		55.269	34000
	b	15.600	6.800	162.533	400	0		49.488	22500
	c	14.800	7.800	148.200	300	10		60.745	12000
avg		15.467	6.800	156.756	300	3	0.024	55.167	22833
2	a	55.200	11.200	163.467	850	0		11.274	23000
	b	42.600	10.400	150.933	1300	40		33.114	15500
	c	49.600	9.600	165.067	3400	10		14.158	23000
avg		49.133	10.400	159.822	1850	17	0.023	19.516	20500
3	a	54.800	18.400	109.600	300	0		33.859	12500
	b	92.000	20.400	128.933	1000	0		44.203	10500
	c	62.800	15.600	131.067	200	0		46.865	21000
avg		69.867	18.133	123.200	500	0	0.108	41.642	14667
4	a	152.609	4.348	138.319	4850	50		41.946	21000
	b	49.500	4.000	134.667	4250	10		37.694	15500
	c	157.273	7.727	130.939	3000	10		29.050	22000
avg		119.794	5.358	134.642	4033	23	0.033	36.230	19500
5	a	9.333	0.500	183.500	3150	10		41.138	12000
	b	7.667	0.333	167.667	4850	10		32.684	31000
	c	10.500	1.167	189.500	4650	0		25.254	9500
avg		9.167	0.667	180.222	4217	7	0.015	33.025	17500
6	a	18.000	6.200	145.800	900	20		10.906	30000
	b	15.800	6.400	150.933	1650	30		13.192	5000
	c	18.400	6.600	148.067	1450	10		9.933	17000
avg		17.400	6.400	148.267	1333	20	0.030	11.344	17333
1	a	34.722	18.056	108.611	1200	10		61.347	21600
	b	45.429	11.429	88.571	2680	20		67.207	15400
	c	34.667	6.667	97.333	2000	20		59.612	16000
avg		38.273	12.050	98.172	1960	17	0.046	62.722	17667

site	sample	fungi-s (cfu/ml)	O2 C-s (mg Cm^3/hr)
1	a		
	b		
	c		
avg		n/a	n/a
2	a		
	b		
	c		
avg		n/a	n/a
3	a		
	b		
	c		
avg		n/a	n/a
4	a		
	b		
	c		
avg		n/a	n/a
5	a		
	b		
	c		
avg		n/a	n/a
6	a		
	b		
	c		
avg		n/a	n/a
1	a	1500	
	b	4000	
	c	4500	
avg		3333	1.537
2	a	7500	
	b	320000	
	c	16500	
avg		12000	1.810
3	a	3500	
	b	1500	
	c	3500	
avg		2833	1.924
4	a	6500	
	b	3000	
	c	3500	
avg		4333	2.157
5	a	4000	
	b	2000	
	c	4500	
avg		3500	1.364
6	a	5000	
	b	5000	
	c	3200	
avg		4400	0.900
1	a	2300	
	b	2100	
	c	2800	
avg		2400	3.211

site	sample	date	temp (°C)	DO (mg/L)	pH	turb (NTU)	cond (mS)	depth (m)	flow (km/h)	T Alk mg $CaCO_3$/L
2	a	9/2/02	25.00	4.31	8.43	6.50	544	0.510	0.00	247.50
	b	9/2/02	24.90	4.22	8.41	4.00	529	0.535	0.00	247.50
	c	9/2/02	25.00	4.15	8.42	3.90	551	0.465	0.00	247.50
avg		9/2/02	24.97	4.23	8.42	4.80	541	0.503	0.00	247.50
3	a	9/2/02	26.30	2.94	8.68	80.00	617	0.415	0.00	316.25
	b	9/2/02	27.30	3.18	8.72	120.00	592	0.360	0.00	233.75
	c	9/2/02	26.70	2.90	8.71	80.00	630	0.505	0.00	233.75
avg		9/2/02	26.77	3.01	8.70	93.33	613	0.427	0.00	261.25
4	a	9/2/02	23.40	12.54	8.14	19.60	251	0.435	0.00	323.13
	b	9/2/02	22.10	12.48	8.13	20.30	226	0.470	0.00	316.25
	c	9/2/02	22.80	12.20	8.12	20.20	256	0.460	0.00	316.25
avg		9/2/02	22.77	12.41	8.13	20.03	244	0.455	0.00	318.54
5	a	9/2/02	19.60	5.32	8.26	4.96	568	0.420	0.00	316.25
	b	9/2/02	19.60	6.10	8.25	10.30	566	0.460	0.00	316.25
	c	9/2/02	19.70	5.70	8.22	16.30	568	0.260	0.00	323.13
avg		9/2/02	19.63	5.71	8.24	10.52	567	0.380	0.00	318.54
6	a	9/2/02	20.90	2.46	8.18	10.16	487	0.135	0.00	288.75
	b	9/2/02	20.70	2.42	8.17	17.60	486	0.080	0.00	309.38
	c	9/2/02	20.80	2.41	8.16	24.60	487	0.150	0.00	302.50
avg		9/2/02	20.80	2.43	8.17	17.45	487	0.122	0.00	300.21
1	a	10/6/02	16.50	2.75	7.85	30.0	606	0.39	0.86	223.13
	b	10/6/02	16.30	3.19	7.84	25.0	615	0.44	0.57	242.25
	c	10/6/02	16.50	3.25	7.84	31.0	598	0.26	0.57	229.50
avg		10/6/02	16.43	3.06	7.84	28.7	606	0.36	0.67	231.63
2	a	10/6/02	16.30	1.84	7.87	8.5	546	0.47	0.00	204.00
	b	10/6/02	16.30	1.84	7.86	9.7	538	0.51	0.00	216.75
	c	10/6/02	16.30	1.84	7.86	7.2	543	0.54	0.00	229.50
avg		10/6/02	16.30	1.84	7.86	8.5	542	0.51	0.00	216.75
3	a	10/6/02	16.90	0.05	8.55	75.0	689	0.37	0.00	248.63
	b	10/6/02	16.50	0.05	8.55	80.0	694	0.23	0.00	242.25
	c	10/6/02	16.90	0.05	8.55	70.0	677	0.44	0.00	242.25
avg		10/6/02	16.77	0.05	8.55	75.0	687	0.35	0.00	244.38
4	a	10/6/02	14.00	5.39	8.39	31.0	667	0.47	0.00	331.50
	b	10/6/02	14.10	4.74	8.37	9.2	668	0.51	0.00	331.50
	c	10/6/02	13.90	5.24	8.54	3.9	667	0.38	0.00	325.13
avg		10/6/02	14.00	5.12	8.43	14.7	667	0.45	0.00	329.38
5	a	10/6/02	16.10	0.90	7.72	10.0	618	0.33	0.00	408.00
	b	10/6/02	15.80	0.89	7.72	6.6	620	0.39	0.00	350.63
	c	10/6/02	16.10	0.88	7.72	4.7	620	0.20	0.00	325.13
avg		10/6/02	16.00	0.89	7.72	7.1	619	0.30	0.00	361.25
6	a	10/6/02								
	b	10/6/02								
	c	10/6/02								
avg		10/6/02	dry	dry	dry	dry	dry	dry	dry	dry
1	a	11/12/02	8.60	2.52	7.86	31	655	0.330	0.60	267.75
	b	11/12/02	8.20	2.75	7.85	7.7	655	0.480	0.00	280.50
	c	11/12/02	8.60	2.81	7.84	22	655	0.515	0.00	255.00
avg		11/12/02	8.47	2.69	7.85	20.23	655	0.442	0.20	267.75
2	a	11/12/02	8.80	0.40	6.86	15	589	0.450	0.00	223.13
	b	11/12/02	8.90	0.41	6.86	22	589	0.685	0.00	235.88
	c	11/12/02	8.80	0.34	6.86	20	589	0.730	0.00	229.50
avg		11/12/02	8.83	0.38	6.86	19	589	0.622	0.00	229.50
3	a	11/12/02	7.80	4.27	8.20	10	679	0.540	0.00	76.50

site	sample	hardn mg $CaCO_3$/L	TS-w (mg/L)	VTS-w (mg/L)
2	a	251.32	452.000	105.333
	b	271.92	449.333	125.333
	c	263.68	418.667	109.333
avg		262.31	440.000	113.333
3	a	201.88	541.333	102.667
	b	220.42	566.667	101.333
	c	214.24	520.000	109.333
avg		212.18	542.667	104.444
4	a	292.52	314.667	97.333
	b	317.24	310.667	98.667
	c	315.18	334.667	94.667
avg		308.31	320.000	96.889
5	a	335.78	364.000	117.333
	b	337.84	410.667	116.000
	c	346.08	402.667	144.000
avg		339.90	392.444	125.778
6	a	265.74	320.000	102.667
	b	267.80	346.667	117.333
	c	284.28	389.333	114.667
avg		272.61	352.000	111.556
1	a	301.10	444.000	174.667
	b	297.17	442.667	178.667
	c	301.10	450.667	166.667
avg		299.79	445.778	173.333
2	a	230.26	369.333	162.667
	b	222.38	364.000	162.667
	c	224.35	360.000	156.000
avg		225.66	364.444	160.444
3	a	190.90	509.333	170.667
	b	196.80	505.333	152.000
	c	196.80	522.667	177.333
avg		194.83	512.444	166.667
4	a	326.69	420.000	102.667
	b	320.78	400.000	102.667
	c	320.78	401.333	110.667
avg		322.75	407.111	105.333
5	a	344.40	509.333	128.000
	b	354.24	464.000	121.333
	c	338.50	425.333	124.000
avg		345.71	466.222	124.444
6	a			
	b			
	c			
avg		dry	dry	dry
1	a	336.53	456.000	109.333
	b	318.82	392.000	95.467
	c	303.00	425.333	108.000
avg		319.45	424.444	104.267
2	a	251.90	372.000	126.667
	b	267.65	418.667	125.333
	c	259.78	402.667	120.000
avg		259.78	397.778	124.000
3	a	259.78	385.333	93.333

site	sample	SS-w (mg/L)	VSS-w (mg/L)	VDS (mg/L)	bact-w (cfu/ml)	fungi-w (cfu/ml)	O2 C-w (mg/L/hr)	VTS-s (mg/g)	bact-s (cfu/ml)
2	a	17.000	5.000	100.333	2020	110		8.687	13100
	b	10.462	4.000	121.333	3680	230		9.471	25800
	c	10.769	4.615	104.718	6320	490		7.096	12400
avg		12.744	4.538	108.795	4007	277	0.018	8.418	17100
3	a	86.842	16.316	86.351	2800	210		20.421	3400
	b	153.333	30.833	70.500	2420	490		26.544	4600
	c	78.824	14.118	95.216	3600	90		24.899	8900
avg		106.333	20.422	84.022	2940	263	0.077	23.954	5633
4	a	35.600	6.800	90.533	1160	110		27.043	216000
	b	33.455	3.273	95.394	3400	0		24.613	107000
	c	30.909	5.818	88.849	1540	100		25.948	134000
avg		33.321	5.297	91.592	2033	70	0.032	25.868	152333
5	a	16.600	0.800	116.533	3060	50		5.922	11000
	b	52.800	1.000	115.000	2410	280		6.356	10900
	c	35.000	1.000	143.000	2950	110		7.042	18200
avg		34.800	0.933	124.844	2807	147	0.018	6.440	13367
6	a	18.333	5.667	97.000	480	0		9.865	145000
	b	49.000	5.000	112.333	1060	60		18.865	66000
	c	103.871	7.097	107.570	3620	10		15.705	161000
avg		57.068	5.921	105.634	1720	23	0.040	14.812	124000
1	a	48.800	8.000	166.667	1680	0		35.153	160000
	b	40.800	6.400	172.267	1790	20		37.182	125000
	c	45.600	15.200	151.467	2000	40		45.777	101000
avg		45.067	9.867	163.467	1823	20	0.038	39.371	128667
2	a	33.143	8.857	153.810	2050	0		11.641	115000
	b	85.500	7.500	155.167	1130	10		49.304	179000
	c	21.333	8.222	147.778	1830	40		8.297	86000
avg		46.659	8.193	152.251	1670	17	0.033	23.081	126667
3	a	100.833	27.500	143.167	7100	0		19.722	8400
	b	96.825	26.984	125.016	6000	30		19.017	12000
	c	92.500	48.333	129.000	3100	50		17.894	9200
avg		96.720	34.272	132.394	5400	27	0.039	18.878	9867
4	a	48.000	7.429	95.238	880	40		23.239	950000
	b	22.857	5.429	97.238	1310	30		39.125	2430000
	c	13.600	6.600	104.067	180	60		34.303	920000
avg		28.152	6.486	98.848	790	43	0.030	32.222	1433333
5	a	123.200	15.200	112.800	710	0		24.792	143000
	b	52.286	5.429	115.905	970	20		9.147	33000
	c	21.300	3.067	120.933	850	10		12.118	103000
avg		65.595	7.898	116.546	843	10	0.027	15.352	93000
6	a								
	b								
	c								
avg		dry	dry	dry	dry	dry	dry	dry	dry
1	a	88.000	11.600	97.733	1390	40		49.595	405000
	b	14.000	9.200	86.267	1540	320		40.122	360000
	c	58.400	12.400	95.600	850	0		43.854	395000
avg		53.467	11.067	93.200	1260	120	0.029	44.524	386667
2	a	40.000	20.667	106.000	1720	60		12.777	6400
	b	78.723	26.064	99.270	1940	140		8.824	25800
	c	70.000	27.647	92.353	920	310		4.481	19400
avg		62.908	24.793	99.207	1527	170	0.005	8.694	17200
3	a	11.143	8.000	85.333	2030	240		29.678	23400

site	sample	fungi-s (cfu/ml)	O2 C-s (mg Cm^3/hr)
2	a	410	
	b	360	
	c	290	
avg		353	2.190
3	a	200	
	b	150	
	c	270	
avg		207	1.817
4	a	10	
	b	520	
	c	10	
avg		180	1.410
5	a	10	
	b	280	
	c	10	
avg		100	0.611
6	a	340	
	b	60	
	c	500	
avg		300	1.310
1	a	1300	
	b	1100	
	c	400	
avg		933	2.311
2	a	2000	
	b	4700	
	c	2100	
avg		2933	2.070
3	a	700	
	b	500	
	c	600	
avg		600	1.136
4	a	6100	
	b	7500	
	c	4600	
avg		6067	0.765
5	a	1300	
	b	300	
	c	500	
avg		700	2.188
6	a		
	b		
	c		
avg		dry	dry
1	a	700	
	b	2600	
	c	1900	
avg		1733	1.761
2	a	100	
	b	1900	
	c	800	
avg		933	0.050
3	a	500	

site	sample	date	temp (°C)	DO (mg/L)	pH	turb (NTU)	cond (mS)	depth (m)	flow (km/h)	T Alk mg $CaCO_3$/L
	b	11/12/02	7.90	4.29	8.19	11	679	0.575	0.00	395.25
	c	11/12/02	7.80	4.33	8.21	10	679	0.490	0.00	140.25
avg		11/12/02	7.83	4.30	8.20	10	679	0.535	0.00	204.00
4	a	11/12/02	8.70	2.48	8.39	55	494.3	0.335	0.00	267.75
	b	11/12/02	8.80	2.44	8.39	60	494.4	0.555	0.00	255.00
	c	11/12/02	8.80	2.46	8.37	60	494.3	0.570	0.00	255.00
avg		11/12/02	8.77	2.46	8.38	58	494.3	0.487	0.00	259.25
5	a	11/12/02	6.30	6.69	8.25	3.75	563	0.450	0.00	242.25
	b	11/12/02	6.40	6.70	8.16	7.35	563	0.490	0.00	248.63
	c	11/12/02	6.30	6.85	8.20	4.02	563	0.350	0.00	248.63
avg		11/12/02	6.33	6.75	8.20	5.04	563	0.430	0.00	246.50
6	a	11/12/02	7.70	1.36	8.08	4.70	739	0.170	0.00	408.00
	b	11/12/02	7.80	1.34	8.06	6.20	738	0.160	0.00	408.00
	c	11/12/02	7.70	1.32	8.06	2.50	739	0.070	0.00	433.50
avg		11/12/02	7.73	1.34	8.07	4.47	739	0.133	0.00	416.50
1	a	1/8/03	1.30	5.96	8.43	37.30	377	0.125	0.00	255.00
	b	1/8/03	0.90	5.73	8.44	15.50	377	0.105	0.00	255.00
	c	1/8/03	1.30	5.94	8.42	34.10	377	0.115	0.00	255.00
avg		1/8/03	1.17	5.88	8.43	28.97	377	0.115	0.00	255.00
2	a	1/8/03	2.00	5.57	8.48	8.67	362	0.350	0.38	267.75
	b	1/8/03	1.70	5.56	8.48	12.20	362	0.450	0.57	255.00
	c	1/8/03	2.10	5.58	8.48	12.00	362	0.400	0.81	248.63
avg		1/8/03	1.93	5.57	8.48	10.96	362	0.400	0.59	257.13
3	a	1/8/03	2.10	7.04	8.32	9.97	393	0.200	0.00	274.13
	b	1/8/03	1.80	7.03	8.32	8.62	393	0.350	0.00	248.63
	c	1/8/03	2.10	7.02	8.32	8.39	393	0.505	0.00	255.00
avg		1/8/03	2.00	7.03	8.32	8.99	393	0.352	0.00	259.25
4	a	1/8/03	4.20	7.38	8.32	29.20	276	0.090	0.00	267.75
	b	1/8/03	4.50	7.36	8.32	100.00	276	0.135	0.00	267.75
	c	1/8/03	1.20	7.26	8.32	17.40	276	0.100	0.00	248.62
avg		1/8/03	3.30	7.33	8.32	48.87	276	0.108	0.00	261.37
5	a	1/8/03	3.20	8.72	8.41	9.84	386	0.190	0.00	248.63
	b	1/8/03	3.00	8.74	8.41	1.57	387	0.235	0.00	274.13
	c	1/8/03	3.20	8.70	8.42	3.29	387	2.165	0.00	261.38
avg		1/8/03	3.13	8.72	8.41	4.90	387	0.863	0.00	261.38
6	a	1/8/03	2.60	6.80	8.45	6.92	331	0.095	0.00	235.88
	b	1/8/03	2.30	6.77	8.45	5.55	331	0.083	0.00	242.25
	c	1/8/03	2.40	6.73	8.44	3.06	331	0.065	0.00	261.38
avg		1/8/03	2.43	6.77	8.45	5.18	331	0.081	0.00	246.50
1	a	3/12/03	5.70	8.16	8.42	6.30	638	0.410	0.00	216.75
	b	3/12/03	5.60	8.61	8.42	5.59	638	0.470	0.00	229.50
	c	3/12/03	5.70	8.83	8.42	6.98	638	0.471	0.00	229.50
avg		3/12/03	5.67	8.53	8.42	6.29	638	0.450	0.00	225.25
2	a	3/12/03	6.60	5.12	8.38	2.30	600	0.410	0.00	216.75
	b	3/12/03	6.10	5.12	8.38	2.91	600	0.485	0.00	229.50
	c	3/12/03	6.10	5.11	8.38	2.19	600	0.390	0.00	229.50
avg		3/12/03	6.27	5.12	8.38	2.47	600	0.428	0.00	225.25
3	a	3/12/03	8.40	11.72	8.93	9.20	777	0.480	0.00	235.88
	b	3/12/03	7.90	11.35	8.93	10.76	777	0.500	0.00	223.13
	c	3/12/03	8.20	11.30	8.93	10.30	777	0.375	0.00	235.88
avg		3/12/03	8.17	11.46	8.93	10.09	777	0.452	0.00	231.63
4	a	3/12/03	12.70	8.89	8.68	5.30	552	0.200	0.00	235.88
	b	3/12/03	13.10	8.95	8.68	5.98	552	0.310	0.00	229.50

site	sample	hardn mg $CaCO_3$/L	TS-w (mg/L)	VTS-w (mg/L)
	b	242.06	382.667	85.333
	c	228.29	384.000	85.333
avg		243.38	384.000	88.000
4	a	247.97	374.667	89.333
	b	263.71	456.000	92.000
	c	267.65	422.667	77.333
avg		259.78	417.778	86.222
5	a	285.36	326.667	109.333
	b	291.26	329.333	100.000
	c	287.33	316.000	81.333
avg		287.98	324.000	96.889
6	a	330.62	434.667	100.000
	b	354.24	438.667	92.000
	c	362.11	441.333	92.000
avg		348.99	438.222	94.667
1	a	387.25	582.667	124.000
	b	346.39	589.333	129.333
	c	369.74	536.000	105.333
avg		367.79	569.333	119.556
2	a	344.44	422.667	117.333
	b	332.77	438.667	114.667
	c	338.60	438.667	109.333
avg		338.60	433.333	113.778
3	a	276.33	512.000	92.000
	b	284.12	516.000	92.000
	c	284.12	513.333	92.000
avg		281.52	513.778	92.000
4	a	284.12	362.667	62.667
	b	284.12	620.000	70.667
	c	286.06	358.667	61.333
avg		284.77	447.111	64.889
5	a	356.12	429.333	98.667
	b	334.71	381.333	88.000
	c	330.82	378.667	85.333
avg		340.55	396.444	90.667
6	a	268.55	350.667	106.667
	b	278.28	344.000	92.000
	c	288.01	330.667	80.000
avg		278.28	341.778	92.889
1	a	396.98	410.667	114.667
	b	319.14	430.667	130.667
	c	332.77	457.333	136.000
avg		349.63	432.889	127.111
2	a	289.95	384.000	114.667
	b	305.52	382.667	110.667
	c	307.47	388.000	118.667
avg		300.98	384.889	114.667
3	a	323.04	486.667	108.000
	b	286.06	496.000	118.667
	c	278.28	494.667	116.000
avg		295.79	492.444	114.222
4	a	270.49	366.667	94.667
	b	295.79	398.667	114.667

site	sample	SS-w (mg/L)	VSS-w (mg/L)	VDS (mg/L)	bact-w (cfu/ml)	fungi-w (cfu/ml)	O2 C-w (mg/L/hr)	VTS-s (mg/g)	bact-s (cfu/ml)
	b	16.000	6.000	79.333	1750	20		26.528	13700
	c	10.857	9.428	75.905	1600	160		28.996	38200
avg		12.667	7.809	80.190	1793	140	0.040	28.401	25100
4	a	133.000	27.500	61.833	183	370		42.857	274000
	b	226.000	37.333	54.667	1600	450		21.644	203000
	c	168.000	26.000	51.333	2050	360		39.721	220000
avg		175.667	30.278	55.944	1278	393	0.046	34.741	232333
5	a	7.600	6.000	103.333	7400	60		4.640	131000
	b	32.800	8.000	92.000	11700	290		8.122	174000
	c	11.600	1.600	79.733	7000	510		7.200	73000
avg		17.333	5.200	91.689	8700	287	0.039	6.654	126000
6	a	20.400	12.400	87.600	1440	0		12.726	142000
	b	23.200	9.200	82.800	2630	80		15.480	281000
	c	6.571	8.571	83.429	1950	30		18.626	238000
avg		16.724	10.057	84.610	2007	37	0.020	15.611	220333
1	a	154.800	22.800	101.200	1360	110		75.311	209000
	b	162.400	26.400	102.933	1220	140		80.066	436000
	c	118.800	12.000	93.333	1330	100		82.982	206000
avg		145.333	20.400	99.156	1303	117	0.010	79.453	283667
2	a	36.800	14.400	102.933	710	50		4.997	171000
	b	54.800	15.200	99.467	880	180		20.201	179000
	c	64.400	14.400	94.933	660	60		11.562	97000
avg		52.000	14.667	99.111	750	97	0.025	12.253	149000
3	a	17.200	8.400	83.600	1700	60		29.326	191000
	b	4.000	5.200	86.800	1980	60		27.171	318000
	c	4.000	2.000	94.000	1250	100		29.217	255000
avg		8.400	5.200	88.133	1643	73	0.018	28.571	254667
4	a	74.857	8.857	53.810	880	20		2.501	147000
	b	352.000	12.400	45.867	720	20		22.614	96000
	c	93.600	12.800	48.533	480	30		20.333	188000
avg		173.486	11.352	49.403	693	23	n/a	15.149	143667
5	a	54.200	10.000	88.667	1260	0		11.290	136000
	b	12.200	5.400	82.600	530	10		14.397	108000
	c	26.200	7.200	78.133	380	10		8.339	74000
avg		30.867	7.533	83.133	723	7	0.001	11.342	106000
6	a	25.333	14.000	92.667	1860	40		9.050	235000
	b	10.667	3.667	88.333	330	10		20.095	158000
	c	11.000	5.667	74.333	610	0		7.666	189000
avg		15.667	7.778	85.111	933	17	0.040	12.270	194000
1	a	16.000	5.143	109.524	1370	20		53.626	119000
	b	13.429	4.857	125.810	790	70		52.868	76000
	c	33.143	6.571	129.429	510	20		75.516	130000
avg		20.857	5.524	121.587	890	37	0.006	60.670	108333
2	a	4.571	4.857	109.810	690	0		8.848	190000
	b	5.143	4.286	106.381	560	0		20.327	129000
	c	4.857	4.000	114.667	330	0		14.919	85000
avg		4.857	4.381	110.286	527	0	0.013	14.698	134667
3	a	19.429	5.714	102.286	930	10		34.519	31000
	b	17.143	5.143	113.524	410	10		33.700	80000
	c	15.714	4.286	111.714	1180	50		33.591	31000
avg		17.429	5.048	109.175	840	23	0.068	33.937	47333
4	a	9.714	4.286	90.381	540	20		4.391	69000
	b	23.714	4.857	109.810	450	0		3.929	36000

site	sample	fungi-s (cfu/ml)	O2 C-s (mg Cm^3/hr)
	b	2300	
	c	3300	
avg		2033	0.996
4	a	6200	
	b	10600	
	c	5500	
avg		7433	2.072
5	a	800	
	b	2000	
	c	2300	
avg		1700	0.799
6	a	2100	
	b	2800	
	c	8200	
avg		4367	0.410
1	a	1300	
	b	5900	
	c	3500	
avg		3567	3.747
2	a	3900	
	b	4900	
	c	2400	
avg		3733	2.580
3	a	23000	
	b	22000	
	c	22000	
avg		22333	0.105
4	a	2400	
	b	2500	
	c	3300	
avg		2733	n/a
5	a	3500	
	b	3900	
	c	2900	
avg		3433	0.144
6	a	3200	
	b	1000	
	c	500	
avg		1567	1.120
1	a	2200	
	b	2200	
	c	2100	
avg		2167	3.927
2	a	22000	
	b	20000	
	c	30000	
avg		24000	0.440
3	a	2100	
	b	4000	
	c	2300	
avg		2800	1.495
4	a	3600	
	b	900	

site	sample	date	temp (°C)	DO (mg/L)	pH	turb (NTU)	cond (mS)	depth (m)	flow (km/h)	T Alk mg $CaCO_3$/L
	c	3/12/03	12.50	9.04	8.68	3.72	552	0.340	0.00	229.50
avg		3/12/03	12.77	8.96	8.68	5.00	552	0.283	0.00	231.63
5	a	3/12/03	8.50	13.75	8.76	18.70	581	0.487	0.00	229.50
	b	3/12/03	8.30	13.56	8.75	33.20	581	0.583	0.00	216.76
	c	3/12/03	8.50	13.64	8.76	10.34	581	0.456	0.00	229.50
avg		3/12/03	8.43	13.65	8.76	20.75	581	0.509	0.00	225.25
6	a	3/12/03	6.90	14.66	8.88	1.83	518	0.235	0.00	204.00
	b	3/12/03	6.80	14.53	8.87	1.95	518	0.275	0.00	204.00
	c	3/12/03	6.90	14.60	8.86	2.53	518	0.285	0.00	216.75
avg		3/12/03	6.87	14.60	8.87	2.10	518	0.265	0.00	208.25
1	a	4/30/03	18.80	8.56	8.26	27.00	639	0.230	0.00	242.50
	b	4/30/03	18.30	8.54	8.27	23.50	638	0.220	0.00	255.00
	c	4/30/03	18.40	8.49	8.28	18.80	638	0.300	0.00	248.63
avg		4/30/03	18.50	8.53	8.27	23.10	638	0.250	0.00	248.71
2	a	4/30/03	18.20	6.95	8.17	39.30	610	0.380	0.57	248.63
	b	4/30/03	18.00	7.01	8.17	33.70	610	0.325	1.15	242.25
	c	4/30/03	18.20	6.99	8.17	15.10	610	0.250	0.57	248.63
avg		4/30/03	18.13	6.98	8.17	29.37	610	0.318	0.76	246.50
3	a	4/30/03	23.30	5.59	8.54	68.00	687	0.200	0.57	242.25
	b	4/30/03	23.10	5.60	8.54	47.10	686	0.215	0.63	242.25
	c	4/30/03	22.80	5.59	8.53	57.90	686	0.275	0.62	242.25
avg		4/30/03	23.07	5.59	8.54	57.67	686	0.230	0.61	242.25
4	a	4/30/03	22.90	7.20	8.09	4.14	566	0.220	0.86	255.00
	b	4/30/03	23.00	7.21	8.09	4.18	566	0.355	0.00	248.63
	c	4/30/03	22.70	7.17	8.09	10.37	566	0.180	0.00	248.63
avg		4/30/03	22.87	7.19	8.09	6.23	566	0.252	0.29	250.75
5	a	4/30/03	21.40	11.32	8.00	30.10	567	0.285	0.00	242.25
	b	4/30/03	21.30	11.33	8.01	5.44	568	0.400	0.00	235.88
	c	4/30/03	21.40	11.32	8.02	16.70	567	0.360	0.00	235.88
avg		4/30/03	21.37	11.32	8.01	17.41	567	0.348	0.00	238.00
6	a	4/30/03	23.30	8.33	8.05	7.41	511	0.245	0.00	210.00
	b	4/30/03	23.30	8.33	8.05	5.70	511	0.205	0.00	38.00
	c	4/30/03	23.30	8.34	8.05	4.55	511	0.090	0.00	216.75
avg		4/30/03	23.30	8.33	8.05	5.89	511	0.180	0.00	210.38
1	a	6/2/03	14.70	5.95	8.63	22.00	660	0.21		306.00
	b	6/2/03	14.30	5.96	8.62	27.60	664	0.24		248.63
	c	6/2/03	14.30	5.94	8.62	18.70	666	0.27		184.88
avg		6/2/03	14.43	5.95	8.62	22.77	663	0.240	n/a	246.50
2	a	6/2/03	15.90	5.79	8.23	26.00	637	0.555		235.88
	b	6/2/03	15.90	5.81	8.23	36.50	637	0.445		248.63
	c	6/2/03	15.90	5.84	8.23	34.00	638	0.430		242.25
avg		6/2/03	15.90	5.81	8.23	32.17	637	0.477	n/a	242.25
3	a	6/2/03	16.60	6.32	8.29	43.00	645	0.510		235.88
	b	6/2/03	16.60	6.30	8.29	34.80	646	0.315		235.88
	c	6/2/03	16.60	6.31	8.29	38.30	645	0.390		248.63
avg		6/2/03	16.60	6.31	8.29	38.70	645	0.405	n/a	240.13
4	a	6/2/03	16.20	6.29	8.47	5.20	600	0.170		261.38
	b	6/2/03	16.10	6.35	8.46	10.09	600	0.160		280.50
	c	6/2/03	16.20	6.30	8.44	4.41	600	0.080		267.75
avg		6/2/03	16.17	6.31	8.46	6.57	600	0.137	n/a	269.88
5	a	6/2/03	14.40	10.06	8.57	3.34	626	0.545		242.25
	b	6/2/03	15.30	10.04	8.57	3.14	626	0.495		255.00
	c	6/2/03	15.40	9.99	8.56	3.06	626	0.390		267.75

site	sample	hardn	TS-w	VTS-w
		mg $CaCO_3$/L	(mg/L)	(mg/L)
	c	88.01	402.667	116.000
avg		218.10	389.333	108.444
5	a	291.90	414.667	105.333
	b	315.25	461.333	93.333
	c	284.12	376.000	89.333
avg		297.09	417.333	96.000
6	a	260.76	294.667	70.667
	b	245.20	305.333	81.333
	c	256.87	320.000	77.333
avg		254.28	306.667	76.444
1	a	303.38	464.000	188.000
	b	334.90	476.000	177.333
	c	323.08	461.333	162.667
avg		320.45	467.111	176.000
2	a	299.44	469.333	152.000
	b	309.29	514.667	173.333
	c	305.35	409.333	145.333
avg		304.69	464.444	156.889
3	a	303.38	541.333	165.333
	b	273.83	552.000	157.333
	c	273.38	494.667	146.667
avg		283.53	529.333	156.444
4	a	271.86	361.333	116.000
	b	285.65	357.333	118.667
	c	297.47	385.333	116.000
avg		284.99	368.000	116.889
5	a	287.62	466.667	192.000
	b	275.80	390.667	192.000
	c	303.38	465.333	188.000
avg		288.93	440.889	190.667
6	a	256.10	329.333	141.333
	b	248.22	320.000	150.667
	c	252.16	338.667	152.000
avg		252.16	329.333	148.000
1	a	338.91	401.333	181.333
	b	323.68	358.667	182.667
	c	304.64	376.000	162.667
avg		322.41	378.667	175.556
2	a	289.41	384.000	157.333
	b	300.83	464.000	154.667
	c	300.83	373.333	150.667
avg		297.02	407.111	154.222
3	a	281.79	494.667	201.333
	b	282.17	469.333	225.333
	c	281.14	457.333	228.000
avg		281.70	473.778	218.222
4	a	300.83	461.333	177.333
	b	297.02	480.000	201.333
	c	279.89	469.333	
avg		292.58	470.222	189.333
5	a	312.26	454.667	218.667
	b		477.333	198.667
	c	300.86	440.000	206.667

site	sample	SS-w (mg/L)	VSS-w (mg/L)	VDS (mg/L)	bact-w (cfu/ml)	fungi-w (cfu/ml)	O2 C-w (mg/L/hr)	VTS-s (mg/g)	bact-s (cfu/ml)
	c	15.714	3.429	112.571	450	0		4.601	44000
avg		16.381	4.190	104.254	480	7	0.005	4.307	49667
5	a	66.857	6.286	99.048	330	20		5.621	122000
	b	133.429	14.000	79.333	550	10		26.994	85000
	c	37.714	7.143	82.191	660	0		11.312	104000
avg		79.333	9.143	86.857	513	10	0.023	14.642	103667
6	a	3.429	5.143	65.524	890	0		11.283	61000
	b	8.571	2.000	79.333	1670	0		10.186	49000
	c	8.857	5.429	71.905	460	0		16.057	85000
avg		6.952	4.191	72.254	1007	0	0.010	12.508	65000
1	a	57.200	112.200	176.800	460	0		75.506	39000
	b	62.000	114.400	162.933	310	0		63.777	63000
	c	55.600	10.800	151.867	1030	0		53.150	35000
avg		58.267	79.133	163.867	600	0	0.030	64.144	45667
2	a	107.200	12.800	139.200	320	0		8.838	157000
	b	130.500	45.500	127.833	540	0		11.369	31000
	c	29.600	6.000	139.333	310	0		8.707	47000
avg		89.100	21.433	135.456	390	0	0.040	9.638	78333
3	a	134.000	48.500	116.833	980	0		37.161	78000
	b	123.871	49.677	107.656	1230	0		33.964	15000
	c	81.000	41.500	105.167	620	0		34.588	53000
avg		112.957	46.559	109.885	943	0	0.070	35.237	48667
4	a	10.667	5.667	110.333	1040	0		16.846	98000
	b	14.800	8.400	110.267	550	0		8.647	72000
	c	41.389	8.056	107.944	430	0		7.656	31000
avg		22.285	7.374	109.515	673	0	0.040	11.050	67000
5	a	89.429	16.286	175.714	150	0		10.373	129000
	b	16.286	8.571	183.429	10	0		10.190	95000
	c	87.200	43.600	144.400	650	0		7.467	113000
avg		64.305	22.819	167.848	270	0	0.100	9.343	112333
6	a	6.571	18.000	123.333	20	2000		10.430	67000
	b	7.143	18.286	132.381	20	0		11.916	34000
	c	4.571	18.571	133.429	200	0		9.829	26000
avg		6.095	18.286	129.714	80	667	0.070	10.725	42333
1	a	46.333	11.000	170.333	2350	0		84.455	130000
	b	70.800	16.400	166.267	3210	0		83.282	283000
	c	53.200	14.000	148.667	1930	0		82.660	178000
avg		56.778	13.800	161.756	2497	0	0.049	83.466	197000
2	a	61.429	9.524	147.810	5800	160		6.683	650000
	b	96.000	15.500	139.167	11500	30		51.001	970000
	c	72.000	14.000	136.667	4400	20		43.422	290000
avg		76.476	13.008	141.214	7233	70	0.019	33.702	636667
3	a	64.800	8.800	192.533	15100	0		33.012	235000
	b	54.000	8.400	216.933	3300	0		33.458	35000
	c	60.400	10.000	218.000	3600	0		34.089	77000
avg		59.733	9.067	209.156	7333	0	0.008	33.519	115667
4	a	22.200	4.200	173.133	570	0		4.962	6300
	b	114.000	13.200	188.133	1520	0		2.938	5800
	c	14.000	3.200		460	0		3.604	17200
avg		50.067	6.867	180.633	850	0	0.033	3.835	9767
5	a	7.250	2.250	216.417	270	0		9.465	133000
	b	5.800	4.200	194.467	640	0		6.695	52000
	c	7.400	1.200	205.467	2760	0		13.208	118000

site	sample	fungi-s (cfu/ml)	O2 C-s (mg Cm^3/hr)
	c	1200	
avg		1900	0.018
5	a	2300	
	b	2500	
	c	2700	
avg		2500	0.576
6	a	2800	
	b	2100	
	c	4200	
avg		3033	0.100
1	a	5500	
	b	3500	
	c	5200	
avg		4733	4.000
2	a	1900	
	b	2200	
	c	3700	
avg		2600	2.560
3	a	3300	
	b	3000	
	c	2200	
avg		2833	2.390
4	a	3200	
	b	4500	
	c	2200	
avg		3300	4.110
5	a	5100	
	b	3000	
	c	2300	
avg		3467	1.870
6	a	2800	
	b	2100	
	c	2300	
avg		2400	2.610
1	a	400	
	b	2700	
	c	5200	
avg		2767	4.570
2	a	2000	
	b	2200	
	c	2600	
avg		2267	0.775
3	a	600	
	b	1200	
	c	900	
avg		900	0.820
4	a	300	
	b	200	
	c	800	
avg		433	0.877
5	a	3700	
	b	1500	
	c	3500	

site	sample	date	temp (°C)	DO (mg/L)	pH	turb (NTU)	cond (mS)	depth (m)	flow (km/h)	T Alk mg $CaCO_3$/L
avg		6/2/03	15.03	10.03	8.57	3.18	626	0.477	n/a	255.00
6	a	6/2/03	14.80	7.71	8.35	3.49	617	0.310		242.25
	b	6/2/03	14.90	7.68	8.35	3.40	617	0.325		242.25
	c	6/2/03	14.80	7.70	8.34	3.23	617	0.215		248.63
avg		6/2/03	14.83	7.70	8.35	3.37	617	0.283	n/a	244.38

site	sample	hardn	TS-w	VTS-w
		mg $CaCO_3$/L	(mg/L)	(mg/L)
avg		306.5600	457.333	208.000
6	a	281.79	374.667	153.333
	b	274.18	356.000	153.333
	c	281.79	374.667	153.333
avg		279.25	368.444	153.333

site	sample	SS-w (mg/L)	VSS-w (mg/L)	VDS (mg/L)	bact-w (cfu/ml)	fungi-w (cfu/ml)	O2 C-w (mg/L/hr)	VTS-s (mg/g)	bact-s (cfu/ml)
avg		6.817	2.550	205.450	1223	0	0.003	9.789	101000
6	a	4.500	4.667	148.667	18700	0		7.056	123000
	b	4.833	1.333	152.000	3800	0		7.159	57000
	c	6.667	4.167	149.167	3300	0		10.579	104000
avg		5.333	3.389	149.944	8600	0	0.004	8.265	94667

site	sample	fungi-s (cfu/ml)	O2 C-s (mg Cm^3/hr)
avg		2900	0.353
6	a	3000	
	b	2200	
	c	4300	
avg		3167	0.357

Appendix B: Raw data for 4 Stream Habitat Assessment Procedures for all sample sites.

	EB Embarras				
SHAP	1	2	3	4	Avg
Bot Sub	1	2	1	2	**1.5**
Depo	2	2	2	3	**2.25**
Sub Stab	2	2	2	1	**1.75**
Instr Cover	4	3	1	2	**2.5**
Pool Sub	6	7	2	3	**4.5**
Pool Qual	3	2	6	6	**4.25**
Pool Var	1	1	2	3	**1.75**
CC	7	10	10	10	**9.25**
Bank Veg	9	8	5	9	**7.75**
Land Use	4	4	4	4	**4**
Flow Refug	1	1	4	5	**2.75**
Chan Alt	3	3	7	6	**4.75**
Chan Sin	3	3	7	8	**5.25**
W/D ratio	5	5	4	3	**4.25**
Hydr Div	1	1	2	2	**1.5**
TOTAL	52	54	59	67	**58**

	Scattering Fork				
SHAP	1	2	3	4	Avg
Bot Sub	1	2	1	2	**1.5**
Depo	1	2	1	1	**1.25**
Sub Stab	5	5	1	2	**3.25**
Instr Cover	1	2	1	1	**1.25**
Pool Sub	1	2	1	1	**1.25**
Pool Qual	2	2	2	2	**2**
Pool Var	1	1	2	2	**1.5**
CC	2	2	2	2	**2**
Bank Veg	3	3	5	4	**3.75**
Land Use	2	3	2	1	**2**
Flow Refug	1	1	2	2	**1.5**
Chan Alt	3	2	3	4	**3**
Chan Sin	3	4	2	3	**3**
W/D ratio	2	3	5	5	**3.75**
Hydr Div	1	1	1	2	**1.25**
TOTAL	29	35	31	34	**32.25**

	Polecat Creek				
SHAP	1	2	3	4	Avg
Bot Sub	18	19	13	12	**15.5**
Depo	11	11	10	9	**10.25**
Sub Stab	16	15	14	14	**14.75**
Instr Cover	5	7	10	12	**8.5**
Pool Sub	14	16	16	16	**15.5**
Pool Qual	12	10	12	12	**11.5**
Pool Var	10	9	14	14	**11.75**
CC	12	11	12	12	**11.75**
Bank Veg	9	9	8	5	**7.75**
Land Use	6	7	5	6	**6**
Flow Refug	5	5	9	11	**7.5**
Chan Alt	8	8	7	7	**7.5**
Chan Sin	6	5	10	7	**7**
W/D ratio	11	9	14	14	**12**
Hydr Div	11	8	11	10	**10**
TOTAL	154	149	165	161	**157.25**

	Brushy Fork				
SHAP	1	2	3	4	**Avg**
Bot Sub	8	7	10	10	**8.75**
Depo	6	5	7	6	**6**
Sub Stab	5	4	9	11	**7.25**
Instr Cover	8	4	9	10	**7.75**
Pool Sub	15	7	12	13	**11.75**
Pool Qual	10	8	12	12	**10.5**
Pool Var	6	4	13	14	**9.25**
CC	6	6	10	11	**8.25**
Bank Veg	10	9	9	12	**10**
Land Use	3	5	4	4	**4**
Flow Refug	7	4	6	7	**6**
Chan Alt	5	5	7	7	**6**
Chan Sin	4	4	6	9	**5.75**
W/D ratio	9	7	9	12	**9.25**
Hydr Div	5	4	9	10	**7**
TOTAL	107	83	132	148	**117.5**
	Hurricane Creek				
SHAP	1	2	3	4	**Avg**
Bot Sub	2	3	1	1	**1.75**
Depo	2	2	2	2	**2**
Sub Stab	2	3	1	2	**2**
Instr Cover	2	2	5	4	**3.25**
Pool Sub	2	4	1	1	**2**
Pool Qual	3	2	4	4	**3.25**
Pool Var	2	2	1	1	**1.5**
CC	10	10	10	11	**10.25**
Bank Veg	3	2	2	2	**2.25**
Land Use	4	3	4	3	**3.5**
Flow Refug	3	2	4	4	**3.25**
Chan Alt	4	3	3	3	**3.25**
Chan Sin	4	4	4	4	**4**
W/D ratio	5	5	3	2	**3.75**
Hydr Div	2	2	1	1	**1.5**
TOTAL	50	49	46	45	**47.5**
	Greasy Creek				
SHAP	1	2	3	4	**Avg**
Bot Sub	8	8	10	6	**8**
Depo	8	5	8	5	**6.5**
Sub Stab	10	9	10	10	**9.75**
Instr Cover	7	5	6	7	**6.25**
Pool Sub	11	11	12	12	**11.5**
Pool Qual	7	6	7	6	**6.5**
Pool Var	5	2	5	5	**4.25**
CC	10	10	10	9	**9.75**
Bank Veg	12	13	12	9	**11.5**
Land Use	5	4	6	8	**5.75**
Flow Refug	9	6	5	5	**6.25**
Chan Alt	7	7	8	7	**7.25**
Chan Sin	10	8	11	11	**10**
W/D ratio	11	9	9	8	**9.25**
Hydr Div	7	6	8	8	**7.25**
TOTAL	127	109	127	116	**119.75**