ABSTRACT

Tullos, Desiree D. An Investigation of the Environmental Conditions and Processes Associated with Benthic Community Composition in Restored and Upstream Reaches of the North Carolina Piedmont (Under the direction of Gregory D. Jennings)

Benthic community response to restoration activities was investigated at 27 pairs of streams in an upstream-downstream study in the Piedmont of North Carolina. This was accomplished through various approaches to acquire different perspectives for exploring meaningful responses of the benthos to restoration. The four overall methods applied for this investigation are:

- traditional statistical analysis of environmental variables and common community indices,
- multivariate analysis of the community composition and their associated environment,
- development and application of a procedure for measuring habitat quality enhancement through the presence of specialists, and
- development of qualitative models for predicting community response.

While this investigation was applied to a wide range of land uses and the impacts of the landscape were demonstrated to be of importance in structuring benthic communities, constructive observations and conclusions can be made from the results. Each approach to exploring benthic community response provided unique insight into the effects of restoration activities on the biota and the means by which these effects are measured. The high variability of the physical and biological data constrained statistical inference, and illustrate the limited ability of paired t-tests with complex datasets. These results suggest more comprehensive methods may be required to determine meaningful responses from these complex communities. The multivariate analyses provide an alternative approach to exploring the effects of restoration. Results indicated a simplification of community occurred in restored reaches and suggested a strong influence of disrupted sediment transport may be responsible for the difference in communities. The development and application of a measure of habitat enhancement was also developed from this dataset. This study considered the presence of habitat specialists as indication of successful restoration of habitats. Finally, this data was used to develop Qualitative Reasoning (QR) models of the stream-watershed interactions, and simulate how those interactions affect benthic communities through the causal relations. The results identify areas for future research, specifically with respect to the relative importance of habitat and trophic conditions to the benthic macroinvertebrates. Further, these models provide a unique application of QR in stream ecology, and demonstrate the potential for application of QR in the education, research, and restoration of ecological systems. Combined, these studies contribute constructive knowledge to the science of stream restoration, the application of bioassessment, and the field of benthic ecology.

AN INVESTIGATION OF THE ENVIRONMENTAL CONDITIONS AND PROCESSES ASSOCIATED WITH BENTHIC COMMUNITY COMPOSITION IN RESTORED AND UPSTREAM REACHES OF THE NORTH CAROLINA PIEDMONT

by

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BIOGRAPHY

Desiree D. Tullos was born in Nashville, TN on September 1st, 1979. She earned her bachelor's degree from the University of Tennessee in Civil Engineering before moving to NC State University for a master's degree. Also in Civil Engineering, her master's project included a study of the flood effects of deforestation in an urbanizing watershed, performed under the direction of Rooney H. Malcom. Desiree entered the doctoral program at NC State in Biological Engineering under Dr. Greg Jennings in the fall of 2002 and will complete the program in May, 2005.

You are a child of the universe,
no less than the trees and the stars;
you have a right to be here.
And whether or not it is clear to you,
no doubt the universe is unfolding as it should.
-max ehrman

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INTRODUCTION

As streams respond to increasing urbanization and agricultural pressures, the aquatic communities, dependent on the stability of the physical and trophic structure in those ecosystems, decline (Roy et al. 2003). For example, the increase in magnitude and frequency of large storm events in urban areas results in increased scouring bank erosion (Horne and Goldman 1994). Effects of livestock access and increased nutrient loads from agricultural areas result in trampled streambanks, overgrowth of algae and macrophytes within the stream channel (Heliovaara and Vaisanen 1993, salmonrecovery.gov), and blanketing of coarse bed material with fine sediments (salmonrecovery.gov). Stream corridors may also suffer from removal of riparian vegetation, disrupted sediment transport, removal of meandering pattern through channelization, and imbalance of energy resources as a result of various anthropogenic activities.

The practice of stream restoration was developed in response to such "human activities [that] have severely altered and impaired aquatic ecosystems for centuries, [and] which has led to a decline in the ecosystem services provided by streams and rivers (NRC 1992, Wilcove and Bean 1994, Karr and Chu 1999)" (Moerke et al. 2004). For the past five years in North Carolina (http://www.nceep.net/), the application of stream restoration principles has attempted to mitigate these impaired ecosystems through hardening measures such as bank protection, grade controls, flow deflection/concentration, and bank stabilization (Brown 2000), as well as redefining channel dimensions, constructing new meanders, and revegetating streambanks and riparian areas to recreate more natural pattern, profile, and dimension. While numerous formal definitions exist, the National Research Council has defined stream restoration as the "various techniques used to replicate the hydrological, morphological, and ecological features that have been lost in a stream due to urbanization, farming, or other disturbance" (National Research Council 1992). However, many of the early restoration design approaches, including some of those studied for this project, focused more on the hydrologic and morphologic features, with less emphasis on comprehensive ecological restoration. This approach resulted in manipulation and restoration of channel geometry and form, but neglected restoration of overall stream function. As the science of stream restoration has matured, however, a shift from this form-focused approach to a broader view of streams as functioning ecosystems has occurred.

This critical shift of restoration focus is evident by the evolution from traditional monitoring of physical channel stability measures exclusively to advanced monitoring designs evaluating both biotic and abiotic integrity. Bioassessments, commonly used to evaluate "the biological condition of a water body [using] biological surveys and other direct measurements of the resident biota," have a rich and successful history in monitoring water quality (US EPA 1999). More recently, as scientists and regulators sought a more comprehensive approach to stream restoration monitoring, the application of benthic macroinvertebrate communities as an indication of successful stream recovery has initiated biomonitoring programs and research evaluating benthic responses to restoration activities.

Benthic macroinvertebrates, those aquatic insects living in or around the sediments and substrates of streams, have consistently shown sensitivity to complex ecological disturbances not well detected by chemical or physical indicators alone (Ohio EPA 1990). These organisms signal spatial and temporal disturbances that may not be evident from water quality monitoring or physical habitat assessment, making the monitoring of benthic communities valuable for evaluation of restoration activities. However, because such a wide range of physical, chemical, and biological interactions influences these organisms, exposing the true responses to habitat restoration activities can involve a complex suite of signals from the biota.

This feature of benthic communities makes determination of meaningful benthic response to restoration activities a complicated endeavor. It is the exploration of meaningful feedback from these complex communities that is the focus of this study.

The difficulty of biological assessment

The monitoring and assessment of restoration activities is an essential feature of this developing science, as it is important to document temporal effects and to "report failures so that project inadequacies can be identified and similar mistakes can be avoided in the future (Kondolf 1988)" (Moerke et al. 2004). However, determining the impacts of stream restoration is not a trivial or generic task because "assessing restoration success is not easily amenable to hypothesis testing using controlled experiments. At the scales involved, there are problems with balanced experimental design, lack of controls, and the time-course of experimentation (Michener 1997)" (Muotka and Laasonen 2002).

The complex nature of stream ecosystems requires exploration of a variety of approaches, with the focus of the biological function contributing a particularly complex level to these intricate and fascinating systems. Determining efficient monitoring features may be the simplest choice in the assessment of these projects. However, understanding and isolating the natural variation and adjustment, which varies across geographic, watershed, and local scales, of streams is a great challenge to the science. Further, the development and definition of expectations for stream restoration projects is a formidable responsibility, with influences of land use, stakeholders' concerns, and temporal uncertainty all contributing to this challenge.

Current Project

This dissertation explores benthic community responses to stream restoration activities, with various approaches applied to investigate the ecologically meaningful feedback. It is recognized that "benthic macroinvertebrates are capable of reflecting different anthropogenic perturbations through changes in structure or function in the assemblages and thus enable an overall assessment of streams" (Hering et al. 2004). Further, these organisms provide the fundamental base of the larger food web, making their existence essential to a functioning stream corridor ecosystem. Thus, it is essential that "the rehabilitation of lotic ecosystems [involve] an interdisciplinary approach that is focused upon recreating habitat characteristics and dynamics that will attract plant and animal colonists and support a sustainable ecosystem" (Gore 2001). The potential of benthic macroinvertebrates for detecting and supporting a functioning aquatic ecosystem is significant.

However, revealing meaningful responses is difficult. While "it is easy to measure decreases in dissolved oxygen downstream of a water treatment plant, increases in sedimentation downstream of a construction site, or changes in insolation following clearcutting, the difficulty is establishing to what degree these changes affect an ecosystem, how much they are outside the natural range of variability or disturbance frequency, and how these changes interact with other physical, chemical, or biological factors" (Nedeau et al. 2003). Thus, the complexity of stream ecosystems is reflected in benthic macroinvertebrates and isolating specific responses is often difficult. Further, the various numerical alternatives for benthic community description may influence the exhibited response. Determining which feature of a community is relevant to the changes initiated by restoration activities is a debated and nontrivial task, and one to which this study contributes constructive knowledge.

At each of the twenty-seven paired sites, benthic macroinvertebrates were collected according to the Qual5 method defined by the North Carolina Division of Water Quality (NCDENR 2003). Twenty environmental variables were also measured and recorded at each of these sites to characterize the physical and chemical conditions of the streams. This information was then used to investigate the effects of the restoration on the biological conditions.

This study explored how benthic communities were different in pairs of restored streams and associated upstream reaches. The four overall methods applied for this investigation are:

- traditional statistical analysis of common community metrics and indices,
- multivariate analysis of the community composition and their associated environment,
- development and application of a procedure for measuring habitat quality enhancement through the presence-absence of specialists, and
- development of qualitative models for predicting community response.

Chapter 1 describes simple paired t-test analysis, applied to compare the means of the twenty environmental variables, as well as five descriptions of community structure. These community measures include the Q diversity statistic (Kempton and Taylor 1976), Shannon's diversity index (Shannon and Weaver 1949), Simpson's dominance index (Simpson 1949), EPT taxa richness, NCBI (Lenat 1993), and Functional Feeding Groups (Merritt and Cummins 1996).

Multivariate techniques have been demonstrated to be superior to traditional indices for some applications (Reynoldson et al. (1997), Bailey et al. (1998), and Milner & Oswood (2000)). Chapter 2 presents the ordination of benthic communities and associated with environmental features of the streams, providing a unique perspective on the impacts of restoration activities on benthic communities. Non-metric Multidimensional Scaling (NMS) (Kruskal 1964) was applied to the family level benthic composition data, with overlays of the twenty environmental variables. While many ordination methods are available, NMS was selected due to its lack of assumptions regarding species response and environmental variable relations. Further, the requirement of this method for the user to define the dimensionality of the dataset, based on several criterion of a stable ordination analysis, provides insightful distinctions between datasets.

Chapter 3 explored the use of habitat specialists as indicator species for four habitat types: woody debris, coarse bed material, fine root hairs, and leaf packs. Comparison of the presence or absence of three specialists, for each habitat type, in the restored reaches relative to their upstream counterparts was used to indicate the success of the restoration activities in enhancing these benthic habitats. Habitat specialists were selected through an indicator species analysis (Dufrene and Legendre 1997), extensive literature review of habitat colonization studies, and consultation with local experts. Habitat ‘scores’ were then calculated based on both the individual habitat types and then combined into an overall habitat score.

Chapters 4 and 5 describe the development and simulation of QR models for predicting benthic community response to stream restoration, with comparison of alternative management options, in urban, stable, and agricultural watersheds. These Qualitative Reasoning (QR) models were developed according to the compositional approach

(Falkenhaier and Forbus 1991) and defined through Qualitative Process Theory (Forbus 1984). This approach defines systems by a library of partial knowledge model components. These partial models capture the extensive, but fragmented, base of existing knowledge on benthic ecology, with the modeling of ecological theory from the bottom-up confirming the validity of the structure and logic used to build this qualitative model. The aggregation of these partial models was first applied to demonstrate the effects of urbanization and riparian deforestation on benthic communities, defined simply as 'tolerant', 'mix', or 'intolerant.' This model was then extended to make predictions about the responses of benthic communities to four management practices: riparian restoration, construction of storm water Best Management Practices (BMPs), streambank stabilization, and a simplified stream restoration.

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CHAPTER 1

Characterization of Environmental Conditions and Benthic Insect Communities of Recently Restored and Upstream Reach Pairs in the Piedmont of North Carolina

Characterization of Environmental Conditions and Benthic Insect Communities of Recently Restored and Upstream Reach Pairs in the Piedmont of North Carolina

Abstract

To explore the impacts of restoration activities on biotic and abiotic features of North Carolina Piedmont streams, the environmental condition and benthic macroinvertebrate community composition of twenty-seven upstream-restored reach pairs were compared. Twenty environmental variables and numerous descriptions of biotic integrity, including taxa dominance and Simpson's Index, Functional Feeding Group (FFG) assemblages, North Carolina Biotic Index (NCBI), EPT taxa richness, Shannon Index, and the Q statistic diversity measures were evaluated to characterize the between-pair differences for a single site assessment. Paired t-tests were used to test the null hypothesis of no difference for each biotic and abiotic characteristic. The results indicated no statistical difference in the substrate characteristics of the restored and upstream reaches. Determination of a true similarity or difference in upstream and restored riparian areas was difficult due to conflicting indicators. No statistical difference was found for two of the variables describing riparian condition (woody debris volume and % cover), but statistical differences were found for several other variables (% woody coverage, infiltration, BEHI, and dry biomass). While the Q statistic diversity measure was found to be statistically different in the pairs, all other common community descriptions, including the Shannon diversity measure, lacked distinctness to detect differences. The strengths and weaknesses of each bioindicator for detecting the impacts of restoration activities are discussed, emphasizing the importance of bioindicator selection for reflecting targeted biological response. The cumulative results suggest an ambiguous impact of restoration activities on physical and biological stability, and they demonstrate

how the univariate t-test comparison applied here may not be the most appropriate way to explore the responses of complex ecological systems. The remarkably high variances demonstrated by the environmental variables and community descriptions, a function of the range of land uses evaluated for this study and the naturally high variability in stream ecosystems, suggest a low statistical power in the dataset. Thus, the inconsistent response in both the physical and biological features of the paired sites may be a result of this simplistic analytical method and not a true feature of the complex site conditions and variable interactions. A notable distinction between the pairs is evident through the consistent reduction in the variances of restored reach environmental variables and community descriptions as compared to the upstream counterparts. This reduction in complexity of both the physical and biological features of the restored streams suggests that homogenization of environmental condition and simplification of biotic communities may be a result of these early, form-focused restoration designs.

Introduction

As streams respond to increasing urbanization and agricultural pressures, aquatic communities, dependent on the stability of the physical and trophic structure in those ecosystems, decline (Roy et al. 2003). The increase in magnitude and frequency of large storm events in urban areas results in increased scouring bank erosion (Horne and Goldman 1994). Livestock access and increased nutrient loads from agricultural areas result in trampled streambanks, overgrowth of algae and macrophytes within the stream channel (Heliovaara and Vaisanen 1993, salmonrecovery.gov), and blanketing of coarse bed material with fine sediments (salmonrecovery.gov). Stream corridors may also suffer from removal of riparian vegetation, disrupted sediment transport, removal of meandering pattern through channelization, and imbalance of energy resources as a result of various anthropogenic activities. Responses of benthic communities can be seen as shifts toward low-oxygen-tolerant and autotrophic insects, as well as insects with morphological adaptations for living in unstable, fine-grained substrates.

For the past five years in North Carolina (http://www.nceep.net/), stream restoration practices have attempted to mitigate these increased stresses through hardening measures such as bank protection, grade controls, flow deflection/concentration, and bank stabilization (Brown 2000), as well as redefining channel dimensions, constructing new meanders, and revegetating streambanks and riparian areas to recreate a more natural pattern, profile, and dimension. While numerous formal definitions exist, the National Research Council has defined stream restoration as the "various techniques used to replicate the hydrological, morphological, and ecological features that have been lost in a stream due to urbanization, farming, or other disturbance" (National Research Council 1992). However, many of the early restoration design approaches, including some of those studied for this project, focused more on the hydrological and morphological features, with less emphasis on comprehensive ecological restoration.

This approach resulted in manipulation and restoration of channel geometry and form, but neglected restoration of overall stream function. As the science of stream restoration has matured, however, a shift from this form-focused approach to a broader view of streams as functioning ecosystems has occurred.

The evolution of the stream restoration science is demonstrated by the shift from monitoring an exclusive focus of physical channel stability measures to advanced monitoring designs evaluating both biotic and abiotic integrity. Bioassessments, commonly used to evaluate "the biological condition of a water body [using] biological surveys and other direct measurements of the resident biota," have a rich and successful history in monitoring water quality (EPA 1999). More recently, as scientists and regulators have sought a more comprehensive approach to stream restoration monitoring, the application of benthic macroinvertebrate communities as an indication of successful stream recovery has resulted in biomonitoring programs and research evaluating benthic responses to restoration activities.

Benthic macroinvertebrates, those aquatic insects living in or around the sediments and substrates of streams, have consistently shown sensitivity to complex ecological disturbances not well detected by chemical or physical indicators alone (Ohio EPA 1990). These organisms respond to spatial and temporal disturbances that may not be evident from water quality monitoring or physical habitat assessment, making the monitoring of benthic communities valuable for evaluation of restoration activities. However, because such a wide range of physical, chemical, and biological interactions influences these organisms, determining their true responses to habitat restoration activities can involve the interpretation of a complex suite of signals from the biota.
This feature of benthic communities makes determination of meaningful benthic response to restoration activities a complicated endeavor.

Methods/Materials

Study Sites

A total of 27 pairs of restored and upstream reaches were studied across the Piedmont of North Carolina for this project (Figure 1). Study sites were sampled from May to August of 2003 and 2004 to minimize seasonal effects on environmental variables and aquatic insects. Sites were limited to drainage areas of 13km^2 or smaller to further minimize environmental and community variation, with streams demonstrating a bankfull width range of 2.1m to 11.2m. The sites' Soil Conservation Service Curve Numbers (SCS-CN) ranged from 54 to 83 (Soil Conservation Service 1975), with landscapes varying from urban to agricultural to rural settings. Riparian area conditions varied, including mature and immature forest, herbaceous cover, and lawn grass. Stream substrates were composed of anything from silt to coarse gravel, with a median particle diameter range of .01 mm to 32mm, and water slopes measured from as little as 0.07% to as high as 2.67%. These characteristics represent the broad range of physical conditions at these sites, influencing the feeding and morphological features of the benthic communities collected.

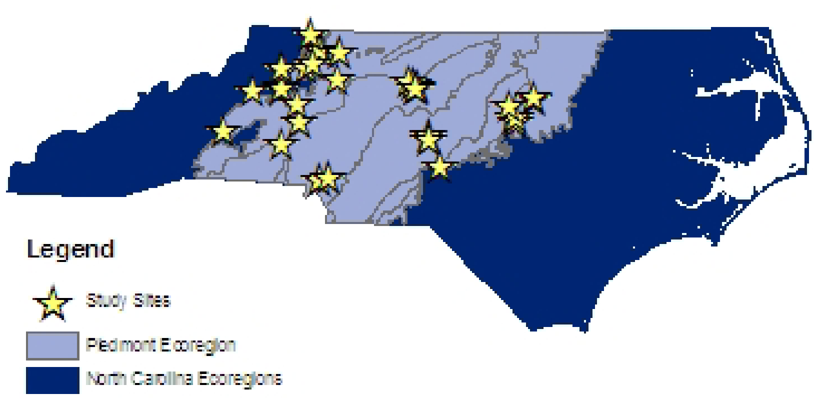

Figure 1 – Location of study sites in the North Carolina Piedmont. The Piedmont spans the central part of the state, bounded by the coastal plain to the east and the mountains to the west.

Environmental Characterization

Twenty environmental variables, detailed in Table 1, were measured to characterize the condition of the stream corridor. All variables were tested for normality prior to analysis and were log transformed if skewness coefficients exceeded 1.0. Data that required this transformation are noted in Table 1 with a *, with only the raw, untransformed means and the variances reported in the table for interpretability.

These variables were chosen to represent various aspects of the stream corridor, including characterization of the streambed particles, flow conditions, energy expended across the reach, the riparian condition, the trophic processes, streambank stability, habitat heterogeneity, and general water quality. A brief summary of these features is provided.

The "D90" and "% sand or finer" variables represent important features of the particle size distribution, calculated to characterize the streambed. The D90 is the size particle for which 90% of the sample is finer; it relates to the thickness of the active bed layer (Abbe and Montgomery 1996). When only fine particles move during high-flow events, this indicates a lack of coarse bed material in the stream, a critical condition for benthic organisms because "sand and silt are generally the least favorable substrates for supporting aquatic organisms and support the fewest species and individuals" (FISRWG 1998). Percentage sand or finer represents the contrasting finer fraction of the bed particles, and it provides a simplistic measure of embeddedness, or "the degree to which fine sediments surrounds coarse substrates" (Sylte and Fischenich 2002). Open pore spaces between coarse sediments are critical habitat for many benthic organisms, and sedimentation of these habitats often results in a well-recognized loss of sensitive taxa requiring coarse substrates and hyporheic zone access (Boulton et al. 1997).

Flow conditions were characterized by the "SCS-CN" and the "friction factor". The SCS-CN reflects the volume of runoff contributed by a watershed (Soil Conservation Service 1975) through difference in the land use and soil conditions. Friction factor (f) is a measure of the boundary resistance to flow and is a function of flow depth and particle size at bankfull flows. Developed by researchers in the fluid mechanics field, including Moody (1944) and Rouse (1946), the friction factor is typically used in hydraulic engineering to represent the frictional resistance in pipe flow but was applied here as a reflection of bed heterogeneity.

Equation 1 – Friction Factor f (from Leopold, Wolman, and Miller 1964)

$$\frac{1}{\sqrt{f}} = 2.03 Log\left(\frac{3.11d}{D_{84}}\right)$$

d = bankfull depth (ft)

D_{84} = particle size for which 84% of the distribution is finer (mm)

The "Width-Depth Ratio (WDR)" and "water slope" were calculated to describe the energy expended across the reach. The width-depth ratio "indicates the shape of the channel cross-section (ratio of bankfull width/mean bankfull depth)" (Rosgen 1996), increasing as channels widen in response to increased capacity requirements or imbalanced sediment transport. The water surface slope "is a major determinant of river channel morphology, and of the related sediment, hydraulic, and biological functions" (Rosgen 1996), and was measured as the change in water surface elevation across the length of the longitudinal profile.

The riparian condition was characterized through variables such as "% woody coverage", "% herbaceous coverage", and "infiltration". Percentage woody coverage and % herbaceous coverage reflect the abundance of woody and herbaceous vegetation across transects perpendicular to the stream. Infiltration was measured to investigate the level of compaction by heavy equipment during construction of restoration activities, which often affects the survival of vegetation following construction.

"Percentage stream cover" and "detrital biomass" were calculated as surrogates for trophic conditions in the streams. Percentage stream cover represents the amount of the stream shaded from direct sunlight, influencing the growth of algae, periphyton, and macrophytes. Detritus, the leaf material originating outside of the stream channel, serves as a crucial energy source for shredding and scraping taxa and subsequently for filtering/gathering collectors downstream. Detrital material is associated with well-forested areas but also washes downstream during seasonal flooding. Thus, even in unforested areas, organic leaf material may be present if well-forested riparian areas exist upstream and retentive material is present.

Streambank stability is represented by the "Bank Erosion Hazard Index (BEHI)" (Rosgen 2001). This index of bank erodability utilizes "key streambank characteristics ... identified [to] be sensitive to the various processes of erosion" (Rosgen 2001). With this method, risk of bank erosion is ranked from very low to extreme based on a ranking of five factors related to streambank vegetative and geometric features:

- Bank height ratio (bank height/bankfull height)
- Root depth/Bankfull height
- Root density
- Bank slope
- Percentage surface area protected

Habitat heterogeneity is represented by the "volume of woody debris" and the "ratio of pools" per length of the longitudinal profile. The amount of woody debris in a stream is indicative of the supply from a mature forest in the riparian areas adjacent to the stream. Fallen branches and tree trunks serve as crucial habitat for many organisms, including the case-building caddisflies of the Limnephilidae family and many of the riffle beetles in the Elmidae family. Woody material also serves as refugia for other insects during high-flow events. The number of pools across the longitudinal profile provided a measure of the habitat heterogeneity in the reaches. Pools provide important energy dissipation for streams, with finer bed material typically found in these deeper and flatter-sloped features.

"Specific conductivity" and "dissolved oxygen (DO)" were measured at each site to characterize the general quality of the water. Specific conductivity reflects the total dissolved salts (ions) in the water and provides an approximation of water quality. DO measures the concentration of free molecular oxygen dissolved in water and indicates a stream's ability to support aquatic life. Some taxa, including many in the Stonefly order, are particularly sensitive to low DO conditions, while other, such as Chironomidae larvae, are adapted to live in streams were oxygen has been depleted.

<u>Benthic Macroinvertebrates</u>

Benthic macroinvertebrates were collected according to North Carolina Division of Water Quality (NCDWQ) Qual 5 method (NCDENR 2003). This protocol includes sampling insects from one riffle with a kicknet and one sweep net collection from bank habitats, fine mesh wash of rock/log, one leaf pack wash, and visual collections. Insects were picked from samples, preserved in 95% ethanol in the field and then brought back to the lab for identification to species when possible.

Numerous methods exist for describing benthic community structure and function (Karr and Chu 1999), and for this study, several of these descriptions were compared. They characterized the communities by a variety of approaches, including aspects of water quality tolerance (NCBI and EPT taxa richness), community diversity (Q statistic and Shannon Diversity), taxa dominance (dominant families and Simpson Index), and feeding mechanisms (Functional Feeding Groups).

Perhaps the most common bioindicators are the suite of biotic indices used to "summarize information on the tolerance of the macroinvertebrate community" for water quality conditions (Lenat 1993). Two of the most pervasive biotic indices in North Carolina were applied to these data: the North Carolina Biotic Index (NCBI) and the Ephemeroptera, Plecoptera, Trichoptera (EPT) taxa richness metric.

The NCBI (Lenat 1993) is an abundance-based index combining water quality tolerance values into a single index, with increasing NCBI scores reflecting increasing degradation of water quality. The EPT richness metric (Penrose et al. 1980) originated in the late 1970s under the non-point source monitoring program in North Carolina and is equal to the number of different mayfly, stonefly, and caddisfly taxa present in a sample. This metric is widely used for the well-documented sensitivity of these taxa to poor water quality conditions. Theoretically, the presence of EPT taxa indicates high-water quality and frequently areas of high quality habitats as well. However, a few of the EPT taxa are generalists relative to habitats, making the EPT richness metric less reliable for detecting changes in habitat quality than it is for water quality.

Community dominance refers to an organism that occurs in substantially larger abundances than other taxa with which it coexists. If a community were largely composed of a single taxon, this simplification of the biota may be a response to a physical or biological pressure. Dominant taxa could control community structure because they are the more competitive, more successful at avoiding predation, or more tolerant of poor water quality or habitat conditions, and generally are able to "specialize on the prevailing environmental complex of the aquatic ecosystem … Studies show that tolerant species are present in nearly all streams, but are dominants only in polluted systems (Nuzzo 1986, Lenat 1988, Bode 1988)" (Shackleford 1988).

While visually examining the differences in dominant taxa can be a constructive way to study similarities or differences in site dominance, Simpson's index (Simpson 1949) is a common quantitative measure of dominance that can be statistically tested for differences among sites. This index is simply the probability that any two individuals drawn at random from an infinitely large community belong to different taxa (Equation 2). Simpson's index is heavily weighted toward the abundances of the most common taxa in the sample and is less sensitive to taxa richness. While this probability indicates the level of evenness in communities, it does not take into account which types of organisms are present. This metric does represent an important aspect of the community structure, but it does not distinguish between communities spread evenly across tolerant or intolerant organisms, making interpretation of this measure a superficial but worthwhile inquiry of community structure.

Equation 2 – Simpson's Index of Dominance (from Magurran 1988)

$$D = \sum \frac{\left(n_i\left(n_i - 1\right)\right)}{\left(N\left(N-1\right)\right)}$$

n_i = number of individuals in the i^{th} species

N = total number of individuals

To explore the difference in community diversity of upstream and restored reaches, two alpha (within habitat) diversity indices were calculated: the Shannon Index and the Q statistic. The Shannon Index (Shannon and Weaver 1949) is essentially a measure of the complexity of a community (Equation 3). This index is based on information theory;

the diversity of the natural system is encoded as signals from the community and, for ecological applications, is a function of the number of taxa (or richness) and the evenness of their distribution. Consequently, increases in taxa richness or distributional evenness result in an increase in the Shannon Index, with maximum diversity reached when all taxa are equally abundant. Although this is a widely used index of diversity, some of its fundamental assumptions make justification for using it difficult. The method requires that all individuals be randomly sampled, that the population is indefinitely large, and that all species in the community are represented (Magurran 1988). Incomplete sampling introduces significant error and rare taxa bias, which results from a failure to include all species from the community in the sample. Acknowledging that the collection method used for this project was a qualitative one, as most benthic sampling methods are, and that the organisms were often not randomly sampled, Shannon's index is reported.

Equation 3 – Shannon's Index of Diversity (from Magurran 1988)

$$H' = -\sum p_i \ln p_i$$

p_i = the proportional abundance of the i^{th} species

The Q statistic, proposed by Kempton and Taylor in 1976, was also calculated as a measure of community diversity, using the slope of the inter-quartile range (between the 25% and 75% quartiles) of the cumulative species abundance curve. This method originated from conventional statistics to avoid the bias of the distribution ends and has been successfully used in describing ecological diversity (Hill et al. 2003, Belaoussoff et al. 2003). It has been shown to be much less sensitive to the most abundant and rare species in the sample and is instead biased towards the richness of the sample. The Q statistic, calculated using Equation 4, has been called a "unique and valuable index for the detection of stress" (Hill et al. 2003).

Equation 4 – Q statistic of Diversity (from Magurran 1988)

$$Q = \frac{\frac{1}{2}n_{R1} + \sum_{R1+1}^{R2-1} n_r + \frac{1}{2}n_{R2}}{\log(R2/R1)}$$

n_R= the total number of species with abundance R
S = the total number of species in the sample
R1 and R2 are the 25% and 75% quartiles
N_{R1} = the number of individuals in the class where R1 falls
N_{R2} = the number of individuals in the class where R2 Falls.

Functional groups "can be defined as a group of not necessarily related species exploiting a common resource base in a similar fashion," which consequently respond similarly to disturbances to their commonly essential resource (Belaoussoff et al. 2003). Functional Feeding Groups (FFGs), therefore, refer to the organization of aquatic insects by their method for acquiring food resources and "comprise information on production, trophic dynamics, and interaction and availability of food sources" (Ofenbock et al. 2004). FFGs are divided into shredders, scrapers, macrophyte piercers, filtering and gathering collectors, omnivores, and predators (Merritt and Cummins 1996). These groups reflect the dominant processes controlling energy cycling in a stream system as described by the River Continuum Concept (Vannote et al. 1980). The presence and proportional abundance of FFGs provide unique information about the biotic integrity because "they measure an aspect of the functioning rather than just the structure of the macroinvertebrate community" (Merritt and Cummins 1996).

Study Design

For this project, paired t-tests were performed to determine statistical differences in environmental variables and community descriptions. A $P<0.05$ significance level was chosen for rejecting the null hypothesis of no difference. Statistical analyses were performed within JMP software, version 5.1.1.

Several caveats are required regarding the nature of stream restoration science and the application of those principles at these study sites. Data measurements and benthic collections were made early in the restoration recovery period, as the age of the studied restoration projects ranged from one to four years. Given the limited understanding of recovery times following restoration activities, and given that some of the study streams may still be stabilizing in response to construction activities, this study does not attempt to investigate the temporal evolution of the sites. Instead, this study attempts a snapshot assessment of the early responses of benthic macroinvertebrates to restoration activities. Thus, the reference to 'restored sites' within this paper refers to those sites to which stream restoration practices have been applied, though not necessarily a restoration to the natural pre-development condition.

Further, it is important to note that some of the upstream reaches were not in what is often considered 'reference' condition. Several of the upstream urban sites were notably degraded from watershed activities and removal of riparian areas. However, in this modified upstream-downstream study design, the upstream reach was simply used as a control for comparison to the restored reach, to represent the initial condition from which the restored reach was expected to deviate, with the assumption that watershed conditions similarly affect the upstream and restored reaches. Finally, while this investigation considered a wide range of environmental factors affecting the benthic community both at the watershed and local reach scales, it is recognized that there area other influences, such as predator-prey relations, colonization sources, and unmeasured water pollutants, that may be responsible for some of the variation demonstrated in the dataset.

Table 1 – Variables used to characterize environmental condition of stream reaches. Note that the variables indicated by a * required a log transformation prior to analysis for approximating normality in the dataset. Means and variances reported are for untransformed data.

Variable	Description	Influence	Upstream Mean	Variance	Restored Mean	Variance	P
Canopy cover*	visually estimated from center of channel	percentage of stream exposed to direct sunlight	0.59	0.09	0.20	0.03	0.117
riparian herbaceous cover	Visually estimated across 40' transects at cross sections	potential for nutrient removal and addition of organic material to stream	67	916.0	77	734.0	0.249
riparian woody cover	Visually estimated across 40' transects at cross sections	potential for nutrient removal and addition of organic material	53	994.2	37	783.6	0.044
detrital biomass in kicknet*	leaf material retained in kicknet collected, dried at 60°C for 24 hrs, and weighed to obtain dry mass	amount of allochthonous material available to shredding organisms	5.9	46.4	2.4	18.6	0.004
drainage area*	determined in ArcGIS using USGS 30m DEMs and ArcHydro; visually verified for accuracy	indication of flow volume	1.6	2.2	1.8	2.4	0.185
SCS - Curve Number (CN)	determined in ArcGIS using LULC and CGIA county soil surveys layers	Volume of runoff contributed by watershed	63	74.4	63	69.5	0.709
woody debris/longitudinal profile*	diameter and length of woody debris measured along length of longitudinal profile	diversity of available habitat	0.04	0.0	0.00	0.00	0.111
friction factor (f)*	from Leopold, Wolman, and Miller (1964)	flow resistance and irregularity of channel features	6.4	440.2	1.1	14.9	0.274
D90*	substrate sampled according to Harrelson et al. (1994)	surrogate for bed mobility and availability of coarse habitat material	115	42810	57	1879	0.649
% sand or finer	substrate sampled according to Harrelson et al. (1994)	surrogate for substrate embeddedness	56	223.4	56	283.8	0.556
water surface slope	survey data collected using a builder's level	energy to carry water and sediment through channel	0.0076	0.0	0.0072	0.0	0.872
pool frequency ratio	number of pools (1.5x riffle depth) occurring in longitudinal profile	indication of substrate habitat diversity	0.02	0.0	0.01	0.0	0.0002
riparian infiltration	See USDA (2001)	indicative of groundwater connectivity and critical component of riparian vegetation	831	3E6	2817	10E8	0.001
Bank Erosion Hazard Index (BEHI)	See Rosgen (2001)	potential of steambanks to erode, adding fine sediments and removing habitat	21	81.5	16	70.8	0.035
Width Depth Ratio (WDR)	ratio of bankfull width to bankfull depth	balance of sediment erosion and deposition across the channel	12	30.6	16	114.7	0.190
Dissolved Oxygen	reported in %, YSI model 85 digital meter	requirement for many organisms and a response to increased nutrient loads and decomposition of macrophytes	92	974.0	90	935.4	0.796
Specific Conductance	reported in mS/cm, YSI model 85 digital meter	general water quality surrogate, a measure of the amount of charged material dissolved in the water	48	501.0	47	483.1	0.544
Inches of Rainfall in last 30 days	Nearest USGS gaging station determined in ArcGIS and rainfall data summed for 30 days prior to benthic sampling	indication of baseflow condition at time of benthic collection	5.2	6.4	5.2	6.4	0.326

Results

Results - Physical Characteristics

Results of the paired t-test comparison of physical characteristics, made to investigate abiotic differences of the stream pairs in response to restoration activities, are reported in Table 1. Statistical variance was reported due to the high variability of some of the measured attributes in the reaches. The following discussion summarizes results presented in Table 1 that represent unexpected or conflicting indications of restoration effects.

Three of the physical features of these streams, % sand or finer, D90, and friction factor, were not found to be statistically different between the upstream and restored reaches. The mean values of % sand or finer are approximately 56% for both reaches, emphasizing the impacts of sediment load from the watershed and upstream bank erosion. D90 was also not found to be statistically different between the reaches. However, the considerable difference in the mean values of D90 (115mm upstream and 57mm restored) suggests that a difference does exist. There was no statistical difference for the friction factor as well, though the difference in the means is substantial (upstream $f = 6.4$, restored $f = 1.1$). It is suggested that the high variance in the larger fraction of the bed characterization reduced statistical power and constrained statistical inference. Notice in Equation 1 that the friction factor f is a function of particle size distribution. Notably, this relation of friction factor is to the D84, representing the particle two standard deviations larger than the mean size (Leopold et al. 1964). Consequently, the effect of variation on these larger particles may affect the ability to detect a difference in D90 and friction factor, where the means indicate that a difference in the upstream and restored reach features does exist.

The effects of the restoration activities on the condition of the riparian area, as described by the comparisons considered here, are unclear. No statistical difference was found in restored and upstream pairs for two decisive variables: volume of woody debris in the stream and the canopy cover over the stream. No difference in restored and upstream reach pairs suggests a failure of the restoration projects to enhance the functionality of the riparian area and the consequent habitat functions within the stream. However, other characteristics of the riparian condition, including infiltration, % woody coverage, Bank Erosion Hazard Index (BEHI), and detrital biomass, were found to be statistically different in upstream and restored reaches. Infiltration, % woody coverage, and detrital biomass all showed a statistical decrease in restored reaches when compared to upstream counterparts. However, erosion potential (BEHI) of restored reaches was statistically lower than of upstream reaches, suggesting a positive impact of restoration activities on bank stability.

These contradictions indicate that the effects of restoration activities on riparian condition are complex. The similarity of stream canopy cover and volume of woody debris suggests that these paired riparian corridors have more in common that was anticipated. However, the differences in woody vegetation coverage, BEHI, infiltration, and dry biomass all indicate some disparity in the conditions of the riparian areas. The interpretation of the differences in detrital biomass is particularly difficult because a reduced amount of this allochthonous material could be a result of a reduced source from the adjacent riparian area or a limited ability of the reach to retain the detrital matter washed in from upstream. The lack of difference in D90 and woody debris, both providing potential for retaining detritus, suggest that the reduction of detrital material in restored reaches may not be due to a decreased retention, but instead is caused by decreased supply from the adjacent woody vegetation. However, woody vegetation coverage was not found to be statistically different. These conflicting indications of riparian function may be either promising or misleading indications of restored reach functions.

Results - Biological Community Measures

The differences in benthic organisms of restored and upstream reaches were assessed through various community descriptions and indices. To characterize the communities and explore the suitability of the various descriptions for investigating restored communities, two common biotic indices, a dominant taxa list and index, community diversity measures, and the proportional abundances of functional feeding groups were calculated. Means, variances, and paired t-test significances of the comparisons are detailed in Tables 2 and 3.

Table 2 – Common metrics used to characterize biological communities

Community description	Upstream Mean	Variance	Restored Mean	Variance	P
NCBI	4.00	2.44	4.42	1.38	0.11
EPT richness	10.56	90.72	11.23	69.38	0.45
Simpson's Dominance	6.50	13.47	5.93	5.05	0.29
Shannon Diversity	1.98	0.33	1.96	0.15	0.76
Q statistic	4.24	4.96	3.52	2.86	0.02

This analysis found no statistical difference in the upstream and restored reach NCBI values. While the NCBI "is intended for examination of the general level of pollution," (Lenat 1993), no difference in NCBI values was expected because the sites were intentionally paired to isolate the effects of water quality in an upstream-downstream approach.

There was also no statistical difference in EPT taxa richness between the paired sites. However, it is worthwhile to examine the range of EPT richness and the potential implications of this variation in water quality. The upstream reaches had an EPT richness range from 0 to 33, and the restored reaches had an EPT richness range from 1 to 29. These results are indicative of the wide range of water quality conditions experienced by the benthic organisms as a result of the multiple land uses associated with these sites. This effect of this variance on the statistical analysis constrains inference. Because the influence of water quality conditions on these organisms is so strong (Ohio EPA 1990), consideration should be taken in future study to isolate water quality effects through land use discrimination.

This study found no significant difference between upstream and restored reaches in the Shannon diversity measure. However, the Q statistic diversity measure was significantly lower for the restored reaches than for upstream reaches, indicating a significant decrease in the diversity of restored reaches. This result contrasts with the finding of no difference in the Shannon diversity measure.

Table 3 shows the dominant taxa for each site and land use. Two features are of interest: the percentage of the community dominated by a single family and the implications of that family dominance with respect to stress tolerance. In general, dominant organisms greater than 35% indicates poor stream quality, between 23%-35% indicates fair stream quality and less than 25% indicates good stream quality (EPA 1996). Sites with particularly high proportions of their community composed of a single family, such as the Sussman's Park upstream reach that contained 67% Chironomidae, exhibit lower diversity. In contrast, sites where dominant taxa account for lower proportions of the total community such as the upstream reach of Bob's Creek, have higher diversity because the community is spread across a larger number of taxa. When conditions are suitable for a single controlling taxon, this typically indicates some perturbation to the ecosystem that excludes the survival of more sensitive or less competitive organisms.

Table 3 – Dominant taxa and land uses, sorted by land use. Sites with two land uses listed indicate a shift in landscape activities from the upstream reach, listed first, to the restored reach land use, frequently occurring in watersheds where localized livestock access has resulted in degradation to the stream and consequently, the need for restoration activities. Of interest are those sites with a high proportion of the benthic community represented by a single organism, indicating a simplification of community structure.

		Upstream		**Restored**	
Stream	Land Use	Dominant Taxa	% Composition	Dominant Taxa	% Composition
Big Warrior Crk	agricultural	Hydropsychidae	34%	Baetidae	31%
Deaton	agricultural	Chironomidae	53%	Chironomidae	28%
Suck creek	agricultural	Hydropsychidae	34%	Heptageniidae	30%
Bethel Church Crk	rural	Simuliidae	43%	Simuliidae	45%
Bob's Crk	rural	Leutridae	17%	Baetidae	27%
Brown Branch	rural	Heptageniidae	17%	Hydropsychidae	16%
Brushy Fork	rural	Baetidae	32%	Baetidae	35%
Kraft	rural	Heptageniidae	17%	Baetidae	29%
Lyle Crk	rural	Philopotamidae	27%	Chironomidae	27%
Pott Crk	rural	Baetidae	28%	Libellulidae	23%
Caviness	rural	Chironomidae	39%	Perlidae	37%
Beaver creek	rural	Heptageniidae	15%	Baetidae	20%
Little Bugaboo	rural	Chironomidae	38%	Capiniidae	20%
Little Pine	rural	Uenoidae	20%	Baetidae	24%
Jumping Run Crk	rural/agricultural	Leptophlebiidae	22%	Chironomidae	26%
Little Warrior Crk	rural/agricultural	Leutridae	58%	Hydropsychidae	26%
Yates mill	rural/agricultural	Hydropsychidae	15%	Chironomidae	44%
Purlear	rural/agricultural	Baetidae	15%	Chironomidae	32%
Edsel Place	urban	Baetidae	41%	Simuliidae	38%
Lindley	urban	Hydropsychidae	46%	Chironomidae	36%
Price Park	urban	Chironomidae	57%	Chironomidae	28%
Sedgefield	urban	Baetidae	38%	Hydropsychidae	37%
Sussman's Park	urban	Chironomidae	67%	Simuliidae	47%
Abbott	urban	Chironomidae	48%	Chironomidae	41%
Kentwood	urban	Oligocheata	30%	Hydropsychidae	33%
Spring Valley	urban	Baetidae	54%	Chironomidae	39%
Austin	urban	Chironomidae	27%	Chironomidae	22%

Paired t-test comparisons of the Simpson index found no statistical difference in community dominance. A difference in the Simpson index would have indicated more complexity of one of the communities. The mean value of the upstream reaches (6.5) was slightly higher than that of the restored reaches (5.9). Though statistically insignificant, as the 1/D value increases, the chances of randomly drawing a different insect in replication decreases, indicating a slightly lower dominance of a single family in the upstream reaches. These results indicate a general similarity in the evenness of the distributions, though not necessarily a similarity in the overall community structures, as illustrated by several of the sites in Table 3.

Table 4 – Functional Feeding Group Assemblages at restored and upstream sties. As the P values demonstrate, statistical difference was not detected for any of the functional feeding groups. Both upstream and restored reaches were dominated by filtering collectors, accounting for an average of about 30% of the FFG at both sites.

Functional Feeding Group	Upstream Mean	Variance	Restored Mean	Variance	P
Predator	0.17	0.02	0.20	0.03	0.33
Omnivore	0.10	0.03	0.13	0.01	0.37
Gathering Collector	0.20	0.02	0.17	0.01	0.18
Filtering Collector	0.28	0.03	0.34	0.03	0.19
Scraper	0.12	0.02	0.09	0.01	0.10
Shredder	0.12	0.02	0.08	0.00	0.14

No piercing organisms were found at these sites and thus were not included.

The average percentages and p-values (Table 4) for each functional feeding group comparison indicate a lack of statistical difference in all functional feeding groups at these sites.

Discussion

For this study, the physical and biological conditions of pairs of upstream and restored reaches were compared. While physical monitoring provides valuable insight into the stability of a stream reach, the concept that "restoration seeks to establish a condition that is self-regenerating, self-adapting, and self-maintaining," (Jorgensen and Yarbrough 2003) indicates that the biological integrity of restored streams is of nontrivial importance. Simultaneous consideration of the numerous physical and biological features of a stream corridor is necessary to get an accurate depiction of ecological quality. Because "the stream corridor must be viewed as a single functioning unit or ecosystem with numerous connections and interactions between components" (FISRWG 1998), the neglect of any one component gives an incomplete, and often misleading, description of the true quality of a stream ecosystem. The misleading character of incomplete descriptions is illustrated by these results that provide conflicting interpretations of the physical and biological integrity. The results of this work demonstrate that streams are complicated ecosystems and that highly variable dataset can lead to inconsistent information. Further, the choice of benthic community description was shown to have an effect on the determination of biological integrity, which could have significant influence on the determination of functional improvement of a restored stream.

Stream corridor features

Through paired t-tests, the variables D90, % sand or finer, and friction factor f demonstrated no statistical differences in the sediment transport characteristics of the upstream and restored reaches. Paired t-test analyses did indicate differences in the upstream and restored reach riparian conditions. While the numerical descriptions for volume of woody debris and percentage of the stream shaded by tree canopy cover were both found to be statistically similar, several other variables, including dry biomass, woody coverage, BEHI, and infiltration were found to be statistically different. These conflicting results are difficult to interpret, with subjective (% cover, woody coverage, BEHI) and objective (volume of woody debris and infiltration) measurements accounting for both differences and similarities in the analyses.

Comprehensive evaluation of both biotic and abiotic integrity is needed because measuring simple physical or biological features can lead to unreliable conclusions about ecosystem recovery.

The statistical difference found between upstream and restored reach detrital biomass may indicate a difference in retention of detritus, typically associated with coarse bed material and woody debris located within streams. For example, Negishi and Richardson (2003) found an increase in detrital retention as a result of boulder addition and a consequent increase in total macroinvertebrate abundances in second order streams of British Columbia. Given the statistical decrease in the mass of detritus found in the restored reaches, the lack of difference in large substrate material (D90) and volume of woody debris in the pairs is puzzling.

Benthic community measures

The biological conditions of restored and upstream reaches were evaluated using several descriptions of community structure and function. These biological indicators were chosen to explore the signals provided by: 1) biotic indices, 2) measures of dominance or evenness 3) diversity descriptions, and 4) the trophic condition of the streams. Nearly all descriptions of the benthic communities found no statistical difference between the upstream and restored reaches, and the interpretation and value of each were discussed. Further, the variances of these community descriptions were lower at all of the restored sites, indicating a loss of complexity in benthic macroinvertebrate samples.

This study was designed to isolate water quality effects through the pairing of sites. Because the North Carolina Biotic Index (NCBI) and EPT taxa richness measures were designed to “reflect the influence of chemical pollutants” (NCDENR 2003), and “historically, restoration has not been conducted to achieve water quality improvement,” (Jorgensen and Yarbrough 2003) the ability of these metrics to assess restoration success at these sites is questionable. Further testing should be performed to confirm the lack of statistical response of these metrics to restoration activities.

While the definition of ‘restoration’ has taken many forms (Berger 1990, Jorgensen and Yarbrough 2003, SER 2003), the effect of restoration activities on water quality is largely undocumented. In a search of 294 stream corridor restoration papers, the EPA found “only 7.5% of all available references contained water quality data” (Jorgensen and Yarbrough 2003). It is acknowledged that stream restoration projects often reduce sediment load through restricting streambank erosion and channel incision. However, because the NCBI and EPT metrics “may not measure impacts that are largely due to sediment” (NCDENR 2003), these water quality bioassessments may not be the most appropriate measures for evaluating the impacts of restoration on benthic community composition and function. Consequently, the lack of difference in restored and upstream sites may not be a reliable indication of a lack of impact of restoration activities on resident biota.

Investigation of the dominant family in the benthic communities provided insight into the evenness of the community distribution. Dominant taxa were listed and community dominance was described by Simpson's index, a commonly used measure weighted toward the abundances of the most common organisms. No statistical difference in upstream and restored sites was found using Simpson's index. However, Table 2 demonstrates that there are differences between the sites' dominant communities. Simpson's index reports evenness, or the influence of dominant taxa on the community distribution, but it makes no distinction regarding the ecological significance of the dominant organisms (i.e. whether a community is evenly distributed across very sensitive taxa or very tolerant taxa). Table 2 demonstrates that the dominant family in several of the stream pairs does vary, particularly when urban sites with highly degraded water quality are not considered. The dominance of particularly sensitive or insensitive taxa is a well-accepted indicator of the quality and function of the stream ecosystem. Knowledge of the functional aspects of the dominant organism, such as feeding or respiratory patterns, assists in interpreting the significance of the relative abundance of dominating taxa in an aquatic ecosystem.

Sites dominated by the Chironomidae family, for example, are typically characterized as lower in water or habitat quality due to the generally high tolerance of the organisms. Though the Chironomidae family is very diverse, with over 1000 species in North America and many within-family ecological differences, "if midge larvae are very numerous and account for the majority of the community, that is an indication of poor environmental health caused by some type of pollution" (Voshell 2002). These taxa are commonly associated with high levels of fine organic material, as they consume the organic component of the fine sediment in which they live. Ten of the restored sites were dominated by this family, compared to the Chironomiidae dominance of seven of the upstream reach sites. All but one of the Chironomidae-dominated were located in urban or agricultural watersheds where fine organic material is in high abundance, creating ideal conditions for these organisms to feed and dominate in the low dissolved oxygen concentrations intolerable for many of the other organisms. Another example is the dragonfly family of Libellulidae, which dominated the restored reach of Pott Creek. This sediment-skimming dragonfly has the morphological features to survive in fine-sediment streams; its long legs and flat body help prevent it from sinking into the mud. By examining the particle size distribution, we see that the restored reach of Pott Creek had a D90 of 0.03mm, falling into Wentworth's silt sediment class (Wentworth 1922). Thus, the dominant taxon accurately represented the unusual substrate condition at this site.

Several of the upstream sites had more sensitive or habitat-specific taxa dominating their communities. The Leutridae stonefly, found shredding CPOM in leaf packs; the Leptophlebidae mayfly, a fine organic gatherer whose habitat is in protected areas of streams; and the Philopotamidae and Uenoidae caddisflies, typically found attached to coarse substrates or woody debris, are all examples of organisms sensitive to environmental conditions and which signal the presence and function of some specific habitat niche. Comparison of the measured physical characteristics (dry biomass, volume woody debris, and D90) of these sites confirms the presence of the habitat features at these sites for supporting the dominant taxa. These ecologically meaningful distinctions in community dominance were not detected by Simpson's dominance index, suggesting a limitation of using such measures in evaluating stream restoration.

Two measures of diversity were presented for evaluating differences in these paired sites. The Shannon Index, biased to the very rare taxa in a sample, reported no difference for the upstream and restored reaches, while the Q statistic was found to be statistically different between the pairs. These conflicting responses demonstrate how "the choice of appropriate indicators of change is of paramount importance" (Brooks et al. 2002) when considering benthic community response to restoration activities.

Two features of these common community measures introduce uncertainty about their credibility: index bias and ecological meaning. The bias of rare (Simpson's index) or abundant (Shannon's index) organisms without any knowledge of their importance as bioindicators may provide misleading indications of success or failure of restoration activities. The Q statistic considers a unique aspect of the community in the fraction of the community that occurs with intermediate abundance by discarding both the very rare and very common taxa. However, along with Simpson's and Shannon's indices, the value and interpretability of these indices are questionable because they all treat "species as if they were completely interchangeable with one another" (Holsinger 2003), finding no contrast among communities associated with high or low ecological quality. These demonstrations of community distribution may not be the most appropriate for evaluating stream restoration activities, as they provide no information about the quality of the taxa or the ecological significance of the communities.

Functional feeding groups (FFGs) are presented as the only measure of community function, in contrast to the other community structure measurements. However, no statistical distinction was found for any of the feeding groups, as detailed in Table 3. This finding contradicts the conventional wisdom regarding restoration impacts, as demonstrated by   Muotka and Laasonen (2002) with an increase in scraper community densities following restoration activities and opening of riparian canopies during construction. The biological and environmental characteristics of these sites do not provide a strong indication whether a difference in the trophic conditions does or does not exist. The lack of difference in percentage of scrapers in this study corresponds with the findings of canopy cover similarity discussed in the comparison of upstream and restored reach riparian conditions. However, the lack of statistical difference in these shredder organisms, which serve as the "initial component in processing allochthonous detrital inputs" (Lemly & Hilderbrand 2000), seems to contradict the statistical difference in detrital biomass discussed in the analysis of physical variables.

These ambiguous results illustrate why metrics should be "ecologically relevant to the biological assemblage or community under study ... and sensitive to stressors and provide a response that can be discriminated from natural variation" (Ofenbock et al. 2004). To more accurately assess the impact of restoration activities, there is a need for a consistent description of community that signals the response of benthic communities to changes in habitat quality.

The effects of site variability on statistical analysis further complicate the determination of differences between the upstream and restored sites. Variance characterizes the dispersion within a dataset, measuring how much each value deviates from the mean. The large variances, and correspondingly low statistical power, of these data may constrain statistical inference from variables characterizing the paired reaches. The inconsistency of environmental and biological differences of these sites highlights the simplicity of the paired t-test approach and its inability to treat complex datasets with high variability.

While the sources of variance are likely due to the range of land uses included in this study and the natural variability of stream ecosystems, it is important to note several sources of artificial variance likely reflected in this data. For example, consistently characterizing the particle size distribution of a stream is a challenging task (Petrie 1998). Some variables, including canopy cover, riparian vegetation cover, and BEHI, employed visual estimations, requiring consistency and calibration of the data collector measurements. Finally, while the benthic macroinvertebrate collection method is qualitative in nature and the data are undoubtedly appropriate for numerical analysis, minor variability in communities collected may be a result of equal effort, but unequal collections.

Perhaps the most notable feature of this dataset is the difference in variances in upstream and restored reach variables and communities. The upstream reaches repeatedly demonstrated higher variances than the restored reaches, with 70% of the environmental variables exhibiting greater variance upstream. This trend was also true for every benthic community description, with 22% to 63% reduction in variance across the calculated measures at restored sites. These data were collected in exactly the same manner for the upstream and restored sites, so the decrease in variance of restored sites cannot be explained by data measurement error.

This consistent decrease in variance suggests a homogenization of the environment in these restored streams and the consequential simplification of benthic communities. Many of the early restoration projects were focused on stabilization measures, hardening streambanks and beds to restrict lateral and vertical movement. These data suggest that the implications of this historical, single-minded approach to channel stabilization may have serious implications to the biological communities.

Lack of statistical differences between upstream and restored sites may reflect true similarities in the pairs, collection and measurement procedures, natural variation in bug communities, or the subjective nature of some physical measurements. However, the conflicting results are likely indicative of the nonlinear, multivariate nature of stream ecosystems. Measurement of some single aspect of physical or biological conditions is undeniably deficient, making detection of any strong signal or pattern difficult. Further, the approach of summarizing differences through paired t-tests may not be well-suited for accurate evaluations of ecological differences. Instead, multivariate analyses may be more appropriate for detecting patterns and differences in communities and ecosystems. Because "multivariate analyses were developed for finding patterns," (Karr and Chu 1999) these methods can provide a clearer, contextually-based perception of benthic community trends for researching biological responses to various insults and influences. Because benthic macroinvertebrates are a crucial component of an effective stream restoration monitoring program, the need for tools to accurately measure their responses is urgent and essential.

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CHAPTER 2

Benthic Community Simplification as an Early Response to Stream Restoration Activities in the North Carolina Piedmont?

Submitted to Restoration Ecology

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Benthic Community Simplification as an Early Response to Stream Restoration Activities in the North Carolina Piedmont?

Abstract

Restoring benthic communities in impaired stream ecosystems is a sensitive and complex task that requires an interdisciplinary understanding of the physical, chemical, and biological conditions to which benthic organisms respond. This study examined how these conditions were associated with the structure of benthic communities in a comparison of 27 pairs of restored and upstream reaches of the North Carolina Piedmont. Benthic macroinvertebrate communities were analyzed using Nonmetric Multi-Dimensional Scaling (NMS), with overlays of 20 environmental variables that were measured to characterize the stream corridor. These analyses demonstrate the compositional and environmental differences in upstream and recently restored reaches and facilitate comparison of the River Continuum Concept (Vannote et al. 1980) and the Process Domain Concept (Montgomery 1999) for interpreting benthic communities in disturbed streams. Specifically, we found that 1) compositional patterns in restored reach communities were inherently less complex (one-dimensional) relative to those in upstream reach communities (three-dimensional), and 2) restored reach communities appear to be influenced primarily by sediment transport characteristics whereas upstream reach communities appear to be influenced by a variety of watershed and riparian corridor features. These results suggest that the disturbances associated with restoration practices result in simplification of the restored reach communities and the responsiveness of these communities to a limited subset of environmental constraints. Further, we found that the consequences of these local disturbances are not congruent with the River

Continuum Concept, and that the Process Domains Concept presents an appropriate alternative for studying benthic organisms in these disturbed streams.

Introduction

Increasing urbanization and agricultural development have resulted in a decline in the physical and energetic stability of streams, as well as in the aquatic communities dependent on this stability. Stream restoration practices have attempted to mitigate for increased watershed stresses through channel hardening measures such as bank protection, grade controls, flow deflection/concentration, and bank stabilization (Brown 2000), as well as redefining channel pattern, profile, and dimension, constructing new meanders, and revegetating streambanks and riparian areas. In addition to recreating natural channel geometry, habitat enhancement is another common objective of current stream restoration projects (Moerke et al. 2004).

This study investigated the potential for these combined activities to assist in the recovery of communities of benthic macroinvertebrates, those aquatic insects living in or around the substrates of streams. Because benthic macroinvertebrates have shown sensitivity to complex ecological disturbances not well detected by chemical or physical indicators alone (Ohio EPA 1990), this study focused on their responses to restoration activities by comparing the community composition and the environmental conditions in newly restored and upstream reaches. The results are valuable for understanding the biotic responses to stream restoration activities and for improving designs to ensure that these impacts to the biological integrity are ultimately productive and beneficial to its recovery.

Identifying and describing environmental gradients associated with the structure of lotic communities is a common objective of stream ecology studies (Walters et al. 2003), including the one described within this paper. Of interest are the biotic and abiotic patterns in pairs of restored and unrestored upstream reaches to investigate how: 1) communities in newly restored streams differ from those in upstream reaches in composition and in the environmental features to which they respond, 2) an empirically based study can further discussion of the appropriateness of ecological conceptual models for benthic communities in increasingly common disturbed reaches.

To address these objectives, Nonmetric Multi-dimensional Scaling (NMS) was performed independently on data describing benthic communities of restored and upstream reaches. Overlays of environmental variables on the resulting ordinations illustrate how these variables correlate with variation in community composition. These analyses reveal distinctions in the upstream and restored reach biota through the variables to which they correlate, the number of axes required to efficiently describe the communities, and the amount of the original, multi-dimensional structure represented in the final, reduced-dimensional ordinations.

The ability of two conceptual stream ecosystem models, the River Continuum Concept (RCC) and the Process Domains Concept (PDC), to represent benthic communities was evaluated through the examination of the variables to which the upstream and restored reach benthic macroinvertebrate communities corresponded. The dispute over how and where to apply these concepts has been largely theoretical thus far, particularly in recently disturbed systems, such as restored streams, where the governing concept is not clear. Montgomery (1999) admitted in introducing the PDC that data do not readily exist for validating it. A study by Walters et al. (2003), however, has since supported the Process Domain Concept (PDC) by demonstrating that a mosaic, rather than a continuum, best represented fish assemblages in a north Georgia river basin.

This study provides unique information about the environmental-benthic relationships justifying fundamental characteristics of these concepts. These relationships indicate whether environmental variables associated the resource gradients of river-wide processes (RCC) or physical disturbance regimes at the local scale (PDC) have more influence on the structure of benthic communities in restored streams, when compared to the upstream reaches.

Background

River Continuum Concept and Process Domains Concept

Vannote et al. (1980) introduced the well-known River Continuum Concept (RCC) to describe the structure and function of aquatic ecosystems through the continuous physical and trophic transitions, including the biotic responses, these systems experience from the headwaters to the mouth of rivers. The RCC suggests that these biotic responses conform to cooperative behavior for effective utilization of energy resource gradients, creating communities downstream that capitalize on upstream processing inefficiencies. This model describes energy inputs and processing as a function of changing physical attributes associated with increasing stream order, to which the benthic macroinvertebrate communities respond.

The Process Domains Concept (PDC), introduced by Montgomery (1999), describes spatially definable areas of community structure that are characterized by distinct arrangements of geomorphic processes. These community-defining processes govern habitat attributes and dynamics through disturbance regimes, including response potential and recovery time, which are controlled by the hydrology, sediment supply and transport, and presence of woody debris, among other physical properties. Thus, spatial context and variability are significant to the local geomorphic context and disturbance history of a stream reach. In contrast to the RCC, it is these local controls, rather than the collective upstream conditions, that influence habitat and thus community composition in a given reach. This concept recognizes and accounts for the variation exhibited on the local scale of these aquatic ecosystems, reflecting the influences on resident organisms. This control of community composition and dynamics through local habitat discontinuity and disturbance is arguably neglected by the RCC in its continuous, broader-scale theory.

While neither concept suggests a universal model for the consequences of specific processes on lotic systems, both concepts do share the similarity of purpose in their attempt to link physical characteristics of an aquatic ecosystem to its macroinvertebrate community structure. This may be where the similarities end, however, as the RCC relates landscape gradients of the physical environment to stream order, while the PDC organizes the physical attributes of landscapes into unique, discontinuous units moving downstream.

Methods

Study Sites

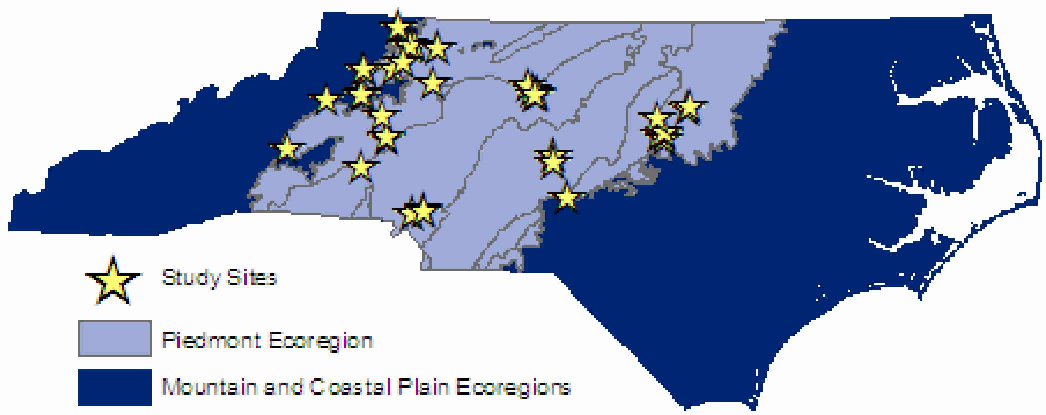

Figure 1. Location of study sites in the North Carolina central Piedmont, bounded by the coastal plain to the east and the mountains to the west.

Twenty-seven pairs of newly restored and upstream reaches were studied across the Piedmont of North Carolina (Figure 1), with twenty variables measured to characterize the environmental conditions at each site (Table 1). Study sites were sampled from May to August of 2003 and 2004 to minimize seasonal effects on environmental variables and aquatic insects. Further, sites were limited to drainage areas of 13km^2 or smaller to minimize the environmental and community variation associated with increasing watershed size. Soil Conservation Service Curve Number (SCS-CN), reflecting land use and the soil conditions, ranged from 54 to 83 (Soil Conservation Service 1975), with landscapes varying from urban to agricultural to rural. Riparian area conditions varied from mature to immature forest, herbaceous cover, and lawn grass. Stream substrates varied from silt to coarse gravel, with a median particle diameter range of 0.01 mm to 32mm, water slopes measured from 0.07 to 2.67%, and a bankfull width range of 2.1m to 11.2m. We felt that such variation in environmental conditions should be reflected in community composition. It is the implications of these varied conditions, and the community responses to them, that are the central motivation of this study.

Table 1. Variables and methods used to characterize the stream corridor at upstream and restored reach study sites for Nonmetric Multi-Dimensional Scaling.

Variable	*Data Collection Method*
riparian herbaceous cover	visually estimated across 40' transects at cross sections
riparian woody cover	visually estimated across 40' transects at cross sections
detrital biomass in kicknet	leaf material collected, dried, and weighed
Drainage area	determined in ArcGIS using USGS 30m DEMs and ArcHydro; visually verified for accuracy
SCS - Curve Number (CN)	determined in ArcGIS using 1999 HAZUS LULC and CGIA county soil surveys layers
woody debris/longitudinal profile	diameter and length of woody debris measured along length of longitudinal profile
friction factor (f)	$\boxed{\frac{1}{\sqrt{f}} = 2.03 Log\left(\frac{3.11d}{D_{84}}\right)}$ from Leopold, Wolman, and Miller (1964)
D90 - 90% finer than	substrate sampled according to modified Wolman pebble count technique Harrelson et al. (1994)
% sand or finer	substrate sampled according to modified Wolman pebble count technique Harrelson et al. (1994)
water slope	survey data collected using an engineer's level, calculated as change in elevation over longitudinal profiles
pool frequency ratio	number of pools (1.5x riffle depth) occurring in longitudinal profile
Riparian infiltration	see USDA (2001)
hydrologic soil group	determined in ArcGIS using CGIA county soil surveys layers and paper county soil surveys for Hydrologic Soil Groups
Bank Erosion Hazard Index (BEHI)	see Rosgen (2001)
Bank Height Ratio (BHR)	ratio of maximum depth at the top of low bank to maximum bankfull depth
Width Depth Ratio (WDR)	ratio of bankfull width to bankfull depth
Dissolved Oxygen	reported in %, YSI model 85 digital meter
Specific Conductance	reported in mS/cm, YSI model 85 digital meter
Inches of Rainfall in last 30 days	nearest USGS gaging station determined in ArcGIS and rainfall data summed for 30 days prior to benthic sampling

Benthic Macroinvertebrates

Benthic macroinvertebrates were collected according to North Carolina Division of Water Quality (NCDWQ) Qual 5 method (NCDENR 2003). This protocol includes sampling insects from one riffle using a kicknet, one sweep net collection from bank habitats, fine mesh wash of rock/log, one leaf pack wash, and visual collections. Insects were picked from samples, preserved in 95% ethanol in the field, and brought back to the lab for identification to species when possible.

These collections were summarized by family level abundances for this analysis. Marchant et al. 1995, Growns et al. (1995), Furse et al. (1984), Corkum (1989), Warwick (1988), Bowman and Bailey (1997), Herman and Heip (1988), and Bailey et al. (2001) have all successfully used family-level data for ordination analysis of benthic communities. These studies demonstrated how similar responses and ecological requirements of related species are evident at the family level.

At the family level, abundance data were converted into two formats for analysis and comparison: log transformed and relative abundances. The log transformation was performed as $\log(x+k)$, where x is the taxa abundance and k is a constant equal to 1, for this analysis to remove zeros for the log transformation and avoid undefined values. This transformation results in a reduction in the effect of highly abundant taxa by reducing the magnitude of large values relative to small values. The relative abundances were calculated as the number of organisms collected (abundance) within each family divided by the total number of organisms in all families combined. Relative abundances, or occurrence rates, are a measure of the proportional frequency of the taxa in the community. Duplicating the analyses with these different formats was useful for verifying the ordination solutions and patterns.

Non-Metric Multidimensional Scaling

Nonmetric Multidimensional Scaling (NMS), performed in PCORD (McCune & Mefford 1999), was chosen for analyzing the community data. NMS (Kruskal 1964) is a nonparametric, multivariate, and iterative ordination procedure, selected because it requires no assumption regarding the nature of the community response to underlying environmental gradients and because it has been shown to be robust even with noisy and nonlinear data (Minchin 1987). Several studies (Hawkins et al. 1997; McCormick et al. 2000; Heino et al. 2002; Clark 1999) have explored benthic community patterns with NMS to investigate the compositional differences between sites or treatments and elucidate trends in cause and effect from these differences (Warwick 1988). For this study, NMS was performed on newly restored and upstream reach community data independently to explore the effect of restoration on benthic macroinvertebrates at these sites through patterns in the community data. Further, the relative strength of the environmental variable correlations to the ordination axes suggests the scale and type of dominant influences on benthic communities.

The environmental variables associated with community composition variation demonstrate how variables characterizing processes, such as energy cycling and disturbance regime, correlate with the structure of benthic communities.

An advantage of applying NMS is the unique insight provided by the flexible dimensionality of this method. The final solution and appropriate number of dimensions was selected to minimize both the stress and instability. Verification of the final solution was accomplished by: 1) comparing calculated final stress for each dimensional solution to Kruskal's stress standards (1964), 2) minimizing solution instability to 0.0001 when possible, and 3) the use of scree plots, to illustrate the decrease in stress for each additional dimension. To ensure that the most stable solution and global minima were reached, 40 runs with random starting positions were performed for each analysis. In addition, one hundred Monte Carlo simulations were performed to confirm that the relationships found by the ordination were greater than those determined by chance with randomized datasets at the $P<0.05$ significance level. The Bray-Curtis distance measure was chosen for this study to represent between-site differences because it preserves sensitivity in heterogeneous datasets. Rare taxa were not downweighted or removed to avoid distorting model sensitivity and under-representing site dissimilarities (Cao et al. 1998).

Study Design

Caveats should be mentioned regarding the nature of the stream restoration science and the application of those principles at these study sites. Data measurements and benthic collections were made early in the restoration recovery period for these sites, as the age of these restoration projects ranged from 1 to 4 years. Each of the restoration projects for this study included full manipulation of the channel pattern, profile, and dimension, often resulting in cutting an entirely new channel and/or floodplain. Given our limited understanding of the recovery time required following such activities and the potential that some of the study streams were still stabilizing in response to construction activities at the time of assessment, this study did not attempt to investigate the temporal evolution of the sites. Instead, these data provide a snapshot assessment of early responses of benthic communities to restoration activities. Thus, the reference to 'restored sites' within this paper refers to those sites to which stream restoration practices have been applied, though not necessarily a restoration to the pre-development, natural condition.

Further, it is important to note that the upstream reaches were often not of what is considered 'reference' condition. Several of the upstream urban sites were notably degraded from watershed activities and removal of riparian areas. However, in this modified upstream-downstream study design, the upstream reaches are simply used as the controls for comparison to the restored reaches, to represent the initial condition from which the restored reaches are expected to deviate, with the assumption that the conditions of the watershed similarly affect the upstream and restored reaches. Finally, while this investigation considered a wide range of environmental factors affecting the benthic community both at the watershed and local reach scales, it is recognized that other influences exist, such as predator-prey interaction, colonization sources, and unmeasured water pollutants, and that these may be responsible for some of the unexplained variation encountered in the dataset.

Results

Table 2. Results of Nonmetric Multi-Dimensional Scaling for both restored and upstream sites, including the three environmental variables best correlated to ordination axes, stable solution dimensionality, and an indication of how well the intersite distances in the original, fully-dimensional distance matrix are reflected by the intersite distances in the reduced-dimension distance matrix (r^2).

community description	*variable 1*	*variable 2*	*variable 3*	*solution dimension*	*cumulative r^2*
restored log transformed	Width Depth Ratio	% sand or finer	Bank Erosion Hazard Index	1	0.590
restored relative abundances	% sand or finer	Width Depth Ratio	Bank Erosion Hazard Index	1	0.669
upstream log transformed	SCS-CN	dissolved oxygen	friction factor (f)	3	0.887
upstream relative abundances	SCS-CN	friction factor (f)	specific conductivity	3	0.837

A finding of $p<0.05$ for all analyses confirmed significance of these results.

Upstream versus Restored Comparisons

The joint plot diagrams (Figures 2a & 2b) serve to graphically display the between site dissimilarities of community composition in a reduced dimensional space. Compositionally similar communities are plotted near one another in joint plots, while dissimilar communities are plotted at greater distances to each other.

Associated environmental factors (Table 1) are overlaid onto the ordination as vectors from the centroid of the plot, with the length of the vector representing the strength of the fit of the variable to the ordination axis. These data (Table 2, Figures 2a & 2b) demonstrate an apparent association with hydraulic and water quality conditions in the upstream reaches by correspondences to CN, friction factor, dissolved oxygen, and specific conductivity. A three-dimensional solution performed best (i.e. lowest combination of stress and instability) for both the log-transformed and relative abundances datasets of the upstream reach communities.

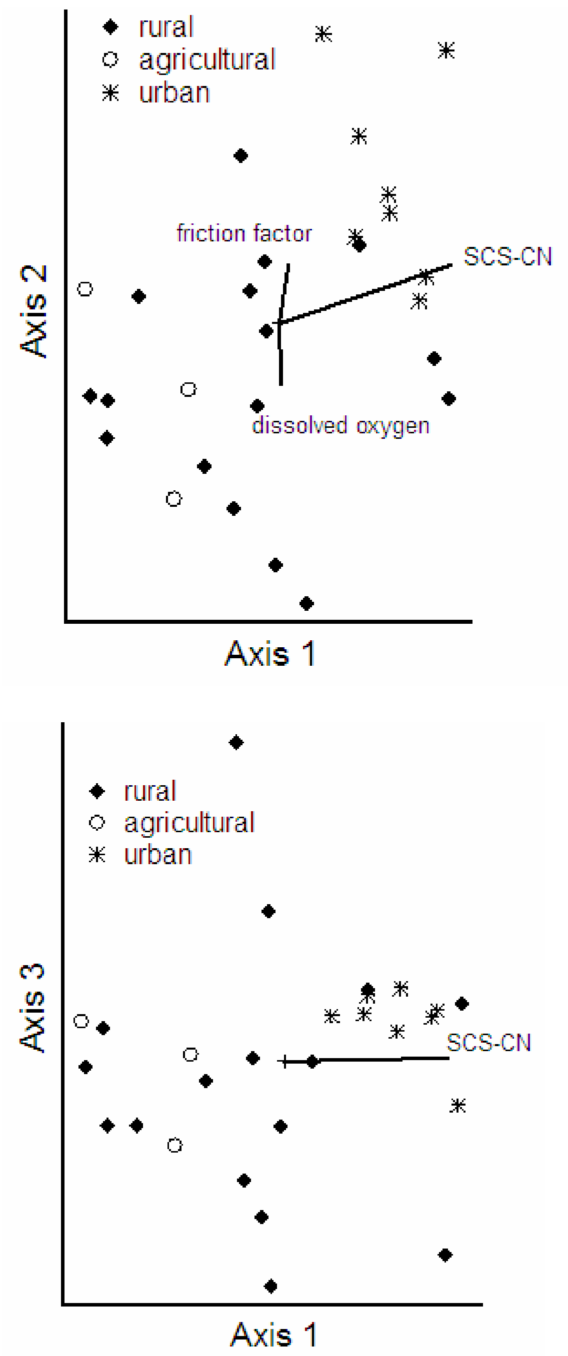

Figure 2a and 2b. Three-dimensional Nonmetric Multi-dimensional Scaling (NMS) solution for the log transformed ordination overlay of upstream reach controlling variables. The SCS-CN has its highest correlation to axis 1, with a Pearson correlation coefficient of 0.66. Dissolved oxygen and friction factor are best correlated with ordination scores on axis 2, described by Pearson coefficients of 0.52 and 0.42, respectively.

The results (Table 3) illustrate the two fundamental ways in which restored reach communities differ from those in the upstream reaches: the final dimensionality and the variables to which community composition correspond. Because the restored reach solutions were most stable and produced the lowest stress on one-dimension, joint plot diagrams cannot be constructed. Instead, variables associated with the energy expended in the stream through the movement of sediment, including percent sand or finer fraction of the particle size distribution, Width Depth Ratio (WDR), and the Bank Erosion Hazard Index (BEHI) were best correlated to the single ordination axis for the restored reach analysis (Table 3).

Table 3. Results of Nonmetric Multi-dimensional Scaling of restored reach sites. Width Depth Ratio (WDR), the % sand or finer fraction of the particle size distribution, and the Bank Erosion Hazard Index (BEHI) were found to most strongly correlate with the single ordination axis.

community description	*variable 1*	*r*	*variable 2*	*r*	*variable 3*	*r*
restored log transformed	WDR	0.63	% sand or finer	0.57	BEHI	0.44
restored relative abundances	% sand or finer	0.56	WDR	0.52	BEHI	0.32

Discussion

Historical damage to aquatic ecosystems occurred in response to stress created by negligent management of water resources. These stresses persist as threats to benthic macroinvertebrates by homogenizing habitats, disturbance regimes, and colonization sources (Stanford et al. 1996; Daily 1997; Rahel 2000). The practice of stream restoration attempts to mitigate for such losses, and critical to the recovery of biotic integrity is the belief that restoration of functional communities follows re-establishment of diverse habitats (Brooks et al. 2002). The results of this study, however, demonstrate a homogenization of benthic communities in restored streams. This suggests that the restoration activities may have reduced heterogeneity in the channels, rather than increasing it, contrasting the principle of restoration as an enhancement opportunity for degraded streams. Further, the local disturbance created by reconstructing stream channels appears to obscure watershed influences on water quality and quantity.

Upstream versus Restored Processes

The results for the upstream reaches demonstrated the correlation of compositional variation in benthic communities with hydraulic and water quality conditions on local and watershed scales, described through the variables SCS-CN, friction factor f, dissolved oxygen, and specific conductivity. The well-known dependency of the benthic community on runoff characteristics is represented here by the strength of the relationship between the ordination scores and runoff volume (SCS-CN) (Figures 2a & 2b). Increased runoff, a common feature of developed areas, may deepen and homogenize stream channels, reducing resistance to flow. These effects of modified flow regimes are reflected in this study by the correlation of community composition to the friction factor, indicative of bed mobility and habitat complexity. The documented relation of benthic macroinvertebrates and water quality conditions (Hilsenhoff 1987; Lenat 1993; Ohio EPA 1990) are demonstrated here by the association of community data with dissolved oxygen and specific conductivity.

The primary influence of sediment transport variables in the restored reaches contrasts the variety and type of influences in upstream reach communities. Because aquatic insects typically show consistent and substantial responses to watershed-wide changes in flow regime (Gore et al. 2001), it is not surprising that the SCS-CN is associated with variation in benthic communities of the upstream reaches. It is notable, however, that this association is absent in the restored reach communities. Further, no association with water quality was identified in the restored reaches, contrasting the upstream reach associations with dissolved oxygen and specific conductivity. Because the sensitivity of benthic macroinvertebrates to water quality conditions is widely used to detect changes in water quality (reference), the observation that neither water quantity nor quality features were associated with benthic communities in restored streams is significant.

The results demonstrate a correspondence of restored reach communities to variables (% sand or finer, WDR, and BEHI) indicative of the channel's ability to move sediment. Because benthic organisms, by definition, live and feed on the substrates of streams and lakes, it is not surprising that disrupted sediment transport potentially has a significant effect on the habitat of these organisms. However, in comparison to the upstream reach associations with water quantity and quality, the limited association of restored reach communities with only sediment transport related variables is a surprise. We suggest that this correspondence is an indication of a significant disturbance of a reach's ability to transport sediment that is related to constructing restoration activities because this relationship was not observed in the upstream reaches.

The dimensionality of the ordination analyses provides another indication of the reduced complexity of the benthic communities in the restored reaches. The representation of all sites by this single axis in restored reaches demonstrates a significant simplification of the communities, implying that a loss of ecosystem complexity, or a shift towards biological homogenization, has occurred in the restored reaches. Further, the cumulative R^2 values (Table 2), between 60-70% of the variation in community composition was captured by a single axis in restored reaches, as compared to the three axes required to capture approximately 85% of the original differences for the upstream reaches. These values emphasize the influence of this single sediment related axis for capturing such a large fraction of the variability when compared with the upstream reaches.

The homogenization demonstrated by the benthic communities, through both the unidimensional solution and singular response to sediment, demonstrates a loss of habitat diversity in these reaches. Habitat homogenization significantly affects a stream's ability to support diverse communities (Brooks et al. 2002), and our observation of simplified communities at the restored sites suggests that a shift in design and construction focus to sedimentary processes may be valuable if restoring biotic integrity is a project goal. Restoration design methods, such as those outlined by Shields et al. (2003), may be used to verify and focus channel design variables on the balance of sediment moving into and out of the system. Further, utilizing restoration activities that minimize disturbances to existing channels, such as livestock exclusion in agricultural areas, may have less overall impact to the benthic communities in streams where minimizing construction impacts is an option.

The River Continuum (RCC) versus Process Domains (PDC) Concepts

The results suggest that a difference in the relevant scale exists at these sites. The significance of local disturbances in the restored reaches is demonstrated by the correlation to a focused group of reach-scale sediment variables. This observation of local organization in the restored reaches is incongruent with the River Continuum Concept's emphasis on river-scale interactions, and demonstrates how the local condition may produce a greater effect on communities than the influences of river-wide processes (Walters 2003).

The PDC suggests that reach-level variation and dynamics in physical habitat both control macroinvertebrate distributions and obscure longitudinal patterns of community structure predicted by the wider scale, 'mean-state' theory of the RCC. The results presented here support this conceptualization, suggesting that the disturbances caused by restoration activities, which occur on a 'local' reach scale rather than a river-wide scale, exert the stronger influence on benthic community composition. At the scale of importance in restoration projects (i.e. reach-scale), local controls, such as disturbances, are critically important (Montgomery 1999).

The role of disturbance is particularly great in lotic ecosystems, relative to other ecosystem types, (Matthaei et al. 2004), with the disturbance caused by restoration activities imposing an ecologically novel condition to which organisms are not adapted (Muotka 2002). The apparent disruption of sediment transport features, suggested by the association of benthic communities with transport-related variables, in restored reaches implies that a substantial disturbance results from the construction of restoration practices. The association with local sediment conditions, rather than the water quantity and quality contributed by the watershed, indicates a significant modification of community influences moving from the upstream into the restored reaches, which we contribute to the effects of construction disturbances.

Further, in consideration of an appropriate concept for describing current conditions of stream ecosystems, it is important to consider that a fundamental principle of the RCC is that it applies to natural, continuous systems where disturbances are both temporary and marginal, and that any deviation from the stated continuum is undesirable and unnatural. Because implementation of restoration activities is an indication of some existing and significant disturbance, some need for improving habitat and function of a reach, and is a very local solution, the RCC may not be appropriate for addressing these disrupted, local processes. Thus, the value of the RCC is that of extracting disturbed systems from undisturbed ecosystems.

With the dramatic decrease in unimpacted streams in the US (USEPA 2000), concepts, such as the PDC, that apply to disturbed systems are beneficial. Particularly with respect to the stream restoration design process, these systems should be considered both on their wide and narrow temporal and spatial scales, including the local disturbances and watershed influences. Predicting and designing restoration activities using concepts based on natural conditions (RCC) to highly disturbed systems may not be an effective way to promote recovery.

Conclusions

The National Research Council has defined stream restoration as the "various techniques used to replicate the hydrological, morphological, and ecological features that have been lost in a stream due to urbanization, farming, or other disturbance" (NRC 1992). However, early restoration projects, including some of those discussed here, focused on manipulation and restoration of channel form, rather than restoration of stream ecosystem function. As the science of stream restoration matures, and scientists learn more about the potential recovery of these systems, a shift from this form-focused approach to a broader view of streams as functioning ecosystems has occurred. The implications of this shift on restoration are critical for building better projects, and the results of the analyses presented here contribute to the knowledge base that makes this shift possible.

These results are presented to illustrate the different processes influencing upstream and recently restored reaches in an effort to improve the science and practice of stream restoration and its potential to assist in the recovery of benthic communities. The restored reach communities demonstrated a consistent association to local disturbances of sediment characteristics, likely generated by construction activities related to channel pattern, profile, and dimension modifications. Minimizing construction impacts and correctly predicting sediment transport are particularly critical to the recovery of benthic communities because they are, by definition, dependent on the sediments for habitat and food resources. Further, that the restored reach communities were so clearly simplified, as exemplified by the one-dimensional ordination solutions, indicates that the damage imposed by construction activities do play a significant role in the diversity and function of the benthic macroinvertebrates.

Studies (Phillips 1993; Palmer et al. 2000) have demonstrated the effects of local erosion and sedimentation on the homogenization of habitats and simplification of communities. Our results support this concept, suggesting two things for improving the design and application of stream restoration practices:

- minimizing massive channel reconstruction may be beneficial in re-establishing benthic communities, and
- a renewed focus on establishing heterogeneous habitats is fundamental to re-establishing heterogeneous communities .

This study emphasizes how traditional views of stream ecology may not apply to these highly disturbed systems, without discarding the value of conventional knowledge. As diminishing numbers of streams fit into the model of a 'natural' stream ecosystem, consideration of alternative concepts that account for deviations from the reference condition may be advantageous. With respect to stream restoration and facilitation of benthic recovery, one must consider the disturbances that hinder the recovery process. Keeping an open mind about where the stream ecosystem is currently (PDC) and to where it is intended to evolve (RCC) will result in the best restoration of biological and geomorphic function of these systems.

The present exploration into the responses of stream communities to restoration efforts provides insight into where improvements may lie in assisting benthic recovery in the Piedmont of North Carolina and elsewhere. However, trends and general expectations may be the most accurate predictions available to designers and ecologists, strengthening the argument for preserving, rather than modifying, these fragile and increasingly disturbed ecosystems. The most comprehensive view is one that considers both short and long term goals, local and landscape influences, and flexibility within these goals and influences as the system moves forward to form and reform our conceptualization of its recovery.

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CHAPTER 3

Development and Application of a Success Indicator for Benthic Habitat Enhancement in the North Carolina Piedmont

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Development and Application of a Success Indictor for Benthic Habitat Enhancement in the North Carolina Piedmont

Abstract

With enhancement of benthic habitat as a central objective in many stream restoration projects, development of a simple but informative measure of the effects of these projects on benthic habitat quality is necessary. This paper describes such a measure, independent of reference reach comparison and water quality conditions, which applies the presence of specialists as indicators of the enhancement of woody debris, coarse bed substrate, fine roots, and leaf pack habitats. Three genera were identified as specialists for each habitat type through an indicator species analysis, extensive literature review, and consultation with local experts. When applied to 27 pairs of upstream-restored Piedmont streams, this method indicates that no change in the presence of habitat specialists was the most frequent result for the four individual habitat types and suggests no enhancement was made. By summing individual habitat scores into composite values, it appears that restoration activities resulted in an overall positive effect on habitat quality for urban streams, though agricultural and rural study sites demonstrated parity in the increases and decreases in specialist presence. This framework for evaluating habitat enhancement may be developed for various hydrogeographic and land use conditions, and is constructive for guiding restoration designs to maximize biotic integrity.

Introduction

As forested watersheds were historically converted to urban and agricultural landscapes, impacts on streams remained largely unrecognized, resulting in degradation of channel stability and aquatic communities. Degradation of habitat that results from modified hydrology, energy processing, and habitat access or quality is considerably damaging to benthic communities (Barbour et al., 1999). Removal of woody debris, sedimentation of coarse bed substrates, decreased retention of detrital material, and erosion of bank habitats occur as natural flow frequencies and volumes are disrupted and riparian areas are converted to more anthropogenically productive uses. As the value of functioning stream ecosystems becomes more widely recognized, and attempts to mitigate the losses of ecosystem function have given rise to the science of stream restoration.

The National Research Council defines stream restoration as the "various techniques used to replicate the hydrological, morphological, and ecological features that have been lost in a stream due to urbanization, farming, or other disturbance" (National Research Council, 1992). Various practices are applied in an attempt to re-create the natural pattern, profile, and dimension of the channel, as well as to re-establish floodplain connection, functioning aquatic and terrestrial habitat, and riparian services. Because these hydrologic, morphologic, and ecologic features are so interrelated, successful restoration requires a comprehensive design approach and a comprehensive knowledge of the strongest influences on controlling the vitality of aquatic ecosystems (Nedeau et al., 2003). This is particularly true as restoration goals and criteria move beyond channel form into ecological function, which necessitates the application of biotic integrity as an indicator of stream function.

Biotic integrity is dependent on the physical, chemical, and biological condition of the stream, and it is this physical component that restoration activities attempt to enhance. Because diverse communities in aquatic ecosystems are principally dependent on functioning habitat (Barbour et al., 1999), re-establishing aquatic habitat has become a fundamental component of this developing science.

Consequently, a key goal of stream restoration is often to re-establish high-quality aquatic habitats to facilitate the natural recovery process following disturbance (Moerke et al., 2004). While it is widely recognized that diverse communities are consistently found in heterogeneous habitats (Pianka, 1967; Woodin, 1981; Boomsma and Van Loon, 1982; Schlosser, 1982), determining the success of re-establishing of diverse and accessible habitats is rarely a trivial task. The use of benthic macroinvertebrates has been proposed for assessing the habitat component of a stream restoration success criterion (Brown, 2000). However, while it is recognized that benthic macroinvertebrates have distinct habitat preferences unassociated with water quality conditions, (Barbour et al., 1996), the use of benthic macroinvertebrates for detecting enhancement by stream restoration activities is still under debate. This debate is largely due to the frequently inconsistent signals given by generic community descriptions and the inappropriate assumption that each metric provides similar ecological responses (Vlek et al., 2004). Various metrics do exist for describing unique aspects of the macroinvertebrate community (Vlek et al., 2004), though biotic indicators of habitat enhancement do not currently exist for widespread application. Common multimetric indices, such as the Benthic Index of Biotic Integrity (B-IBI) (Kerans and Karr, 1994) and the Invertebrate Community Index (ICI) (Ohio EPA, 1987) are largely a function of diversity, which may not be sensitive enough to detect ecologically significant community shifts following restoration. Alternatively, biotic indices, such as the North Carolina Biotic Index (Lenat, 1993) and the Family Biotic Index (Hilsenhoff, 1988), are based on tolerance of water quality conditions. However, the effects of stream restoration on water quality are largely undocumented (Jorgensen and Yarbrough, 2003), making the use of such indices inappropriate for judging the success of restoration activities.

The measurement of habitat enhancement resulting from restoration activities is further complicated by the lack of knowledge regarding what level of variation is natural following significant disturbances such as those created by constructing restoration activities (Nedeau et al., 2003) and the timeline for recovery of biological communities following such disturbances. In spite of the challenges facing enhancement assessment, determination of the success of restoration activities is necessary for those seeking mitigation credits (i.e., compensatory action to improve quality of a degraded stream for unavoidable impacts to another stream), as well as for documenting the effectiveness of measures for re-establishing functional stream ecosystems.

For this study, application of these traditional metrics was rejected in order to isolate habitat enhancement caused by stream restoration activities and to avoid the difficulties associated with distinguishing the natural community variation within these metrics. The development of habitat criteria that distinguish meaningful biotic responses and are relevant to the stress of interest is an important and urgent task (Ofenbock et al., 2004). This concern has led to the development and application of an alternative approach to assessing habitat enhancement as presented here, using the presence-absence of specialists to indicate the effects of restoration activities.

Background

While the entire stream ecosystem provides habitat for the various benthic macroinvertebrates, this study focused on four specific habitat types in restored streams in the Piedmont of North Carolina: woody debris, coarse bed material, fine roots, and leaf packs. Two other significant habitat types not considered here include sand and aquatic mosses. Sand habitats were not considered because: 1) the collection method (QUAL5) for this study does not sample low-velocity areas of streams, primarily pools, where sand is naturally found (NCDENR, 2003), and 2) the dominance of sand habitats in higher-velocity areas is not a desirable habitat to be 'restored' in these gravel-bed streams. It is important to emphasize that the sites examined in this study are Piedmont streams; the application of this methodology in other ecoregions, such as the coastal plain, would require careful reconsideration of the natural and desirable habitat types and organisms.

The second habitat type not considered in this study is aquatic mosses. The role of mosses in stream ecosystem processes is significant (retention of fine particles, flow refugia for invertebrates) (Suren and Winterbourn, 1992). However, the incidence of aquatic mosses is limited due their seasonality (Barbour et al., 1999) and moderate growth rate. Further, it has been shown that mosses are often damaged during the construction of restoration activities by heavy equipment (Sand-Jensen et al., 1999). Because moss populations are slow to mature and expand, their widespread presence following major disturbances, such as that associated with restoration activities, is unlikely (Muotka et al., 2002). These features of aquatic mosses make determining successful restoration of this habitat difficult and unreasonable within traditional monitoring periods.

Following is a detailed discussion of the four habitats considered for this study.

Woody Debris

For the past two centuries, the removal of woody debris obstructions from streams and rivers was a prevalent management practice to enhance navigation and reduce flooding (Benke et al., 1985). Geomorphologic responses to woody debris removal include erosional downcutting (Bilby, 1984), widening (Maser et al., 1998), increased bedload transport, redistribution of gravel bars, and thalweg shifting (Smith et al., 1993a, 1993b). Biologically, these woody 'obstructions' provide well-documented benthic habitat (Harmon et al., 1986) and have been shown by Benke et al. (1984) to comprise a significant fraction of the benthic macroinvertebrate production while only accounting for a minor proportion of the actual habitat. Further, the retention of organic material by woody debris plays a considerable role in the energy processing of streams (Benke et al., 1984), and the resilience and perseverance of a stream is influenced by the presence of woody material in a stream (Lemly and Hilderbrand, 2000). Consequently, re-establishing woody debris to streams should result in more diverse and abundant benthic macroinvertebrate communities (Benke et al., 1985).

Coarse Bed Substrate

Coarse bed substrates are a common but fundamental riffle habitat (Barbour et al., 1999) for the many clinger taxa. It has been found that these habitats provide the greatest diversity and density of benthic macroinvertebrates (Hynes, 1970; Hart, 1978). However, these habitats are often and easily degraded in urban and agricultural landscapes when overwhelming loads of fine sediments enter the stream. These fine sediments embed larger particles by filling the spaces between them, removing access to interstitial space habitats, and ultimately blanketing the coarse bed material that serves as critical habitat for many benthic macroinvertebrates. Fine sediment deposition has been shown to have significant impact on the benthic taxa utilizing this habitat. One example is the larvae of the Stenonema mayfly, which is commonly found under loose substrates but rarely present in embedded substrates (Kondratieff and Voshell, 1980). The particles are deposited when the load of fine sediments from the landscape and from streambank erosion exceeds the capacity of the channel to move it. Therefore, to restore natural sediment transport and re-establish coarse substrate habitats, minimization of overwhelming fine sediments from within and outside the channel and the return of natural flow regimes to the channel are necessary.

Fine Roots

Vegetation along streambanks provides necessary habitat for many of the climber insects, those that have evolutionary adaptations for vegetative habitats along streambanks, including overhanging branches and roots (Merritt and Cummins, 1996). Benthic larvae are often found in the vegetation of undercut banks (Barbour et al., 1999; Bouchard, 2004) because adults, including the damselflies Argia and Calopteryx, will oviposit on the submerged vegetation (Borror, 1934). These rooty habitats are often removed by streambank erosion as shear stresses increase in response to disruptions in sediment transport and natural flow regimes. The restoration of such habitats is quickly accomplished, however, by re-establishing herbaceous vegetation along streambanks (Manolis, 2003).

Leaf Packs

Leaf packs provide another essential habitat for benthic organisms in the Piedmont of North Carolina. While detrital material is often available in disturbed stream systems, the retentive capacity of channels has often been lost due to restrictive stream management that removed retentive structures, such as woody debris and large bed material. Traditional management of urban and agricultural settings to increase productivity of an area has frequently resulted in the displacement and straightening, or channelization, of streams. In addition to the disruption of riffle-pool complexes, increased velocities, disrupted sediment transport, and destruction of habitat diversity (FISRWG, 1998), channelization results in a substantial loss in the ability for a stream to retain allochthonous materials (Muotka et al., 2002). While supply is not always limited even in disturbed areas, the seasonality of detrital material from fall leaf litter (Cuffney and Wallace, 1989), makes retention a critical feature for sustaining benthic communities year-round (Lemly & Hilderbrand, 2000).

Detrital matter provides essential habitats to many organisms, including the Peltoperlidae stoneflies, in addition to serving as the foundational layer of the food resources for the entire aquatic ecosystem (Vannote et al., 1980). The potential for restoration of these habitat types is great. The increased presence of woody debris and large bed material, as well as increases in bed heterogeneity, has been shown to increase the retention of leaf material (Lemly and Hilderbrand, 2000; Negishi and Richardson, 2003; Benke et al., 1985).

Methods / Materials

Study Site Characterization

A total of 27 pairs of restored and upstream reaches were studied across the Piedmont of North Carolina for this project (Figure 1). Study sites were sampled from May to August of 2003 and 2004 to minimize seasonal effects on environmental variables and aquatic insects. Sites were limited to drainage areas of $13km^2$ or smaller to further minimize environmental and community variation, with streams demonstrating a bankfull width range of 2.1m to 11.2m. Soil Conservation Service Curve Number (SCS-CN) ranged from 54 to 83 (Soil Conservation Service, 1975), with landscapes varying from urban to agricultural to rural settings. Riparian area conditions included mature and immature forest, herbaceous cover, and lawn grass. Stream substrates were composed of anything from silt to coarse gravel, with a median particle diameter range of .01 mm to 32mm, and water slopes measuring from as little as 0.07% to as high as 2.67%. These characteristics represent the broad range of physical conditions at these sites, influencing the morphological and habitat features of the benthic macroinvertebrates collected.

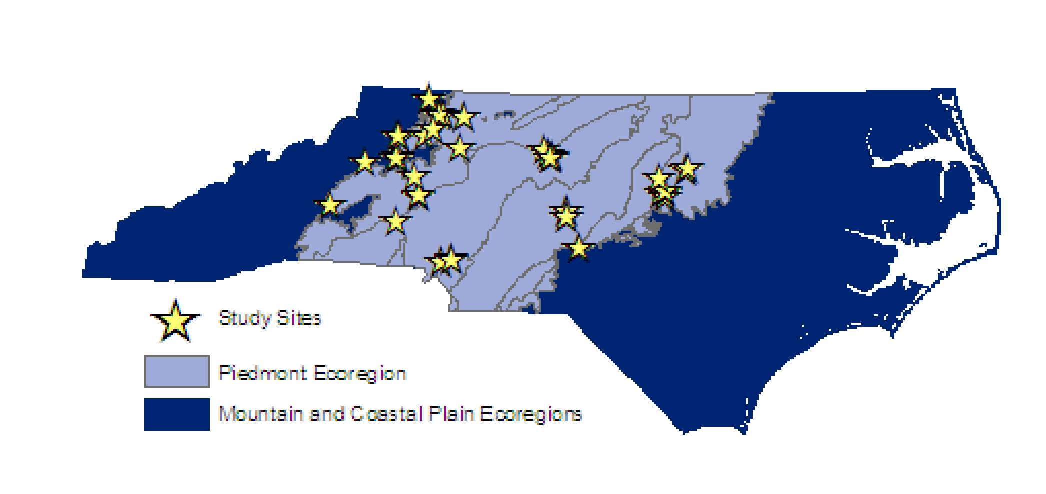

Fig 1. Location of study sites in the North Carolina Piedmont. The Piedmont spans the central part of the state, bounded by the coastal plain to the east and the mountains to the west.

Organisms were collected according to the North Carolina Division of Water Quality (NCDWQ) QUAL5 method (NCDENR, 2003). This protocol includes sampling insects from one riffle using a kicknet, one sweep net collection from bank habitats, fine mesh wash of rock/log, one leaf pack wash, and visual collections. Insects were picked from samples, preserved in 95% ethanol in the field, and brought back to the lab for identification to species when possible. Insects were not separated by habitat for these samples.

<u>Study Design</u>

In an upstream-downstream approach, benthic macroinvertebrates were collected within each restored reach segment, as well as within a reach upstream of the project tie-in to investigate the effects of restoration activities on habitat quality given similar watershed conditions. It is important to note that several of the upstream reaches were not in what is often considered 'reference' condition. Several of the upstream urban sites were notably degraded by watershed activities and removal of riparian areas. However, in this modified upstream-downstream study design, the upstream reach was simply used as a control for comparison to the restored reach, to represent the initial condition from which the restored reach was assume to deviate, with the assumption that the watershed conditions similarly affect the upstream and restored reaches. A discussion of the advantages and implications of this approach is provided in the Conclusions section.

Further, it is worth noting that benthic collections were made early in the recovery period for stream restoration, as the age of these projects ranged from one to four years. Given the limited understanding of the recovery time of restored streams, and that some of the study streams were potentially still stabilizing in response to construction activities at the time of assessment, this study does not attempt to investigate the temporal evolution of the sites, but instead takes a snapshot assessment of early responses of benthic communities to restoration activities. Thus, the term 'restored sites' within this paper refers to those sites to which stream restoration practices have been applied, without suggesting that sites have been restored to the natural, pre-development condition.

Indicator Species Determination

The enhancement of benthic habitat was investigated through the presence of of 'indicator' genera. A perfect indicator taxon is consistent and restricted to the group it represents (McCune and Grace, 2002), meaning that the organism is always present and occurs primarily in a particular habitat, treatment, or area. Three indicator genera were identified for each of the four habitat types through the use of an indicator species analysis (Dufrene and Legendre, 1997), an extensive literature review of habitat colonization studies, and consultation with local experts on benthic ecology.

The first approach used in the development of this habitat specialist list was an indicator species analysis using data collected on Little Garvin Creek in the Piedmont of South Carolina (Young, 2004). The watershed for this stream is 6.8 km^2, with the majority of the area under agricultural applications. This stream has an average water surface slope of 0.4% and bankfull width of 6m. These features demonstrate the similarity in channel geometry and watershed condition of Little Garvin to the study sites evaluated within this paper, making the habitats and benthic organisms found in this reach appropriate for comparison with our study sites.

Benthic macroinvertebrates were sampled seven times in Little Garvin Creek. Each sample was collected and identified by habitat, resulting in a list of species found for each habitat type. These data were then used in an indicator species analysis within PCORD software (McCune and Mefford, 1999). This analysis combines the abundance and frequency of occurrence information of each taxon for each group into a single Indicator Value (IV). The groups analyzed for this analysis are the previously described four habitat types, with the faithfulness and abundance of each species collected at Little Garvin Creek providing the species indicator value for each habitat. One hundred Monte Carlo randomized simulations of the data were performed to ensure that these indicator values were statistically more significant than could occur by chance.

An extensive literature review followed, taking advantage of the numerous habitat colonization studies. These studies (Table 1) varied by ecoregion of study, stream type, and geographical location, but provided support for selected indicator taxa. This indicator list was then confirmed by local experts with 20-30 years of field experience in the Piedmont of North Carolina.

Genera with low tolerance values were then removed from the list. This was accomplished by excluding insects with a water quality tolerance value of 4.5 or lower as listed in NCDENR's Benthic Standard Operating Procedures (2003). Organisms below this tolerance value have demonstrated elevated intolerance to poor water quality conditions. This elimination of water quality influence was performed to ensure that the effects of habitat restoration or loss were isolated and detected. Finally, species were combined into the genera taxonomic level for this list (Table 1).

Each of the restored and upstream study sites was then queried to determine the presence of habitat specialists. The presence of an indicator genus reflected one score point, so that sites with all genera for all habitats received a score of 12 (3 genera per habitat, 4 habitats). The upstream score was then subtracted from the restored reach score to reflect the change in habitat quality as a result of the restoration activities. An increase in the presence of habitat specialists at a restored site, as compared to a paired upstream site, is taken to indicate an enhancement of habitat quality. The change in the presence of specialists was examined by each habitat type, as well as by the composite, overall habitat quality. An example demonstrates how these values were calculated.

A negative score indicates that more habitat specialists were found at the upstream site than in the restored site; a positive score indicates the collection of more habitat specialists at the restored site than at its upstream counterpart. For example, a negative score on the leaf pack habitats likely indicates a reduction in retentive capacity, since the upstream watershed and detrital supply should be similar in this upstream-downstream study design. In contrast, a positive score on coarse bed material may suggest a success of the restoration activities in stabilizing streambanks and reducing fine sediment loads from the watershed. The sum of the individual habitat scores is also provided for an indication of overall habitat enhancement in response to restoration activities.

Site D - upstream
Woody debris taxa:
Macronychus (no) + Stenochironomus (no) + Ancyronyx (no) = 0 + 0 + 0 = 0

Coarse bed material taxa:
Stenonema (no) + Stenacron (no) + Hydropsyche (no) = 0 + 0 + 0 = 0

Fine root taxa:
Calopteryx (no) + Argia (no) + Ischnura (no) = 0 + 0 + 0 = 0

Leaf pack taxa:
Tipula (no) + Leptophlebia (no) + Isoperla (no) = 0 + 0 + 0 = 0

Upstream Combined Habitat score = 0

Site D - restored
Woody debris taxa:
Macronychus (no) + Stenochironomus (no) + Ancyronyx (no) = 0 + 0 + 0 = 0

Coarse bed material taxa:
Stenonema (yes) + Stenacron (no) + Hydropsyche (no) = 1 + 0 + 0 = 1

Fine root taxa:
Calopteryx (no) + Argia (no) + Ischnura (yes) = 0 + 0 + 1 = 1

Leaf pack taxa:
Tipula (yes) + Leptophlebia (no) + Isoperla (no) = 1 + 0 + 0 = 1

Restored Combined Habitat Score = 3

Composite Site Score = Restored – Upstream = 3 – 0 = 3

This example illustrates no improvement in woody debris habitat, a common trend at these sites. However, an improvement in the remaining three habitats for the restored reach is shown, resulting in an overall habitat score of +3 for the restored site.

Results

The indicator species analysis proved to be minimally constructive, with a more robust dataset likely generating more relationships between indicator species and associated habitats. While this analysis identified a few taxa as reliable indicators of the various habitat types, only the Stenonema mayfly, an indicator for coarse bed substrate habitat, met the tolerance value criteria of 4.5 or greater at a statistical significance of α=0.05. Consequently, the remaining habitat specialists were determined through colonization study reviews and local expert consultations.

The determination of specialists provided a basis by which to judge the enhancement of specific habitats through restoration activities. It is important to note, however, that while woody debris and coarse bed substrate are distinct habitats, some organisms will colonize either in the absence of preferred habitat. These organisms are considered facultative users, such as the Stenonema mayfly or the Hydropsyche caddisfly. While these taxa typically prefer coarse bed material, they are commonly abundant on woody material in sandier streams where coarse bed material is not present (Drury and Kelso, 2000).

Table 1. Specialist list and supporting literature for each of the four habitat types. Tolerance Values (TV) listed, with increasing tolerance values representing increasing tolerance to poor water quality, are for the most common species within the genus if not provided by genus in NCDENR 2003. Literature supporting the use of indicator genera includes colonization studies as well as texts on the specific benthic organisms.

woody debris	Indicator Genera	TV	Supporting Literature
	MACRONYCHUS (Coleoptera)	4.6	Magoulick (1998), Drury and Kelso (2000), Nilsen and Larimore (1973), Smock et al. (1985), Brown (1987), Phillips (2003)
	STENOCHIRONOMUS (Diptera)	6.5	Magoulick (1998), Dudley and Anderson (1982), Armitage et al. (1995), Braccia and Batzer (2001), Borkent (1984), Benke et al. (1984), Phillips (2003), O'Conner (1991)
	ANCYRONYX (Coleoptera)	6.5	ry and Kelso (2000), Smock et al. (1985), rp et al. (1985), Benke et al. (1984), llips (2003)
coarse bed material	Indicator Genera	TV	Supporting Literature
	STENONEMA (Ephemeroptera)	5.5	Richardson and Tarter (1976), Kondratieff and Voshell (1980), Berner and Pescador (1988), Lamp and Britt (1981)
	STENACRON (Ephemeroptera)	6.9	Berner and Pescador (1988), Edmunds et al. (1976), Lamp and Britt (1981), Flowers and Hilsenhoff (1978), Flowers and Hilsenhoff (1975), McShaffrey and McCafferty (1986)
	HYDROPSYCHE (Trichoptera)	7.8	Bouchard (2004), Georgian and Thorp (1992), Hickin (1968)
fine roots	Indicator Genera	TV	Supporting Literature
	CALOPTERYX (Odonata)	7.8	Manolis (2003), Westfall and May (1996)
	ARGIA (Odonata)	8.2	Borror (1934), Phillips (2003)
	ISCHNURA (Odonata)	9.5	Bouchard (2004), Cannings and Doerksen (1979)
leaf packs	Indicator Genera	TV	Supporting Literature
	TIPULA (Diptera)	7.3	Cummins et al. (1973), Peterson and Cummins (1974), Griffith and Perry (1993)
	LEPTOPHLEBIA (Ephemeroptera)	6.2	Edmunds, et al. (1976), Peterson and Cummins (1974)
	ISOPERLA (Plecoptera)	5.4	Egglishaw (1964), Reice (1980), Dobson (1994), Stewart and Stark (1988)

Table 2. Habitat specialist presence results by individual habitats and land use. The habitat scores for the twenty-seven sites are summarized by land use. For each site, the difference column represents the change in presence of habitat specialists from the upstream to the restored reach. Summaries are provided by each habitat type, indicating the positive, negative, and null effects of the restoration activities on the presence of these specialists at all of the sites.

Site Name	Upstream Woody Sum	Restored Woody Sum	Woody debris difference	Upstream Coarse Sum	Restored Coarse Sum	Coarse Bed Material Difference	Upstream Fine Roots Sum	Restored Fine Roots Sum	Fine Roots Difference	Upstream Leaf Sum	Restored Leaf Sum	Leaf Pack Difference
AGRICULTURAL 1	0	0	0	2	2	0	0	1	1	1	2	1
AGRICULTURAL 2	0	0	0	2	2	0	1	0	-1	2	0	-2
AGRICULTURAL 3	0	0	0	0	2	2	0	2	2	2	0	-2
AGRICULTURAL 4	0	0	0	3	0	-3	1	0	-1	2	1	-1
AGRICULTURAL 5	0	0	0	2	2	0	1	0	-1	1	1	0
AGRICULTURAL 6	0	0	0	2	1	-1	0	0	0	1	0	-1
AGRICULTURAL 7	0	0	0	2	2	0	1	1	0	1	2	1
RURAL 1	0	1	1	1	0	-1	0	0	0	0	1	1
RURAL 10	0	0	0	3	2	-1	1	1	0	3	2	-1
RURAL 11	2	2	0	2	1	-1	2	2	0	1	1	0
RURAL 12	1	2	1	1	2	1	1	1	0	1	0	-1
RURAL 2	1	1	0	1	1	0	0	0	0	0	1	1
RURAL 3	1	0	-1	3	2	-1	0	0	0	0	1	1
RURAL 4	1	0	-1	1	1	0	0	1	1	1	1	0
RURAL 5	0	0	0	2	1	-1	0	0	0	2	1	-1
RURAL 6	0	0	0	2	2	0	1	0	-1	0	0	0
RURAL 7	0	0	0	2	0	-2	1	1	0	0	0	0
RURAL 8	0	0	0	1	0	-1	0	1	1	0	0	0
RURAL 9	0	0	0	0	1	1	0	1	1	0	1	1
URBAN 1	0	0	0	1	1	0	0	0	0	0	1	1
URBAN 2	0	0	0	1	1	0	0	1	1	1	1	0
URBAN 3	0	0	0	0	2	2	0	0	0	0	1	1
URBAN 4	0	0	0	1	1	0	0	2	2	1	0	-1
URBAN 5	0	0	0	0	1	1	0	1	1	0	0	0
URBAN 6	0	0	0	0	1	1	0	0	0	0	0	0
URBAN 7	0	0	0	1	1	0	1	0	-1	1	1	0
URBAN 8	0	0	0	1	1	0	1	2	1	1	0	-1

woody debris	positive	2	coarse bed material	positive	7	fine roots	positive	9	leaf packs	positive	8
	negative	2		negative	6		negative	5		negative	9
	no change	23		no change	12		no change	13		no change	11

Table 3. Composite scores of habitat specialist presence results by land use. By examining the relative number of positive and negative composite scores for the 27 sites, restoration activities appear to have had a negative effect on the presence of habitat specialists nearly as often as a positive effect.

Site Name	Upstream overall	Restored overall	Overall Site Score
AGRICULTURAL 1	3	5	2
AGRICULTURAL 2	5	2	-3
AGRICULTURAL 3	2	4	2
AGRICULTURAL 4	6	1	-5
AGRICULTURAL 5	4	3	-1
AGRICULTURAL 6	3	1	-2
AGRICULTURAL 7	4	5	1
RURAL 1	1	2	1
RURAL 10	7	5	-2
RURAL 11	7	6	-1
RURAL 12	4	5	1
RURAL 2	2	3	1
RURAL 3	4	3	-1
RURAL 4	3	3	0
RURAL 5	4	2	-2
RURAL 6	3	2	-1
RURAL 7	3	1	-2
RURAL 8	1	1	0
RURAL 9	0	3	3
URBAN 1	1	2	1
URBAN 2	2	3	1
URBAN 3	0	3	3
URBAN 4	2	3	1
URBAN 5	0	2	2
URBAN 6	0	1	1
URBAN 7	3	2	-1
URBAN 8	3	3	0
	Composite Site Scores	positive	12
		negative	10
		no change	3

Discussion

The application of this methodology indicates the need for improved restoration designs for re-establishing habitats (particularly woody debris, coarse bed material, and leaf packs) and illustrates the significant potential for restoring these habitats in urban areas.

Site Scores by Individual Habitats

By examining the sum of the positive, negative, and no-change values for each habitat individually, it appears that no change in specialists was the most frequent result of restoration. The frequency of zeros, as seen by comparison of restored sites to their upstream counterparts, indicates that neither improvement nor degradation to the quality of each habitat type can be attributed to the restoration activities at a majority of the sites.

The lack of response in habitat specialists was most notable for the woody debris habitat, which exhibited no change in specialists at 23 of the 27 sites. Although re-establishing woody debris to streams has been identified as a measure for enhancing benthic productivity (Benke et al., 1985), these data illustrate little improvement in this critical habitat and suggest a need for focusing restoration designs to include woody debris in streams. Further, because woody debris is so often responsible for retention of detrital material, it is suggested that the return of woody debris to streams will positively influence the presence of leaf pack specialists as well.

A greater number of fine root habitats exhibited positive effects than any other habitat type (9 positive and 5 negative), which suggests that these habitats are more often successfully re-established than other habitat types. The parity of the positive and negative responses of habitat specialists to restoration for these other types (woody debris: 2 positive and 2 negative; coarse substrate: 7 positive and 6 negative; leaf packs: 8 positive and 9 negative) indicates that, generally, restoration may not be having a positive impact on benthic habitats in Piedmont streams. It is discouraging to note that as many habitats appear to be degraded by restoration activities as are enhanced by them. However, as these restoration projects were all designed during the early years of stream restoration science, these data may not accurately reflect current philosophies and design approaches.

Composite Site Scores by Land Use

By summing all of the habitat scores into a single value, the net positive or negative effect of the restoration activities was examined. The results for the urban sites are the most consistent and the most encouraging. Of the eight urban sites studied (Table 2), six indicated a positive overall response to the restoration activities (of the remaining two sites, one demonstrated no change and the other showed a negative net effect). While construction of dams and bridges, channelization, bank erosion, and loss of riparian habitats (Waters, 1995; Woody and Armitage, 1997; 1999) all result in sedimentation of benthic habitats in the urban watershed, it appears that stream restoration can overcome these negative impacts by enhancing local habitat conditions.

Agricultural and rural sites do not show the same clear overall improvement in habitat. The agricultural sites produced three positive and four negative composite habitat scores. For the rural sites, four positive and six negative overall scores are observed, with two rural sites demonstrating no change. These findings support the idea that, though some restoration projects were successful, these early restoration designs in agricultural and rural settings were not effectively enhancing benthic habitat a majority of the time.

Methodology Implications

It has been recognized that the quality of aquatic habitats may be the most influential feature in structuring benthic communities (Rankin, 1995). The application of stream restoration practices has great potential for re-establishing habitats in areas where they have been degraded. Understanding and measuring the effectiveness of restoration activities in enhancing benthic communities is important for determining whether projects meet stated goals, as well as for advancing the science of stream restoration. However, determining the success of restoration efforts is not a simple endeavor, and requires the selection of relevant criteria that reflect the transitions initiated by restoration activities (Brooks et al. 2002).

This paper describes a framework for evaluating the effectiveness of restoration activities on habitat enhancement. This evaluation procedure is independent of water quality conditions through the use of water-quality-tolerant taxa and provides an indication of the direction of change resulting from restoration activities without the requirement of determining a specific endpoint community. A central advantage of this approach is the lack of comparison of the 'treatment' stream with a 'reference' reach, as is common in traditional biological monitoring. Dominants-in-common (DIC) is one such commonly monitored bioindicator, applied to determine the ecological condition because dominant organisms represent the existing environmental features and influences (Shackleford, 1988). This metric requires the comparison of the treatment stream with a reference reach, representing the least impaired streams (Parsons et al., 2002) and often the desirable endpoint community, to determine the similarity of the dominant organisms. However, this reference condition is often difficult to identify and impossible to restore due to irreconcilable watershed pressures, particularly in urban streams. Thus, the approach described in this paper evaluates an alternative perspective on restoration impacts by comparing post-restoration data to an upstream or pre-construction condition. The result is only the derivative of the impact: Has habitat quality improved, decreased, or remained the same? This approach, while providing limited information on the magnitude of the impact, bypasses troubling questions:

- How much similarity to the reference condition is possible?
- How much similarity to the reference condition is enough to signify success?

The development and application of this habitat restoration indicator provides insight into measurement and success determination of attempts to enhance a critical component of aquatic ecosystems. However, preserving natural habitats is fundamental to supporting robust benthic macroinvertebrate communities (Rankin, 1995), and the application of restoration activities indicates that an irretrievable loss has already occurred. Our success as engineers and ecologists in providing favorable conditions for these essential organisms may lie in our ability to protect and preserve the remaining high-quality streams, providing both habitat for the benthic organisms and opportunities for sustainable research by future students.

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CHAPTER 4

A Qualitative Model for Analyzing the Effects of Anthropogenic Activities in the Watershed on Benthic Macroinvertebrate Communities

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A Qualitative Model for Analyzing the Effects of Anthropogenic Activities in the Watershed on Benthic Macroinvertebrate Communities

Abstract

This paper presents a Qualitative Reasoning (QR) simulation model for analyzing the impacts of watershed development and riparian deforestation on benthic macroinvertebrates. A study of 54 stream sites in the Piedmont of North Carolina, USA provided the knowledge foundation for the model development. A conceptualization of the anthropogenic activities and effects was established and then transferred into the Qualitative Process Theory (QPT). Using the composition approach, watershed-stream corridor interactions were defined by a total of eight model fragments. These partial behavior models were used to progress impacts on the benthic community within the qualitative model. Simulation results of the two activities in the watershed lead to tolerant benthic communities. However, watershed development primarily impacts habitat quality while riparian deforestation affects both habitat quality and trophic condition. Further, a significant increase in the number of states generated by the riparian deforestation scenario indicates a greater ambiguity in this system definition, and reflects the increased complexity as a result of the interactions with both habitat quality and trophic condition. This application of QR in stream ecology studies submits: (1) the explicit definitions of watershed and stream corridor interactions, (2) the demonstration of the consequent impacts of these interactions on benthic macroinvertebrates, and (3) the identification of knowledge gaps, such as the relative importance of habitat and trophic features on the benthic macroinvertebrates, for directing future ecological research, and (4) the demonstration of some of the benefits and limitations of applying QR to ecological systems, including the sensitivity to weakly defined systems, as meaningful contributions.

Introduction

Conversion of natural landscapes to urban and agricultural uses impacts stream ecosystems and the organization of benthic communities in several ways. As forested watersheds urbanize to accommodate residential, commercial, and industrial needs, the volume and intensity of storm events increase due to the reduced infiltration within the watershed. These runoff events often carry higher sediment and nutrient loads. In addition, these urban storm events may increase habitat sedimentation from streambank erosion. Deforesting riparian areas reduces the supply of Large Woody Debris (LWD) and detrital matter and increases water temperature through reduced shading. These ecological services provided by stream corridors are valuable for supporting habitat quality and nutrient processing in the stream. Nevertheless, buffers and restrictions on the activity within riparian zones remain limited in many areas.

With already 45% of streams in the US designated as either threatened or impaired (USEPA 2000), it is worthwhile to develop accessible knowledge concerning both the value of the lost function of streams and the potential that management and restoration efforts may provide to disturbed stream ecology. However, management of "aquatic ecosystems requires an intimidatingly sophisticated level of knowledge of the spatial context and causal linkages among human actions, watershed processes, channel conditions, and ecosystem response" (Montgomery 2001). For example, while it is well known that diminished biological diversity results from a history of channel straightening, dredging, damming, development, and pollution, the task of unifying these concepts into a comprehensive and explicit presentation remains. By implementing educational models, more efficient approaches may be developed for minimizing and mitigating the impacts of stakeholder decisions and management alternatives within the watershed.

Traditional models are often inappropriate for comprehensive description of the complex nature of stream ecosystems. Complex mathematical and numerical models may "fail to capture the mechanisms that actually explain the observed behavior" (Salles and Bredeweg 2003). This is particularly true over larger temporal and spatial scales, where variation in system response is significant and commonly unpredictable. Though all models are a simplification of the system of interest, Karr and Chu note that exploration of ecology theories "depends on, and indeed values, both parts and processes – that is, both structure and function in these systems" (Karr and Chu 1999). The "explicit representations of causality that can support explanations about system's structure and behavior," provided by Qualitative Reasoning (QR), are essential to developing holistic approaches to preservation and restoration (Salles et al. 2003) of aquatic ecosystems.

Qualitative Reasoning provides an opportunity for building models by defining, managing, and applying a unique aspect of ecological knowledge. It satisfies the need for aggregation, articulation, and calculation of well-accepted but abstract ecological theories that are not empirically supported with long-term data. Further, QR presents an approach for discovering and discussing the causal evolutions of system behavior. In the absence of a comprehensive and robust dataset, this method may be an alternative to traditional mathematical models. Further, such QR models can guide research direction by organizing knowledge about a system and identifying where fundamental gaps in the knowledge exist.

Here, a QR model was developed to describe and predict changes in benthic communities in response to changes in the physical and chemical quality of a stream ecosystem induced by anthropogenic activities within the watershed. This paper outlines background on the need for using QR to describe this system, the details of the ecosystem modelled, how QR was used to represent this system, and how simulation results can be interpreted. Finally, a comparison of two modelled anthropogenic activities, discussion on the value and applicability of QR models to stream ecosystems, and an overview of future model revisions are given.

Material and Methods

Study sites

This QR model was built based on the study of 54 streams in the Piedmont of North Carolina, USA. During the summers of 2003 and 2004, watershed and stream corridor characterizations were performed, with eighteen variables measured to summarize the riparian features, energy processing, watershed condition, geomorphology, sediment transport, water quality, and climate of the sites (Tullos 2005). These stream sites drained watersheds of $13 km^2$ or smaller, with land use ranging rural, agricultural, and urban settings. Riparian areas conditions varied from mature to immature forest, herbaceous cover, and lawn grass. Stream substrates were composed of silt, various sands, and gravels, with median particle diameters ranging from 0.01 mm to 32mm. All sites were located in a transitional area between mountains and coastal plain, resulting in water slopes ranging from 0.07% to 2.67%. Average rainfall was around 115 cm/yr, with the wettest season occurring in early fall, after data collection was completed.

Aquatic Macroinvertebrate Community

Benthic macroinvertebrates were collected at each of these sites (Tullos 2005). These organisms were selected as the response variable in this model because they have been shown to consistently respond to the stresses contributed by changes in land use (Lenat and Crawford 1994) and have shown sensitivity to complex ecological disturbances not well detected by chemical or physical indicators alone (Ohio EPA 1990). In this paper, the benthic community response was modelled to represent biological feedback in terms of tolerances to habitat quality and trophic conditions. Such a shift in community tolerance was demonstrated at these sites. Of the stream sites in rural watersheds, 91% were dominated by intolerant taxa, such as stoneflies, caddisflies, and mayflies, in contrast to 38% of sites in agricultural watersheds and 44% of sites in urban watershed (Tullos 2005). This reduced dominance of sensitive taxa represents replacement by more tolerant organisms that are adapted to degraded conditions, such as chironomids in agricultural areas and oligocheata in urban areas.

Defining ecological relationships

Field observations and statistical relationships of these sites were articulated into a conceptual model of the watershed-stream corridor interactions (Figure 1). Tullos (2005) performed two statistical analyses: Non-metric Multidimensional Scaling (NMS) of community composition and paired t-tests of environmental characteristics and community descriptions. NMS results were applied to determine with which environmental variables benthic communities varied most consistently, while the paired t-tests helped define the relationships between the environmental variables, discovering either a positive, negative, or absent nature of the relationships. These results (Tullos 2005) and qualitative field observations provided the ecological expert knowledge and the quantity relationships to develop the QR model presented here.

Qualitative Process Theory

A technique described as the compositional approach (Falkenhainer and Forbus 1991) was adopted for developing this qualitative model as an aggregate of smaller, partial system behavior components to describe overall system behavior. S*tatic fragments* are defined as those model components that do not change with time, while the *process fragments* include the components that define the relationships in the model. The watershed and stream corridor were modelled through a combination of static and process fragments in the Qualitative Process Theory (QPT) (Forbus 1984).

Developing a qualitative simulation model by components has the principal benefit of explicitly representing causal relations. This building by parts leads to a validation process by which accuracy checking is made for each of the partial behavior models to evaluate a comprehensive response. Constructing and testing small aspects of the larger model replaces the validation process, confirming consistency and accuracy of the predictions with well-understood behavior derived from the underlying study (Tullos 2005).

This process-oriented ontology (Forbus 1984) initiates system changes through active processes, the effects of which may propagate to the whole system via causal relations. Direct influences (I+ and I-) and qualitative proportionalities (P+ and P-) were used as model primitives to represent mathematical functions and causal dependencies. Direct influences are used to calculate the derivative of a state variable from the rate of a process. For example, an increase in watershed development has a positive influence on sediment load. Qualitative proportionalities represent the transfer of indirect influences onto subsequent quantities, as with monotonic functions. For example, the increased sediment load has a negative proportionality on habitat quality. A simulator engine was used to generate potential states and state transitions based on the transition rules described through QPT.

This model was implemented within the graphical interface HOMER (Bessa Machado and Bredeweg 2002), simulated within the reasoning engine GARP (Bredeweg 1992), and inspected within VisiGARP (Bouwer and Bredeweg 2001). Within these three software components, respectively, model fragments are defined simulations are performed, and simulation results are inspected.

Results

<u>Conceptual Model</u>

The model was first designed conceptually as shown in Figure 1. The process 'Watershed development' refers to urbanization of natural areas, with consequential increases in nutrient and sediment loads, increased water temperature and effective discharge. These environmental variables subsequently affect the trophic condition (nutrient load), and the habitat stability (sediment load, water temperature, and effective discharge). 'Riparian tree survival' is an indication of the presence and maturity of woody riparian vegetation in the area adjacent to the channel, which consequently results in reduction of excess nutrient loads from surface water, stabilization of streambanks, and a significant supply of detrital biomass, canopy cover, and woody debris. These variables, in turn, affect the trophic condition (nutrient load, detrital biomass, canopy cover), and habitat stability (streambank erosion, detrital biomass, woody debris, sediment load, water temperature, median diameter), both directly and indirectly. This conceptual model was then expanded into the Qualitative Reasoning model.

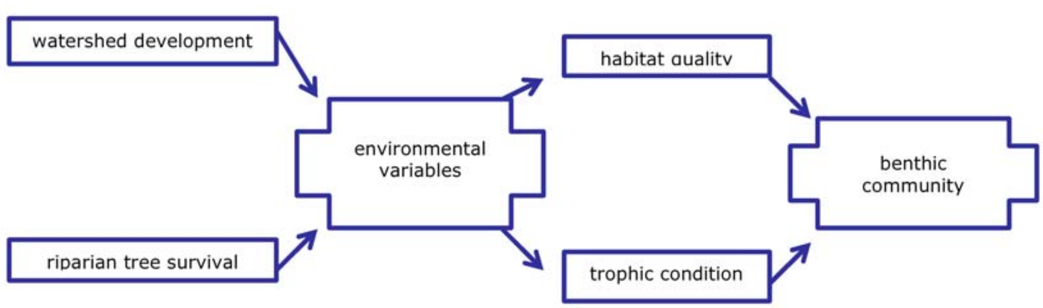


Figure 1 – Conceptual model – Two independent activities define the development of a watershed and the deforestation of riparian areas. These activities affect variables characterizing the watershed and stream corridor, which consequently affect the trophic condition of the stream and the quality and constancy of various benthic habitats. Both cause changes in the benthic community.

Model Structure

Fourteen variables were used in the QR model, including four process rates, and ten consequence variables (Table 1). For these variables, three Quantity Spaces (QS) were applied in the form of {interval,point,interval}: one QS for the process rates, one QS for the consequence variables, and a unique QS for the benthic community response. The {minus, zero, plus} QS applied to process rates refers to the operative condition of the influence. The values of the consequence variables were defined by a {reduced, normal, increased} quantity space, and the benthic community was represented as {tolerant, mix, intolerant} to represent the sensitivity to habitat quality and trophic conditions. Scenarios provide these initial qualitative values from which the simulation evolves. To explore the effects of the two activities on a stable watershed,

- the benthic community was assigned an initial intolerant quantity space,
- the active process is assigned a plus quantity space,
- and all other dependent variables values start at the center quantity space.

Table 1 – Quantities Used to Describe Model Structure - The quantities used to describe the relevant features of a watershed and stream corridor, their functional definition within the model, and the quantity space, or potential qualitative values, are listed.

quantities	definition	quantity space
benthic community	consequence variable	intolerant, mix, tolerant
canopy cover	consequence variable	increased, normal, reduced
median diameter	consequence variable	increased, normal, reduced
detritus	consequence variable	increased, normal, reduced
woody debris	consequence variable	increased, normal, reduced
water temperature	consequence variable	increased, normal, reduced
streambank erosion	consequence variable	increased, normal, reduced
nutrient load	consequence variable	increased, normal, reduced
effective discharge	consequence variable	increased, normal, reduced
sediment load	consequence variable	increased, normal, reduced
riparian tree survival	process rate	Minus, zero, plus
physical habitat stability	process rate	Minus, zero, plus
trophic shifts	process rate	Minus, zero, plus
watershed development	process rate	Minus, zero, plus

These quantities were used to define eight static and process fragments in the compiled model. Two static fragments, ‘stream’ and ‘watershed’, are used to model the components that do not change with time, and are detailed in Figures A1 and A2, respectively. The six process fragments define the relations between the static fragments and allow development of the modelled system. As illustrated in the conceptual model (Figure 1), two process fragments define the impacts of watershed development and riparian condition on specific variables characterizing the stream or watershed. A third process fragment then describes how the variables impacted by watershed and riparian conditions translate to the dominant energy resource in a stream. Another fragment defines how these conditions affect the quality of habitat in the stream. Finally, two process fragments propagate the preceding indirect influences to progress changes on the benthic community composition. A summary of the defined relationships for each scenario is provided (Figures 2 and 3).

Figure 2 – Causal Dependencies for Watershed Development – This model applied 23 relationships to define the direct and indirect influences of watershed development.

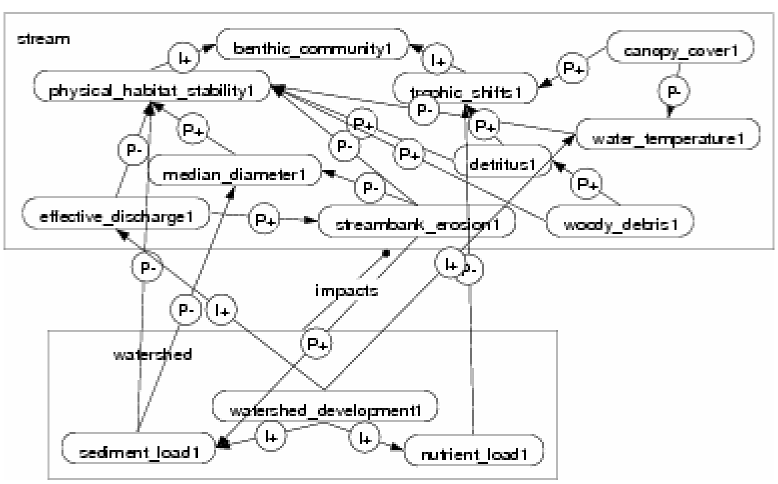
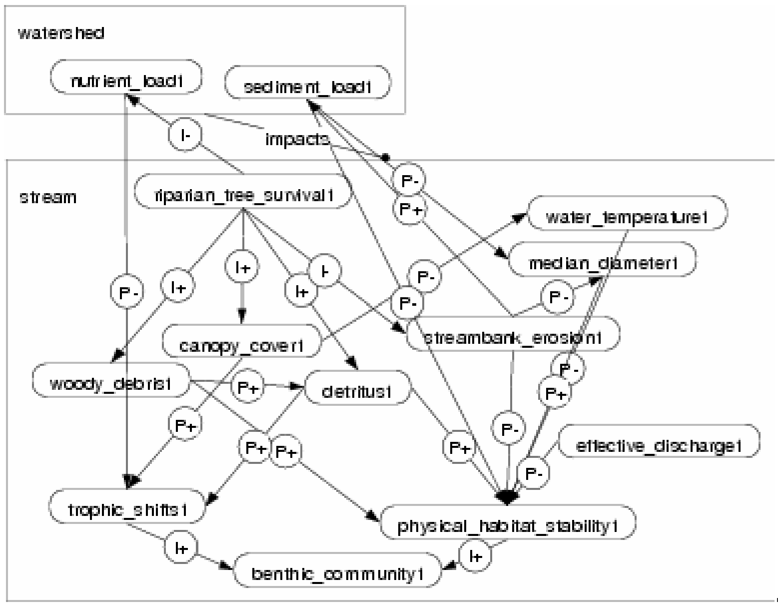


Figure 3 – Causal Dependencies for Riparian Deforestation – This model applied 18 relationships to define the direct and indirect influences of deforesting a riparian area.



Simulations results

Value history diagrams, representing the set of values each quantity can hold according to the transition rules defined in the model, display how variables changed as the modelled system evolved. For both scenarios described, two value histories are provided: the minimum path through the system and an uncondensed path that illustrates one alternative transition of the values through the system. Both are correct predictions based on the transition rules set in the development of the model.

The watershed development simulation (Figure 2) generated 65 states, with one single initial and final state, with sample transition paths shown in Figure 4 (a,b). As expected, a decrease in habitat quality is seen in these sample simulation results, along with a move towards tolerant benthic communities in the final state, which was the same for all paths. For this model, the differences in the paths lengths or transitions do not represent meaningful disparity between the simulations of this model. The simulator simply generates all possible paths through the specified transition rules, and the differences of variables transitions do not appear to be of consequence.

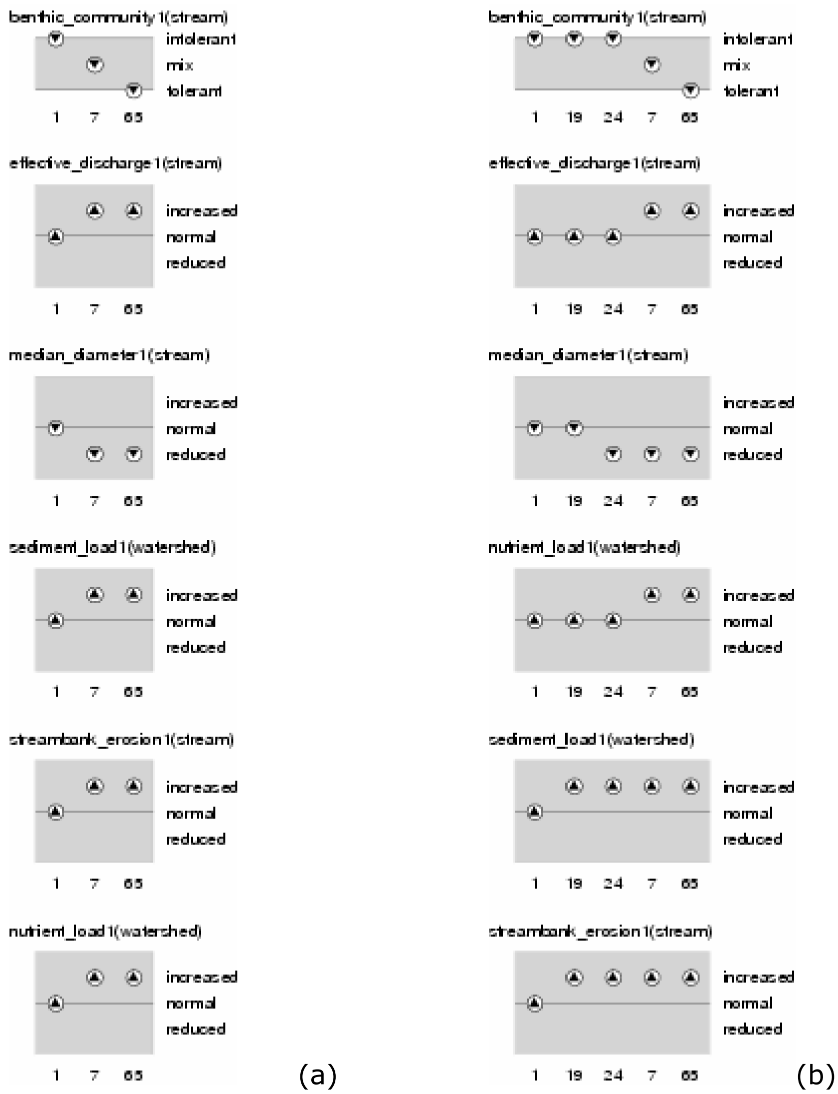


Figure 4 (a,b) – Value History for Watershed Development. Value history (a) represents the most condensed transition path from the first to the final state. Value history (b) illustrates a longer path, with the intermediate steps demonstrating an alternative transition of states. The positive watershed development process consequently affected six variables in this simulation.

The riparian deforestation model (Figure 5) illustrates how benthic communities move towards tolerant taxa, or those that can survive under more autotrophic systems with higher nutrients and fine sediments, warmer waters, and decreased supply of detrital material and woody debris. This scenario generated 385 total states, significantly more than the developing watershed, but again, with single initial and final states. The habitat degradation resulting from removal riparian forest is expressed in Figure 5 (a,b) as a trend towards tolerant insect communities. All riparian deforestation paths produced an intolerant and stable benthic community for the initial state. This is of interest, as it contrasts with the initial state for the developing watershed condition, which generated a value of intolerant but decreasing (unstable). Further, the greater number of states generated by this model reflects the wider range of variables affected by the deforestation of riparian areas. While urbanization is certainly destructive to aquatic ecosystems, it largely affects the habitat quality. The deforestation of riparian areas affects both habitat quality and trophic conditions, generating a more complex, and more ambiguous, result.

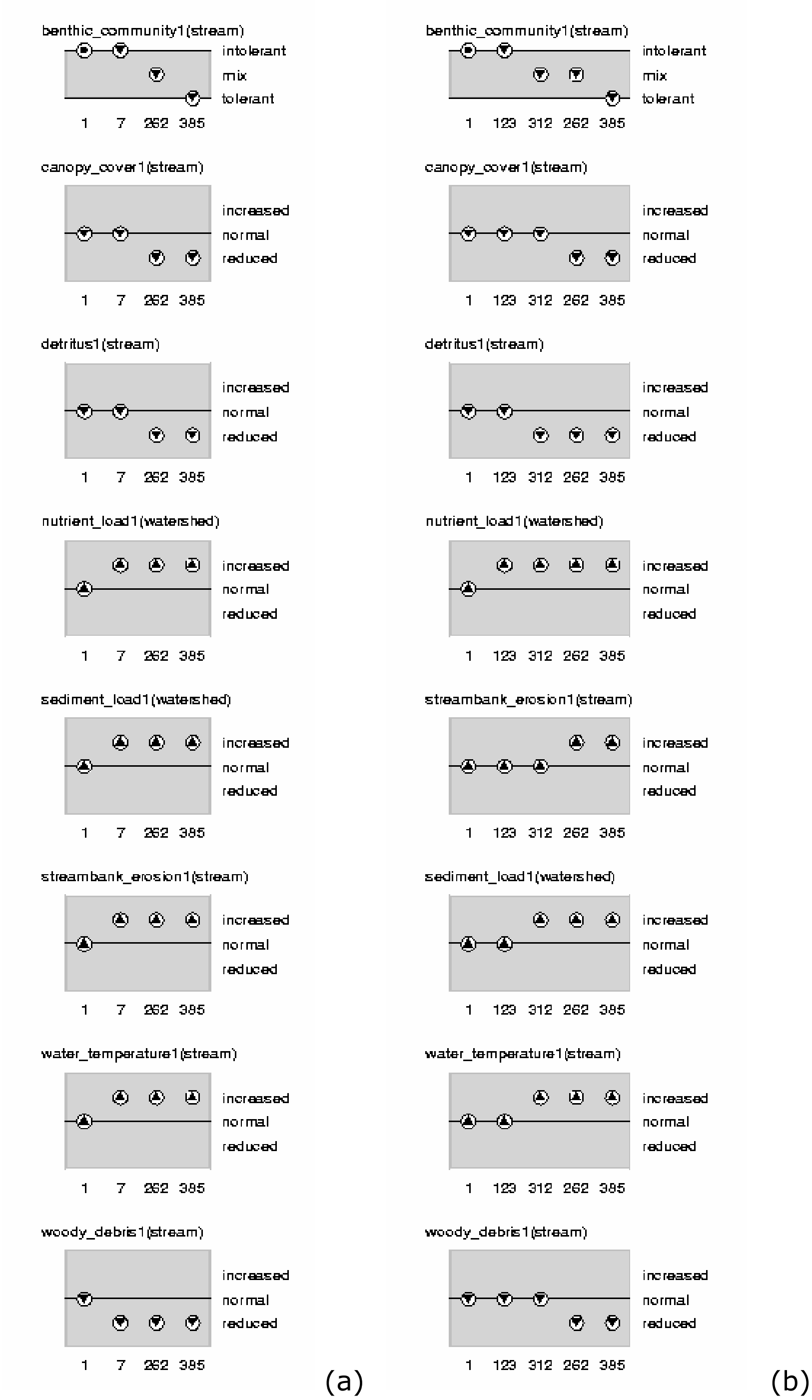


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Figure 5 (a,b) – Value Histories for Riparian Deforestation. Value history (a) represents the most condensed transition path from the first to the final state. Value history (b) illustrates a longer, alternative transition of states. Eight variables were subsequently affected by the positive riparian deforestation process, illustrating a slightly greater complexity in this model when compared to the six variables affected by watershed development.

Discussion

Benthic macroinvertebrate communities have long been recognized for their significance to stream ecology. However, due to high natural variances of field data, statistical analysis is often inconclusive. One advantage of developing this model for studying stream ecosystem response was the use of ecological expert knowledge about macroinvertebrate communities that may not be appropriate for traditional statistics (Tullos 2005). Application of Qualitative Reasoning for ecological and population prediction is not a new concept. Many researchers (Kamps and Peli 1995, Guerrin 1991, Guerrin and Dumas 2001, Salles and Bredeweg 1997, Salles and Bredeweg 2003,Salles et al. 2003, Rykiel 1989, and Wolfe 1986) have used QR as educational and predictive tools.

While reputable models exist for studying stream ecosystems, (RIVPACS (Wright 2000), AUSRIVAS (Davies 2000; Simpson and Norris, 2000), BEAST Reynoldson *et al.*, 2000, and PHABSIM (Waddle 2001), the application of QR models in stream ecology studies is still a new approach, providing explicit causal linkages between watersheds and stream ecosystems. This is accomplished without the necessity of well-defined numerical relationships or distributional assumptions.

This paper presents the development of a QR model based on field observations of physical and biological stream characteristics. It is an explicit exhibition of the interactions between watershed and stream corridor features, summarizing statistically inconclusive data into meaningful relationships. Further, this model uses these relationships to demonstrate how manipulation of these watershed and stream corridor features may impact benthic communities. Like any model, this paper presents a simplification of stream ecosystems. However, the thorough investigation of data collected at the study sites streams suggests that the relevant aspects of these ecosystems are included in this model.

Simulation results for both scenarios, watershed activities and riparian deforestation, resulted in a tolerant benthic community. However, important distinctions in the modelled response of the benthic communities to each scenario include: (1) the initial state values, (2) the predicted paths, and (3) the number of states generated by the simulation. Comparison of the simulation results between the two scenarios demonstrates an interesting difference in the first state predicted by the simulations. The development of a stable watershed generated an initial benthic community that was immediately affected by the influences of this activity. In contrast, the riparian deforestation scenario generated an initial state where the consequence variables responded, but the benthic community remained unaffected at the value intolerant. This creates a longer minimum path for the riparian deforestation model, and suggests a more indirect effect of riparian deforestation on the benthic communities as the simulator resolves the influences.

The simulated paths demonstrate how influences propagate through the quantity definitions. In the watershed development simulation, the quantities affected were most frequently associated with habitat characteristics, having a single variable reflect the change onto trophic condition. In contrast, the riparian deforestation model demonstrates influences of multiple variables on both habitat stability and trophic condition, creating considerably more potential combinations of values than the watershed development scenario and a resulting larger state transition graph through the increased complexity of trophic condition influences.

This larger state transition graph, with 357 states, for the riparian deforestation model indicates a substantial amount of ambiguity in the defined system. It is important to consider that "ambiguity refers to alternative correct behaviors predicted because information is lacking...[rather than] incorrectly predicted behaviors that do not occur for the real system" (Salles and Bredeweg 2003). Thus, this enormous state generation reflects the limited constraint defined for this modeled system. The transition or movement of variables across the quantity spaces is provided to the simulator by the user-defined transition rules, and if these rules are not specific and well-defined, the simulator can generate an ambiguous model with an enormous number of variable combinations. While ambiguity is not typically a desirable feature of QR models, it can be informative for identifying where gaps in knowledge exist.

Reducing ambiguity in qualitative models is accomplished by constraining quantity spaces and through the use of correspondences and inequalities to represent the relative amounts of direct and indirect influences. This model assumed all influences were equal because so little is known about the comparative importance of different habitats and stressors on benthic community. The study of ambiguity in QR models such as this may be used to identify where these gaps in knowledge exist. Does water temperature have a greater influence on benthic communities than the nutrient load? Questions such as these are useful for prioritizing research and management options, with definition of these types of relationships providing better causal relations for designing and predicting about these stream ecosystems.

Conclusions

The contributions of this study are threefold: (1) the explicit definitions of watershed and stream corridor interactions, (2) demonstration of the consequent impacts of these interactions on benthic macroinvertebrates, and (3) the identification of knowledge gaps for directing future ecological research. This demonstration of the opportunity QR provides to the study of stream ecology is beneficial to both fields.

Future extension of this model to include predictive features is desirable. A fundamental simplification of this model is that of direct dependence of community composition on trophic and habitat disturbance control. This model neglects other factors that influence benthic communities, such as predation, competition, and distance to recolonization source. These effects of biological interaction are disregarded in this model in an effort to isolate the impacts of anthropogenic activities on benthic communities and simplify model interpretation. Population dynamic model libraries have been developed (Salles and Bredeweg 2003) and could potentially be applied to this study in the future. Further, revision of the model fragments developed by this paper provides the opportunity for adaptation to alternative stream types or sizes. Finally, the model fragments defined here provide the foundation for exploring how mitigating activities may affect the response of benthic communities in disturbed systems. Addition of agent fragments, or "model actors that enforce changes upon a system" (Bredeweg 1992), to the existing fragment library may provide insight into the effectiveness of defined management options for enhancing benthic integrity

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CHAPTER 5

Explorations of Qualitative Models for Predicting Benthic Community Response to Four Management Alternatives for Stream Degradation

Explorations of Qualitative Models for Predicting Benthic Community Response to Four Management Alternatives for Stream Degradation

Abstract

Prediction about ecological systems is challenging due to the intricate nature of these systems and the difficulties associated with describing and enumerating this complexity. Qualitative Reasoning (QR) models provide one technique for synthesizing knowledge about ecological systems and exploring their responses to various influences. For this study, QR models were developed according to the compositional approach defined by Faulkenheimer and Forbus (1991), describing a system by a library of partial knowledge model components. These partial models captured the extensive, but fragmented, base of existing knowledge on benthic ecology and were used to make predictions about the responses of benthic communities in urban, agricultural, and stable watersheds to four stream management practices: riparian restoration, construction of storm water Best Management Practices (BMPs), streambank stabilization, and a simplified stream restoration model. The model results provide insight into the causal relations associated with restoring biological integrity to degraded stream ecosystems and on the applicability of QR models for these types of analysis. While discrimination between management alternatives is not appropriate with this model as developed, the explicit description of causal relations from watershed to stream biota and the identification of knowledge gaps represent constructive contributions.

Introduction

As degradation to stream ecosystems continues (USEPA 2000), effective protection measures are of critical importance. However, determining how and which management options have the greatest potential for supporting biological integrity is not a simple endeavor, and several difficult questions arise. How much and what kind of data should be collected? How will the data be analyzed? What ecosystem descriptor should be chosen? How can the effects be isolated and verified? Qualitative Reasoning (QR) models of stream ecosystems may provide a solution to the intimidating and complicated task of exploring their responses to various activities. This study presents such a model, constructed to represent a stream ecosystem with qualitative variables and processes and to explore the impacts of management alternatives on benthic communities.

it has been suggested that "most of the pattern in large-scale studies of diverse communities lies in the qualitative differences" (Marchant, Barmuta, and Chessman 1995), making Qualitative Reasoning about ecosystems an attractive method for organizing the broad inventory of ecological concepts (Neumann and Bredeweg 2004, Salles et al. 2003). QR models are able to capture the "considerable amount of knowledge in [ecologists] heads" (Salles and Bredeweg 2003), and present this knowledge in a formal and logical format. These QR models are often aggregates of smaller partial models, or fragments, which individually, describe only a single process or component, but combined, provide insight into the comprehensive, ecosystem-wide response and by "explain[ing] the behavior of populations in terms of the basic processes that determine it" (Salles and Bredeweg 2003).

Background

To begin any study of ecological impacts, definition of the relevant response variables is necessary. For this study, ecosystem response is represented using an aquatic insect community description. Benthic macroinvertebrates, those sediment-living organisms which can be identified with the naked eye and which lack a backbone, were selected for ecosystem response variables because these communities are well-recognized indicators of the function of the wider stream ecosystem (Ohio EPA 1990).

A recent increase in "emphasis on water quality, resource protection needs, increased BMP maintenance costs, and identified shortcomings" has advanced the urgency for effective storm water management (MDE 2000). To investigate the potential for minimizing and mitigating impacts to biological communities, this model simulated four management options to investigate benthic community response: construction of storm water BMPs, riparian restoration, streambank stabilization, and a simplified stream restoration. A discussion of each management alternative follows.

Storm water runoff increases in volume and frequency as watersheds develope, carrying with it increased loads of sediments, nutrients, and other contaminants as it drains the watershed. Numerous Best Management Practices (BMPs) have been designed to minimize the impacts of this degradation in storm water condition, including wet and dry ponds, wetlands, vegetated swales, media filters, and bioretention areas (MDE 2000). The impacts of BMPs on biological function are not well studied, as they are not regularly implemented or monitored for their impacts on biological integrity. Rather, water quality criteria are typically the focus, as in Florida, where the DEP suggests "Design of BMPs [be] based on site-specific conditions, technical, institutional and economic feasibility, and the water quality standards of the receiving waters" (FDEP 2004).

Riparian deforestation historically occurred in areas where the agricultural productivity and developmental value of land adjacent to streams is significant.
However, the ecosystem services provided by these areas adjacent to the stream are numerous, including dissipation of stream energy, filtration of sediment, floodwater retention, streambank stabilization (FISRWG 1998). Because "physical conditions in riparian zones are excellent indicators of what is happening in a stream," (FISRWG 1998), return of these areas to a functioning condition can greatly benefit the biological integrity within the stream.

Bank stabilization is another management alternative for minimizing the impact to aquatic ecosystems. Streambank erosion can be very destructive to benthic communities as fine root hair habitats along banks are removed by mass wasting and the addition of fine sediments removes access to coarse substrates. Stabilization of these banks can be accomplished through regrading of steep slopes, heavy planting of live stakes, hydroseeding, geotextiles and mats, or numerous bioengineering approaches.

The final management option is a simplified model of stream restoration. While only a recent practice, "the ecological and societal benefits of river corridor...restoration are substantial" (USEPA 2004). Restoration activities typically include reconstructing natural pattern, profile, and dimension in the channel, as well as streambank stabilization, revegetation, and recreation or reconnection of floodplain access.
With increasing concern over stream ecosystem degradation and the rising debate over the best way to manage and restore them, this model sought to define an aquatic ecosystem and the processes influencing benthic communities within it, then simulate different management options against the degrading pressures from the watershed. Evaluation and interpretation of how the model propagates causal relations and predicts the evolution of conflicted responses may provides insight to the potential response of

the benthic communities to the aggregated supporting and degrading pressures on aquatic ecosystems.

Materials and Methods

QPT - The 'Language' of QR

The technique taken for defining this system is described as the compositional approach (Falkenhaier and Forbus 1991), which involves the development and aggregation of smaller, partial system behavior components, or model fragments, to describe overall system behavior. These fragments "capture knowledge about the behavior of system parts and are used to assemble states of behavior" (Salles and Bredeweg 2003). The universal ecological knowledge, or domain theory, of stream ecosystems is then represented in the QR language of causal dependencies established by the Qualitative Process Theory (Forbus 1984). Finally, the simulator generates potential states, or outcomes, by "recursively consulting the library for applicable model fragments" (Salles and Bredeweg 2003), as defined by the transition rules specified by the user.

Developing a QR model by small components has several advantages. Certainly a principal benefit is the explicit representation of causal relations in a system. Further, this building by parts leads to a validation process, by which accuracy checking was made for each of the partial behavior models. Because minimal numerical data exist with which to compare these modeled responses, constructing and testing very small aspects of the larger model replaced the validation process, confirming consistency and accuracy of the predictions with well-understood behavior derived from empirical and heuristic ecological knowledge.

For each partial behavior model, quantities and the relationships between them the must be defined. To accomplish this, each quantity is assigned a quantity space, or the qualitative values that a quantity can hold, which are defined in sets of alternating points and intervals. An example is {reduced, normal, increased}, meaning that values can either hold the point 'normal' or the intervals 'increased' or 'reduced.' More descriptive quantity space values can be applied for quantities requiring more meaningful definition. For example, the quantity 'bug community' was assigned a quantity space of {intolerant, mix, tolerant}, which is unique to the benthic organisms. The abstract definitions for these quantities are necessary because "there are not many obvious landmarks that uniquely characterize qualitative distinct behavior of an ecological system," (Salles and Bredeweg 1997). These generic descriptions can be applied to express theoretical boundaries to a range of variables, so that while these values may be numerically different within these spaces, they are qualitatively the same, representing a degrading or enhancement to the ecosystem.

With the quantities defined, Qualitative Process Theory (QPT) provided the formalized language for defining how one quantity affects other quantities (Forbus 1984). To summarize, these causal relationships are characterized by direct and indirect influences. Direct influences (I+ and I-), initialize change in the system through a process. Indirect influences (P+ and P-), known also as proportionalities, are used to propagate changes of a dependent quantity, initialized by a direct influence, to another dependent quantity. Thus, quantities are "changed indirectly as a consequence of the changes processes make on the directly influenced parameters." (Forbus 1984) For example, an increase in the process rate 'watershed development' has a positive *influence* on sediment load, which in turn has a negative *proportionality* to habitat stability.

It is the resolution of the combined influences that this study sought to investigate. Within QPT, "when a quantity is simultaneously influenced by more than one direct or indirect influences, their effects are combined," (Bredeweg and Salles 2003) so that, typically, "an answer can be found by sorting the influences into positive and negative sets and using inequality information to prove that one set of influences must, taken together, be larger than the other set" (Forbus 1984). These combined, comprehensive effects, reflecting both the supporting influences of management alternatives and the compromising influences of degrading watershed conditions represent how the consequence variables are assigned values.

More detailed descriptions of qualitative process theory can be found in various sources (Bredeweg 1992, Forbus 1984). Models were built using the graphical interface HOMER (Bessa Machado and Bredeweg 2002), simulated within the reasoning engine GARP (Bredeweg 1992), and inspected within VisiGARP (Bouwer and Bredeweg 2001). Within these three components, respectively, model fragments are defined simulations are performed, and simulation results are inspected.

Developing the QR model

A limited set of quantities (Table 1) were chosen to describe the system. These variables were selected from a comprehensive list used to characterize 54 stream sites in the Piedmont of North Carolina in an independent study (Tullos 2005). Field observations and statistical relationships of these sites were articulated into a conceptual model of the watershed-stream corridor interactions. Two statistical analyses were performed on the collected data; Non-metric Multidimensional Scaling (NMS) of community composition and paired t-tests of environmental characteristics and community descriptions were made. NMS results were applied to determine with which environmental variables benthic communities varied most consistently, while the paired t-tests helped define the relationships between the environmental variables, discovering either a positive, negative, or absent nature of the relationships. The results of these studies (Tullos 2005), in addition to qualitative field observations, provided the foundation for this model definition and the quantity relationships.

Table 1 - Quantities Used to Describe Model Structure. Process rates initialize evolution of the system through direct influences, while consequence variables propagate these changes through indirect influences.

quantities	Definition	quantity space
bug community	consequence variable	intolerant, mix, tolerant
canopy cover	consequence variable	increased, normal, reduced
median diameter	consequence variable	increased, normal, reduced
detritus	consequence variable	increased, normal, reduced
woody debris	consequence variable	increased, normal, reduced
water temperature	consequence variable	increased, normal, reduced
streambank erosion	consequence variable	increased, normal, reduced
nutrient load	consequence variable	increased, normal, reduced
effective discharge	consequence variable	increased, bankfull, reduced
sediment load	consequence variable	increased, normal, reduced
riparian tree survival	process rate	minus, zero, plus
physical habitat stability	process rate	minus, zero, plus
trophic shifts	process rate	minus, zero, plus
watershed development	process rate	minus, zero, plus
restores	process rate	zero, plus

These quantities were used to define the model as a base configuration of several model fragments, or partial models. Initial scenarios and management options were then added to this base model to simulate the influences of the four management practices, as illustrated in Figure 1. The model then produces a sequence to depict potential evolutionary paths, called state transitions, where a state refers to the combination of possible values for all quantities at a single step in the path.

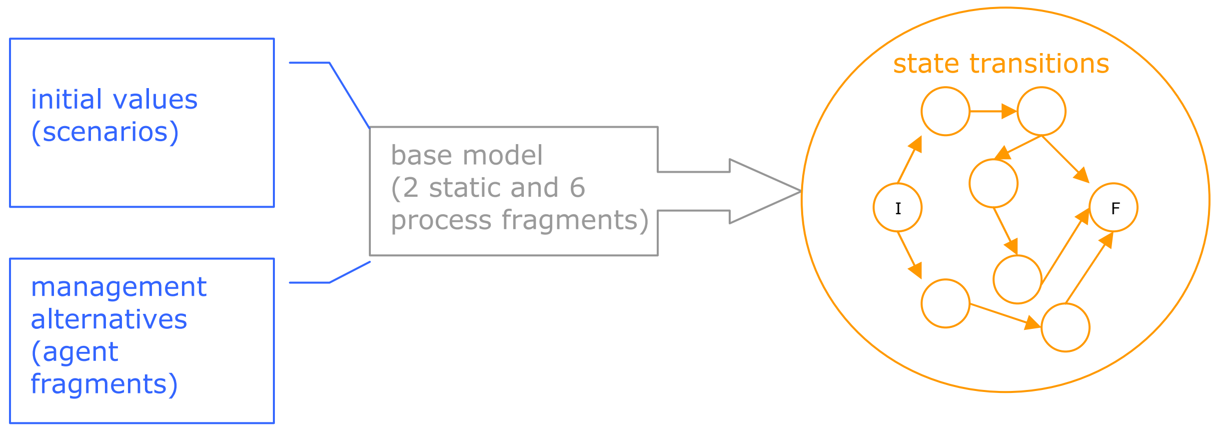


Figure 1 – Components of a Qualitative Model. This diagram represents how this QR model was constructed, beginning with the base model, and through the addition of scenarios and agent fragments, result in a state transition graph illustrating potential paths from the initial condition (I) to the final condition (F).

<u>Model Structure</u>

The premise behind the compositional approach (Falkenhainer and Forbus 1991) to QR modeling includes aggregation of partial behavior models. The collection of the smallest relevant entities into a larger, comprehensive model representing the compilation of all processes and influences effectively derives "the behavior of a complete system from the behavior of its constituents" (Bredeweg and Salles 2003).

For this study, a base model was developed from 2 static and 6 process fragments. This same base configuration was applied to every management simulation. Static fragments provide descriptive components that do not change with time, while process fragments initiate changes in the system through an inequality in system elements. A diagram of the base model fragments and their dependencies, defined by the process fragments, is provided (Figure 2), with greater detail on the development and validation of this base model available (Tullos 2004).

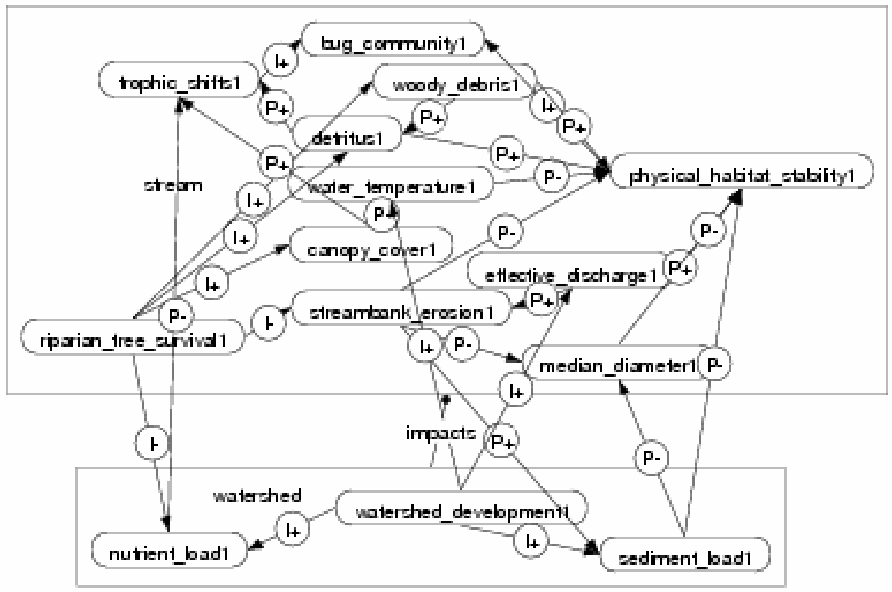


Figure 2 – Causal dependencies for the two static fragments for the developing watershed. As previously noted, 'I' represents a direct influence while 'P' represents the resulting indirect influences (Proportionalities). The sign for each relationship is important. For proportionalities, a change in a parameter (Par1) causes a change in second parameter (Par2) in the same direction (P+), or in the opposite direction (P-). With influences, the response depends on the parameter value. For example, if the qualitative value of Par2 is greater than zero, then Par1 tends to increase (I+) or decrease (I-) as a result of Par1. If the qualitative value of Par2 is less than zero, then Par1 tends to decrease (I+) or to increase (I-) (Bredeweg 1992).

Four independent 'agent fragment' models were added to the eight base fragments to define the impacts of the described management practices. Within QR models, "agent models are used to model actors that enforce changes upon a system" (Bredeweg 1992). For this model, the agent fragments represent the various management alternatives. Each management option is described by its influence on a single or a number of variables in the system, which the model propagates through the base model fragments, described by Figure 2, to determine the comprehensive response of the benthic community. These alternatives are illustrated in Figures 3-6.

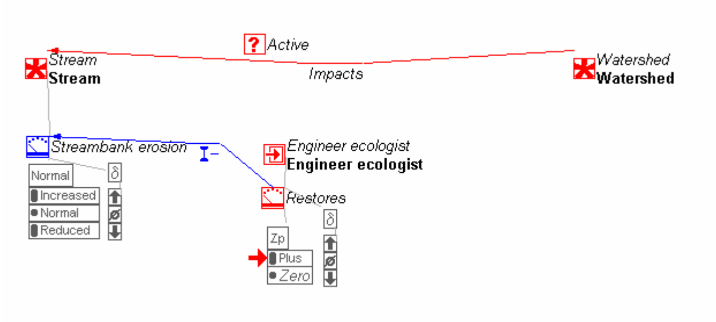


Figure 3 – Agent fragment: Streambank stabilization - This management option simply decreases the variable streambank erosion, which then propagates changes in the median diameter, sediment load, and finally the bug community in the stream.

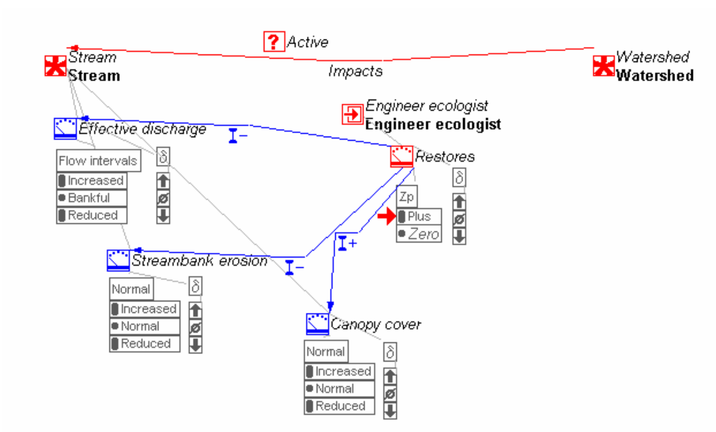


Figure 4 – Agent fragment: Simplified restoration - For this agent fragment, the effect of streambank revegetation is represented by the variable, canopy cover, which simply refers to the amount of vegetation shading the stream. Effective discharge is decreased to simulate the effect of reconnecting floodplain access. Finally, streambank erosion is reduced as a result of channel regrading to minimize shear stress along banks. These three variables propagate to affect 4 other variables, including median particle diameter, sediment load, water temperature, and ultimately, the bug community. It is recognized that the practice of stream restoration is considerably more complicated than this representation, however, this very simplified view was necessary for defining an interpretable model.

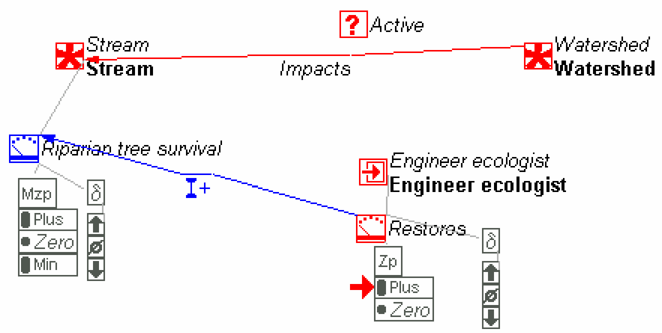


Figure 5 – Agent fragment: Riparian reforestation – Riparian restoration was modeled using the rate variable, 'Riparian tree survival,' which propagated changes in 8 consequent variables: woody debris, water temperature, streambank erosion, sediment load, nutrient load, detritus, canopy cover, and finally the bug community.

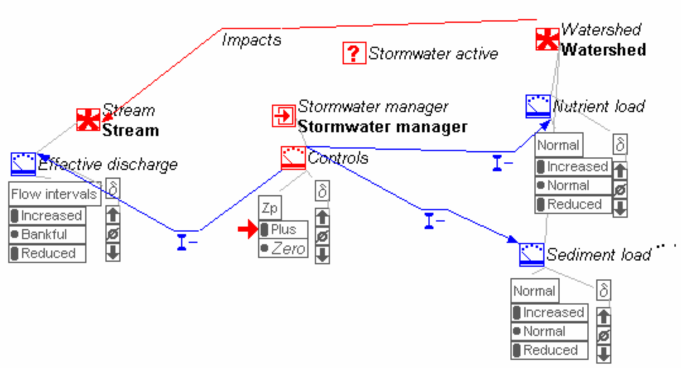


Figure 6 – Agent fragment: Storm water BMPs - While many different BMPs exist and each performs different water quality and quantity functions, we examined a general BMP retention of nutrients, sediment, and flow. This fragment illustrates how BMPs were modeled to reduce nutrient load, sediment load, and effective discharge, consequently affecting 3 more state variables, including median particle diameter, streambank erosion, and bug community.

Finally, the four agent fragments, along the base model fragments and the user-designated initial values for the variables, are then combined to predict the different potential values and transitions the list of variables may take. This initial condition is called the scenario and defines the values for each quantity when the simulation begins. Three landscapes were simulated with the described model fragments: urban, stable, and agricultural. Descriptions and diagrams of how these landscapes were defined with scenarios are provided in Figures 7-9. These initial conditions were shown to have a significant effect on the number of predicted states, and this feature of qualitative modeling is discussed in further detail in the results section.

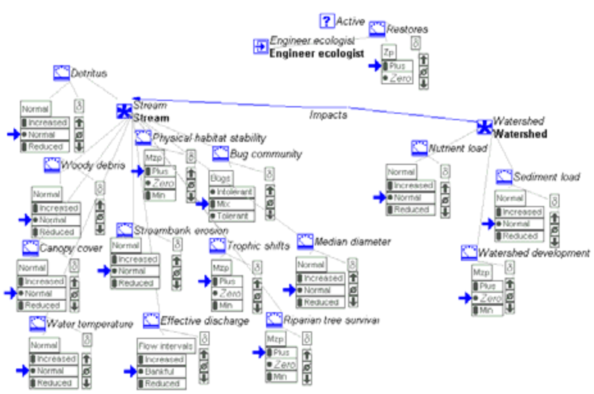


Figure 7 – Stable watershed initial scenario - This scenario represents a watershed where quantities are set to stable conditions. This representation is land use independent, such that a normal amount of detritus, for example, could apply to a deciduous mountain landscape or a coastal plain system dominated by pines. The effective discharge returns a natural frequency and volume of flow events at this normal quantity space, the watershed is not developing, and the riparian area is present and functioning.

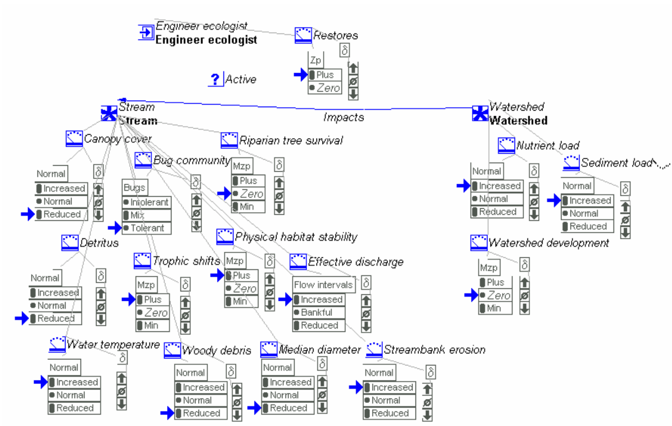


Figure 8 – Urban watershed initial scenario - This scenario represents a worst-case condition for a watershed that has undergone urban development. The urban watershed has several important influences including the addition of nutrients from lawn fertilization, increase of sediment load from construction runoff, increases in water temperature as it crosses asphalt and other heated, impervious surfaces. Further, this increase in impervious surfaces results in an effective discharge that is greater than bankfull in frequency and volume, often resulting in channel widening, represented by

increases in streambank erosion, and incision. Further, increased effective discharge may result in flushing of detritus and woody debris habitat from the reach. Streambank erosion may remove shading bank vegetation, reducing canopy cover, and along with sediment load, propagate to affect the median diameter, a critical habitat feature for benthic macroinvertebrates. However, the riparian area is present and functioning in this scenario, and it is the resolution of these conflicting influences by the QR model that is of importance.

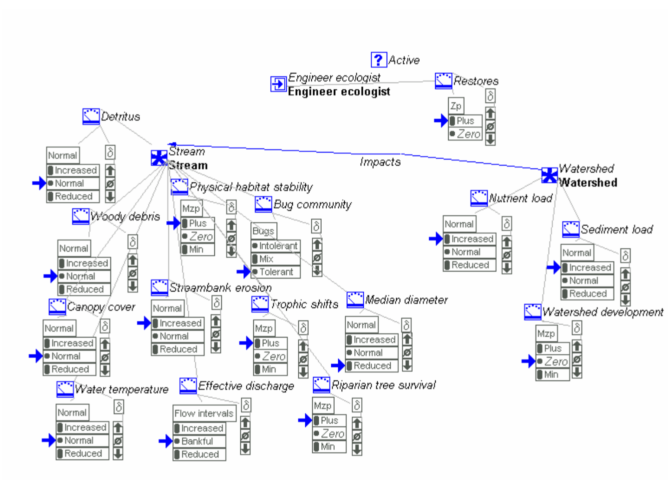


Figure 9 – Agricultural watershed initial scenario - This scenario is used to reflect a watershed in which livestock agriculture and crop farming dominate the land use. Nutrient loads are increased due to fertilizer application. Streambank erosion is increased as a result of livestock access to the stream and bank trampling. Tilling and grazing often increase the landscape erosion, resulting in a higher sediment load delivered to the stream, reducing the median diameter in the stream.

Results

A selection of simulation sets is presented. The first section provides model results for the different management options in the agricultural setting. The second section demonstrates the sensitivity of these models to initial starting condition by illustrating the effects of changing a single quantity value in the scenario for storm water BMPs. Finally, comparison is made between the model results of two landscape settings; a stable and an agricultural watershed.

The numbers of states generated by the simulations for each management alternative and for the different land uses are listed in Table 2. Two features are of interest: 1) a single final state was predicted for every model run, and 2) the illustration of the differences in number of states for the various watershed conditions.

Table 2 – Numerical summary of states predicted. Note how the stable watershed variables all have shorter minimum paths. The additional quantity space transitions provided in the urban and agricultural scenarios make the paths longer. While "the formalism used for representing quantity spaces strongly interacts with the representation of time," a shorter minimum path does not necessarily reflect a 'faster' recovery in real life (Bredeweg 1992).

	scenario	total states generated	minimum path length
Urban			
	riparian restoration	14,309	5
	stream restoration	489	5
	bank stabilization	46	4
	storm water BMPs	487	4
Agricultural			
	riparian restoration	117	4
	stream restoration	81	4
	bank stabilization	21	4
	storm water BMPs	61	4
Stable			
	riparian restoration	357	3
	stream restoration	129	3
	bank stabilization	17	3
	storm water BMPs	65	3

To illustrate some of the key observations of this study, for Figures 10 to 18, two figures are presented. The state transition graph illustrates the paths generated by the simulator from the initial condition to the final state. The value history is an example of a single potential path that the system may take in response to the changes imposed on it, representing "what happens to objects over time" (Forbus 1984). Only the variables that were affected by the management option are included, and the length of the provided example paths is the minimum predicted by the model simulations. Numerous path lengths were generated for each model, with the quantity values along the paths indicating the resolution of the conflicting variables. The shortest, most direct paths, provided here, indicate the most simplified path in the evolution of the variables and responses. The difference in lengths of the shortest path is of particular interest in when comparing these simulation results. A longer minimum path suggests a more complex response model, and the values at intermediate states along this path signify the alternative combinations the quantities can take as the simulator resolves the transition rules.

Effects of Management Practices on an Agricultural watershed

The modeled effects of the different management options on bug communities in an agricultural watershed are presented. Each model contained the same base static and process fragment inputs, as well as the same agricultural scenario, where quantity spaces are set to the middle value of 'normal' except nutrient load, sediment load, and streambank erosion (Figure 9) to represent agricultural impacts. The results from the four modeled management options are illustrated in Figures 10-13.

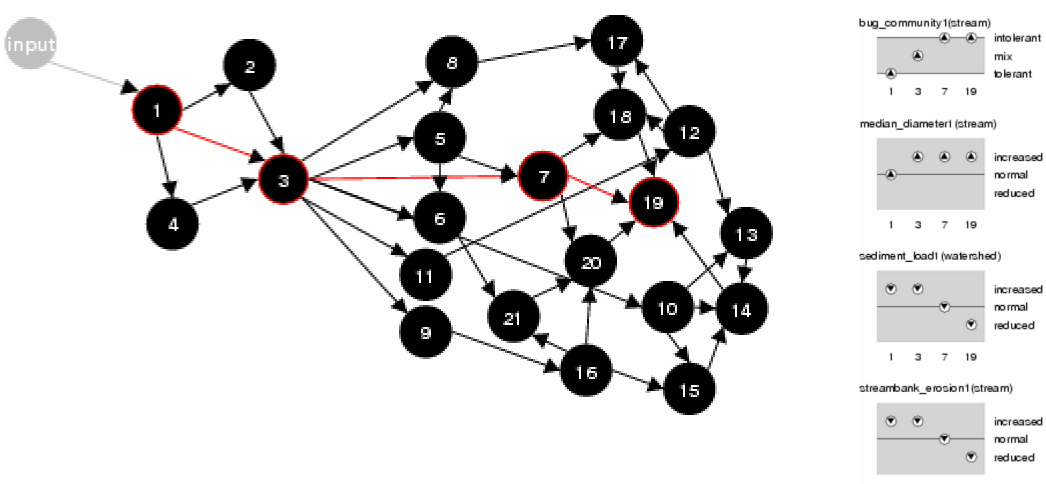


Figure 10 - Bank Stabilization in an agricultural watershed; State transition graph and value histories This simple management option shows a positive response of the benthic community to streambank stabilization. This result is not incredibly insightful, except for demonstrating the causal relationships between streambank erosion and the quality of the bug community. Twenty-one total states were generated for this model configuration, demonstrating a well-defined, or unambiguous, model for the system. A single common state, number 3, represents when the bug community passes over the point quantity space 'mix.'

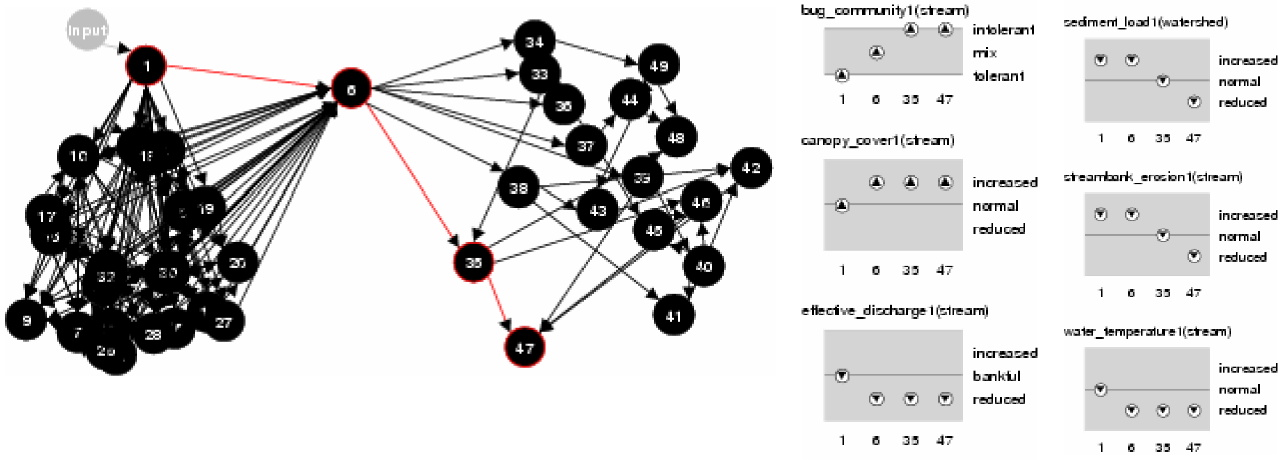


Figure 11 - Stream restoration in an agricultural watershed; State transition graph and value histories. This is model of simplified stream restoration produced eighty-one total states, indicating a less constrained model than for the bank stabilization. The common state for all paths at which the bug community value crosses 'mix' for this simulation is number six. The clusters between states 1 and 6 represent all of the potential combinations of variables that can be made before the benthic community shifts to the value 'mix' in state 6.

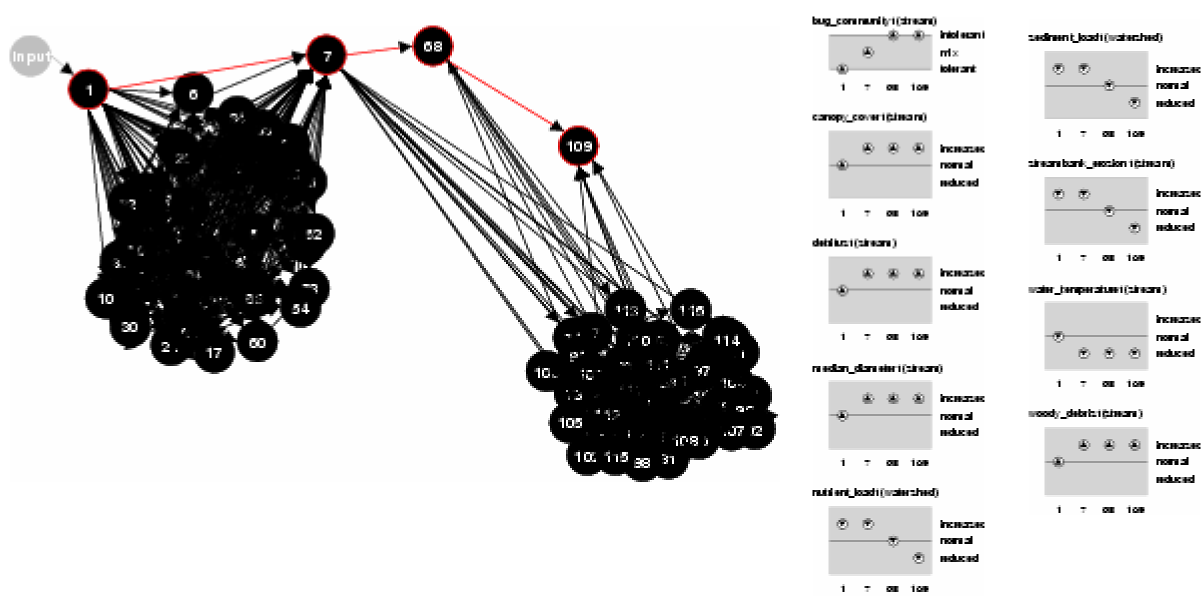


Figure 12 - Riparian reforestation in an agricultural watershed; State transition graph and value histories. This scenario generated 117 states, with all paths possessing the common state of seven. The ambiguity in this model is greater due to the number of variables and relationships affected by this management practice, resulting in this increased number of potential states.

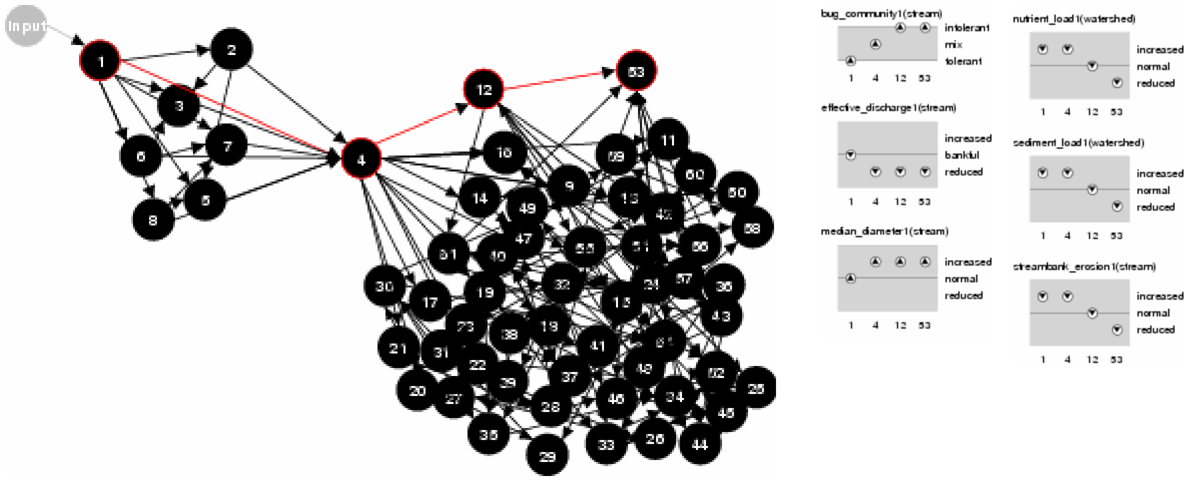


Figure 13 – Storm water BMPs in an agricultural watershed; State transition graph and value histories. Sixty-one total states were generated for this simulation of storm water BMPs in an agricultural watershed. The greatest variation in these state transitions occurred after the value for bug community had passed the point value 'mix' at state four. For this configuration, the consequence variables continue to respond after the bug community had reached the quantity space 'intolerant,' resulting in a positive derivative for the bug community while in this quantity space. This is possible because the intolerant quantity space is an interval, as compared to the point space 'mix,' and influences from the consequence variables can continue to affect the bug community.

To summarize these results, all management alternatives show a positive effect on the bug community and ultimately resulted in a single final state. This singular resolution reflects the model representation of management impacts and system evolution to a steady state. Qualitative models do not always result in a steady state solution and that this one does is an artifact of the model representation of the ecological system described. Every final state for these models represents the best condition possible through the values of the quantities. This is a feature of the quantity space definition, and because the highest quantity space for all quantities is an interval, the model is not forced to resolve this final state to a derivative of zero. Thus, a 'steady' state is never reached.

The presence of a 'common' state in all simulations produces a simpler state transition graph. This state is reached when the influences affecting the bug community are great enough to move the quantity from the interval 'tolerant' to point value 'mix.' This is a result of the organization of the {interval, point, interval} quantity space, and demonstrates how the model is responding to the transition rules defined as model input. A quantity space with a center interval value and an end point value would not have produced this common state, and would have resulted in a 'steady' final state.

Comparing the different management options in agricultural landscapes suggests that some of the causal relations are more complex and undefined, but is not particularly insightful for determining which management options has the potential for best supporting biological integrity. That the simulator resolved all of the conflicting influences to a positive response from the bug community may be the most interesting result from these simulations.

Effect of Initial Condition on Model Results

Like any model, how the system is defined plays a fundamental role in the predicted outcomes, and is demonstrated here with two examples. The first example reveals how changing a single variable, bug community, affects the results of the storm water BMP model. The second example illustrates how changing from a stable scenario to an agricultural one can alter the results significantly. The implications of initial conditions on the state transition graph and value histories are substantial.

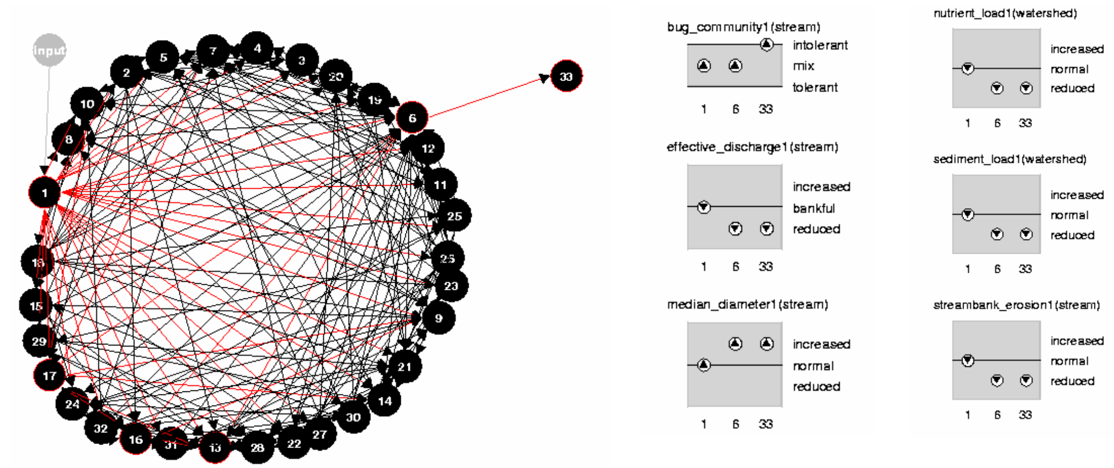


Figure 14 – Storm water management in a stable watershed with 'mix' initial bug community; State transition graph and value histories

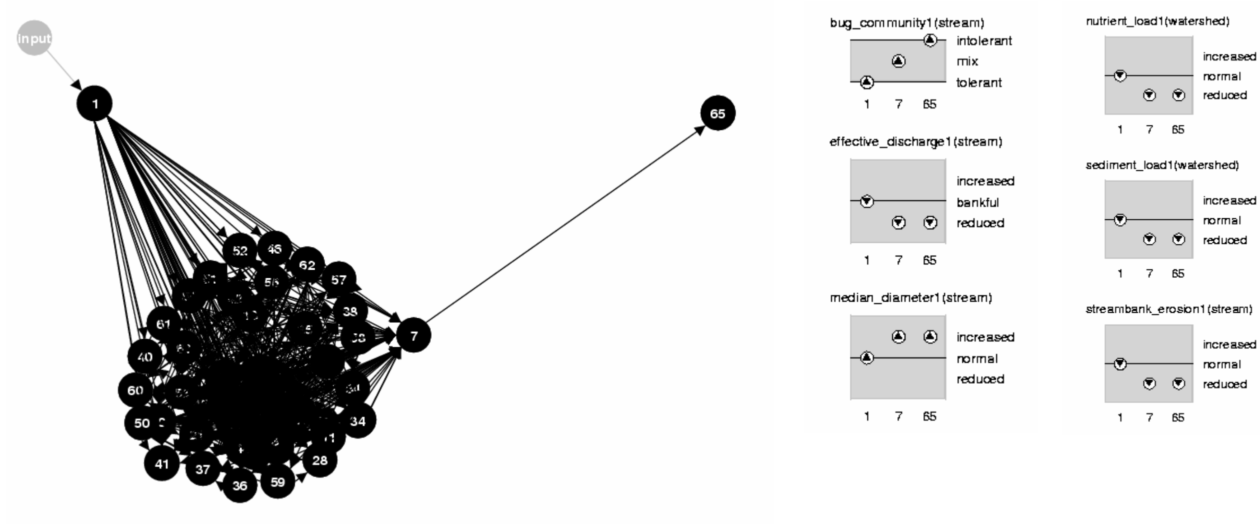


Figure 15 – Storm water management in a stable watershed with 'tolerant' initial bug community; State transition graph and value histories

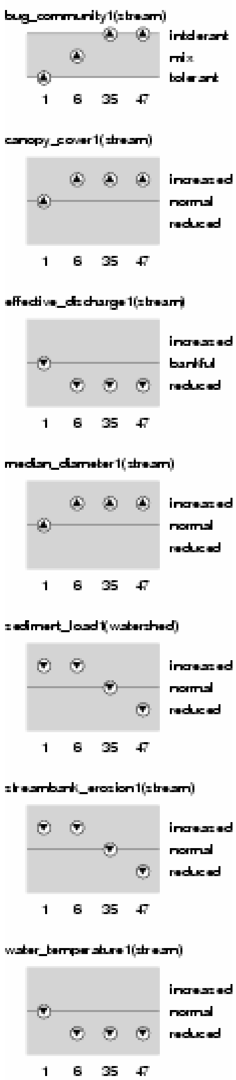
While the value histories are exactly the same, fewer states were generated when the simulations were run with the initial value for bug community set to 'mix' as compared to 'tolerant.' This difference in state prediction demonstrates how the model matches all possible combinations of variable quantity spaces and why, consequently, nearly twice as many states were generated with the initial 'tolerant' bug community. These figures demonstrate how changing a single consequence variable, 'bug community', by a single quantity space, from 'mix' to 'tolerant,' profoundly affects the state transitions graph (Results: Stormwater BMPs). The 'mix' bug community scenario generated thirty-three states, whereas sixty-five potential states were generated from changing this single initial value from 'mix' to 'tolerant'.

This increase in the number of states and potential outcomes reflects a potential dilemma in applying QR models to ecological systems. This sensitivity to initial conditions was found to be the case with all QR models in this study, as the influence of the initial values had an amplifying affect on the number of states and paths generated. Because the simulator generates "combinations of all the possible values for these quantities according to their quantity spaces and the constraints introduced by the applicable model fragments" (Salles and Bredeweg 2003), the effects of changing the initial value of a single quantity, demonstrated with the simplest management model (Storm water BMP) in Figures 14 and 15, is burgeoned with the more complex agent fragments. This is evident in the overwhelming and uninterpretible number of states generated by the riparian reforestation model, which predicted over 14,000 states when variables are set to represent the urban watershed condition. This indicates a high level of ambiguity, or lack of constraint, in the model and suggests that more information is needed to refine the relationships. However, "behaviors resulting from ambiguity should not be confused with spurious behaviors (for examples Kuipers 1986). Spurious behaviors refer to incorrectly predicted behaviors that do not occur for the real system. Ambiguity refers to alternative correct behaviors predicted because information is lacking" (Salles and Bredeweg 2003). While constructive for identifying gaps in fundamental knowledge, this ambiguity in QR models may well be its greatest obstacle to widespread application because it can result in generation of state transition graphs too large to interpret.

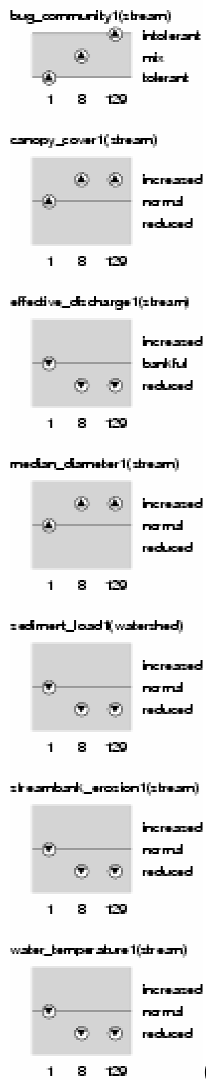
Reducing ambiguity in qualitative models is accomplished by constraining quantity spaces and through the use of inequalities to represent the relative amounts of direct and indirect influences. Because so little is known about the relative importance of the various influence on habitat and trophic conditions on the benthic community, this model assumed all influences were equal. For example, it has been shown that the effect of minor water temperature variations on an intolerant benthic macroinvertebrate in a headwater stream is significant (Sweeney 1992). However, water temperature may not be as significant of an influence in large rivers where temperature fluxuations are buffered by the large water volume in the channel. Thus, restricting the model to a specific ecoregion and stream type could reduce some of this ambiguity. However, some of these relationships are not known, and the study of ambiguity in QR models such as this could be used to identify where these gaps in knowledge exist. Does woody debris habitat have a greater influence on benthic communities than the coarse bed material? Definition of these types of relationships would provide better causal relations for studying and predicting about these stream ecosystems.

Effects of landscape condition

The stable watershed scenario has fewer spaces for the model to cross, and for most simulations, generates models with fewer states (Table 2).



(a) Agricultural



(b) Stable

Figure 16 – Comparison of simplified stream restoration in agricultural (a) and stable (b) landscape settings. By examining the minimum paths, these simulations demonstrate the same processes propagating through the system. Only the initial values for the variables streambank erosion, nutrient load, and streambank erosion differ for the two, and this difference results in a longer, and ultimately more ambiguous prediction for the agricultural landscape.

Discussion

This paper presents a model for investigating how Qualitative Reasoning can be used to predict the cumulative responses of the benthic community to the management alternatives under different landscapes. Due to the complex nature of these ecosystems, like mathematical or numerical models, development of manageable and interpretable QR representations is difficult. Many ecological models are found to be "intractable (and perhaps unpredictable) owing to [their] complexity" (Gillman and Hails 1997).

Two results are of particular interest. The intended comparison of different management alternatives was not incredibly insightful because 1) all of the management options resolved to a positive response from the bug community, and 2) the overwhelming ambiguity in many of modeled systems make interpretation and comparison impractical.

Consistent positive responses from the bug community

That the simulator resolved all of the conflicting influences to a positive response from the bug community may be the most interesting result from these simulations. In the value histories for Figures 10-14, each final state exhibits an intolerant bug community, with a positive derivative. This consistent final condition is a reflection of two things: the model definition of the system and the simulator resolution of the conflicting influences on the bug community.

With any model, the results are a reflection of the modeler's, often subjective, understanding of both the modeling architecture and the system being defined. The choices for representing the system features are frequently not straightforward and QR models are no exception. The choice of quantity space definition as interval, point, interval was made to reflect a single 'normal' condition, with the intervals above and below this point representing the range of states that could be described as 'reduced' or 'increased.' By using points at the ends of the quantity spaces, the model is required to assign the final state a zero derivative because no further increase can be made beyond this point. As it is modeled, the bug community and consequence variables never reach a ‘steady’ state condition because of this end interval space assignment of positive or negative derivatives.

That the simulator resolved all of the influences into a positive response from the bug community is an interesting result. As noted in the methods section, simultaneous influences are combined to determine the final condition. A consistent positive response of the bug community reflects the resolution of all beneficial and degrading influences, and suggests that all of the management alternatives have significant potential for supporting biotic integrity in stream ecosystems.

However, the relative strength of the management alternatives may not be appropriately discerned from this model due to the large ambiguity in the model definition, discussed below. While not completely trivializing this model and the implication of the results, the original objective of exploring the predictive capacity of this model was somewhat unproductive.

Ambiguity in the defined system: friend and foe

As suggested by Jorgensen (1999), “ecological modelling has two primary difficulties that limit its effectiveness: obtaining reliable parameters and how to build ecosystem properties into the models. Constructing an ecosystem model requires a detailed understanding of ecosystem function in order to determine the appropriate level of complexity” (Morrall 2003). Building an appropriate level of complexity into this model became a conflict between providing an informative result and negligently overdefining the ecosystem. Further, the effectiveness of a model is only as good as its interpretability, and the sensitivity of this model to changes in a single quantity, demonstrated by Figures 14 and 15, suggests a restricted interpretability as it is currently defined.

This sensitivity was amplified by the impacted landscapes, with urban areas generating an exaggerated number of potential states and an unreasonable result to interpret. The generation of "enormous state graphs predicting a large number of possible behaviors," as was shown with these simulations, is the result of ambiguity in the model definition (Bredeweg and Salles 2003). It reflects both the lack of knowledge about the system; simulation of ambiguous models is often due to the lack of constraint on the quantity relations. Relationships between the quantities can be defined by assigning derivatives, to indicate the rate of change in a variable, correspondences (or inequalities) between quantity spaces. Neither of these quantity relations were included in this model, however, due to lack of existing knowledge defining the relative importance of different habitat and trophic influences on the benthic communities. If the relative importance of coarse bed material to habitat quality was known to be greater than woody debris, this relationship could be defined within the model and would result in a reduction in the number of potential states. Consequently, all influences had an equal impact on the overall response. Thus, this ambiguity provides an investigative tool "that drives data acquisition...or points out the need for specific (empirical) research programs" (Bredeweg and Salles 2003). While this limitedly constrained system reduces the applicability of the model for testing the effects of management alternatives, the results are useful for identifying gaps in fundamental knowledge about causal relations in ecosystems. Though the relative strengths of the habitat and trophic influences are definable within QR through correspondences and inequalities of quantity spaces, the knowledge needed to define these relations represents the missing level of detail needed to constrain the simulations.

The exploration of the predictive capacity of QR models, such as this, is important for testing the applicability and ease of transitioning QR into mainstream ecology. These results suggest that regionally specific models, with greater constraint on quantity value relations, are probably most appropriate for use in QR. This model may provide a foundation for regional consultants and regulators to further refine fitting specific responses for explicit stream ecosystems. However, "implementing a new agent or a new attribute requires knowledge about QR model building and a good understanding of the problem" (Neumann and Bredeweg 2004). While ecologists may very well understand their own domain theory, the vocabulary and theory of QR is not always uncomplicated. Consequently, the widespread application of QR in ecology will require more simplistic tools for developing and interpreting these qualitative models.

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CONCLUSIONS

Chapter 1 - Traditional statistical analyses

Simple paired t-tests were used to compare the means of the environmental variables, as well as five descriptions of community structure including those defining the diversity (Q statistic and Shannon's diversity index), community dominance (Simpson's dominance index and dominant family list), water quality (EPT taxa richness and NCBI), and feeding mechanisms (Functional Feeding Groups). The results show no statistical difference in the substrate characteristics of the restored and upstream reaches. T-tests did find statistical differences in four of the variables describing riparian condition (infiltration, % woody coverage, Bank Erosion Hazard Index (BEHI), and detrital biomass). However, a lack of difference in two other riparian variables (% canopy cover and volume of woody debris) makes determination of a true difference in upstream and restored riparian areas difficult. The comparisons of the biotic measures were also inconsistent. While the Q statistic diversity measure was found to be statistically different in the pairs, the Shannon diversity measure was not, providing a conflicting indication of the true effects of restoration activities on community diversity. This conflicting biological feedback demonstrates how the approach selected for describing the community determines whether a difference in biotic integrity is found, and illustrates the importance in choosing a bioindicator that accurately reflects the biological response to a specific stress or influence. The remaining community descriptions were not found to be statistically different between the reaches. These cumulative results suggest an ambiguous impact of restoration activities on the physical and biological stability and this ambiguity is likely related to the high variability and complexity of the sites. These results of this study demonstrate how the univariate t-test comparisons applied here may not be the most appropriate way to explore the trends and responses of complex ecological systems. Further, while the variance was likely related to some of the discrepancy in the results, a consistent reduction in variance was demonstrated for the restored reach environmental variables and biotic measures. This reduced variability suggests a homogenization of the physical and biological features of the streams as a result of restoration, and emphasizes the need for focusing restoration designs on re-establishing heterogeneity in the channels.

Chapter 2 - Multivariate analyses

Non-metric Multidimensional Scaling (NMS) was applied to the family level benthic composition data, with overlays of the twenty environmental variables. The flexible dimensionality of this method was fundamental as it revealed a distinct difference in the upstream and restored reach communities. While the upstream reach analyses stabilized on three dimensions, the restored reach communities required only a single dimension. This reduced dimensionality indicates a simplification of the communities, moving from the upstream reaches into the restored streams. Further, the environmental variables associated with the paired communities were remarkably different. The ordination axes in upstream reaches were correlated to variables such as the SCS-Curve Number (Soil Conservation Service 1975), indicating the level of development within the watershed, two features of water quality, and a measure of bed resistance to flow. This dependency of upstream reaches on a variety of watershed and local influences severely contrasted the restored reach results, which found only sediment transport related variables, including the percentage sand or finer, Width-Depth Ratio (WDR), and Bank Erosion Hazard Index (BEHI) to be related to the community composition at these sites. These results provide insight into the effects of restoration activities on benthic communities. Recognition of the channel processes most influential to benthic communities is critical to the development and application of a more knowledgeable perspective for restoration design to assist in better overall biological recovery.

Chapter 3 - Habitat Specialists

This study explored the use of habitat specialists as indicator species for four habitat types: woody debris, coarse bed material, fine roots, and leaf packs. The differences between the upstream and restored reaches were most frequently zero, indicating no change in the habitats as a result of restoration. However, at sites that demonstrated a change from upstream to restored reaches, the stream restoration activities appear to have been most successful at improving fine root habitats, providing little increase or decrease in the quality of the remaining woody debris, coarse bed substrate, and leaf pack habitats. Combined, the restoration activities appear to result in a positive impact for urban streams but in a marginal effect in rural and agricultural streams. The implications suggest the need for a renewed focus on restoration of specific habitat types and consideration of habitat enhancement potential, with respect to land use, prior to construction of restoration practices.

Chapters 4 and 5 - Qualitative Reasoning Models

This study describes the development and simulation of QR models for predicting benthic community response to stream restoration, with comparison of alternative management options, in urban, stable, and agricultural watersheds. While discrimination between management alternatives is not appropriate with this model, the foundation for region-specific model refinement and identification of knowledge gaps represent constructive results. Further, the model results provide insight into the causal relations associated with restoring biological integrity to degraded stream ecosystems and on the applicability of QR models for these types of analysis.

Effects of Land Use

Recognizing the effects that land use have on benthic communities, the potential for inconsistent responses to restoration activities in this study of urban, agricultural, and rural watersheds is significant. Consequently, to investigate the effects of land uses for obscuring restoration effects, a cluster analysis was performed on the community composition data. This procedure groups sites based on their dissimilarities in composition, with the Bray-Curtis distance measure and Flexible Beta (β=-.25) group linkage, chosen for this analysis. The objective for performing these cluster analysis was to explore the question: Is the effect of land use more powerful than the effects of restoration in structuring the communities?

Results of the cluster analysis are presented in Figures 1 through 3 as dendrograms. These figures demonstrate how the cluster analysis grouped the sites, with overlays of the land use (Figure 1), and the whether the sites were restored or unrestored (Figures 2 and 3).

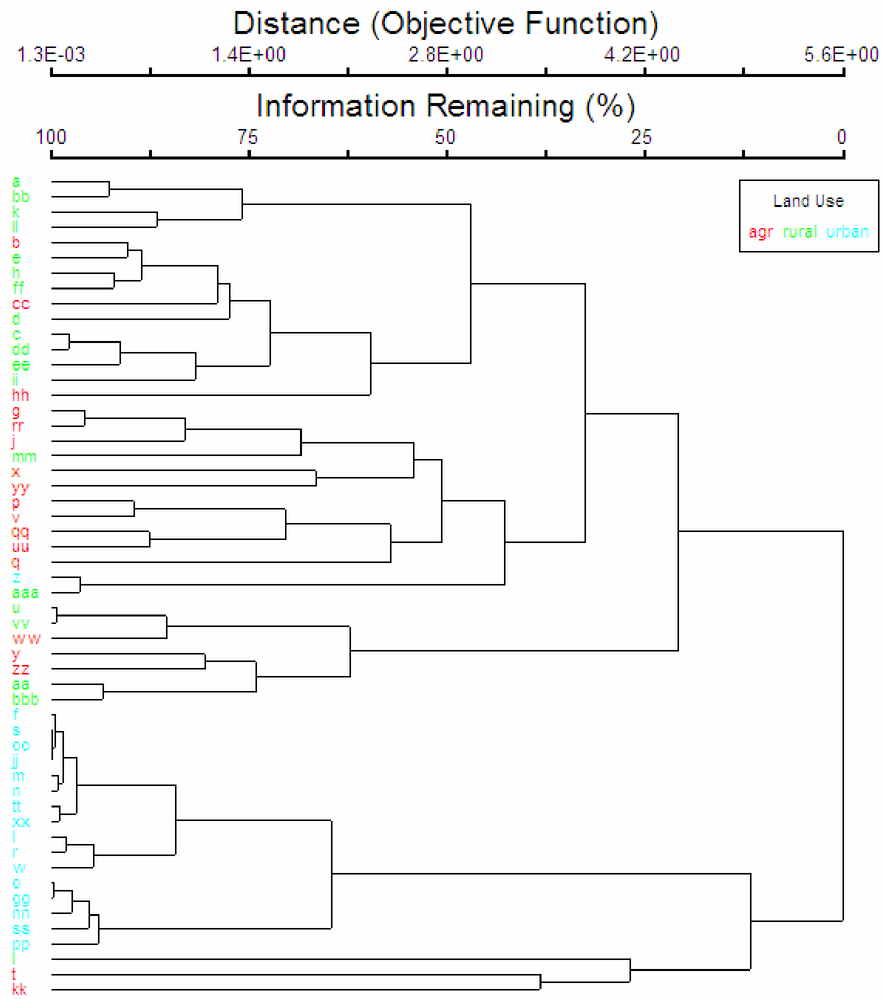

Figure 1 – Dendrogram of all sites with land use overlay. This cluster analysis illustrates how, with only two groups defined, all of the urban sites cluster together, suggesting a strong influence of urbanization on benthic community composition. It also demonstrates how the rural and agricultural sites are not particularly distinct in their benthic communities.

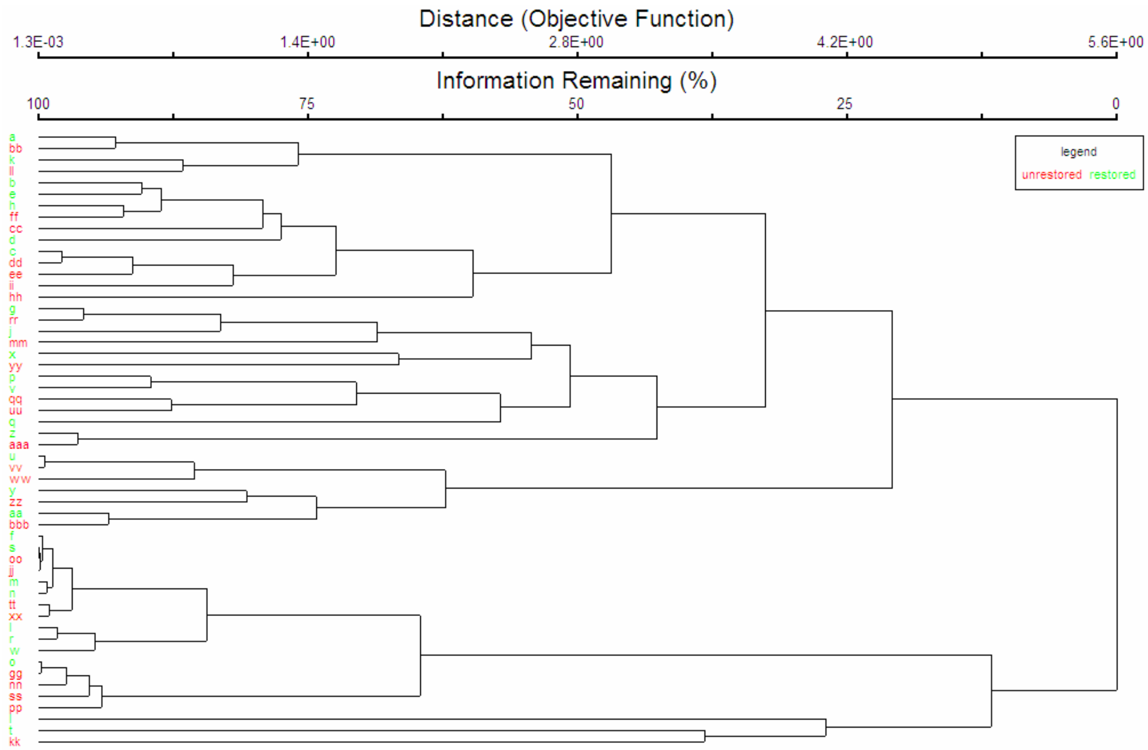

Figure 2 – Dendrogram of all sites with restored and unrestored overlay. This cluster analysis demonstrates a lack of difference in the upstream and restored reach communities. Because no distinction is made between the restored and upstream reaches, one may conclude that restoration had no effect on the benthic communities. Note, however, that this is exactly the same dendrogram as shown in Figure 1, and that the sites clustered the same as before, with urban land uses grouped at the bottom of the dendrogram.

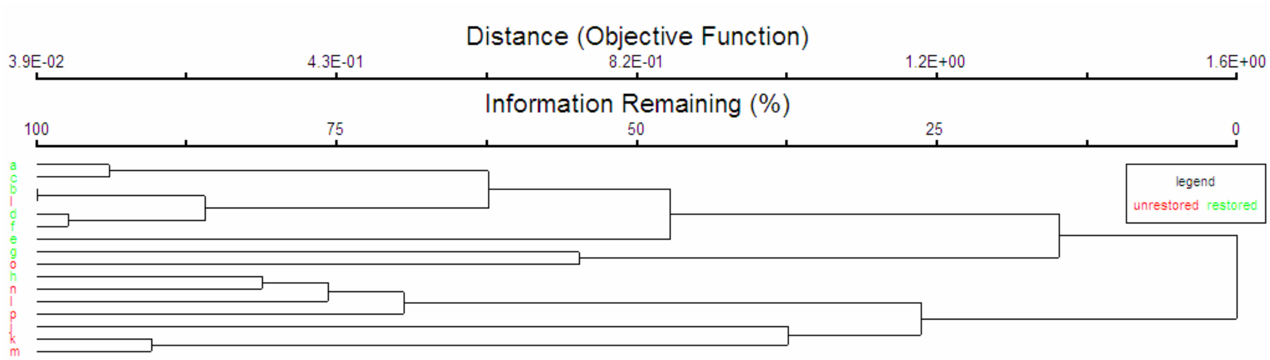

Figure 3 – Dendrogram of agricultural sites only with restored and unrestored overlay. When comparing the sites of a single land use, agricultural for this case, the cluster analysis demonstrates a more distinct clustering by the restored-unrestored reaches. This clustering demonstrates how the effects of land use can influence benthic communities and the interpretation of biological signals.

Conclusions

This study attempted to explore, through a number of approaches, the response of benthic communities to stream restoration activities over a range of land uses. However, the effects of land use on benthic ecology are well documented and recognized (Lenat and Crawford 1994), and these effects were demonstrated in various ways within this study:

- The cluster dendrograms illustrate how determining the effects of restoration may require landscape specific analyses

- The effect of the various land uses, as well as the naturally high variability of stream ecosystems, constrained traditional statistical inference.

- The differing signals of habitat specialist presence in the three land uses imply that the impacts of the restoration activities were not the same across those landscapes.

- The overwhelming complexity of the urban scenario in the qualitative models demonstrates that how the differing influences affect the communities is largely related to land use.

While complicating the interpretations, these effects of land use do not restrict the value of the study observations. The limited ability of paired t-tests to detect differences suggests more comprehensive methods may be required to statistically determine responses from these complex communities. The multivariate analysis provides a unique perspective on restoration, suggesting a simplification of community composition following restoration, and the strong influence of disrupted sediment transport may be responsible for the difference in communities. The development and application of a habitat restoration measure using the presence of key indicator taxa is an original and significant contribution to the investigation of benthic macroinvertebrates as indicators of stream restoration success. Finally, the development and simulation of Qualitative Reasoning (QR) models define causal relations between conditions influencing benthic communities and their responses, demonstrating the need for more extensive knowledge about the relative importance of these relations and the potential for application of QR in the education, research, and restoration of ecological systems.

Future study should revisit these concepts with renewed focus on specific land uses and aquatic ecosystems. The use of specialists to assess re-establishment of habitats would benefit from a more comprehensive indicator species analysis to numerically define the taxa associated with specific habitat types. The qualitative models should be redefined in an ecoregion and land use specific scenario, provided the relative importance of the different influences is known. The development of a consistent and long-term physical and biological monitoring program would provide valuable insight into relating these various habitats to their ability for supporting diverse communities, as well as associating specific restoration practices to their effectiveness in re-establishing channel form and function.

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APPENDICES

APPENDIX A – SITE CHARACTERIZATIONS

APPENDIX B – BENTHIC MACROINVERTEBRATE COLLECTIONS

APPENDIX A – SITE CHARACTERIZATIONS

abbott restored

riparian condition

% herbaceous	visually estimated across 40' transects at cross sections	100
% woody	visually estimated across 40' transects at cross sections	40
riparian infiltration (s)	measured according to USDA (2001) procedure	760
dry biomass (g)	leaf material collected, dried, and weighed	0.15
% cover	visually estimated by looking up from channel centerline	0.3

habitat quality

volume woody debris/longitudinal profile (ft^2)	diameter and length of woody debris measured along length of longitudinal profile	0.0029
pool frequency ratio	number of pools (1.5x riffle depth) occurring in longitudinal profile	0.018
specific conductance	reported in mS/cm, YSI model 85 digital meter	52.4
dissolved oxygen	reported in %, YSI model 85 digital meter	85.8
inches of rainfall in last 30 days	nearest USGS gaging station determined in ArcGIS and rainfall data summed for 30 days prior to benthos collection	2.43

stream power and sediment transport

friction factor	from Leopold, Wolman, and Miller (1964)	0.14
water slope (ft/ft)	survey data collected using a builder's level	0.0053
BEHI	estimated using Rosgen 2001 method	9.7
d90 (mm)	substrate sampled according to modified Wolman pebble count technique Harrelson et al (1994)	64
% sand or finer	substrate sampled according to modified Wolman pebble count technique Harrelson et al (1994)	50
WDR	ratio of bankfull width to bankfull depth	11.8
BHR	ratio of maximum depth at the top of low bank to maximum bankfull depth	1.2

watershed characteristics

drainage area (mi^2)	determined in ArcGIS using USGS 30m DEMs and ArcHydro; visually verified for accuracy	0.644
curve number	determined in ArcGIS using 1999 HAZUS LULC and CGIA county soil surveys layers	70

biological condition

Q statistic	(Kempton and Taylor 1976) as a measure of community diversity; calculated as the slope of the inter-quartile range on the cumulative species curve	2.73
EPT taxa richness	number of Mayflies, Stoneflies, and Caddisflies (water and habitat sensitive) taxa in a sample	3
Simpson's 1/D	(Simpson 1949) a measure of community dominance that accounts for both species richness and proportion	4.48
Shannon's I	(Shannon and Weaver 1949) a measure of communtiy diversity by estimating the order or complexity in the community	1.74

abbott upstream

riparian condition

% herbaceous	visually estimated across 40' transects at cross sections	90
% woody	visually estimated across 40' transects at cross sections	50
riparian infiltration (s)	measured according to USDA (2001) procedure	187
dry biomass (g)	leaf material collected, dried, and weighed	2.83
% cover	visually estimated by looking up from channel centerline	0.75

habitat quality

volume woody debris/longitudinal profile (ft^2)	diameter and length of woody debris measured along length of longitudinal profile	0.006
pool frequency ratio	number of pools (1.5x riffle depth) occurring in longitudinal profile	0.0222
specific conductance	reported in mS/cm, YSI model 85 digital meter	52.5
dissolved oxygen	reported in %, YSI model 85 digital meter	53.9
inches of rainfall in last 30 days	nearest USGS gaging station determined in ArcGIS and rainfall data summed for 30 days prior to benthos collection	

stream power and sediment transport

friction factor	from Leopold, Wolman, and Miller (1964)	0.394
water slope (ft/ft)	survey data collected using a builder's level	0.0124
BEHI	estimated using Rosgen 2001 method	15
d90 (mm)	substrate sampled according to modified Wolman pebble count technique Harrelson et al (1994)	50
% sand or finer	substrate sampled according to modified Wolman pebble count technique Harrelson et al (1994)	51
WDR	ratio of bankfull width to bankfull depth	6.7
BHR	ratio of maximum depth at the top of low bank to maximum bankfull depth	1.0

watershed characteristics

drainage area (mi^2)	determined in ArcGIS using USGS 30m DEMs and ArcHydro; visually verified for accuracy	0.644
curve number	determined in ArcGIS using 1999 HAZUS LULC and CGIA county soil surveys layers	70

biological condition

Q statistic	(Kempton and Taylor 1976) as a measure of community diversity; calculated as the slope of the inter-quartile range on the cumulative species curve	2.51
EPT taxa richness	number of Mayflies, Stoneflies, and Caddisflies (water and habitat sensitive) taxa in a sample	2
Simpson's 1/D	(Simpson 1949) a measure of community dominance that accounts for both species richness and proportion	3.73
Shannon's I	(Shannon and Weaver 1949) a measure of communtiy diversity by estimating the order or complexity in the community	1.61

austin restored

riparian condition

% herbaceous	visually estimated across 40' transects at cross sections	90
% woody	visually estimated across 40' transects at cross sections	60
riparian infiltration (s)	measured according to USDA (2001) procedure	170
dry biomass (g)	leaf material collected, dried, and weighed	0
% cover	visually estimated by looking up from channel centerline	20

habitat quality

volume woody debris/longitudinal profile (ft^2)	diameter and length of woody debris measured along length of longitudinal profile	0
pool frequency ratio	number of pools (1.5x riffle depth) occurring in longitudinal profile	0.0024
specific conductance	reported in mS/cm, YSI model 85 digital meter	68.3
dissolved oxygen	reported in %, YSI model 85 digital meter	88.6
inches of rainfall in last 30 days	nearest USGS gaging station determined in ArcGIS and rainfall data summed for 30 days prior to benthos collection	5.82

stream power and sediment transport

friction factor	from Leopold, Wolman, and Miller (1964)	0.2373
water slope (ft/ft)	survey data collected using a builder's level	0.0013
BEHI	estimated using Rosgen 2001 method	3.2
d90 (mm)	substrate sampled according to modified Wolman pebble count technique Harrelson et al (1994)	1.3
% sand or finer	substrate sampled according to modified Wolman pebble count technique Harrelson et al (1994)	84
WDR	ratio of bankfull width to bankfull depth	8.8
BHR	ratio of maximum depth at the top of low bank to maximum bankfull depth	1.0

watershed characteristics

drainage area (mi^2)	determined in ArcGIS using USGS 30m DEMs and ArcHydro; visually verified for accuracy	4.62
curve number	determined in ArcGIS using 1999 HAZUS LULC and CGIA county soil surveys layers	58.7

biological condition

Q statistic	(Kempton and Taylor 1976) as a measure of community diversity; calculated as the slope of the inter-quartile range on the cumulative species curve	3.91
EPT taxa richness	number of Mayflies, Stoneflies, and Caddisflies (water and habitat sensitive) taxa in a sample	10
Simpson's 1/D	(Simpson 1949) a measure of community dominance that accounts for both species richness and proportion	8
Shannon's I	(Shannon and Weaver 1949) a measure of communtiy diversity by estimating the order or complexity in the community	2.29

austin upstream

riparian condition

% herbaceous	visually estimated across 40' transects at cross sections	15
% woody	visually estimated across 40' transects at cross sections	75
riparian infiltration (s)	measured according to USDA (2001) procedure	12
dry biomass (g)	leaf material collected, dried, and weighed	28.5
% cover	visually estimated by looking up from channel centerline	0.95

habitat quality

volume woody debris/longitudinal profile (ft^2)	diameter and length of woody debris measured along length of longitudinal profile	0.006
pool frequency ratio	number of pools (1.5x riffle depth) occurring in longitudinal profile	0.014
specific conductance	reported in mS/cm, YSI model 85 digital meter	81.4
dissolved oxygen	reported in %, YSI model 85 digital meter	90
inches of rainfall in last 30 days	nearest USGS gaging station determined in ArcGIS and rainfall data summed for 30 days prior to benthos collection	5.82

stream power and sediment transport

friction factor	from Leopold, Wolman, and Miller (1964)	27
water slope (ft/ft)	survey data collected using a builder's level	0.003
BEHI	estimated using Rosgen 2001 method	38
d90 (mm)	substrate sampled according to modified Wolman pebble count technique Harrelson et al (1994)	10
% sand or finer	substrate sampled according to modified Wolman pebble count technique Harrelson et al (1994)	67
WDR	ratio of bankfull width to bankfull depth	27.8
BHR	ratio of maximum depth at the top of low bank to maximum bankfull depth	2.0

watershed characteristics

drainage area (mi^2)	determined in ArcGIS using USGS 30m DEMs and ArcHydro; visually verified for accuracy	4.08
curve number	determined in ArcGIS using 1999 HAZUS LULC and CGIA county soil surveys layers	60.5

biological condition

Q statistic	(Kempton and Taylor 1976) as a measure of community diversity; calculated as the slope of the inter-quartile range on the cumulative species curve	5.43
EPT taxa richness	number of Mayflies, Stoneflies, and Caddisflies (water and habitat sensitive) taxa in a sample	6
Simpson's 1/D	(Simpson 1949) a measure of community dominance that accounts for both species richness and proportion	8.3
Shannon's I	(Shannon and Weaver 1949) a measure of communtiy diversity by estimating the order or complexity in the community	2.46

beaver creek restored

riparian condition

% herbaceous	visually estimated across 40' transects at cross sections	60
% woody	visually estimated across 40' transects at cross sections	40
riparian infiltration (s)	measured according to USDA (2001) procedure	2200
dry biomass (g)	leaf material collected, dried, and weighed	4.17
% cover	visually estimated by looking up from channel centerline	0.3

habitat quality

volume woody debris/longitudinal profile (ft^2)	diameter and length of woody debris measured along length of longitudinal profile	0.0028
pool frequency ratio	number of pools (1.5x riffle depth) occurring in longitudinal profile	0.0105
specific conductance	reported in mS/cm, YSI model 85 digital meter	19.3
dissolved oxygen	reported in %, YSI model 85 digital meter	156.4
inches of rainfall in last 30 days	nearest USGS gaging station determined in ArcGIS and rainfall data summed for 30 days prior to benthos collection	4.08

stream power and sediment transport

friction factor	from Leopold, Wolman, and Miller (1964)	0.19
water slope (ft/ft)	survey data collected using a builder's level	0.01
BEHI	estimated using Rosgen 2001 method	10.7
d90 (mm)	substrate sampled according to modified Wolman pebble count technique Harrelson et al (1994)	84
% sand or finer	substrate sampled according to modified Wolman pebble count technique Harrelson et al (1994)	48
WDR	ratio of bankfull width to bankfull depth	10.4
BHR	ratio of maximum depth at the top of low bank to maximum bankfull depth	1.1

watershed characteristics

drainage area (mi^2)	determined in ArcGIS using USGS 30m DEMs and ArcHydro; visually verified for accuracy	5.5
curve number	determined in ArcGIS using 1999 HAZUS LULC and CGIA county soil surveys layers	59.5

biological condition

Q statistic	(Kempton and Taylor 1976) as a measure of community diversity; calculated as the slope of the inter-quartile range on the cumulative species curve	6.08
EPT taxa richness	number of Mayflies, Stoneflies, and Caddisflies (water and habitat sensitive) taxa in a sample	29
Simpson's 1/D	(Simpson 1949) a measure of community dominance that accounts for both species richness and proportion	11.82
Shannon's I	(Shannon and Weaver 1949) a measure of communtiy diversity by estimating the order or complexity in the community	2.74

beaver creek upstream

riparian condition

% herbaceous	visually estimated across 40' transects at cross sections	70
% woody	visually estimated across 40' transects at cross sections	80
riparian infiltration (s)	measured according to USDA (2001) procedure	102
dry biomass (g)	leaf material collected, dried, and weighed	7.21
% cover	visually estimated by looking up from channel centerline	0.8

habitat quality

volume woody debris/longitudinal profile (ft^2)	diameter and length of woody debris measured along length of longitudinal profile	0
pool frequency ratio	number of pools (1.5x riffle depth) occurring in longitudinal profile	0.02
specific conductance	reported in mS/cm, YSI model 85 digital meter	20.9
dissolved oxygen	reported in %, YSI model 85 digital meter	150.4
inches of rainfall in last 30 days	nearest USGS gaging station determined in ArcGIS and rainfall data summed for 30 days prior to benthos collection	4.08

stream power and sediment transport

friction factor	from Leopold, Wolman, and Miller (1964)	0.212
water slope (ft/ft)	survey data collected using a builder's level	0.011
BEHI	estimated using Rosgen 2001 method	10
d90 (mm)	substrate sampled according to modified Wolman pebble count technique Harrelson et al (1994)	300
% sand or finer	substrate sampled according to modified Wolman pebble count technique Harrelson et al (1994)	49
WDR	ratio of bankfull width to bankfull depth	18
BHR	ratio of maximum depth at the top of low bank to maximum bankfull depth	1.0

watershed characteristics

drainage area (mi^2)	determined in ArcGIS using USGS 30m DEMs and ArcHydro; visually verified for accuracy	5.23
curve number	determined in ArcGIS using 1999 HAZUS LULC and CGIA county soil surveys layers	60

biological condition

Q statistic	(Kempton and Taylor 1976) as a measure of community diversity; calculated as the slope of the inter-quartile range on the cumulative species curve	6.05
EPT taxa richness	number of Mayflies, Stoneflies, and Caddisflies (water and habitat sensitive) taxa in a sample	31
Simpson's 1/D	(Simpson 1949) a measure of community dominance that accounts for both species richness and proportion	13.06
Shannon's I	(Shannon and Weaver 1949) a measure of communtiy diversity by estimating the order or complexity in the community	2.75

bethel church restored

riparian condition

% herbaceous	visually estimated across 40' transects at cross sections	100
% woody	visually estimated across 40' transects at cross sections	20
riparian infiltration (s)	measured according to USDA (2001) procedure	305
dry biomass (g)	leaf material collected, dried, and weighed	4.58
% cover	visually estimated by looking up from channel centerline	0.2

habitat quality

volume woody debris/longitudinal profile (ft^2)	diameter and length of woody debris measured along length of longitudinal profile	0.02
pool frequency ratio	number of pools (1.5x riffle depth) occurring in longitudinal profile	0.0125
specific conductance	reported in mS/cm, YSI model 85 digital meter	na
dissolved oxygen	reported in %, YSI model 85 digital meter	na
inches of rainfall in last 30 days	nearest USGS gaging station determined in ArcGIS and rainfall data summed for 30 days prior to benthos collection	5.35

stream power and sediment transport

friction factor	from Leopold, Wolman, and Miller (1964)	0.219
water slope (ft/ft)	survey data collected using a builder's level	0.013
BEHI	estimated using Rosgen 2001 method	14.6
d90 (mm)	substrate sampled according to modified Wolman pebble count technique Harrelson et al (1994)	14
% sand or finer	substrate sampled according to modified Wolman pebble count technique Harrelson et al (1994)	70
WDR	ratio of bankfull width to bankfull depth	12.1
BHR	ratio of maximum depth at the top of low bank to maximum bankfull depth	1.9

watershed characteristics

drainage area (mi^2)	determined in ArcGIS using USGS 30m DEMs and ArcHydro; visually verified for accuracy	0.65
curve number	determined in ArcGIS using 1999 HAZUS LULC and CGIA county soil surveys layers	56

biological condition

Q statistic	(Kempton and Taylor 1976) as a measure of community diversity; calculated as the slope of the inter-quartile range on the cumulative species curve	2.92
EPT taxa richness	number of Mayflies, Stoneflies, and Caddisflies (water and habitat sensitive) taxa in a sample	2
Simpson's 1/D	(Simpson 1949) a measure of community dominance that accounts for both species richness and proportion	3.8
Shannon's I	(Shannon and Weaver 1949) a measure of communtiy diversity by estimating the order or complexity in the community	1.72

bethel church upstream

riparian condition

% herbaceous	visually estimated across 40' transects at cross sections	20
% woody	visually estimated across 40' transects at cross sections	100
riparian infiltration (s)	measured according to USDA (2001) procedure	63
dry biomass (g)	leaf material collected, dried, and weighed	4.44
% cover	visually estimated by looking up from channel centerline	69.63

habitat quality

volume woody debris/longitudinal profile (ft^2)	diameter and length of woody debris measured along length of longitudinal profile	0.74
pool frequency ratio	number of pools (1.5x riffle depth) occurring in longitudinal profile	0.0233
specific conductance	reported in mS/cm, YSI model 85 digital meter	na
dissolved oxygen	reported in %, YSI model 85 digital meter	na
inches of rainfall in last 30 days	nearest USGS gaging station determined in ArcGIS and rainfall data summed for 30 days prior to benthos collection	5.35

stream power and sediment transport

friction factor	from Leopold, Wolman, and Miller (1964)	0.186
water slope (ft/ft)	survey data collected using a builder's level	0.0058
BEHI	estimated using Rosgen 2001 method	22
d90 (mm)	substrate sampled according to modified Wolman pebble count technique Harrelson et al (1994)	22
% sand or finer	substrate sampled according to modified Wolman pebble count technique Harrelson et al (1994)	70
WDR	ratio of bankfull width to bankfull depth	7.9
BHR	ratio of maximum depth at the top of low bank to maximum bankfull depth	1.2

watershed characteristics

drainage area (mi^2)	determined in ArcGIS using USGS 30m DEMs and ArcHydro; visually verified for accuracy	0.65
curve number	determined in ArcGIS using 1999 HAZUS LULC and CGIA county soil surveys layers	56

biological condition

Q statistic	(Kempton and Taylor 1976) as a measure of community diversity; calculated as the slope of the inter-quartile range on the cumulative species curve	2.05
EPT taxa richness	number of Mayflies, Stoneflies, and Caddisflies (water and habitat sensitive) taxa in a sample	4
Simpson's 1/D	(Simpson 1949) a measure of community dominance that accounts for both species richness and proportion	4.04
Shannon's I	(Shannon and Weaver 1949) a measure of communtiy diversity by estimating the order or complexity in the community	1.79

big warrior restored

riparian condition

% herbaceous	visually estimated across 40' transects at cross sections	95
% woody	visually estimated across 40' transects at cross sections	50
riparian infiltration (s)	measured according to USDA (2001) procedure	7200
dry biomass (g)	leaf material collected, dried, and weighed	0.41
% cover	visually estimated by looking up from channel centerline	0.05

habitat quality

volume woody debris/longitudinal profile (ft^2)	diameter and length of woody debris measured along length of longitudinal profile	0
pool frequency ratio	number of pools (1.5x riffle depth) occurring in longitudinal profile	0
specific conductance	reported in mS/cm, YSI model 85 digital meter	na
dissolved oxygen	reported in %, YSI model 85 digital meter	na
inches of rainfall in last 30 days	nearest USGS gaging station determined in ArcGIS and rainfall data summed for 30 days prior to benthos collection	7.32

stream power and sediment transport

friction factor	from Leopold, Wolman, and Miller (1964)	0.0897
water slope (ft/ft)	survey data collected using a builder's level	0.0182
BEHI	estimated using Rosgen 2001 method	11.2
d90 (mm)	substrate sampled according to modified Wolman pebble count technique Harrelson et al (1994)	90
% sand or finer	substrate sampled according to modified Wolman pebble count technique Harrelson et al (1994)	38
WDR	ratio of bankfull width to bankfull depth	15.7
BHR	ratio of maximum depth at the top of low bank to maximum bankfull depth	1.3

watershed characteristics

drainage area (mi^2)	determined in ArcGIS using USGS 30m DEMs and ArcHydro; visually verified for accuracy	0.75
curve number	determined in ArcGIS using 1999 HAZUS LULC and CGIA county soil surveys layers	59

biological condition

Q statistic	(Kempton and Taylor 1976) as a measure of community diversity; calculated as the slope of the inter-quartile range on the cumulative species curve	5.23
EPT taxa richness	number of Mayflies, Stoneflies, and Caddisflies (water and habitat sensitive) taxa in a sample	20
Simpson's 1/D	(Simpson 1949) a measure of community dominance that accounts for both species richness and proportion	6.84
Shannon's I	(Shannon and Weaver 1949) a measure of communtiy diversity by estimating the order or complexity in the community	2.28

big warrior upstream

riparian condition

% herbaceous	visually estimated across 40' transects at cross sections	95
% woody	visually estimated across 40' transects at cross sections	30
riparian infiltration (s)	measured according to USDA (2001) procedure	45
dry biomass (g)	leaf material collected, dried, and weighed	11.57
% cover	visually estimated by looking up from channel centerline	0.3

habitat quality

volume woody debris/longitudinal profile (ft^2)	diameter and length of woody debris measured along length of longitudinal profile	0.036
pool frequency ratio	number of pools (1.5x riffle depth) occurring in longitudinal profile	0.0161
specific conductance	reported in mS/cm, YSI model 85 digital meter	na
dissolved oxygen	reported in %, YSI model 85 digital meter	na
inches of rainfall in last 30 days	nearest USGS gaging station determined in ArcGIS and rainfall data summed for 30 days prior to benthos collection	7.32

stream power and sediment transport

friction factor	from Leopold, Wolman, and Miller (1964)	0.0865
water slope (ft/ft)	survey data collected using a builder's level	0.0228
BEHI	estimated using Rosgen 2001 method	22
d90 (mm)	substrate sampled according to modified Wolman pebble count technique Harrelson et al (1994)	64
% sand or finer	substrate sampled according to modified Wolman pebble count technique Harrelson et al (1994)	52
WDR	ratio of bankfull width to bankfull depth	15.1
BHR	ratio of maximum depth at the top of low bank to maximum bankfull depth	2.6

watershed characteristics

drainage area (mi^2)	determined in ArcGIS using USGS 30m DEMs and ArcHydro; visually verified for accuracy	1.3
curve number	determined in ArcGIS using 1999 HAZUS LULC and CGIA county soil surveys layers	58

biological condition

Q statistic	(Kempton and Taylor 1976) as a measure of community diversity; calculated as the slope of the inter-quartile range on the cumulative species curve	4.55
EPT taxa richness	number of Mayflies, Stoneflies, and Caddisflies (water and habitat sensitive) taxa in a sample	17
Simpson's 1/D	(Simpson 1949) a measure of community dominance that accounts for both species richness and proportion	5.96
Shannon's I	(Shannon and Weaver 1949) a measure of communtiy diversity by estimating the order or complexity in the community	2.17

bobs creek restored

riparian condition

% herbaceous	visually estimated across 40' transects at cross sections	85
% woody	visually estimated across 40' transects at cross sections	5
riparian infiltration (s)	measured according to USDA (2001) procedure	105
dry biomass (g)	leaf material collected, dried, and weighed	3.35
% cover	visually estimated by looking up from channel centerline	0.05

stream power and sediment transport

friction factor	from Leopold, Wolman, and Miller (1964)	0.0829
water slope (ft/ft)	survey data collected using a builder's level	0.0068
BEHI	estimated using Rosgen 2001 method	14
d90 (mm)	substrate sampled according to modified Wolman pebble count technique Harrelson et al (1994)	68
% sand or finer	substrate sampled according to modified Wolman pebble count technique Harrelson et al (1994)	18
WDR	ratio of bankfull width to bankfull depth	29.5
BHR	ratio of maximum depth at the top of low bank to maximum bankfull depth	2.2

habitat quality

volume woody debris/longitudinal profile (ft^2)	diameter and length of woody debris measured along length of longitudinal profile	0.001
pool frequency ratio	number of pools (1.5x riffle depth) occurring in longitudinal profile	0.0159
specific conductance	reported in mS/cm, YSI model 85 digital meter	na
dissolved oxygen	reported in %, YSI model 85 digital meter	na
inches of rainfall in last 30 days	nearest USGS gaging station determined in ArcGIS and rainfall data summed for 30 days prior to benthos collection	3.1

watershed characteristics

drainage area (mi^2)	determined in ArcGIS using USGS 30m DEMs and ArcHydro; visually verified for accuracy	1.93
curve number	determined in ArcGIS using 1999 HAZUS LULC and CGIA county soil surveys layers	55

biological condition

Q statistic	(Kempton and Taylor 1976) as a measure of community diversity; calculated as the slope of the inter-quartile range on the cumulative species curve	4.68
EPT taxa richness	number of Mayflies, Stoneflies, and Caddisflies (water and habitat sensitive) taxa in a sample	19
Simpson's 1/D	(Simpson 1949) a measure of community dominance that accounts for both species richness and proportion	8.76
Shannon's I	(Shannon and Weaver 1949) a measure of communtiy diversity by estimating the order or complexity in the community	2.48

bobs creek upstream

riparian condition

% herbaceous	visually estimated across 40' transects at cross sections	40
% woody	visually estimated across 40' transects at cross sections	90
riparian infiltration (s)	measured according to USDA (2001) procedure	55
dry biomass (g)	leaf material collected, dried, and weighed	8.46
% cover	visually estimated by looking up from channel centerline	0.45

habitat quality

volume woody debris/longitudinal profile (ft^2)	diameter and length of woody debris measured along length of longitudinal profile	0.008
pool frequency ratio	number of pools (1.5x riffle depth) occurring in longitudinal profile	0.0081
specific conductance	reported in mS/cm, YSI model 85 digital meter	na
dissolved oxygen	reported in %, YSI model 85 digital meter	na
inches of rainfall in last 30 days	nearest USGS gaging station determined in ArcGIS and rainfall data summed for 30 days prior to benthos collection	3.1

stream power and sediment transport

friction factor	from Leopold, Wolman, and Miller (1964)	0.074
water slope (ft/ft)	survey data collected using a builder's level	0.0056
BEHI	estimated using Rosgen 2001 method	31
d90 (mm)	substrate sampled according to modified Wolman pebble count technique Harrelson et al (1994)	84
% sand or finer	substrate sampled according to modified Wolman pebble count technique Harrelson et al (1994)	58
WDR	ratio of bankfull width to bankfull depth	12.1
BHR	ratio of maximum depth at the top of low bank to maximum bankfull depth	2.1

watershed characteristics

drainage area (mi^2)	determined in ArcGIS using USGS 30m DEMs and ArcHydro; visually verified for accuracy	1.93
curve number	determined in ArcGIS using 1999 HAZUS LULC and CGIA county soil surveys layers	55

biological condition

Q statistic	(Kempton and Taylor 1976) as a measure of community diversity; calculated as the slope of the inter-quartile range on the cumulative species curve	7.21
EPT taxa richness	number of Mayflies, Stoneflies, and Caddisflies (water and habitat sensitive) taxa in a sample	16
Simpson's 1/D	(Simpson 1949) a measure of community dominance that accounts for both species richness and proportion	10.42
Shannon's I	(Shannon and Weaver 1949) a measure of communtiy diversity by estimating the order or complexity in the community	2.56

brown branch restored

riparian condition

% herbaceous	visually estimated across 40' transects at cross sections	5
% woody	visually estimated across 40' transects at cross sections	90
riparian infiltration (s)	measured according to USDA (2001) procedure	306
dry biomass (g)	leaf material collected, dried, and weighed	7.59
% cover	visually estimated by looking up from channel centerline	0.45

stream power and sediment transport

friction factor	from Leopold, Wolman, and Miller (1964)	0.0995
water slope (ft/ft)	survey data collected using a builder's level	0.0084
BEHI	estimated using Rosgen 2001 method	13.2
d90 (mm)	substrate sampled according to modified Wolman pebble count technique Harrelson et al (1994)	55
% sand or finer	substrate sampled according to modified Wolman pebble count technique Harrelson et al (1994)	46
WDR	ratio of bankfull width to bankfull depth	18.2
BHR	ratio of maximum depth at the top of low bank to maximum bankfull depth	1.3

habitat quality

volume woody debris/longitudinal profile (ft^2)	diameter and length of woody debris measured along length of longitudinal profile	0.005
pool frequency ratio	number of pools (1.5x riffle depth) occurring in longitudinal profile	0.0188
specific conductance	reported in mS/cm, YSI model 85 digital meter	na
dissolved oxygen	reported in %, YSI model 85 digital meter	na
inches of rainfall in last 30 days	nearest USGS gaging station determined in ArcGIS and rainfall data summed for 30 days prior to benthos collection	10.04

watershed characteristics

drainage area (mi^2)	determined in ArcGIS using USGS 30m DEMs and ArcHydro; visually verified for accuracy	0.989
curve number	determined in ArcGIS using 1999 HAZUS LULC and CGIA county soil surveys layers	60

biological condition

Q statistic	(Kempton and Taylor 1976) as a measure of community diversity; calculated as the slope of the inter-quartile range on the cumulative species curve	6.01
EPT taxa richness	number of Mayflies, Stoneflies, and Caddisflies (water and habitat sensitive) taxa in a sample	18
Simpson's 1/D	(Simpson 1949) a measure of community dominance that accounts for both species richness and proportion	11.01
Shannon's I	(Shannon and Weaver 1949) a measure of communtiy diversity by estimating the order or complexity in the community	2.61

brown branch upstream

riparian condition

% herbaceous	visually estimated across 40' transects at cross sections	20
% woody	visually estimated across 40' transects at cross sections	60
riparian infiltration (s)	measured according to USDA (2001) procedure	46
dry biomass (g)	leaf material collected, dried, and weighed	20.63
% cover	visually estimated by looking up from channel centerline	0.6

stream power and sediment transport

friction factor	from Leopold, Wolman, and Miller (1964)	0.1398
water slope (ft/ft)	survey data collected using a builder's level	0.0015
BEHI	estimated using Rosgen 2001 method	27.8
d90 (mm)	substrate sampled according to modified Wolman pebble count technique Harrelson et al (1994)	30
% sand or finer	substrate sampled according to modified Wolman pebble count technique Harrelson et al (1994)	64
WDR	ratio of bankfull width to bankfull depth	7.5
BHR	ratio of maximum depth at the top of low bank to maximum bankfull depth	1.4

habitat quality

volume woody debris/longitudinal profile (ft^2)	diameter and length of woody debris measured along length of longitudinal profile	0.073
pool frequency ratio	number of pools (1.5x riffle depth) occurring in longitudinal profile	0.0079
specific conductance	reported in mS/cm, YSI model 85 digital meter	na
dissolved oxygen	reported in %, YSI model 85 digital meter	na
inches of rainfall in last 30 days	nearest USGS gaging station determined in ArcGIS and rainfall data summed for 30 days prior to benthos collection	10

watershed characteristics

drainage area (mi^2)	determined in ArcGIS using USGS 30m DEMs and ArcHydro; visually verified for accuracy	1
curve number	determined in ArcGIS using 1999 HAZUS LULC and CGIA county soil surveys layers	60

biological condition

Q statistic	(Kempton and Taylor 1976) as a measure of community diversity; calculated as the slope of the inter-quartile range on the cumulative species curve	7.46
EPT taxa richness	number of Mayflies, Stoneflies, and Caddisflies (water and habitat sensitive) taxa in a sample	21
Simpson's 1/D	(Simpson 1949) a measure of community dominance that accounts for both species richness and proportion	12.97
Shannon's I	(Shannon and Weaver 1949) a measure of communtiy diversity by estimating the order or complexity in the community	2.76

brushy fork restored

riparian condition

% herbaceous	visually estimated across 40' transects at cross sections	100
% woody	visually estimated across 40' transects at cross sections	65
riparian infiltration (s)	measured according to USDA (2001) procedure	45
dry biomass (g)	leaf material collected, dried, and weighed	3.44
% cover	visually estimated by looking up from channel centerline	0.2

habitat quality

volume woody debris/longitudinal profile (ft^2)	diameter and length of woody debris measured along length of longitudinal profile	0.02
pool frequency ratio	number of pools (1.5x riffle depth) occurring in longitudinal profile	0.0087
specific conductance	reported in mS/cm, YSI model 85 digital meter	na
dissolved oxygen	reported in %, YSI model 85 digital meter	na
inches of rainfall in last 30 days	nearest USGS gaging station determined in ArcGIS and rainfall data summed for 30 days prior to benthos collection	6.7

stream power and sediment transport

friction factor	from Leopold, Wolman, and Miller (1964)	0.234
water slope (ft/ft)	survey data collected using a builder's level	0.0091
BEHI	estimated using Rosgen 2001 method	11.5
d90 (mm)	substrate sampled according to modified Wolman pebble count technique Harrelson et al (1994)	50
% sand or finer	substrate sampled according to modified Wolman pebble count technique Harrelson et al (1994)	54
WDR	ratio of bankfull width to bankfull depth	8.6
BHR	ratio of maximum depth at the top of low bank to maximum bankfull depth	1.5

watershed characteristics

drainage area (mi^2)	determined in ArcGIS using USGS 30m DEMs and ArcHydro; visually verified for accuracy	3.8
curve number	determined in ArcGIS using 1999 HAZUS LULC and CGIA county soil surveys layers	55

biological condition

Q statistic	(Kempton and Taylor 1976) as a measure of community diversity; calculated as the slope of the inter-quartile range on the cumulative species curve	4.08
EPT taxa richness	number of Mayflies, Stoneflies, and Caddisflies (water and habitat sensitive) taxa in a sample	18
Simpson's 1/D	(Simpson 1949) a measure of community dominance that accounts for both species richness and proportion	5.23
Shannon's I	(Shannon and Weaver 1949) a measure of communtiy diversity by estimating the order or complexity in the community	2.04

brushy fork upstream

riparian condition

% herbaceous	visually estimated across 40' transects at cross sections	100
% woody	visually estimated across 40' transects at cross sections	0
riparian infiltration (s)	measured according to USDA (2001) procedure	30
dry biomass (g)	leaf material collected, dried, and weighed	3.11
% cover	visually estimated by looking up from channel centerline	0

habitat quality

volume woody debris/longitudinal profile (ft^2)	diameter and length of woody debris measured along length of longitudinal profile	0
pool frequency ratio	number of pools (1.5x riffle depth) occurring in longitudinal profile	0.0229
specific conductance	reported in mS/cm, YSI model 85 digital meter	na
dissolved oxygen	reported in %, YSI model 85 digital meter	na
inches of rainfall in last 30 days	nearest USGS gaging station determined in ArcGIS and rainfall data summed for 30 days prior to benthos collection	6.65

stream power and sediment transport

friction factor	from Leopold, Wolman, and Miller (1964)	0.103
water slope (ft/ft)	survey data collected using a builder's level	0.0119
BEHI	estimated using Rosgen 2001 method	23.5
d90 (mm)	substrate sampled according to modified Wolman pebble count technique Harrelson et al (1994)	1000
% sand or finer	substrate sampled according to modified Wolman pebble count technique Harrelson et al (1994)	52
WDR	ratio of bankfull width to bankfull depth	8.8
BHR	ratio of maximum depth at the top of low bank to maximum bankfull depth	1.5

watershed characteristics

drainage area (mi^2)	determined in ArcGIS using USGS 30m DEMs and ArcHydro; visually verified for accuracy	3.8
curve number	determined in ArcGIS using 1999 HAZUS LULC and CGIA county soil surveys layers	55

biological condition

Q statistic	(Kempton and Taylor 1976) as a measure of community diversity; calculated as the slope of the inter-quartile range on the cumulative species curve	6.13
EPT taxa richness	number of Mayflies, Stoneflies, and Caddisflies (water and habitat sensitive) taxa in a sample	13
Simpson's 1/D	(Simpson 1949) a measure of community dominance that accounts for both species richness and proportion	5.37
Shannon's I	(Shannon and Weaver 1949) a measure of communtiy diversity by estimating the order or complexity in the community	2.04

caviness restored

riparian condition		
% herbaceous	visually estimated across 40' transects at cross sections	100
% woody	visually estimated across 40' transects at cross sections	5
riparian infiltration (s)	measured according to USDA (2001) procedure	170
dry biomass (g)	leaf material collected, dried, and weighed	0
% cover	visually estimated by looking up from channel centerline	0.3

habitat quality		
volume woody debris/longitudinal profile (ft^2)	diameter and length of woody debris measured along length of longitudinal profile	0.016
pool frequency ratio	number of pools (1.5x riffle depth) occurring in longitudinal profile	0.018
specific conductance	reported in mS/cm, YSI model 85 digital meter	42.2
dissolved oxygen	reported in %, YSI model 85 digital meter	69.5
inches of rainfall in last 30 days	nearest USGS gaging station determined in ArcGIS and rainfall data summed for 30 days prior to benthos collection	1.51

stream power and sediment transport		
friction factor	from Leopold, Wolman, and Miller (1964)	0.35
water slope (ft/ft)	survey data collected using a builder's level	0.0075
BEHI	estimated using Rosgen 2001 method	12
d90 (mm)	substrate sampled according to modified Wolman pebble count technique Harrelson et al (1994)	75
% sand or finer	substrate sampled according to modified Wolman pebble count technique Harrelson et al (1994)	59
WDR	ratio of bankfull width to bankfull depth	8.2
BHR	ratio of maximum depth at the top of low bank to maximum bankfull depth	1.1

watershed characteristics		
drainage area (mi2)	determined in ArcGIS using USGS 30m DEMs and ArcHydro; visually verified for accuracy	3.2
curve number	determined in ArcGIS using 1999 HAZUS LULC and CGIA county soil surveys layers	60

biological condition		
Q statistic	(Kempton and Taylor 1976) as a measure of community diversity; calculated as the slope of the inter-quartile range on the cumulative species curve	1.94
EPT taxa richness	number of Mayflies, Stoneflies, and Caddisflies (water and habitat sensitive) taxa in a sample	11
Simpson's 1/D	(Simpson 1949) a measure of community dominance that accounts for both species richness and proportion	3.49
Shannon's I	(Shannon and Weaver 1949) a measure of communtiy diversity by estimating the order or complexity in the community	1.51

caviness upstream

riparian condition

% herbaceous	visually estimated across 40' transects at cross sections	85
% woody	visually estimated across 40' transects at cross sections	65
riparian infiltration (s)	measured according to USDA (2001) procedure	112
dry biomass (g)	leaf material collected, dried, and weighed	12.3
% cover	visually estimated by looking up from channel centerline	0.8

habitat quality

volume woody debris/longitudinal profile (ft^2)	diameter and length of woody debris measured along length of longitudinal profile	0
pool frequency ratio	number of pools (1.5x riffle depth) occurring in longitudinal profile	0.024
specific conductance	reported in mS/cm, YSI model 85 digital meter	34.3
dissolved oxygen	reported in %, YSI model 85 digital meter	109.2
inches of rainfall in last 30 days	nearest USGS gaging station determined in ArcGIS and rainfall data summed for 30 days prior to benthos collection	1.5

stream power and sediment transport

friction factor	from Leopold, Wolman, and Miller (1964)	0.33
water slope (ft/ft)	survey data collected using a builder's level	0.0073
BEHI	estimated using Rosgen 2001 method	22
d90 (mm)	substrate sampled according to modified Wolman pebble count technique Harrelson et al (1994)	2
% sand or finer	substrate sampled according to modified Wolman pebble count technique Harrelson et al (1994)	76
WDR	ratio of bankfull width to bankfull depth	3.6
BHR	ratio of maximum depth at the top of low bank to maximum bankfull depth	1.0

watershed characteristics

drainage area (mi^2)	determined in ArcGIS using USGS 30m DEMs and ArcHydro; visually verified for accuracy	1.1
curve number	determined in ArcGIS using 1999 HAZUS LULC and CGIA county soil surveys layers	59

biological condition

Q statistic	(Kempton and Taylor 1976) as a measure of community diversity; calculated as the slope of the inter-quartile range on the cumulative species curve	4.32
EPT taxa richness	number of Mayflies, Stoneflies, and Caddisflies (water and habitat sensitive) taxa in a sample	9
Simpson's 1/D	(Simpson 1949) a measure of community dominance that accounts for both species richness and proportion	4.48
Shannon's I	(Shannon and Weaver 1949) a measure of communtiy diversity by estimating the order or complexity in the community	1.91

deaton restored

riparian condition

% herbaceous	visually estimated across 40' transects at cross sections	85
% woody	visually estimated across 40' transects at cross sections	15
riparian infiltration (s)	measured according to USDA (2001) procedure	2200
dry biomass (g)	leaf material collected, dried, and weighed	21.6
% cover	visually estimated by looking up from channel centerline	0.15

habitat quality

volume woody debris/longitudinal profile (ft^2)	diameter and length of woody debris measured along length of longitudinal profile	0.0004
pool frequency ratio	number of pools (1.5x riffle depth) occurring in longitudinal profile	0.022
specific conductance	reported in mS/cm, YSI model 85 digital meter	61.9
dissolved oxygen	reported in %, YSI model 85 digital meter	71
inches of rainfall in last 30 days	nearest USGS gaging station determined in ArcGIS and rainfall data summed for 30 days prior to benthos collection	1.32

stream power and sediment transport

friction factor	from Leopold, Wolman, and Miller (1964)	0.81
water slope (ft/ft)	survey data collected using a builder's level	0.0022
BEHI	estimated using Rosgen 2001 method	10
d90 (mm)	substrate sampled according to modified Wolman pebble count technique Harrelson et al (1994)	31
% sand or finer	substrate sampled according to modified Wolman pebble count technique Harrelson et al (1994)	76
WDR	ratio of bankfull width to bankfull depth	12.8
BHR	ratio of maximum depth at the top of low bank to maximum bankfull depth	1.2

watershed characteristics

drainage area (mi^2)	determined in ArcGIS using USGS 30m DEMs and ArcHydro; visually verified for accuracy	0.33
curve number	determined in ArcGIS using 1999 HAZUS LULC and CGIA county soil surveys layers	60

biological condition

Q statistic	(Kempton and Taylor 1976) as a measure of community diversity; calculated as the slope of the inter-quartile range on the cumulative species curve	4.15
EPT taxa richness	number of Mayflies, Stoneflies, and Caddisflies (water and habitat sensitive) taxa in a sample	9
Simpson's 1/D	(Simpson 1949) a measure of community dominance that accounts for both species richness and proportion	5.19
Shannon's I	(Shannon and Weaver 1949) a measure of communtiy diversity by estimating the order or complexity in the community	1.93

deaton upstream

riparian condition		
% herbaceous	visually estimated across 40' transects at cross sections	80
% woody	visually estimated across 40' transects at cross sections	25
riparian infiltration (s)	measured according to USDA (2001) procedure	105
dry biomass (g)	leaf material collected, dried, and weighed	2.68
% cover	visually estimated by looking up from channel centerline	0.8

habitat quality		
volume woody debris/longitudinal profile (ft^2)	diameter and length of woody debris measured along length of longitudinal profile	0.004
pool frequency ratio	number of pools (1.5x riffle depth) occurring in longitudinal profile	0.027
specific conductance	reported in mS/cm, YSI model 85 digital meter	54.8
dissolved oxygen	reported in %, YSI model 85 digital meter	112.1
inches of rainfall in last 30 days	nearest USGS gaging station determined in ArcGIS and rainfall data summed for 30 days prior to benthos collection	1.32

stream power and sediment transport		
friction factor	from Leopold, Wolman, and Miller (1964)	0.31
water slope (ft/ft)	survey data collected using a builder's level	0.013
BEHI	estimated using Rosgen 2001 method	17
d90 (mm)	substrate sampled according to modified Wolman pebble count technique Harrelson et al (1994)	64
% sand or finer	substrate sampled according to modified Wolman pebble count technique Harrelson et al (1994)	59
WDR	ratio of bankfull width to bankfull depth	5.0
BHR	ratio of maximum depth at the top of low bank to maximum bankfull depth	1.1

watershed characteristics		
drainage area (mi^2)	determined in ArcGIS using USGS 30m DEMs and ArcHydro; visually verified for accuracy	0.29
curve number	determined in ArcGIS using 1999 HAZUS LULC and CGIA county soil surveys layers	60

biological condition		
Q statistic	(Kempton and Taylor 1976) as a measure of community diversity; calculated as the slope of the inter-quartile range on the cumulative species curve	1.21
EPT taxa richness	number of Mayflies, Stoneflies, and Caddisflies (water and habitat sensitive) taxa in a sample	4
Simpson's 1/D	(Simpson 1949) a measure of community dominance that accounts for both species richness and proportion	2.88
Shannon's I	(Shannon and Weaver 1949) a measure of communtiy diversity by estimating the order or complexity in the community	1.29

edsel place restored

riparian condition

% herbaceous	visually estimated across 40' transects at cross sections	75
% woody	visually estimated across 40' transects at cross sections	50
riparian infiltration (s)	measured according to USDA (2001) procedure	7200
dry biomass (g)	leaf material collected, dried, and weighed	1.38
% cover	visually estimated by looking up from channel centerline	0.1

habitat quality

volume woody debris/longitudinal profile (ft^2)	diameter and length of woody debris measured along length of longitudinal profile	0.001
pool frequency ratio	number of pools (1.5x riffle depth) occurring in longitudinal profile	0.061
specific conductance	reported in mS/cm, YSI model 85 digital meter	na
dissolved oxygen	reported in %, YSI model 85 digital meter	na
inches of rainfall in last 30 days	nearest USGS gaging station determined in ArcGIS and rainfall data summed for 30 days prior to benthos collection	6.05

stream power and sediment transport

friction factor	from Leopold, Wolman, and Miller (1964)	0.093
water slope (ft/ft)	survey data collected using a builder's level	0.0041
BEHI	estimated using Rosgen 2001 method	26.6
d90 (mm)	substrate sampled according to modified Wolman pebble count technique Harrelson et al (1994)	80
% sand or finer	substrate sampled according to modified Wolman pebble count technique Harrelson et al (1994)	60
WDR	ratio of bankfull width to bankfull depth	11.9
BHR	ratio of maximum depth at the top of low bank to maximum bankfull depth	1.6

watershed characteristics

drainage area (mi^2)	determined in ArcGIS using USGS 30m DEMs and ArcHydro; visually verified for accuracy	0.71
curve number	determined in ArcGIS using 1999 HAZUS LULC and CGIA county soil surveys layers	70

biological condition

Q statistic	(Kempton and Taylor 1976) as a measure of community diversity; calculated as the slope of the inter-quartile range on the cumulative species curve	1.29
EPT taxa richness	number of Mayflies, Stoneflies, and Caddisflies (water and habitat sensitive) taxa in a sample	3
Simpson's 1/D	(Simpson 1949) a measure of community dominance that accounts for both species richness and proportion	3.92
Shannon's I	(Shannon and Weaver 1949) a measure of communtiy diversity by estimating the order or complexity in the community	1.49

edsel place upstream

riparian condition

% herbaceous	visually estimated across 40' transects at cross sections	80
% woody	visually estimated across 40' transects at cross sections	15
riparian infiltration (s)	measured according to USDA (2001) procedure	705
dry biomass (g)	leaf material collected, dried, and weighed	0.89
% cover	visually estimated by looking up from channel centerline	0.5

habitat quality

volume woody debris/longitudinal profile (ft^2)	diameter and length of woody debris measured along length of longitudinal profile	0.02
pool frequency ratio	number of pools (1.5x riffle depth) occurring in longitudinal profile	0.0369
specific conductance	reported in mS/cm, YSI model 85 digital meter	na
dissolved oxygen	reported in %, YSI model 85 digital meter	na
inches of rainfall in last 30 days	nearest USGS gaging station determined in ArcGIS and rainfall data summed for 30 days prior to benthos collection	6.05

stream power and sediment transport

friction factor	from Leopold, Wolman, and Miller (1964)	0.8169
water slope (ft/ft)	survey data collected using a builder's level	0.0036
BEHI	estimated using Rosgen 2001 method	42
d90 (mm)	substrate sampled according to modified Wolman pebble count technique Harrelson et al (1994)	4
% sand or finer	substrate sampled according to modified Wolman pebble count technique Harrelson et al (1994)	86
WDR	ratio of bankfull width to bankfull depth	17.8
BHR	ratio of maximum depth at the top of low bank to maximum bankfull depth	2.0

watershed characteristics

drainage area (mi^2)	determined in ArcGIS using USGS 30m DEMs and ArcHydro; visually verified for accuracy	0.6
curve number	determined in ArcGIS using 1999 HAZUS LULC and CGIA county soil surveys layers	70

biological condition

Q statistic	(Kempton and Taylor 1976) as a measure of community diversity; calculated as the slope of the inter-quartile range on the cumulative species curve	3.54
EPT taxa richness	number of Mayflies, Stoneflies, and Caddisflies (water and habitat sensitive) taxa in a sample	3
Simpson's 1/D	(Simpson 1949) a measure of community dominance that accounts for both species richness and proportion	4.13
Shannon's I	(Shannon and Weaver 1949) a measure of communtiy diversity by estimating the order or complexity in the community	1.46

jumping run creek restored

riparian condition		
% herbaceous	visually estimated across 40' transects at cross sections	50
% woody	visually estimated across 40' transects at cross sections	50
riparian infiltration (s)	measured according to USDA (2001) procedure	7200
dry biomass (g)	leaf material collected, dried, and weighed	0.56
% cover	visually estimated by looking up from channel centerline	0.15

habitat quality		
volume woody debris/longitudinal profile (ft^2)	diameter and length of woody debris measured along length of longitudinal profile	0.001
pool frequency ratio	number of pools (1.5x riffle depth) occurring in longitudinal profile	0.0149
specific conductance	reported in mS/cm, YSI model 85 digital meter	na
dissolved oxygen	reported in %, YSI model 85 digital meter	na
inches of rainfall in last 30 days	nearest USGS gaging station determined in ArcGIS and rainfall data summed for 30 days prior to benthos collection	9.22

stream power and sediment transport		
friction factor	from Leopold, Wolman, and Miller (1964)	0.196
water slope (ft/ft)	survey data collected using a builder's level	0.0089
BEHI	estimated using Rosgen 2001 method	12.2
d90 (mm)	substrate sampled according to modified Wolman pebble count technique Harrelson et al (1994)	35
% sand or finer	substrate sampled according to modified Wolman pebble count technique Harrelson et al (1994)	68
WDR	ratio of bankfull width to bankfull depth	16
BHR	ratio of maximum depth at the top of low bank to maximum bankfull depth	2.3

watershed characteristics		
drainage area (mi^2)	determined in ArcGIS using USGS 30m DEMs and ArcHydro; visually verified for accuracy	1.2
curve number	determined in ArcGIS using 1999 HAZUS LULC and CGIA county soil surveys layers	55

biological condition		
Q statistic	(Kempton and Taylor 1976) as a measure of community diversity; calculated as the slope of the inter-quartile range on the cumulative species curve	2.4
EPT taxa richness	number of Mayflies, Stoneflies, and Caddisflies (water and habitat sensitive) taxa in a sample	9
Simpson's 1/D	(Simpson 1949) a measure of community dominance that accounts for both species richness and proportion	6.15
Shannon's I	(Shannon and Weaver 1949) a measure of communtiy diversity by estimating the order or complexity in the community	1.96

jumping run creek upstream

riparian condition

% herbaceous	visually estimated across 40' transects at cross sections	45
% woody	visually estimated across 40' transects at cross sections	45
riparian infiltration (s)	measured according to USDA (2001) procedure	75
dry biomass (g)	leaf material collected, dried, and weighed	0
% cover	visually estimated by looking up from channel centerline	0.45

stream power and sediment transport

friction factor	from Leopold, Wolman, and Miller (1964)	0.1399
water slope (ft/ft)	survey data collected using a builder's level	0.0062
BEHI	estimated using Rosgen 2001 method	32.2
d90 (mm)	substrate sampled according to modified Wolman pebble count technique Harrelson et al (1994)	50
% sand or finer	substrate sampled according to modified Wolman pebble count technique Harrelson et al (1994)	52
WDR	ratio of bankfull width to bankfull depth	10.7
BHR	ratio of maximum depth at the top of low bank to maximum bankfull depth	1.3

habitat quality

volume woody debris/longitudinal profile (ft^2)	diameter and length of woody debris measured along length of longitudinal profile	0.031
pool frequency ratio	number of pools (1.5x riffle depth) occurring in longitudinal profile	0.0265
specific conductance	reported in mS/cm, YSI model 85 digital meter	na
dissolved oxygen	reported in %, YSI model 85 digital meter	na
inches of rainfall in last 30 days	nearest USGS gaging station determined in ArcGIS and rainfall data summed for 30 days prior to benthos collection	9.22

watershed characteristics

drainage area (mi^2)	determined in ArcGIS using USGS 30m DEMs and ArcHydro; visually verified for accuracy	1.2
curve number	determined in ArcGIS using 1999 HAZUS LULC and CGIA county soil surveys layers	55

biological condition

Q statistic	(Kempton and Taylor 1976) as a measure of community diversity; calculated as the slope of the inter-quartile range on the cumulative species curve	5.9
EPT taxa richness	number of Mayflies, Stoneflies, and Caddisflies (water and habitat sensitive) taxa in a sample	10
Simpson's 1/D	(Simpson 1949) a measure of community dominance that accounts for both species richness and proportion	8.56
Shannon's I	(Shannon and Weaver 1949) a measure of communtiy diversity by estimating the order or complexity in the community	2.36

kentwood restored

riparian condition

% herbaceous	visually estimated across 40' transects at cross sections	60
% woody	visually estimated across 40' transects at cross sections	75
riparian infiltration (s)	measured according to USDA (2001) procedure	2200
dry biomass (g)	leaf material collected, dried, and weighed	2
% cover	visually estimated by looking up from channel centerline	0.25

habitat quality

volume woody debris/longitudinal profile (ft^2)	diameter and length of woody debris measured along length of longitudinal profile	0
pool frequency ratio	number of pools (1.5x riffle depth) occurring in longitudinal profile	0.0148
specific conductance	reported in mS/cm, YSI model 85 digital meter	81.1
dissolved oxygen	reported in %, YSI model 85 digital meter	58.2
inches of rainfall in last 30 days	nearest USGS gaging station determined in ArcGIS and rainfall data summed for 30 days prior to benthos collection	2.76

stream power and sediment transport

friction factor	from Leopold, Wolman, and Miller (1964)	0.186
water slope (ft/ft)	survey data collected using a builder's level	0.006
BEHI	estimated using Rosgen 2001 method	11.7
d90 (mm)	substrate sampled according to modified Wolman pebble count technique Harrelson et al (1994)	73
% sand or finer	substrate sampled according to modified Wolman pebble count technique Harrelson et al (1994)	49
WDR	ratio of bankfull width to bankfull depth	13
BHR	ratio of maximum depth at the top of low bank to maximum bankfull depth	1.0

watershed characteristics

drainage area (mi^2)	determined in ArcGIS using USGS 30m DEMs and ArcHydro; visually verified for accuracy	1.2
curve number	determined in ArcGIS using 1999 HAZUS LULC and CGIA county soil surveys layers	83

biological condition

Q statistic	(Kempton and Taylor 1976) as a measure of community diversity; calculated as the slope of the inter-quartile range on the cumulative species curve	1.1
EPT taxa richness	number of Mayflies, Stoneflies, and Caddisflies (water and habitat sensitive) taxa in a sample	4
Simpson's 1/D	(Simpson 1949) a measure of community dominance that accounts for both species richness and proportion	4.24
Shannon's I	(Shannon and Weaver 1949) a measure of communtiy diversity by estimating the order or complexity in the community	1.52

kentwood upstream

riparian condition

% herbaceous	visually estimated across 40' transects at cross sections	50
% woody	visually estimated across 40' transects at cross sections	85
riparian infiltration (s)	measured according to USDA (2001) procedure	68
dry biomass (g)	leaf material collected, dried, and weighed	1.83
% cover	visually estimated by looking up from channel centerline	0.7

stream power and sediment transport

friction factor	from Leopold, Wolman, and Miller (1964)	0.307
water slope (ft/ft)	survey data collected using a builder's level	0.0007
BEHI	estimated using Rosgen 2001 method	32
d90 (mm)	substrate sampled according to modified Wolman pebble count technique Harrelson et al (1994)	100
% sand or finer	substrate sampled according to modified Wolman pebble count technique Harrelson et al (1994)	30
WDR	ratio of bankfull width to bankfull depth	16.4
BHR	ratio of maximum depth at the top of low bank to maximum bankfull depth	1.3

habitat quality

volume woody debris/longitudinal profile (ft^2)	diameter and length of woody debris measured along length of longitudinal profile	0
pool frequency ratio	number of pools (1.5x riffle depth) occurring in longitudinal profile	0.0167
specific conductance	reported in mS/cm, YSI model 85 digital meter	83.9
dissolved oxygen	reported in %, YSI model 85 digital meter	59
inches of rainfall in last 30 days	nearest USGS gaging station determined in ArcGIS and rainfall data summed for 30 days prior to benthos collection	2.76

watershed characteristics

drainage area (mi^2)	determined in ArcGIS using USGS 30m DEMs and ArcHydro; visually verified for accuracy	1.1
curve number	determined in ArcGIS using 1999 HAZUS LULC and CGIA county soil surveys layers	76

biological condition

Q statistic	(Kempton and Taylor 1976) as a measure of community diversity; calculated as the slope of the inter-quartile range on the cumulative species curve	1.23
EPT taxa richness	number of Mayflies, Stoneflies, and Caddisflies (water and habitat sensitive) taxa in a sample	3
Simpson's 1/D	(Simpson 1949) a measure of community dominance that accounts for both species richness and proportion	4.3
Shannon's I	(Shannon and Weaver 1949) a measure of communtiy diversity by estimating the order or complexity in the community	1.55

kraft restored

riparian condition

% herbaceous	visually estimated across 40' transects at cross sections	90
% woody	visually estimated across 40' transects at cross sections	30
riparian infiltration (s)	measured according to USDA (2001) procedure	7200
dry biomass (g)	leaf material collected, dried, and weighed	0
% cover	visually estimated by looking up from channel centerline	0

habitat quality

volume woody debris/longitudinal profile (ft^2)	diameter and length of woody debris measured along length of longitudinal profile	0
pool frequency ratio	number of pools (1.5x riffle depth) occurring in longitudinal profile	0.0151
specific conductance	reported in mS/cm, YSI model 85 digital meter	na
dissolved oxygen	reported in %, YSI model 85 digital meter	na
inches of rainfall in last 30 days	nearest USGS gaging station determined in ArcGIS and rainfall data summed for 30 days prior to benthos collection	9.81

stream power and sediment transport

friction factor	from Leopold, Wolman, and Miller (1964)	0.1197
water slope (ft/ft)	survey data collected using a builder's level	0.0091
BEHI	estimated using Rosgen 2001 method	25.2
d90 (mm)	substrate sampled according to modified Wolman pebble count technique Harrelson et al (1994)	86
% sand or finer	substrate sampled according to modified Wolman pebble count technique Harrelson et al (1994)	46
WDR	ratio of bankfull width to bankfull depth	14.4
BHR	ratio of maximum depth at the top of low bank to maximum bankfull depth	1.7

watershed characteristics

drainage area (mi^2)	determined in ArcGIS using USGS 30m DEMs and ArcHydro; visually verified for accuracy	3.5
curve number	determined in ArcGIS using 1999 HAZUS LULC and CGIA county soil surveys layers	55

biological condition

Q statistic	(Kempton and Taylor 1976) as a measure of community diversity; calculated as the slope of the inter-quartile range on the cumulative species curve	5.28
EPT taxa richness	number of Mayflies, Stoneflies, and Caddisflies (water and habitat sensitive) taxa in a sample	14
Simpson's 1/D	(Simpson 1949) a measure of community dominance that accounts for both species richness and proportion	7.04
Shannon's I	(Shannon and Weaver 1949) a measure of communtiy diversity by estimating the order or complexity in the community	2.25

kraft upstream

riparian condition

% herbaceous	visually estimated across 40' transects at cross sections	95
% woody	visually estimated across 40' transects at cross sections	95
riparian infiltration (s)	measured according to USDA (2001) procedure	600
dry biomass (g)	leaf material collected, dried, and weighed	5.03
% cover	visually estimated by looking up from channel centerline	0.85

habitat quality

volume woody debris/longitudinal profile (ft^2)	diameter and length of woody debris measured along length of longitudinal profile	0.01
pool frequency ratio	number of pools (1.5x riffle depth) occurring in longitudinal profile	0.0265
specific conductance	reported in mS/cm, YSI model 85 digital meter	na
dissolved oxygen	reported in %, YSI model 85 digital meter	na
inches of rainfall in last 30 days	nearest USGS gaging station determined in ArcGIS and rainfall data summed for 30 days prior to benthos collection	9.81

stream power and sediment transport

friction factor	from Leopold, Wolman, and Miller (1964)	0.1054
water slope (ft/ft)	survey data collected using a builder's level	0.0034
BEHI	estimated using Rosgen 2001 method	14.8
d90 (mm)	substrate sampled according to modified Wolman pebble count technique Harrelson et al (1994)	93
% sand or finer	substrate sampled according to modified Wolman pebble count technique Harrelson et al (1994)	52
WDR	ratio of bankfull width to bankfull depth	19.7
BHR	ratio of maximum depth at the top of low bank to maximum bankfull depth	1.8

watershed characteristics

drainage area (mi^2)	determined in ArcGIS using USGS 30m DEMs and ArcHydro; visually verified for accuracy	3.5
curve number	determined in ArcGIS using 1999 HAZUS LULC and CGIA county soil surveys layers	55

biological condition

Q statistic	(Kempton and Taylor 1976) as a measure of community diversity; calculated as the slope of the inter-quartile range on the cumulative species curve	6.49
EPT taxa richness	number of Mayflies, Stoneflies, and Caddisflies (water and habitat sensitive) taxa in a sample	24
Simpson's 1/D	(Simpson 1949) a measure of community dominance that accounts for both species richness and proportion	11.25
Shannon's I	(Shannon and Weaver 1949) a measure of communtiy diversity by estimating the order or complexity in the community	2.65

lindley restored

riparian condition

% herbaceous	visually estimated across 40' transects at cross sections	90
% woody	visually estimated across 40' transects at cross sections	15
riparian infiltration (s)	measured according to USDA (2001) procedure	1
dry biomass (g)	leaf material collected, dried, and weighed	3.95
% cover	visually estimated by looking up from channel centerline	0.15

habitat quality

volume woody debris/longitudinal profile (ft^2)	diameter and length of woody debris measured along length of longitudinal profile	0.003
pool frequency ratio	number of pools (1.5x riffle depth) occurring in longitudinal profile	0.0119
specific conductance	reported in mS/cm, YSI model 85 digital meter	na
dissolved oxygen	reported in %, YSI model 85 digital meter	na
inches of rainfall in last 30 days	nearest USGS gaging station determined in ArcGIS and rainfall data summed for 30 days prior to benthos collection	7.1

stream power and sediment transport

friction factor	from Leopold, Wolman, and Miller (1964)	0.066
water slope (ft/ft)	survey data collected using a builder's level	0.0035
BEHI	estimated using Rosgen 2001 method	11.6
d90 (mm)	substrate sampled according to modified Wolman pebble count technique Harrelson et al (1994)	200
% sand or finer	substrate sampled according to modified Wolman pebble count technique Harrelson et al (1994)	50
WDR	ratio of bankfull width to bankfull depth	11.8
BHR	ratio of maximum depth at the top of low bank to maximum bankfull depth	1.5

watershed characteristics

drainage area (mi^2)	determined in ArcGIS using USGS 30m DEMs and ArcHydro; visually verified for accuracy	2.2
curve number	determined in ArcGIS using 1999 HAZUS LULC and CGIA county soil surveys layers	72

biological condition

Q statistic	(Kempton and Taylor 1976) as a measure of community diversity; calculated as the slope of the inter-quartile range on the cumulative species curve	3.13
EPT taxa richness	number of Mayflies, Stoneflies, and Caddisflies (water and habitat sensitive) taxa in a sample	6
Simpson's 1/D	(Simpson 1949) a measure of community dominance that accounts for both species richness and proportion	4.72
Shannon's I	(Shannon and Weaver 1949) a measure of communtiy diversity by estimating the order or complexity in the community	1.88

lindley upstream

riparian condition

% herbaceous	visually estimated across 40' transects at cross sections	65
% woody	visually estimated across 40' transects at cross sections	75
riparian infiltration (s)	measured according to USDA (2001) procedure	120
dry biomass (g)	leaf material collected, dried, and weighed	3.96
% cover	visually estimated by looking up from channel centerline	0.4

habitat quality

volume woody debris/longitudinal profile (ft^2)	diameter and length of woody debris measured along length of longitudinal profile	0.001
pool frequency ratio	number of pools (1.5x riffle depth) occurring in longitudinal profile	0.0169
specific conductance	reported in mS/cm, YSI model 85 digital meter	na
dissolved oxygen	reported in %, YSI model 85 digital meter	na
inches of rainfall in last 30 days	nearest USGS gaging station determined in ArcGIS and rainfall data summed for 30 days prior to benthos collection	7.1

stream power and sediment transport

friction factor	from Leopold, Wolman, and Miller (1964)	0.031
water slope (ft/ft)	survey data collected using a builder's level	0.0012
BEHI	estimated using Rosgen 2001 method	11
d90 (mm)	substrate sampled according to modified Wolman pebble count technique Harrelson et al (1994)	512
% sand or finer	substrate sampled according to modified Wolman pebble count technique Harrelson et al (1994)	24
WDR	ratio of bankfull width to bankfull depth	20.4
BHR	ratio of maximum depth at the top of low bank to maximum bankfull depth	2.0

watershed characteristics

drainage area (mi^2)	determined in ArcGIS using USGS 30m DEMs and ArcHydro; visually verified for accuracy	2.2
curve number	determined in ArcGIS using 1999 HAZUS LULC and CGIA county soil surveys layers	72

biological condition

Q statistic	(Kempton and Taylor 1976) as a measure of community diversity; calculated as the slope of the inter-quartile range on the cumulative species curve	1.36
EPT taxa richness	number of Mayflies, Stoneflies, and Caddisflies (water and habitat sensitive) taxa in a sample	4
Simpson's 1/D	(Simpson 1949) a measure of community dominance that accounts for both species richness and proportion	3.25
Shannon's I	(Shannon and Weaver 1949) a measure of communtiy diversity by estimating the order or complexity in the community	1.37

little bugaboo restored

riparian condition

% herbaceous	visually estimated across 40' transects at cross sections	45
% woody	visually estimated across 40' transects at cross sections	100
riparian infiltration (s)	measured according to USDA (2001) procedure	36
dry biomass (g)	leaf material collected, dried, and weighed	0.36
% cover	visually estimated by looking up from channel centerline	0.2

habitat quality

volume woody debris/longitudinal profile (ft^2)	diameter and length of woody debris measured along length of longitudinal profile	0
pool frequency ratio	number of pools (1.5x riffle depth) occurring in longitudinal profile	0.012
specific conductance	reported in mS/cm, YSI model 85 digital meter	16.8
dissolved oxygen	reported in %, YSI model 85 digital meter	108
inches of rainfall in last 30 days	nearest USGS gaging station determined in ArcGIS and rainfall data summed for 30 days prior to benthos collection	7.98

stream power and sediment transport

friction factor	from Leopold, Wolman, and Miller (1964)	0.279
water slope (ft/ft)	survey data collected using a builder's level	0.0089
BEHI	estimated using Rosgen 2001 method	5.2
d90 (mm)	substrate sampled according to modified Wolman pebble count technique Harrelson et al (1994)	50
% sand or finer	substrate sampled according to modified Wolman pebble count technique Harrelson et al (1994)	48
WDR	ratio of bankfull width to bankfull depth	6.1
BHR	ratio of maximum depth at the top of low bank to maximum bankfull depth	1.0

watershed characteristics

drainage area (mi^2)	determined in ArcGIS using USGS 30m DEMs and ArcHydro; visually verified for accuracy	1
curve number	determined in ArcGIS using 1999 HAZUS LULC and CGIA county soil surveys layers	60

biological condition

Q statistic	(Kempton and Taylor 1976) as a measure of community diversity; calculated as the slope of the inter-quartile range on the cumulative species curve	5.77
EPT taxa richness	number of Mayflies, Stoneflies, and Caddisflies (water and habitat sensitive) taxa in a sample	26
Simpson's 1/D	(Simpson 1949) a measure of community dominance that accounts for both species richness and proportion	8.5
Shannon's I	(Shannon and Weaver 1949) a measure of communtiy diversity by estimating the order or complexity in the community	2.42

little bugaboo upstream

riparian condition

% herbaceous	visually estimated across 40' transects at cross sections	85
% woody	visually estimated across 40' transects at cross sections	50
riparian infiltration (s)	measured according to USDA (2001) procedure	156
dry biomass (g)	leaf material collected, dried, and weighed	3.9
% cover	visually estimated by looking up from channel centerline	0.8

stream power and sediment transport

friction factor	from Leopold, Wolman, and Miller (1964)	0.308
water slope (ft/ft)	survey data collected using a builder's level	0.001
BEHI	estimated using Rosgen 2001 method	22
d90 (mm)	substrate sampled according to modified Wolman pebble count technique Harrelson et al (1994)	40
% sand or finer	substrate sampled according to modified Wolman pebble count technique Harrelson et al (1994)	56
WDR	ratio of bankfull width to bankfull depth	14.7
BHR	ratio of maximum depth at the top of low bank to maximum bankfull depth	1.4

habitat quality

volume woody debris/longitudinal profile (ft^2)	diameter and length of woody debris measured along length of longitudinal profile	0.0055
pool frequency ratio	number of pools (1.5x riffle depth) occurring in longitudinal profile	0.015
specific conductance	reported in mS/cm, YSI model 85 digital meter	23.3
dissolved oxygen	reported in %, YSI model 85 digital meter	98.1
inches of rainfall in last 30 days	nearest USGS gaging station determined in ArcGIS and rainfall data summed for 30 days prior to benthos collection	7.98

watershed characteristics

drainage area (mi^2)	determined in ArcGIS using USGS 30m DEMs and ArcHydro; visually verified for accuracy	1
curve number	determined in ArcGIS using 1999 HAZUS LULC and CGIA county soil surveys layers	60

biological condition

Q statistic	(Kempton and Taylor 1976) as a measure of community diversity; calculated as the slope of the inter-quartile range on the cumulative species curve	5.86
EPT taxa richness	number of Mayflies, Stoneflies, and Caddisflies (water and habitat sensitive) taxa in a sample	17
Simpson's 1/D	(Simpson 1949) a measure of community dominance that accounts for both species richness and proportion	5.61
Shannon's I	(Shannon and Weaver 1949) a measure of communtiy diversity by estimating the order or complexity in the community	2.27

little pine restored

riparian condition

% herbaceous	visually estimated across 40' transects at cross sections	100
% woody	visually estimated across 40' transects at cross sections	10
riparian infiltration (s)	measured according to USDA (2001) procedure	115
dry biomass (g)	leaf material collected, dried, and weighed	1.1
% cover	visually estimated by looking up from channel centerline	10

habitat quality

volume woody debris/longitudinal profile (ft^2)	diameter and length of woody debris measured along length of longitudinal profile	0
pool frequency ratio	number of pools (1.5x riffle depth) occurring in longitudinal profile	0.0053
specific conductance	reported in mS/cm, YSI model 85 digital meter	22.8
dissolved oxygen	reported in %, YSI model 85 digital meter	100.4
inches of rainfall in last 30 days	nearest USGS gaging station determined in ArcGIS and rainfall data summed for 30 days prior to benthos collection	6.06

stream power and sediment transport

friction factor	from Leopold, Wolman, and Miller (1964)	0.267
water slope (ft/ft)	survey data collected using a builder's level	0.0053
BEHI	estimated using Rosgen 2001 method	13.7
d90 (mm)	substrate sampled according to modified Wolman pebble count technique Harrelson et al (1994)	60
% sand or finer	substrate sampled according to modified Wolman pebble count technique Harrelson et al (1994)	50
WDR	ratio of bankfull width to bankfull depth	8
BHR	ratio of maximum depth at the top of low bank to maximum bankfull depth	1.5

watershed characteristics

drainage area (mi^2)	determined in ArcGIS using USGS 30m DEMs and ArcHydro; visually verified for accuracy	3.2
curve number	determined in ArcGIS using 1999 HAZUS LULC and CGIA county soil surveys layers	60

biological condition

Q statistic	(Kempton and Taylor 1976) as a measure of community diversity; calculated as the slope of the inter-quartile range on the cumulative species curve	4.6
EPT taxa richness	number of Mayflies, Stoneflies, and Caddisflies (water and habitat sensitive) taxa in a sample	29
Simpson's 1/D	(Simpson 1949) a measure of community dominance that accounts for both species richness and proportion	6.97
Shannon's I	(Shannon and Weaver 1949) a measure of communtiy diversity by estimating the order or complexity in the community	2.29

little pine upstream

riparian condition

% herbaceous	visually estimated across 40' transects at cross sections	100
% woody	visually estimated across 40' transects at cross sections	5
riparian infiltration (s)	measured according to USDA (2001) procedure	70
dry biomass (g)	leaf material collected, dried, and weighed	1.46
% cover	visually estimated by looking up from channel centerline	0.15

habitat quality

volume woody debris/longitudinal profile (ft^2)	diameter and length of woody debris measured along length of longitudinal profile	0.01
pool frequency ratio	number of pools (1.5x riffle depth) occurring in longitudinal profile	0.0107
specific conductance	reported in mS/cm, YSI model 85 digital meter	33.5
dissolved oxygen	reported in %, YSI model 85 digital meter	71.9
inches of rainfall in last 30 days	nearest USGS gaging station determined in ArcGIS and rainfall data summed for 30 days prior to benthos collection	6.06

stream power and sediment transport

friction factor	from Leopold, Wolman, and Miller (1964)	0.26
water slope (ft/ft)	survey data collected using a builder's level	0.0054
BEHI	estimated using Rosgen 2001 method	11
d90 (mm)	substrate sampled according to modified Wolman pebble count technique Harrelson et al (1994)	42
% sand or finer	substrate sampled according to modified Wolman pebble count technique Harrelson et al (1994)	54
WDR	ratio of bankfull width to bankfull depth	12.6
BHR	ratio of maximum depth at the top of low bank to maximum bankfull depth	1.4

watershed characteristics

drainage area (mi^2)	determined in ArcGIS using USGS 30m DEMs and ArcHydro; visually verified for accuracy	3.2
curve number	determined in ArcGIS using 1999 HAZUS LULC and CGIA county soil surveys layers	60

biological condition

Q statistic	(Kempton and Taylor 1976) as a measure of community diversity; calculated as the slope of the inter-quartile range on the cumulative species curve	6.24
EPT taxa richness	number of Mayflies, Stoneflies, and Caddisflies (water and habitat sensitive) taxa in a sample	25
Simpson's 1/D	(Simpson 1949) a measure of community dominance that accounts for both species richness and proportion	7.75
Shannon's I	(Shannon and Weaver 1949) a measure of communtiy diversity by estimating the order or complexity in the community	2.38

little warrior restored

riparian condition

% herbaceous	visually estimated across 40' transects at cross sections	90
% woody	visually estimated across 40' transects at cross sections	0
riparian infiltration (s)	measured according to USDA (2001) procedure	7200
dry biomass (g)	leaf material collected, dried, and weighed	0.78
% cover	visually estimated by looking up from channel centerline	0

stream power and sediment transport

friction factor	from Leopold, Wolman, and Miller (1964)	0.111
water slope (ft/ft)	survey data collected using a builder's level	0.0056
BEHI	estimated using Rosgen 2001 method	19.9
d90 (mm)	substrate sampled according to modified Wolman pebble count technique Harrelson et al (1994)	46
% sand or finer	substrate sampled according to modified Wolman pebble count technique Harrelson et al (1994)	54
WDR	ratio of bankfull width to bankfull depth	4.9
BHR	ratio of maximum depth at the top of low bank to maximum bankfull depth	1.3

habitat quality

volume woody debris/longitudinal profile (ft^2)	diameter and length of woody debris measured along length of longitudinal profile	0
pool frequency ratio	number of pools (1.5x riffle depth) occurring in longitudinal profile	0.0101
specific conductance	reported in mS/cm, YSI model 85 digital meter	na
dissolved oxygen	reported in %, YSI model 85 digital meter	na
inches of rainfall in last 30 days	nearest USGS gaging station determined in ArcGIS and rainfall data summed for 30 days prior to benthos collection	7.2

watershed characteristics

drainage area (mi^2)	determined in ArcGIS using USGS 30m DEMs and ArcHydro; visually verified for accuracy	0.9
curve number	determined in ArcGIS using 1999 HAZUS LULC and CGIA county soil surveys layers	56

biological condition

Q statistic	(Kempton and Taylor 1976) as a measure of community diversity; calculated as the slope of the inter-quartile range on the cumulative species curve	2.96
EPT taxa richness	number of Mayflies, Stoneflies, and Caddisflies (water and habitat sensitive) taxa in a sample	11
Simpson's 1/D	(Simpson 1949) a measure of community dominance that accounts for both species richness and proportion	5.68
Shannon's I	(Shannon and Weaver 1949) a measure of communtiy diversity by estimating the order or complexity in the community	1.97

little warrior upstream

riparian condition

% herbaceous	visually estimated across 40' transects at cross sections	15
% woody	visually estimated across 40' transects at cross sections	40
riparian infiltration (s)	measured according to USDA (2001) procedure	21
dry biomass (g)	leaf material collected, dried, and weighed	12.9
% cover	visually estimated by looking up from channel centerline	0.4

habitat quality

volume woody debris/longitudinal profile (ft^2)	diameter and length of woody debris measured along length of longitudinal profile	0.03
pool frequency ratio	number of pools (1.5x riffle depth) occurring in longitudinal profile	0.0391
specific conductance	reported in mS/cm, YSI model 85 digital meter	na
dissolved oxygen	reported in %, YSI model 85 digital meter	na
inches of rainfall in last 30 days	nearest USGS gaging station determined in ArcGIS and rainfall data summed for 30 days prior to benthos collection	7.2

stream power and sediment transport

friction factor	from Leopold, Wolman, and Miller (1964)	0.086
water slope (ft/ft)	survey data collected using a builder's level	0.014
BEHI	estimated using Rosgen 2001 method	30.3
d90 (mm)	substrate sampled according to modified Wolman pebble count technique Harrelson et al (1994)	46
% sand or finer	substrate sampled according to modified Wolman pebble count technique Harrelson et al (1994)	52
WDR	ratio of bankfull width to bankfull depth	11.5
BHR	ratio of maximum depth at the top of low bank to maximum bankfull depth	1.4

watershed characteristics

drainage area (mi^2)	determined in ArcGIS using USGS 30m DEMs and ArcHydro; visually verified for accuracy	0.26
curve number	determined in ArcGIS using 1999 HAZUS LULC and CGIA county soil surveys layers	55

biological condition

Q statistic	(Kempton and Taylor 1976) as a measure of community diversity; calculated as the slope of the inter-quartile range on the cumulative species curve	5
EPT taxa richness	number of Mayflies, Stoneflies, and Caddisflies (water and habitat sensitive) taxa in a sample	6
Simpson's 1/D	(Simpson 1949) a measure of community dominance that accounts for both species richness and proportion	2.41
Shannon's I	(Shannon and Weaver 1949) a measure of communtiy diversity by estimating the order or complexity in the community	1.24

lyle creek restored

riparian condition

% herbaceous	visually estimated across 40' transects at cross sections	90
% woody	visually estimated across 40' transects at cross sections	60
riparian infiltration (s)	measured according to USDA (2001) procedure	7200
dry biomass (g)	leaf material collected, dried, and weighed	4.04
% cover	visually estimated by looking up from channel centerline	0.6

habitat quality

volume woody debris/longitudinal profile (ft^2)	diameter and length of woody debris measured along length of longitudinal profile	0
pool frequency ratio	number of pools (1.5x riffle depth) occurring in longitudinal profile	0.0081
specific conductance	reported in mS/cm, YSI model 85 digital meter	na
dissolved oxygen	reported in %, YSI model 85 digital meter	na
inches of rainfall in last 30 days	nearest USGS gaging station determined in ArcGIS and rainfall data summed for 30 days prior to benthos collection	5.4

stream power and sediment transport

friction factor	from Leopold, Wolman, and Miller (1964)	0.225
water slope (ft/ft)	survey data collected using a builder's level	0.0074
BEHI	estimated using Rosgen 2001 method	35
d90 (mm)	substrate sampled according to modified Wolman pebble count technique Harrelson et al (1994)	43
% sand or finer	substrate sampled according to modified Wolman pebble count technique Harrelson et al (1994)	56
WDR	ratio of bankfull width to bankfull depth	21.1
BHR	ratio of maximum depth at the top of low bank to maximum bankfull depth	2.4

watershed characteristics

drainage area (mi^2)	determined in ArcGIS using USGS 30m DEMs and ArcHydro; visually verified for accuracy	0.3
curve number	determined in ArcGIS using 1999 HAZUS LULC and CGIA county soil surveys layers	55

biological condition

Q statistic	(Kempton and Taylor 1976) as a measure of community diversity; calculated as the slope of the inter-quartile range on the cumulative species curve	5.9
EPT taxa richness	number of Mayflies, Stoneflies, and Caddisflies (water and habitat sensitive) taxa in a sample	8
Simpson's 1/D	(Simpson 1949) a measure of community dominance that accounts for both species richness and proportion	6.41
Shannon's I	(Shannon and Weaver 1949) a measure of communtiy diversity by estimating the order or complexity in the community	2.15

lyle creek upstream

riparian condition

% herbaceous	visually estimated across 40' transects at cross sections	95
% woody	visually estimated across 40' transects at cross sections	95
riparian infiltration (s)	measured according to USDA (2001) procedure	10
dry biomass (g)	leaf material collected, dried, and weighed	4.47
% cover	visually estimated by looking up from channel centerline	0.85

habitat quality

volume woody debris/longitudinal profile (ft^2)	diameter and length of woody debris measured along length of longitudinal profile	0.104
pool frequency ratio	number of pools (1.5x riffle depth) occurring in longitudinal profile	0.0141
specific conductance	reported in mS/cm, YSI model 85 digital meter	na
dissolved oxygen	reported in %, YSI model 85 digital meter	na
inches of rainfall in last 30 days	nearest USGS gaging station determined in ArcGIS and rainfall data summed for 30 days prior to benthos collection	5.4

stream power and sediment transport

friction factor	from Leopold, Wolman, and Miller (1964)	0.053
water slope (ft/ft)	survey data collected using a builder's level	0.0093
BEHI	estimated using Rosgen 2001 method	15.2
d90 (mm)	substrate sampled according to modified Wolman pebble count technique Harrelson et al (1994)	128
% sand or finer	substrate sampled according to modified Wolman pebble count technique Harrelson et al (1994)	46
WDR	ratio of bankfull width to bankfull depth	6.7
BHR	ratio of maximum depth at the top of low bank to maximum bankfull depth	1.6

watershed characteristics

drainage area (mi^2)	determined in ArcGIS using USGS 30m DEMs and ArcHydro; visually verified for accuracy	0.12
curve number	determined in ArcGIS using 1999 HAZUS LULC and CGIA county soil surveys layers	55

biological condition

Q statistic	(Kempton and Taylor 1976) as a measure of community diversity; calculated as the slope of the inter-quartile range on the cumulative species curve	6.52
EPT taxa richness	number of Mayflies, Stoneflies, and Caddisflies (water and habitat sensitive) taxa in a sample	12
Simpson's 1/D	(Simpson 1949) a measure of community dominance that accounts for both species richness and proportion	9
Shannon's I	(Shannon and Weaver 1949) a measure of communtiy diversity by estimating the order or complexity in the community	2.55

pott creek restored

riparian condition

% herbaceous	visually estimated across 40' transects at cross sections	60
% woody	visually estimated across 40' transects at cross sections	2
riparian infiltration (s)	measured according to USDA (2001) procedure	7200
dry biomass (g)	leaf material collected, dried, and weighed	0
% cover	visually estimated by looking up from channel centerline	0.02

habitat quality

volume woody debris/longitudinal profile (ft^2)	diameter and length of woody debris measured along length of longitudinal profile	0
pool frequency ratio	number of pools (1.5x riffle depth) occurring in longitudinal profile	0.0033
specific conductance	reported in mS/cm, YSI model 85 digital meter	na
dissolved oxygen	reported in %, YSI model 85 digital meter	na
inches of rainfall in last 30 days	nearest USGS gaging station determined in ArcGIS and rainfall data summed for 30 days prior to benthos collection	5.9

stream power and sediment transport

friction factor	from Leopold, Wolman, and Miller (1964)	0.227
water slope (ft/ft)	survey data collected using a builder's level	0.0006
BEHI	estimated using Rosgen 2001 method	38.3
d90 (mm)	substrate sampled according to modified Wolman pebble count technique Harrelson et al (1994)	0.03
% sand or finer	substrate sampled according to modified Wolman pebble count technique Harrelson et al (1994)	98
WDR	ratio of bankfull width to bankfull depth	19.9
BHR	ratio of maximum depth at the top of low bank to maximum bankfull depth	1.2

watershed characteristics

drainage area (mi^2)	determined in ArcGIS using USGS 30m DEMs and ArcHydro; visually verified for accuracy	0.6
curve number	determined in ArcGIS using 1999 HAZUS LULC and CGIA county soil surveys layers	56

biological condition

Q statistic	(Kempton and Taylor 1976) as a measure of community diversity; calculated as the slope of the inter-quartile range on the cumulative species curve	2.97
EPT taxa richness	number of Mayflies, Stoneflies, and Caddisflies (water and habitat sensitive) taxa in a sample	6
Simpson's 1/D	(Simpson 1949) a measure of community dominance that accounts for both species richness and proportion	7.56
Shannon's I	(Shannon and Weaver 1949) a measure of communtiy diversity by estimating the order or complexity in the community	2

pott creek upstream

riparian condition

% herbaceous	visually estimated across 40' transects at cross sections	90
% woody	visually estimated across 40' transects at cross sections	10
riparian infiltration (s)	measured according to USDA (2001) procedure	7200
dry biomass (g)	leaf material collected, dried, and weighed	0
% cover	visually estimated by looking up from channel centerline	0.1

habitat quality

volume woody debris/longitudinal profile (ft^2)	diameter and length of woody debris measured along length of longitudinal profile	0.002
pool frequency ratio	number of pools (1.5x riffle depth) occurring in longitudinal profile	0.0042
specific conductance	reported in mS/cm, YSI model 85 digital meter	na
dissolved oxygen	reported in %, YSI model 85 digital meter	na
inches of rainfall in last 30 days	nearest USGS gaging station determined in ArcGIS and rainfall data summed for 30 days prior to benthos collection	5.9

stream power and sediment transport

friction factor	from Leopold, Wolman, and Miller (1964)	0.123
water slope (ft/ft)	survey data collected using a builder's level	0.0015
BEHI	estimated using Rosgen 2001 method	13.5
d90 (mm)	substrate sampled according to modified Wolman pebble count technique Harrelson et al (1994)	0.12
% sand or finer	substrate sampled according to modified Wolman pebble count technique Harrelson et al (1994)	96
WDR	ratio of bankfull width to bankfull depth	8.0
BHR	ratio of maximum depth at the top of low bank to maximum bankfull depth	1.9

watershed characteristics

drainage area (mi^2)	determined in ArcGIS using USGS 30m DEMs and ArcHydro; visually verified for accuracy	0.6
curve number	determined in ArcGIS using 1999 HAZUS LULC and CGIA county soil surveys layers	56

biological condition

Q statistic	(Kempton and Taylor 1976) as a measure of community diversity; calculated as the slope of the inter-quartile range on the cumulative species curve	3.27
EPT taxa richness	number of Mayflies, Stoneflies, and Caddisflies (water and habitat sensitive) taxa in a sample	0
Simpson's 1/D	(Simpson 1949) a measure of community dominance that accounts for both species richness and proportion	6.31
Shannon's I	(Shannon and Weaver 1949) a measure of communtiy diversity by estimating the order or complexity in the community	2.01

price park restored

riparian condition		
% herbaceous	visually estimated across 40' transects at cross sections	50
% woody	visually estimated across 40' transects at cross sections	50
riparian infiltration (s)	measured according to USDA (2001) procedure	7200
dry biomass (g)	leaf material collected, dried, and weighed	3.86
% cover	visually estimated by looking up from channel centerline	0.4

habitat quality		
volume woody debris/longitudinal profile (ft^2)	diameter and length of woody debris measured along length of longitudinal profile	0
pool frequency ratio	number of pools (1.5x riffle depth) occurring in longitudinal profile	0.0029
specific conductance	reported in mS/cm, YSI model 85 digital meter	na
dissolved oxygen	reported in %, YSI model 85 digital meter	na
inches of rainfall in last 30 days	nearest USGS gaging station determined in ArcGIS and rainfall data summed for 30 days prior to benthos collection	5.4

stream power and sediment transport		
friction factor	from Leopold, Wolman, and Miller (1964)	0.2
water slope (ft/ft)	survey data collected using a builder's level	0.0071
BEHI	estimated using Rosgen 2001 method	22.2
d90 (mm)	substrate sampled according to modified Wolman pebble count technique Harrelson et al (1994)	28
% sand or finer	substrate sampled according to modified Wolman pebble count technique Harrelson et al (1994)	32
WDR	ratio of bankfull width to bankfull depth	9.0
BHR	ratio of maximum depth at the top of low bank to maximum bankfull depth	1.7

watershed characteristics		
drainage area (mi^2)	determined in ArcGIS using USGS 30m DEMs and ArcHydro; visually verified for accuracy	1
curve number	determined in ArcGIS using 1999 HAZUS LULC and CGIA county soil surveys layers	67

biological condition		
Q statistic	(Kempton and Taylor 1976) as a measure of community diversity; calculated as the slope of the inter-quartile range on the cumulative species curve	1.05
EPT taxa richness	number of Mayflies, Stoneflies, and Caddisflies (water and habitat sensitive) taxa in a sample	4
Simpson's 1/D	(Simpson 1949) a measure of community dominance that accounts for both species richness and proportion	4.5
Shannon's I	(Shannon and Weaver 1949) a measure of communtiy diversity by estimating the order or complexity in the community	1.58

price park upstream

riparian condition

% herbaceous	visually estimated across 40' transects at cross sections	40
% woody	visually estimated across 40' transects at cross sections	90
riparian infiltration (s)	measured according to USDA (2001) procedure	7200
dry biomass (g)	leaf material collected, dried, and weighed	2.39
% cover	visually estimated by looking up from channel centerline	0.5

habitat quality

volume woody debris/longitudinal profile (ft^2)	diameter and length of woody debris measured along length of longitudinal profile	0.079
pool frequency ratio	number of pools (1.5x riffle depth) occurring in longitudinal profile	0.0451
specific conductance	reported in mS/cm, YSI model 85 digital meter	na
dissolved oxygen	reported in %, YSI model 85 digital meter	na
inches of rainfall in last 30 days	nearest USGS gaging station determined in ArcGIS and rainfall data summed for 30 days prior to benthos collection	5.4

stream power and sediment transport

friction factor	from Leopold, Wolman, and Miller (1964)	0.056
water slope (ft/ft)	survey data collected using a builder's level	0.0033
BEHI	estimated using Rosgen 2001 method	27.3
d90 (mm)	substrate sampled according to modified Wolman pebble count technique Harrelson et al (1994)	15
% sand or finer	substrate sampled according to modified Wolman pebble count technique Harrelson et al (1994)	62
WDR	ratio of bankfull width to bankfull depth	7.7
BHR	ratio of maximum depth at the top of low bank to maximum bankfull depth	1.9

watershed characteristics

drainage area (mi^2)	determined in ArcGIS using USGS 30m DEMs and ArcHydro; visually verified for accuracy	1
curve number	determined in ArcGIS using 1999 HAZUS LULC and CGIA county soil surveys layers	67

biological condition

Q statistic	(Kempton and Taylor 1976) as a measure of community diversity; calculated as the slope of the inter-quartile range on the cumulative species curve	0.91
EPT taxa richness	number of Mayflies, Stoneflies, and Caddisflies (water and habitat sensitive) taxa in a sample	1
Simpson's 1/D	(Simpson 1949) a measure of community dominance that accounts for both species richness and proportion	2.42
Shannon's I	(Shannon and Weaver 1949) a measure of communtiy diversity by estimating the order or complexity in the community	1.04

purlear restored

riparian condition		
% herbaceous	visually estimated across 40' transects at cross sections	100
% woody	visually estimated across 40' transects at cross sections	10
riparian infiltration (s)	measured according to USDA (2001) procedure	2200
dry biomass (g)	leaf material collected, dried, and weighed	0
% cover	visually estimated by looking up from channel centerline	0
stream power and sediment transport		
friction factor	from Leopold, Wolman, and Miller (1964)	1.16
water slope (ft/ft)	survey data collected using a builder's level	0.0099
BEHI	estimated using Rosgen 2001 method	7
d90 (mm)	substrate sampled according to modified Wolman pebble count technique Harrelson et al (1994)	30
% sand or finer	substrate sampled according to modified Wolman pebble count technique Harrelson et al (1994)	43
WDR	ratio of bankfull width to bankfull depth	15.8
BHR	ratio of maximum depth at the top of low bank to maximum bankfull depth	1.2

habitat quality		
volume woody debris/longitudinal profile (ft^2)	diameter and length of woody debris measured along length of longitudinal profile	0.0018
pool frequency ratio	number of pools (1.5x riffle depth) occurring in longitudinal profile	0.0119
specific conductance	reported in mS/cm, YSI model 85 digital meter	34.4
dissolved oxygen	reported in %, YSI model 85 digital meter	88.1
inches of rainfall in last 30 days	nearest USGS gaging station determined in ArcGIS and rainfall data summed for 30 days prior to benthos collection	2.2
watershed characteristics		
drainage area (mi^2)	determined in ArcGIS using USGS 30m DEMs and ArcHydro; visually verified for accuracy	1.2
curve number	determined in ArcGIS using 1999 HAZUS LULC and CGIA county soil surveys layers	60
biological condition		
Q statistic	(Kempton and Taylor 1976) as a measure of community diversity; calculated as the slope of the inter-quartile range on the cumulative species curve	5.77
EPT taxa richness	number of Mayflies, Stoneflies, and Caddisflies (water and habitat sensitive) taxa in a sample	17
Simpson's 1/D	(Simpson 1949) a measure of community dominance that accounts for both species richness and proportion	5.81
Shannon's I	(Shannon and Weaver 1949) a measure of communtiy diversity by estimating the order or complexity in the community	2.1

purlear upstream

riparian condition		
% herbaceous	visually estimated across 40' transects at cross sections	100
% woody	visually estimated across 40' transects at cross sections	50
riparian infiltration (s)	measured according to USDA (2001) procedure	121
dry biomass (g)	leaf material collected, dried, and weighed	2.33
% cover	visually estimated by looking up from channel centerline	0.8

habitat quality		
volume woody debris/longitudinal profile (ft^2)	diameter and length of woody debris measured along length of longitudinal profile	0.0023
pool frequency ratio	number of pools (1.5x riffle depth) occurring in longitudinal profile	0.0138
specific conductance	reported in mS/cm, YSI model 85 digital meter	30.7
dissolved oxygen	reported in %, YSI model 85 digital meter	87.1
inches of rainfall in last 30 days	nearest USGS gaging station determined in ArcGIS and rainfall data summed for 30 days prior to benthos collection	2.2

stream power and sediment transport		
friction factor	from Leopold, Wolman, and Miller (1964)	0.082
water slope (ft/ft)	survey data collected using a builder's level	0.0198
BEHI	estimated using Rosgen 2001 method	9
d90 (mm)	substrate sampled according to modified Wolman pebble count technique Harrelson et al (1994)	98
% sand or finer	substrate sampled according to modified Wolman pebble count technique Harrelson et al (1994)	51
WDR	ratio of bankfull width to bankfull depth	17.2
BHR	ratio of maximum depth at the top of low bank to maximum bankfull depth	1.4

watershed characteristics		
drainage area (mi^2)	determined in ArcGIS using USGS 30m DEMs and ArcHydro; visually verified for accuracy	1.2
curve number	determined in ArcGIS using 1999 HAZUS LULC and CGIA county soil surveys layers	60

biological condition		
Q statistic	(Kempton and Taylor 1976) as a measure of community diversity; calculated as the slope of the inter-quartile range on the cumulative species curve	6.95
EPT taxa richness	number of Mayflies, Stoneflies, and Caddisflies (water and habitat sensitive) taxa in a sample	33
Simpson's 1/D	(Simpson 1949) a measure of community dominance that accounts for both species richness and proportion	13.68
Shannon's I	(Shannon and Weaver 1949) a measure of communtiy diversity by estimating the order or complexity in the community	2.86

sedgefield restored

riparian condition

% herbaceous	visually estimated across 40' transects at cross sections	95
% woody	visually estimated across 40' transects at cross sections	0
riparian infiltration (s)	measured according to USDA (2001) procedure	7200
dry biomass (g)	leaf material collected, dried, and weighed	1.24
% cover	visually estimated by looking up from channel centerline	0

habitat quality

volume woody debris/longitudinal profile (ft^2)	diameter and length of woody debris measured along length of longitudinal profile	0.003
pool frequency ratio	number of pools (1.5x riffle depth) occurring in longitudinal profile	0.0135
specific conductance	reported in mS/cm, YSI model 85 digital meter	na
dissolved oxygen	reported in %, YSI model 85 digital meter	na
inches of rainfall in last 30 days	nearest USGS gaging station determined in ArcGIS and rainfall data summed for 30 days prior to benthos collection	4.42

stream power and sediment transport

friction factor	from Leopold, Wolman, and Miller (1964)	0.161
water slope (ft/ft)	survey data collected using a builder's level	0.0091
BEHI	estimated using Rosgen 2001 method	26.2
d90 (mm)	substrate sampled according to modified Wolman pebble count technique Harrelson et al (1994)	23
% sand or finer	substrate sampled according to modified Wolman pebble count technique Harrelson et al (1994)	66
WDR	ratio of bankfull width to bankfull depth	10.6
BHR	ratio of maximum depth at the top of low bank to maximum bankfull depth	2.1

watershed characteristics

drainage area (mi^2)	determined in ArcGIS using USGS 30m DEMs and ArcHydro; visually verified for accuracy	0.3
curve number	determined in ArcGIS using 1999 HAZUS LULC and CGIA county soil surveys layers	77

biological condition

Q statistic	(Kempton and Taylor 1976) as a measure of community diversity; calculated as the slope of the inter-quartile range on the cumulative species curve	1.28
EPT taxa richness	number of Mayflies, Stoneflies, and Caddisflies (water and habitat sensitive) taxa in a sample	5
Simpson's 1/D	(Simpson 1949) a measure of community dominance that accounts for both species richness and proportion	3.88
Shannon's I	(Shannon and Weaver 1949) a measure of communtiy diversity by estimating the order or complexity in the community	1.47

sedgefield upstream

riparian condition

% herbaceous	visually estimated across 40' transects at cross sections	90
% woody	visually estimated across 40' transects at cross sections	10
riparian infiltration (s)	measured according to USDA (2001) procedure	3060
dry biomass (g)	leaf material collected, dried, and weighed	1.88
% cover	visually estimated by looking up from channel centerline	0.1

habitat quality

volume woody debris/longitudinal profile (ft^2)	diameter and length of woody debris measured along length of longitudinal profile	0
pool frequency ratio	number of pools (1.5x riffle depth) occurring in longitudinal profile	0.0171
specific conductance	reported in mS/cm, YSI model 85 digital meter	na
dissolved oxygen	reported in %, YSI model 85 digital meter	na
inches of rainfall in last 30 days	nearest USGS gaging station determined in ArcGIS and rainfall data summed for 30 days prior to benthos collection	4.4

stream power and sediment transport

friction factor	from Leopold, Wolman, and Miller (1964)	0.097
water slope (ft/ft)	survey data collected using a builder's level	0.0035
BEHI	estimated using Rosgen 2001 method	23.5
d90 (mm)	substrate sampled according to modified Wolman pebble count technique Harrelson et al (1994)	30
% sand or finer	substrate sampled according to modified Wolman pebble count technique Harrelson et al (1994)	60
WDR	ratio of bankfull width to bankfull depth	8.5
BHR	ratio of maximum depth at the top of low bank to maximum bankfull depth	1.9

watershed characteristics

drainage area (mi^2)	determined in ArcGIS using USGS 30m DEMs and ArcHydro; visually verified for accuracy	0.2
curve number	determined in ArcGIS using 1999 HAZUS LULC and CGIA county soil surveys layers	79

biological condition

Q statistic	(Kempton and Taylor 1976) as a measure of community diversity; calculated as the slope of the inter-quartile range on the cumulative species curve	0.91
EPT taxa richness	number of Mayflies, Stoneflies, and Caddisflies (water and habitat sensitive) taxa in a sample	1
Simpson's 1/D	(Simpson 1949) a measure of community dominance that accounts for both species richness and proportion	2.23
Shannon's I	(Shannon and Weaver 1949) a measure of communtiy diversity by estimating the order or complexity in the community	1.13

spring valley restored

riparian condition

% herbaceous	visually estimated across 40' transects at cross sections	10
% woody	visually estimated across 40' transects at cross sections	25
riparian infiltration (s)	measured according to USDA (2001) procedure	34
dry biomass (g)	leaf material collected, dried, and weighed	0.26
% cover	visually estimated by looking up from channel centerline	0.15

habitat quality

volume woody debris/longitudinal profile (ft^2)	diameter and length of woody debris measured along length of longitudinal profile	0.0004
pool frequency ratio	number of pools (1.5x riffle depth) occurring in longitudinal profile	0.0042
specific conductance	reported in mS/cm, YSI model 85 digital meter	71.5
dissolved oxygen	reported in %, YSI model 85 digital meter	97.6
inches of rainfall in last 30 days	nearest USGS gaging station determined in ArcGIS and rainfall data summed for 30 days prior to benthos collection	4

stream power and sediment transport

friction factor	from Leopold, Wolman, and Miller (1964)	0.203
water slope (ft/ft)	survey data collected using a builder's level	0.0062
BEHI	estimated using Rosgen 2001 method	13.3
d90 (mm)	substrate sampled according to modified Wolman pebble count technique Harrelson et al (1994)	130
% sand or finer	substrate sampled according to modified Wolman pebble count technique Harrelson et al (1994)	45
WDR	ratio of bankfull width to bankfull depth	9.2
BHR	ratio of maximum depth at the top of low bank to maximum bankfull depth	1.2

watershed characteristics

drainage area (mi^2)	determined in ArcGIS using USGS 30m DEMs and ArcHydro; visually verified for accuracy	0.2
curve number	determined in ArcGIS using 1999 HAZUS LULC and CGIA county soil surveys layers	80

biological condition

Q statistic	(Kempton and Taylor 1976) as a measure of community diversity; calculated as the slope of the inter-quartile range on the cumulative species curve	2.39
EPT taxa richness	number of Mayflies, Stoneflies, and Caddisflies (water and habitat sensitive) taxa in a sample	3
Simpson's 1/D	(Simpson 1949) a measure of community dominance that accounts for both species richness and proportion	3.46
Shannon's I	(Shannon and Weaver 1949) a measure of communtiy diversity by estimating the order or complexity in the community	1.5

spring valley upstream

riparian condition

% herbaceous	visually estimated across 40' transects at cross sections	90
% woody	visually estimated across 40' transects at cross sections	60
riparian infiltration (s)	measured according to USDA (2001) procedure	1345
dry biomass (g)	leaf material collected, dried, and weighed	0.88
% cover	visually estimated by looking up from channel centerline	0.8

habitat quality

volume woody debris/longitudinal profile (ft^2)	diameter and length of woody debris measured along length of longitudinal profile	0.0014
pool frequency ratio	number of pools (1.5x riffle depth) occurring in longitudinal profile	0.026
specific conductance	reported in mS/cm, YSI model 85 digital meter	73.8
dissolved oxygen	reported in %, YSI model 85 digital meter	88.1
inches of rainfall in last 30 days	nearest USGS gaging station determined in ArcGIS and rainfall data summed for 30 days prior to benthos collection	4

stream power and sediment transport

friction factor	from Leopold, Wolman, and Miller (1964)	0.126
water slope (ft/ft)	survey data collected using a builder's level	0.0224
BEHI	estimated using Rosgen 2001 method	19
d90 (mm)	substrate sampled according to modified Wolman pebble count technique Harrelson et al (1994)	200
% sand or finer	substrate sampled according to modified Wolman pebble count technique Harrelson et al (1994)	51
WDR	ratio of bankfull width to bankfull depth	10.6
BHR	ratio of maximum depth at the top of low bank to maximum bankfull depth	1.4

watershed characteristics

drainage area (mi^2)	determined in ArcGIS using USGS 30m DEMs and ArcHydro; visually verified for accuracy	0.2
curve number	determined in ArcGIS using 1999 HAZUS LULC and CGIA county soil surveys layers	80

biological condition

Q statistic	(Kempton and Taylor 1976) as a measure of community diversity; calculated as the slope of the inter-quartile range on the cumulative species curve	1.37
EPT taxa richness	number of Mayflies, Stoneflies, and Caddisflies (water and habitat sensitive) taxa in a sample	4
Simpson's 1/D	(Simpson 1949) a measure of community dominance that accounts for both species richness and proportion	2.73
Shannon's I	(Shannon and Weaver 1949) a measure of communtiy diversity by estimating the order or complexity in the community	1.26

suck creek restored

riparian condition		
% herbaceous	visually estimated across 40' transects at cross sections	70
% woody	visually estimated across 40' transects at cross sections	60
riparian infiltration (s)	measured according to USDA (2001) procedure	630
dry biomass (g)	leaf material collected, dried, and weighed	0.5
% cover	visually estimated by looking up from channel centerline	0.05

stream power and sediment transport		
friction factor	from Leopold, Wolman, and Miller (1964)	0.269
water slope (ft/ft)	survey data collected using a builder's level	0.002
BEHI	estimated using Rosgen 2001 method	11.5
d90 (mm)	substrate sampled according to modified Wolman pebble count technique Harrelson et al (1994)	45
% sand or finer	substrate sampled according to modified Wolman pebble count technique Harrelson et al (1994)	33
WDR	ratio of bankfull width to bankfull depth	13.5
BHR	ratio of maximum depth at the top of low bank to maximum bankfull depth	1.0

habitat quality		
volume woody debris/longitudinal profile (ft^2)	diameter and length of woody debris measured along length of longitudinal profile	0.0103
pool frequency ratio	number of pools (1.5x riffle depth) occurring in longitudinal profile	0.015
specific conductance	reported in mS/cm, YSI model 85 digital meter	30.6
dissolved oxygen	reported in %, YSI model 85 digital meter	120.5
inches of rainfall in last 30 days	nearest USGS gaging station determined in ArcGIS and rainfall data summed for 30 days prior to benthos collection	1.5

watershed characteristics		
drainage area (mi^2)	determined in ArcGIS using USGS 30m DEMs and ArcHydro; visually verified for accuracy	4.6
curve number	determined in ArcGIS using 1999 HAZUS LULC and CGIA county soil surveys layers	71

biological condition		
Q statistic	(Kempton and Taylor 1976) as a measure of community diversity; calculated as the slope of the inter-quartile range on the cumulative species curve	3.03
EPT taxa richness	number of Mayflies, Stoneflies, and Caddisflies (water and habitat sensitive) taxa in a sample	5
Simpson's 1/D	(Simpson 1949) a measure of community dominance that accounts for both species richness and proportion	5.46
Shannon's I	(Shannon and Weaver 1949) a measure of communtiy diversity by estimating the order or complexity in the community	1.97

suck creek upstream

riparian condition

% herbaceous	visually estimated across 40' transects at cross sections	50
% woody	visually estimated across 40' transects at cross sections	80
riparian infiltration (s)	measured according to USDA (2001) procedure	645
dry biomass (g)	leaf material collected, dried, and weighed	1.8
% cover	visually estimated by looking up from channel centerline	0.95

stream power and sediment transport

friction factor	from Leopold, Wolman, and Miller (1964)	0.266
water slope (ft/ft)	survey data collected using a builder's level	0.0059
BEHI	estimated using Rosgen 2001 method	12
d90 (mm)	substrate sampled according to modified Wolman pebble count technique Harrelson et al (1994)	52
% sand or finer	substrate sampled according to modified Wolman pebble count technique Harrelson et al (1994)	56
WDR	ratio of bankfull width to bankfull depth	12.2
BHR	ratio of maximum depth at the top of low bank to maximum bankfull depth	1.0

habitat quality

volume woody debris/longitudinal profile (ft^2)	diameter and length of woody debris measured along length of longitudinal profile	0.0005
pool frequency ratio	number of pools (1.5x riffle depth) occurring in longitudinal profile	0.0241
specific conductance	reported in mS/cm, YSI model 85 digital meter	30.8
dissolved oxygen	reported in %, YSI model 85 digital meter	133.9
inches of rainfall in last 30 days	nearest USGS gaging station determined in ArcGIS and rainfall data summed for 30 days prior to benthos collection	1.5

watershed characteristics

drainage area (mi^2)	determined in ArcGIS using USGS 30m DEMs and ArcHydro; visually verified for accuracy	4.6
curve number	determined in ArcGIS using 1999 HAZUS LULC and CGIA county soil surveys layers	71

biological condition

Q statistic	(Kempton and Taylor 1976) as a measure of community diversity; calculated as the slope of the inter-quartile range on the cumulative species curve	2.34
EPT taxa richness	number of Mayflies, Stoneflies, and Caddisflies (water and habitat sensitive) taxa in a sample	3
Simpson's 1/D	(Simpson 1949) a measure of community dominance that accounts for both species richness and proportion	4.36
Shannon's I	(Shannon and Weaver 1949) a measure of communtiy diversity by estimating the order or complexity in the community	1.73

sussmans park restored

riparian condition

% herbaceous	visually estimated across 40' transects at cross sections	50
% woody	visually estimated across 40' transects at cross sections	50
riparian infiltration (s)	measured according to USDA (2001) procedure	252
dry biomass (g)	leaf material collected, dried, and weighed	0
% cover	visually estimated by looking up from channel centerline	0.5

habitat quality

volume woody debris/longitudinal profile (ft^2)	diameter and length of woody debris measured along length of longitudinal profile	0.001
pool frequency ratio	number of pools (1.5x riffle depth) occurring in longitudinal profile	0.0137
specific conductance	reported in mS/cm, YSI model 85 digital meter	na
dissolved oxygen	reported in %, YSI model 85 digital meter	na
inches of rainfall in last 30 days	nearest USGS gaging station determined in ArcGIS and rainfall data summed for 30 days prior to benthos collection	5.4

stream power and sediment transport

friction factor	from Leopold, Wolman, and Miller (1964)	0.0791
water slope (ft/ft)	survey data collected using a builder's level	0.002
BEHI	estimated using Rosgen 2001 method	18.6
d90 (mm)	substrate sampled according to modified Wolman pebble count technique Harrelson et al (1994)	128
% sand or finer	substrate sampled according to modified Wolman pebble count technique Harrelson et al (1994)	64
WDR	ratio of bankfull width to bankfull depth	16.8
BHR	ratio of maximum depth at the top of low bank to maximum bankfull depth	2.5

watershed characteristics

drainage area (mi^2)	determined in ArcGIS using USGS 30m DEMs and ArcHydro; visually verified for accuracy	1
curve number	determined in ArcGIS using 1999 HAZUS LULC and CGIA county soil surveys layers	79

biological condition

Q statistic	(Kempton and Taylor 1976) as a measure of community diversity; calculated as the slope of the inter-quartile range on the cumulative species curve	0.87
EPT taxa richness	number of Mayflies, Stoneflies, and Caddisflies (water and habitat sensitive) taxa in a sample	3
Simpson's 1/D	(Simpson 1949) a measure of community dominance that accounts for both species richness and proportion	3.01
Shannon's I	(Shannon and Weaver 1949) a measure of communtiy diversity by estimating the order or complexity in the community	1.14

sussmans park upstream

riparian condition

% herbaceous	visually estimated across 40' transects at cross sections	90
% woody	visually estimated across 40' transects at cross sections	10
riparian infiltration (s)	measured according to USDA (2001) procedure	210
dry biomass (g)	leaf material collected, dried, and weighed	0
% cover	visually estimated by looking up from channel centerline	0.1

habitat quality

volume woody debris/longitudinal profile (ft^2)	diameter and length of woody debris measured along length of longitudinal profile	0.001
pool frequency ratio	number of pools (1.5x riffle depth) occurring in longitudinal profile	0.0131
specific conductance	reported in mS/cm, YSI model 85 digital meter	na
dissolved oxygen	reported in %, YSI model 85 digital meter	na
inches of rainfall in last 30 days	nearest USGS gaging station determined in ArcGIS and rainfall data summed for 30 days prior to benthos collection	5.4

stream power and sediment transport

friction factor	from Leopold, Wolman, and Miller (1964)	0.1089
water slope (ft/ft)	survey data collected using a builder's level	0.0033
BEHI	estimated using Rosgen 2001 method	16
d90 (mm)	substrate sampled according to modified Wolman pebble count technique Harrelson et al (1994)	56
% sand or finer	substrate sampled according to modified Wolman pebble count technique Harrelson et al (1994)	68
WDR	ratio of bankfull width to bankfull depth	8.5
BHR	ratio of maximum depth at the top of low bank to maximum bankfull depth	1.7

watershed characteristics

drainage area (mi^2)	determined in ArcGIS using USGS 30m DEMs and ArcHydro; visually verified for accuracy	1
curve number	determined in ArcGIS using 1999 HAZUS LULC and CGIA county soil surveys layers	79

biological condition

Q statistic	(Kempton and Taylor 1976) as a measure of community diversity; calculated as the slope of the inter-quartile range on the cumulative species curve	0.91
EPT taxa richness	number of Mayflies, Stoneflies, and Caddisflies (water and habitat sensitive) taxa in a sample	1
Simpson's 1/D	(Simpson 1949) a measure of community dominance that accounts for both species richness and proportion	2.23
Shannon's I	(Shannon and Weaver 1949) a measure of communtiy diversity by estimating the order or complexity in the community	1.13

yates mill restored

riparian condition			habitat quality		
% herbaceous	visually estimated across 40' transects at cross sections	100	volume woody debris/longitudinal profile (ft^2)	diameter and length of woody debris measured along length of longitudinal profile	0.0003
% woody	visually estimated across 40' transects at cross sections	35	pool frequency ratio	number of pools (1.5x riffle depth) occurring in longitudinal profile	0
riparian infiltration (s)	measured according to USDA (2001) procedure	170	specific conductance	reported in mS/cm, YSI model 85 digital meter	58.5
dry biomass (g)	leaf material collected, dried, and weighed	0.91	dissolved oxygen	reported in %, YSI model 85 digital meter	38.6
% cover	visually estimated by looking up from channel centerline	0.6	inches of rainfall in last 30 days	nearest USGS gaging station determined in ArcGIS and rainfall data summed for 30 days prior to benthos collection	2.5
stream power and sediment transport			**watershed characteristics**		
friction factor	from Leopold, Wolman, and Miller (1964)	20.3	drainage area (mi^2)	determined in ArcGIS using USGS 30m DEMs and ArcHydro; visually verified for accuracy	0.1
water slope (ft/ft)	survey data collected using a builder's level	0.015	curve number	determined in ArcGIS using 1999 HAZUS LULC and CGIA county soil surveys layers	62
BEHI	estimated using Rosgen 2001 method	16.6	**biological condition**		
d90 (mm)	substrate sampled according to modified Wolman pebble count technique Harrelson et al (1994)	17	Q statistic	(Kempton and Taylor 1976) as a measure of community diversity; calculated as the slope of the inter-quartile range on the cumulative species curve	3.73
% sand or finer	substrate sampled according to modified Wolman pebble count technique Harrelson et al (1994)	73	EPT taxa richness	number of Mayflies, Stoneflies, and Caddisflies (water and habitat sensitive) taxa in a sample	1
WDR	ratio of bankfull width to bankfull depth	9.5	Simpson's 1/D	(Simpson 1949) a measure of community dominance that accounts for both species richness and proportion	4.29
BHR	ratio of maximum depth at the top of low bank to maximum bankfull depth	1.8	Shannon's I	(Shannon and Weaver 1949) a measure of communtiy diversity by estimating the order or complexity in the community	1.76

yates mill upstream

riparian condition

% herbaceous	visually estimated across 40' transects at cross sections	20
% woody	visually estimated across 40' transects at cross sections	50
riparian infiltration (s)	measured according to USDA (2001) procedure	93
dry biomass (g)	leaf material collected, dried, and weighed	
% cover	visually estimated by looking up from channel centerline	0.9

habitat quality

volume woody debris/longitudinal profile (ft^2)	diameter and length of woody debris measured along length of longitudinal profile	0.0068
pool frequency ratio	number of pools (1.5x riffle depth) occurring in longitudinal profile	0.027
specific conductance	reported in mS/cm, YSI model 85 digital meter	54.1
dissolved oxygen	reported in %, YSI model 85 digital meter	49.3
inches of rainfall in last 30 days	nearest USGS gaging station determined in ArcGIS and rainfall data summed for 30 days prior to benthos collection	2.4

stream power and sediment transport

friction factor	from Leopold, Wolman, and Miller (1964)	0.362
water slope (ft/ft)	survey data collected using a builder's level	0.0065
BEHI	estimated using Rosgen 2001 method	11
d90 (mm)	substrate sampled according to modified Wolman pebble count technique Harrelson et al (1994)	18
% sand or finer	substrate sampled according to modified Wolman pebble count technique Harrelson et al (1994)	38
WDR	ratio of bankfull width to bankfull depth	9.5
BHR	ratio of maximum depth at the top of low bank to maximum bankfull depth	1.1

watershed characteristics

drainage area (mi^2)	determined in ArcGIS using USGS 30m DEMs and ArcHydro; visually verified for accuracy	0.3
curve number	determined in ArcGIS using 1999 HAZUS LULC and CGIA county soil surveys layers	64

biological condition

Q statistic	(Kempton and Taylor 1976) as a measure of community diversity; calculated as the slope of the inter-quartile range on the cumulative species curve	5.05
EPT taxa richness	number of Mayflies, Stoneflies, and Caddisflies (water and habitat sensitive) taxa in a sample	13
Simpson's 1/D	(Simpson 1949) a measure of community dominance that accounts for both species richness and proportion	12.04
Shannon's I	(Shannon and Weaver 1949) a measure of communtiy diversity by estimating the order or complexity in the community	2.61

APPENDIX B – BENTHIC MACROINVERTEBRATE COLLECTIONS

Stream Name: Jumping Run restored
Sample Date: 2003

Tolerance Values

Tolerance values were taken from *NCDWQ Master List of Benthic Macroinvertebrates*

Funtional Feeding Designations

PA	Parasite	FC	Filter/collector
PR	Predator	SC	Scraper
OM	Omnivore	SH	Shredder
GC	Gatherer/collector	PI	Piercer

Habit/Behavior Designations

cn	clinger	sw	swimmer
cb	climber	dv	diver
sp	sprawler	sk	skater
bu	burrower		

	Tolerance Values	Functional Feeding Designations	Habit/ Behavior Designations	Restored
Phylum Arthropoda				
Class Crustacea				
Order Decapoda				
Cambaridae		GC		
Class Insecta				
Order Coleoptera				
Elmidae				
Stenelmis sp.	5.1	SC		
Order Diptera				
Chironimidae				
subfamily Chironominae				
Endochironomus	7.79	SH		
Polypedilum aviceps	3.65	SH		**7**
Rheotanytarsus sp.	5.89	FC		**1**
Tanytarsus sp.	6.76	FC		**2**
subfamily Orthocladiinae				
Cricotopus bicinctus C/O sp 1	8.54	OM		**2**
Parametriocnemus sp.	3.65	GC	sp	**1**
Thienemanniella sp.	5.86	GC		**1**
Tvetina ba varcia grp (E sp1)	3.65	GC		**3**
subfamily Tanypodinae				
Conchapelopia Group	8.42	PR		**3**
Hayesomyia sp.		PR	sp	**2**
Larsia sp.	9.3	PR		**1**
Natarsia sp.	9.95	PR	sp	**1**
Simuliidae				
Simulium sp.	4	FC		**15**
Tipulidae				
Tipula sp.	7.33	SH		
Order Ephemeroptera				
Baetidae				
Baetis pluto	4.28	GC	sw	**17**
Ephemerellidae				
Eurylophella sp.	4.34	SC	cn	
Heptageniidae				
Stenacron interpunctatum	6.87	OM		
Stenonema sp.		SC		**3**
Stenonema modestum	5.5	SC	cn	**1**
Isonychiidae				
Isonychia sp.	3.45	FC	sw	**6**
Leptophlebiidae				
Paraleptophlebia sp.	0.94	GC	sw	
Order Heteroptera				
Veliidae				
Microvelia sp.		PR		
Order Lepidoptera				
Noctuiidae		SH		
Order Megaloptera				
Corydalidae				
Nigronia fasciatus	5.55	PR		**2**
Sialidae				
Sialis sp.	7.17	PR		
Order Plecoptera				
Leutridae				
Leuctra sp.	0.67	SH	sp	**1**
Peltoperlidae				
Tallaperla sp.	1.2		cn	**1**
Perlidae		PR		**2**
Order Odonata				
Coenagrionidae				
Argia sp.	8.17	PR		
Gomphidae				
Stylogomphus albistylus	4.72	PR		
Order Trichoptera				
Hydropsychidae				
Cheumatopsyche sp.	6.22	FC		
Diplectrona modesta	2.21	FC	cn	
Hydropsyche betteni	7.78	FC		**18**
Philopotamidae				
Chimarra sp.	2.76	FC	cn	**3**

Stream Name: Jumping Run upstream
Sample Date: 2003

Tolerance Values

Tolerance values were taken from *NCDWQ Master List of Benthic Macroinvertebrates*

Funtional Feeding Designations

PA	Parasite	FC	Filter/collector
PR	Predator	SC	Scraper
OM	Omnivore	SH	Shredder
GC	Gatherer/collector	PI	Piercer

Habit/Behavior Designations

cn	clinger	sw	swimmer
cb	climber	dv	diver
sp	sprawler	sk	skater
bu	burrower		

	Tolerance Values	Functional Feeding Designations	Habit/ Behavior Designations	Upstream
Phylum Arthropoda				
Class Crustacea				
Order Decapoda				
Cambaridae		GC		**2**
Class Insecta				
Order Coleoptera				
Elmidae				
Stenelmis sp.	5.1	SC		**1**
Order Diptera				
Chironimidae				
subfamily Chironominae				
Endochironomus	7.79	SH		**1**
Polypedilum aviceps	3.65	SH		**1**
Rheotanytarsus sp.	5.89	FC		
Tanytarsus sp.	6.76	FC		
subfamily Orthocladiinae				
Cricotopus bicinctus C/O sp 1	8.54	OM		
Parametriocnemus sp.	3.65	GC	sp	**1**
Thienemanniella sp.	5.86	GC		
Tvetina ba varcia grp (E sp1)	3.65	GC		**1**
subfamily Tanypodinae				
Conchapelopia Group	8.42	PR		**1**
Hayesomyia sp.		PR	sp	
Larsia sp.	9.3	PR		
Natarsia sp.	9.95	PR	sp	
Simuliidae				
Simulium sp.	4	FC		**12**
Tipulidae				
Tipula sp.	7.33	SH		**4**
Order Ephemeroptera				
Baetidae				
Baetis pluto	4.28	GC	sw	**2**
Ephemerellidae				
Eurylophella sp.	4.34	SC	cn	**1**
Heptageniidae				
Stenacron interpunctatum	6.87	OM		**4**
Stenonema sp.		SC		**10**
Stenonema modestum	5.5	SC	cn	**3**
Isonychiidae				
Isonychia sp.	3.45	FC	sw	
Leptophlebiidae				
Paraleptophlebia sp.	0.94	GC	sw	**19**
Order Heteroptera				
Veliidae				
Microvelia sp.		PR		**8**
Order Lepidoptera				
Noctuiidae		SH		**1**
Order Megaloptera				
Corydalidae				
Nigronia fasciatus	5.55	PR		
Sialidae				
Sialis sp.	7.17	PR		**1**
Order Plecoptera				
Leutridae				
Leuctra sp.	0.67	SH	sp	**2**
Peltoperlidae				
Tallaperla sp.	1.2		cn	
Perlidae		PR		**4**
Order Odonata				
Coenagrionidae				
Argia sp.	8.17	PR		**1**
Gomphidae				
Stylogomphus albistylus	4.72	PR		**5**
Order Trichoptera				
Hydropsychidae				
Cheumatopsyche sp.	6.22	FC		**1**
Diplectrona modesta	2.21	FC	cn	**2**

Stream Name: Brown Branch restored
Sample Date: 2003

Tolerance Values

Tolerance values were taken from*NCDWQ Master List of Benthic Macroinvertebrates*

Funtional Feeding Designations

PA	Parasite	FC	Filter/collector
PR	Predator	SC	Scraper
OM	Omnivore	SH	Shredder
GC	Gatherer/collector	PI	Piercer

Habit/Behavior Designations

cn	clinger	sw	swimmer
cb	climber	dv	diver
sp	sprawler	sk	skater
bu	burrower		

	Tolerance Values	Functional Feeding Designations	Habit/ Behavior Designations	Restored
Class Oligochaeta	6	GC		**3**
Class Insecta				
Order Coleoptera				
Dryopidae				
Helichus sp.	4.6	SH	cb	
Elmidae				
Dubiraphia sp.	5.93	GC		
Microcylloepus pusillus	2.11	GC		
Optioservus sp.	2.36	SC		**1**
Hydrophilidae		PR		
Tropisternis sp.	9.68	PR		**2**
Psephenidae				
Ectopria nervosa	4.16	SC		
Order Diptera				
Ceratopogonidae				
Palpomyia-Bezzia cmplx		PR		**20**
Chironimidae				
subfamily Chironominae				
Polypedilum aviceps	3.65	SH		
Polypedilum fallax	6.39	SH		**1**
Polypedilum scalaenum grp	8.4	SH		**1**
Rheotanytarsus sp.	5.89	FC		**1**
subfamily Orthocladiinae				
Tvetina ba varcia grp (E sp1)	3.65	GC		**2**
subfamily Tanypodinae				
Conchapelopia Group	8.42	PR		**3**
Nilotanypus sp.	3.9	PR	sp	
Simuliidae				
Simulium sp.	4	FC		**18**
Tipulidae				
Antocha sp.	4.25	GC		
Dicranota sp.	0	PR		**1**
Hexatoma sp.	4.31	PR	bu	
Pseudolimnophila sp.		PR		**2**
Tipula sp.	7.33	SH		**1**
Order Ephemeroptera				
Baetidae				
Baetis intercalaris	4.99	OM		**3**
Baetis pluto	4.28	GC	sw	**24**
Centroptilium sp.	6.6	GC		**1**
Plauditus sp.				**6**
Pseudocloeon sp.		SC		**1**
Baetiscidae				
Baetisca sp.	3.4	GC		**1**
Ephemerellidae				
Serratella difciens	2.75	GC		**8**
Ephemeridae				
Ephemera sp.		GC	bu	
Heptageniidae				
Epeoru rubidus	1.22	SC		
Stenacron carolina	1.14	SC		
Stenonema sp.		SC		**2**
Stenonema modestum	5.5	SC	cn	**2**
Isonychiidae				
Isonychia sp.	3.45	FC	sw	**1**
Order Lepidoptera				
Noctuiidae		SH		**1**
Order Megaloptera				
Corydalidae				
Corydalus cornutus	5.16	PR	cn	**3**
Nigronia serricornis	4.95	PR	cn	**2**
Sialidae				
Sialis sp.	7.17	PR		
Order Plecoptera				
Chloroperlidae		PR	cn	
Leutridae				
Leuctra sp.	0.67	SH	sp	**1**
Peltoperlidae				
Tallaperla sp.	1.2		cn	**14**
Perlidae		PR		
Eccoptura xanthenes	3.74	PR	cn	**4**
Perlodidae				
Malirekus hastatus	1.15	PR		**4**
Order Odonata				
Aeshnidae				
Boyeria vinosa	5.89	PR	cb	**1**
Cordulegastridae				
Cordulegaster sp.	5.73	PR		**7**
Cordulegaster maculata	5.7	PR	sp	**9**
Gomphidae				
Lanthus sp.	1.77	PR		**6**
Stylogomphus albistylus	4.72	PR		**1**
Order Trichoptera				
Glossosomatidae				
Glossosoma sp.	1.55	SC		**2**
Hydropsychidae				
Ceratopsyche sparna	2.72	FC		**26**
Cheumatopsyche sp.	6.22	FC		
Diplectrona modesta	2.21	FC	cn	
Hydropsyche sp.		FC		
Hydropsyche betteni	7.78	FC		**3**
Rhyacophilidae				
Rhyacophila fuscula	1.88	PR		**1**

Stream Name: Brown Branch upstream
Sample Date: 2003

Tolerance Values

Tolerance values were taken from *NCDWQ Master List of Benthic Macroinvertebrates*

Funtional Feeding Designations

PA	Parasite	FC	Filter/collector
PR	Predator	SC	Scraper
OM	Omnivore	SH	Shredder
GC	Gatherer/collector	PI	Piercer

Habit/Behavior Designations

cn	clinger	sw	swimmer
cb	climber	dv	diver
sp	sprawler	sk	skater
bu	burrower		

	Tolerance Values	Functional Feeding Designations	Habit/ Behavior Designations	Upstream
Class Oligochaeta	6	GC		**1**
Class Insecta				
Order Coleoptera				
Dryopidae				
Helichus sp.	4.6	SH	cb	**3**
Elmidae				
Dubiraphia sp.	5.93	GC		**1**
Microcylloepus pusillus	2.11	GC		**3**
Optioservus sp.	2.36	SC		
Hydrophilidae		PR		
Tropisternis sp.	9.68	PR		
Psephenidae				
Ectopria nervosa	4.16	SC		**1**
Order Diptera				
Ceratopogonidae				
Palpomyia-Bezzia cmplx		PR		
Chironimidae				
subfamily Chironominae				
Polypedilum aviceps	3.65	SH		**6**
Polypedilum fallax	6.39	SH		
Polypedilum scalaenum grp	8.4	SH		
Rheotanytarsus sp.	5.89	FC		
subfamily Orthocladiinae				
Tvetina ba varcia grp (E sp1)	3.65	GC		**1**
subfamily Tanypodinae				**1**
Conchapelopia Group	8.42	PR		
Nilotanypus sp.	3.9	PR	sp	**2**
Simuliidae				
Simulium sp.	4	FC		**19**
Tipulidae				
Antocha sp.	4.25	GC		
Dicranota sp.	0	PR		**1**
Hexatoma sp.	4.31	PR	bu	**2**
Pseudolimnophila sp.		PR		**1**
Tipula sp.	7.33	SH		
Order Ephemeroptera				
Baetidae				
Baetis intercalaris	4.99	OM		**1**
Baetis pluto	4.28	GC	sw	**7**
Centroptilium sp.	6.6	GC		
Plauditus sp.				
Pseudocloeon sp.		SC		
Baetiscidae				
Baetisca sp.	3.4	GC		
Ephemerellidae				
Serratella difciens	2.75	GC		
Ephemeridae				
Ephemera sp.		GC	bu	**2**
Heptageniidae				
Epeoru rubidus	1.22	SC		**1**
Stenacron carolina	1.14	SC		**1**
Stenonema sp.		SC		**28**
Stenonema modestum	5.5	SC	cn	
Isonychiidae				
Isonychia sp.	3.45	FC	sw	
Order Lepidoptera				
Noctuiidae		SH		
Order Megaloptera				
Corydalidae				
Corydalus cornutus	5.16	PR	cn	
Nigronia serricornis	4.95	PR	cn	
Sialidae				
Sialis sp.	7.17	PR		**1**
Order Plecoptera				
Chloroperlidae		PR	cn	**1**
Leutridae				
Leuctra sp.	0.67	SH	sp	**11**
Peltoperlidae				
Tallaperla sp.	1.2		cn	**13**
Perlidae		PR		
Eccoptura xanthenes	3.74	PR	cn	**3**
Perlodidae				
Malirekus hastatus	1.15	PR		**8**
Order Odonata				
Aeshnidae				
Boyeria vinosa	5.89	PR	cb	**6**
Cordulegastridae				
Cordulegaster sp.	5.73	PR		**3**
Cordulegaster maculata	5.7	PR	sp	
Gomphidae				
Lanthus sp.	1.77	PR		**2**
Order Trichoptera				
Glossosomatidae				
Glossosoma sp.	1.55	SC		**4**
Hydropsychidae				
Cheumatopsyche sp.	6.22	FC		**2**
Diplectrona modesta	2.21	FC	cn	**5**
Hydropsyche sp.		FC		**2**
Hydropsyche betteni	7.78	FC		**4**
Lepidostomatidae				
Lepidostoma sp.	0.9	SH		**1**
Limnephilidae				
Pycnopsyche gentilis	0.57			**1**
Pycnopsyche luculenta/sonso	2.5	SH		**1**
Philopotamidae				
Dolophilodes sp.	0.81	GC		**22**
Rhyacophilidae				
Rhyacophila sp.	3.86	PR		**7**

Stream Name: Lyle Creek restored
Sample Date: 2003

Tolerance Values

Tolerance values were taken from *NCDWQ Master List of Benthic Macroinvertebrates*

Funtional Feeding Designations

PA	Parasite	FC	Filter/collector
PR	Predator	SC	Scraper
OM	Omnivore	SH	Shredder
GC	Gatherer/collector	PI	Piercer

Habit/Behavior Designations

cn	clinger	sw	swimmer
cb	climber	dv	diver
sp	sprawler	sk	skater
bu	burrower		

	Tolerance Values	Functional Feeding Designations	Habit/ Behavior Designations	Restored
Phylum Arthropoda				
Class Crustacea				
Order Decapoda				
Cambaridae		GC		
Class Insecta				
Order Coleoptera				
Dryopidae				
Helichus sp.	4.6	SH	cb	**2**
Dytiscidae				
Neoporus sp.				
Elmidae				
Stenelmis sp.	5.1	SC		
Ptilodactylidae				
Anchytarsus bicolor	3.64	SH	sp	**2**
Order Diptera				
Chironimidae				
subfamily Chironominae				
Polypedilum aviceps	3.65	SH		**14**
Polypedilum fallax	6.39	SH		
Polypedilum illinoense grp	9	SH		**1**
Polypedilum scalaenum grp	8.4	SH		**1**
subfamily Diamesinae				
Diamesa sp.	8.12	GC	sp	**1**
subfamily Orthocladiinae				
Parametriocnemus sp.	3.65	GC	sp	**2**
Tvetina ba varcia grp (E sp1)	3.65	GC		**2**
subfamily Tanypodinae				
Conchapelopia Group	8.42	PR		**2**
Culicidae				
Anopheles sp.	8.58	FC	sw	**1**
Simuliidae				
Simulium sp.	4	FC		**19**
Order Ephemeroptera				
Baetidae				
Baetis intercalaris	4.99	OM		**12**
Baetis pluto	4.28	GC	sw	**3**
Heptageniidae				
Stenonema sp.		SC		**4**
Stenonema modestum	5.5	SC	cn	**1**
Order Heteroptera				
Veliidae				
Microvelia sp.		PR		**2**
Order Lepidoptera				
Noctuiidae		SH		**1**
Order Megaloptera				
Corydalidae				
Nigronia fasciatus	5.55	PR		**2**
Nigronia serricornis	4.95	PR	cn	**1**
Sialidae				
Sialis sp.	7.17	PR		**2**
Order Plecoptera				
Leutridae				
Leuctra sp.	0.67	SH	sp	
Perlidae		PR		**4**
Perlesta placida	4.72	PR		**1**
Order Odonata				
Aeshnidae				
Boyeria vinosa	5.89	PR	cb	**1**
Gomphidae				
Lanthus sp.	1.77	PR		**1**
Order Trichoptera				
Hydropsychidae				
Cheumatopsyche sp.	6.22	FC		
Diplectrona modesta	2.21	FC	cn	
Hydropsyche betteni	7.78	FC		**2**
Philopotamidae				
Chimarra sp.	2.76	FC	cn	
Dolophilodes sp.	0.81	GC		**1**

Stream Name: Lyle Creek upstream
Sample Date: 2003

Tolerance Values

Tolerance values were taken from *NCDWQ Master List of Benthic Macroinvertebrates*

Funtional Feeding Designations

PA	Parasite	FC	Filter/collector
PR	Predator	SC	Scraper
OM	Omnivore	SH	Shredder
GC	Gatherer/collector	PI	Piercer

Habit/Behavior Designations

cn	clinger	sw	swimmer
cb	climber	dv	diver
sp	sprawler	sk	skater
bu	burrower		

	Tolerance Values	Functional Feeding Designations	Habit/ Behavior Designations	Upstream
Phylum Arthropoda				
Class Crustacea				
Order Decapoda				
Cambaridae		GC		**5**
Class Insecta				
Order Coleoptera				
Dryopidae				
Helichus sp.	4.6	SH	cb	**8**
Dytiscidae				
Neoporus sp.				**2**
Elmidae				
Stenelmis sp.	5.1	SC		**1**
Ptilodactylidae				
Anchytarsus bicolor	3.64	SH	sp	**5**
Order Diptera				
Chironimidae				
subfamily Chironominae				
Polypedilum aviceps	3.65	SH		**2**
Polypedilum fallax	6.39	SH		**1**
subfamily Diamesinae				
Diamesa sp.	8.12	GC	sp	
subfamily Orthocladiinae				
Parametriocnemus sp.	3.65	GC	sp	**2**
Tvetina ba varcia grp (E sp1)	3.65	GC		
Dixidae				
Dixa sp.	2.55	GC		**5**
Simuliidae				
Simulium sp.	4	FC		**14**
Tipulidae				
Pseudolimnophila sp.		PR		**1**
Order Ephemeroptera				
Baetidae				
Baetis intercalaris	4.99	OM		**8**
Baetis pluto	4.28	GC	sw	**1**
Heptageniidae				
Stenonema sp.		SC		**1**
Stenonema modestum	5.5	SC	cn	
Isonychiidae				
Isonychia sp.	3.45	FC	sw	**1**
Order Heteroptera				
Veliidae				
Microvelia sp.		PR		**2**
Order Megaloptera				
Corydalidae				
Nigronia fasciatus	5.55	PR		
Nigronia serricornis	4.95	PR	cn	**1**
Order Plecoptera				
Leutridae				
Leuctra sp.	0.67	SH	sp	**1**
Perlidae		PR		**8**
Perlesta placida	4.72	PR		
Order Odonata				
Aeshnidae				
Boyeria vinosa	5.89	PR	cb	**2**
Calopterygidae		PR		
Calopteryx maculata	7.78	PR		**2**
Cordulegastridae				
Cordulegaster maculata	5.7	PR	sp	**1**
Gomphidae				
Lanthus sp.	1.77	PR		**3**
Order Trichoptera				
Hydropsychidae				
Cheumatopsyche sp.	6.22	FC		**2**
Diplectrona modesta	2.21	FC	cn	**4**
Hydropsyche betteni	7.78	FC		**2**
Philopotamidae				
Chimarra sp.	2.76	FC	cn	**1**
Dolophilodes sp.	0.81	GC		**30**
Wormaldia sp.	0.65	FC		**1**

Stream Name: Price Park restored
Sample Date: 2003

Tolerance Values

Tolerance values were taken from *NCDWQ Master List of Benthic Macroinvertebrates*

Funtional Feeding Designations

PA	Parasite	FC	Filter/collector
PR	Predator	SC	Scraper
OM	Omnivore	SH	Shredder
GC	Gatherer/collector	PI	Piercer

Habit/Behavior Designations

cn	clinger	sw	swimmer
cb	climber	dv	diver
sp	sprawler	sk	skater
bu	burrower		

Taxon	Tolerance Values	Functional Feeding Designations	Habit/ Behavior Designations	Restored
Class Oligochaeta	6	GC		**6**
Class Insecta				
Order Coleoptera				
Lampyridae				
Order Diptera				
Chironimidae				
subfamily Chironominae				
Cryptochironomus sp.	6.4	PR		**1**
Dicrotendipes sp.	8.1	GC		**1**
Microtendipes sp.	5.53	FC		**1**
Polypedilum aviceps	3.65	SH		**2**
Polypedilum flavum		SH		**6**
Polypedilum illinoense grp	9	SH		
Rheotanytarsus sp.	5.89	FC		
Tanytarsus sp.	6.76	FC		
subfamily Diamesinae				
Potthastia longimana	6.46	GC		**1**
subfamily Orthocladiinae				
Cricotopus bicinctus C/O sp 1	8.54	OM		**2**
Cricotopus triannulatus, C. infuscatus C/O sp 5	9.04			**1**
Eukiefferiella claripennis	5.58	GC		**3**
Parametriocnemus sp.	3.65	GC	sp	**2**
Thienemanniella sp.	5.86	GC		**1**
subfamily Tanypodinae				
Conchapelopia Group	8.42	PR		**6**
Hayesomyia sp.		PR	sp	**6**
Natarsia sp.	9.95	PR	sp	**1**
Simuliidae				
Simulium sp.	4	FC		**16**
Tipulidae				
Tipula sp.	7.33	SH		**8**
Order Ephemeroptera				
Baetidae				
Baetis intercalaris	4.99	OM		**28**
Heptageniidae				
Stenonema sp.		SC		**1**
Order Odonata				
Aeshnidae				
Boyeria vinosa	5.89	PR	cb	
Cordulegastridae				
Cordulegaster maculata	5.7	PR	sp	**1**
Order Trichoptera				
Hydropsychidae				
Cheumatopsyche sp.	6.22	FC		**23**
Hydropsyche betteni	7.78	FC		**10**

Stream Name: Price Park upstream

Sample Date: 2003

Tolerance Values

Tolerance values were taken from *NCDWQ Master List of Benthic Macroinvertebrates*

Funtional Feeding Designations

PA	Parasite	FC	Filter/collector
PR	Predator	SC	Scraper
OM	Omnivore	SH	Shredder
GC	Gatherer/collector	PI	Piercer

Habit/Behavior Designations

cn	clinger	sw	swimmer
cb	climber	dv	diver
sp	sprawler	sk	skater
bu	burrower		

Taxon	Tolerance Values	Functional Feeding Designations	Habit/ Behavior Designations	Upstream
Class Oligochaeta	6	GC		
Class Insecta				
Order Coleoptera				
Lampyridae				**1**
Order Diptera				
Chironimidae				
subfamily Chironominae				
Cryptochironomus sp.	6.4	PR		
Dicrotendipes sp.	8.1	GC		
Microtendipes sp.	5.53	FC		**3**
Polypedilum aviceps	3.65	SH		
Polypedilum flavum		SH		
Polypedilum illinoense grp	9	SH		**3**
Rheotanytarsus sp.	5.89	FC		**1**
Tanytarsus sp.	6.76	FC		**1**
subfamily Tanypodinae				
Conchapelopia Group	8.42	PR		**1**
Hayesomyia sp.		PR	sp	**3**
Natarsia sp.	9.95	PR	sp	**4**
Simuliidae				
Simulium sp.	4	FC		**9**
Order Odonata				
Aeshnidae				
Boyeria vinosa	5.89	PR	cb	**1**
Order Trichoptera				
Hydropsychidae				
Cheumatopsyche sp.	6.22	FC		**1**

Stream Name: Sussman's restored

Sample Date: 2003

Tolerance Values

Tolerance values were taken from *NCDWQ Master List of Benthic Macroinvertebrates*

Funtional Feeding Designations

PA	Parasite	FC	Filter/collector
PR	Predator	SC	Scraper
OM	Omnivore	SH	Shredder
GC	Gatherer/collector	PI	Piercer

Habit/Behavior Designations

cn	clinger	sw	swimmer
cb	climber	dv	diver
sp	sprawler	sk	skater
bu	burrower		

					Tolerance Values	Functional Feeding Designations	Habit/ Behavior Designations	Restored
Class Oligochaeta					6	GC		**3**
Class Insecta								
	Order Diptera							
		Chironimidae						
		subfamily Chironominae						
			Chironomus sp.		9.63	GC		
			Polypedilum fallax		6.39	SH		
			Polypedilum illinoense grp		9	SH		
			Polypedilum scalaenum grp		8.4	SH		**1**
		subfamily Orthocladiinae						**1**
			Cricotopus triannulatus, C. infuscatus C/O sp 5		9.04			
			Rheocricotopus sp.		7.3	GC		**1**
		subfamily Tanypodinae						
			Conchapelopia Group		8.42	PR		**2**
			Natarsia sp.		9.95	PR	sp	**3**
		Culicidae						
			Anopheles sp.		8.58	FC	sw	
		Empididae			7.57	PR	sp	**1**
		Sciomyzidae				PR		
		Simuliidae						
			Simulium sp.		4	FC		**17**
	Order Ephemeroptera							
		Baetidae						
			Baetis intercalaris		4.99	OM		**10**
	Order Odonata							
		Coenagrionidae						
			Argia sp.		8.17	PR		**2**
	Order Trichoptera							
		Hydropsychidae						
			Cheumatopsyche sp.		6.22	FC		**11**
			Hydropsyche betteni		7.78	FC		**7**

Stream Name: Sussman's upstream
Sample Date: 2003

Tolerance Values

Tolerance values were taken from *NCDWQ Master List of Benthic Macroinvertebrates*

Funtional Feeding Designations

PA	Parasite	FC	Filter/collector
PR	Predator	SC	Scraper
OM	Omnivore	SH	Shredder
GC	Gatherer/collector	PI	Piercer

Habit/Behavior Designations

cn	clinger	sw	swimmer
cb	climber	dv	diver
sp	sprawler	sk	skater
bu	burrower		

	Tolerance Values	Functional Feeding Designations	Habit/ Behavior Designations	Upstream
Class Oligochaeta	6	GC		**3**
Class Insecta				
Order Diptera				
Chironimidae				
subfamily Chironominae				
Chironomus sp.	9.63	GC		**9**
Polypedilum fallax	6.39	SH		**1**
Polypedilum illinoense grp	9	SH		**1**
Polypedilum scalaenum grp	8.4	SH		
subfamily Orthocladiinae				
Cricotopus triannulatus, C. infuscatus C/O sp 5	9.04			**2**
Rheocricotopus sp.	7.3	GC		
subfamily Tanypodinae				
Conchapelopia Group	8.42	PR		**1**
Natarsia sp.	9.95	PR	sp	
Culicidae				
Anopheles sp.	8.58	FC	sw	**1**
Empididae	7.57	PR	sp	
Sciomyzidae		PR		**1**
Simuliidae				
Simulium sp.	4	FC		**1**
Order Ephemeroptera				
Baetidae				
Baetis intercalaris	4.99	OM		**3**
Order Heteroptera				
Notonectidae				
Notonecta sp.	8.71	PR		**1**

Stream Name: Lindley restored
Sample Date: 2003

Tolerance Values

Tolerance values were taken from *NCDWQ Master List of Benthic Macroinvertebrates*

Funtional Feeding Designations

PA	Parasite	FC	Filter/collector
PR	Predator	SC	Scraper
OM	Omnivore	SH	Shredder
GC	Gatherer/collector	PI	Piercer

Habit/Behavior Designations

cn	clinger	sw	swimmer
cb	climber	dv	diver
sp	sprawler	sk	skater
bu	burrower		

				Tolerance Values	Functional Feeding Designations	Habit/ Behavior Designations	Restored
Phylum Annelida							
Class Oligochaeta				6	GC		**10**
Class Hirudinea					PR		**1**
Phylum Arthropoda							
Class Crustacea							
	Order Decapoda						
		Cambaridae			GC		**9**
Class Insecta							
	Order Coleoptera						
		Dytiscidae					
			Coptotomus sp.	9.26	PR	sw	**1**
			Neoporus sp.				
		Elmidae					
			Dubiraphia sp.	5.93	GC		**1**
			Stenelmis sp.	5.1	SC		
		Hydrophilidae			PR		
			Anacaena sp.				**1**
	Order Diptera						
		Chironimidae					
		subfamily Chironominae					
			Chironomus sp.	9.63	GC		**1**
			Polypedilum flavum		SH		**4**
			Polypedilum illinoense grp	9	SH		**7**
			Rheotanytarsus sp.	5.89	FC		**8**
			Tanytarsus sp.	6.76	FC		**2**
			Tribelos sp.	6.31	GC		**3**
		subfamily Orthocladiinae					
			Cricotopus bicinctus C/O sp 1	8.54	OM		**10**
			Orthocladius carlatus		GC		
		subfamily Tanypodinae					
			Ablabesmyia mallochi	7.19	OM		**2**
			Conchapelopia Group	8.42	PR		**1**
			Hayesomyia sp.		PR	sp	**2**
		Culicidae					
			Anopheles sp.	8.58	FC	sw	**3**
		Simuliidae					
			Simulium sp.	4	FC		**1**
		Stratiomyidae					
			Odontomyia sp.		GC		**1**
		Tipulidae					
			Tipula sp.	7.33	SH		**1**
	Order Ephemeroptera						
		Baetidae					
			Baetis intercalaris	4.99	OM		**14**
		Caenidae					
			Caenis sp.	7.41	GC	sp	**1**
	Order Heteroptera						
		Saldidae			PR		**1**
		Veliidae					
			Microvelia sp.		PR		**1**
	Order Odonata						
		Aeshnidae					
			Basiaeschna janata	7.35	PR		**1**
		Coenagrionidae					
			Ischnura sp.	9.52	PR	cb	**8**
	Order Trichoptera						
		Hydropsychidae			FC		**1**
			Cheumatopsyche sp.	6.22	FC		**8**
			Hydropsyche sp.		FC		**4**
			Hydropsyche betteni	7.78	FC		**15**
Phylum Mollusca							
Class Pelecypoda							
		Ancylidae			SC		
			Ferrissia sp.	6.55	SC		**1**

Stream Name: Lindley upstream

Sample Date: 2003

Tolerance Values

Tolerance values were taken from *NCDWQ Master List of Benthic Macroinvertebrates*

Funtional Feeding Designations

PA	Parasite	FC	Filter/collector
PR	Predator	SC	Scraper
OM	Omnivore	SH	Shredder
GC	Gatherer/collector	PI	Piercer

Habit/Behavior Designations

cn	clinger	sw	swimmer
cb	climber	dv	diver
sp	sprawler	sk	skater
bu	burrower		

	Tolerance Values	Functional Feeding Designations	Habit/ Behavior Designations	Upstream
Phylum Annelida				
Class Oligochaeta	6	GC		**15**
Class Hirudinea		PR		
Phylum Arthropoda				
Class Crustacea				
Order Decapoda				
Cambaridae		GC		**1**
Class Insecta				
Order Coleoptera				
Elmidae				
Dubiraphia sp.	5.93	GC		
Stenelmis sp.	5.1	SC		**1**
Order Diptera				
Chironimidae				
subfamily Chironominae				
Chironomus sp.	9.63	GC		
Polypedilum flavum		SH		**3**
Polypedilum illinoense grp	9	SH		
Rheotanytarsus sp.	5.89	FC		**5**
Tanytarsus sp.	6.76	FC		**1**
Tribelos sp.	6.31	GC		
subfamily Orthocladiinae				
Cricotopus bicinctus C/O sp 1	8.54	OM		
Orthocladius carlatus		GC		**1**
subfamily Tanypodinae				
Conchapelopia Group	8.42	PR		**2**
Hayesomyia sp.		PR	sp	**1**
Simuliidae				
Simulium sp.	4	FC		**7**
Stratiomyidae				
Odontomyia sp.		GC		
Tipulidae				
Tipula sp.	7.33	SH		**2**
Order Ephemeroptera				
Baetidae				
Baetis intercalaris	4.99	OM		**25**
Order Trichoptera				
Hydropsychidae		FC		**1**
Cheumatopsyche sp.	6.22	FC		**18**
Hydropsyche sp.		FC		
Hydropsyche betteni	7.78	FC		**23**
Phylum Mollusca				
Class Pelecypoda				
Ancylidae		SC		
Ferrissia sp.	6.55	SC		
Lymnaeidae				
Fossaria sp.	8	SC		**1**
Physidae				
Physella sp.	8.84	SC		**1**

Stream Name: Pott Creek restored
Sample Date: 2003

Tolerance Values

Tolerance values were taken from *NCDWQ Master List of Benthic Macroinvertebrates*

Funtional Feeding Designations

PA	Parasite	FC	Filter/collector
PR	Predator	SC	Scraper
OM	Omnivore	SH	Shredder
GC	Gatherer/collector	PI	Piercer

Habit/Behavior Designations

cn	clinger	sw	swimmer
cb	climber	dv	diver
sp	sprawler	sk	skater
bu	burrower		

				Tolerance Values	Functional Feeding Designations	Habit/ Behavior Designations	Upstream
Phylum Arthropoda							
Class Crustacea							
	Order Amphidipoda						
		Hyalellidae					
			Hyalella sp.	7.75	GC		**8**
Class Insecta							
	Order Coleoptera						
		Hydrophilidae			PR		
			Berosus sp.	8.43	PR		**1**
			Tropisternis sp.	9.68	PR		**1**
	Order Diptera						
		Chironimidae					
		subfamily Chironominae					
			Microtendipes sp.	5.53	FC		**1**
			Polypedilum illinoense grp	9	SH		**1**
		subfamily Tanypodinae					
			Conchapelopia Group	8.42	PR		**1**
		Empididae		7.57	PR	sp	**1**
		Simuliidae					
			Simulium sp.	4	FC		**5**
	Order Ephemeroptera						
		Baetidae					
			Baetis pluto	4.28	GC	sw	**18**
		Ephemerellidae					
			Serratella difciens	2.75	GC		**3**
		Heptageniidae					
			Stenonema sp.		SC		**4**
			Stenonema modestum	5.5	SC	cn	**11**
	Order Heteroptera						
		Corixidae					
			Trichocorixa sp.		PR		**1**
	Order Orthoptera						**1**
	Order Odonata						
		Aeshnidae					
			Anax sp.		PR		
			Basiaeschna janata	7.35	PR		**2**
		Calopterygidae			PR		
			Calopteryx maculata	7.78	PR		**8**
	Order Trichoptera						
		Hydropsychidae			FC		
			Cheumatopsyche sp.	6.22	FC		**5**
			Hydropsyche betteni	7.78	FC		**1**

Stream Name: Pott upstream

Sample Date: 2003

Tolerance Values

Tolerance values were taken from *NCDWQ Master List of Benthic Macroinvertebrates*

Funtional Feeding Designations

PA	Parasite	FC	Filter/collector
PR	Predator	SC	Scraper
OM	Omnivore	SH	Shredder
GC	Gatherer/collector	PI	Piercer

Habit/Behavior Designations

cn	clinger	sw	swimmer
cb	climber	dv	diver
sp	sprawler	sk	skater
bu	burrower		

Taxon	Tolerance Values	Functional Feeding Designations	Habit/ Behavior Designations	Upstream
Phylum Arthropoda				
Class Crustacea				
Order Amphidipoda				
Hyalellidae				
Hyalella sp.	7.75	GC		**8**
Class Insecta				
Order Coleoptera				
Hydrophilidae		PR		
Berosus sp.	8.43	PR		**1**
Tropisternis sp.	9.68	PR		**1**
Order Diptera				
Chironimidae				
subfamily Chironominae				
Microtendipes sp.	5.53	FC		**1**
Polypedilum illinoense grp	9	SH		**1**
subfamily Tanypodinae				
Conchapelopia Group	8.42	PR		**1**
Empididae	7.57	PR	sp	**1**
Simuliidae				
Simulium sp.	4	FC		**5**
Order Ephemeroptera				
Baetidae				
Baetis pluto	4.28	GC	sw	**18**
Ephemerellidae				
Serratella difciens	2.75	GC		**3**
Heptageniidae				
Stenonema sp.		SC		**4**
Stenonema modestum	5.5	SC	cn	**11**
Order Heteroptera				
Corixidae				
Trichocorixa sp.		PR		**1**
Order Orthoptera				**1**
Order Odonata				
Aeshnidae				
Anax sp.		PR		
Basiaeschna janata	7.35	PR		**2**
Calopterygidae		PR		
Calopteryx maculata	7.78	PR		**8**
Order Trichoptera				
Hydropsychidae		FC		
Cheumatopsyche sp.	6.22	FC		**5**
Hydropsyche betteni	7.78	FC		**1**

Stream Name: Bob's Creek restored
Sample Date: 2003

Tolerance Values

Tolerance values were taken from *NCDWQ Master List of Benthic Macroinvertebrates*

Funtional Feeding Designations

PA	Parasite	FC	Filter/collector
PR	Predator	SC	Scraper
OM	Omnivore	SH	Shredder
GC	Gatherer/collector	PI	Piercer

Habit/Behavior Designations

cn	clinger	sw	swimmer
cb	climber	dv	diver
sp	sprawler	sk	skater
bu	burrower		

	Tolerance Values	Functional Feeding Designations	Habit/ Behavior Designations	Restored
Phylum Annelida				
Class Oligochaeta	6	GC		**1**
Class Insecta				
Order Coleoptera				
Dryopidae				
Helichus sp.	4.6	SH	cb	**1**
Elmidae				
Macronychus glabratus	4.58	OM	cn	**1**
Optioservus sp.	2.36	SC		
Stenelmis sp.	5.1	SC		**1**
Gyrinidae				
Dineutus sp.	5.54	PR	sw	**5**
Psephenidae				
Ectopria sp.	4.16	SC		**1**
Psephenus herricki	2.35	SC		**5**
Order Diptera				
Chironimidae				
subfamily Chironominae				
Microtendipes sp.	5.53	FC		
Polypedilum aviceps	3.65	SH		**3**
Polypedilum illinoense grp	9	SH		**1**
subfamily Orthocladiinae				
Cardiocladius sp.	5.87	PR	cn	**4**
Corynoneura sp.	6.01	GC		**1**
Nanocladius sp.	7.07	GC		**1**
Parametriocnemus sp.	3.65	GC	sp	**3**
Thienemanniella sp.	5.86	GC		**1**
Tvetina ba varcia grp (E sp1)	3.65	GC		**2**
subfamily Tanypodinae				
Ablabesmyia mallochi	7.19	OM		**1**
Hayesomyia sp.		PR	sp	**1**
Dixidae				
Dixa sp.	2.55	GC		
Simuliidae				
Simulium sp.	4	FC		**21**
Tipulidae				
Antocha sp.	4.25	GC		**1**
Order Ephemeroptera				
Baetidae				
Baetis intercalaris	4.99	OM		**55**
Plauditus sp.				**6**
Pseudocloeon sp.		SC		**1**
Heptageniidae				
Stenonema modestum	5.5	SC	cn	**13**
Isonychiidae				
Isonychia sp.	3.45	FC	sw	**1**
Leptophlebiidae				
Paraleptophlebia sp.	0.94	GC	sw	**1**
Order Megaloptera				
Corydalidae				
Nigronia serricornis	4.95	PR	cn	**3**
Order Plecoptera				
Leutridae				
Leuctra sp.	0.67	SH	sp	**12**
Nemouridae				
Amphinemeura sp.	3.33	SH		**1**
Peltoperlidae				
Tallaperla sp.	1.2		cn	**9**
Perlidae		PR		
Acroneuria abnormis	2.06	PR		**4**
Perlesta placida	4.72	PR		**8**
Order Odonata				
Gomphidae				
Lanthus sp.	1.77	PR		**2**
Ophiogomphus sp.	5.54	PR	bu	**13**
Order Trichoptera				
Hydropsychidae		FC		
Ceratopsyche sparna	2.72	FC		**2**
Cheumatopsyche sp.	6.22	FC		**7**
Hydropsyche betteni	7.78	FC		**6**
Hydropsyche venularis	4.96	FC		**1**
Philopotamidae				
Dolophilodes sp.	0.81	GC		**5**
Rhyacophilidae				
Rhyacophila sp.		PR		**1**
Rhyacophila carolina	0	PR		**2**
Rhyacophila fuscula	1.88	PR		**1**

Stream Name: Bob's Creek upstream
Sample Date: 2003

Tolerance Values

Tolerance values were taken from *NCDWQ Master List of Benthic Macroinvertebrates*

Funtional Feeding Designations

PA	Parasite	FC	Filter/collector
PR	Predator	SC	Scraper
OM	Omnivore	SH	Shredder
GC	Gatherer/collector	PI	Piercer

Habit/Behavior Designations

cn	clinger	sw	swimmer
cb	climber	dv	diver
sp	sprawler	sk	skater
bu	burrower		

	Tolerance Values	Functional Feeding Designations	Habit/ Behavior Designations	Upstream
Phylum Annelida				
Class Oligochaeta	6	GC		**2**
Class Insecta				
Order Coleoptera				
Dryopidae				
Helichus sp.	4.6	SH	cb	**3**
Elmidae				
Macronychus glabratus	4.58	OM	cn	**1**
Optioservus sp.	2.36	SC		**1**
Stenelmis sp.	5.1	SC		
Gyrinidae				
Dineutus sp.	5.54	PR	sw	**1**
Psephenidae				
Ectopria sp.	4.16	SC		
Psephenus herricki	2.35	SC		**8**
Ptilodactylidae				
Anchytarsus bicolor	3.64	SH	sp	**2**
Order Diptera				
Chironimidae				
subfamily Chironominae				
Microtendipes sp.	5.53	FC		**1**
Polypedilum aviceps	3.65	SH		**3**
Polypedilum illinoense grp	9	SH		
subfamily Orthocladiinae				
Nanocladius sp.	7.07	GC		**1**
Thienemanniella sp.	5.86	GC		**1**
subfamily Tanypodinae				
Ablabesmyia mallochi	7.19	OM		
Conchapelopia Group	8.42	PR		**1**
Hayesomyia sp.		PR	sp	**1**
Dixidae				
Dixa sp.	2.55	GC		**1**
Simuliidae				
Simulium sp.	4	FC		**3**
Tipulidae				
Antocha sp.	4.25	GC		
Dicranota sp.	0	PR		**1**
Hexatoma sp.	4.31	PR	bu	**3**
Order Ephemeroptera				
Baetidae				
Baetis intercalaris	4.99	OM		**6**
Plauditus sp.				
Pseudocloeon sp.		SC		**1**
Heptageniidae				
Epeorus sp.	1.27	SC	cn	**1**
Stenonema sp.		SC		**11**
Stenonema exiguum	3.83	OM		**1**
Stenonema modestum	5.5	SC	cn	**8**
Isonychiidae				
Isonychia sp.	3.45	FC	sw	**1**
Order Megaloptera				
Corydalidae				
Nigronia serricornis	4.95	PR	cn	**6**
Order Plecoptera				
Leutridae				
Leuctra sp.	0.67	SH	sp	**30**
Nemouridae				
Amphinemeura sp.	3.33	SH		
Peltoperlidae				
Tallaperla sp.	1.2		cn	**15**
Perlidae		PR		**2**
Acroneuria abnormis	2.06	PR		**3**
Perlesta placida	4.72	PR		**1**
Order Odonata				
Aeshnidae				
Boyeria vinosa	5.89	PR	cb	**1**
Gomphidae				
Lanthus sp.	1.77	PR		**2**
Ophiogomphus sp.	5.54	PR	bu	**1**
Order Trichoptera				
Hydropsychidae		FC		**1**
Ceratopsyche sparna	2.72	FC		
Cheumatopsyche sp.	6.22	FC		**2**
Philopotamidae				
Dolophilodes sp.	0.81	GC		**21**
Rhyacophilidae				
Rhyacophila sp.		PR		**1**

Stream Name: Edsel restored

Sample Date: 2003

Tolerance Values

Tolerance values were taken from *NCDWQ Master List of Benthic Macroinvertebrates*

Funtional Feeding Designations

PA	Parasite	FC	Filter/collector
PR	Predator	SC	Scraper
OM	Omnivore	SH	Shredder
GC	Gatherer/collector	PI	Piercer

Habit/Behavior Designations

cn	clinger	sw	swimmer
cb	climber	dv	diver
sp	sprawler	sk	skater
bu	burrower		

Taxon	Tolerance Values	Functional Feeding Designations	Habit/ Behavior Designations	Restored
Phylum Annelida				
Class Oligochaeta	6	GC		**2**
Phylum Arthropoda				
Class Crustacea				
Order Decapoda				
Cambaridae		GC		**2**
Class Insecta				
Order Diptera				
Chironimidae				
subfamily Chironominae				
Chironomus sp.	9.63	GC		**2**
Polypedilum illinoense grp	9	SH		**3**
Polypedilum scalaenum grp	8.4	SH		**3**
subfamily Tanypodinae				
Ablabesmyia mallochi	7.19	OM		
Hayesomyia sp.		PR	sp	
Natarsia sp.	9.95	PR	sp	**4**
Zavrelimyia sp.	9.11			**1**
Simuliidae				
Simulium sp.	4	FC		**34**
Tipulidae				
Tipula sp.	7.33	SH		**1**
Order Ephemeroptera				
Baetidae				
Baetis intercalaris	4.99	OM		**21**
Order Heteroptera				
Veliidae				
Microvelia sp.		PR		**1**
Order Orthoptera				**1**
Order Trichoptera				
Hydropsychidae		FC		
Cheumatopsyche sp.	6.22	FC		**10**
Hydropsyche betteni	7.78	FC		**5**

Stream Name: Edsel upstream

Sample Date: 2003

Tolerance Values

Tolerance values were taken from *NCDWQ Master List of Benthic Macroinvertebrates*

Funtional Feeding Designations

PA	Parasite	FC	Filter/collector
PR	Predator	SC	Scraper
OM	Omnivore	SH	Shredder
GC	Gatherer/collector	PI	Piercer

Habit/Behavior Designations

cn	clinger	sw	swimmer
cb	climber	dv	diver
sp	sprawler	sk	skater
bu	burrower		

Taxon	Tolerance Values	Functional Feeding Designations	Habit/ Behavior Designations	Upstream
Phylum Annelida				
Class Oligochaeta	6	GC		**2**
Phylum Arthropoda				
Class Crustacea				
Order Decapoda				
Cambaridae		GC		**4**
Class Insecta				
Order Diptera				
Chironimidae				
subfamily Chironominae				
Polypedilum illinoense grp	9	SH		**1**
Polypedilum scalaenum grp	8.4	SH		**2**
subfamily Tanypodinae				
Ablabesmyia mallochi	7.19	OM		**1**
Hayesomyia sp.		PR	sp	**2**
Natarsia sp.	9.95	PR	sp	**1**
Zavrelimyia sp.	9.11			
Simuliidae				
Simulium sp.	4	FC		**6**
Order Ephemeroptera				
Baetidae				
Baetis intercalaris	4.99	OM		**14**
Order Trichoptera				
Hydropsychidae		FC		
Cheumatopsyche sp.	6.22	FC		**1**
Hydropsyche betteni	7.78	FC		**2**

Stream Name: Sedgefield restored

Sample Date: 2003

Tolerance Values

Tolerance values were taken from *NCDWQ Master List of Benthic Macroinvertebrates*

Funtional Feeding Designations

PA	Parasite	FC	Filter/collector
PR	Predator	SC	Scraper
OM	Omnivore	SH	Shredder
GC	Gatherer/collector	PI	Piercer

Habit/Behavior Designations

cn	clinger	sw	swimmer
cb	climber	dv	diver
sp	sprawler	sk	skater
bu	burrower		

Taxon	Tolerance Values	Functional Feeding Designations	Habit/ Behavior Designations	Restored
Phylum Annelida				
Class Oligochaeta	6	GC		**3**
Class Insecta				
Order Coleoptera				
Hydrophilidae		PR		
Enochrus sp.	8.75	GC		**1**
Order Diptera				
Chironimidae				
subfamily Chironominae				
Chironomus sp.	9.63	GC		
Phaenopsectra sp.	6.5	SC		**1**
Polypedilum illinoense grp	9	SH		**8**
Rheotanytarsus sp.	5.89	FC		**1**
subfamily Orthocladiinae				
Cricotopus bicinctus C/O sp 1	8.54	OM		**6**
Cricotopus sylvestris grp		OM		**2**
Eukiefferiella claripennis	5.58	GC		**2**
Orthocladius dorenus C/O sp 7	5.57	GC		**2**
Rheocricotopus sp.	7.3	GC		**1**
subfamily Tanypodinae				
Conchapelopia Group	8.42	PR		**2**
Hayesomyia sp.		PR	sp	**9**
Empididae	7.57	PR	sp	
Simuliidae				
Simulium sp.	4	FC		**17**
Order Ephemeroptera				
Baetidae				
Baetis intercalaris	4.99	OM		**34**
Order Heteroptera				
Saldidae		PR		**1**
Order Odonata				
Calopterygidae		PR		
Calopteryx maculata	7.78	PR		**1**
Coenagrionidae				
Ischnura sp.	9.52	PR	cb	**2**
Order Trichoptera				
Hydropsychidae		FC		**2**
Cheumatopsyche sp.	6.22	FC		**13**
Hydropsyche sp.		FC		**6**
Hydropsyche betteni	7.78	FC		**31**

Stream Name: Sedgefield upstream

Sample Date: 2003

Tolerance Values

Tolerance values were taken from *NCDWQ Master List of Benthic Macroinvertebrates*

Funtional Feeding Designations

PA	Parasite	FC	Filter/collector
PR	Predator	SC	Scraper
OM	Omnivore	SH	Shredder
GC	Gatherer/collector	PI	Piercer

Habit/Behavior Designations

cn	clinger	sw	swimmer
cb	climber	dv	diver
sp	sprawler	sk	skater
bu	burrower		

Taxon	Tolerance Values	Functional Feeding Designations	Habit/ Behavior Designations	Upstream
Phylum Annelida				
Class Oligochaeta	6	GC		**1**
Phylum Arthropoda				
Class Crustacea				
Order Decapoda				
Cambaridae		GC		**4**
Class Insecta				
Order Diptera				
Chironimidae				
subfamily Chironominae				
Chironomus sp.	9.63	GC		**1**
Phaenopsectra sp.	6.5	SC		
Polypedilum illinoense grp	9	SH		**1**
Rheotanytarsus sp.	5.89	FC		**1**
subfamily Tanypodinae				
Conchapelopia Group	8.42	PR		
Hayesomyia sp.		PR	sp	**9**
Empididae	7.57	PR	sp	**1**
Simuliidae				
Simulium sp.	4	FC		**3**
Tipulidae				
Tipula sp.	7.33	SH		**1**
Order Ephemeroptera				
Baetidae				
Baetis intercalaris	4.99	OM		**19**
Order Trichoptera				
Hydropsychidae		FC		
Cheumatopsyche sp.	6.22	FC		**8**
Hydropsyche sp.		FC		
Hydropsyche betteni	7.78	FC		**2**

Stream Name: Kraft restored
Sample Date: 2003

Tolerance Values

Tolerance values were taken from *NCDWQ Master List of Benthic Macroinvertebrates*

Funtional Feeding Designations

PA	Parasite	FC	Filter/collector
PR	Predator	SC	Scraper
OM	Omnivore	SH	Shredder
GC	Gatherer/collector	PI	Piercer

Habit/Behavior Designations

cn	clinger	sw	swimmer
cb	climber	dv	diver
sp	sprawler	sk	skater
bu	burrower		

	Tolerance Values	Functional Feeding Designations	Habit/ Behavior Designations	Restored
Phylum Arthropoda				
Class Crustacea				
Order Decapoda				
Cambaridae		GC		
Class Insecta				
Order Coleoptera				
Hydrophilidae		PR		
Helochares maculicollis		OM		**1**
Psephenidae				
Ectopria sp.	4.16	SC		
Psephenus herricki	2.35	SC		**2**
Order Diptera				
Chironimidae				
subfamily Chironominae				
Polypedilum aviceps	3.65	SH		**3**
subfamily Orthocladiinae				
Parametriocnemus sp.	3.65	GC	sp	**2**
Simuliidae				
Simulium sp.	4	FC		**16**
Tipulidae				
Antocha sp.	4.25	GC		**3**
Order Ephemeroptera				
Baetidae				
Baetis intercalaris	4.99	OM		**13**
Baetis pluto	4.28	GC	sw	**5**
Plauditus sp.				**5**
Pseudocloeon sp.		SC		**10**
Caenidae				
Caenis sp.	7.41	GC	sp	**1**
Heptageniidae				
Stenonema sp.		SC		**2**
Stenonema modestum	5.5	SC	cn	**3**
Isonychiidae				
Isonychia sp.	3.45	FC	sw	**7**
Leptophlebiidae				
Paraleptophlebia sp.	0.94	GC	sw	**2**
Order Plecoptera				
Leutridae				
Leuctra sp.	0.67	SH	sp	**14**
Peltoperlidae				
Tallaperla sp.	1.2		cn	**1**
Perlidae		PR		
Acroneuria abnormis	2.06	PR		**3**
Order Odonata				
Aeshnidae				
Boyeria vinosa	5.89	PR	cb	**1**
Gomphidae				
Ophiogomphus sp.	5.54	PR	bu	**3**
Stylogomphus albistylus	4.72	PR		**2**
Order Trichoptera				
Hydropsychidae		FC		
Cheumatopsyche sp.	6.22	FC		**1**
Limnephilidae				
Pycnopsyche scabripennis	2.5	SH		**1**

Stream Name: Kraft upstream
Sample Date: 2003

Tolerance Values

Tolerance values were taken from *NCDWQ Master List of Benthic Macroinvertebrates*

Funtional Feeding Designations

PA	Parasite	FC	Filter/collector
PR	Predator	SC	Scraper
OM	Omnivore	SH	Shredder
GC	Gatherer/collector	PI	Piercer

Habit/Behavior Designations

cn	clinger	sw	swimmer
cb	climber	dv	diver
sp	sprawler	sk	skater
bu	burrower		

	Tolerance Values	Functional Feeding Designations	Habit/ Behavior Designations	Upstream
Phylum Arthropoda				
Class Crustacea				
Order Decapoda				
Cambaridae		GC		**2**
Class Insecta				
Order Coleoptera				
Dryopidae				
Helichus sp.	4.6	SH	cb	**1**
Elmidae				
Optioservus sp.	2.36	SC		**1**
Psephenidae				
Ectopria sp.	4.16	SC		**1**
Psephenus herricki	2.35	SC		**8**
Order Diptera				
Chironimidae				
subfamily Chironominae				
Polypedilum aviceps	3.65	SH		**1**
Dixidae				
Dixa sp.	2.55	GC		**3**
Simuliidae				
Simulium sp.	4	FC		**4**
Tipulidae				
Antocha sp.	4.25	GC		**2**
Dicranota sp.	0	PR		**1**
Order Ephemeroptera				
Baetidae				
Baetis intercalaris	4.99	OM		**8**
Baetis pluto	4.28	GC	sw	**11**
Plauditus sp.				**11**
Pseudocloeon sp.		SC		**2**
Ephemerellidae				
Serratella difciens	2.75	GC		**1**
Heptageniidae				
Epeorus sp.	1.27	SC	cn	**6**
Epeorus dispar	1.03	SC		**1**
Stenacron pallidum	2.72	OM		**1**
Stenonema sp.		SC		**10**
Stenonema modestum	5.5	SC	cn	**9**
Isonychiidae				
Isonychia sp.	3.45	FC	sw	**7**
Leptophlebiidae				
Paraleptophlebia sp.	0.94	GC	sw	**15**
Order Megaloptera				
Corydalidae				
Corydalus cornutus	5.16	PR	cn	**1**
Order Plecoptera				
Leutridae				
Leuctra sp.	0.67	SH	sp	**23**
Perlidae		PR		
Acroneuria abnormis	2.06	PR		**10**
Perlesta placida	4.72	PR		**2**
Perlodidae				
Isoperla holochlora	0	PR		**1**
Order Odonata				
Aeshnidae				
Boyeria vinosa	5.89	PR	cb	**1**
Gomphidae				
Ophiogomphus sp.	5.54	PR	bu	**5**
Order Trichoptera				
Glossosomatidae				
Glossosoma sp.	1.55	SC		**1**
Hydropsychidae		FC		
Ceratopsyche sparna	2.72	FC		**6**
Cheumatopsyche sp.	6.22	FC		**2**
Philopotamidae				
Dolophilodes sp.	0.81	GC		**7**
Polycentropodidae				
Polycentropus sp.	3.53	PR	cn	**1**
Psychomyiidae				
Lype diversa	4.05	SC		**1**
Psychomyia flavida	2.91	SC		**2**
Uenoidae				
Neophylax sp.	2.2	SC		**1**

Stream Name: Brushy Fork restored
Sample Date: 2003

Tolerance Values

Tolerance values were taken from *NCDWQ Master List of Benthic Macroinvertebrates*

Funtional Feeding Designations

PA	Parasite	FC	Filter/collector
PR	Predator	SC	Scraper
OM	Omnivore	SH	Shredder
GC	Gatherer/collector	PI	Piercer

Habit/Behavior Designations

cn	clinger	sw	swimmer
cb	climber	dv	diver
sp	sprawler	sk	skater
bu	burrower		

	Tolerance Values	Functional Feeding Designations	Habit/ Behavior Designations	Restored
Phylum Annelida				
Class Oligochaeta	6	GC		**1**
Phylum Arthropoda				
Class Crustacea				
Order Decapoda				
Cambaridae		GC		**1**
Class Insecta				
Order Coleoptera				
Elmidae				
Optioservus sp.	2.36	SC		**1**
Stenelmis sp.	5.1	SC		**1**
Order Diptera				
Chironimidae				
subfamily Chironominae				
Cryptochironomus sp.	6.4	PR		**1**
Microtendipes sp.	5.53	FC		**1**
Phaenopsectra sp.	6.5	SC		
Polypedilum aviceps	3.65	SH		**10**
Polypedilum flavum		SH		**2**
Polypedilum illinoense grp	9	SH		**1**
Rheotanytarsus sp.	5.89	FC		**1**
Tanytarsus sp.	6.76	FC		**1**
subfamily Orthocladiinae				
Cardiocladius sp.	5.87	PR	cn	**4**
Cricotopus bicinctus C/O sp 1	8.54	OM		**1**
Cricotopus triannulatus, C. infuscatus C/O sp 5	9.04			**22**
Eukiefferiella claripennis	5.58	GC		**7**
Parametriocnemus sp.	3.65	GC	sp	**2**
Thienemanniella sp.	5.86	GC		**5**
subfamily Tanypodinae				
Conchapelopia Group	8.42	PR		**4**
Hayesomyia sp.		PR	sp	**5**
Natarsia sp.	9.95	PR	sp	**1**
Simuliidae				
Simulium sp.	4	FC		**18**
Tipulidae				
Antocha sp.	4.25	GC		**7**
Dicranota sp.	0	PR		**2**
Hexatoma sp.	4.31	PR	bu	**3**
Tipula sp.	7.33	SH		
Order Ephemeroptera				
Baetidae				**1**
Accentrella sp.	4	GC	sw	**3**
Baetis intercalaris	4.99	OM		**69**
Baetis pluto	4.28	GC	sw	**20**
Centroptilium sp.	6.6	GC		
Plauditus sp.				**13**
Pseudocloeon sp.		SC		**19**
Caenidae				
Caenis sp.	7.41	GC	sp	**2**
Ephemerellidae				
Serratella difciens	2.75	GC		**2**
Heptageniidae				
Stenonema sp.		SC		
Stenonema modestum	5.5	SC	cn	**23**
Leptophlebiidae				
Paraleptophlebia sp.	0.94	GC	sw	**8**
Order Megaloptera				
Corydalidae				
Corydalus cornutus	5.16	PR	cn	**1**
Nigronia serricornis	4.95	PR	cn	**6**
Order Plecoptera				
Leutridae				
Leuctra sp.	0.67	SH	sp	**19**
Perlidae		PR		**1**
Acroneuria abnormis	2.06	PR		**1**
Order Odonata				
Aeshnidae				
Boyeria grafiana	6.05	PR		**1**
Boyeria vinosa	5.89	PR	cb	**3**
Calopterygidae		PR		
Calopteryx maculata	7.78	PR		**1**
Gomphidae				
Lanthus sp.	1.77	PR		**2**
Stylogomphus albistylus	4.72	PR		**2**
Order Trichoptera				
Glossosomatidae				
Glossosoma sp.	1.55	SC		**1**
Hydropsychidae		FC		
Ceratopsyche sparna	2.72	FC		**6**
Cheumatopsyche sp.	6.22	FC		**8**
Hydropsyche sp.		FC		**6**
Hydropsyche betteni	7.78	FC		**14**

Stream Name: Brushy Fork upstream
Sample Date: 2003

Tolerance Values

Tolerance values were taken from *NCDWQ Master List of Benthic Macroinvertebrates*

Funtional Feeding Designations

PA	Parasite	FC	Filter/collector
PR	Predator	SC	Scraper
OM	Omnivore	SH	Shredder
GC	Gatherer/collector	PI	Piercer

Habit/Behavior Designations

cn	clinger	sw	swimmer
cb	climber	dv	diver
sp	sprawler	sk	skater
bu	burrower		

	Tolerance Values	Functional Feeding Designations	Habit/ Behavior Designations	Upstream
Phylum Annelida				
Class Oligochaeta	6	GC		
Phylum Arthropoda				
Class Crustacea				
Order Decapoda				
Cambaridae		GC		**2**
Class Insecta				
Order Coleoptera				
Dytiscidae				
Laccophilus sp.		PR		**1**
Elmidae				
Macronychus glabratus	4.58	OM	cn	**1**
Optioservus sp.	2.36	SC		
Stenelmis sp.	5.1	SC		
Gyrinidae				
Dineutus sp.	5.54	PR	sw	**1**
Hydrophilidae		PR		
Tropisternis sp.	9.68	PR		**1**
Order Diptera				
Chironimidae				
subfamily Chironominae				
Cryptochironomus sp.	6.4	PR		**3**
Microtendipes sp.	5.53	FC		**6**
Phaenopsectra sp.	6.5	SC		**4**
Polypedilum aviceps	3.65	SH		**2**
Polypedilum flavum		SH		**3**
Polypedilum illinoense grp	9	SH		
Rheotanytarsus sp.	5.89	FC		**2**
Tanytarsus sp.	6.76	FC		**1**
subfamily Orthocladiinae				
Cardiocladius sp.	5.87	PR	cn	
Cricotopus bicinctus C/O sp 1	8.54	OM		
Cricotopus triannulatus, C. infuscatus C/O sp 5	9.04			
Eukiefferiella claripennis	5.58	GC		
Parametriocnemus sp.	3.65	GC	sp	**1**
Thienemanniella sp.	5.86	GC		
subfamily Tanypodinae				
Conchapelopia Group	8.42	PR		
Hayesomyia sp.		PR	sp	**3**
Natarsia sp.	9.95	PR	sp	
Simuliidae				
Simulium sp.	4	FC		**8**
Tipulidae				
Antocha sp.	4.25	GC		
Dicranota sp.	0	PR		
Hexatoma sp.	4.31	PR	bu	
Tipula sp.	7.33	SH		**1**
Order Ephemeroptera				
Baetidae				
Accentrella sp.	4	GC	sw	
Baetis intercalaris	4.99	OM		**11**
Baetis pluto	4.28	GC	sw	**4**
Centroptilium sp.	6.6	GC		**2**
Plauditus sp.				**6**
Pseudocloeon sp.		SC		**15**
Caenidae				
Caenis sp.	7.41	GC	sp	**1**
Ephemerellidae				
Serratella difciens	2.75	GC		
Heptageniidae				**1**
Stenonema sp.		SC		**1**
Stenonema modestum	5.5	SC	cn	**10**
Order Megaloptera				
Corydalidae				
Corydalus cornutus	5.16	PR	cn	
Nigronia serricornis	4.95	PR	cn	**1**
Order Plecoptera				
Leutridae				
Leuctra sp.	0.67	SH	sp	**3**
Perlidae		PR		
Acroneuria abnormis	2.06	PR		**1**
Order Odonata				
Aeshnidae				
Boyeria grafiana	6.05	PR		
Boyeria vinosa	5.89	PR	cb	**3**
Gomphidae				
Lanthus sp.	1.77	PR		**2**
Stylogomphus albistylus	4.72	PR		**2**
Order Trichoptera				
Hydropsychidae		FC		
Ceratopsyche sparna	2.72	FC		**1**
Cheumatopsyche sp.	6.22	FC		**1**

Stream Name: Little Warrior restored
Sample Date: 2003

Tolerance Values

Tolerance values were taken from *NCDWQ Master List of Benthic Macroinvertebrates*

Funtional Feeding Designations

PA	Parasite	FC	Filter/collector
PR	Predator	SC	Scraper
OM	Omnivore	SH	Shredder
GC	Gatherer/collector	PI	Piercer

Habit/Behavior Designations

cn	clinger	sw	swimmer
cb	climber	dv	diver
sp	sprawler	sk	skater
bu	burrower		

				Tolerance Values	Functional Feeding Designations	Habit/ Behavior Designations	Restored
Class Insecta							
	Order Coleoptera						
		Haliplidae					
			Peltodytes sp.	8.73	SH		**1**
		Hydrophilidae			PR		
			Enochrus sp.	8.75	GC		**1**
		Ptilodactylidae					
			Anchytarsus bicolor	3.64	SH	sp	
	Order Diptera						
		Chironimidae					
		subfamily	Chironominae				
			Polypedilum flavum		SH		9
			Polypedilum illinoense grp	9	SH		
		subfamily	Tanypodinae				
			Conchapelopia Group	8.42	PR		**4**
		Dixidae					
			Dixa sp.	2.55	GC		
		Simuliidae					
			Simulium sp.	4	FC		**18**
		Tipulidae					
			Tipula sp.	7.33	SH		
	Order Ephemeroptera						
		Baetidae					
			Baetis intercalaris	4.99	OM		**6**
			Baetis pluto	4.28	GC	sw	**15**
			Pseudocloeon sp.		SC		**7**
		Ephemeridae					
			Ephemera blanda	2.24	GC		**1**
		Heptageniidae					
			Stenonema modestum	5.5	SC	cn	**1**
		Tricorythidae					
			Tricorythodes sp.	5.06	GC	sp	**1**
	Order Lepidoptera						
		Noctuiidae			SH		
	Order Megaloptera						
		Corydalidae					
			Corydalus cornutus	5.16	PR	cn	**1**
			Nigronia fasciatus	5.55	PR		
	Order Orthoptera						**1**
	Order Plecoptera						
		Leutridae					
			Leuctra sp.	0.67	SH	sp	**1**
	Order Odonata						
		Aeshnidae					
			Boyeria grafiana	6.05	PR		**1**
			Boyeria vinosa	5.89	PR	cb	**2**
		Calopterygidae			PR		
			Calopteryx maculata	7.78	PR		**9**
			Hetaerina sp.	5.61	PR		
		Coenagrionidae					
			Argia sp.	8.17	PR		**2**
		Gomphidae			PR		**1**
	Order Trichoptera						
		Hydropsychidae			FC		**4**
			Cheumatopsyche sp.	6.22	FC		**3**
			Diplectrona modesta	2.21	FC	cn	
			Hydropsyche sp.		FC		**2**
			Hydropsyche betteni	7.78	FC		**20**

Stream Name: Little Warrior upstream
Sample Date: 2003

Tolerance Values

Tolerance values were taken from *NCDWQ Master List of Benthic Macroinvertebrates*

Funtional Feeding Designations

PA	Parasite	FC	Filter/collector
PR	Predator	SC	Scraper
OM	Omnivore	SH	Shredder
GC	Gatherer/collector	PI	Piercer

Habit/Behavior Designations

cn	clinger	sw	swimmer
cb	climber	dv	diver
sp	sprawler	sk	skater
bu	burrower		

				Tolerance Values	Functional Feeding Designations	Habit/ Behavior Designations	Upstream
Class Insecta							
	Order Coleoptera						
		Haliplidae					
			Peltodytes sp.	8.73	SH		
		Hydrophilidae			PR		
			Enochrus sp.	8.75	GC		
		Ptilodactylidae					
			Anchytarsus bicolor	3.64	SH	sp	**2**
	Order Diptera						
		Chironimidae					
		subfamily Chironominae					
			Polypedilum flavum		SH		
			Polypedilum illinoense grp	9	SH		**1**
		Dixidae					
			Dixa sp.	2.55	GC		**1**
		Tipulidae					
			Tipula sp.	7.33	SH		**1**
	Order Ephemeroptera						
		Ephemeridae					
			Ephemera blanda	2.24	GC		**1**
	Order Lepidoptera						
		Noctuiidae			SH		**1**
	Order Megaloptera						
		Corydalidae					
			Corydalus cornutus	5.16	PR	cn	
			Nigronia fasciatus	5.55	PR		**3**
	Order Orthoptera						
	Order Plecoptera						
		Leutridae					
			Leuctra sp.	0.67	SH	sp	**74**
		Peltoperlidae					
			Tallaperla sp.	1.2		cn	**1**
		Perlidae			PR		**1**
			Acroneuria sp.		PR		
		Perlodidae			PR		**4**
	Order Odonata						
		Calopterygidae			PR		**1**
	Order Trichoptera						
		Hydropsychidae			FC		
			Diplectrona modesta	2.21	FC	cn	**37**

Stream Name: Big Warrior restored
Sample Date: 2003

Tolerance Values

Tolerance values were taken from *NCDWQ Master List of Benthic Macroinvertebrates*

Funtional Feeding Designations

PA	Parasite	FC	Filter/collector
PR	Predator	SC	Scraper
OM	Omnivore	SH	Shredder
GC	Gatherer/collector	PI	Piercer

Habit/Behavior Designations

cn	clinger	sw	swimmer
cb	climber	dv	diver
sp	sprawler	sk	skater
bu	burrower		

	Tolerance Values	Functional Feeding Designations	Habit/ Behavior Designations	Restored
Phylum Annelida				
Class Oligochaeta	6	GC		
Class Insecta				
Order Coleoptera				
Hydrophilidae		PR		
Tropisternis sp.	9.68	PR		**1**
Psephenidae				
Psephenus herricki	2.35	SC		**3**
Order Diptera				
Chironimidae				
subfamily Chironominae				
Polypedilum flavum		SH		**1**
Rheotanytarsus sp.	5.89	FC		**1**
subfamily Orthocladiinae				
Brillia sp.	5.18	SH		
Cardiocladius sp.	5.87	PR	cn	**5**
Eukiefferiella brehmi group	2.72	GC		**7**
Eukiefferiella claripennis	5.58	GC		**3**
Parametriocnemus sp.	3.65	GC	sp	
Thienemanniella sp.	5.86	GC		**1**
subfamily Tanypodinae				
Conchapelopia Group	8.42	PR		**2**
Hayesomyia sp.		PR	sp	**2**
Zavrelimyia sp.	9.11			
Simuliidae				
Simulium sp.	4	FC		**22**
Tipulidae				
Antocha sp.	4.25	GC		**1**
Helius sp.		GC	bu	
Tipula sp.	7.33	SH		**1**
Order Ephemeroptera				
Baetidae				
Accentrella sp.	4	GC	sw	**3**
Baetis intercalaris	4.99	OM		**34**
Baetis pluto	4.28	GC	sw	**12**
Plauditus sp.				**14**
Pseudocloeon sp.		SC		**3**
Caenidae				
Caenis sp.	7.41	GC	sp	**1**
Ephemerellidae				
Serratella difciens	2.75	GC		**2**
Heptageniidae				
Stenonema modestum	5.5	SC	cn	**5**
Isonychiidae				
Isonychia sp.	3.45	FC	sw	
Leptophlebiidae				
Paraleptophlebia sp.	0.94	GC	sw	**2**
Tricorythidae				
Tricorythodes sp.	5.06	GC	sp	**1**
Order Heteroptera				
Gelastocoridae				
Gelostocoris sp.		PR	sk	**1**
Order Plecoptera				
Leutridae				
Leuctra sp.	0.67	SH	sp	**9**
Peltoperlidae				
Tallaperla sp.	1.2		cn	**4**
Perlidae		PR		
Acroneuria abnormis	2.06	PR		**1**
Acroneuria arenosa	2.3	PR		
Order Odonata				
Aeshnidae				
Boyeria vinosa	5.89	PR	cb	**1**
Calopterygidae		PR		
Calopteryx maculata	7.78	PR		**3**
Gomphidae		PR		
Dromogomphus spinosus	5.92	PR		
Ophiogomphus sp.	5.54	PR	bu	**7**
Order Trichoptera				
Glossosomatidae				
Glossosoma sp.	1.55	SC		
Hydropsychidae		FC		**4**
Ceratopsyche sparna	2.72	FC		**2**
Cheumatopsyche sp.	6.22	FC		**2**
Diplectrona modesta	2.21	FC	cn	**2**
Hydropsyche sp.		FC		
Hydropsyche betteni	7.78	FC		**8**
Philopotamidae				
Chimarra sp.	2.76	FC	cn	**2**
Dolophilodes sp.	0.81	GC		**11**

Stream Name: Big Warrior upstream
Sample Date: 2003

Tolerance Values

Tolerance values were taken from *NCDWQ Master List of Benthic Macroinvertebrates*

Funtional Feeding Designations

PA	Parasite	FC	Filter/collector
PR	Predator	SC	Scraper
OM	Omnivore	SH	Shredder
GC	Gatherer/collector	PI	Piercer

Habit/Behavior Designations

cn	clinger	sw	swimmer
cb	climber	dv	diver
sp	sprawler	sk	skater
bu	burrower		

	Tolerance Values	Functional Feeding Designations	Habit/ Behavior Designations	Upstream
Phylum Annelida				
Class Oligochaeta	6	GC		**2**
Class Insecta				
Order Coleoptera				
Elmidae				
Stenelmis sp.	5.1	SC		**2**
Gyrinidae				
Dineutus sp.	5.54	PR	sw	**2**
Order Diptera				
Chironimidae				
subfamily Chironominae				
Polypedilum flavum		SH		**1**
Rheotanytarsus sp.	5.89	FC		**1**
subfamily Orthocladiinae				
Brillia sp.	5.18	SH		**1**
Cardiocladius sp.	5.87	PR	cn	
Eukiefferiella brehmi group	2.72	GC		**2**
Eukiefferiella claripennis	5.58	GC		**1**
Parametriocnemus sp.	3.65	GC	sp	**3**
Thienemanniella sp.	5.86	GC		
subfamily Tanypodinae				
Conchapelopia Group	8.42	PR		**9**
Hayesomyia sp.		PR	sp	**1**
Zavrelimyia sp.	9.11			**1**
Empididae	7.57	PR	sp	**1**
Ptychopteridae				
Bittacomorpha claviceps		GC		**1**
Simuliidae				
Simulium sp.	4	FC		**22**
Tipulidae				
Antocha sp.	4.25	GC		
Helius sp.		GC	bu	**1**
Tipula sp.	7.33	SH		**1**
Order Ephemeroptera				
Baetidae				
Accentrella sp.	4	GC	sw	
Baetis intercalaris	4.99	OM		**1**
Baetis pluto	4.28	GC	sw	**3**
Caenidae				
Caenis sp.	7.41	GC	sp	**2**
Ephemerellidae				
Serratella difciens	2.75	GC		**14**
Heptageniidae				
Stenonema modestum	5.5	SC	cn	**37**
Isonychiidae				
Isonychia sp.	3.45	FC	sw	**8**
Order Megaloptera				
Corydalidae				
Nigronia serricornis	4.95	PR	cn	**1**
Order Plecoptera				
Leutridae				
Leuctra sp.	0.67	SH	sp	**5**
Peltoperlidae				
Tallaperla sp.	1.2		cn	**1**
Perlidae		PR		
Acroneuria arenosa	2.3	PR		**2**
Order Odonata				
Aeshnidae				
Boyeria vinosa	5.89	PR	cb	**1**
Gomphidae		PR		
Dromogomphus spinosus	5.92	PR		**1**
Ophiogomphus sp.	5.54	PR	bu	**12**
Order Trichoptera				
Glossosomatidae				
Glossosoma sp.	1.55	SC		**1**
Hydropsychidae		FC		
Ceratopsyche sparna	2.72	FC		**3**
Cheumatopsyche sp.	6.22	FC		**10**
Diplectrona modesta	2.21	FC	cn	
Hydropsyche sp.		FC		**7**
Hydropsyche betteni	7.78	FC		**66**
Philopotamidae				
Chimarra sp.	2.76	FC	cn	**10**
Dolophilodes sp.	0.81	GC		**19**
Wormaldia sp.	0.65	FC		**1**
Phylum Mollusca				
Class Pelecypoda				
Pleuroceridae				
Elimia sp.	2.46	SC		**1**

Stream Name: Bethel Church restored
Sample Date: 2003

Tolerance Values

Tolerance values were taken from *NCDWQ Master List of Benthic Macroinvertebrates*

Funtional Feeding Designations

PA	Parasite	FC	Filter/collector
PR	Predator	SC	Scraper
OM	Omnivore	SH	Shredder
GC	Gatherer/collector	PI	Piercer

Habit/Behavior Designations

cn	clinger	sw	swimmer
cb	climber	dv	diver
sp	sprawler	sk	skater
bu	burrower		

Taxon	Tolerance Values	Functional Feeding Designations	Habit/ Behavior Designations	Restored
Phylum Arthropoda				
Class Crustacea				
Order Decapoda				
Cambaridae				
Cambarus sp.	7.62	GC		**13**
Class Insecta				
Order Coleoptera				
Dryopidae				
Helichus sp.	4.6	SH	cb	**3**
Dytiscidae				
Laccophilus sp.		PR		**1**
Neoporus sp.				
Elmidae				
Macronychus glabratus	4.58	OM	cn	**1**
Stenelmis sp.	5.1	SC		**1**
Hydrophilidae		PR		
Cymbiodyta sp.			sw	
Enochrus sp.	8.75	GC		**1**
Order Diptera				
Chironimidae				
subfamily Chironominae				
Microtendipes sp.	5.53	FC		
Paracladopelma sp.	5.51	GC		**1**
Polypedilum aviceps	3.65	SH		**6**
Polypedilum flavum		SH		**3**
Polypedilum illinoense grp	9	SH		**1**
subfamily Tanypodinae				
Conchapelopia Group	8.42	PR		**3**
Hayesomyia sp.		PR	sp	**4**
Ptychopteridae				
Bittacomorpha claviceps		GC		**2**
Simuliidae				
Simulium sp.	4	FC		**60**
Tipulidae				
Limonia sp.	9.64	SH	bu	**1**
Tipula sp.	7.33	SH		**1**
Order Ephemeroptera				
Baetidae				
Baetis intercalaris	4.99	OM		**5**
Pseudocloeon sp.		SC		**20**
Order Heteroptera				
Veliidae				
Microvelia sp.		PR		**3**
Order Megaloptera				
Sialidae				
Sialis sp.	7.17	PR		**1**
Order Odonata				
Cordulegastridae				
Cordulegaster sp.	5.73	PR		
Cordulegaster maculata	5.7	PR	sp	**1**
Gomphidae		PR		
Stylogomphus albistylus	4.72	PR		**1**

Stream Name: Bethel Church upstream
Sample Date: 2003

Tolerance Values

Tolerance values were taken from *NCDWQ Master List of Benthic Macroinvertebrates*

Funtional Feeding Designations

PA	Parasite	FC	Filter/collector
PR	Predator	SC	Scraper
OM	Omnivore	SH	Shredder
GC	Gatherer/collector	PI	Piercer

Habit/Behavior Designations

cn	clinger	sw	swimmer
cb	climber	dv	diver
sp	sprawler	sk	skater
bu	burrower		

Taxon	Tolerance Values	Functional Feeding Designations	Habit/ Behavior Designations	Upstream
Phylum Arthropoda				
Class Crustacea				
Order Decapoda				
Cambaridae				
Cambarus sp.	7.62	GC		**1**
Class Insecta				
Order Coleoptera				
Dryopidae				
Helichus sp.	4.6	SH	cb	**3**
Dytiscidae				
Laccophilus sp.		PR		
Neoporus sp.				**1**
Elmidae				
Macronychus glabratus	4.58	OM	cn	
Stenelmis sp.	5.1	SC		**2**
Hydrophilidae		PR		
Cymbiodyta sp.			sw	**1**
Enochrus sp.	8.75	GC		
Order Diptera				
Chironimidae				
subfamily Chironominae				
Microtendipes sp.	5.53	FC		**1**
Paracladopelma sp.	5.51	GC		**1**
Polypedilum aviceps	3.65	SH		**1**
Polypedilum flavum		SH		**7**
Polypedilum illinoense grp	9	SH		**1**
subfamily Orthocladiinae				
Parametriocnemus sp.	3.65	GC	sp	**1**
Tvetina ba varcia grp (E sp1)	3.65	GC		**1**
subfamily Tanypodinae				
Conchapelopia Group	8.42	PR		**4**
Hayesomyia sp.		PR	sp	**2**
Culicidae				
Anopheles sp.	8.58	FC	sw	**3**
Dixidae				
Dixa sp.	2.55	GC		**5**
Simuliidae				
Simulium sp.	4	FC		**33**
Order Ephemeroptera				
Baetidae				
Baetis intercalaris	4.99	OM		**4**
Pseudocloeon sp.		SC		
Heptageniidae				**1**
Stenonema modestum	5.5	SC	cn	**2**
Order Megaloptera				
Corydalidae				
Nigronia fasciatus	5.55	PR		**1**
Nigronia serricornis	4.95	PR	cn	**1**
Order Odonata				
Cordulegastridae				
Cordulegaster sp.	5.73	PR		**1**
Order Trichoptera				
Hydropsychidae		FC		
Cheumatopsyche sp.	6.22	FC		**1**

Stream Name: Beaver restored
Sample Date: 2004

Tolerance Values

Tolerance values were taken from *NCDWQ Master List of Benthic Macroinvertebrates*

Funtional Feeding Designations

PA	Parasite	FC	Filter/collector
PR	Predator	SC	Scraper
OM	Omnivore	SH	Shredder
GC	Gatherer/collector	PI	Piercer

Habit/Behavior Designations

cn	clinger	sw	swimmer
cb	climber	dv	diver
sp	sprawler	sk	skater
bu	burrower		

	Tolerance Values	Functional Feeding Group	Habit/ Behavior Type	Total Organisms
Phylum Annelida				
Class Oligochaeta	6	GC		**3**
Class Insecta				
Order Coleoptera				
Dryopidae				
Helichus sp.	4.6	SH	cb	**1**
Dytiscidae				
Dytiscus sp.		PR	sw	**3**
Psephenidae				
Psephenus herricki	2.35	SC	cn	**3**
Ptilodactylidae				
Anchytarsus bicolor	3.64	SH	sp	**1**
Order Diptera				
Chironimidae				
subfamily Chironominae				
Microtendipes sp.	5.53	FC	cn	**3**
Phaenopsectra sp.	6.5	SC	cn	**3**
Polypedilum aviceps	3.65	SH		**3**
Zavrelia sp.	5.3	GC	sw	**1**
subfamily Diamesinae				**1**
Potthastia sp.	6.4	OM	sp	**1**
subfamily Orthocladiinae				
Brillia sp.	5.18	SH	bu	**1**
Eukiefferiella sp.	5.58	GC		**1**
Orthocladius sp.	9.11	GC		**1**
Parametriocnemus sp.	3.65	GC	sp	**1**
Dixidae				
Dixa sp.	2.55	GC	sw	**1**
Simuliidae				
Simulium sp.	4	FC	cn	**10**
Tipulidae				
Antocha sp.	4.25	GC	cn	**10**
Dicranota sp.	0	PR		**1**
Tipula sp.	7.33	SH	bu	**3**
Order Ephemeroptera				
Baetidae				
Accentrella sp.	4	GC	sw	**1**
Baetis sp.		GC	sw	**1**
Baetis intercalaris	4.99	OM	sw	**10**
Baetis flavistriga	6.58	GC	sw	**10**
Baetis pluto	4.28	GC	sw	**10**
Baetis propinquus	5.77	OM	sw	**10**
Centroptilium sp.	6.6	GC	sw	**1**
Caenidae				
Caenis sp.	7.41	GC	sp	**3**
Ephemerellidae				
Ephemerella sp.	2.04	GC	cn	**3**
Eurylophella sp.	4.34	SC	cn	**3**
Serratella difciens	2.75	GC		**10**
Heptageniidae				
Leucrocuta sp.	2.4	SC	cn	**10**
Stenonema modestum	5.5	SC	cn	**10**
Isonychiidae				
Isonychia sp.	3.45	FC	sw	**1**
Leptophlebiidae				
Paraleptophlebia sp.	0.94	GC	sw	**10**
Order Megaloptera				
Corydalidae				
Corydalus cornutus	5.16	PR	cn	**1**
Nigronia serricornis	4.95	PR	cn	**1**
Order Plecoptera				
Capniidae				
Allocapnia sp.	2.52	SH	sp	**10**
Peltoperlidae				
Tallaperla sp.	1.2	SH	cn	**1**
Perlidae				
Acroneuria abnormis	2.06	PR	cn	**3**
Perlesta sp.	4.7	PR	cn	**10**
Perlodidae		PR	cn	
Isoperla holochlora	0	PR	cn	**1**
Order Odonata				
Aeshnidae				
Boyeria vinosa	5.89	PR	cb	**3**
Calopterygidae		PR		
Calopteryx sp.	7.78	PR	cb	**3**
Gomphidae				
Stylogomphus albistylus	4.72	PR	bu	**3**
Order Trichoptera				
Glossosomatidae				
Glossosoma sp.	1.55	SC		**1**
Hydropsychidae				
Ceratopsyche sparna	2.72	FC	cn	**10**
Cheumatopsyche sp.	6.22	FC	cn	**10**
Hydropsyche sp.		FC	cn	**1**
Hydropsyche betteni	7.78	FC	cn	**3**
Limnephilidae				
Pycnopsyche sp.	2.52	SH	cn	**1**
Pycnopsyche guttifer	2.58	SH	cn	**1**
Philopotamidae				
Dolophilodes sp.	0.81	GC	cn	**1**
Uenoidae				
Neophylax sp.	2.2	SC	cn	**10**

Stream Name: Beaver upstream
Sample Date: 2004

Tolerance Values

Tolerance values were taken from *NCDWQ Master List of Benthic Macroinvertebrates*

Funtional Feeding Designations

PA	Parasite	FC	Filter/collector
PR	Predator	SC	Scraper
OM	Omnivore	SH	Shredder
GC	Gatherer/collector	PI	Piercer

Habit/Behavior Designations

cn	clinger	sw	swimmer
cb	climber	dv	diver
sp	sprawler	sk	skater
bu	burrower		

	Tolerance Values	Functional Feeding Group	Habit/ Behavior Type	Total Organisms
Phylum Annelida				
Class Oligochaeta	6	GC		**4**
Class Insecta				
Order Coleoptera				
Dryopidae				
Helichus sp.	4.6	SH	cb	**1**
Elmidae				
Promoresia tardella	0	SC	cn	**1**
Psephenidae				
Ectopria nervosa	4.16	SC	cn	**1**
Psephenus herricki	2.35	SC	cn	**10**
Order Diptera				
Chironimidae				
subfamily Chironominae				
Microtendipes sp.	5.53	FC	cn	**3**
Pagastia sp.	1.8	GC		**3**
Phaenopsectra sp.	6.5	SC	cn	**6**
Polypedilum aviceps	3.65	SH		**3**
Polypedilum flavum		SH		**3**
Polypedilum scalaenum grp	8.4	SH		**3**
subfamily Orthocladiinae				
Parametriocnemus lundbecki	3.65	GC	sp	**1**
Thienemanniella sp.	5.86	GC	sp	**1**
subfamily Tanypodinae				
Conchapelopia Group	8.42	PR	sp	**3**
Dixidae				
Dixa sp.	2.55	GC	sw	**1**
Simuliidae				
Simulium sp.	4	FC	cn	**10**
Tipulidae				
Antocha sp.	4.25	GC	cn	**3**
Dicranota sp.		PR		**1**
Tipula sp.	7.33	SH	bu	**1**
Order Ephemeroptera				
Baetidae				
Accentrella sp.	4	GC	sw	**1**
Baetis sp.		GC	sw	**3**
Baetis intercalaris	4.99	OM	sw	**10**
Baetis flavistriga	6.58	GC	sw	**3**
Baetis macdunnoughi		GC	sw	**0**
Baetis pluto	4.28	GC	sw	**3**
Baetis propinquus	5.77	OM	sw	**3**
Caenidae				
Caenis sp.	7.41	GC	sp	**1**
Ephemerellidae				
Ephemerella sp.	2.04	GC	cn	**4**
Eurylophella sp.	4.34	SC	cn	**3**
Serratella difciens	2.75	GC	cn	**3**
Serratella serratoides	1.66	GC	cn	**3**
Heptageniidae				
Epeorus sp.	1.27	SC	cn	**10**
Leucrocuta sp.	2.4	SC		**10**
Stenacron sp.	6.87	SC	cn	**3**
Stenonema modestum	5.5	SC	cn	**10**
Stenonema pudicum	2.01	SC	cn	**1**
Leptophlebiidae				
Leptophlebia sp.	6.23	GC	sw	
Paraleptophlebia sp.	0.94	GC	sw	**10**
Order Megaloptera				
Corydalidae				
Nigronia serricornis	4.95	PR	cn	**1**
Order Plecoptera				
Capniidae				
Allocapnia sp.	2.52	SH	sp	**10**
Peltoperlidae				
Tallaperla sp.	1.2	SH	cn	**1**
Perlidae				
Acroneuria abnormis	2.06	PR	cn	**3**
Perlesta sp.	4.7	PR	cn	**10**
Perlodidae		PR		
Isoperla holochlora	0	PR	cn	**1**
Order Odonata				
Aeshnidae				
Boyeria vinosa	5.89	PR	cb	**1**
Calopterygidae		PR		
Calopteryx sp.	7.78	PR	cb	**3**
Gomphidae				
Gomphus sp.	5.8	PR	bu	**3**
Stylogomphus albistylus	4.72	PR	bu	**3**
Order Trichoptera				
Glossosomatidae				
Glossosoma sp.	1.55	SC		**3**
Hydropsychidae				
Ceratopsyche sparna	2.72	FC	cn	**10**
Cheumatopsyche sp.	6.22	FC	cn	**10**
Hydropsyche sp.		FC	cn	**1**
Hydropsyche betten	7.78	FC	cn	**3**
Limnephilidae				
Pycnopsyche sp.	2.52	SH	cn	**1**
Rhyacophilidae				
Rhyacophila fuscula	1.88	PR	cn	**10**
Uenoidae				
Neophylax sp.	2.2	SC	cn	**10**

Stream Name: Purlear restored
Sample Date: 2004

Tolerance Values

Tolerance values were taken from *NCDWQ Master List of Benthic Macroinvertebrates*

Funtional Feeding Designations

PA	Parasite	FC	Filter/collector
PR	Predator	SC	Scraper
OM	Omnivore	SH	Shredder
GC	Gatherer/collector	PI	Piercer

Habit/Behavior Designations

cn	clinger	sw	swimmer
cb	climber	dv	diver
sp	sprawler	sk	skater
bu	burrower		

	Tolerance Values	Functional Feeding Group	Habit/ Behavior Type	Total Organisms
Phylum Annelida				
Class Oligochaeta	6	GC		**4**
Class Insecta				
Order Coleoptera				
Dytiscidae				
Dytiscus sp.		PR	sw	**1**
Laccophilus sp.		PR	sw	**3**
Elmidae				
Optioservus sp.	2.36	SC	cn	**1**
Promoresia tardella	0	SC	cn	**1**
Hydrophilidae		PR		
Tropisternis sp.	9.68	PR	cb	**1**
Order Diptera				
Chironimidae				
subfamily Chironominae				
Microtendipes sp.	5.53	FC	cn	**10**
Polypedilum aviceps	3.65	SH		**2**
Polypedilum scalaenum grp	8.4	SH		**1**
Rheotanytarsus sp.	5.89	FC	cn	**10**
subfamily Orthocladiinae				
Eukiefferiella sp.	5.58	GC		**1**
Parametriocnemus lundbecki	3.65	GC	sp	**3**
subfamily Tanypodinae				
Conchapelopia Group	8.42	PR	sp	**10**
Empididae	7.57	PR	sp	**1**
Simuliidae				
Simulium sp.	4	FC	cn	**1**
Tipulidae				
Antocha sp.	4.25	GC	cn	**1**
Tipula sp.	7.33	SH	bu	**1**
Order Ephemeroptera				
Baetidae				
Accentrella sp.	4	GC	sw	**3**
Baetis sp.		GC	sw	**3**
Baetis intercalaris	4.99	OM	sw	**10**
Baetis flavistriga	6.58	GC	sw	**3**
Baetis pluto	4.28	GC	sw	**1**
Caenidae				
Caenis sp.	7.41	GC	sp	**1**
Ephemerellidae				
Serratella difciens	2.75	GC	cn	**1**
Heptageniidae				
Stenonema modestum	5.5	SC	cn	**10**
Isonychiidae				
Isonychia sp.	3.45	FC	sw	**3**
Order Plecoptera				
Capniidae				
Allocapnia sp.	2.52	SH	sp	**10**
Peltoperlidae				
Tallaperla sp.	1.2	SH	cn	**1**
Perlidae				
Perlesta sp.	4.7	PR	cn	**1**
Order Trichoptera				
Hydropsychidae				
Ceratopsyche sparna	2.72	FC	cn	**3**
Cheumatopsyche sp.	6.22	FC	cn	**10**
Hydropsyche sp.		FC	cn	**3**
Hydropsyche betteni	7.78	FC	cn	**10**
Limnephilidae				
Pycnopsyche guttifer	2.58	SH	cn	**1**

Stream Name: Purlear upstream
Sample Date: 2004

Tolerance Values

Tolerance values were taken from *NCDWQ Master List of Benthic Macroinvertebrates*

Funtional Feeding Designations

PA	Parasite	FC	Filter/collector
PR	Predator	SC	Scraper
OM	Omnivore	SH	Shredder
GC	Gatherer/collector	PI	Piercer

Habit/Behavior Designations

cn	clinger	sw	swimmer
cb	climber	dv	diver
sp	sprawler	sk	skater
bu	burrower		

	Tolerance Values	Functional Feeding Group	Habit/ Behavior Type	Total Organisms
Class Insecta				
Order Coleoptera				
Dryopidae				
Helichus sp.	4.6	SH	cb	**3**
Elmidae				
Optioservus sp.	2.36	SC	cn	**3**
Promoresia tardella	0	SC	cn	**1**
Gyrinidae				
Gyrinus sp.	6.17	PR	sw	**1**
Ptilodactylidae				
Anchytarsus bicolor	3.64	SH	sp	**1**
Order Diptera				
Ceratopogonidae				
Palpomyia-Bezzia cmplx		PR	bu	**1**
Chironimidae				
subfamily Chironominae				
Cryptochironomus sp.	6.4	PR	sp	**3**
Eukiefferiella brevicalcar	2.2	GC	sp	**1**
Microtendipes sp.	5.53	FC	cn	**1**
Pagastia sp.	1.8	GC		**1**
Rheotanytarsus sp.	5.89	FC	cn	**1**
Stempellina sp.	0	GC		**1**
subfamily Orthocladiinae				
Parametriocnemus lundbecki	3.65	GC	sp	**1**
subfamily Tanypodinae				
Conchapelopia Group	8.42	PR	sp	**3**
Ptychopteridae				
Bittacomorpha sp.		GC	cn	**1**
Simuliidae				
Simulium sp.	4	FC	cn	**1**
Tipulidae				
Antocha sp.	4.25	GC	cn	**1**
Dicranota sp.	0	PR		**1**
Order Ephemeroptera				
Baetidae				
Accentrella sp.	4	GC	sw	**10**
Baetis sp.		GC	sw	**1**
Baetis flavistriga	6.58	GC	sw	**10**
Baetis pluto	4.28	GC	sw	**3**
Baetis propinquus	5.77	OM	sw	**10**
Paracleodes sp.	6	GC	sw	**3**
Caenidae				
Caenis sp.	7.41	GC	sp	**1**
Ephemerellidae				
Drunella conestee	0	PR	cn	**1**
Ephemerella sp.	2.04	GC	cn	**1**
Eurylophella sp.	4.34	SC	cn	**3**
Serratella difciens	2.75	GC	cn	**10**
Heptageniidae				
Epeorus sp.	1.27	SC	cn	**10**
Leucrocuta sp.	2.4	SC	cn	**1**
Stenonema modestum	5.5	SC	cn	**10**
Isonychiidae				
Isonychia sp.	3.45	FC	sw	**3**
Order Plecoptera				
Capniidae				
Allocapnia sp.	2.52	SH	sp	**10**
Peltoperlidae				
Tallaperla sp.	1.2	SH	cn	**10**
Perlidae				
Acroneuria abnormis	2.06	PR		**10**
Perlesta sp.	4.7	PR	cn	**10**
Perlodidae		PR		
Isoperla holochlora	0	PR		**3**
Remenus Bilobatus	0.3			**1**
Pteronarcyidae				
Pteronarcys sp.	1.67	SH		**10**
Order Odonata				
Aeshnidae				
Boyeria vinosa	5.89	PR	cb	**3**
Calopterygidae		PR		
Calopteryx sp.	7.78	PR	cb	**1**
Cordulegastridae				
Cordulegaster sp.	5.73	PR	bu	**1**
Gomphidae				
Gomphus sp.	5.8	PR	bu	**1**
Ophiogomphus sp.	5.54	PR	bu	**3**
Stylogomphus albistylus	4.72	PR	bu	**3**
Order Trichoptera				
Glossosomatidae				
Glossosoma sp.	1.55	SC	cn	**10**
Hydropsychidae				
Ceratopsyche sparna	2.72	FC	cn	**10**
Cheumatopsyche sp.	6.22	FC	cn	**1**
Diplectrona modesta	2.21	FC	cn	**10**
Hydropsyche betteni	7.78	FC	cn	**3**
Lepidostomatidae				
Lepidostoma sp.	0.9	SH		**1**
Limnephilidae				
Pycnopsyche sp.	2.52	SH	cn	**3**
Pycnopsyche guttifer	2.58	SH	cn	**10**
Philopotamidae				
Dolophilodes sp.	0.81	GC	cn	**10**
Rhyacophilidae				
Rhyacophila fuscula	1.88	PR	cn	**3**
Uenoidae				
Neophylax sp.	2.2	SC	cn	**3**

Stream Name: Little Pine Restored
Sample Date: 2004

Tolerance Values

Tolerance values were taken from *NCDWQ Master List of Benthic Macroinvertebrates*

Funtional Feeding Designations

PA	Parasite	FC	Filter/collector
PR	Predator	SC	Scraper
OM	Omnivore	SH	Shredder
GC	Gatherer/collector	PI	Piercer

Habit/Behavior Designations

cn	clinger	sw	swimmer
cb	climber	dv	diver
sp	sprawler	sk	skater
bu	burrower		

	Tolerance Values	Functional Feeding Group	Habit/ Behavior Type	Total Organisms
Phylum Annelida				
Class Oligochaeta	6	GC		**8**
Class Insecta				
Order Coleoptera				
Elmidae				
Ancyronyx variegatus	6.49	OM	cn	**1**
Macronychus glabratus	4.58	OM	cn	**4**
Optioservus sp.	2.36	SC	cn	**10**
Promoresia sp.	2.35	SC	cn	**9**
Stenelmis sp.	5.1	SC	cn	**6**
Psephenidae				
Psephenus herricki	2.35	SC	cn	**3**
Order Diptera				
Chironimidae				
subfamily Chironominae				
Cryptochironomus sp.	6.4	PR	sp	**2**
Microtendipes pedellus grp	5.53	FC	cn	**1**
Microtendipes rydalensis grp	5.53	FC	cn	**6**
Parachironomus sp.	9.42	PR	sp	**1**
Phaenopsectra sp.	6.5	SC	cn	**1**
Polypedilum aviceps	3.65	SH		**6**
Polypedilum fallax	6.39	SH		**2**
Stictochironomous sp.	6.52	OM	bu	**4**
subfamily Diamesinae				
Potthastia sp.	6.4	OM	sp	**1**
subfamily Orthocladiinae				
Cardiocladius sp.	5.87	PR	bu	**3**
Corynoneura sp.	6.01	GC		**2**
Eukiefferiella sp.	5.58	GC	sp	**2**
Orthocladius sp.	9.11	GC		**2**
Parametriocnemus sp.	3.65	GC	sp	**4**
Tvetina ba varcia grp (E sp1)	3.65	GC	sp	**2**
Tvetenia (discoloripes grp) vitracies	3.61	GC	sp	**1**
subfamily Tanypodinae				
Conchapelopia Group	8.42	PR	sp	**1**
Dixidae				
Dixa sp.	2.55	GC	sw	**2**
Empididae	7.57	PR	sp	**3**
Simuliidae				
Simulium sp.	4	FC		**1**
Tipulidae				
Antocha sp.	4.25	GC	cn	**16**
Order Ephemeroptera				
Baetidae				
Accentrella sp.	4	GC	sw	**4**
Baetis sp.		GC	sw	**1**
Baetis intercalaris	4.99	OM	sw	**41**
Baetis flavistriga	6.58	GC	sw	**4**
Baetis pluto	4.28	GC	sw	**19**
Callibaetis sp.			sw	**1**
Plauditus			sw	**24**
Procleon			sw	**2**
Pseudocloeon sp.		SC	sw	**12**
Ephemerellidae				
Serratella sp.	2.75	GC	cn	**1**
Serratella difciens	2.75	GC	cn	**1**
Heptageniidae				
Leucrocuta sp.	2.4	SC	cn	**1**
Stenonema sp.		SC	cn	**6**
Stenonema modestum	5.5	SC	cn	**8**
Stenonema pudicum	2.01	SC	cn	**20**
Isonychiidae				
Isonychia sp.	3.45	FC	sw	**36**
Tricorythidae				
Tricorythodes sp.	5.06	GC	sp	**4**
Order Megaloptera				
Corydalidae				
Nigronia serricornis	4.95	PR	cn	**1**
Order Plecoptera				
Capniidae				
Allocapnia sp.	2.52	SH	sp	**21**
Peltoperlidae				
Tallaperla sp.	1.2	SH	cn	**1**
Perlidae				
Acroneuria abnormis	2.06	PR	cn	**2**
Paragnetina immarginata	1.38	PR	cn	**1**
Perlesta sp.	4.7	PR	cn	**4**
Order Odonata				
Aeshnidae				
Basiaeschna janata	7.35	PR	cb	**1**
Boyeria vinosa	5.89	PR	cb	**3**
Calopterygidae		PR		
Calopteryx sp.	7.78	PR	cb	**10**
Order Trichoptera				
Brachycentridae				
Brachycentrus sp.	2.08	FC	cn	**1**
Hydropsychidae				
Cheumatopsyche sp.	6.22	FC	cn	**8**
Hydropsyche betteni	7.78	FC	cn	**2**
Symphitopsyche spp.		FC	cn	**95**
Limnephilidae				
Pycnopsyche sp.	2.52	SH		**1**
Rhyacophilidae				
Rhyacophila fuscula	1.88	PR	cn	**1**
Uenoidae				
Neophylax sp.	2.2	SC	cn	**4**

Stream Name: Little Pine Upstream
Sample Date: 2004

Tolerance Values

Tolerance values were taken from *NCDWQ Master List of Benthic Macroinvertebrates*

Funtional Feeding Designations

PA	Parasite	FC	Filter/collector
PR	Predator	SC	Scraper
OM	Omnivore	SH	Shredder
GC	Gatherer/collector	PI	Piercer

Habit/Behavior Designations

cn	clinger	sw	swimmer
cb	climber	dv	diver
sp	sprawler	sk	skater
bu	burrower		

	Tolerance Values	Functional Feeding Group	Habit/ Behavior Type	Total Organisms
Phylum Annelida				
Class Oligochaeta	6	GC		**5**
Class Insecta				
Order Coleoptera				
Elmidae				
Macronychus glabratus	4.58	OM	cn	**2**
Optioservus sp.	2.36	SC	cn	**15**
Oulimnius latiusculus	1.78	SC	cn	**1**
Promoresia sp.	2.35	SC		**3**
Hydrophilidae		PR		
Enochrus spp.		GC	bu	**1**
Tropisternis sp.	9.68	PR		**2**
Psephenidae				
Psephenus herricki	2.35	SC	cn	**1**
Order Diptera				
Chironimidae				
subfamily Chironominae				
Chironomus sp.	9.63	GC	bu	**3**
Cryptochironomus sp.	6.4	PR	sp	**1**
Parachironomus sp.	9.42	PR	sp	**1**
Phaenopsectra sp.	6.5	SC	cn	**3**
Polypedilum sp.	6	SH		**2**
Polypedilum aviceps	3.65	SH		**18**
Polypedilum scalaenum grp	8.4	SH		**1**
Stictochironomous sp.	6.52	OM	bu	**2**
subfamily Diamesinae				
Potthastia sp.		OM	sp	**1**
Diamesa		GC	sp	**3**
subfamily Orthocladiinae				
Brillia sp.	5.18	SH	bu	**29**
Cricotopus sp.	9.04	SH	cn	**3**
Eukiefferiella sp.	5.58	GC	sp	**1**
Orthocladius sp.	9.11	GC		**1**
Thienemanniella sp.	5.86	GC		**1**
Tvetina ba varcia grp (E sp1)	3.65	GC	sp	**1**
subfamily Tanypodinae				
Conchapelopia Group	8.42	PR	sp	**1**
Rheopelopia sp.	2.9	PR	sp	**2**
Culicidae				
Anopheles sp.	8.58	FC	sw	**10**
Dixidae				
Dixa sp.	2.55	GC	sw	**1**
Empididae	7.57	PR	sp	**4**
Tipulidae				
Antocha sp.	4.25	GC	cn	**31**
Order Ephemeroptera				
Baetidae				
Accentrella sp.	4	GC	sw	**1**
Plauditus sp.			sw	**13**
Baetis intercalaris	4.99	OM	sw	**56**
Baetis flavistriga	6.58	GC	sw	**8**
Baetis pluto	4.28	GC	sw	**5**
Procleon			sw	**1**
Pseudocloeon sp.		SC	sw	**3**
Baetisca sp.	3.4	GC		**1**
Ephemerellidae				
Serratella sp.	2.75	GC	cn	**1**
Ephemeridae				
Hexagenia sp.	4.9	GC	bu	**2**
Heptageniidae				
Leucrocuta sp.	2.4	SC	cn	**1**
Stenonema sp.		SC	cn	**2**
Stenonema modestum	5.5	SC	cn	**10**
Stenonema pudicum	2.01	SC	cn	**14**
Isonychiidae				
Isonychia sp.	3.45	FC	sw	**12**
Leptophlebiidae				
Paraleptophlebia sp.	0.94	GC	sw	**4**
Tricorythidae				
Tricorythodes sp.	5.06	GC	sp	**1**
Order Megaloptera				
Corydalidae				
Nigronia serricornis	4.95	PR	cn	**3**
Sialidae				
Sialis sp.	7.17	PR		**1**
Order Plecoptera				
Capniidae				
Allocapnia sp.	2.52	SH	sp	**26**
Perlidae				
Acroneuria sp.		PR	cn	**1**
Perlesta sp.	4.7	PR	cn	**1**
Order Odonata				
Aeshnidae				
Boyeria vinosa	5.89	PR	cb	**3**
Calopterygidae		PR		
Calopteryx sp.	7.78	PR	cb	**6**
Order Trichoptera				
Hydropsychidae				
Cheumatopsyche sp.	6.22	FC	cn	**3**
Symphitopsyche spp.		FC	cn	**76**
Limnephilidae				
Pycnopsyche sp.	2.52	SH		**1**
Rhyacophilidae				
Rhyacophila sp.	3.86	PR	cn	**2**

Stream Name: Austin upstream
Sample Date: 2004

Tolerance Values

Tolerance values were taken from *NCDWQ Master List of Benthic Macroinvertebrates*

Funtional Feeding Designations

PA	Parasite	FC	Filter/collector
PR	Predator	SC	Scraper
OM	Omnivore	SH	Shredder
GC	Gatherer/collector	PI	Piercer

Habit/Behavior Designations

cn	clinger	sw	swimmer
cb	climber	dv	diver
sp	sprawler	sk	skater
bu	burrower		

	Tolerance Values	Functional Feeding Group	Habit/ Behavior Type	Total Organisms
Phylum Annelida				
Class Oligochaeta	6	GC		**15**
Class Insecta				
Order Coleoptera				
Dryopidae				
Helichus sp.	4.6	SH	cb	**3**
Elmidae				
Ancyronyx variegatus	6.49	OM	cn	**10**
Microcylloepus pusillus	2.11	GC	cn	**10**
Stenelmis sp.	5.1	SC	cn	**1**
Ptilodactylidae				
Anchytarsus bicolor	3.64	SH	sp	**1**
Order Diptera				
Chironimidae				
subfamily Chironominae				
Cryptochironomus sp.	6.4	PR	sp	**10**
Microtendipes sp.	5.53	FC	cn	**1**
Phaenopsectra sp.	6.5	SC	cn	**3**
Polypedilum aviceps	3.65	SH		**10**
Polypedilum illinoense grp	9	SH		**3**
Rheotanytarsus sp.	5.89	FC	cn	**10**
Stenochironomus sp.	6.45	SH		**1**
subfamily Orthocladiinae				
Nanocladius sp.	7.07	GC	sp	**1**
Rheocricotopus sp.	7.3	GC	sp	**3**
Thienemanniella sp.	5.86	GC		**1**
subfamily Tanypodinae				
Conchapelopia Group	8.42	PR	sp	**10**
Natarsia sp.	9.95	PR	sp	**3**
Simuliidae				
Simulium sp.	4	FC	cn	**1**
Tabanidae				
Chrysops sp.	6.73	PR	sp	**1**
Tipulidae				
Tipula sp.	7.33	SH	bu	**3**
Order Ephemeroptera				
Baetidae				
Heptageniidae				
Stenonema modestum	5.5	SC	cn	**10**
Isonychiidae				
Isonychia sp.	3.45	FC	sw	**1**
Tricorythidae				
Tricorythodes sp.	5.06	GC	sp	**3**
Order Megaloptera				
Corydalidae				
Nigronia serricornis	4.95	PR	cn	**3**
Order Odonata				
Aeshnidae				
Boyeria vinosa	5.89	PR	cb	**10**
Calopterygidae		PR		
Calopteryx dimidiata	7.78	PR	cb	**10**
Coenagrionidae				
Argia sp.	8.17	PR	cb	**3**
Gomphidae				
Hagenius brevistylus	3.99	PR	sp	**1**
Ophiogomphus sp.	5.54	PR	bu	**10**
Progomphus obscurus	8.22	PR	bu	**10**
Order Trichoptera				
Hydropsychidae				
Cheumatopsyche sp.	6.22	FC	cn	**10**
Hydropsyche betteni	7.78	FC	cn	**10**
Leptoceridae				
Oecetis sp.	5.7	PR		**1**

Stream Name: Austin restored
Sample Date: 2004

Tolerance Values

Tolerance values were taken from *NCDWQ Master List of Benthic Macroinvertebrates*

Funtional Feeding Designations

PA	Parasite	FC	Filter/collector
PR	Predator	SC	Scraper
OM	Omnivore	SH	Shredder
GC	Gatherer/collector	PI	Piercer

Habit/Behavior Designations

cn	clinger	sw	swimmer
cb	climber	dv	diver
sp	sprawler	sk	skater
bu	burrower		

	Tolerance Values	Functional Feeding Group	Habit/ Behavior Type	Total Organisms
Phylum Annelida				
Class Oligochaeta	6	GC		**4**
Class Insecta				
Order Coleoptera				
Dytiscidae				
Hydroporus sp.	8.62	PR	sw	**10**
Elmidae				
Ancyronyx variegatus	6.49	OM	cn	**10**
Macronychus glabratus	4.58	OM	cn	**1**
Hydrophilidae		PR		
Tropisternis sp.	9.68	PR		**1**
Order Diptera				
Chironimidae				
subfamily Chironominae				
Micropsectra sp.	1.52	GC		**3**
Polypedilum aviceps	3.65	SH		**3**
Polypedilum illinoense grp	9	SH		**1**
Rheotanytarsus sp.	5.89	FC		**1**
subfamily Orthocladiinae				
Cricotopus cylindracues C/O sp 14	2.28	SH		**10**
Rheocricotopus sp.	7.3	GC		**1**
Thienemanniella sp.	5.86	GC		**3**
subfamily Tanypodinae				
Ablabesmyia sp.	7.2	PR	sp	**3**
Conchapelopia Group	8.42	PR	sp	**1**
Procladius sp.	9.1	PR	sp	**1**
Tipulidae				
Tipula sp.	7.33	SH	bu	**1**
Order Ephemeroptera				
Baetidae				
Baetis sp.		GC	sw	**1**
Baetis flavistriga	6.58	GC		**1**
Baetis propinquus	5.77	OM		**10**
Cloeon sp.		GC	sw	**10**
Heptageniidae				
Stenonema modestum	5.5	SC	cn	**3**
Isonychiidae				
Isonychia sp.	3.45	FC	sw	**1**
Tricorythidae				
Tricorythodes sp.	5.06	GC	sp	**10**
Order Odonata				
Aeshnidae				
Boyeria vinosa	5.89	PR	cb	**1**
Calopterygidae		PR		
Calopteryx sp.	7.78	PR	cb	**1**
Coenagrionidae				
Argia sp.	8.17	PR	cb	**10**
Enallagma sp.	8.91	PR	cb	**10**
Gomphidae				
Progomphus obscurus	8.22	PR	bu	**3**
Libellulidae				
Plathemis lydia		PR	sp	**3**
Order Trichoptera				
Hydropsychidae				
Cheumatopsyche sp.	6.22	FC	cn	**1**
Leptoceridae				
Oecetis sp.	5.7	PR		**1**
Triaenodes trardus	4.58	SH		**3**

Stream Name: Little Bugaboo restored
Sample Date: 2004

Tolerance Values

Tolerance values were taken from *NCDWQ Master List of Benthic Macroinvertebrates*

Funtional Feeding Designations

PA	Parasite	FC	Filter/collector
PR	Predator	SC	Scraper
OM	Omnivore	SH	Shredder
GC	Gatherer/collector	PI	Piercer

Habit/Behavior Designations

cn	clinger	sw	swimmer
cb	climber	dv	diver
sp	sprawler	sk	skater
bu	burrower		

	Tolerance Values	Functional Feeding Group	Habit/ Behavior Type	Total Organisms
Phylum Annelida				
Class Oligochaeta	6	GC		**14**
Class Insecta				
Order Coleoptera				
Dryopidae				
Helichus sp.	4.6	SH	cb	**1**
Elmidae				
Optioservus sp.	2.36	SC	cn	**2**
Promoresia sp.	2.35	SC	cn	**2**
Stenelmis sp.	5.1	SC	cn	**1**
Hydrophilidae		PR		
Enochrus spp.		GC	bu	**1**
Sperchopsis tessellatus	6.5	OM	cb	**1**
Order Diptera				
Chironimidae				
subfamily Chironominae				
Microtendipes pedellus grp	5.53	FC	cn	**5**
Polypedilum aviceps	3.65	SH		**14**
Polypedilum scalaenum grp	8.4	SH		**5**
Rheotanytarsus sp.	5.89	FC	cn	**5**
Tanytarsus sp.	6.76	FC		**9**
subfamily Orthocladiinae				
Aspectrotanypus johnsoni		PR		**2**
Cricotopus bicinctus C/O sp 1	8.54	OM	cn	**3**
Parametriocnemus sp.	3.65	GC	sp	**2**
subfamily Tanypodinae				
Brundiniellla eumorpha	1.71			**1**
Conchapelopia Group	8.42	PR	sp	**25**
Larsia sp.	9.3	PR	sp	**1**
Rheopelopia sp.	2.9	PR	sp	**2**
Culicidae				
Anopheles sp.	8.58	FC	sw	**9**
Empididae	7.57	PR	sp	**1**
Ptychopteridae				
Bittacomorpha sp.		GC	bu	**1**
Simuliidae				
Simulium sp.	4	FC	cn	**40**
Tipulidae				
Pseudolimnophila sp.		PR	bu	**1**
Tipula sp.	7.33	SH	bu	**4**
Order Ephemeroptera				
Baetidae				
Dipehtor hageni			sw	**1**
Baetis sp.		GC	sw	**5**
Acerpenna pygmaea		GC		**1**
Baetis flavistriga	6.58	GC	sw	**28**
Baetis pluto	4.28	GC	sw	**10**
Caenidae				
Caenis sp.	7.41	GC	sp	**4**
Ephemerellidae				
Serratella sp.	2.75	GC	cn	**26**
Heptageniidae				
Stenonema modestum	5.5	SC	cn	**75**
Stenonema pudicum	2.01	SC	cn	**5**
Isonychiidae				
Isonychia sp.	3.45	FC	sw	**25**
Leptophlebiidae				
Paraleptophlebia sp.	0.94	GC	sw	**8**
Order Megaloptera				
Corydalidae				
Nigronia fasciatus	5.55	PR	cn	**5**
Nigronia serricornis	4.95	PR	cn	**1**
Sialidae				
Sialis sp.	7.17	PR		**1**
Order Plecoptera				
Capniidae				
Allocapnia sp.	2.52	SH	sp	**103**
Chloroperlidae		PR	cn	**1**
Peltoperlidae				
Tallaperla sp.	1.2	SH	cn	**2**
Perlidae				
Eccoptura xanthenis	3.74	PR	cn	**7**
Perlesta sp.	4.7	PR	cn	**9**
Order Odonata				
Aeshnidae				
Aeshna sp.		PR	cb	**1**
Boyeria vinosa	5.89	PR	cb	**2**
Calopterygidae		PR		
Calopteryx sp.	7.78	PR	cb	**1**
Cordulegastridae				
Cordulegaster sp.	5.73	PR	bu	**1**
Order Trichoptera				
Hydropsychidae				
Cheumatopsyche sp.	6.22	FC	cn	**19**
Diplectrona modesta	2.21	FC	cn	**2**
Hydropsyche betteni	7.78	FC	cn	**32**
Lepidostomatidae				
Lepidostoma sp.	0.9	SH		**1**
Limnephilidae				
Pycnopsyche sp.	2.52	SH		**2**
Philopotamidae				
Dolophilodes sp.	0.81	GC	cn	**2**
Polycentropodidae				
Polycentropus sp.	3.53	PR	cn	**1**
Uenoidae				
Neophylax sp.	2.2	SC	cn	**5**

Stream Name: Little Bugaboo upstream
Sample Date: 2004

Tolerance Values

Tolerance values were taken from *NCDWQ Master List of Benthic Macroinvertebrates*

Funtional Feeding Designations

PA	Parasite	FC	Filter/collector
PR	Predator	SC	Scraper
OM	Omnivore	SH	Shredder
GC	Gatherer/collector	PI	Piercer

Habit/Behavior Designations

cn	clinger	sw	swimmer
cb	climber	dv	diver
sp	sprawler	sk	skater
bu	burrower		

	Tolerance Values	Functional Feeding Group	Habit/ Behavior Type	Total Organisms
Phylum Annelida				
Class Oligochaeta	6	GC		**10**
Class Insecta				
Order Coleoptera				
Dytiscidae				
Laccophilus sp.		PR	sw	**1**
Order Diptera				
Ceratopogonidae				
Palpomyia-Bezzia cmplx		PR	bu	**1**
Chironimidae				
subfamily Chironominae				
Chironomus sp.	9.63	GC	bu	**1**
Cryptochironomus sp.	6.4	PR	sp	**1**
Microtendipes pedellus grp	5.53	FC	cn	**1**
Microtendipes rydalensis grp	5.53	FC	cn	**1**
Parachironomus sp.	9.42	PR	sp	**3**
Paralauterborniella nigrohalteralis	4.77	GC	cn	**3**
Paratanytarus sp.	8.45	GC	sp	**8**
Paratendipes sp.	5.11	GC	bu	**6**
Polypedilum aviceps	3.65	SH		**19**
Polypedilum fallax	6.39	SH		**1**
Rheotanytarsus sp.	5.89	FC	cn	**5**
Tribelos sp.	6.31	GC	bu	**34**
subfamily Orthocladiinae				
Brillia sp.	5.18	SH	bu	**2**
Aspectrotanypus johnsoni		PR		**5**
Parametriocnemus sp.	3.65	GC	sp	**1**
subfamily Tanypodinae				
Conchapelopia Group	8.42	PR	sp	**3**
Larsia sp.	9.3	PR	sp	**1**
Procladius sp.	9.1	PR	sp	**1**
Zavrelimyia sp.	9.11	PR	sp	**4**
Culicidae				
Anopheles sp.	8.58	FC	sw	**1**
Empididae	7.57	PR	sp	**1**
Ptychopteridae				
Bittacomorpha sp.		GC	bu	**2**
Order Ephemeroptera				
Baetidae				
Baetis sp.		GC	sw	**4**
Baetis pluto	4.28	GC	sw	**2**
Caenidae				
Caenis sp.	7.41	GC	sp	**1**
Ephemerellidae				
Serratella difciens	2.75	GC	cn	**2**
Heptageniidae				
Stenonema modestum	5.5	SC	cn	**14**
Stenonema pudicum	2.01	SC	cn	**8**
Isonychiidae				
Isonychia sp.	3.45	FC	sw	**6**
Leptophlebiidae				
Paraleptophlebia sp.	0.94	GC	sw	**6**
Order Megaloptera				
Corydalidae				
Nigronia serricornis	4.95	PR	cn	**8**
Sialidae				
Sialis sp.	7.17	PR		**18**
Order Plecoptera				
Capniidae				
Allocapnia sp.	2.52	SH	sp	**15**
Perlidae				
Eccoptura xanthenis	3.74	PR	cn	**1**
Perlesta sp.	4.7	PR	cn	**2**
Order Odonata				
Aeshnidae				
Basiaeschna janata	7.35	PR	cb	**1**
Boyeria vinosa	5.89	PR	cb	**2**
Calopterygidae		PR		
Calopteryx sp.	7.78	PR	cb	**3**
Gomphidae				
Gomphus sp.	5.8	PR	bu	**4**
Order Trichoptera				
Hydropsychidae				
Cheumatopsyche sp.	6.22	FC	cn	**10**
Diplectrona modesta	2.21	FC	cn	**9**
Hydropsyche betteni	7.78	FC	cn	**14**
Limnephilidae				
Pycnopsyche sp.	2.52	SH		**6**
Odontoceridae				
Psilotreta frontalis	0	SC		**6**
Psychomyiidae				
Lype diversa	4.05	SC		**1**

Stream Name: Suck Creek restored
Sample Date: 2004

Tolerance Values

Tolerance values were taken from *NCDWQ Master List of Benthic Macroinvertebrates*

Funtional Feeding Designations

PA	Parasite	FC	Filter/collector
PR	Predator	SC	Scraper
OM	Omnivore	SH	Shredder
GC	Gatherer/collector	PI	Piercer

Habit/Behavior Designations

cn	clinger	sw	swimmer
cb	climber	dv	diver
sp	sprawler	sk	skater
bu	burrower		

	Tolerance Values	Functional Feeding Group	Habit/ Behavior Type	Total Organisms
Phylum Annelida				
Class Oligochaeta	6	GC		**1**
Class Insecta				
Order Coleoptera				
Elmidae				
Stenelmis sp.	5.1	SC	cn	**35**
Order Diptera				
Procladiini				
Proclaius sp.	9.1	PR	sp	**1**
Chironimidae				
subfamily Chironominae				
Cryptochironomus sp.	6.4	PR	sp	**1**
Dicrotendipes sp.	8.1	GC	bu	**28**
Polypedilum illinoense grp	9	SH		**2**
Tanytarsus sp.	6.76	FC		**6**
subfamily Tanypodinae				
Conchapelopia Group	8.42	PR	sp	**7**
Empididae	7.57	PR	sp	**1**
Tipulidae				
Hexatoma sp.	4.31	PR	bu	**5**
Order Ephemeroptera				
Baetidae				
Accerpenna pygmaea		GC	sw	**2**
Callibaetis sp.		GC	sw	**16**
Caenidae				
Caenis sp.	7.41	GC	sp	**10**
Heptageniidae				
Stenonema modestum	5.5	SC	cn	**52**
Order Megaloptera				
Corydalidae				
Nigronia serricornis	4.95	PR	cn	**7**
Sialidae				
Sialis sp.	7.17	PR		**1**
Order Odonata				
Aeshnidae				
Basiaeschna janata	7.35	PR	cl	**6**
Boyeria vinosa	5.89	PR	cb	**1**
Coenagrionidae				
Enallagma sp.	8.91	PR	cb	**4**
Corduliidae				
Macromia sp.	6.16	PR	sp	**1**
Tetragoneuria sp.	8.57	PR		**1**
Gomphidae				
Gomphus sp.	5.8	PR	bu	**14**
Order Trichoptera				
Hydropsychidae				
Cheumatopsyche sp.	6.22	FC	cn	**3**

Stream Name: Suck Creek upstream
Sample Date: 2004

Tolerance Values

Tolerance values were taken from *NCDWQ Master List of Benthic Macroinvertebrates*

Funtional Feeding Designations

PA	Parasite	FC	Filter/collector
PR	Predator	SC	Scraper
OM	Omnivore	SH	Shredder
GC	Gatherer/collector	PI	Piercer

Habit/Behavior Designations

cn	clinger	sw	swimmer
cb	climber	dv	diver
sp	sprawler	sk	skater
bu	burrower		

	Tolerance Values	Functional Feeding Group	Habit/ Behavior Type	Total Organisms
Phylum Annelida				
Class Oligochaeta	6	GC		**3**
Class Insecta				
Order Coleoptera				
Elmidae				
Stenelmis sp.	5.1	SC	cn	**10**
Hydrophilidae		PR		
Tropisternis sp.	9.68	PR		**1**
Order Diptera				
Chironimidae				
subfamily Chironominae				
Polypedilum aviceps	3.65	SH		**2**
Polypedilum scalaenum grp	8.4	SH		**3**
Rheotanytarsus sp.	5.89	FC	cn	**1**
subfamily Tanypodinae				
Conchapelopia Group	8.42	PR	sp	**2**
Culicidae			sw	**1**
Empididae	7.57	PR	sp	**1**
Tabanidae				
Chrysops sp.	6.73	PR	sp	**2**
Tipulidae				
Hexatoma sp.	4.31	PR	bu	**11**
Tipula sp.	7.33	SH		**6**
Limonia sp.	9.64	SH	bu	**4**
Order Ephemeroptera				
Heptageniidae				
Stenonema pudicum	2.01	SC	cn	**62**
Order Megaloptera				
Corydalidae				
Nigronia serricornis	4.95	PR	cn	**30**
Order Odonata				
Aeshnidae				
Basiaeschna janata	7.35	PR	cl	**1**
Boyeria vinosa	5.89	PR	cb	**2**
Order Trichoptera				
Hydropsychidae				
Cheumatopsyche sp.	6.22	FC	cn	**67**
Hydropsyche betteni	7.78	FC	cn	**6**

Stream Name: Spring Valley upstream
Sample Date: 2004

Tolerance Values

Tolerance values were taken from *NCDWQ Master List of Benthic Macroinvertebrates*

Funtional Feeding Designations

PA	Parasite	FC	Filter/collector
PR	Predator	SC	Scraper
OM	Omnivore	SH	Shredder
GC	Gatherer/collector	PI	Piercer

Habit/Behavior Designations

cn	clinger	sw	swimmer
cb	climber	dv	diver
sp	sprawler	sk	skater
bu	burrower		

	Tolerance Values	Functional Feeding Group	Habit/ Behavior Type	Total Organisms
Phylum Annelida				
Class Oligochaeta	6	GC		**1**
Class Insecta				
Order Coleoptera				
Elmidae				
Promoresia sp.	2.35	SC	cn	**1**
Stenelmis sp.	5.1	SC	cn	**1**
Order Diptera				
Chironimidae				
subfamily Chironominae				
Polypedilum illinoense grp	9	SH		**2**
Polypedilum scalaenum grp	8.4	SH		**3**
Tanytarsus sp.	6.76	FC		**1**
subfamily Orthocladiinae				
Cricotopus bicinctus C/O sp 1	8.54	OM	cn	**1**
Orthocladius sp.	9.11	GC		**1**
subfamily Tanypodinae				
Ablabesmyia sp.	7.2	PR	sp	**1**
Conchapelopia Group	8.42	PR	sp	**12**
Natarsia sp.	9.95	PR	sp	**3**
Simuliidae				
Prosimulium sp.	4.01	FC	cn	**1**
Tipulidae				
Tipula sp.	7.33	SH	bu	**3**
Order Ephemeroptera				
Baetidae				
Baetis flavistriga	6.58	GC	sw	**96**
Order Odonata				
Calopterygidae		PR		
Calopteryx sp.	7.78	PR	cb	**6**
Order Trichoptera				
Hydropsychidae				
Cheumatopsyche sp.	6.22	FC	cn	**12**
Hydropsyche betteni	7.78	FC	cn	**30**
Philopotamidae				
Dolophilodes sp.	0.81	GC	cn	**1**

Stream Name: Spring Valley restored
Sample Date: 2004

Tolerance Values

Tolerance values were taken from *NCDWQ Master List of Benthic Macroinvertebrates*

Funtional Feeding Designations

PA	Parasite	FC	Filter/collector
PR	Predator	SC	Scraper
OM	Omnivore	SH	Shredder
GC	Gatherer/collector	PI	Piercer

Habit/Behavior Designations

cn	clinger	sw	swimmer
cb	climber	dv	diver
sp	sprawler	sk	skater
bu	burrower		

	Tolerance Values	Functional Feeding Group	Habit/ Behavior Type	Total Organisms
Phylum Annelida				
Class Oligochaeta	6	GC		**1**
Class Insecta				
Order Coleoptera				
Dytiscidae				
Laccophilus sp.		PR		**2**
Order Diptera				
Chironimidae				
subfamily Chironominae				
Chironomus sp.	9.63	GC	bu	**1**
Dicrotendipes sp.	8.1	GC	bu	**1**
Paratanytarus sp.	8.45	GC		**1**
Phaenopsectra sp.	6.5	SC	cn	**1**
Polypedilum aviceps	3.65	SH		**3**
Polypedilum scalaenum grp	8.4	SH		**6**
Tanytarsus sp.	6.76	FC		**2**
subfamily Orthocladiinae				
Cricotopus sp.	9.04	SH	cn	**2**
Orthocladius sp.	9.11	GC		**2**
subfamily Tanypodinae				
Ablabesmyia sp.	7.2	PR	sp	**5**
Conchapelopia Group	8.42	PR	sp	**28**
Natarsia sp.	9.95	PR	sp	**10**
Zavrelimyia sp.	9.11		sp	**7**
Ptychopteridae				
Bittacomorpha sp.		GC	bu	**1**
Simuliidae				
Prosimulium sp.	4.01	FC	cn	**1**
Syrphidae				
Eristalis spp.		GC	bu	**1**
Order Ephemeroptera				
Baetidae				
Baetis flavistriga	6.58	GC	sw	**60**
Order Odonata				
Aeshnidae				
Aeshna sp.		PR	cb	**2**
Calopterygidae		PR		
Calopteryx sp.	7.78	PR	cb	**5**
Coenagrionidae				
Argia sp.	8.17	PR	cb	**8**
Enallagma sp.	8.91	PR	cb	**2**
Order Trichoptera				
Hydropsychidae				
Cheumatopsyche sp.	6.22	FC	cn	**10**
Hydropsyche betteni	7.78	FC	cn	**12**

Stream Name: Yates Mill Upstream
Sample Date: 2004

Tolerance Values

Tolerance values were taken from *NCDWQ Master List of Benthic Macroinvertebrates*

Funtional Feeding Designations

PA	Parasite	FC	Filter/collector
PR	Predator	SC	Scraper
OM	Omnivore	SH	Shredder
GC	Gatherer/collector	PI	Piercer

Habit/Behavior Designations

cn	clinger	sw	swimmer
cb	climber	dv	diver
sp	sprawler	sk	skater
bu	burrower		

	Tolerance Values	Functional Feeding Group	Habit/ Behavior Type	Total Organisms
Phylum Annelida				
Class Oligochaeta	6	GC		**15**
Class Insecta				
Order Coleoptera				
Dryopidae				
Helichus sp.	4.6	SH	cb	**1**
Dytiscidae				
Hydroporus sp.	8.62	PR	sw	**10**
Elmidae				
Dubiraphia sp.	5.93	GC	cn	**1**
Stenelmis sp.	5.1	SC	cn	**10**
Order Diptera				
Chironimidae				
subfamily Chironominae				
Chironomus sp.	9.63	GC	bu	**1**
Cryptochironomus sp.	6.4	PR	sp	**1**
Microtendipes sp.	5.53	FC	cn	**1**
Tanytarsus sp.	6.76	FC	bu	**1**
Zavrelia sp.	5.3	GC	sw	**1**
subfamily Orthocladiinae				
Parametriocnemus sp.	3.65	GC	sp	**1**
subfamily Tanypodinae				
Conchapelopia Group	8.42	PR	sp	**1**
Culicidae				
Anopheles sp.	8.58	FC	sw	**1**
Culex sp.		FC	sw	**1**
Dixidae				
Dixa sp.	2.55	GC	sw	**1**
Dixella sp.		GC	sw	**1**
Tipulidae				
Antocha sp.	4.25	GC	bu	**1**
Tipula sp.	7.33	SH	bu	**1**
Order Ephemeroptera				
Baetidae				
Baetis intercalaris	4.99	OM	sw	**1**
Centroptilium sp.	6.6	GC	sw	**3**
Heptageniidae				
Stenacron interpunctatum	6.87	SC	cn	**3**
Stenonema sp.		SC		**3**
Leptophlebiidae				
Paraleptophlebia sp.	0.94	GC	sw	**1**
Order Megaloptera				
Sialidae				
Sialis sp.	7.17	PR		**1**
Order Plecoptera				
Nemouridae				
Amphinemura		OM	sp	**1**
Perlidae				
Perlesta sp.	4.7	PR	cn	**10**
Order Odonata				
Aeshnidae				
Aeshna sp.		PR	cb	**1**
Boyeria vinosa	5.89	PR	cb	**1**
Coenagrionidae				
Argia sp.	8.17	PR	cb	**1**
Gomphidae				
Stylogomphus albistylus	4.72	PR	bu	**1**
Order Trichoptera				
Hydropsychidae				
Cheumatopsyche sp.	6.22	FC	cn	**3**
Diplectrona modesta	2.21	FC	cn	**10**
Hydropsyche betteni	7.78	FC		**3**
Limnephilidae				
Pycnopsyche guttifer	2.58	SH	cn	**1**
Psilotreta		SC	cn	**1**
Philopotamidae				
Chimarra sp.	2.76	FC	cn	**3**

Stream Name: Yates Mill restored
Sample Date: 2004

Tolerance Values

Tolerance values were taken from *NCDWQ Master List of Benthic Macroinvertebrates*

Funtional Feeding Designations

PA	Parasite	FC	Filter/collector
PR	Predator	SC	Scraper
OM	Omnivore	SH	Shredder
GC	Gatherer/collector	PI	Piercer

Habit/Behavior Designations

cn	clinger	sw	swimmer
cb	climber	dv	diver
sp	sprawler	sk	skater
bu	burrower		

	Tolerance Values	Functional Feeding Group	Habit/ Behavior Type	Total Organisms
Phylum Annelida				
Class Oligochaeta	6	GC		**10**
Class Insecta				
Order Coleoptera				
Dytiscidae				
Hydroporus sp.	8.62	PR	sw	**3**
Order Diptera				
Chironimidae				
subfamily Chironominae				
Chironomus sp.	9.63	GC	bu	**3**
Phaenopsectra sp.	6.5	SC		**10**
subfamily Tanypodinae				
Clinotanypus pinguis	8.74	PR	sp	**1**
Procladius sp.	9.1	PR	sp	**10**
Culicidae				
Anopheles sp.	8.58	FC	sw	**3**
Dixidae				
Dixella sp.		GC	sw	**1**
Tipulidae				
Tipula sp.	7.33	SH	bu	**3**
Order Trichoptera				
Limnephilidae				
Pycnopsyche guttifer	2.58	SH	cn	**1**

Stream Name: Kentwood restored
Sample Date: 2004

Tolerance Values

Tolerance values were taken from *NCDWQ Master List of Benthic Macroinvertebrates*

Funtional Feeding Designations

PA	Parasite	FC	Filter/collector
PR	Predator	SC	Scraper
OM	Omnivore	SH	Shredder
GC	Gatherer/collector	PI	Piercer

Habit/Behavior Designations

cn	clinger	sw	swimmer
cb	climber	dv	diver
sp	sprawler	sk	skater
bu	burrower		

	Tolerance Values	Functional Feeding Group	Habit/ Behavior Type	Total Organisms
Class Insecta				
Order Coleoptera				
Order Diptera				
Chironimidae				
subfamily Chironominae				
Phaenopsectra sp.	6.5	SC	cn	**1**
Polypedilum illinoense grp	9	SH		**4**
Tanytarsus sp.	6.76	FC		**1**
subfamily Orthocladiinae				
Cricotopus bicinctus C/O sp 1	8.54	OM	cn	**1**
Eukiefferiella claripennis	5.58	GC	sp	**4**
Rheocricotopus sp.	7.3	GC	sp	**1**
subfamily Tanypodinae				
Ablabesmyia sp.	7.2	GC		**1**
Conchapelopia Group	8.42	PR	sp	**6**
Empididae	7.57	PR	sp	**3**
Tipulidae				
Tipula sp.	7.33	SH	bu	**1**
Order Ephemeroptera				
Baetidae				
Baetis flavistriga	6.58	GC	sw	**23**
Baetis pluto	4.28	GC	sw	**1**
Order Trichoptera				
Hydropsychidae				
Cheumatopsyche sp.	6.22	FC	cn	**8**
Hydropsyche betteni	7.78	FC	cn	**29**

Stream Name: Kentwood upstream
Sample Date: 2004

Tolerance Values

Tolerance values were taken from *NCDWQ Master List of Benthic Macroinvertebrates*

Funtional Feeding Designations

PA	Parasite	FC	Filter/collector
PR	Predator	SC	Scraper
OM	Omnivore	SH	Shredder
GC	Gatherer/collector	PI	Piercer

Habit/Behavior Designations

cn	clinger	sw	swimmer
cb	climber	dv	diver
sp	sprawler	sk	skater
bu	burrower		

	Tolerance Values	Functional Feeding Group	Habit/ Behavior Type	Total Organisms
Class Insecta				
Order Diptera				
Chironimidae				
subfamily Orthocladiinae				
Cricotopus sp.	9.04	SH	cn	**3**
Cricotopus bicinctus C/O sp 1	8.54	OM		**12**
Eukiefferiella claripennis	5.58	GC	sp	**9**
Orthocladius sp.	9.11	GC		**1**
Rheocricotopus sp.	7.3	GC	sp	**1**
subfamily Tanypodinae				
Conchapelopia Group	8.42	PR	sp	**2**
Tipulidae				
Tipula sp.	7.33	SH	bu	**1**
Limonia sp.	9.64	SH	bu	**1**
Order Ephemeroptera				
Baetidae				
Baetis flavistriga	6.58	GC	sw	**16**
Order Odonata				
Aeshnidae				
Boyeria vinosa	5.89	PR	cb	**1**
Coenagrionidae				
Argia sp.	8.17	PR		**1**
Order Trichoptera				
Hydropsychidae				
Cheumatopsyche sp.	6.22	FC	cn	**12**
Hydropsyche betteni	7.78	FC	cn	**14**

Stream Name: Abbott restored
Sample Date: 2004

Tolerance Values

Tolerance values were taken from *NCDWQ Master List of Benthic Macroinvertebrates*

Funtional Feeding Designations

PA	Parasite	FC	Filter/collector
PR	Predator	SC	Scraper
OM	Omnivore	SH	Shredder
GC	Gatherer/collector	PI	Piercer

Habit/Behavior Designations

cn	clinger	sw	swimmer
cb	climber	dv	diver
sp	sprawler	sk	skater
bu	burrower		

	Tolerance Values	Functional Feeding Group	Habit/ Behavior Type	Total Organisms
Phylum Annelida				
Class Oligochaeta	6	GC		**2**
Class Insecta				
Order Coleoptera				
Hydrophilidae		PR		
Enochrus spp.		GC		**1**
Order Diptera				
Chironimidae				
subfamily Chironominae				
Chironomus sp.	9.63	GC	bu	**1**
Polypedilum halterale grp	7.31	SH		**5**
Rheotanytarsus sp.	5.89	FC	cn	**2**
Cricotopus bicinctus C/O sp 1	8.54	OM	cn	**1**
subfamily Tanypodinae				
Ablabesmyia sp.	7.2	PR	sp	**4**
Conchapelopia Group	8.42	PR	sp	**13**
Zavrelimyia sp.	9.11		sp	**1**
Culicidae				
Anopheles sp.	8.58	FC	sw	**8**
Order Ephemeroptera				
Baetidae				
Baetis flavistriga	6.58	GC		**2**
Order Odonata				
Aeshnidae				
Boyeria vinosa	5.89	PR	cb	**2**
Coenagrionidae				
Enallagma sp.	8.91	PR	cb	**9**
Order Trichoptera				
Hydropsychidae				
Cheumatopsyche sp.	6.22	FC	cn	**9**
Hydropsyche betteni	7.78	FC	cn	**2**

Stream Name: Abbott upstream
Sample Date: 2004

Tolerance Values

Tolerance values were taken from *NCDWQ Master List of Benthic Macroinvertebrates*

Funtional Feeding Designations

PA	Parasite	FC	Filter/collector
PR	Predator	SC	Scraper
OM	Omnivore	SH	Shredder
GC	Gatherer/collector	PI	Piercer

Habit/Behavior Designations

cn	clinger	sw	swimmer
cb	climber	dv	diver
sp	sprawler	sk	skater
bu	burrower		

	Tolerance Values	Functional Feeding Group	Habit/ Behavior Type	Total Organisms
Phylum Annelida				
Class Oligochaeta	6	GC		**2**
Class Insecta				
Order Coleoptera				
Hydrophilidae		PR		
Enochrus spp		GC		**1**
Order Diptera				
Chironimidae				
subfamily Chironominae				
Paratendipes sp.	5.11	GC	bu	**1**
Phaenopsectra sp.	6.5	SC	cn	**1**
Polypedilum aviceps	3.65	SH		**3**
Polypedilum scalaenum grp	8.4	SH		**3**
subfamily Tanypodinae				
Conchapelopia Group	8.42	PR	sp	**9**
Natarsia sp.	9.95	PR	sp	**1**
Zavrelimyia sp.	9.11		sp	**1**
Ptychopteridae				
Bittacomorpha sp.		GC	bu	**1**
Simuliidae			cn	
Simulium sp.	4	FC	cn	**2**
Tipulidae				
Limonia sp.	9.64	SH	bu	**1**
Order Ephemeroptera				
Baetidae				
Baetis flavistriga	6.58	GC	sw	**6**
Order Odonata				
Aeshnidae				
Boyeria vinosa	5.89	PR	cb	**1**
Order Trichoptera				
Hydropsychidae				
Cheumatopsyche sp.	6.22	FC	cn	**7**

Stream Name: Deaton restored
Sample Date: 2004

Tolerance Values

Tolerance values were taken from *NCDWQ Master List of Benthic Macroinvertebrates*

Funtional Feeding Designations

PA	Parasite	FC	Filter/collector
PR	Predator	SC	Scraper
OM	Omnivore	SH	Shredder
GC	Gatherer/collector	PI	Piercer

Habit/Behavior Designations

cn	clinger	sw	swimmer
cb	climber	dv	diver
sp	sprawler	sk	skater
bu	burrower		

	Tolerance Values	Functional Feeding Group	Habit/ Behavior Type	Total Organisms
Phylum Annelida				
Class Oligochaeta	6	GC		**3**
Class Insecta				
Order Coleoptera				
Elmidae				
Dubiraphia sp.	5.93	GC	cn	**2**
Stenelmis sp.	5.1	SC	cn	**1**
Gyrinidae				
Dineutus sp.	5.54	PR	sw	**1**
Haliplidae				
Haliplus sp.	8.71	SH	cb	**1**
Peltodytes sp.	8.73	SH	sw	**5**
Hydrophilidae				
Enochrus spp		GC	bu	**6**
Tropisternis sp.	9.68	PR	cb	**42**
Psephenidae				
Psephenus herricki	2.35	SC	cn	**3**
Order Diptera				
Ceratopogonidae				
Palpomyia-Bezzia cmplx		PR	bu	**2**
Chironimidae				
subfamily Chironominae				
Chironomus sp.	9.63	GC	bu	**1**
Cryptochironomus sp.	6.4	PR	sp	**1**
Microtendipes sp.	5.53	FC	cn	**15**
Polypedilum aviceps	3.65	SH		**7**
Rheotanytarsus sp.	5.89	FC	cn	**54**
subfamily Orthocladiinae				
Cricotopus bicinctus C/O sp 1	8.54	OM	cn	**4**
Parametriocnemus sp.	3.65	GC	sp	**1**
Tvetenia sp.	3.65	GC	sp	**1**
subfamily Tanypodinae				
Conchapelopia Group	8.42	PR	sp	**32**
Simuliidae				
Simulium sp.	4	FC	cn	**4**
Tipulidae				
Tipula sp.	7.33	SH	bu	**2**
Order Ephemeroptera				
Baetidae				
Baetis flavistriga	6.58	GC	sw	**4**
Baetis pluto	4.28	GC	sw	**11**
Callibaetis sp.		GC	sw	**1**
Procleon		GC	sw	**1**
Caenidae				
Caenis sp.	7.41	GC	sp	**64**
Heptageniidae				
Stenonema sp.		SC	cn	**1**
Isonychiidae				
Isonychia sp.	3.45	FC	sw	**1**
Order Plecoptera				
Perlidae				
Perlesta sp.	4.7	PR	cn	**14**
Order Odonata				
Coenagrionidae				
Ischnura sp.	9.52	PR	cb	**4**
Gomphidae				
Gomphus sp.	5.8	PR	bu	**1**
Libellulidae				
Plathemis lydia		PR	sp	**1**
Order Trichoptera				
Hydropsychidae				
Cheumatopsyche sp.	6.22	FC	cn	**100**

Stream Name: Deaton upstream
Sample Date: 2004

Tolerance Values

Tolerance values were taken from *NCDWQ Master List of Benthic Macroinvertebrates*

Funtional Feeding Designations

PA	Parasite	FC	Filter/collector
PR	Predator	SC	Scraper
OM	Omnivore	SH	Shredder
GC	Gatherer/collector	PI	Piercer

Habit/Behavior Designations

cn	clinger	sw	swimmer
cb	climber	dv	diver
sp	sprawler	sk	skater
bu	burrower		

	Tolerance Values	Functional Feeding Group	Habit/ Behavior Type	Total Organisms
Phylum Annelida				
Class Oligochaeta	6	GC		**1**
Class Insecta				
Order Diptera				
Chironimidae				
subfamily Chironominae				
Microtendipes sp.	5.53	FC	cn	**1**
Polypedilum aviceps	3.65	SH		**14**
Rheotanytarsus sp.	5.89	FC	cn	**2**
subfamily Tanypodinae				
Conchapelopia Group	8.42	PR	sp	**40**
Rheopelopia sp.	2.9	PR	sp	**1**
Simuliidae				
Simulium sp.	4	FC	cn	**5**
Order Ephemeroptera				
Baetidae				
Baetis flavistriga	6.58	GC	sw	**1**
Baetis pluto	4.28	GC	sw	**17**
Order Megaloptera				
Corydalidae				
Nigronia fasciatus	5.55	PR	cn	**1**
Order Plecoptera				
Perlidae				
Perlesta sp.	4.7	PR	cn	**3**
Order Trichoptera				
Hydropsychidae				
Cheumatopsyche sp.	6.22	FC	cn	**25**

Stream Name: Caviness restored
Sample Date: 2004

Tolerance Values

Tolerance values were taken from *NCDWQ Master List of Benthic Macroinvertebrates*

Funtional Feeding Designations

PA	Parasite	FC	Filter/collector
PR	Predator	SC	Scraper
OM	Omnivore	SH	Shredder
GC	Gatherer/collector	PI	Piercer

Habit/Behavior Designations

cn	clinger	sw	swimmer
cb	climber	dv	diver
sp	sprawler	sk	skater
bu	burrower		

	Tolerance Values	Functional Feeding Group	Habit/ Behavior Type	Total Organisms
Class Insecta				
Order Coleoptera				
Hydrophilidae		PR		
Tropisternis sp.	9.68	PR		**1**
Order Diptera				
Chironimidae				
subfamily Chironominae				
Microtendipes sp.	5.53	FC	cn	**1**
Polypedilum aviceps	3.65	SH		**8**
Rheotanytarsus sp.	5.89	FC		**7**
Tanytarsus sp.	6.76	FC		**1**
subfamily Orthocladiinae				
Cricotopus sp.	9.04	SH	cn	**2**
Cricotopus bicinctus C/O sp 1	8.54	OM	cn	**38**
Synorthocladius sp.	4.36	GC		**1**
Tvetenia sp.	3.65	GC	sp	**12**
Conchapelopia Group	8.42	PR	sp	**21**
Simuliidae				
Simulium sp.	4	FC	cn	**2**
Order Ephemeroptera				
Baetidae				
Accerpenna pygmaea		GC	sw	**3**
Baetis sp.		GC	sw	**5**
Baetis flavistriga	6.58	GC	sw	**7**
Baetis pluto	4.28	GC	sw	**1**
Pseudocloeon sp.		SC	sw	**1**
Ephemerellidae				
Ephemerella sp.	2.04	GC	cn	**1**
Isonychiidae				
Isonychia sp.	3.45	FC	sw	**3**
Order Plecoptera				
Nemouridae				
Amphinemura		OM	sp	**1**
Perlidae				
Perlesta sp.	4.7	PR	cn	**92**
Order Odonata				
Calopterygidae		PR		
Calopteryx sp.	7.78	PR	cb	**2**
Order Trichoptera				
Hydropsychidae				
Cheumatopsyche sp.	6.22	FC	cn	**21**
Limnephilidae				
Pycnopsyche sp.	2.52	SH	cn	**1**

Stream Name: Caviness upstream
Sample Date: 2004

Tolerance Values

Tolerance values were taken from *NCDWQ Master List of Benthic Macroinvertebrates*

Funtional Feeding Designations

PA	Parasite	FC	Filter/collector
PR	Predator	SC	Scraper
OM	Omnivore	SH	Shredder
GC	Gatherer/collector	PI	Piercer

Habit/Behavior Designations

cn	clinger	sw	swimmer
cb	climber	dv	diver
sp	sprawler	sk	skater
bu	burrower		

	Tolerance Values	Functional Feeding Group	Habit/ Behavior Type	Total Organisms
Phylum Annelida				
Class Oligochaeta	6	GC		**1**
Class Insecta				
Order Coleoptera				
Dryopidae				
Helichus sp.	4.6	SH	cb	**1**
Elmidae				
Stenelmis sp.	5.1	SC	cn	**1**
Order Diptera				
Chironimidae				
subfamily Chironominae				
Cladotanytarsus sp.	4.09	GC	cb	**3**
Cryptochironomus sp.	6.4	PR	sp	**3**
Paracladopelma sp.	5.51	GC	sp	**1**
Paratendipes sp.	5.11	GC	bu	**11**
Polypedilum aviceps	3.65	SH		**8**
Polypedilum scalaenum grp	8.4	SH		**2**
Rheotanytarsus sp.	5.89	FC	cn	**7**
Tribelos jucundus	6.3	GC	bu	**2**
subfamily Tanypodinae				
Conchapelopia Group	8.42	PR	sp	**18**
Zavrelimyia sp.	9.11	PR	sp	**2**
Culcidae				
Anopheles sp.	8.58	FC	sw	**2**
Order Ephemeroptera				
Baetidae				
Baetis pluto	4.28	GC	sw	**2**
Diphetor hageni			sw	**1**
Ephemerellidae				
Ephemerella sp.	2.04	GC	cn	**1**
Order Plecoptera				
Nemouridae				
Amphinemura		OM	sp	**3**
Perlidae				
Perlesta sp.	4.7	PR	cn	**36**
Order Odonata				
Cordulegastridae				
Cordulegaster sp.	5.73	PR	bu	**3**
Gomphidae				
Gomphus sp.	5.8	PR	bu	**1**
Order Trichoptera				
Hydropsychidae				
Cheumatopsyche sp.	6.22	FC	cn	**3**
Diplectrona modesta	2.21	FC	cn	**3**
Hydropsyche betteni	7.78	FC	cn	**3**
Limnephilidae				
Pycnopsyche sp.	2.52	SH	cn	**2**