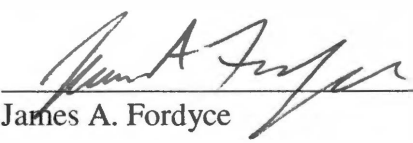


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I am submitting herewith a thesis written by Larry Eugene Everett, Jr. entitled "An Evaluation of the Effects of Small, Man-made Impoundments on Stream Macroinvertebrate Communities and Water Quality in Eastern Tennessee." I have examined the final paper copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Ecology and Evolutionary Biology.

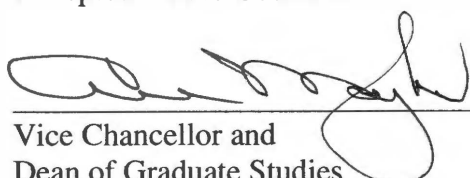

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Thesis
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**An Evaluation of the Effects of Small, Man-made Impoundments on Stream
Macroinvertebrate Communities and Water Quality in Eastern Tennessee**

**A Thesis Presented for the Master of Science Degree
The University of Tennessee, Knoxville**

Larry Eugene Everett, Jr.

December 2005

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Abstract

Semi-quantitative benthic macroinvertebrate samples were collected from riffles above and below four small impoundments in eastern Tennessee. Watershed and habitat surveys and a variety of field measurements were performed for each sample site and each sampling event when appropriate. Samples were collected quarterly (seasonally) during a one-year period. The goal of the study was twofold: (1) to determine whether or not differences in stream macroinvertebrate communities above and below impoundments existed and if so, (2) to attempt to evaluate the possible effects of the impoundments on the downstream benthic community and water quality.

One-hundred and fifty-four distinct macroinvertebrate taxa in 73 families were represented by all samples collected during the study. Multimetric and multivariate analysis methods were utilized to assess semi-quantitative samples. Total number of taxa (Taxa Richness) and number of less tolerant taxa (especially mayflies, stoneflies, and caddisflies) were generally lower in stations below impoundments than in those stations above the impoundments. A number of other biometrics, indices, and water measurements showed similar trends of impairment in below impoundment stations when compared to above impoundment stations. Analysis of variance tests using a number of biometrics and indices indicate that significant differences exist between the macroinvertebrate communities of streams examined. Effects of the impoundments are implicated. However, factors such as other anthropogenic habitat alterations may also be contributing to some impairment trends.

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Chapter I

Introduction

A great deal of research has been aimed at evaluating the ecological effects of large dams, especially those releasing cold, hypolimnetic water, but few studies have examined the impacts of small impoundments on their associated streams (Wotton, 1995; Cortes et al., 1998; Hart et al., 2002; Lessard and Hayes, 2003). Outflows of cold waters, typical of the bottom releases of large reservoirs, frequently cause an easily observable impact to macroinvertebrate communities, often reducing species diversity and the number of intolerant groups (Petts, 1984). Cortes et al. (1998) suggested that the lack of interest in studying small impoundments is likely due to the greater difficulty of clearly identifiable cause and effect relationships.

Small impoundments mostly have surface-release outlets and modify natural flow on a much smaller scale than large dams. Temperature increases within these small impoundments may be significant, especially in cold-water streams during the summer, and is often proportional to increases in surface area and reduced depth. Temperature increases caused by surface-release dams, however, have been poorly studied (Lessard and Hayes, 2003). Temperature plays a strong role in the development and health of macroinvertebrate taxa (Anderson and Wallace, 1996). The impounded portion of a stream and the free-flowing portions commonly provide habitat for unique assemblages of aquatic macroinvertebrates, but with the loss of concentrated flowing water often comes changes in water quality due to altered flow regimes and relative stagnancy. Wotton (1995) stated that the influence of most small surface-release dams only extends a few hundred meters (m), while the influence of larger surface-release dams impacts much greater stream lengths.

Few studies have examined the effects of small, warm surface-release impoundments on downstream communities, although these make up the majority of impoundments in the United States (Wotton, 1995). Impoundments of any significant size may likely cause downstream impacts to habitat. Such habitat changes may affect the variety of substrates available for colonization downstream of dams. Dams generally cause a disconnection between the downstream historical floodplain often leading to reduced production and diversity in both the stream and floodplain habitats (Allan, 1995). Impoundments often reduce the movement of sediment and organic matter, thus affecting both habitat and food availability. Impoundments often inhibit the downstream movement of organic matter, such as leaf fall, affecting the structure of the downstream community. Numerous other physical and chemical factors, such as dissolved oxygen and pH, may become altered as a result of impoundments and have been shown to subsequently affect macroinvertebrate communities.

Some studies have considered productivity of macroinvertebrates downstream of small impoundments compared with that of free-flowing waters (Briggs, 1948; Parker and Voshell, 1983; Mackay and Waters, 1986). One of the earliest of these studies by Briggs (1948) gives evidence of the early bias towards flood control and fisheries

production. Briggs concluded that increases in productivity and resulting stability of outflows were potentially beneficial to stream fish communities. Briggs (1948) did not address reduction in diversity among Ephemeroptera, Plecoptera, and Trichoptera, which comprised 81.3 percent of total collections; only percentages of Trichoptera increased below the dam, while percentages of both Ephemeroptera and Plecoptera decreased. This is likely consistent with an impaired downstream community as Plecoptera and Ephemeroptera are often the first taxa to disappear as a result of water quality degradation.

Others have investigated primarily the ecological effects that result from changes in temperature below impoundments (Wotton, 1995; Lessard and Hayes, 2003). Comparison of changes of the taxonomic and trophic structure of the benthic communities in two small (first order), Appalachian streams with associated beaver impoundments identified both direct (impoundments) and indirect (downstream changes of physical, chemical, and biotic factors) causal relationships (Margolis et al., 2001). Additional comparative studies of water quality above and below small surface water impoundments are needed to further assess the long term impacts of these impoundments and to provide planning, policy, and regulatory guidance to water quality management agencies and others concerned with resource management. It is the objective of this research to further elucidate the effects of small impoundments on benthic macroinvertebrate communities and water quality.

Besides numerous large reservoirs [ranging in size from a hundred to thousands of hectares (ha)], Tennessee has a large number of small man-made impoundments, many of which are not identified on published maps. In Tennessee many of these small man-made impoundments are on small streams. Such small streams cumulatively constitute a large portion of overall stream length (river kilometers) that are currently not being assessed for water quality due to the problematic nature of such numerous headwater assessments. While such impoundments occupy a fairly small overall portion of stream length, their effects may extend much further downstream. For example, increased surface water area within an impoundment and less shade will likely result in proportionally higher or lower than natural downstream temperatures, depending upon the season and climate. Reduced flow variability below small impoundments will often affect organic matter movement and nutrient cycling. These and other factors related to impoundments are likely to have a detrimental effect on downstream aquatic communities as well as terrestrial ecology.

A recent survey of USGS topographic maps by the Tennessee Department of Environment and Conservation identified 1,291 small (less than 121.4 ha) impoundments in Tennessee (www.dep.state.fl.us/water/bioassess/docs/swpba/Kim_Sparks_-SWPBA.pdf). This number is likely much less than the actual number of existing small impoundments in Tennessee. A similar survey by the U.S. Environmental Protection Agency (EPA) estimated that there are over 4,435 dams over 1.8 m high in Georgia. However, a more recent survey of the Upper Oconee watershed in Georgia suggested that only 5 percent of the dams were accounted for in the EPA survey and 100 more were

under construction or awaiting approval in 2003 (www.georgiaencyclopedia.org/nge/Article.jsp?id=h-1180). According to the U.S National Inventory of Dams (<http://crunch.tec.army.mil/nid/webpages/nid.cfm>) the United States had more than 80,000 dams 1.83 m or higher by the year 2000 (Graf, 2003). Graf (2003) claimed that two million dams might actually be present in the United States. The large number of these small impoundments, their widespread distribution throughout the landscape, and their continued construction in streams further supports the need for assessment of their ecological impact.

Anthropogenic alteration of natural flows (mainly impoundments) and nonpoint-source pollution (mainly siltation) have been reported to be responsible for 72 percent of fish imperilment in the southeast (Etnier, 1997). A number of endemic fish species in Tennessee have had their ranges reduced or have been extirpated from entire river systems because of impoundments (Etnier and Starnes, 1993). Most modifications of natural flow regimes to large or small lotic systems are likely to contribute to the general detriment of the health of that system. The Tennessee Division of Water Pollution Control has commonly identified land development and associated habitat alteration, respectively, as a source and cause of pollution of assessed streams (TDEC, 1999; TDEC, 2002). Careful consideration needs to be given to the potential ecological effects that may result from anthropogenic pollution sources or related changes in physiochemical factors such as temperature, dissolved oxygen, pH, conductivity, and nutrients. Such consideration should be incorporated into permit review and regulation in general.

Macroinvertebrate communities have been widely used to assess the biological health of streams. As opposed to physical and chemical measurements taken and representative of only a given moment in time, macroinvertebrates with varying tolerance levels constantly being subjected to the stream environment provide one with a more continuous temporal view of water quality (Rosenburg and Resh, 1996). Macroinvertebrates are sensitive to chemical and physical changes while their limited mobility does not allow them to escape sources of pollution. They are dependent on stable habitat, occupy a vital position in the food chain, and are abundant and easy to collect. A high level of biodiversity of organisms in a given ecosystem is generally considered to be an indication of a healthy environment.

Tennessee's Division of Water Pollution Control (WPC) has chosen macroinvertebrates as the primary indicator organisms for determining the health of streams in Tennessee. WPC has formally adopted regionally based numeric biological criteria or "biocriteria" as required by the U.S. Environmental Protection Agency (EPA) for interpretation of biological data. WPC identified and monitored ninety-eight reference streams in Tennessee's 25 ecological subregions (Griffith et al., 1997) seasonally (spring and fall) between 1996 and 2001 to produce regional reference data (Arnwine and Denton, 2001). This reference data was utilized to develop a standardized multiple metric based biological index for gauging the health of the benthic macroinvertebrate community within similar bioregions (ecological subregion or group of subregions with distinct macroinvertebrate community).

Multivariate analysis was used to determine whether differences between subregions were significant and to develop bioregion data (Arnwine and Denton, 2001). These biometrics undergo annual multivariate testing for reference range calibration, bioregion groupings, and seasonal variability (Arnwine and Denton, 2001). Multiple metrics are a well-recognized method of assessing the health of macroinvertebrate communities. Seven metrics selected for their ability to target measured multiple components of the macroinvertebrate population and estimate different forms of pollution and/or habitat alteration are used to produce a semi-quantitative index or biological score. The score when compared to developed reference criteria allows an assessment of the health of the streams macroinvertebrate community at the time of sampling.

The reference data and associated regionally based scoring index is considered a scientifically defensible method of assessing stream health by comparing the impaired streams with reference conditions (unimpaired streams). The North Carolina Biotic Index (NCBI) of Lenat (1993) has been adapted for use by the Tennessee Division of Water Pollution Control. Tolerance values for taxonomic groups (in this case genera) are weighted based on their relative abundance and used in calculating the NCBI. Additional examples of biometrics include the total number of taxa and the number of taxa of Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies) in a community, and percentages of Ephemeroptera, Plecoptera, and Trichoptera or percentages of Oligochaeta (worms) and Chironomidae (midges). These and other biometrics either combined or individually, may be helpful not only in determining if impairments to water quality exist, but also in elucidating probable causes of the impairments.

The null hypothesis for the study is that there are no significant differences in the upstream and downstream sampling stations. In other words, the impoundment is not affecting the stream below the dam. A possible alternative hypothesis is that significant differences might exist between upstream and downstream stations. One such alternative is that stations upstream of impoundments have healthier macroinvertebrate communities and water quality than those downstream of impoundments. In other words, the impoundment may be resulting in reduced water quality and reduced health of the macroinvertebrate community. The other possible alternative may be that stations downstream of impoundments have healthier macroinvertebrate communities and water quality than those upstream of impoundments. It is more difficult to imagine this type of scenario, but this might occur where the impoundment acts to buffer natural or anthropogenic impacts resulting in improved downstream water quality. Smith Branch, having two upstream and two downstream stations for three of the four sample seasons, received additional analysis to potentially provide a greater indication as to what degree or distance the impoundment may affect downstream macroinvertebrate communities and water quality.

Small man-made impoundments are common features of many low-order, headwater streams in many regions. Such impoundments on perennial streams, especially where other potential impacts are minimal, may provide nearly ideal sites for case studies of the

effects that these impoundments have on downstream ecology. Water quality monitoring conducted by the state of Tennessee and other organizations produces an ever-growing knowledge of background conditions of the surface waters of Tennessee. This monitoring first began with a small number of larger streams or rivers and reservoirs and today attempts to evaluate an increasing number of smaller streams as well continuing to assess the larger water-bodies. As we seek to gain a greater understanding of the anthropogenic effects on water quality and aquatic ecology we must explore the impacts that result from small impoundments.

Chapter II

Description of Study Area

The study area is comprised of four perennial streams with impoundments and their associated watersheds in Anderson, Blount, and Campbell counties, Tennessee. The impoundments, associated streams, and watersheds are indicative of a variety of ecological situations in eastern Tennessee. The study areas represent all three Level III ecoregions of eastern Tennessee and five of the twelve ecological subregions (Level IV ecoregions). More information regarding Level III and Level IV ecoregions can be obtained from the Ecoregions of Tennessee report (Griffith et al., 1997). The impoundments included in the project are representative of a variety of small impoundments. Each station or sample site consisted of a 200 m reach with a variety of suitable riffle habitat. Area measurements of the impoundments and watersheds associated with sample station locations were accomplished using Delorme 3-D Topo Quads software (1999). Each of the four impoundments was located within approximately 70 kilometers (km) of Knoxville, Tennessee (Figure 1). River Kilometer is used to describe the distance of stations and impoundments upstream of the mouth of the stream.

Clear Creek

Clear Creek is a third order tributary to the Clinch River in northeast Anderson County, Tennessee. The stream enters the Clinch River below Norris Dam at approximately River Kilometer 125.8 and has a west flowing aspect. Clear Creek and its associated watershed are within the 67f ecoregion of the Tennessee Ridge and Valley (Griffith et al., 1997; Arnwine et al., 2000). Clear Creek has two small impoundments within 1.4 km of its confluence with the Clinch River. Sample stations were located above and below the upper of the two impoundments (Figure 2). The Civilian Conservation Corps constructed the impoundment in the early 1930s near River Kilometer 1.1. The impoundment is approximately 0.5 ha and nearly 2.5 m at its deepest point. This is the smallest impoundment included in the study.

The well-forested watershed of Clear Creek was measured to be 821 ha at the downstream sample station. This is the largest watershed included in the study. Development within this watershed and especially adjacent to Clear Creek, other than roads and the impoundments, is believed to have had relatively minor impacts on Clear Creek in the past several decades. The remains of a dilapidated water control structure built in the 1930s above the upstream station is a testament to the power of the water that flows through this large watershed. A spring located farther upstream near the head of Clear Creek has served as water source for the City of Norris since 1933. According to Mr. Benny Carden (personal communication), Norris City and Water Manager, the water quality of this water source has not diminished in the thirty-nine years he has been involved in the operation of the water plant.

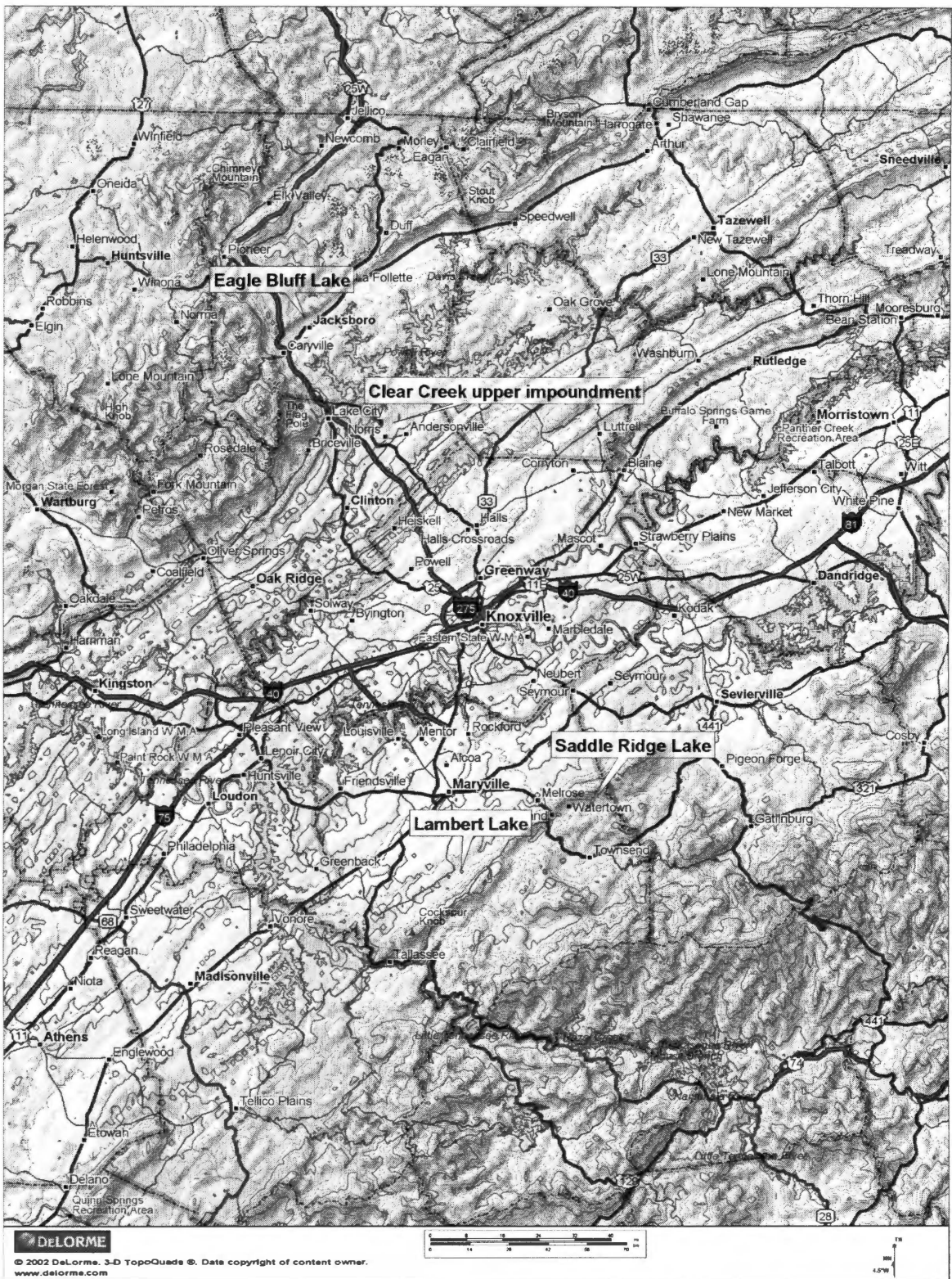


Figure 1. Location of the four impoundments included in the study in relation to Knoxville, Tennessee.



Figure 2. Location of upstream (C1) and downstream (C2) sample stations in Clear Creek above and below the upper impoundment, Anderson County, Tennessee.

The upstream station above of the upper impoundment, located at River Kilometer 1.6 is an ecoregion reference site of the Tennessee Division of Water Pollution Control for which data has been collected since 1996. Portions of the stream within this station are split into two channels with generally shallower riffles than undivided portions. Stream width within the station averaged 2.7 m and average riffle depth was 0.2 m. Gradient within the station was moderate. The substrate was primarily gravel and cobble with some interspersed boulders. Very little evidence of silt was present. Presence of algae was not readily apparent within this station. The canopy throughout this station provided nearly complete shade.

The downstream station was located, at River Kilometer 1.0, 150 m below the dam of the upper impoundment. Average stream width within this station was 2.7 m and average riffle depth was 0.1 m. Gradient within the station was moderate. The riffle substrate was predominately comprised of bedrock and cobble with smaller amounts of boulders and gravel. Very little silt was present. Slight amounts of algae were present within this station. Canopy provided nearly complete shade throughout this station.

Large numbers of reproductive aged trout were observed in the pools of this downstream station during the winter and spring. Trout have on occasion been noted in Clear Creek above both impoundments (Benny Carden, pers. com.). However, Clear Creek is not believed to sustain a naturally reproducing population of trout. Stocking and potentially an occasional upstream dispersal over the dam(s) likely explain the presence of trout in this stream. The heights of the lower and upper dams, respectively, are approximately 1.8 m and 3.7 m high. The Clinch River below Norris Dam is regularly stocked with trout, but the conditions caused by the dam prevent the trout from sustaining themselves naturally (Etnier, 1997).

Eagle Bluff Creek

Eagle Bluff Creek is a first order stream located in central Campbell County northeast of Jacksboro, Tennessee. Eagle Bluff Creek flows south into Dog Creek, which then is directed westward into Cove Lake. The outflow of Cove Lake, Cove Creek, is a tributary of Norris Reservoir, an impoundment of the Clinch River. This system provides an example of a common situation of multiple impoundments from headwaters to large rivers. A 0.7-ha impoundment known as Eagle Bluff Lake is located at River Kilometer 1.3 of Eagle Bluff Creek. Eagle Bluff Lake is approximately 3.5 m at its deepest point. It is approximately 80 years old and the present dam was reconstructed around 1985 (Charles Duncan, pers. com.). Sample stations are located upstream and downstream of Eagle Bluff Lake (Figure 3), respectively, at River Kilometers 1.4 and 1.1. The downstream sample station is located within the 67f ecoregion of the Tennessee Ridge and Valley, while the upstream sample station and greater than 50 percent of the watershed draining to the downstream station are within 69d ecoregion or Cumberland Mountains of the Tennessee Central Appalachians. The largely forested watershed of Eagle Bluff Lake and the downstream sample station was measured to be 23.6 ha. This is the smallest watershed and stream included in the study.

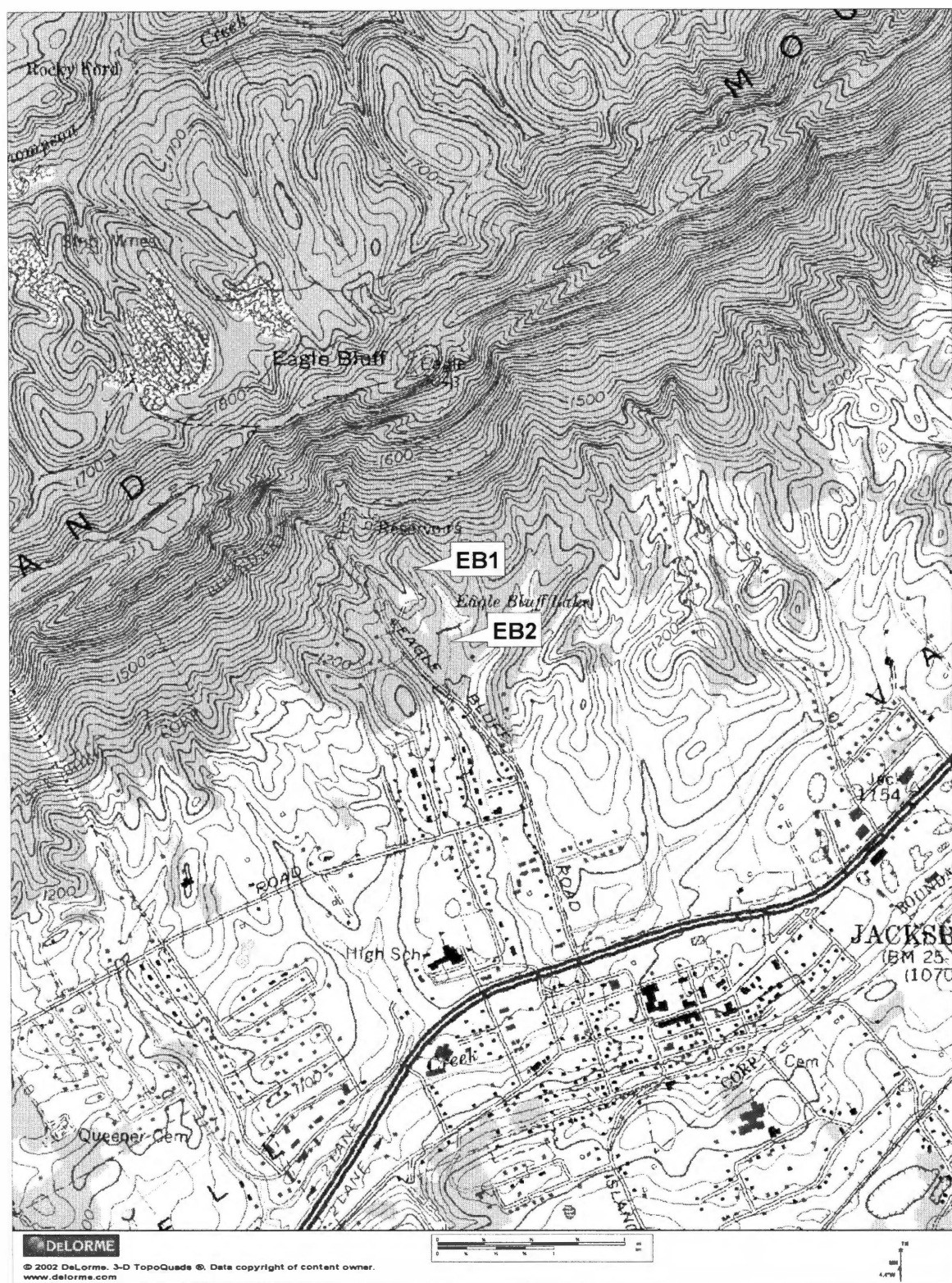


Figure 3. Location of upstream (EB1) and downstream (EB2) sample stations in Eagle Bluff Creek above and below Eagle Bluff Lake, Campbell County, Tennessee.

Several homes are present near the lake. A culvert is in place in the main stream channel a short distance upstream of the upstream sample station. The foundation of a large springhouse built adjacent to the main stream channel circa early 1900 (Charles Duncan, pers. com.) remains intact above of the upstream station. Flow from the springs combine with the main channel flows immediately above the upstream station. The foundation and the springs were expected to create only minor difficulties in the ability to recognize potential differences in the macroinvertebrate community that have resulted from Eagle Bluff Lake. It has been reported that copper sulfate was used, in accordance with directions, in September 2003 to treat an excessive growth of an invasive aquatic plant in the pond (Joe Human, pers. com.). Use of copper sulfate in a pond or other waterbody with a stream connection is prohibited by the Tennessee Water Quality Control Act. This treatment may have had a deleterious effect on downstream macroinvertebrates.

The upstream station, located upstream of Eagle Bluff Lake, averaged 0.9 m in width and riffles averaged 0.1 m in depth. Gradient within this station was generally moderate. Substrate within the riffles of this station included mainly cobble and gravel with some sand and a few boulders. Silt was not readily apparent, except in pool areas. Algae were found to be present in slight amounts. Canopy provided full shading of the stream within this station.

The downstream station, located immediately below Eagle Bluff Lake, had an average width of 0.5 m and an average riffle depth of 0.1 m. Gradient within this station was high due to a small, relatively straight channel. Substrates of riffles within this station were primarily composed of cobble with a small amount of gravel and a few boulders. Sand and clay were present in very small amounts. Silt was not readily apparent within this station. Algae were present in moderate amounts and canopy provided only a small amount of shading within the station. The downstream station has rather extensive habitat alterations apparently resulting from the construction and reconstruction of the dam and the adjacent road. Only manicured grass and a few trees remain along the banks of the downstream station. Mowing the edge of the streams banks has led to excessive stream bank erosion in one area of the downstream station of Eagle Bluff Creek.

Smith Branch

Smith Branch of Reed Creek (hereafter referred to as Smith Branch) is a third order stream located in eastern Blount County, Tennessee. Smith Branch has a north flowing aspect and its associated watershed is located entirely within the 66g ecoregion of the Tennessee Blue Ridge Mountains. Reed Creek flows westward to its confluence with the Little River near Walland, Tennessee. A two-hectare impoundment of Smith Branch, known as Saddle Ridge Lake, is located at River Kilometer 0.6. Saddle Ridge Lake was reportedly 2.4 m at its deepest point when constructed over 40 years ago, but has gradually lost depth as a result of sedimentation and is probably no deeper than 1.8 m (Jack Davis, personal communication).

The watershed of Smith Branch at the most downstream station measures 665.6 ha and is largely forested with scattered residential development and roads. Evidence of slight to moderate silt deposition within Smith Branch appears to have resulted from a combination of poor logging and road building practices, including recent activities. A former smaller impoundment in the headwaters of Smith Branch has now reverted to a shallow wetland habitat. The upstream end of Saddle Ridge Lake contains relatively large amounts of wetlands that may be in part caused by sediment deposition within and adjacent to the stream channel. This along with information regarding the gradual filling in of the impoundment (Jack Davis, pers. com.) due to sedimentation indicates that a significant amount of sediment has entered the stream as a result of surrounding land development. It appears that fine sediments are discharged by the impoundment during high flows and re-suspension of sediments from the lake is also likely.

Two upstream and two downstream sample stations were located in Smith Branch above and below Saddle Ridge Lake (Figure 4). Smith Branch sample stations upstream and downstream of Saddle Ridge Lake located, respectively, at River Kilometer 1.6 and 0.5 were sampled during all quarters. An additional upstream and downstream sample station located, respectively, at River Kilometer 1.0 and 0.2 was selected after the first quarter sampling and was sampled during the last three seasons. These additional sites were chosen for sampling during the remaining three-quarters with the expectation that they would permit greater insight into the assessment of the effects of the impoundment on Smith Branch. It was expected that the additional sites would allow for distance-based analysis of the effects of the impoundment.

The two upstream stations were located upstream of the impoundment at River Kilometer 1.6 and 1.0 of Smith Branch. The upstream station at River Kilometer 1.6 had an average width of 3 m and an average riffle depth of 0.1 m. The upstream station at River Kilometer 1.0 had a slightly narrower average width of 2.5 m and deeper average riffle depth of 0.2 m. Gradient was moderate at both stations. Riffle substrates at both upstream stations were predominately cobble with some gravel and boulders. Substrate at the upstream station at River Kilometer 1.0 contained some bedrock as well. Sand and silt was present in small quantities at both of these sites. Algae were not readily apparent at either of these sites. Canopy was nearly complete at both upstream stations.

Two downstream stations were located at approximately River Kilometers 0.5 and 0.2 of Smith Branch. The station at River Kilometer 0.5 had an average width of 2.7 m and an average riffle depth of 0.1 m. The station near River Kilometer 0.2 had an average width of 2.5 m and an average riffle depth of 0.1 m. Both of these stations were generally of moderate gradient. Riffles within the station at River Kilometer 0.5 were predominately cobble with fair amounts of bedrock and some gravel and boulders. Sand and silt at this station were present in quantities slightly greater than the control stations. Riffles within the station at River Kilometer 0.2 were primarily comprised of boulders with fair amounts of cobble and lesser amounts of gravel and bedrock. Sand and silt were not apparent within this station's riffles. Algae were not readily apparent and canopy provided nearly complete shading within both of the downstream stations.



Figure 4. Location of upstream (SB1, SB2) and downstream (SB3, SB4) sample stations in Smith Branch above and below Saddle Ridge Lake, Blount County, Tennessee.

Big Springs Branch Tributary

An unnamed tributary of Big Springs Branch of Sixmile Creek (hereafter referred to as Big Springs Branch tributary) is a second order stream in central Blount County, Tennessee. The Big Springs Branch tributary has a northwest flowing aspect. Sixmile Creek flows westward to Ninemile Creek, a tributary to the Little Tennessee River. A 6.4-ha impoundment known as Lambert Lake is located at River Kilometer 0.5 of the Big Springs Branch tributary. Lambert Lake was constructed during the 1950s and the dam underwent reconstruction about 1964 (Keith McCord, Sr., pers. com.). Lambert Lake is estimated to be 18.3 m (60 feet) at its deepest point. This is by far the largest impoundment included in the study.

Sample stations upstream and downstream of Lambert Lake (Figure 5) are located, respectively, at River Kilometer 0.6 and 0.3. These stations are within the 67i ecoregion of the Tennessee Ridge and Valley, while greater than 80 percent of their upstream drainage being within the 66e ecoregion of the Tennessee Blue Ridge Mountains. The largely forested watershed of the Big Springs Branch tributary at the downstream sample station was measured to be 184.3 ha. Other than the impoundment, development in the watershed is believed to have had little long-term impact to the Big Springs Branch tributary. Only a single residence is located within the watershed of the sample sites.

The upstream station, located above Lambert Lake, averaged 2 m in width and riffles averaged 0.1 m in depth. Gradient within this station is moderate. The riffle substrate was largely cobble with less gravel and occasional boulders. Sand and silt were present in very small amounts. Algae were not readily apparent within this station. Canopy, especially rhododendron, provided extensive shading within this station.

A portion of the downstream station, located immediately below Lambert Lake, has a divided channel with riffles generally being slightly shallower than undivided portions. The average width of the stream was 2.2 m and riffles averaged 0.1 m deep. Gradient was generally moderate within this station. The riffles were characterized by substrate composed primarily of cobble with lesser amounts of gravel and a few boulders. Sand and silt were present only in very small quantities. Moderate amounts of algae were present although the canopy provided nearly complete shading.

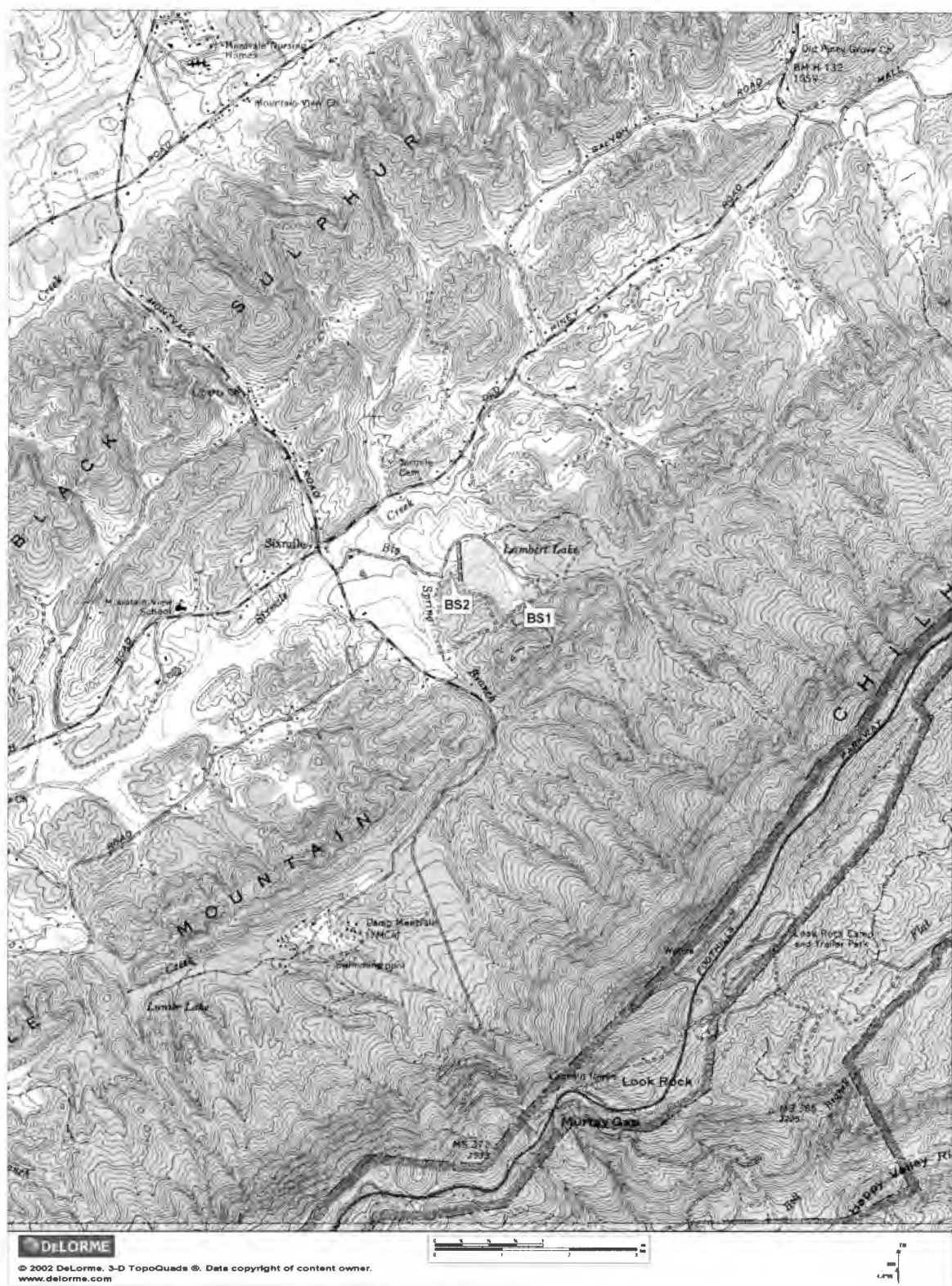


Figure 5. Location of upstream (BS1) and downstream (BS2) sample stations in the Big Springs Branch tributary above and below Lambert Lake, Blount County, Tennessee.

Chapter III

Materials and Methods

Collection of aquatic macroinvertebrates from riffle habitats above and below four small impoundments of perennial, headwater streams was conducted quarterly (seasonally) for one year. Sample periods were summer (mid August), fall (late November and early December), winter (early March), and spring (late May). Measurements of physical water parameters were recorded during each sample collection. In addition, a variety of the surrounding watershed, habitat conditions, and stream characteristics were visually assessed during the sample collections.

Site Selection

Selection of sample sites (stations) of 200 m was based on the following criteria. Sites were to be located upstream and downstream of man-made impoundments of low order (first to third), perennial streams, where impacts other than those resulting from the impoundment itself were believed to be minimal. Preference was for sites with the least amount of evident disturbance, while those having moderate to heavy usage (for example roads, crops, or cattle) were to be avoided. Impoundments were to represent a variety of ecological settings in eastern Tennessee.

The search for sample sites began with a review of topographic maps and the Tennessee Division of Water Pollution Control's permits database (PERMSTAT). Approximately 120 small impoundments were identified by these sources. Field reconnaissance of nearly 45 of these impoundments resulted in selection of four impoundments. A questionnaire survey was sent to persons having knowledge of the history of the lakes and associated streams in order to gain more background information.

Clear Creek Watershed

Clear Creek Station 1 (CC1), Clear Creek Road upstream of Norris Water Treatment Plant and approximately 250 m upstream of upper impoundment, Anderson Co., Norris topo. (137NE), Latitude (Lat.) 36.2133°N, Longitude (Long.) 84.0589°W. This station is also an ecoregion reference site (ECO67F06).

Clear Creek Station 2 (CC2), Located approximately 150 m below upper impoundment and just downstream of Lower Clear Creek Road, Anderson Co., Norris topo. (137NE), Lat. 36.2136°N, Long. 84.0631°W.

Eagle Bluff Creek Watershed

Eagle Bluff Creek Station 1 (EB1), Located approximately 60 m upstream of Eagle Bluff Lake near Forest Lane cul-de-sac, Campbell Co., Jacksboro topo. (136SW), Lat. 36.3436°N, Long. 84.1917°W.

Eagle Bluff Creek Station 2 (EB2), Located approximately 45 m downstream of Eagle Bluff Lake and upstream of Lake Street, Campbell Co., Jacksboro topo. (136SW), Lat. 36.3414°N, Long. 84.1906°W.

Smith Branch Watershed

Smith Branch Station 1 (SB1), Located upstream of Saddle Ridge Road approximately 1.6 km upstream of confluence with Reed Creek and 600 m upstream of Saddle Ridge Lake, Blount Co., Kinzel Springs topo. (148NE), Lat. 35.7314°N, Long. 83.7658°W.

Smith Branch Station 2 (SB2), Located approximately 1.0 km upstream of confluence with Reed Creek and 180 m upstream of Saddle Ridge Lake, Blount Co., Kinzel Springs topo. (148NE), Lat. 35.7327°N, Long. 83.7625°W.

Smith Branch Station 3 (SB3), Located approximately 0.5 km upstream of confluence with Reed Creek and approximately 150 m downstream of Saddle Ridge Lake, Blount Co., Kinzel Springs topo. (148NE), Lat. 35.7372°N, Long. 83.7606°W.

Smith Branch Station 4 (SB4), Located approximately 50 m above East Millers' Cove Road and approximately 0.2 km upstream of confluence with Reed Creek, Blount Co., Kinzel Springs topo. (148NE), Lat. 35.7406°N, Long. 83.7592°W.

Big Springs Branch Tributary Watershed

Big Springs Branch Tributary Station 1 (BS1), Located approximately 75 m upstream of Lambert Lake and approximately 0.6 km upstream of confluence with Big Springs Branch, Blount Co., Blockhouse topo. (148NW), Lat. 35.6573°N, Long. 83.9483°W.

Big Springs Branch Tributary Station 2 (BS2), Located approximately 0.3 km upstream of confluence with Big Springs Branch and approximately 90 m downstream of Lambert Lake outlet, Blount Co., Blockhouse topo. (148NW), Lat. 35.6586°N, Long. 83.9533°W.

Sample Methodology

Sample collection, processing, and analysis were performed in accordance with WPC's macroinvertebrate SOP (TDEC, 2003). Semi-Quantitative Single Habitat samples were collected within a single habitat type, riffles, utilizing the Semi-Quantitative Riffle Kick (SQKICK) and Modified SQKICK techniques. The sampling techniques involve the use of a 500-micron mesh kick net to collect a total of two square meters over a period of 60 seconds from at least two riffles with varied flow velocities for each sample. All samples were returned to WPC's Knoxville Field Office for processing and identification. Measurements of stream temperature, pH, dissolved oxygen, and conductivity were made during each sample collection. Tennessee's water quality standards for fish and aquatic life were used to evaluate these stream measurements. Standards set for fish and aquatic life are the most stringent due to the sensitivity of these organisms.

Habitat assessments were conducted during each sample collection using the habitat data sheets from Rapid Bioassessment Protocols for Use in Wadeable Streams (Barbour et al., 1999). This method numerically assesses the stream for the parameters listed below. Each parameter is assigned a score of 1-20 with 200 being the maximum possible overall score. Overall scores are then compared to ecoregion habitat guidelines to determine to what degree, if any, the level of impairment or non-impairment of the macroinvertebrate community and water quality might be attributed to habitat quality.

Epifaunal Substrate/Available Cover
Embeddedness
Velocity/Depth Regime
Sediment Deposition
Channel Flow Status
Channel Alteration
Frequency of Riffles
Bank Stability
Vegetative Protection
Riparian Vegetative Zone

Watershed characteristics, physical stream characteristics, and additional stream survey information was collected during each sampling event. Percent contribution of various substrate sizes, presence and type of sediment deposits and algae were recorded. Percent cover was measured at each station during each sampling event using a spherical densiometer. Readings were taken mid-stream at one or more location within the sample reach. More than one location within the reach was occasionally measured to obtain a representative average measurement for stations with less evenly distributed canopy. Measurements were taken facing four directions (north, east, south, and west) at each location. Various characteristics of the watershed and stream were evaluated to determine their potential contribution to quality of the biotic community and water quality.

Sample Processing

Samples collected in the field were returned to the laboratory for subsampling, sorting, identification, and enumeration. Samples were reduced to random 200 +/- 20% (160-240) organism subsamples as outlined in WPC's macroinvertebrate SOP (TDEC, 2003). This method is taken directly from section 7.3 (pages 7-9) of the 1999 guidance, Rapid Bioassessment Protocols for Use in Wadeable Streams and Rivers (Barbour et al., 1999).

Sorted subsamples (i.e., benthic macroinvertebrates) were then identified to genus level (whenever possible) or lowest taxonomic unit. Taxonomic identification followed the semi-quantitative samples protocol of the State of Tennessee Division of Water Pollution Control (TDEC, 2003). All organisms were identified to genus except Acari, Nematoda, Hydra, Branchiobdellidae, immature Tubificidae, and Lumbriculidae. In

some instances damaged, immature specimens, or those lacking taxonomic keys to the genus level were identified to family level. Species epithets were used for known monotypic genera and genera with a single eastern North American species. Merritt and Cummins (1996), Thorp and Covich (1991), and Epler (2001) were the primary references used for identifications. Supplementary keys for particular taxonomic groups or life stages were also consulted (e.g., Ross, 1944; Johannsen, 1970; Kenk, 1972; Hitchcock, 1974; Brigham et al., 1982; Burch, 1982; Weiderholm, 1983; Pennak, 1989; Wiggins, 1996; Lugo-Ortiz and McCafferty, 1998; Williams and Bivens, 2001; Stewart and Stark, 2002).

Data Reduction

Following subsampling, sorting, identification, and enumeration of organisms from each semi-quantitative subsample, several biometrics and a multivariate index were used to evaluate the data. A number of these biometrics and their descriptions are taken from WPC's macroinvertebrate SOP (TDEC, 2003).

Taxa Richness (TR) is a measure of the diversity and health of the benthic community through a measurement of the variety of taxa (total number of genera) present. It is expected that richness will increase with higher water quality although severely polluted streams may have a high number of tolerant taxa, such as oligochaetes and chironomids.

EPT Richness (EPT) is the number of taxa collected representing the orders Ephemeroptera, Plecoptera, and Trichoptera. These groups generally appear most sensitive to environmental disturbances and are often the first to be eliminated. Number of EPT taxa increases with increasing water quality.

Percent Contribution of EPT (%EPT) is the relative abundance of the generally intolerant Ephemeroptera, Plecoptera, and Trichoptera individuals compared to the total number of individuals in the subsample. Percent EPT usually increases with increasing water quality.

Percent Oligochaetes and Chironomids (%OC) is the relative abundance of the generally tolerant Oligochaeta and Chironomidae individuals compared to the total number of individuals in the subsample. The %OC increases with increasing amounts of organic pollution.

The North Carolina Biotic Index (NCBI). Hilsenhoff (1987) developed a biotic index to determine the impact of organic pollution to the stream community. Although it may be applicable for other types of pollutants, use of the Hilsenhoff biotic index (HBI) in detecting non-organic pollution effects has not been thoroughly evaluated (Plafkin et al., 1989). The state of North Carolina developed the NCBI as a general way to measure any form of stress or pollution that reduces EPT taxa richness or supports tolerant taxa within the stream community (Lenat, 1993). The NCBI was developed from a larger database than the HBI, but used the HBI data also for guidance. The NCBI is used in the present

study because of the geographical distance of the sites from the streams on which the Hilsenhoff biotic index was developed, and the NCBI's inclusion of more types of pollution. The NCBI evaluates the degree of a wide variety of pollution types by assigning tolerance values to aquatic macroinvertebrates. Like the HBI, tolerance values range from zero to ten, zero representing the most intolerant and ten the most tolerant species. Tolerance values of all organisms in a sample are averaged to provide the biotic index value using the formula below. Water quality and associated degree of pollution were assessed based on the biotic index value ratings identified in Table 1.

$$\text{Biotic Index} = \frac{\sum n_i a_i}{N}$$

Where: N = total number of organisms in a sample/subsample

n_i = number of individuals of each species/genus

a_i = tolerance value

Percent Contribution of Dominant Taxa (%DOM) is the abundance of the most dominant taxa expressed as a percent of abundance of all taxa in subsample. A community dominated by relatively few species reflects environmental stress as indicated by a high percentage of specimens of dominant taxa.

Percent Contribution of Clingers (%CLING) is the abundance of organisms that build fixed retreats or have adaptations to attach to surfaces in flowing waters expressed as a percent of abundance of all taxa in subsample. This metric is expected to decrease in response to degradation of habitat, water quality, or both.

Table 1. Water quality assessment and degree of pollution based on NCBI derived from biotic index score ratings of Hilsenhoff (1987).

Biotic Index	Water Quality	Degree of Pollution
0.00-3.50	Excellent	No apparent pollution
3.51-4.50	Very Good	Possible slight pollution
4.51-5.50	Good	Some pollution
5.51-6.50	Fair	Fairly significant pollution
6.51-7.50	Fairly Poor	Significant pollution
7.51-8.50	Poor	Very significant pollution
8.51-10.00	Very Poor	Severe pollution

The values derived from these first seven biometrics, listed above, were then equalized by assignment of a score of 0, 2, 4 or 6 based on comparison with ecoregion reference data for the appropriate bioregions as identified in the WPC's macroinvertebrate SOP (TDEC, 2003). These equalized scores for each sample are then summed to produce a biological score (TDEC, 2003). This biological score is used to assess the biological condition of the station and level of impairment or non-impairment based on ranked reference data for bioregion and season. Those streams whose scores meet or exceed the proposed biocriteria are considered to have a non-impaired biological condition. Scores less than the proposed biocriteria are considered to have a biological condition of slightly impaired, moderately impaired, or severely impaired depending upon the value of the score. For more detail regarding index score rating and category levels for particular bioregions and seasons refer to Development of Regionally-based Numeric Interpretations of Tennessee's Biological Integrity Criterion (Armwine et al., 2001).

Percent Contribution of Nutrient Tolerant Taxa (%NUTOL) is the abundance of organisms considered to be tolerant to elevated nutrient levels expressed as a percent of abundance of all taxa in the subsample. This biometric was developed by the Kentucky Division of Water Quality (Armwine et al., 2003). Fourteen taxa make up the nutrient tolerant taxa. These taxa include three EPT genera (*Baetis*, *Stenacron*, and *Cheumatopsyche*), two beetle genera (*Stenelmis* and *Psephenus*), four midge genera (*Chironomus*, *Cricotopus*, *Polypedilum*, and *Rheotanytarsus*), a blackfly genus (*Simulium*), one crustacean genus (*Lirceus*), two snail genera (*Elimia* and *Physella*), and the aquatic worms (Oligochaeta). The percentage of nutrient tolerant organisms frequently increases with increased nutrient levels and reduced water quality.

Shannon-Wiener Diversity (H) and Equitability (E_H) were calculated for each station during each season sampled. Shannon-Wiener is frequently used to determine aquatic biodiversity. The formula for Shannon-Wiener diversity (H) as described by Krebs (1989) is:

$$H = - \sum (p_i)(\ln p_i)$$

where p_i = the proportion of individuals in the " i^{th} " taxon of the community. Shannon's index accounts for abundance and equitability (evenness) of specimens of the taxa present. In general, unpolluted waters have values of H ranging between 3 and 4, while extremely polluted waters have values of H that are less than 1. However, caution must be exercised when evaluating this metric as polluted areas may have a high diversity of tolerant organisms.

Equitability is generally considered to be a more sensitive indicator of degradation than diversity when the effect is moderate or slight. Shannon's equitability or evenness (E_H) values were calculated to evaluate the component of diversity due to the distribution

of individuals among the taxa by dividing the calculated diversity (H) by $H_{\max}$ (here $H_{\max} = \ln S$, where S = total number of taxa in the community). Equitability assumes a value between 0 and 1 with 1 being complete evenness. Equitability levels of less than 0.5 are thought to be indicative of environmental degradation. However, values calculated from samples or samples containing less than 100 specimens should be evaluated with caution.

Simpson's Index of Diversity (1-D) was calculated for each subsample. Simpson's index of diversity is a commonly used diversity index that represents the probability that two randomly selected individuals in a community are of different taxa. Krebs (1989) described Simpson's index (D) as follows:

$$D = \sum p_i^2$$

where D is Simpson's index and is defined as the likelihood that two randomly selected individuals from a sample are of the same species, genus, or other category. This index, with a range of 0 to 1 with 0 representing infinite diversity, is less intuitive. Simpson's index of diversity (1-D) with a range of 0 to 1 with 1 now representing infinite diversity is more intuitive and is thus chosen for use in this document. Simpson's Index of Diversity gives relatively little weight to rare taxa and more weight to more abundant taxa.

Jaccard's Coefficient of Community Similarity (CC_J) was calculated for each pair of upstream and downstream stations within a stream for all sample seasons. This metric uses the presence or absence of taxa to gauge the taxonomic similarity between two stations and is useful for comparing impacted and reference reaches (KDOW, 1999). Jaccard's coefficient ranges from 0 to 1, with 0 representing completely dissimilar communities and 1 representing communities that are exactly alike. Jaccard's coefficient is described as:

$$CC_J = \frac{c}{s_1 + s_2 - c}$$

where c = number of shared taxa between communities 1 and 2

s_1 = number of taxa found in community 1

s_2 = number of taxa found in community 2

Comparisons of biological scores, metric values, presence or absence data, and abundance data were used to provide insight into the effects of the impoundments on macroinvertebrate communities within and among streams. Habitat assessments and water parameter measurements were compared to reference data and water quality standards to determine whether any abnormal differences between stations upstream and downstream of impoundments are related to the impoundments.

Quality Assurance

Quality Assurance on each sample set was performed in accordance with WPC's macroinvertebrate SOP (TDEC, 2003). A second experienced taxonomist checked ten percent of all samples analyzed by the initial taxonomist for accuracy in identification and picking efficiency. Any questionable identifications were checked against a reference collection, which has been verified by EPA personnel. All data were reviewed for errors in keypunch and ten percent of all statistical analyses were recalculated.

Statistical Analyses

The main purpose of this study was to evaluate the effects of small impoundments on the macroinvertebrate communities and water quality of the study streams. It is well accepted that ecological field data sets involving abundance counts within communities do not often follow a normal distribution (Potvin and Roff, 1993) and often have unequal variance, thus making parametric analyses questionable. The natural variations within biological communities make statistical analyses and hypothesis testing difficult. Analysis of variance (ANOVA and MANOVA) tests, however, are generally considered to be a robust, parametric method for testing the significance of differences in benthic communities. Analysis of variance tests were performed using SPSS software (SPSS, 2003) and JMP software (SAS, 2004). Multivariate and univariate ANOVA testing of between subject streams, stations (upstream versus downstream), and the interaction of these subject factors was performed for several biometrics to detect differences. The set of dependent variables which ANOVA tests examined were TR, EPT, %EPT, %OC, NCBI, %DOM, %CLING, SQ Index, and %NUTOL. All significance tests were based on an alpha (α) of 0.05 for a confidence level of 95 percent.

Non-metric Multidimensional Scaling (NMS, MDS, NMDS, or NMMDS) of transformed abundance data from upstream and downstream stations within streams was conducted using PC-ORD for windows software (McCune and Mefford, 1999) in order to provide additional analysis of community data. Transformations involved removal of taxa represented by only a single specimen and relativization by maximum abundance for each taxon. Removal of rare taxa is a common and necessary transformation that prevents the effects that these taxa could have on the data matrix and resulting ordination. Without such removal these taxa would be over represented in the dissimilarity matrix (Legendre and Gallaher, 2001; Clarke, 1993).

This NMS method of ordination provides a useful visual aid in making similarity comparisons between macroinvertebrate communities with non-normal distributions (McCune and Grace, 2002). NMS is an iterative search method based on ranked distances. "Stress" is a measure of the difference between distances of various points on the NMS plot compared to the distance matrix of the original data (Clarke, 1993; Legendre and Anderson, 1999). NMS is used here to produce a dissimilarity matrix, in this case of samples from the upstream and downstream communities in various seasons.

NMS results are discussed and ordinations are given for studied streams in which a useful ordination was produced.

Chapter IV

Results and Discussion

Taxonomic Resolution

One-hundred and fifty-four distinct macroinvertebrate taxa in 73 families were identified (Tables A1-A5). Of these, 142 taxa (92.2%) were identified to genus. Three taxa (2.0%) were identified to pairs of closely related genera. Seven taxa (4.6%) were identified only to family. It is not surprising that insects were by far the most common arthropods collected during this study. Midges (Diptera: Chironomidae) constituted 35 (24.7%) of the 142 genera collected. It is important to note that the taxa collected during this project in each of the study streams represent only a portion of macroinvertebrate communities of these streams as only one habitat type was sampled. It is also likely that some rare taxa that are residents within the riffle habitats were not collected or at least not included in subsamples.

Presence or Absence of Tolerant and Intolerant Taxa

It is noteworthy that presence or absence of certain intolerant and tolerant taxa appears to be related to the location of impoundments. Trichoptera genera *Agapetus* (Glossosomatidae) and *Polycentropus* (Polycentropodidae), while represented in all upstream stations, were not collected in stations a short distance below the impoundments being studied. *Polycentropus* was, however, collected in the most downstream station of Smith Branch. The absence of these two Trichoptera taxa in stations just downstream of the impoundments, especially the intolerant *Agapetus* (NCBI=0), suggests that the stream is being impacted by the impoundments. *Diamesa* (Diptera: Chironomidae) were collected in all stations downstream of impoundments, but were not represented in any upstream stations. *Diamesa* is considered very tolerant (NCBI=8.12) and its presence is likely a reflection of the effects of the impoundments.

Taxa such as *Ectopria* (Coleoptera: Eubriidae), *Psephenus* (Coleoptera: Psepheniidae) and *Brillia* (Diptera: Chironomidae) may be particularly intolerant of conditions below impoundments as these taxa were present above, but not below most impoundments. A much larger data set may allow identification of benthic macroinvertebrates that are intolerant of impoundments to a greater degree. Derivation of a metric based on these organisms, as well as taxa tolerant of regulated flows, may further improve the ability of water quality managers to recognize impairment caused by small dams. The absence of certain taxa (for example *Agapetus* and *Psephenus*) from most stations below impoundments when they are regularly present upstream is evidence that these structures result in degradation of the study streams ability to support a diverse native benthic fauna.

Comparison of Between Subject Factors

The multivariate analysis of variance (MANOVA) test was performed among all upstream and downstream stations, excluding SB2 and SB4, for the dependent set of variables (biometrics), except the composite variable SQ Index, with percentage values arcsine transformed for a normal distribution. This MANOVA found overall differences from mean values of the subject biometrics were statistically significant according to Pillai's Trace among all four streams, excluding stations SB2 and SB4, $F_{(24,57)} = 3.405$ and $P < 0.001$. Mean differences were also statistically different according to an F test between all upstream and downstream stations $F_{(8,17)} = 11.588$ and $P < 0.001$. A larger F value in the overall test of sites than in the overall test of streams reveals that stations downstream of the impoundments are significantly different from the stations upstream of the impoundments more so than differences between streams. Similarly MANOVA found mean differences of interaction of factors (upstream and downstream stations dependent upon the stream) to also be statistically significant according to Pillai's Trace $F_{(24,57)} = 2.096$ and $P = 0.012$. A summary of the subsequent univariate tests following the MANOVA test for the set of dependent variables is included in Table 2.

Multivariate analysis of variance tests for all stations were performed to analyze the relative explanatory value of individual biometrics. The resulting canonical correlation from the first eigenvector from the MANOVA test for all stations with percentage values arcsine transformed was very high at 0.92, explaining over 85% of the relationship. The resulting canonical function coefficients and means are given in Table 3. A plot of the canonical coefficient means from the first eigenvector of the biometrics of all upstream and downstream sites is given in Figure 6.

Comparison of Stations Upstream and Downstream of the Upper Impoundment of Clear Creek

Macroinvertebrate Communities

Figures 7-11 show semi-quantitative index scores (biological scores), Taxa Richness (TR), EPT Richness, NCBI values, and Percent EPT, respectively, for Clear Creek stations (CC1 and CC2). Figure 12 displays NMS ordination of the seasonal samples from Clear Creek at the upstream and downstream stations. A synopsis of water measurements from Clear Creek and a number of metrics calculated are presented in Table 4. Jaccard's Coefficient of Community Similarity between the upstream and downstream station for each season is presented in Table 5.

Biological scores for all upstream and downstream samples from Clear Creek (Figure 7), except for the downstream sample collected in the spring (26), were at or above the target score (32) for the bioregion. All samples from the upstream station had an equal or higher biological score than those of the downstream station over all seasons. Biological scores in the spring were the largest (42) upstream and the smallest (26) downstream values for all seasons. Average biological scores were 39 and 33 for the upstream and

Table 2. The results of univariate tests following the two-way MANOVA for dependent variables (biometrics) by stream, and between upstream and downstream stations. The MANOVA tests each of the dependent variables for comparisons among the four streams, between upstream and downstream sites, and comparison of the combined interaction between upstream and downstream sites within each stream.

Source	Dep. Variable	df	Error df	SS	MS	F	<i>P</i>
Stream	TR	3	24	295.125	98.375	4.476	.012
	EPT	3	24	45.000	15.000	2.590	.076
	Trans%EPT	3	24	0.468	0.156	7.183	.001
	NCBI	3	24	2.578	0.859	4.255	.015
	Trans%OC	3	24	0.539	0.180	5.411	.005
	Trans%DOM	3	24	0.069	0.023	2.213	.113
	Trans%CLING	3	24	0.227	0.076	3.257	.039
	SQ Index	3	24	180.500	60.167	4.126	.017
	Trans%NUTOL	3	24	0.168	0.056	1.835	.168
Site	TR	1	24	780.125	780.125	35.494	.000
	EPT	1	24	420.500	420.500	72.604	.000
	Trans%EPT	1	24	0.107	0.107	4.907	.036
	NCBI	1	24	5.437	5.437	26.924	.000
	Trans%OC	1	24	0.110	0.110	3.302	.082
	Trans%DOM	1	24	0.080	0.080	7.642	.011
	Trans%CLING	1	24	0.002	0.002	0.083	.775
	SQ Index	1	24	612.50	612.50	42.000	.000
	Trans%NUTOL	1	24	0.575	0.575	18.806	.000
Stream x Site	TR	3	24	270.125	90.042	4.097	.018
	EPT	3	24	103.000	34.333	5.928	.004
	Trans%EPT	3	24	0.291	0.097	4.466	.013
	NCBI	3	24	2.298	0.766	3.793	.023
	Trans%OC	3	24	0.044	0.015	0.445	.723
	Trans%DOM	3	24	0.045	0.015	1.444	.255
	Trans%CLING	3	24	0.279	0.093	4.000	.019
	SQ Index	3	24	276.500	92.167	6.300	.003
	Trans%NUTOL	3	24	0.090	0.030	0.979	.419

Table 3. The resulting canonical function (CF) coefficients from the first eigenvector from the MANOVA for the set of dependent variables (biometrics) between upstream and downstream stations. Transformed percentile means are given in parentheses.

Dependent variable	CF coefficients	Mean	
		u/s	d/s
TR	-0.0263666	32.750	22.875
EPT	0.08135968	15.75	8.50
%EPT	-0.4320759	59.506 (0.882280)	48.069 (0.76791904)
NCBI	-0.3516812	3.74	4.56
%OC	-0.2698144	10.620 (0.30981444)	20.913 (0.4268907)
%DOM	0.08712095	22.663 (0.49221485)	31.763 (0.59205762)
%CLING	-0.8546761	60.713 (0.89627746)	58.781 (0.88071909)
SQ Index	0.03385216	38.00	29.25
%NUTOL	-0.1432121	26.719 (0.53018044)	51.169 (0.79838129)

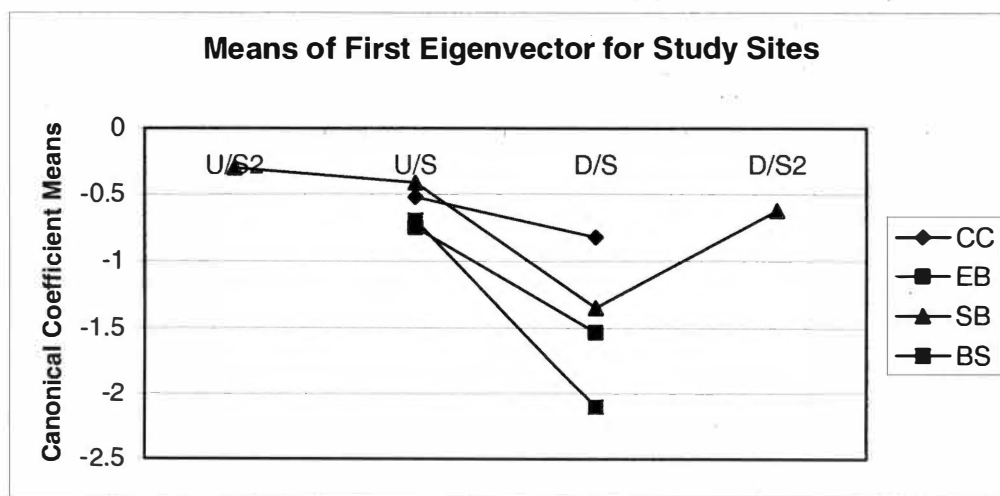


Figure 6. Plot of the canonical coefficient means from the first eigenvector of the biometrics of all upstream and downstream sites. U/S2 and D/S2 represent Smith Branch sites SB2 and SB4, respectively.

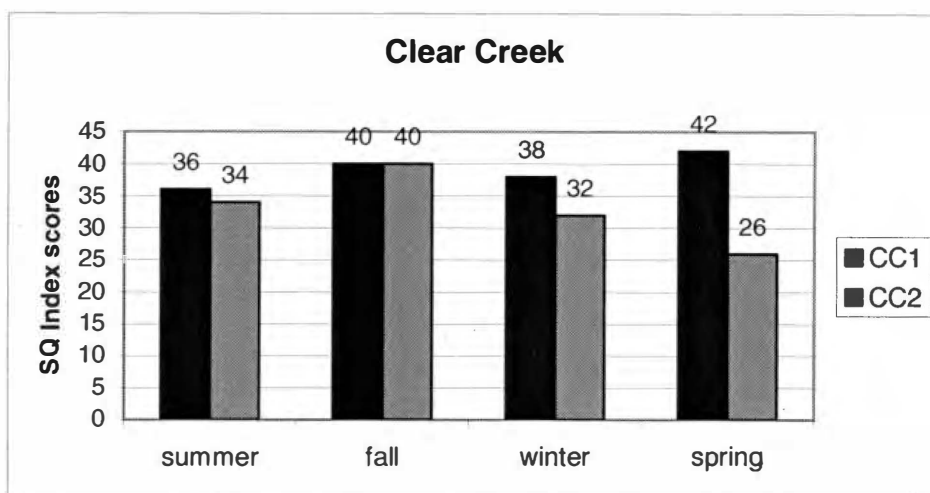


Figure 7. Semi-quantitative index scores for two stations (CC1 and CC2) on Clear Creek, 11 August, 2003 (summer), 1 December 2003 (fall), 5 March 2004 (winter), and 20 May 2004 (spring).

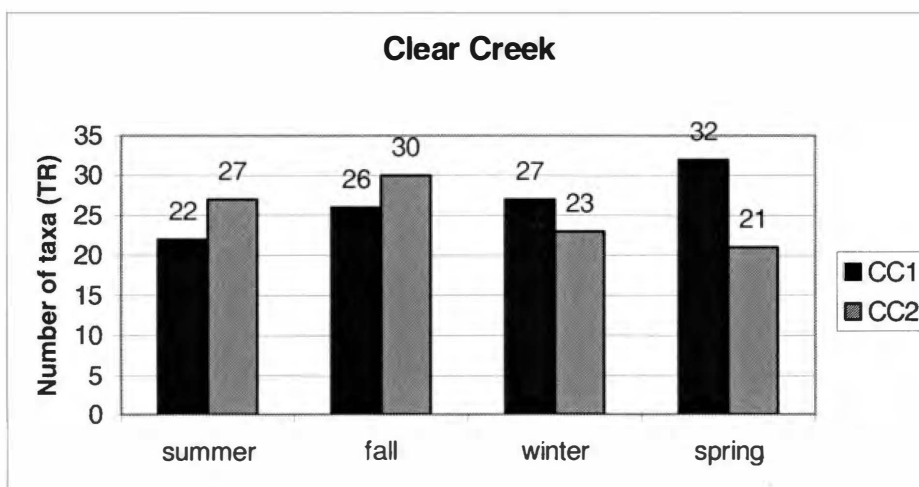


Figure 8. Taxa richness for two stations (CC1 and CC2) on Clear Creek, 11 August, 2003 (summer), 1 December 2003 (fall), 5 March 2004 (winter), and 20 May 2004 (spring).

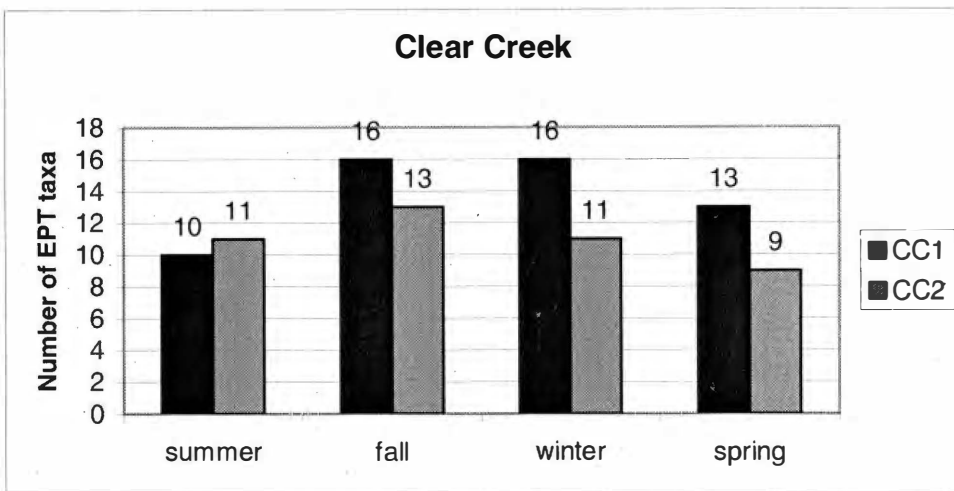


Figure 9. EPT richness for two stations (CC1 and CC2) on Clear Creek, 11 August, 2003 (summer), 1 December 2003 (fall), 5 March 2004 (winter), and 20 May 2004 (spring).

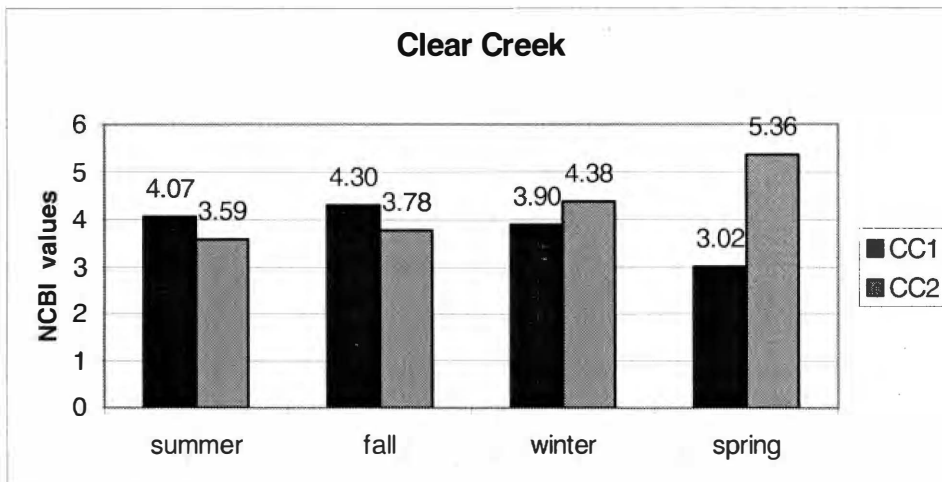


Figure 10. NCBI values for two stations (CC1 and CC2) on Clear Creek, 11 August, 2003 (summer), 1 December 2003 (fall), 5 March 2004 (winter), and 20 May 2004 (spring).

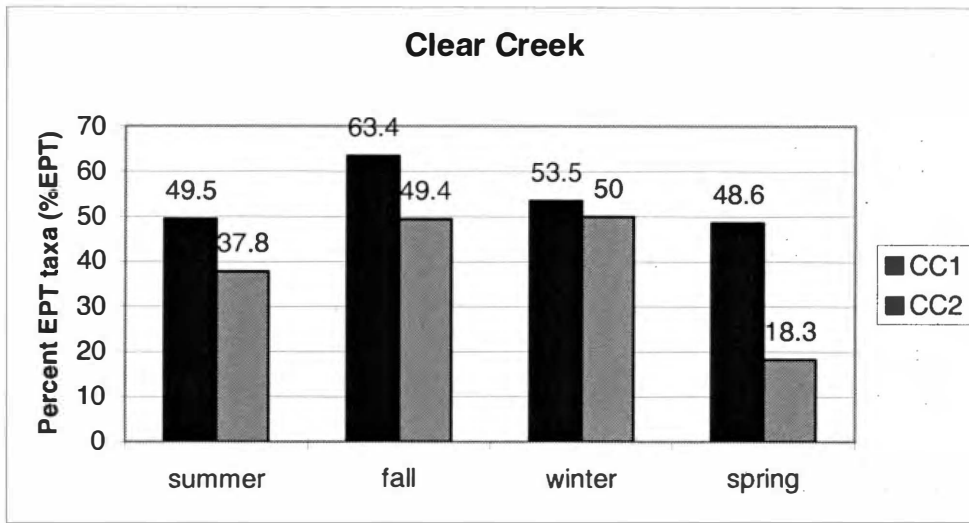


Figure 11. Percent of EPT taxa for two stations (CC1 and CC2) on Clear Creek, 11 August, 2003 (summer), 1 December 2003 (fall), 5 March 2004 (winter), and 20 May 2004 (spring).

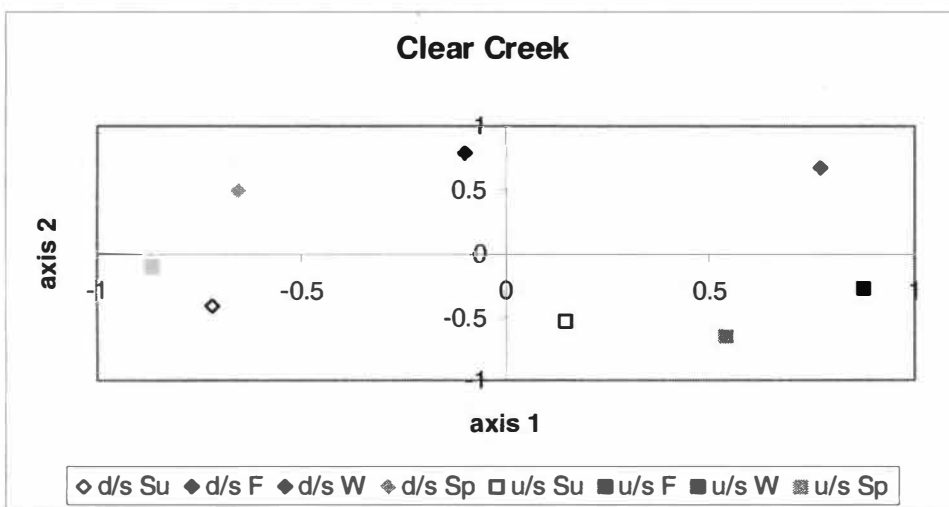


Figure 12. NMS ordination of sample data (stress = 5.38) for stations upstream (u/s) and downstream (d/s) of the upper impoundment of Clear Creek for four seasons (summer Su, fall=F, winter=W, spring=Sp). Plot is based on analysis of transformed taxa abundance data.

Table 4. Selected physical measurements and metrics for stations above (CC1) and below (CC2) the upper impoundment of Clear Creek collected quarterly from August 2003 to May 2004.

Season	Summer		Fall		Winter		Spring	
Site	CC1	CC2	CC1	CC2	CC1	CC2	CC1	CC2
TEMP	15.98	17.01	10.75	9.80	13.95	13.58	15.20	16.90
DO	10.28	9.99	10.98	11.36	12.48	12.51	10.10	9.86
PH	7.86	8.00	7.88	8.11	8.15	8.16	7.88	8.03
COND	132.5	139.1	181.5	254.1	198.0	201.0	227.0	223.0
TR	22	27	26	30	27	23	32	21
EPT	10	11	16	13	16	11	13	9
%EPT	49.5	37.8	63.4	49.4	53.5	50.0	48.6	18.3
%OC	3.8	20.7	2.9	7.9	4.3	3.4	9.4	3.0
NCBI	4.07	3.59	4.30	3.78	3.90	4.38	3.02	5.36
%DOM	24.8	14.4	23.4	18	21.1	35.3	24.3	49.7
%CLING	54.3	41.4	66.3	60.7	50.8	27.4	57.5	19.8
SQ Index	36	34	40	40	38	32	42	26
%NUTOL	58.6	50.9	43.9	41.6	37.3	47.1	24.9	74.1
H	2.48	2.82	2.61	2.84	2.85	2.25	2.83	1.94
EH	0.8	0.85	0.8	0.83	0.87	0.72	0.84	0.64
1-D	0.88	0.92	0.89	0.91	0.91	0.81	0.90	0.72

TEMP = Stream water temperature in degrees celcius at mid-depth

DO = Dissolved Oxygen in mg/l

pH = Measurement for the relative concentration of hydrogen (H+) and hydroxol (OH-) ions in solution

COND = Specific conductivity in $\mu\text{S}/\text{cm}$

TR = Taxa Richness

EPT = Number of Ephemeroptera, Plecoptera, and Trichoptera taxa

%EPT = Percentage of sample represented by EPT

%OC = Percentage of sample represented by Oligochaetes (aquatic worms) and Chironomids (midges)

NCBI = North Carolina Biotic Index

%DOM = Percentage of the sample represented by the most dominant taxa

%CLING = Percentage of the sample represented by taxa with adaptations for clinging in fast flowing water

SQ Index = Semi-quantitative index scores

%NUTOL = Percentage of the sample represented by taxa considered to be tolerant of elevated nutrient levels

H = Shannon-Weiner Diversity Index

EH = Shannon-Weiner Evenness

1-D = Simpson's Index of Diversity

Table 5. Jaccard's Coefficients of Community Similarity (CC_j) for stations upstream (CC1) and downstream (CC2) of the upper impoundment of Clear Creek for each season.

Season	Stream	Stations	CC_j
Summer	Clear Creek	CC1 & CC2	0.48
Fall	Clear Creek	CC1 & CC2	0.37
Winter	Clear Creek	CC1 & CC2	0.43
Spring	Clear Creek	CC1 & CC2	0.36

downstream sites, respectively. Average biological scores for the upstream and downstream station were significantly different, $F_{(1,24)} = 4.937$ and $P = 0.036$. Biological condition of the stations was non-impaired for all samples based on these scores, except for the downstream in the spring, which was rated as partially impaired.

The individual metrics used to formulate the biological scores and the percent nutrient tolerance metric for the upstream and downstream sites were not significantly different than expected from chance alone. Taxa richness (Figure 8) while not statistically different for all samples showed seasonal differences. Average taxa richness value was higher for the upstream (26.8) than the downstream station (25.2). EPT taxa richness values (Figure 9) for the downstream site were lower in three of four seasons and contained only one more taxon in the summer sample than the upstream station. The percentages of samples from the downstream site represented by EPT taxa were lower in all seasons than those of the upstream site (Figure 11). The percentages of samples represented by EPT taxa across all seasons averaged 14.9% less in the downstream station. Greatest differences in percent EPT occurred in the spring and summer.

NCBI values for the upstream samples were all within the "Excellent" or "Very Good" water quality categories. NCBI values for the downstream samples were only slightly higher and were within the "Very Good" or "Good" water quality categories. The largest (5.36) and smallest (3.02) NCBI values were respectively for the downstream station and upstream station in the spring (Figure 10). NCBI values averaged 3.82 and 4.28, respectively, for the upstream and downstream station. The response of these metric values and resulting biological scores for the downstream station were largely in the direction expected due to increased perturbation for all seasons.

Upstream and downstream values for percent of oligochaetes and chironomids, percent dominant taxon, and percent clingers in a sample showed no marked differences. Values in the spring for percentage of sample represented by taxa tolerant of elevated nutrient levels was the lowest of the year upstream (24.9%) and highest of the year downstream (74.1%). This indicates that the impoundment is likely resulting in higher than background nutrient levels.

Shannon-Wiener Diversity Index (H) average values were 2.69 and 2.46 respectively for the upstream and downstream site. The average Shannon-Wiener Evenness Index (E) value for the upstream station (0.8) was slightly larger than for the downstream station (0.76). Simpson's Index of Diversity (1-D) averaged 0.9 and 0.84, respectively, for the upstream and downstream station. These index values indicate that the impoundment, among other things, may be causing slight declines in both the diversity and evenness or stability of the macroinvertebrate community of Clear Creek.

Jaccard's Coefficient of Community Similarity (CC_j) between upstream and downstream stations was 0.48, 0.37, 0.43, 0.36, respectively, for the summer, fall, winter, and spring samples (Table 5). The coefficient values for each season were relatively alike one another and indicate that the communities in Clear Creek are only slightly more dissimilar than similar. Habitat (especially substrate) and water quality differences between the clear creek stations are surely the main reason for the dissimilarity of communities. The Clear Creek stations, however, were consistently more similar over all seasons than any other combination of upstream and downstream stations within each of the streams studied.

NMS produced a three-dimensional solution with a final stress of 5.28 and a final instability of 0.00039. The low stress and low final instability indicate that the ordination of data based on dissimilarity distances provides the best distance-based graphical representation (Figure 12) of the data. Axis 1 and axis 2 of a three-dimensional solution indicate that the upstream and downstream sites for the most part are in two fairly distinct spatial arrangements. The downstream summer sample appears to fall just within the upstream sample grouping. This ordination indicates that the downstream macroinvertebrate community in the summer and the upstream community in the winter may be more similar to each other than other downstream or upstream samples.

The upper impoundment on Clear Creek being rather small and shallow probably acts much like an oversized pool. While much of the data shows slight impairment trends in the majority of indices, metrics, and biological scores, statistical significance is achieved only for the biological scores. The impoundment has an apparent seasonal effect on the stream benthos that is most pronounced in the spring. This resulted in the downstream community being classified as partially impaired in the spring.

Clear Creek supports a healthy and diverse macroinvertebrate community both upstream and downstream of the impoundment. It is therefore an excellent stream for assessing the effects of a very small impoundment in a relatively healthy watershed. Another very similar impoundment is a short distance below the downstream station. It would be interesting to further examine Clear Creek and the effects of both impoundments. Sampling multiple locations downstream of the two impoundments would provide an idea of the extent to which these impoundments have noticeable influence on the macroinvertebrate community. Such a study of Clear Creek would likely give insight into the rare situation that an impoundment is the only habitat alteration or source of potential pollution.

Water Quality

Water temperature downstream of the impoundment was measured 1 and 1.7 Celsius degrees higher than the upstream station, respectively, during spring and summer samples. Water temperature downstream of the impoundment was 0.95 and 0.37 Celsius degrees less than in the upstream, respectively, in the fall and winter. Water temperature above and below the impoundment met water quality criteria during all seasons in terms of both level and difference. Dissolved oxygen levels downstream of the impoundment were slightly lower in the spring and summer and slightly higher in the fall and winter. Dissolved oxygen differences averaged 0.24 mg/l with the greatest difference being 0.38 mg/l higher occurring in the downstream station in the fall. Dissolved oxygen also met water quality criteria during all seasons.

Through all the seasons pH was higher at the downstream site. However, the average difference over all four seasons was only 0.16 standard units. Measured pH values were all within the acceptable range for fish and aquatic life. Specific conductivity was higher for the downstream site in three of four seasons. Conductivity values for the sampling period ranged between a low of 132.5 upstream in the summer and a high of 254.1 downstream in the fall.

The trend of measurements for all of these water quality parameters (Table 4) indicates that the impoundment is having only a slightly detrimental effect on the water quality. For example, water temperature downstream was higher in the spring and summer and lower in the fall and winter. As expected the response of dissolved oxygen appears to be very closely related to temperature differentials caused by the impoundment.

Habitat

Canopy provided nearly complete shading of the stream at both stations. The more obvious habitat differences in the riffles of the upstream and downstream stations are that of the substrate. The riffles of the upstream station had much more gravel and the riffles of the downstream station more bedrock. Bedload within the upstream station appeared more in a state of transition than that of the downstream station. This surely is the result of the impoundment's modification of the hydraulic variability of flood events on the nearby stream. The largest categorical difference in the habitat assessment for the two stations was that of channel alteration. The condition for this parameter in the downstream station was assessed to be marginally suboptimal as a result of a low water ford upstream of the station. The condition assessment of the upstream station was optimal for channel alteration. Habitat assessment scores averaged over all sample periods were respectively 167.5 and 162.25. Habitat assessment scores for the upstream and downstream stations were consistently ranked as non-impaired and very similar.

Comparison of Stations Upstream and Downstream of Eagle Bluff Lake

Macroinvertebrate Communities

Figures 13-20 show semi-quantitative index scores (biological scores), Taxa Richness (TR), EPT Richness, NCBI values, %NUTOL, %EPT, %OC, and %CLING, respectively, for Eagle Bluff Creek stations (EB1 and EB2) for the duration of the study. A synopsis of water parameter measurements from Eagle Bluff Creek and a number of metrics calculated is presented in Table 6. Jaccard's Coefficient of Community Similarity between the upstream and downstream station for each season is presented in Table 7.

The size of the watershed of Eagle Bluff Creek is well below the cutoff value for the 69d subregion reference data of two square miles. According to the Quality System Standard Operating Procedure for Macroinvertebrate Stream Surveys (TDEC, 2002) the reference data biocriteria are not considered comparable to first order streams of small watershed size. However, the comparison of sites upstream and downstream of the impoundment of the stream should offer some information about the effects of the Eagle Bluff Lake. It is expected that in general streams with smaller watershed sizes, such as Eagle Bluff Creek, may rate poorer for biometrics when compared to those with larger watersheds in the same subcoregion. Headwater streams are defined as being near the source and of first or second order. They are often considered to have natural characteristics contributing to reduced species richness and increased potential for inaccurate assessment (Mandaville, 2002). Headwater reaches typically have reduced nutrient levels and productivity.

The metrics for these stations (EB1 and EB2) appear to be relatively similar to data from ecoregion reference streams. The two stations appear to have probable sources of impact other than the impoundment, complicating the analysis. It is suspected that at least some of the metrics for Eagle Bluff Creek will be useful, especially with the variety of statistical analysis applied. Keeping this in mind, comparisons of biocriteria and data in general between the upstream and downstream stations of Eagle Bluff Creek will be made in a similar fashion as done with other streams examined in this study. Total Taxa Richness, EPT Richness, percent clingers, and percent nutrient tolerant taxa were the only metrics that showed significant differences between the stations.

Biological scores (Figure 13) for the upstream station compared with those of the downstream station were not significantly different, $F_{(1,24)} = 0.309$, $P = 0.584$. Biological scores for the downstream station were below the seasonal target score for two of the four seasons, while the upstream station was below the seasonal target score only during the summer. Seasonal target scores for subcoregion 69d are 28 for January through June and 32 for July through December. The u/s site maintained a higher biological score in the fall and spring and was equal to the d/s sample in the winter. The Average biological scores were 32.5 and 30.5 for the upstream and downstream sites, respectively. Biological condition of the upstream station was rated as slightly impaired for the

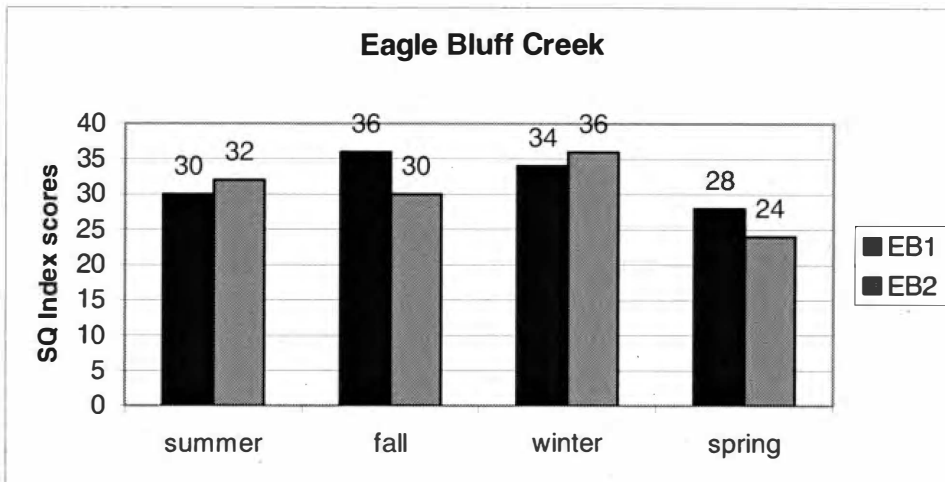


Figure 13. Semi-quantitative index scores for two stations (EB1 and EB2) on Eagle Bluff Creek, 11 August, 2003 (summer), 30 November 2003 (fall), 3 March 2004 (winter), and 20 May 2004 (spring).

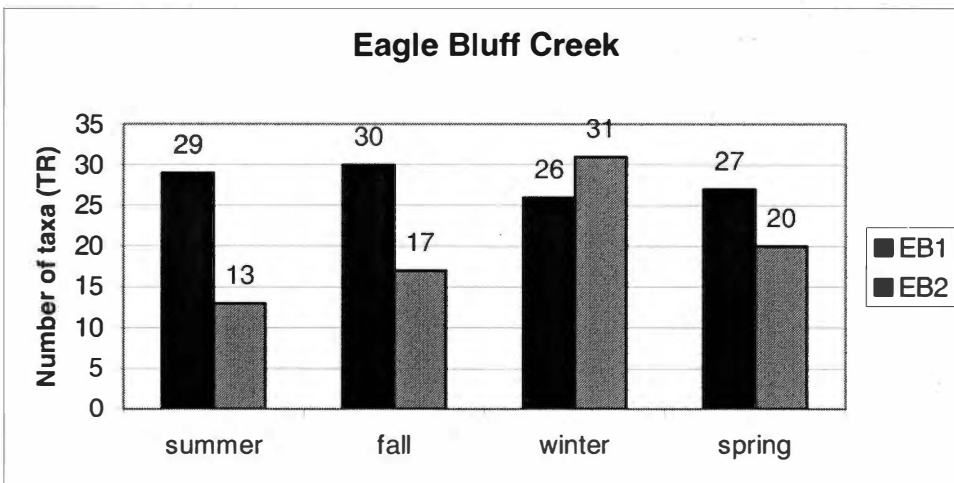


Figure 14. Taxa richness for two stations (EB1 and EB2) on Eagle Bluff Creek, 11 August, 2003 (summer), 30 November 2003 (fall), 3 March 2004 (winter), and 20 May 2004 (spring).

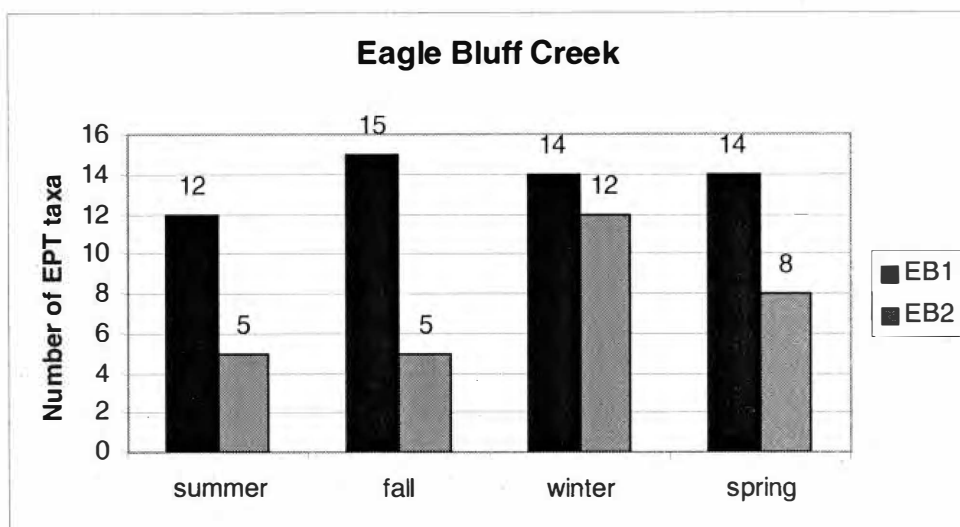


Figure 15. EPT richness for two stations (EB1 and EB2) on Eagle Bluff Creek, 11 August, 2003 (summer), 30 November 2003 (fall), 3 March 2004 (winter), and 20 May 2004 (spring).

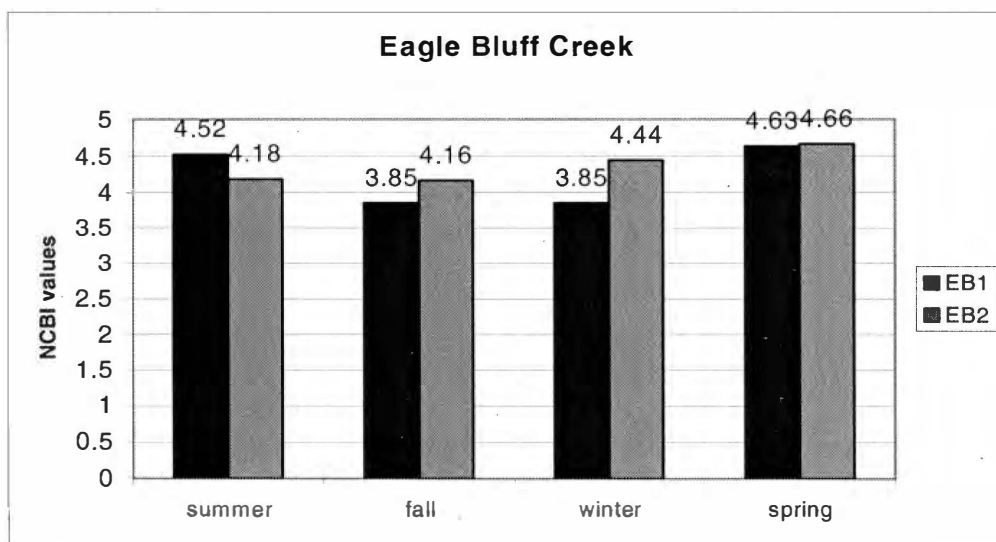


Figure 16. NCBI values for two stations (EB1 and EB2) on Eagle Bluff Creek, 11 August, 2003 (summer), 30 November 2003 (fall), 3 March 2004 (winter), and 20 May 2004 (spring).

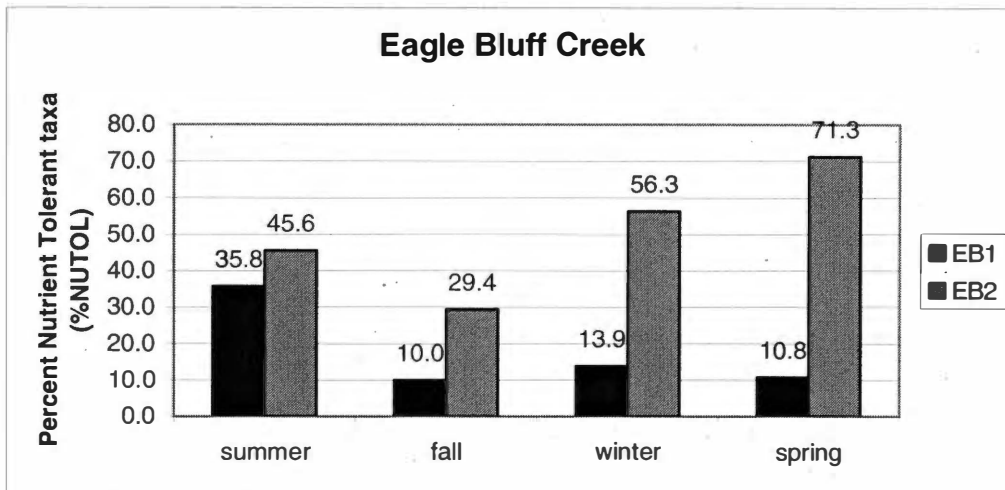


Figure 17. Percent nutrient tolerant taxa for two stations (EB1 and EB2) on Eagle Bluff Creek, 11 August, 2003 (summer), 30 November 2003 (fall), 3 March 2004 (winter), and 20 May 2004 (spring).

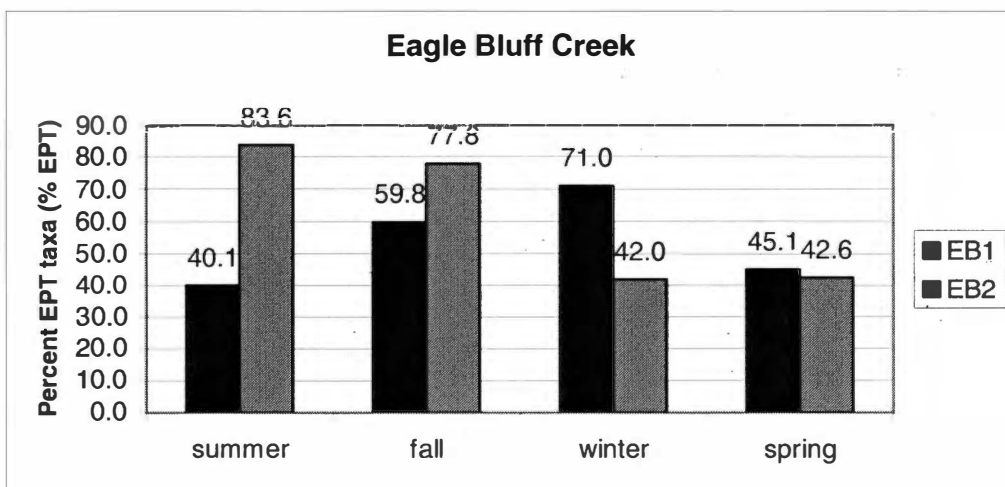


Figure 18. Percent of EPT taxa for two stations (EB1 and EB2) on Eagle Bluff Creek, 11 August, 2003 (summer), 30 November 2003 (fall), 3 March 2004 (winter), and 20 May 2004 (spring).

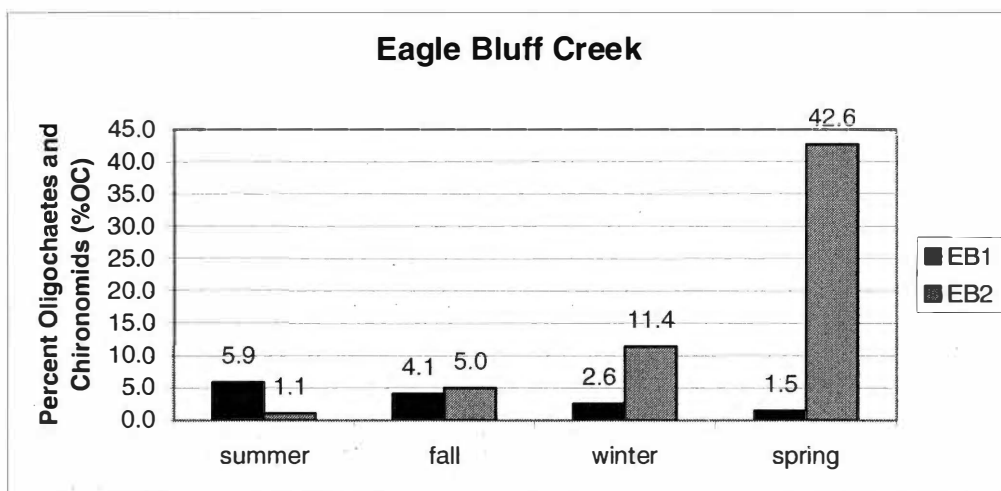


Figure 19. Percent of oligochaetes and chironomids for two stations (EB1 and EB2) on Eagle Bluff Creek, 11 August, 2003 (summer), 30 November 2003 (fall), 3 March 2004 (winter), and 20 May 2004 (spring).

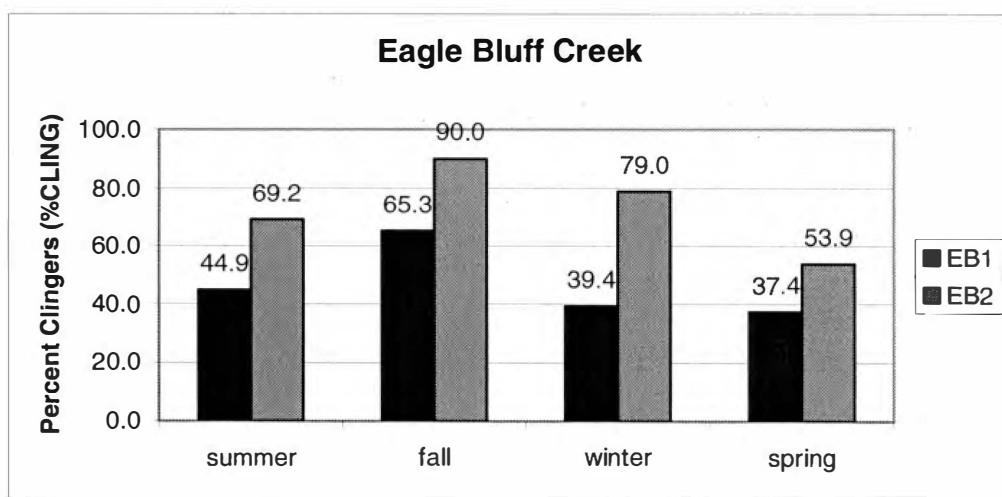


Figure 20. Percent of clingers for two stations (EB1 and EB2) on Eagle Bluff Creek, 11 August, 2003 (summer), 30 November 2003 (fall), 3 March 2004 (winter), and 20 May 2004 (spring).

Table 6. Selected physical measurements and metrics for stations above (EB1) and below (EB2) Eagle Bluff Lake collected quarterly from August 2003 to May 2004.

Season	Summer		Fall		Winter		Spring	
Site	EB1	EB2	EB1	EB2	EB1	EB2	EB1	EB2
TEMP	15.58	24.92	11.19	9.22	13.01	11.55	14.58	23.33
DO	10.27	7.49	10.97	11.34	12.02	13.86	10.19	8.52
PH	7.91	7.89	8.05	8.10	8.28	8.53	7.95	8.12
COND	141.0	148.4	260.0	246.7	229.0	207.0	240.0	187.0
TR	29	13	30	17	26	31	27	20
EPT	12	5	15	5	14	12	14	8
%EPT	40.1	83.6	59.8	77.8	71.0	42.0	45.1	42.6
%OC	5.9	1.1	4.1	5.0	2.6	11.4	1.5	42.6
NCBI	4.52	4.18	3.85	4.16	3.85	4.48	4.63	4.66
%DOM	26.7	28.0	34.1	35.6	24.7	34.9	36.4	39.6
%CLING	44.9	69.2	65.3	90.0	39.4	79.0	37.4	53.9
SQ Index	30	32	36	30	34	36	28	24
%NUTOL	35.8	45.6	10.0	29.4	13.9	56.3	10.8	71.3
H	2.62	1.82	2.51	1.89	2.43	2.43	2.41	2.04
EH	0.78	0.71	0.74	0.67	0.75	0.71	0.73	0.68
1-D	0.88	0.82	0.83	0.78	0.87	0.84	0.83	0.79

TEMP = Stream water temperature in degrees celcius at mid-depth

DO = Dissolved Oxygen in mg/l

pH = Measurement for the relative concentration of hydrogen (H⁺) and hydroxol (OH⁻) ions in solution

COND = Specific conductivity in $\mu\text{S}/\text{cm}$

TR = Taxa Richness

EPT = Number of Ephemeroptera, Plecoptera, and Trichoptera taxa

%EPT = Percentage of sample represented by EPT

%OC = Percentage of sample represented by Oligochaetes (aquatic worms) and Chironomids (midges)

NCBI = North Carolina Biotic Index

%DOM = Percentage of the sample represented by the most dominant taxa

%CLING = Percentage of the sample represented by taxa with adaptations for clinging in fast flowing water

SQ Index = Semi-quantitative index scores

%NUTOL = Percentage of the sample represented by taxa considered to be tolerant of elevated nutrient levels

H = Shannon-Weiner Diversity Index

EH = Shannon-Weiner Evenness

1-D = Simpson's Index of Diversity

Table 7. Jaccard's Coefficients of Community Similarity (CC_J) for stations upstream (EB1) and downstream (EB2) of Eagle Bluff Lake for each season.

Season	Stream	Stations	CC_J
Summer	Eagle Bluff Creek	EB1 & EB2	0.20
Fall	Eagle Bluff Creek	EB1 & EB2	0.15
Winter	Eagle Bluff Creek	EB1 & EB2	0.21
Spring	Eagle Bluff Creek	EB1 & EB2	0.12

summer and non-impaired for the other seasons. Biological condition of the downstream station was slightly impaired for the fall and spring samples and non-impaired for the summer and winter samples.

Taxa richness values for the two stations was significantly different, $F_{(1,24)} = 5.465$ and $P = 0.028$. Taxa richness values were greater u/s in all seasons except the winter sample. Average Taxa richness values were 28 and 20.2, respectively, for the upstream and downstream station. A significant difference was detected in the EPT richness values (Figure 15) between the upstream and downstream stations, $F_{(1,24)} = 13.489$ and $P = 0.001$. These EPT richness values were greater upstream in all seasons averaging nearly twice as much as downstream. Percent EPT values averaged 54% in the upstream station and 61.5% in the downstream station. The higher average Percent EPT values (Figure 18) in the downstream site are in large part due to a high abundance of a few taxa (mainly collectors such as Hydropsychidae and *Chimarra* caddisfly larvae and *Baetis* mayfly nymphs) during the summer and fall. Taxa richness and EPT richness values provide strong evidence that the impoundment has a detrimental effect on the downstream station.

NCBI values (Figure 16) averaged 4.21 and 4.37 for the upstream and downstream stations, respectively. Statistically significant differences for NCBI values between upstream and downstream stations were not detected. All NCBI values were designated as being "Very Good" except for those of the spring collection, which both were just outside of the "Very Good" category within the "Good" category. NCBI values showed a trend of decrease from spring to fall and an increase from the fall through the spring. *Gammarus*, a common and dominant taxon near springs (Smith et al., 2003), was the dominant taxon in the upstream station in the summer and spring and was abundant in all seasons. NCBI values for the upstream site (especially in the spring and fall) were worsened by the large numbers of the tolerant *Gammarus* (Amphipoda: Gammaridae), which has an NCBI value of 9.1.

Upstream and downstream values for percent of oligochaetes and chironomids (%OC) and percent dominant taxon showed no distinct differences, except for %OC in the spring which was much higher downstream (Figure 19). Percentages of samples represented by clinger taxa (Figure 20) were significantly greater, $F_{(1,24)} = 6.975$ and $P =$

0.014, in the downstream station. Average percentages of clingers for the upstream and downstream stations were, respectively, 46.8% and 73%. The large differences detected by this metric are likely related to the fact that the downstream site has swifter riffles due to a narrower channel with higher gradient. Percentages of samples represented by a single dominant taxon were consistently, yet only slightly greater in the downstream site, potentially indicating a less stable downstream community. Average percentages of samples represented by nutrient tolerant organisms were 17.6% and 53.2%, respectively, for the upstream and downstream stations. The upstream station consistently had less nutrient tolerant taxa (Figure 17). The spring influence is likely an important factor in the low percentage of nutrient tolerant taxa present in the upstream station. Percent nutrient tolerant taxa values were significantly greater, $F_{(1,24)} = 9.049$ and $P = 0.006$, in the downstream station. The impoundment is suspected as the most likely cause of the increase in this metric below the impoundment.

Shannon-Wiener Diversity Index (H) average values were 2.49 and 2.04, respectively, for the upstream and downstream station. The average Shannon-Wiener Evenness Index (E) value for the upstream station (0.75) was slightly larger than that of the downstream station (0.69). Simpson's Index of Diversity (1-D) average values were 0.85 and 0.81 respectively for the upstream and downstream station. These index values indicate that the impoundment, among other things, may be causing slight declines in both the diversity and evenness or stability of the macroinvertebrate community of Eagle Bluff Creek.

Jaccard's Coefficient of Community Similarity (CC_J) between the upstream and downstream stations of Eagle Bluff Creek were largely dissimilar (Table 7) with 0.17 being the average over all seasons. The two stations on Eagle Bluff Creek averaged the lowest CC_J values and hence the highest dissimilarity for any upstream downstream combination of stations within a stream. This large dissimilarity is doubtless due at least in part to the differences in habitat and gradient unrelated to the actual impoundment as well as the effects, both direct and indirect, of the impoundment.

NMS produced a one-dimensional solution with a high final stress of 48.34 and a final instability of 0.00001. The high stress indicates that the ordination of data does not provide a useful graphical representation of the data and interpretation is likely useless. Depiction of dissimilarities or distances of the raw data are typically extremely poor for a stress level over 20 (Clarke, 1993). The plot of the ordination data does not show any distinct grouping of the samples and is not produced as a figure in this document.

The majority of metrics for the downstream station confirms that it is more disturbed than the upstream station. Some of this difference appears to be attributable to factors other than the impoundment, such as more degraded habitat at the downstream station. Metrics for these stations may indicate that the upstream station, as well as the downstream station, likely have some impacts related to habitat alteration and the springs. It is believed that the upstream station may not be representative of an undisturbed condition.

Past activities in the stream, for example the springhouse construction, may have contributed to sedimentation, which could have had long-standing effects on microhabitat and subsequently the benthic macroinvertebrate communities. Another potential factor that might be causing reduced species richness in the upstream station may be springs just above the station. These springs could be nutrient-poor and could also contribute to downstream dispersal of silt and other fine sediments, reducing habitat quality. Dominant taxa in the upstream station, such as the amphipod *Gammarus* and *Diplectrona* (Trichoptera: Hydropsychidae), indicate that the springs were likely of considerable influence to this station.

The degree to which factors unrelated to the actual impoundment, such as reduced downstream cover, different gradients, and substrate sizes affect the metrics is very difficult if not impossible to discern. It is conceivable, but does not seem likely, that the downstream macroinvertebrate communities were impacted by the treatment of Eagle Bluff Lake with copper sulfate. Metrics such as percent contribution of EPT taxa and NCBI metrics surely would have been capable of detecting any impairment of significance caused by this aquatic herbicide. No such evidence is clear in these or other metrics or measurements. EPT richness, percent of oligochaetes and chironomids, and percent of nutrient tolerant taxa values appear to implicate the impoundment as a likely cause of observed differences, even though some metrics indicate that the upstream station may have a seasonally and slightly impaired macroinvertebrate community.

Water Quality

Water temperature downstream of Eagle Bluff Lake was approximately nine degrees higher in both the spring and summer and nearly two degrees lower in both the fall and winter. Temperature below the impoundment in the spring and summer far exceeded Tennessee's water quality criteria of a change greater than 3°C, constituting a condition of pollution. Dissolved oxygen was lower downstream in the summer and spring and higher downstream in the fall and winter (Table 6).

Measurements for pH and conductivity did not differ greatly between upstream and downstream stations within most seasons. Measured pH values ranged from 7.89 to 8.53 and were all within the acceptable range for fish and aquatic life. Conductivity values for the sampling period ranged between a low of 141 upstream in the summer and a high of 260 upstream in the fall. Seasonal differences within Eagle Bluff Creek stations were relatively minor with the largest difference in conductivity occurring in the spring. Specific conductivity was higher for the upstream site in three of four seasons, indicating that the impoundment may be causing precipitation of ions. The reduced conductivity below Eagle Bluff Lake in the spring may further support the notion that springs may have a greater influence on the upstream than the downstream station.

The impoundment has an obvious effect of causing the downstream site to have greater variability and less stability for temperature and dissolved oxygen than the upstream site. The impoundment is the most likely cause of the majority of water quality

related changes seen. It is possible that the effects of the impoundment in the winter could cause the observed higher than expected number of total taxa and EPT taxa or this could simply be the random effect of sample variability.

Habitat

Habitat of upstream and downstream stations was different in a number of ways. Canopy measurements averaged over all seasons for the upstream and downstream station were, respectively, 95.5 and 38.8. It is expected that the lack of riparian canopy and hence the reduced input of coarse organic matter at the downstream station are both potential contributors to impairment. Riffle substrate in the downstream station contained larger amounts of cobble, and less gravel. Gradient differences were relatively large between the stations, with the downstream having higher gradient. Slightly greater amounts of silt and algae were present in the downstream station, likely in part as a result of the impoundments reducing flow variability and increasing nutrients, and in part from erosion and lack of shade related to a lack of riparian vegetation. Reduced habitat quality in the upstream stations is believed to be contributing to the difficulty of recognizing the full degree of impairment caused by the impoundment. It is suspected that portions of Eagle Bluff Creek above the current upstream station (EB1) would likely offer more undisturbed conditions, including higher gradient, which would provide better control conditions. Nevertheless, downstream differences in habitat quality would continue to contribute to difficulties in detecting the differences caused as a result of the impoundment.

Habitat assessment scores averaged over all sample periods for the upstream and downstream stations were respectively 148 and 126. Habitat assessment scores were consistently ranked as moderately impaired for both the upstream and downstream stations. The habitat parameters of protective vegetation and riparian vegetative zone width showed the most distinct differences for the upstream and downstream stations. The downstream station had poor and marginal scores, respectively, for habitat assessment categories of vegetative protection and riparian vegetative zone width. Differences in habitat scores between the two stations indicate that habitat is likely strongly correlated with some macroinvertebrate community differences, making effects of the impoundment more difficult to distinguish.

Comparison of Stations Upstream and Downstream of Saddle Ridge Lake

Macroinvertebrate Communities

Figures 21-25 show semi-quantitative index scores (biological scores), taxa richness (TR), EPT richness, NCBI values and %NUTOL, respectively, for Smith Branch stations (SB1, SB2, SB3, and SB4) for the duration of the study. Figure 26 displays NMS ordination of the seasonal samples from Smith Branch at the upstream and downstream stations. A synopsis of water parameter measurements from Smith Branch and a number of metrics calculated are presented in Table 8. Jaccard's Coefficient of Community

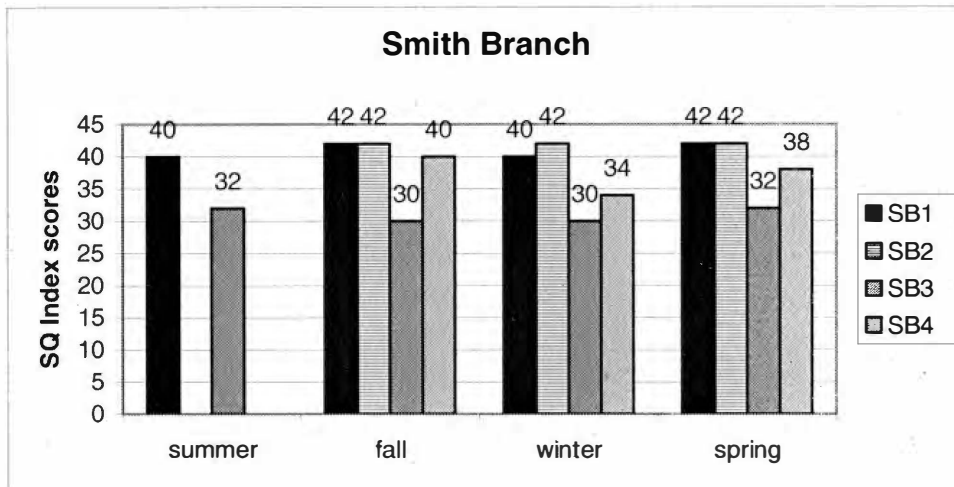


Figure 21. Semi-quantitative index scores for four stations (SB1, SB2, SB3, and SB4) on Smith Branch, 16 August, 2003 (summer), 29 November 2003 (fall), 3 March 2004 (winter), and 21 May 2004 (spring). Only stations SB1 and SB3 were sampled in the summer of 2003.

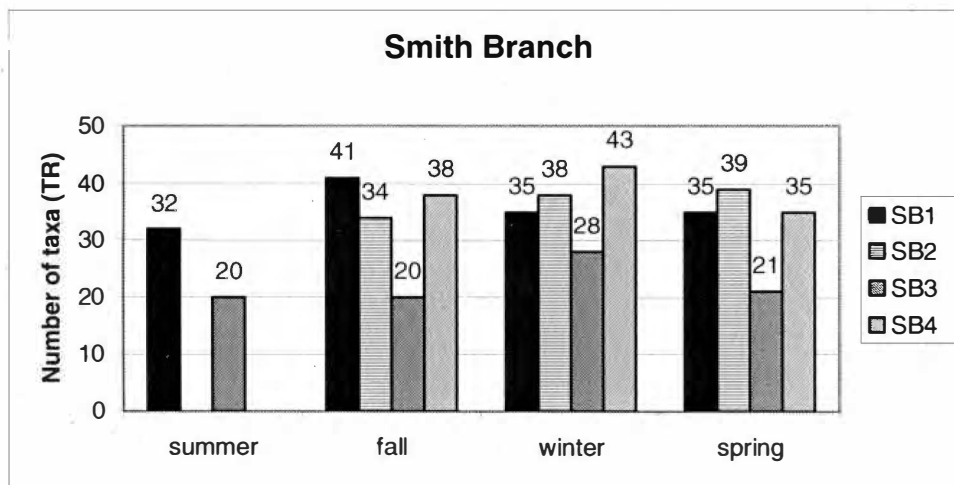


Figure 22. Taxa richness for four stations (SB1, SB2, SB3, and SB4) on Smith Branch, 16 August, 2003 (summer), 29 November 2003 (fall), 3 March 2004 (winter), and 21 May 2004 (spring). Only stations SB1 and SB3 were sampled in the summer of 2003.

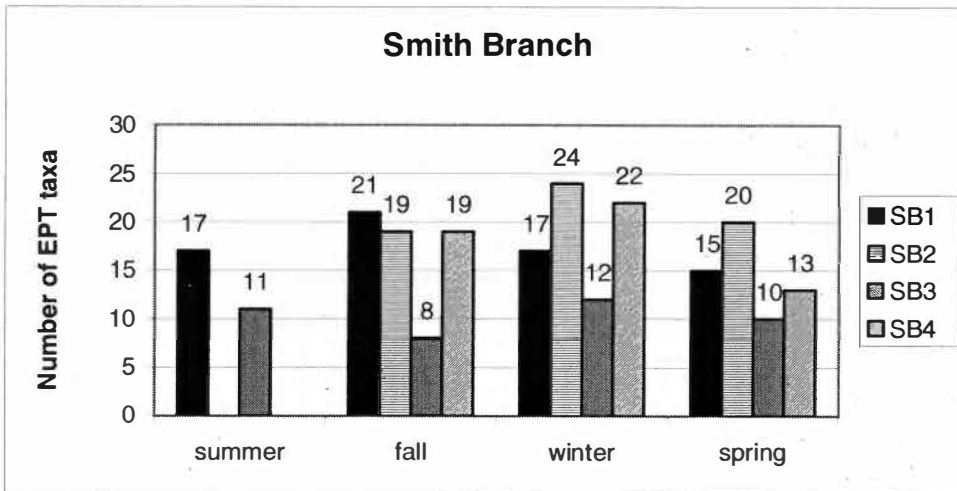


Figure 23. EPT richness for four stations (SB1, SB2, SB3, and SB4) on Smith Branch, 16 August, 2003 (summer), 29 November 2003 (fall), 3 March 2004 (winter), and 21 May 2004 (spring). Only stations SB1 and SB3 were sampled in the summer of 2003.

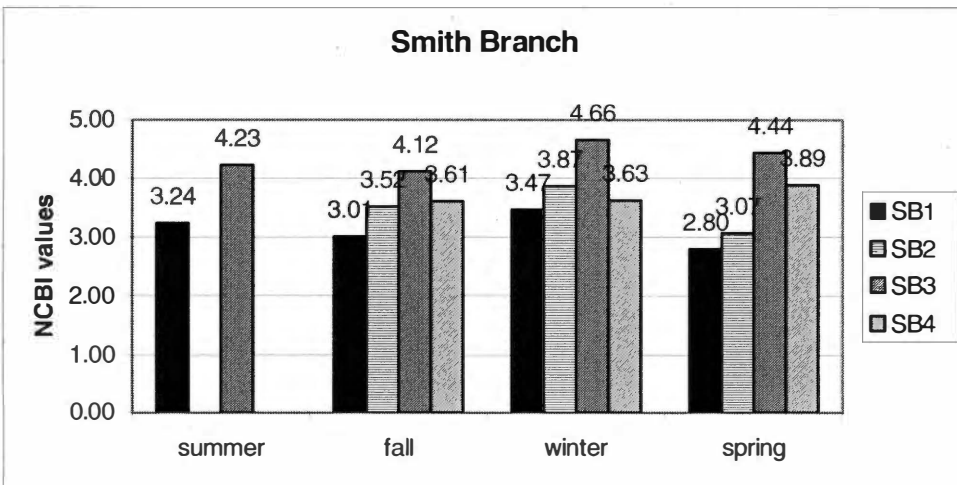


Figure 24. NCBI values for four stations (SB1, SB2, SB3, and SB4) on Smith Branch, 16 August, 2003 (summer), 29 November 2003 (fall), 3 March 2004 (winter), and 21 May 2004 (spring). Only stations SB1 and SB3 were sampled in the summer of 2003.

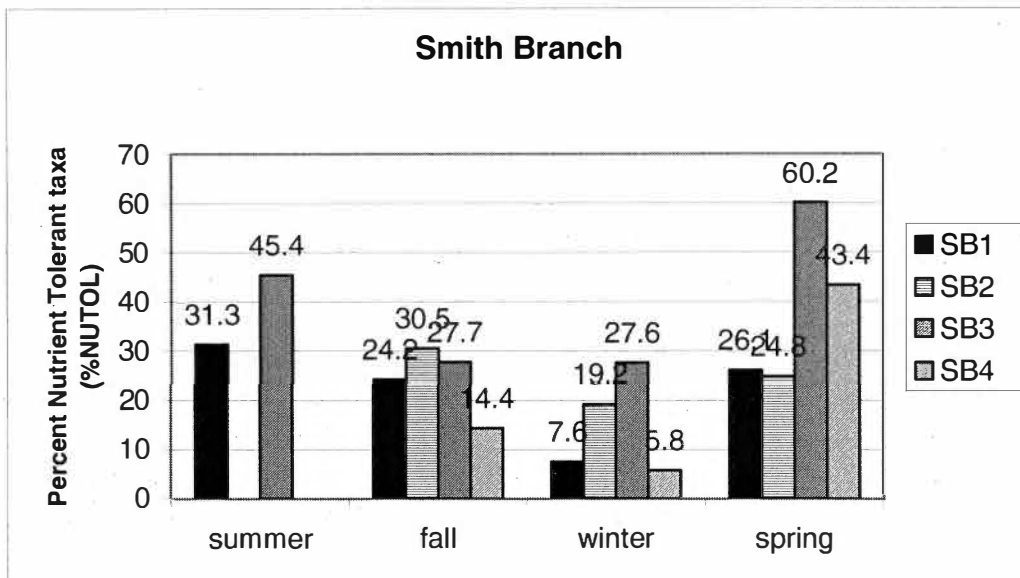


Figure 25. Percent nutrient tolerant taxa for four stations (SB1, SB2, SB3, and SB4) on Smith Branch, 16 August, 2003 (summer), 29 November 2003 (fall), 3 March 2004 (winter), and 21 May 2004 (spring). Only stations SB1 and SB3 were sampled in the summer of 2003.

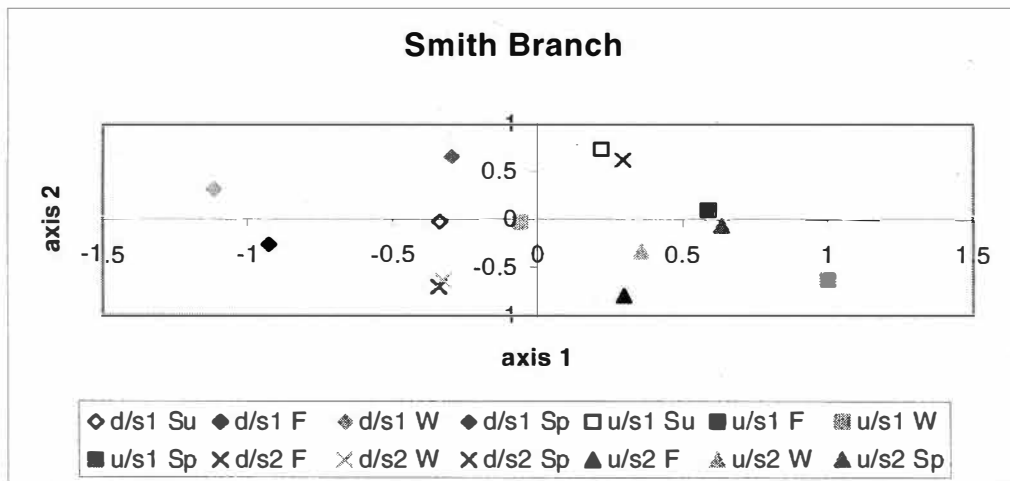


Figure 26. NMS ordination of sample data for stations upstream and downstream of Saddle Ridge Lake in Smith Branch for four seasons (stress = 10.81). Plot is based on analysis of transformed taxa abundance data.

Table 8. Selected physical measurements and metrics for stations above (SB1 and SB2) and below (SB3 and SB4) Saddle Ridge Lake collected quarterly from August 2003 to May 2004.

Season	Summer		Fall				Winter				Spring			
Site	SB1	SB3	SB1	SB2	SB3	SB4	SB1	SB2	SB3	SB4	SB1	SB2	SB3	SB4
TEMP	19.59	24.76	6.22	6.36	7.00	6.99	9.70	10.23	10.23	10.29	16.89	18.42	23.10	20.91
DO	9.27	7.71	11.70	11.54	11.94	12.02	14.11	12.84	12.67	12.75	9.61	9.42	7.73	8.96
PH	7.05	7.21	6.25	6.67	7.07	7.47	7.61	7.33	7.35	7.64	7.21	7.31	7.38	7.54
COND	39.79	50.65	44.83	48.47	59.95	54.65	31.00	33.00	40.00	38.00	55.00	58.00	61.00	64.00
TR	32	20	41	34	20	38	35	38	28	43	35	39	21	35
EPT	17	11	21	19	8	19	17	24	12	22	15	20	10	13
%EPT	72.1	86.7	74.2	85.5	86.9	75.6	56.3	76.0	49.8	55.8	76.8	66.5	57.3	51.5
%OC	11.9	0.5	12.9	9.1	8.7	16.1	21.3	19.7	42.5	38.3	6.9	20.2	24.6	22.6
NCBI	3.24	4.23	3.01	3.52	4.12	3.61	3.47	3.87	4.66	3.63	2.80	3.08	4.44	3.89
%DOM	14.9	33.2	18.8	26.8	32.5	44.4	18.8	16.3	14.9	29.6	20.2	10.6	17.1	19.1
%CLING	71.6	84.2	81.2	85.4	79.6	75.0	64.5	65.9	41.6	26.7	62.1	65.1	66.8	72.3
SQ Index	40	32	42	42	30	40	40	42	30	34	42	42	32	38
%NUTOL	31.3	45.4	24.2	30.5	27.7	14.4	7.6	19.2	27.6	5.8	26.1	24.8	60.2	43.4
H	2.98	2.02	3.03	2.79	2.14	2.48	2.99	3.10	2.76	2.70	2.87	3.22	2.60	2.94
EH	0.86	0.67	0.83	0.79	0.71	0.67	0.84	0.85	0.83	0.72	0.81	0.88	0.85	0.83
1-D	0.93	0.79	0.92	0.89	0.81	0.79	0.92	0.93	0.92	0.86	0.91	0.94	0.90	0.91

TEMP = Stream water temperature in degrees celcius at mid-depth

DO = Dissolved Oxygen in mg/l

pH = Measurement for the relative concentration of hydrogen (H⁺) and hydroxol (OH⁻) ions in solution

COND = Specific conductivity in $\mu\text{S}/\text{cm}$

TR = Taxa Richness

EPT = Number of Ephemeroptera, Plecoptera, and Trichoptera taxa

%EPT = Percentage of sample represented by EPT

%OC = Percentage of sample represented by Oligochaetes (aquatic worms) and Chironomids (midges)

NCBI = North Carolina Biotic Index

%DOM = Percentage of the sample represented by the most dominant taxa

%CLING = Percentage of the sample represented by taxa with adaptations for clinging in fast flowing water

SQ Index = Semi-quantitative index scores

%NUTOL = Percentage of the sample represented by taxa considered to be tolerant of elevated nutrient levels

H = Shannon-Weiner Diversity Index

EH = Shannon-Weiner Eveness

1-D = Simpson's Index of Diversity

Similarity between the various combinations of upstream and downstream stations for each season is presented in Table 9.

Statistical significance testing was performed for pairwise comparison of SB1 and SB3. F test values and associated probability (P) values for statistically significant results are given for this SB1 and SB3 comparison. Because of the larger number of stations, additional significance testing was performed for pairwise comparisons between each station and results showing significance are discussed below without associated F and P values.

Biological scores (Figure 21) for SB3 were significantly different from all other stations within this stream. Pairwise comparison of biological scores for SB1 and SB3 yielded a significant mean difference, $F_{(1,24)} = 14.243$, $P = 0.001$. Significant differences in biological scores were not detected between SB1, SB2, and SB4. Biological scores were well above the target score (32) for both upstream stations in all sampled seasons. SB4 was above the target score in all three samples. These biological scores averaged 41, 42, 31, and 37.3, respectively, for the SB1, SB2, SB3, and SB4 stations. Biological scores for SB3 were 32 in the spring and summer and 30 in the fall and winter. This indicates that the station SB3, a short distance below the impoundment, has a slightly impaired biological condition during part of the year. Biological condition was non-impaired for SB1, SB2, and SB4 stations for all seasons. SB3 station was rated as non-impaired for the summer and spring samples due to being equal to the target score of 32, but was considered to be slightly impaired for the fall and winter samples. Biological scores for SB4 in the winter and spring indicate that the impoundment may be having some seasonal lasting downstream effects. The anticipation that the added dilution of tributaries below the lake and SB3 would improve biological scores at SB4 now seems justified.

Taxa richness values (Figure 22) for SB3 were significantly different from those of all other sites in Smith Branch during this study. Pairwise comparison of taxa richness for SB1 and SB3 yielded a significant mean difference, $F_{(1,24)} = 16.584$, $P < 0.000$. Average taxa richness for SB1, SB2, SB3, and SB4 were, respectively, 35.8, 37, 22.2, and 38.7. EPT richness values for SB3 were significantly different than the three other stations. Pairwise comparison of EPT richness for SB1 and SB3 yielded a significant mean difference, $F_{(1,24)} = 18.151$, $P < 0.000$. EPT richness was much lower for SB3 than both upstream stations and SB4 in the fall and winter (Figure 23). EPT richness for SB3 in the spring was only slightly lower than SB4. The average EPT richness value for SB1, SB2, SB3, and SB4 were, respectively, 17.5, 21, 10.2, and 18. Percentage of EPT taxa represented in the different stations was not significantly different for any pairwise comparison.

NCBI values (Figure 24) for SB3 were significantly larger than for both upstream stations, but not significantly larger than for SB4. Pairwise comparison of NCBI values between SB1 and SB3 detected a significant difference, $F_{(1,24)} = 15.045$, $P = 0.001$. SB1, SB2, and SB4 NCBI values were within the "Excellent" to "Very Good" categories. SB3

Table 9. Jaccard's Coefficients of Community Similarity (CC_j) for all stations upstream (SB1 and SB2) and downstream (SB3 and SB4) of Saddle Ridge Lake for each season.

Season	Stream	Stations	CC_j
Summer	Smith Branch	SB1 & SB3	0.27
Fall	Smith Branch	SB1 & SB2	0.27
Fall	Smith Branch	SB1 & SB3	0.15
Fall	Smith Branch	SB1 & SB4	0.27
Fall	Smith Branch	SB2 & SB3	0.32
Fall	Smith Branch	SB2 & SB4	0.31
Fall	Smith Branch	SB3 & SB4	0.32
Winter	Smith Branch	SB1 & SB2	0.40
Winter	Smith Branch	SB1 & SB3	0.29
Winter	Smith Branch	SB1 & SB4	0.44
Winter	Smith Branch	SB2 & SB3	0.32
Winter	Smith Branch	SB2 & SB4	0.37
Winter	Smith Branch	SB3 & SB4	0.36
Spring	Smith Branch	SB1 & SB2	0.51
Spring	Smith Branch	SB1 & SB3	0.24
Spring	Smith Branch	SB1 & SB4	0.37
Spring	Smith Branch	SB2 & SB3	0.30
Spring	Smith Branch	SB2 & SB4	0.37
Spring	Smith Branch	SB3 & SB4	0.40

NCBI values were higher with a range between "Very Good" and "Good" categories indicating some impacts. Average NCBI values for SB1, SB2, SB3, and SB4 were, respectively, 3.13, 3.49, 4.36, and 3.73.

Percent of oligochaetes and chironomids showed significant differences between upstream and downstream stations only in the winter samples. No trends were evident in the metrics for percent dominant taxon and percent clingers. Percent nutrient tolerant taxa values were not significantly different between any of the four stations. Average percentage of nutrient tolerant individuals for SB1, SB2, SB3, and SB4 were, respectively, 22.3, 24.8, 40.2, and 21.2. The highest percentages of nutrient tolerant individuals for all sites occurred in SB3 in the spring (60.2%) and summer (45.4%). The greater presence of nutrient tolerant organisms at the SB3 station in three of four seasons indicates that this station is likely more impacted than the other stations as a result of the impoundment.

Shannon-Wiener Diversity Index (H) average values were 2.97, 3.04, 2.38, and 2.71, respectively, for SB1, SB2, SB3, and SB4. All sites are indicative of high diversity with the two upstream sites averaging the highest diversity. Shannon-Wiener Evenness Index (E) average values for the two upstream sites (0.84) were slightly larger than the SB3 site (0.76) and SB4 site (0.74). Average Simpson's Index of Diversity (1-D) values were 0.92, 0.92, 0.86, and 0.85, respectively, for the stations SB1, SB2, SB3, and SB4. These

index values indicate that the impoundment, among other things, may be causing slight declines in both the diversity and evenness of the downstream macroinvertebrate communities of Smith Branch.

Jaccard's Coefficient of Community Similarity (CC_J) averaged over all seasons ranged from 0.24 to 0.39, for all possible comparisons between each pair of stations within Smith Branch. The two lowest average CC_J values were 0.24 and 0.31, respectively, for SB1 and SB3 pair and SB2 and SB3 pair. SB1 and SB2 comparison generally had the highest CC_J (Table 9) and consequently the least dissimilarity. It seems reasonable to say that the two upstream stations are most alike and the downstream station SB3 is most dissimilar from the upstream stations.

NMS produced a three-dimensional solution with a final stress of 10.81 and a final instability of 0.00001. The low stress and low final instability indicate that the ordination of data based on dissimilarity distances provides the best distance-based graphical representation (Figure 26) of the data. Axis 1 and axis 2 of a three-dimensional solution indicate that the four stations for the most part are in fairly distinct spatial arrangements. The downstream station SB3 samples form a cluster that is more separate and hence more different than all other sample groupings, which tend to be slightly interspersed among each other. This indicates that the station just below the dam has a macroinvertebrate community that is more dissimilar than the other three stations. This further supports the idea that the impoundment is having a detrimental effect on the macroinvertebrate communities of Smith Branch.

The impoundment, among other things, is having an effect on the macroinvertebrate fauna of Smith Branch as indicated by the level of significance of differences from group means for multiple biometrics, reference data comparisons, and presence/absence data. A most plausible explanation for the level of impairment indicated by the macroinvertebrates from SB4 being less than that of SB3 may be because of dilution resulting from the additional tributaries that enter Smith Branch between SB3 and SB4.

Water Quality

Temperature for SB3 was 5.17 celcius degrees higher than SB1 in the summer (Table 8). SB3 averaged 4.36 celcius degrees higher than all other sites in the spring and was 6.21 and 4.68 celcius degrees higher respectively than SB1 and SB2 in the spring. The difference in temperature of SB3 compared to SB1 in the summer and both SB1 and SB2 in the spring represent violations of Tennessee water quality criteria constituting pollution and indicate that the impoundment is degrading water quality. Dissolved oxygen was lowest in the spring, summer, and winter in SB3. Dissolved oxygen at SB1, SB2, SB3, and SB4 were, respectively, 9.61, 9.42, 7.73, and 8.96. The greatest differences in pH occurred during the fall. Fall pH values for SB1, SB2, SB3, and SB4 were, respectively, 6.25, 6.67, 7.07, and 7.47. Conductivity was consistently elevated in both downstream sites. Conductivity values ranged between a low of 31 in the winter at SB1 and a high of 64 in the spring at SB4. Based on water quality parameter trends,

Saddle Ridge Lake appears to be having a detrimental effect on the water quality of SB3 and to a lesser extent SB4.

Habitat

Canopy provided upwards of 80 percent shade for all stations. The SB2 and SB3 stations had more bedrock than SB1 and SB4 and cobble was the predominant substrate in two upstream stations. SB3 station consistently scored the lowest and SB1 scored highest for nearly all habitat parameters compared to the other stations. Habitat assessment scores averaged over all sample periods for the SB1, SB2, SB3, and SB4 stations were, respectively, 164.25, 155.00, 134.50, and 152.00. Habitat assessment scores were consistently ranked as moderately impaired for all stations. Sediment is suspected in having an affect on Smith Branch as a whole and is certainly in part responsible for the consistent moderately impaired habitat scores. The effects that sediments deposited in the impoundment have on the water quality of the impoundment and the downstream water quality are likely detrimental. The greater amount of silt and sediment deposition evident at SB3 may be the result of finer sediments deposited in the impoundment being re-suspended during spates and discharged to the downstream, which is unable to be easily washed further downstream due to the dams reduction of natural high flow regimes.

Comparison of Stations Upstream and Downstream of Lambert Lake

Macroinvertebrate Communities

Figures 27-32 show semi-quantitative index scores (biological scores), taxa richness (TR), EPT richness, NCBI, %NUTOL, and %EPT values, respectively, for the Big Springs Branch tributary stations (BS1 and BS2) for the duration of the study. Figure 33 displays NMS ordination of the seasonal samples from the Big Springs Branch tributary at the upstream and downstream stations. A synopsis of water parameter measurements from the Big Springs Branch tributary and a number of metrics calculated is presented in Table 10. Jaccard's Coefficient of Community Similarity between the upstream and downstream station for each season is presented in Table 11.

Biological scores for the upstream and downstream stations (Figure 27) were significantly different, $F_{(1,24)} = 43.62$ and $P < 0.001$. Average biological scores for the upstream and downstream samples were, respectively, 40 and 22.5. The upstream station consistently scored well above the target score of 32 and the downstream site was consistently less than the target score. Biological condition of the upstream station consistently was non-impaired. The Biological condition of the downstream station was ranked as moderately impaired for the winter sample and slightly impaired for all other seasons.

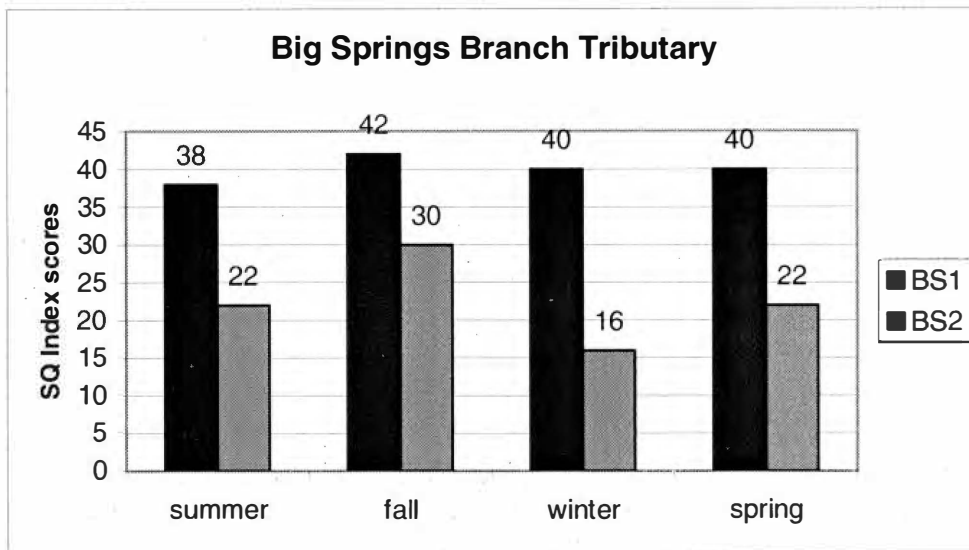


Figure 27. Semi-quantitative index scores for two stations (BS1 and BS2) on the Big Springs Branch tributary, 17 August, 2003 (summer), 2 December 2003 (fall), 5 March 2004 (winter), and 21 May 2004 (spring).

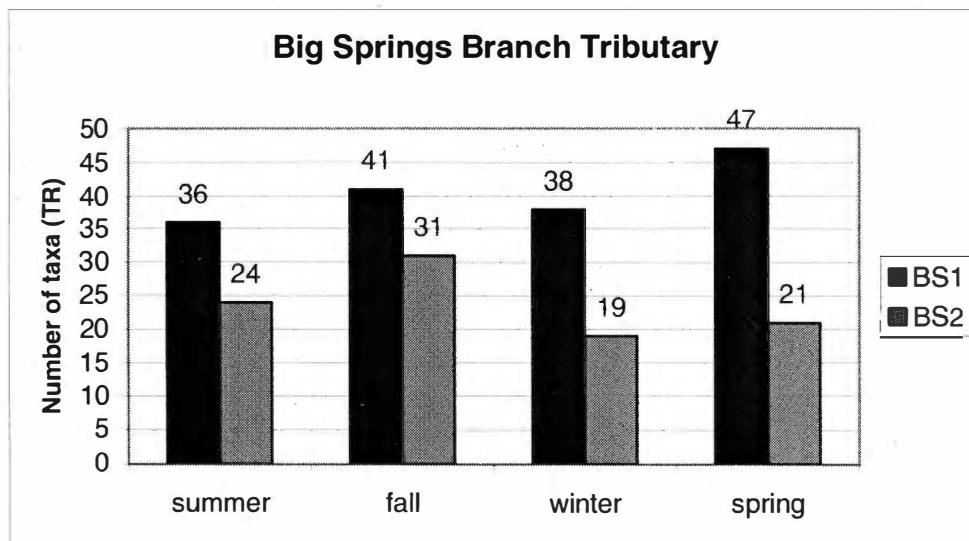


Figure 28. Taxa richness for two stations (BS1 and BS2) on the Big Springs Branch tributary, 17 August, 2003 (summer), 2 December 2003 (fall), 5 March 2004 (winter), and 21 May 2004 (spring).

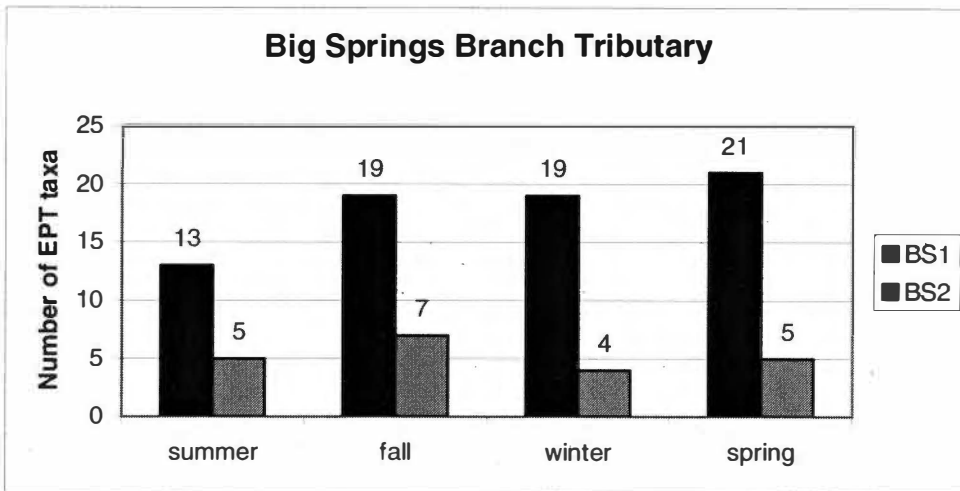


Figure 29. EPT richness for two stations (BS1 and BS2) on the Big Springs Branch tributary, 17 August, 2003 (summer), 2 December 2003 (fall), 5 March 2004 (winter), and 21 May 2004 (spring).

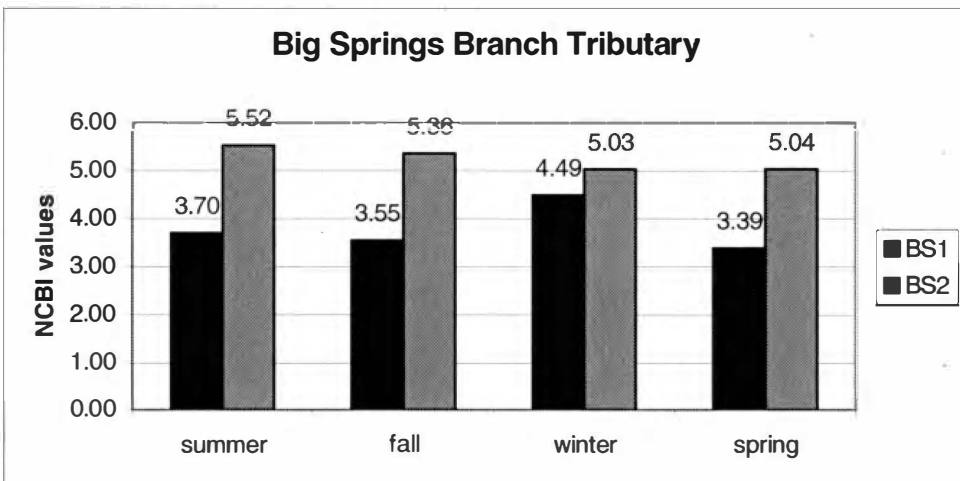


Figure 30. NCBI values for two stations (BS1 and BS2) on the Big Springs Branch tributary, 17 August, 2003 (summer), 2 December 2003 (fall), 5 March 2004 (winter), and 21 May 2004 (spring).

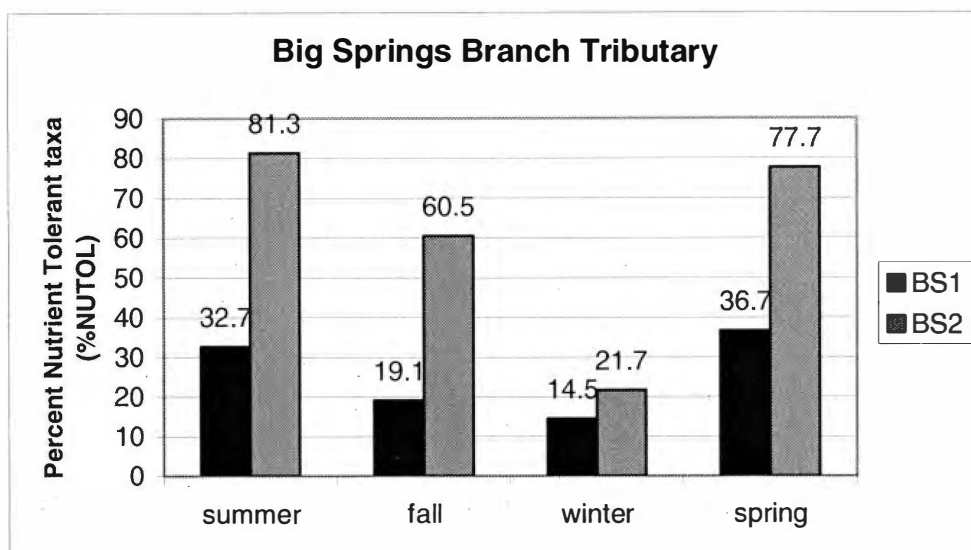


Figure 31. Percent of nutrient tolerant taxa for two stations (BS1 and BS2) on the Big Springs Branch tributary, 17 August, 2003 (summer), 2 December 2003 (fall), 5 March 2004 (winter), and 21 May 2004 (spring).

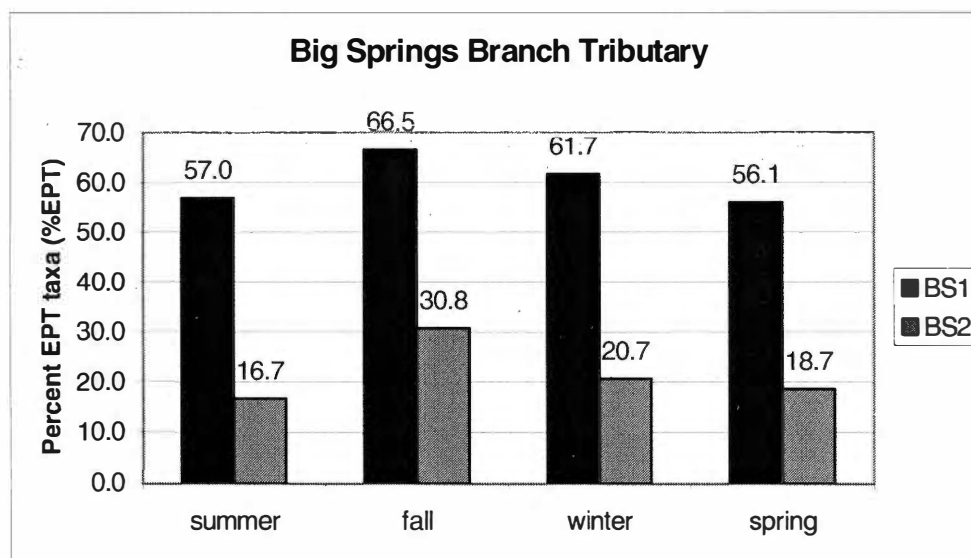


Figure 32. Percent of EPT taxa for two stations (BS1 and BS2) on the Big Springs Branch tributary, 17 August, 2003 (summer), 2 December 2003 (fall), 5 March 2004 (winter), and 21 May 2004 (spring).

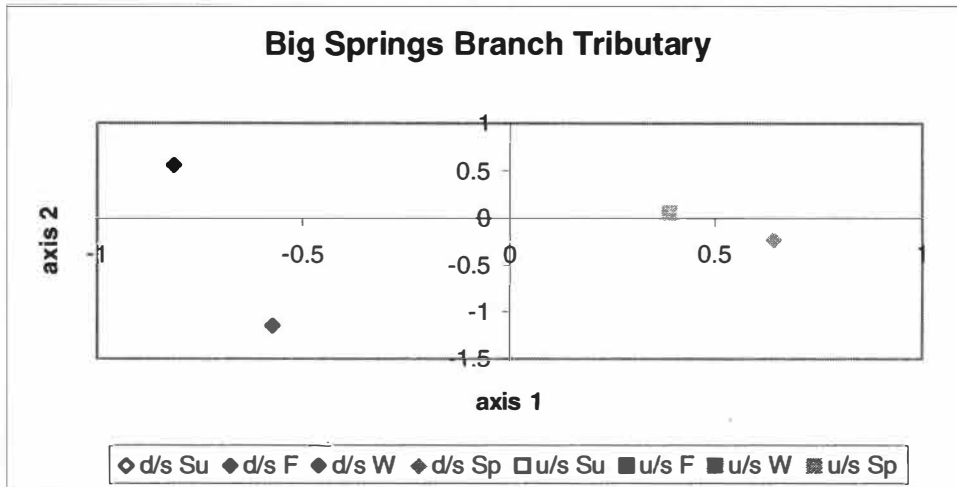


Figure 33. NMS ordination of sample data for stations upstream and downstream of Lambert Lake in the Big Springs Branch tributary for four seasons (stress = 0.00039). Some of the ordination points are not visible because other points in the same location mask them. The downstream summer (d/s Su, ◇) point is in the same location as the downstream fall (d/s F, ◆) point and all upstream points are located together.

Table 10. Selected physical measurements and metrics for stations above (BS1) and below (BS2) Lambert Lake for collected quarterly from August 2003 to May 2004.

Season	Summer		Fall		Winter		Spring	
Site	BS1	BS2	BS1	BS2	BS1	BS2	BS1	BS2
TEMP	19.91	24.44	8.09	10.21	11.98	8.85	18.57	18.10
DO	8.77	7.57	10.97	11.10	12.70	14.07	9.29	9.53
PH	6.28	6.29	5.71	6.03	7.32	7.43	7.24	7.18
COND	23	20.88	23.81	31.59	18.00	24.00	37.00	28.00
TR	36	24	41	31	38	19	47	21
EPT	13	5	19	7	19	4	21	5
%EPT	57.0	16.7	66.5	30.8	61.7	20.7	56.1	18.7
%OC	28.7	70.8	21.4	18.6	19.1	55.4	13.1	18.1
NCBI	3.70	5.49	3.53	5.36	4.49	5.03	3.39	5.04
%DOM	17.9	33.8	27.2	23.6	10.2	41.3	19.0	56.6
%CLING	69.5	60.0	72.3	66.6	66.0	27.2	67.9	72.9
SQ Index	38	22	42	30	40	16	40	22
%NUTOL	32.7	81.3	19.1	60.5	14.5	21.7	36.7	77.7
H	2.96	2.08	3.00	2.55	3.24	1.96	3.13	1.77
EH	0.83	0.66	0.81	0.75	0.89	0.66	0.81	0.58
1-D	0.92	0.80	0.90	0.87	0.95	0.77	0.92	0.65

TEMP = Stream water temperature in degrees celcius at mid-depth

DO = Dissolved Oxygen in mg/l

pH = Measurement for the relative concentration of hydrogen (H+) and hydroxol (OH-) ions in solution

COND = Specific conductivity in $\mu\text{S}/\text{cm}$

TR = Taxa Richness

EPT = Number of Ephemeroptera, Plecoptera, and Trichoptera taxa

%EPT = Percentage of sample represented by EPT

%OC = Percentage of sample represented by Oligochaetes (aquatic worms) and Chironomids (midges)

NCBI = North Carolina Biotic Index

%DOM = Percentage of the sample represented by the most dominant taxa

%CLING = Percentage of the sample represented by taxa with adaptations for clinging in fast flowing water

SQ Index = Semi-quantitative index scores

%NUTOL = Percentage of the sample represented by taxa considered to be tolerant of elevated nutrient levels

H = Shannon-Weiner Diversity Index

EH = Shannon-Weiner Evenness

1-D = Simpson's Index of Diversity

Table 11. Jaccard's Coefficients of Community Similarity (CC_J) for stations upstream (BS1) and downstream (BS2) of Lambert Lake for each season.

Season	Stream	Stations	CC_J
Summer	Big Springs Branch tributary	BS1 & BS2	0.18
Fall	Big Springs Branch tributary	BS1 & BS2	0.24
Winter	Big Springs Branch tributary	BS1 & BS2	0.19
Spring	Big Springs Branch tributary	BS1 & BS2	0.26

Taxa richness values (Figure 28) were also significantly higher, $F_{(1,24)} = 25.53$ and $P < 0.001$, for the upstream station versus the downstream station. Average Taxa richness values for the upstream and downstream were, respectively, 40.5 and 23.8. EPT richness values (Figure 29) for the upstream station were also significantly greater, $F_{(1,24)} = 56.137$ and $P < 0.001$, than the downstream station and average values were, respectively, 18 and 5.2. Percentage of EPT per sample was significantly higher, $F_{(1,24)} = 15.367$ and $P = 0.001$, for the upstream station (Figure 32). Average percent EPT values for the upstream and downstream stations were, respectively, 60.3 and 21.7. Average NCBI values for the upstream and downstream stations were, respectively, 3.78 and 5.23. NCBI values (Figure 30) for the upstream station samples were indicative of "Excellent" to "Very Good" categories. The downstream values were all within the "Good" category, but were nearly "Fair" (5.51-6.50) in the summer (5.49) and winter (5.36).

Percentage of oligochaetes and chironomids and percentage of clingers were the only metrics where statistical significance at the $\alpha = 0.05$ level was not found for comparison between upstream and downstream stations of Big Springs Branch tributary. Percentage of samples represented by a single dominant taxon averaged 18.6 and 38.8, respectively, for the upstream and downstream stations. The difference between the upstream and downstream samples for this metric was significant, $F_{(1,24)} = 10.042$ and $P = 0.004$. The values for percent nutrient tolerant taxa were significantly greater for the downstream station, $F_{(1,24)} = 8.929$ and $P = 0.006$, than for the upstream station (Figure 31). Average percent of the samples represented by nutrient tolerant taxa in the upstream and downstream were, respectively, 25.75 and 60.30.

The average Shannon-Wiener Diversity (H) Index values were 3.08 and 2.09, respectively, for the upstream and downstream sites. Average Shannon-Wiener Evenness (E) Index value for the upstream site (0.84) compared to the downstream site (0.66) was the largest difference of any above and below impoundment comparison among studied streams. The differences in these indices suggest, among other things, that the macroinvertebrate community of the Big Springs Branch tributary is impacted both in terms of diversity and evenness by the impoundment.

Jaccard's Coefficient of Community Similarity (CC_J) for the upstream and downstream stations of Big Springs Branch tributary (Table 11) were largely dissimilar

with 0.22 being the average over all seasons. This large dissimilarity in the upstream and downstream macroinvertebrate communities is unquestionably due in large part to the direct and indirect effects of the impoundment on habitat and water quality.

NMS produced a three-dimensional solution with an extremely low final stress of 0.00039 and a final instability of 0.00001. This very low stress and low final instability indicate that the ordination of data based on dissimilarity distances provides a very accurate distance-based graphical representation (Figure 33) of the data. Axis 1 and axis 2 of a three-dimensional solution indicate that the two stations occupy distinct spatial arrangements. All upstream station samples form a tight cluster indicating very little dissimilarity in the seasonal macroinvertebrate communities above Lambert Lake. The downstream samples for the summer and fall clustered to indicate very little dissimilarity from each other, while the downstream winter and spring were quite different from each other and from the downstream summer and fall. This indicates that the station just below the dam has a less stable and less diverse macroinvertebrate community that is very different from the station above Lambert Lake. This further supports the idea that the impoundment is having a detrimental effect on the macroinvertebrate communities of the Big Springs Branch tributary.

The direction and extent of differences in the majority of metrics strongly suggest that Lambert Lake is causing the most dramatic differences in the downstream benthic communities of all the streams and associated stations examined in this study. This is not surprising, since it has often been suggested that larger impoundments are generally expected to have greater impacts (Petts, 1984; Wotton, 1995), and Lambert Lake is 12.8, 9.1, and 3.2 times larger, respectively, than the Clear Creek impoundment, Eagle Bluff Lake, and Saddle Ridge Lake.

Water Quality

Water temperature at the downstream site was higher in the summer and fall and was lower in the winter and spring than at the upstream site (Table 10). Downstream temperature was 4.53 celcius degrees higher in the summer and 2.12 degrees higher in the fall than the upstream site. Downstream temperature was 3.13 degrees less in the winter and only 0.47 less in the spring than the upstream site. Temperature differences in the summer and winter each represent an exceedence (greater than 3°C change) of the water quality criteria for temperature and constitute pollution. Dissolved oxygen was lowest during the summer in the downstream site (7.57) compared to the upstream site (8.77). Dissolved oxygen was highest upstream in the winter (12.7) and in the downstream site also during the winter (14.07). These values also represent the greatest seasonal differences for dissolved oxygen.

The greatest differences in pH occurred during the fall. Fall values for pH were 5.71 upstream and 6.03 downstream. Conductivity was elevated in the downstream site during the fall and winter and lower downstream in the spring and summer. Conductivity values ranged between a low of 18 upstream in the winter and a high of 37 in the upstream

during the spring. Lambert Lake appears to be having a detrimental effect on the water quality of the downstream site due to its size, configuration, and the resulting flow-through rate.

Habitat

Canopy at both stations provided nearly complete shading of the stream. Both stations contained relatively similar substrates and gradient. Silt deposits and algae, while not apparent within the upstream station, were considered moderate in the downstream station. This presence of silt deposits and algae within the downstream station are most likely the result of the impoundment causing a decrease in flow variability and an increase in nutrients, respectively. Habitat assessment scores averaged over all sample periods for the upstream and downstream stations, respectively, were 181.75 and 157.00. The differences in these scores for the downstream station are likely an indirect result of the dam's reducing natural flow variability of the downstream channel. One such affect of this reduced variability of flow may be that larger amounts of fine particulate matter are not scoured from the interstices of the substrate, resulting in general degradation of the quality of habitat. Other affects might include loss of alluvial coarse particulate organic matter from the watershed above the dam. Habitat assessment scores for the upstream and downstream stations, while distinctly different, were both consistently ranked as non-impaired for all samples.

Chapter V

Conclusions and Recommendations

The purpose of this study was to examine the effects of a variety of small, man-made impoundments on the macroinvertebrate communities and water quality in order to allow generalizations to be made regarding the impacts caused by such impoundments of streams. The basis of the question “do impoundments affect the diversity and composition of the macroinvertebrate community and water quality”, is based in conventional hypothesis testing. In this instance, the null hypothesis (H_0) and an alternative hypothesis (H_A) are stated as:

H_0 : the impoundment does not affect the diversity and composition of the macroinvertebrate community and water quality.

H_A : the impoundment does affect the diversity and composition of the macroinvertebrate community and water quality.

The results of this study provide strong evidence to reject the null hypothesis that small impoundments have no effect on the diversity and composition of the macroinvertebrate community and water quality. The four streams and their associated impoundments provided an excellent opportunity for studying the effects of small man-made impoundments on downstream macroinvertebrates and water quality. The impoundments and associated stations were selected because their watersheds appeared to have the fewest potential impacts to the streams other than those caused by the impoundments. However, none of the study watersheds was completely without noticeable impacts other than the impoundment, including upstream stations. Other recognizable impacts are discussed and are thought not to significantly complicate the analysis. It is therefore expected that any large differences between the macroinvertebrate communities of these stations above and below their associated impoundment were primarily the result of the effects of the impoundment.

Differences in the upstream and downstream macroinvertebrate communities, water quality, and habitat data for the two stations of Clear Creek were the smallest of all streams studied. As was anticipated, the well-forested watershed along with the impoundment's narrow, shallow shape would reduce the chance of stagnation and related water quality degradation. The short flow-through time combined with a well-shaded stream channel both appeared to reduce the level of impairment caused by the impoundment. Clear Creek produced significant differences between the upstream and downstream station only for the cumulative semi-quantitative index scores. The largest differences from metrics in Clear Creek were detected in the spring, providing strong evidence of the impoundment impacting the downstream macroinvertebrate community. Temperature (1.8°C higher downstream in spring) is considered to be a driving force in differences in the upstream and downstream communities even though the impoundment has a short retention time. Despite the upper impoundment, the downstream station of Clear Creek (CC2) appears to support a relatively diverse, but seasonally more tolerant macroinvertebrate community.

Eagle Bluff Creek was the most difficult of the four study streams in assessing the effects of the impoundment. This appears to be due in part to the differences in gradient, substrate and cover between the two stations, as well as the influence of springs. During the search for impoundments for this study it became more apparent that there were few instances where streams with impoundments did not have a variety of other disturbances. Both stations appeared to be more impacted than was originally anticipated. Some upstream metrics occasionally showed signs of degradation greater of than those of the downstream station, which was unexpected. Nevertheless a number of the metrics, especially percentage of nutrient tolerant taxa and EPT richness, combined with water quality measurements and habitat assessments indicate that Eagle Bluff Lake is contributing to the impairment of the downstream community. The impoundment caused increased temperature downstream in summer and spring to exceed state standards by approximately three times. These temperature differences alone have significant implications for the downstream macroinvertebrate community. Establishment of a quality riparian zone could improve the downstream station of Eagle Bluff Creek. However, downstream effects of the impoundment would be difficult to greatly reduce without its complete removal and restoration of the currently impounded channel.

Smith Branch and Saddle Ridge Lake provided a very good case study of a small impoundment and the potential for degradation continuing for considerable distance downstream. The downstream station nearest the impoundment (SB3) consistently showed trends of degradation compared to both upstream stations, which were overall very similar. In this case evidence that the effects of the impoundment continued to harm the quality of the water and the macroinvertebrate communities were still present nearly a half-mile downstream of the impoundment. Seasonal temperature increases and subsequent decreases in dissolved oxygen caused by the impoundment appear to be persistent downstream though gradually lessened in the most downstream station. The most downstream station (SB4) had a macroinvertebrate community that was consistently healthier when compared to the station a short distance below the lake (SB3). A number of metrics, including taxa richness, EPT richness, and NCBI, were at comparable levels for the upstream stations and the most downstream station (SB4) indicating a likely general water quality improvement downstream of station SB3.

The differences in the macroinvertebrate communities and water quality of the upstream and downstream stations of the Big Springs Branch tributary were the most pronounced of all the streams assessed. All but two of the nine metrics in which ANOVA tests were performed, were found to be statistically different between the two stations. Richness, tolerance, diversity and evenness indices along with water measurements and habitat assessments attest that Lambert Lake has caused considerable degradation to the downstream macroinvertebrate community and water quality. The temperature of the downstream station in the summer and winter exceeded state standards by 3 and 2 times, respectively. The stream below Lambert Lake is effectively warmer in the summer and colder in the winter than the stream above the lake as a result of increased surface area. The Big Springs Branch tributary and its associated watershed appeared to have the fewest apparent impacts beyond those resulting from the

impoundment of all streams studied. Yet the degree of impairment to the macroinvertebrate community caused by Lambert Lake was the most severe of any of the impoundments included in this project. This is not surprising given Lambert Lake is much larger (3.5 to 18 times) larger than the other impoundments included in the study.

The effects of small impoundments are in some respects similar to the effects of large impoundments. The effects of small impoundments on macroinvertebrate communities and water quality are likely to be more difficult to detect than those of larger impoundments. Careful collection and review of the appropriate data should allow for recognition of effects, both direct and indirect, caused by impoundment even where other impacts exist. Benthic macroinvertebrates being poikilotherms are strongly affected by the temperature of their stream environment (Wotton, 1995; Lessard and Hayes 2003). Macroinvertebrate assemblages below impoundments are therefore more likely to be composed of fewer intolerant species and more generalists or tolerant taxa (Petts, 1984) as a result of changes, for example in temperature, zooplankton, and dissolved oxygen. Diversity of EPT taxa in stations a short distance below each impoundment was consistently reduced as compared to the upstream stations. Filterers, collectors, and gatherers such as Simuliidae, Hydropsychidae, certain Chironomidae, and *Chimarra* were found to be typical dominant taxa a short distance below dams.

The general degree of change and potential harm to a stream is expected to increase proportionally with an increase in the impoundment size. Changes in the natural characteristics of a stream as caused by an impoundment can generally be expected to have deleterious effects. Evidence of precipitation of metals or accumulation of other potentially toxic substances that might result from impoundment, although not evident in any of the streams included in this study, are possible in some regions of eastern Tennessee. Problems such as iron precipitation have been commonly observed below a number of impoundments in the Cumberland Plateau and Highland Rim physiographic provinces of eastern and middle Tennessee.

Careful consideration of the physical changes that may result due to an impoundment's shape, exposure to weather, and manner of discharge, will provide valuable insight into the expected effects that it may have on water quality. Stream impoundments have the potential to cause long-lasting degradation to water quality and habitat resulting in the inability of a naturally healthy and diverse macroinvertebrate community to persist. Water quality and other resource managers have a responsibility to prevent any such degradation and assure that resources held in public trust are protected for both present and future generations. Activities that may potentially or are likely to cause reductions in the water quality and potentially impair a streams classified uses should be avoided and minimized whenever possible.

In time, many man-made impoundments, especially where erosion is higher, will eventually be filled by alluvial deposition. Formation of wetlands, restoration of a stream channel, and water quality improvement will likely follow. Dam removal and stream or river restoration projects are being conducted in a number of states, such as Pennsylvania

and Wisconsin, in part to restore natural flow regimes and improve water quality. It is expected that the results of such dam removal projects will prove beneficial and that other states will begin to use the information gained. It is recommended that dam removal case studies be performed whenever possible with an attempt to assess the potential short-term and long-term effects on water quality and stream ecological health. Such studies should begin, if possible, with a thorough evaluation of water quality and biological conditions prior to dam removal.

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Appendix

Table A1. List of taxa identified from all project collections August 2003 to May 2004 and stations in which they appeared.

Station	CC1	CC2	EB1	EB2	BS1	BS2	SB1	SB2	SB3	SB4
TAXA										
Coelenterata										
Hydroida										
Hydridae										
Hydra spp.				X		X				
Nematoda										
Mermithida										
Mermithidae										
Und. spp.			X	X	X		X	X	X	X
Turbellaria										
Tricladida										
Planaridae										
<i>Cura</i> spp.		X	X	X	X	X		X		X
<i>Dugesia tigrina</i>				X		X				
Annelida										
Oligochaeta										
Branchiobdellida										
Und. family										X
Lumbriculida										
Lumbriculidae										

Table A1. Continued

Station	CC1	CC2	EB1	EB2	BS1	BS2	SB1	SB2	SB3	SB4
TAXA										
Und. spp.	X	X	X	X	X	X	X			X
Tubificida										
Naididae										
<i>Nais</i> spp.		X				X			X	X
<i>Slavina appendiculata</i>							X			
<i>Specaria josinae</i>		X	X	X	X	X			X	X
Tubificidae										
Und. spp. imm. w/ capilliform chaetae			X							
Arthropoda										
Arachnida										
Hydracarina										
Und. Family		X								
Crustacea										
Amphipoda										
Crangonyctidae										
<i>Stygobromus</i> spp.	X									
Gammaridae										
<i>Gammarus</i> spp.			X							
Copepoda										
Cyclopidae										

Table A1. Continued

Station	CC1	CC2	EB1	EB2	BS1	BS2	SB1	SB2	SB3	SB4
TAXA										
Und. spp.						X				
Harpactocoididae										
Und. spp.							X			
Decapoda										
Cambaridae										
<i>Cambarus</i> spp.	X	X			X				X	
Und. spp.	X	X			X				X	
Isopoda										
Asellidae										
<i>Lirceus</i> spp.	X	X	X	X						
Insecta										
Coleoptera										
Elmidae										
<i>Dubiraphia</i> spp.										X
<i>Macronychus glabratus</i>	X			X						
<i>Optioservus</i> spp.	X	X	X	X	X	X		X	X	
<i>Ouilimnius latiusculus</i>	X	X	X	X	X	X	X	X		X
<i>Stenelmis</i> spp.	X		X	X	X	X	X			
Eubriidae										
<i>Ectopria</i> spp.	X	X	X		X		X	X		

Table A1. Continued

Station	CC1	CC2	EB1	EB2	BS1	BS2	SB1	SB2	SB3	SB4
TAXA										
Hydrophilidae										
<i>Hydrobiomorpha</i> spp.									X	
<i>Paracymus</i> spp.	X									
Psephenidae										
<i>Psephenus herricki</i>	X	X	X	X	X		X	X	X	X
Ptilodactylidae										
<i>Anchytarsus bicolor</i>					X					
Staphylinidae										
<i>Bledius</i> spp.	X									
Diptera										
Athericidae										
<i>Atherix lantha</i>									X	X
Blephariceridae										
<i>Blepharicera</i> spp.							X			X
Ceratopogonidae										
<i>Atrichopogon</i> spp.			X			X		X	X	
<i>Bezzia/Palpomyia</i> spp.							X			
<i>Probezzia</i> spp.	X				X	X	X	X		
<i>Dasyhelea</i> spp.						X				
Chaoboridae										

Table A1. Continued

Station	CC1	CC2	EB1	EB2	BS1	BS2	SB1	SB2	SB3	SB4
TAXA										
<i>Chaoborus</i> spp.						X			X	
Chironomidae										
<i>Brillia</i> spp.					X		X	X		X
<i>Cardiocladius</i> spp.		X								
<i>Conchapelopia</i> spp.	X	X	X	X	X	X	X	X	X	X
<i>Corynoneura</i> spp.	X	X		X		X	X	X		X
<i>Cricotopus/Orthocladius</i> spp.					X	X				
<i>Cricotopus</i> spp.				X		X			X	X
<i>Demicryptochironomus</i> spp.	X									
<i>Diamesa</i> spp.		X		X		X			X	X
<i>Diplocladius cultriger</i>						X				
<i>Endochironomus</i> spp.						X				
<i>Eukiefferiella</i> spp.		X		X	X	X	X	X	X	X
<i>Heleniella</i> spp.								X		
<i>Lopescladius</i> spp.					X		X	X		
<i>Micropsectra dubia</i>	X									
<i>Microtendipes</i> spp.					X		X	X		X
<i>Nanocladius</i> spp.					X	X				
<i>Neozavrelia</i> spp.										X
<i>Nilotanypus</i> spp.							X			

Table A1. Continued

Station	CC1	CC2	EB1	EB2	BS1	BS2	SB1	SB2	SB3	SB4
TAXA										
<i>Orthocladus</i> spp.		X		X		X	X		X	X
<i>Parachaetocladus</i> spp.							X			
<i>Parachironomus</i> spp.			X			X				
<i>Parakiefferiella</i> spp.										X
<i>Paraphaenocladus</i> spp.				X						
<i>Parametriocnemus</i> spp.	X	X	X	X	X	X	X	X	X	X
<i>Phaenopsectra</i> spp.		X			X	X				X
<i>Potthastia</i> spp.						X				
<i>Rheocricotopus</i> spp.						X	X	X	X	
<i>Rheotanytarsus</i> spp.	X			X	X	X	X	X	X	X
<i>Stempellina</i> spp.			X					X		
<i>Stempellinella</i> spp.	X		X		X		X	X		X
<i>Synorthocladus semivirens</i>		X								
<i>Tanytarsus</i> spp.	X	X			X	X	X	X	X	X
<i>Thienemanniella</i> spp.		X					X		X	
<i>Tribelos</i> spp.										X
<i>Trissopelopia</i> spp.										X
<i>Tvetenia</i> spp.	X	X	X	X	X	X	X	X	X	X
Und. spp.	X	X	X			X	X	X	X	X
Dixidae										

Table A1. Continued

Station	CC1	CC2	EB1	EB2	BS1	BS2	SB1	SB2	SB3	SB4
TAXA										
<i>Dixa</i> spp.	X				X					
Empididae										
<i>Chelifera</i> spp.	X	X	X						X	
<i>Clinocera</i> spp.					X	X				X
<i>Hemerodromia</i> spp.				X	X	X			X	
Und. spp. (pupae)	X	X		X	X	X				X
Psychodidae										
<i>Psychoda</i> spp.	X									
Simuliidae										
<i>Cnephia</i> spp.								X		
<i>Prosimulium</i> spp.					X		X	X	X	X
<i>Simulium</i> spp.	X	X	X	X	X	X	X	X	X	X
Und spp.				X	X					
Tipulidae										
<i>Antocha</i> spp.		X	X		X	X	X		X	X
<i>Dicranota</i> spp.						X		X		
<i>Hexatoma</i> spp.	X				X		X	X		
<i>Pilaria</i> spp.			X		X			X		
<i>Tipula</i> spp.	X	X	X		X	X	X	X	X	X
Ephemeroptera										

Table A1. Continued

Station	CC1	CC2	EB1	EB2	BS1	BS2	SB1	SB2	SB3	SB4
TAXA										
Ameletidae										
<i>Ameletus</i> spp.					X			X		X
Baetidae										
<i>Acentrella</i> spp.	X	X	X		X	X	X	X	X	X
<i>Acerpenna</i> spp.				X						
<i>Baetis</i> spp.	X	X	X	X	X	X	X	X	X	X
Und.spp.	X		X	X	X		X		X	X
Baetiscidae										
<i>Baetisca</i> spp.							X	X		X
Caenidae										
<i>Caenis</i> spp.									X	
Ephemerellidae										
<i>Attanella attenuata</i>	X	X								
<i>Drunella</i> spp.							X	X		
<i>Ephemerella</i> spp.		X	X	X	X		X	X		X
<i>Eurylophella</i> spp.					X		X			X
<i>Serratella</i> spp.					X		X	X	X	X
Und. spp.		X					X	X		
Ephemeridae										
<i>Ephemera</i> spp.					X					

Table A1. Continued

Station	CC1	CC2	EB1	EB2	BS1	BS2	SB1	SB2	SB3	SB4
TAXA										
Heptageniidae										
<i>Cinygmula subaequalis</i>			X					X		
<i>Epeorus</i> spp.	X	X			X		X	X		X
<i>Leucrocuta</i> spp.	X				X		X	X	X	X
<i>Stenacron</i> spp.	X			X				X		X
<i>Stenonema</i> spp.	X		X		X	X	X	X	X	X
Und. spp.	X		X		X	X	X	X	X	
Isonychiidae										
<i>Isonychia</i> spp.	X	X			X		X	X	X	X
Leptophlebiidae										
<i>Habrophlebia vibrans</i>							X			
<i>Habrophlebiodes</i> spp.					X	X				X
<i>Paraleptophlebia</i> spp.	X	X	X	X	X		X	X		X
Und. spp.	X	X	X	X	X		X	X		
Hemiptera										
Veliidae										
<i>Microvelia</i> spp.			X		X					
<i>Rhagovelia obesa</i>					X					
Megaloptera										
Corydalidae										

Table A1. Continued

Station	CC1	CC2	EB1	EB2	BS1	BS2	SB1	SB2	SB3	SB4
TAXA										
<i>Corydalus cornutus</i>						X				X
<i>Nigronia</i> spp.			X		X	X				X
Odonata										
Anisoptera										
Aeshnidae										
<i>Boyeria</i> spp.					X			X		
Cordulegastridae										
<i>Cordulegaster</i> spp.			X				X			
Gomphidae										
<i>Lanthus vernalis</i>	X	X	X		X	X	X	X		X
Zygoptera										
Coenagrionidae										
<i>Argia</i> spp.					X	X				
<i>Enallagma/Ischnura</i> spp.									X	X
Plecoptera										
Capniidae										
<i>Allocapnia</i> spp.			X				X		X	
Und. spp.							X			
Chloroperlidae										
<i>Sweltsa</i> spp.	X	X					X	X		X

Table A1. Continued

Station	CC1	CC2	EB1	EB2	BS1	BS2	SB1	SB2	SB3	SB4
TAXA										
Und. spp.	X									
Leuctridae										
<i>Leuctra</i> spp.	X	X	X		X	X	X	X	X	X
Nemouridae										
<i>Amphinemura</i> spp.	X	X	X	X	X	X	X	X	X	X
<i>Soyedina</i> spp.							X			X
Und. spp.							X			
Peltoperlidae										
<i>Peltoperla</i> spp.			X							
<i>Tallaperla</i> spp.					X	X		X	X	X
Perlidae										
<i>Acroneuria</i> spp.							X	X	X	X
<i>Agnetina</i> spp.							X			
<i>Beloneuria</i> spp.					X			X		
<i>Perlesta</i> spp.				X						
Und. spp.	X	X			X		X	X		X
Perlodidae										
<i>Isoperla</i> spp.					X					
Und. spp.			X	X						
Pteronarcyidae										

Table A1. Continued

Station	CC1	CC2	EB1	EB2	BS1	BS2	SB1	SB2	SB3	SB4
TAXA										
<i>Pteronarcys</i> spp.					X			X		
Taeniopterygidae										
<i>Taeniopteryx</i> spp.		X								
Trichoptera										
Glossosomatidae										
<i>Agapetus</i> spp.	X		X		X		X	X		
<i>Glossosoma nigrior</i>	X	X	X		X		X	X	X	
Goeridae										
<i>Goera</i> spp.	X						X			
Hydropsychidae										
<i>Ceratopsyche</i> spp.	X	X	X	X		X	X	X	X	X
<i>Cheumatopsyche</i> spp.	X	X	X	X	X	X	X	X	X	X
<i>Diplectrona modesta</i>	X	X	X	X	X		X	X		
<i>Hydropsyche</i> spp.	X	X	X	X	X	X	X	X	X	X
Und spp.	X			X			X	X	X	X
Hydroptilidae										
<i>Leucotrichia pictipes</i>										X
Lepidostomatidae										
<i>Lepidostoma</i> spp.			X		X			X		
Leptoceridae										

Table A1. Continued

Station	CC1	CC2	EB1	EB2	BS1	BS2	SB1	SB2	SB3	SB4
TAXA										
<i>Mystacides sepulchralis</i>	X									
Und. spp.							X			
Limnephilidae										
<i>Pycnopsyche</i> spp.			X							X
Philopotamidae										
<i>Chimarra</i> spp.			X	X	X	X		X	X	X
<i>Dolophiloides distinctus</i>					X		X	X	X	X
<i>Wormaldia</i> spp.							X			
Und. spp.					X					
Polycentropodidae										
<i>Polycentropus</i> spp.	X		X		X		X	X		X
Psychomyiidae										
<i>Lype diversa</i>					X					
<i>Psychomyia</i> spp.		X								
Rhyacophilidae										
<i>Rhyacophila</i> spp.	X	X	X	X	X	X	X	X	X	X
Uenoidae										
<i>Neophylax</i> spp.	X	X	X	X	X		X	X	X	X
Mollusca										
Bivalvia										

Table A1. Continued

[illegible]

Table A2. Taxa collected at Clear Creek stations upstream (CC1) and downstream (CC2) of upper impoundment by sampling date.

Season	Summer		Fall		Winter		Spring	
Sampling date	8/11/03		12/1/03		3/5/04		5/20/04	
Sampling station	CC1	CC2	CC1	CC2	CC1	CC2	CC1	CC2
TAXA								
Annelida								
Oligochaeta								
Lumbriculida								
Und. spp.	5	30	3	3	5			4
Tubificida								
Naididae								
<i>Nais</i> spp.				2				
<i>Specaria appendiculata</i>						1		
Arthropoda								
Arachnida								
Hydracarina								
Und. family								3
Crustacea								
Amphipoda								
Crangonyctidae								
<i>Stygobromus</i> spp.			1					
Decapoda								

Table A2. Continued

Season	Summer		Fall		Winter		Spring	
Sampling date	8/11/03		12/1/03		3/5/04		5/20/04	
Sampling station	CC1	CC2	CC1	CC2	CC1	CC2	CC1	CC2
TAXA								
Cambaridae								
<i>Cambarus</i> spp.		1	1					
Und. spp.		1			1	1		
Isopoda								
Asellidae								
<i>Lirceus</i> spp.	52	11	48	14	39	72	21	98
Insecta								
Coleoptera								
Elmidae								
<i>Macronychus glabratus</i>			1					
<i>Optioservus</i> spp.	4	14	2	5		1	6	5
<i>Ouilimnius latiusculus</i>	13	8	12	15	17	4	16	6
<i>Stenelmis</i> spp.					1			
Eubriidae								
<i>Ectopria</i> spp.		1			1		3	
Hydrophilidae								
<i>Paracymus</i> spp.							1	
Psephenidae								

Table A2. Continued

Season	Summer		Fall		Winter		Spring	
Sampling date	8/11/03		12/1/03		3/5/04		5/20/04	
Sampling station	CC1	CC2	CC1	CC2	CC1	CC2	CC1	CC2
TAXA								
<i>Psephenus herricki</i>	1	8		2		1		4
Staphylinidae								
<i>Bledius</i> spp.							2	
Diptera								
Ceratopogonidae								
<i>Probezzia</i> spp.							1	
Chironomidae								
<i>Cardiocladius</i> spp.				1				
<i>Conchapelopia</i> spp.	1	9					3	
<i>Corynoneura</i> spp.							1	1
<i>Demicryptochironomus</i> spp.	1							
<i>Diamesa</i> spp.				1				
<i>Eukiefferiella</i> spp.				1				
<i>Micropsectra dubia</i>					1			
<i>Orthocladius</i> spp.				2		1		
<i>Parametriocnemus</i> spp.		5		1			3	
<i>Phaenopsectra</i> spp.		1						
<i>Polypedilum</i> spp.				1			3	

Table A2. Continued

Season	Summer		Fall		Winter		Spring	
Sampling date	8/11/03		12/1/03		3/5/04		5/20/04	
Sampling station	CC1	CC2	CC1	CC2	CC1	CC2	CC1	CC2
TAXA								
<i>Rheotanytarsus</i> spp.	1							
<i>Stempellinella</i> spp.							2	
<i>Synorthocladius semivirens</i>				1				
<i>Tanytarsus</i> spp.			3			3		
<i>Thienemanniella</i> spp.								1
<i>Tvetenia</i> spp.		1				2	4	
Und. spp.		1		1			1	
Dixidae								
<i>Dixa</i> spp.					1			
Empididae								
<i>Chelifera</i> spp.		3		1	1	4		
Und. spp. (pupae)							1	1
Psychodidae								
<i>Psychoda</i> spp.							6	
Simuliidae								
<i>Simulium</i> spp.	18	3			13	5	3	
Tipulidae								
<i>Antocha</i> spp.				2				

Table A2. Continued

Season	Summer		Fall		Winter		Spring	
Sampling date	8/11/03		12/1/03		3/5/04		5/20/04	
Sampling station	CC1	CC2	CC1	CC2	CC1	CC2	CC1	CC2
TAXA								
<i>Hexatoma</i> spp.	2				1			
<i>Tipula</i> spp.			1	4			1	
Ephemeroptera								
Baetidae								
<i>Acentrella</i> spp.				2	15	42	2	1
<i>Baetis</i> spp.	27	24	6	5	3	8	5	7
Und.spp.			1					
Ephemerellidae								
<i>Attanella attenuata</i>		1	2					
<i>Ephemerella</i> spp.				3		20		12
Und. spp.				3		7		1
Heptageniidae								
<i>Epeorus</i> spp.	6		7		13	1	3	
<i>Leucrocuta</i> spp.			12		11			
<i>Stenacron</i> spp.					1			
<i>Stenonema</i> spp.			1					
Und. spp.	1		8		2			
Isonychiidae								

Table A2. Continued

Season	Summer		Fall		Winter		Spring	
Sampling date	8/11/03		12/1/03		3/5/04		5/20/04	
Sampling station	CC1	CC2	CC1	CC2	CC1	CC2	CC1	CC2
TAXA								
<i>Isonychia</i> spp.		1	1		4		3	
Leptophlebiidae								
<i>Paraleptophlebia</i> spp.					1		2	2
Und. spp.		2			2		1	
Odonata								
Gomphidae								
<i>Lanthus vernalis</i>	1	9		1	1		2	6
Plecoptera								
Chloroperlidae								
<i>Sweltsa</i> spp.	16	17	8	2	3			
Und. spp.							1	
Leuctridae								
<i>Leuctra</i> spp.	19	17	2	5	3		44	3
Nemouridae								
<i>Amphinemura</i> spp.					12	7		
Perlidae								
Und. spp.	1	1						
Taeniopterygidae								

Table A2. Continued

Season	Summer		Fall		Winter		Spring	
Sampling date	8/11/03		12/1/03		3/5/04		5/20/04	
Sampling station	CC1	CC2	CC1	CC2	CC1	CC2	CC1	CC2
TAXA								
<i>Taeniopteryx</i> spp.				1				
Trichoptera								
Glossosomatidae								
<i>Agapetus</i> spp.					2		16	
<i>Glossosoma nigrrior</i>	18		16	1	7	4	1	2
Goeridae								
<i>Goera</i> spp.			1					
Hydropsychidae								
<i>Ceratopsyche</i> spp.	1			2				
<i>Cheumatopsyche</i> spp.	12	5	30	15	3	2		2
<i>Diplectrona modesta</i>	1	7	25	18	9	6	5	4
<i>Hydropsyche</i> spp.	1	7	1	24	1	2	1	2
Und spp.	1							
Leptoceridae								
<i>Mystacides sepulchralis</i>			1					
Polycentropodidae								
<i>Polycentropus</i> spp.							1	

Table A2. Continued

Season	Summer		Fall		Winter		Spring	
Sampling date	8/11/03		12/1/03		3/5/04		5/20/04	
Sampling station	CC1	CC2	CC1	CC2	CC1	CC2	CC1	CC2
TAXA								
Psychomyiidae								
<i>Psychomyia</i> spp.		2						
Rhyacophilidae								
<i>Rhyacophila</i> spp.			2	1		2		
Uenoidae								
<i>Neophylax</i> spp.			6	6	7	1	3	
Mollusca								
Gastropoda								
Mesogastropoda								
Pleuroceridae								
<i>Elimia</i> spp.	7	32	3	32	4	7	13	31
Platyhelminthes								
Turbellaria								
Tricladida								
Planaridae								
<i>Cura</i> spp.								1

Table A3. Taxa collected at Eagle Bluff Creek stations upstream (EB1) and downstream (EB2) of Eagle Bluff Lake by sampling date.

Season	Summer		Fall		Winter		Spring	
Sampling date	8/11/03		11/30/03		3/3/04		5/20/04	
Sampling station	EB1	EB2	EB1	EB2	EB1	EB2	EB1	EB2
TAXA								
Annelida								
Oligochaeta								
Lumbriculida								
Lumbriculidae								
Und. spp.		1		2	3	1		3
Tubificida								
Naididae								
<i>Specaria appendiculata</i>	1					2		
Tubificidae								
Und. spp. imm. w/ capilliform chaetae			1					
Crustacea								
Amphipoda								
Gammaridae								
<i>Gammarus</i> spp.	50		27		39		71	
Isopoda								
Asellidae								
<i>Lirceus</i> spp.		1	4		3			

Table A3. Continued

Season	Summer		Fall		Winter		Spring	
Sampling date	8/11/03		11/30/03		3/3/04		5/20/04	
Sampling station	EB1	EB2	EB1	EB2	EB1	EB2	EB1	EB2
TAXA								
Insecta								
Coleoptera								
Elmidae								
<i>Macronychus glabratus</i>				1				
<i>Optioservus</i> spp.	1			1		1		2
<i>Ouilimnius latiusculus</i>	2		8		4	1	6	
<i>Stenelmis</i> spp.		20	1	15		80	1	25
Eubriidae								
<i>Ectopria</i> spp.	10		8		6		3	
Psephenidae								
<i>Psephenus herricki</i>	1	2				1		
Diptera								
Ceratopogonidae								
<i>Atrichopogon</i> spp.			1					
Chironomidae								
<i>Conchapelopia</i> spp.				3		2	1	1
<i>Corynoneura</i> spp.				1				
<i>Cricotopus</i> spp.						2		1

Table A3. Continued

Season	Summer		Fall		Winter		Spring	
Sampling date	8/11/03		11/30/03		3/3/04		5/20/04	
Sampling station	EB1	EB2	EB1	EB2	EB1	EB2	EB1	EB2
TAXA								
<i>Diamesa</i> spp.						2		
<i>Eukiefferiella</i> spp.			1			6		1
<i>Micropsectra</i> spp.			1					
<i>Orthocladius</i> spp.				1				
<i>Paraphaenocladus</i> spp.						2		
<i>Parametriocnemus</i> spp.	6		3	1		1		
<i>Polypedilum</i> spp.	3	1				5		91
<i>Rheotanytarsus</i> spp.								1
<i>Stempellina</i> spp.			1					
<i>Stempellinella</i> spp.							1	
<i>Tvetenia</i> spp.				1	1	3	1	
Empididae								
<i>Chelifera</i> spp.	1						4	
<i>Hemerodromia</i> spp.		1		1		1		
Und. spp. (pupae)								1
Simuliidae								
<i>Simulium</i> spp.	1			6		17		4
Und spp.						1		

Table A3. Continued

Season	Summer		Fall		Winter		Spring	
Sampling date	8/11/03		11/30/03		3/3/04		5/20/04	
Sampling station	EB1	EB2	EB1	EB2	EB1	EB2	EB1	EB2
TAXA								
Tipulidae								
<i>Antocha</i> spp.	3							
<i>Pilaria</i> spp.					1			
<i>Tipula</i> spp.	1		3					
Ephemeroptera								
Baetidae								
<i>Acentrella</i> spp.							2	
<i>Acerpenna</i> spp.		4				11		
<i>Baetis</i> spp.	6	45	3	1	21		8	4
Und. spp.	4						2	1
Ephemerellidae								
<i>Ephemerella</i> spp.			1		1	1		
Heptageniidae								
<i>Cinygmula subaequalis</i>					2			
<i>Stenacron</i> spp.				1		5		1
<i>Stenonema</i> spp.							1	
Und. spp.	1							
Leptophlebiidae								

Table A3. Continued

Season	Summer		Fall		Winter		Spring	
Sampling date	8/11/03		11/30/03		3/3/04		5/20/04	
Sampling station	EB1	EB2	EB1	EB2	EB1	EB2	EB1	EB2
TAXA								
<i>Paraleptophlebia</i> spp.			1		1		2	2
Und. spp.					1			1
Hemiptera								
Veliidae								
<i>Microvelia</i> spp.					1			
Megaloptera								
Corydalidae								
<i>Nigronia</i> spp.	1							
Odonata								
Anisoptera								
Cordulegastridae								
<i>Cordulegaster</i> spp.			1				1	
Gomphidae								
<i>Lanthus vernalis</i>	2		2		1		3	
Plecoptera								
Capniidae								
<i>Allocaonia</i> spp.			9					
Leuctridae								

Table A3. Continued

Season	Summer		Fall		Winter		Spring	
Sampling date	8/11/03		11/30/03		3/3/04		5/20/04	
Sampling station	EB1	EB2	EB1	EB2	EB1	EB2	EB1	EB2
TAXA								
<i>Leuctra</i> spp.	21		1		2		18	
Nemouridae								
<i>Amphinemura</i> spp.			1		57	1	5	
Peltoperlidae								
Perlidae								
<i>Perlesta</i> spp.								1
Perlodidae								
Und. spp.	1					1	2	
Trichoptera								
Glossosomatidae								
<i>Agapetus</i> spp.					16		25	
<i>Glossosoma nigrrior</i>	6		2		1		1	
Hydropsychidae								
<i>Ceratopsyche</i> spp.			1			4		12
<i>Cheumatopsyche</i> spp.	3	10	1	28		16		33
<i>Diplectrona modesta</i>	18		58		34	1	6	
<i>Hydropsyche</i> spp.	3	37	2	43		28		11
Und spp.		5		3				3

Table A3. Continued

Season	Summer		Fall		Winter		Spring	
Sampling date	8/11/03		11/30/03		3/3/04		5/20/04	
Sampling station	EB1	EB2	EB1	EB2	EB1	EB2	EB1	EB2
TAXA								
Lepidostomatidae								
<i>Lepidostoma</i> spp.					2		6	
Limnephilidae								
<i>Pycnopsyche</i> spp.			5					
Philopotamidae								
<i>Chimarra</i> spp.	3	51		64		24		29
Polycentropodidae								
<i>Polycentropus</i> spp.			1		2		1	
Rhyacophilidae								
<i>Rhyacophila</i> spp.	6		1	11	16	1	4	
Uenoidae								
<i>Neophylax</i> spp.	1		2		6	3		
Cnidaria								
Hydroida								
Hydridae								
<i>Hydra</i> spp.						2		
Mollusca								
Gastropoda								

Table A3. Continued

Season	Summer		Fall		Winter		Spring	
Sampling date	8/11/03		12/1/03		3/5/04		5/20/04	
Sampling station	EB1	EB2	EB1	EB2	EB1	EB2	EB1	EB2
TAXA								
Mesogastropoda								
Hydrobiidae								
Und. spp.	1							
Pleuroceridae								
<i>Elimia</i> spp.	25		7		5		12	
Nematoda								
Mermithida								
Mermithidae								
Und. spp.					2	1		
Platyhelminthes								
Turbellaria								
Tricladida								
Planaridae								
<i>Cura</i> spp.	1	3	1	7	1	2	2	1
<i>Dugesia tigrina</i>	3							

Table A4. Taxa collected at Smith Branch stations upstream (SB1 and SB2) and downstream (SB3 and SB4) of Saddle Ridge Lake by sampling date.

Season	Summer		Fall				Winter				Spring			
Sampling date	8/16/03		11/29/03				3/3/04				5/21/04			
Sampling station	SB1	SB3	SB1	SB2	SB3	SB4	SB1	SB2	SB3	SB4	SB1	SB2	SB3	SB4
TAXA														
Annelida														
Oligochaeta														
Branchiobdellida														
Branchiobdellidae														
Und. spp.														1
Lumbriculida														
Lumbriculidae														
Und. spp	1					1					2			1
Tubificida														
Naididae														
<i>Nais</i> spp.									20	2			1	
<i>Slavina appendiculata</i>			1											
<i>Specaria josinae</i>					2	7								1
Arthropoda														
Crustacea														
Harpacticoida (Copepoda)														
Harpactocoididae														

Table A4. Continued

Season	Summer		Fall				Winter				Spring			
Sampling date	8/16/03		11/29/03				3/3/04				5/21/04			
Sampling station	SB1	SB3	SB1	SB2	SB3	SB4	SB1	SB2	SB3	SB4	SB1	SB2	SB3	SB4
TAXA														
Und. spp.			1											
Decapoda														
Cambaridae														
<i>Cambarus</i> spp.														
Und spp.					1									
Insecta														
Coleoptera														
Elmidae														
<i>Dubiraphia</i> spp.						1								
<i>Optioservus</i> spp.		2		1								1		
<i>Ouilimnius latiusculus</i>	12		12	1		1	16			3	15	4		1
<i>Stenelmis</i> spp.			1											
Eubriidae														
<i>Ectopria</i> spp.			1								1	3		
Hydrophilidae														
<i>Hydrobiomorpha</i> spp.		1												
Psephenidae														
<i>Psephenus herricki</i>	8	6		1		4					5	8		3

Table A4. Continued

Season	Summer		Fall				Winter				Spring			
Sampling date	8/16/03		11/29/03				3/3/04				5/21/04			
Sampling station	SB1	SB3	SB1	SB2	SB3	SB4	SB1	SB2	SB3	SB4	SB1	SB2	SB3	SB4
TAXA														
Diptera														
Athericidae														
<i>Atherix lantha</i>		1				1								
Blephariceridae														
<i>Blepharicera</i> spp.											1			2
Ceratopogonidae														
<i>Atrichopogon</i> spp.		2										1		
<i>Bezzia/Palpomyia</i> spp.							5							
<i>Probezzia</i> spp.			2	2				2			1			
Chaoboridae														
<i>Chaoborus</i> spp.					1									
Chironomidae														
<i>Brillia</i> spp.				2			1			1				
<i>Conchapelopia</i> spp.								1		1	2	8	2	
<i>Corynoneura</i> spp.						1	1			1		1		
<i>Cricotopus</i> spp.									14	3				
<i>Diamesa</i> spp.									25	3				
<i>Eukiefferiella</i> spp.			1					1	1		1			3

Table A4. Continued

Season	Summer		Fall				Winter				Spring			
Sampling date	8/16/03		11/29/03				3/3/04				5/21/04			
Sampling station	SB1	SB3	SB1	SB2	SB3	SB4	SB1	SB2	SB3	SB4	SB1	SB2	SB3	SB4
TAXA														
<i>Heleniella</i> spp.								1						
<i>Lopescladius</i> spp.	1										2	1		
<i>Microtendipes</i> spp.	6		12	2		4	2	4			1	2		7
<i>Neozavrelia</i> spp.										1				
<i>Nilotanytus</i> spp.	1													
<i>Orthocladius</i> spp.							1						1	4
<i>Parachaetocladius</i> spp.			1											
<i>Parakiefferiella</i> spp.										1				
<i>Parametriocnemus</i> spp.			1	1	6	7	7	4	10	40		6	6	19
<i>Phaenopsectra</i> spp.										1				
<i>Polypedilum</i> spp.	7		4	1	1	1	1			2	1	2	8	2
<i>Rheocricotopus</i> spp.							1	1	1			2		
<i>Rheotanytarsus</i> spp.	3	1	1	1	5	3		1	3			3	26	4
<i>Stempellina</i> spp.				2										
<i>Stempellinella</i> spp.			1	1			1			12				5
<i>Tanytarsus</i> spp.	4		1			3	22	23	7	15	3		4	2
<i>Thienemanniella</i> spp.	1		1				1		1					
<i>Tribelos</i> spp.						1								

Table A4. Continued

Season	Summer		Fall				Winter				Spring			
Sampling date	8/16/03		11/29/03				3/3/04				5/21/04			
Sampling station	SB1	SB3	SB1	SB2	SB3	SB4	SB1	SB2	SB3	SB4	SB1	SB2	SB3	SB4
TAXA														
Und. spp. (pupae)														1
Simuliidae														
<i>Cnephia</i> spp.								1						
<i>Prosimulium</i> spp.			1				3	3	6	1				1
<i>Simulium</i> spp.	1	9			1		4		5	2	2	8	36	45
Tipulidae														
<i>Antocha</i> spp.	2		2				1		1	1	1	1		3
<i>Dicranota</i> spp.												1		
<i>Hexatoma</i> spp.	4		2				3	2			3	1		
<i>Pilaria</i> spp.				1										
<i>Tipula</i> spp.				2	3	1					1			
Ephemeroptera														
Ameletidae														
<i>Ameletus</i> spp.				1		1				2				
Baetidae														
<i>Acentrella</i> spp.	2							5	2	1	14	8	12	4
<i>Baetis</i> spp.	18	18	3	3			1	4		3	41	23	24	11
Und.spp.	2	1												3

Table A4. Continued

Season	Summer		Fall				Winter				Spring			
Sampling date	8/16/03		11/29/03				3/3/04				5/21/04			
Sampling station	SB1	SB3	SB1	SB2	SB3	SB4	SB1	SB2	SB3	SB4	SB1	SB2	SB3	SB4
TAXA														
Baetiscidae														
<i>Baetisca</i> spp.			3			1		1						
Caenidae														
<i>Caenis</i> spp.		1												
Ephemerellidae														
<i>Drunella</i> spp.								3			1	4		
<i>Ephemerella</i> spp.			3	2			3	3		1	6	2		
<i>Eurylophella</i> spp.						2	1			3				
<i>Serratella</i> spp.							37	13	3	1				
Und. spp.							3	4						
Heptageniidae														
<i>Cinygmula subaequalis</i>				1				1						
<i>Epeorus</i> spp.	2		6	9			4	9		3		4		
<i>Leucrocuta</i> spp.	1	1	13	3			4	5		1	7	5		
<i>Stenacron</i> spp.								1		1		1		
<i>Stenonema</i> spp.	16	7	29	20	20	80	13	19	6	21	9	8	6	5
Und. spp.	2			2	2		5	13						
Isonychiidae														

Table A4. Continued

Season	Summer		Fall				Winter				Spring			
Sampling date	8/16/03		11/29/03				3/3/04				5/21/04			
Sampling station	SB1	SB3	SB1	SB2	SB3	SB4	SB1	SB2	SB3	SB4	SB1	SB2	SB3	SB4
TAXA														
<i>Isonychia</i> spp.	8	3		1	21	9		1	9	3			6	
Leptophlebiidae														
<i>Habrophlebia vibrans</i>											1			
<i>Habrophlebiodes</i> spp.						1								
<i>Paraleptophlebia</i> spp.			3					3		1		1		1
Und. spp.	2		2									3		
Megaloptera														
Corydalidae														
<i>Corydalus cornutus</i>										1				
<i>Nigronia</i> spp.						2								
Odonata														
Anisoptera														
Aeshnidae														
<i>Boyeria</i> spp.	1													
Cordulegastridae														
<i>Cordulegaster</i> spp.			1											
Gomphidae														
<i>Lanthus vernalis</i>	4		1	1		3	2			4				1

Table A4. Continued

Season	Summer		Fall				Winter				Spring			
Sampling date	8/16/03		11/29/03				3/3/04				5/21/04			
Sampling station	SB1	SB3	SB1	SB2	SB3	SB4	SB1	SB2	SB3	SB4	SB1	SB2	SB3	SB4
TAXA														
Zygoptera														
Coenagrionidae														
<i>Enallagma/Ischnura</i> spp.					1	1								
Plecoptera														
Capniidae														
<i>Allocaenia</i> spp.			12						1					
Und. spp.			3											
Chloroperlidae														
<i>Sweltsa</i> spp.	6		3					1		2		1		2
Leuctridae														
<i>Leuctra</i> spp.	30		3	15		4	8	4	1	5	30	18		19
Nemouridae														
<i>Amphinemura</i> spp.							20	16	33	71				
<i>Soyedina</i> spp.			2			1								
Und. spp.			1											
Peltoperlidae														
<i>Tallaperla</i> spp.						1						4	3	2
Perlidae														

Table A4. Continued

Season	Summer		Fall				Winter				Spring			
Sampling date	8/16/03		11/29/03				3/3/04				5/21/04			
Sampling station	SB1	SB3	SB1	SB2	SB3	SB4	SB1	SB2	SB3	SB4	SB1	SB2	SB3	SB4
TAXA														
<i>Acroneuria</i> spp.	14	1	4	5	4	1	1	4			4	4		
<i>Agnetina</i> spp.	1													
<i>Beloneuria</i> spp.												1		
Und. spp.										1	3	11		2
Pteronarcyidae														
<i>Pteronarcys</i> spp.				1										
Trichoptera														
Glossosomatidae														
<i>Agapetus</i> spp.											4	1		
<i>Glossosoma</i> spp.	7			1		1	2		1					
Goeridae														
<i>Goera</i> spp.			1											
Hydropsychidae														
<i>Ceratopsyche</i> spp.		1	1				1				7		15	4
<i>Cheumatopsyche</i> spp.	25	55	35	44	48	10	9	34	19	1	2	9	32	35
<i>Diplectrona</i> spp.	4		2				2	1						
<i>Hydropsyche</i> spp.	1	15		1	9	1			3	1		1	4	
Und spp.	2			1	6						11	28	4	16

Table A4. Continued

Season	Summer		Fall				Winter				Spring			
Sampling date	8/16/03		11/29/03				3/3/04				5/21/04			
Sampling station	SB1	SB3	SB1	SB2	SB3	SB4	SB1	SB2	SB3	SB4	SB1	SB2	SB3	SB4
TAXA														
Hydroptilidae														
<i>Leucotrichia</i> spp.						1								
Lepidostomatidae														
<i>Lepidostoma</i> spp.				1										
Leptoceridae														
Und. spp.	1													
Limnephilidae														
<i>Pycnopsyche</i> spp.						2								
Philopotamidae														
<i>Chimarra</i> spp.		65		9	67	10		7	30	3			14	8
<i>Dolophiloides distinctus</i>	1	2	3	7		1	4	1			14	6		5
<i>Wormaldia</i> spp.			1											
Polycentropodidae														
<i>Polycentropus</i> spp.			1			3		1		1	1	1		
Rhyacophilidae														
<i>Rhyacophila</i> spp.			3	4	1	1	1	2		6		3	1	4
Uenoidae														
<i>Neophylax</i> spp.			1	9	1	6	2	2	2	2	1			

Table A4. Continued

Season	Summer		Fall				Winter				Spring			
Sampling date	8/16/03		11/29/03				3/3/04				5/21/04			
Sampling station	SB1	SB3	SB1	SB2	SB3	SB4	SB1	SB2	SB3	SB4	SB1	SB2	SB3	SB4
TAXA														
Mollusca														
Bivalvia														
Veneroida														
Corbiculidae														
<i>Corbicula fluminea</i>		1				1							1	1
Gastropoda														
Mesogastropoda														
Lymnadae														
<i>Fossaria</i> spp.									1					
Nematoda														
Mermithida														
Mermithidae														
Und. spp.		3			1					1	3	1	1	
Platyhelminthes														
Turbellaria														
Tricladida														
Planariidae														
<i>Cura</i> spp.								1						1

Table A5. Taxa collected at Big Springs Branch tributary stations upstream (BS1) and downstream (BS2) of Lambert Lake by sampling date.

Season	Summer		Fall		Winter		Spring	
Sampling date	8/17/03		12/2/03		3/5/04		5/21/04	
Sampling site	BS1	BS2	BS1	BS2	BS1	BS2	BS1	BS2
TAXA								
Annelida								
Oligochaeta								
Lumbriculida								
Lumbriculidae								
Und. spp.	16	4		11	3	1		1
Tubificida								
Naididae								
<i>Nais spp.</i>		1				1		
<i>Specaria appendiculata</i>		3	2	1	1			
Arthropoda								
Crustacea								
Cyclopoida (Copepoda)								
Cyclopidae								
Und. spp.				1				
Decapoda								
Cambaridae								
<i>Cambarus spp.</i>	1							
Und. spp.	1						1	

Table A5. Continued

Season	Summer		Fall		Winter		Spring	
Sampling date	8/17/03		12/2/03		3/5/04		5/21/04	
Sampling station	BS1	BS2	BS1	BS2	BS1	BS2	BS1	BS2
TAXA								
Insecta								
Coleoptera								
Elmidae								
<i>Optioservus</i> spp.	3		2	3	3			
<i>Ouilimnius latiusculus</i>			3	2	3		2	
<i>Stenelmis</i> spp.	1	2	1				4	
Eubriidae								
<i>Ectopria</i> spp.	3							
Psephenidae								
<i>Psephenus herricki</i>	8		2		1		2	
Ptilodactylidae								
<i>Anchytarsus bicolor</i>			3		2		1	
Diptera								
Ceratopogonidae								
<i>Atrichopogon</i> spp.				1				
<i>Probezzia</i> spp.			1				1	1
<i>Dasyhelea</i> spp.						1		
Chaoboridae								

Table A5. Continued

Season	Summer		Fall		Winter		Spring	
Sampling date	8/17/03		12/2/03		3/5/04		5/21/04	
Sampling station	BS1	BS2	BS1	BS2	BS1	BS2	BS1	BS2
TAXA								
<i>Chaoborus</i> spp.				10				
Chironomidae								
<i>Brillia</i> spp.			1					
<i>Conchapelopia</i> spp.		9			1	1		
<i>Corynoneura</i> spp.				1				
<i>Cricotopus/Orthocladius</i> spp.							5	5
<i>Cricotopus</i> spp.				11				
<i>Diamesa</i> spp.						4		
<i>Diplocladius</i> spp.		1		1				
<i>Endochironomus</i> spp.				1		1		
<i>Eukiefferiella</i> spp.			1		3		1	2
<i>Lopescladius</i> spp.	1		1				1	
<i>Microtendipes</i> spp.	13		9		7		3	
<i>Nanocladius</i> spp.	2	1				1		
<i>Nilotanytus</i> spp.							1	
<i>Orthocladius</i> spp.						76		
<i>Parachironomus</i> spp.		1						
<i>Parametriocnemus</i> spp.	5	3	3	2			7	1

Table A5. Continued

Season	Summer		Fall		Winter		Spring	
Sampling date	8/17/03		12/2/03		3/5/04		5/21/04	
Sampling station	BS1	BS2	BS1	BS2	BS1	BS2	BS1	BS2
TAXA								
<i>Phaenopsectra</i> spp.	2			1				
<i>Polypedilum</i> spp.	8	62	10	1			5	7
<i>Potthastia</i> spp.		1						
<i>Rheocricotopus</i> spp.		1		1				
<i>Rheotanytarsus</i> spp.	7	81	1	3	3		1	2
<i>Stempellinella</i> spp.	2		1		4		2	
<i>Tanytarsus</i> spp.	8		8		23		2	1
<i>Tvetenia</i> spp.		1		1		17	3	10
Und. spp.		1		1				1
Dixidae								
<i>Dixa</i> spp.			1					
Empididae								
<i>Clinocera</i> spp.		3					2	
<i>Hemerodromia</i> spp.		1	1		1	1		
Und. spp. (pupae)		1					1	
Simuliidae								
<i>Prosimulium</i> spp.					8			
<i>Simulium</i> spp.	4	19	3	44	15	33	45	94

Table A5. Continued

Season	Summer		Fall		Winter		Spring	
Sampling date	8/17/03		12/2/03		3/5/04		5/21/04	
Sampling station	BS1	BS2	BS1	BS2	BS1	BS2	BS1	BS2
TAXA								
Und spp.					5			
Tipulidae								
<i>Antocha</i> spp.	1					1		
<i>Dicranota</i> spp.								2
<i>Hexatoma</i> spp.	2		2		4		4	
<i>Pilaria</i> spp.	2							
<i>Tipula</i> spp.		2					3	2
Ephemeroptera								
Ameletidae								
<i>Ameletus</i> spp.			1					
Baetidae								
<i>Acentrella</i> spp.					1	5		
<i>Baetis</i> spp.	2				3		17	2
Und.spp.					1		1	
Ephemerellidae								
<i>Ephemerella</i> spp.			3		24			
<i>Eurylophella</i> spp.			3					
Ephemeridae								

Table A5. Continued

Season	Summer		Fall		Winter		Spring	
Sampling date	8/17/03		12/2/03		3/5/04		5/21/04	
Sampling station	BS1	BS2	BS1	BS2	BS1	BS2	BS1	BS2
TAXA								
<i>Ephemera</i> spp.	9							
Heptageniidae								
<i>Epeorus</i> spp.			6		12		3	
<i>Leucrocuta</i> spp.							1	
<i>Stenonema</i> spp.	12		47	4	24		24	
Und. spp.			1	1				
Isonychiidae								
<i>Isonychia</i> spp.							1	
Leptophlebiidae								
<i>Habrophlebia vibrans</i>							1	
<i>Habrophlebiodes</i> spp.		1	2					
<i>Paraleptophlebia</i> spp.			3		11		2	
Und. spp.	3		1				5	
Hemiptera								
Veliidae								
<i>Microvelia</i> spp.							3	
<i>Rhagovelia obesa</i>							1	
Megaloptera								

Table A5. Continued

Season	Summer		Fall		Winter		Spring	
Sampling date	8/17/03		12/2/03		3/5/04		5/21/04	
Sampling station	BS1	BS2	BS1	BS2	BS1	BS2	BS1	BS2
TAXA								
Corydalidae								
<i>Corydalus cornutus</i>						1		
<i>Nigronia</i> spp.	2			5	1			
Odonata								
Anisoptera								
Aeshnidae								
<i>Boyeria</i> spp.	1		1					
Gomphidae								
<i>Lanthus vernalis</i>	2			2	1		1	
Zygoptera								
Coenagrionidae								
<i>Argia</i> spp.				1			1	
Plecoptera								
Leuctridae								
<i>Leuctra</i> spp.	40		8	2	6		27	
Nemouridae								
<i>Amphinemura</i> spp.	1		1	1	17	19	3	4
Peltoperlidae								

Table A5. Continued

Season	Summer		Fall		Winter		Spring	
Sampling date	8/17/03		12/2/03		3/5/04		5/21/04	
Sampling station	BS1	BS2	BS1	BS2	BS1	BS2	BS1	BS2
TAXA								
<i>Tallaperla</i> spp.			1				10	3
Perlidae								
<i>Beloneuria</i> spp.					1			
Und. spp.							1	
Perlodidae								
<i>Isoperla</i> spp.			2					
Pteronacyidae								
<i>Pteronarcys</i> spp.	1		1		3		4	
Trichoptera								
Glossosomatidae								
<i>Agapetus</i> spp.							1	
<i>Glossosoma nigrrior</i>	2		1		5			1
Hydropsychidae								
<i>Ceratopsyche</i> spp.		2						
<i>Cheumatopsyche</i> spp.	27	23	14	46	8	5	13	21
<i>Diplectrona modesta</i>	21		3		11		1	
<i>Hydropsyche</i> spp.		5		4	1	9		
Lepidostomatidae								

Table A5. Continued

Season	Summer		Fall		Winter		Spring	
Sampling date	8/17/03		12/2/03		3/5/04		5/21/04	
Sampling station	BS1	BS2	BS1	BS2	BS1	BS2	BS1	BS2
TAXA								
<i>Lepidostoma</i> spp.					5		1	
Philopotamidae								
<i>Chimmara</i> spp.	1	8	1	1				
<i>Dolophiloides distinctus</i>	5		10		2		9	
Und. spp.							1	
Polycentropodidae								
<i>Polycentropus</i> spp.					2		1	
Psychomyiidae								
<i>Lype diversa</i>			1		2			
Rhyacophilidae								
<i>Rhyacophila</i> spp.	3		4	1	6		3	
Uenoidae								
Hydridae						5		
<i>Hydra</i> spp.						5		
<i>Neophylax</i> spp.							1	
Cnidaria								
Hydroida								
Mollusca								

Table A5. Continued

Season	Summer		Fall		Winter		Spring	
Sampling date	8/17/03		12/2/03		3/5/04		5/21/04	
Sampling station	BS1	BS2	BS1	BS2	BS1	BS2	BS1	BS2
TAXA								
Bivalvia								
Veneroida								
Corbiculidae								
<i>Corbicula fluminea</i>								1
Spaeriidae								
<i>Psidium</i> spp.				15				
Gastropoda								
Limnophila								
Physidae								
<i>Physella</i> spp.				1				2
Mesogastropoda								
Lymnaidae								
<i>Fossaria</i> spp.								2
Nematoda								
Mermithida								
Mermithidae								
Und. spp.								
Platyhelminthes								

Table A5. Continued

[illegible]

Vita

Larry E. Everett, Jr., was born in Metairie, Louisiana on 20 February 1973. He lived in Slidell, Louisiana from age 5 until 16 and attended Slidell Junior High and Slidell High Schools. In 1989 his family moved to Knoxville, Tennessee where he graduated from Farragut High School in 1991. He attended the University of Tennessee, Knoxville and in 1996 received a Bachelor of Science in Plant and Soil Science with a concentration in Environmental Science and Natural Resources and a minor in Biology. He has worked for Tennessee's Department of Environment and Conservation, Division of Water Pollution Control since 1998. He is a member of the Southeastern Water Pollution Biologists Association. While working full-time he returned to the University of Tennessee, entering the graduate program in January 2001. He received a Master of Science degree in Ecology and Evolutionary Biology in December 2005.

He and his wife, Colleen, currently reside in Jefferson County, Tennessee.

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