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A comparison of biological indices and water quality for different land uses

Julie Suzanne Tindell

To the Graduate Council:

I am submitting herewith a thesis written by Julie Suzanne Tindell entitled "A comparison of biological indices and water quality for different land uses." I have examined the final electronic 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 Biosystems Engineering Technology.

Ronald E. Yoder, Major Professor

We have read this thesis and recommend its acceptance:

J. Larry Wilson, D. Raj Raman

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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A Comparison of Biological Indices and Water Quality for Different Land Uses

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

Julie Suzanne Tindell
May 1999

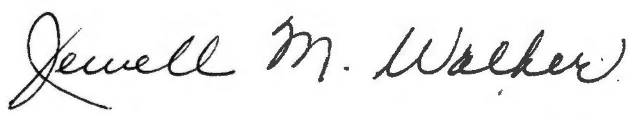
DEDICATION

This thesis is dedicated to my parents

Mr. Thomas H. Walker

and

Mrs. Jewell M. Walker



Who have given me encouragement and invaluable educational opportunities

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Finally, my greatest debt is owed to my husband, Jason. His love and patience has been there for me throughout my study.

Abstract

Five subwatersheds in the Sweetwater Valley of Tennessee were sampled from October 1997 to March 1999 comparing biological and chemical methodologies for each of the different land uses. The five subwatersheds were: (1) wooded, (2) urban, (3) mixed, (4) agricultural, and (5) rural. In each subwatershed fish sampling was conducted in the spring of 1998 along with macroinvertebrate sampling in the fall of 1997, spring 1998, and fall 1998. Also, water quality parameters such as fecal coliforms, chloride, nitrate, sulfate, ammonia, biological oxygen demand (BOD), and total suspended solids (TSS) were sampled weekly from April 17, 1997 to September 30, 1998. Other water quality parameters such as dissolved oxygen (DO), pH, electrical conductivity, and water temperature were analyzed at high and low flows in all subwatershed stream reaches.

The Index of Biotic Integrity (IBI) in the spring of 1998 revealed values for each subwatershed that ranged from 20 (very poor) in the wooded stream reach, 22 (very poor) for the urban stream reach, 32 (poor) for both mixed and rural stream reaches, and 38 (poor/fair) in the agricultural stream reach. Ephemeroptera, Plecoptera, and Trichoptera (EPT) values also ranged from poor to fair. The rural stream reach was rated as fair and the other four stream reaches were rated as poor by EPT sampling. All water quality constituents were within EPA water quality standards, except fecal coliforms. The *in situ* water quality parameters were within the State of Tennessee standards for aquatic life.

Results from biotic indices and water quality constituents did not agree among the five subwatersheds since water quality standards were within EPA standards, except fecal coliforms, and the biotic indices were poor to poor/fair for stream health. This suggested that physical parameters were influencing the aquatic habitat. From the habitat analyses all of the subwatersheds were rated poor for homogenous substrate, channelization, and lack of vegetated riparian zones. It appeared that as development and human population increased, physical conditions and stream health were degraded. IBI scores generally improved with decreased development and population densities. The subwatershed with the least amount of anthropogenic activities was the agricultural subwatershed which scored the highest IBI (38), the lowest fecal coliform counts, and the best physical parameters. It was felt that the wider vegetated riparian zones in the agricultural steam reach reduced sediment entering the stream therefore providing better habitat than in the other subwatershed stream reaches.

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Chapter 1

Introduction

The Clean Water Act of 1977 explicitly mandated the maintenance of chemical, physical, and biological integrity of water resources in the United States (Angermeir and Schlosser, 1987). Concerns about degraded stream health have prompted much research on water quality. Most studies today recognize the need for an integrated approach of monitoring stream health. The complementary and reinforcing data from chemical, physical, and biological monitoring provide the most complete information for proper water management (Metcalfe, 1989). Water management today has few concerns with point source pollutants. This is attributed to the strict federal and state regulations that require monitoring of industrial, municipal, and agricultural point discharges into our waterways. Unfortunately, nonpoint source pollutants are not as easily detected, complicating the enforcement of regulations. In a 1984 report to Congress, the United States Environmental Protection Agency (EPA) concluded that nonpoint pollution was a leading cause of the nation's remaining water quality problems (Novotny and Chester, 1989). Much of the nation's nonpoint pollution is caused by anthropogenic activities on the land, with different land uses contributing different amounts of nonpoint pollutants.

Biological Monitoring

Biological monitoring serves as a survey of stream health. Resident biota in streams increase the likelihood of detecting episodic events (e.g., spills, dumping, treatment plant malfunctions), toxic nonpoint source pollution (e.g., agricultural pesticides), and cumulative pollution (i.e., multiple impacts over time or continuous low-level stress) (EPA, 1996).

Fish are a commonly used indicator species of water quality because they spend their entire life cycle in the water. Fish are long lived, easy to identify, and the public can easily relate to the presence or absence of fish. Also, fish integrate the effects of watershed degradation and are typically present in all but the most ephemeral or polluted aquatic habitats (Fausch et al., 1984). Knowledge of fish characteristics such as trophic guilds, desirable habitats, and pollution sensitivity has aided in the development of biological indices. For regional application, these indices have been modified, making the Index of Biological Integrity (IBI) a beneficial tool for assessing stream health.

Macroinvertebrates are also good indicators of the water quality in a stream for many reasons. There are numerous species, which are easily sampled, that indicate localized disturbances and that are highly sensitive to various pollutants. Three orders are well known indicator species for pollution sensitivity: Ephemoroptera, Plecoptera, and Trichoptera (EPT)

(Lenat, 1993). Many chemical, physical, and biological factors affect benthic macroinvertebrate distributions. Some of the physical factors influencing benthic macroinvertebrates are substrate type and complexity (Resh, 1977) and detritus quality and quantity (Hynes et al., 1974). Certain organisms may prefer specific food types and quantities and may be distributed accordingly (Schwenneker and Hellenthal, 1984). Land uses not only disturb food webs and substrate characteristics, but also influence the abundance and distribution of macroinvertebrates in response to land use activities. A study conducted by Hogg and Norris (1991) demonstrated a negative effect of runoff from land clearing and development on benthic macroinvertebrate numbers and on species richness in pool areas of a river.

Chemical Analysis

Biological monitoring should not replace chemical methods of testing water quality, but rather, should provide supplementary information. Since concentration and length of exposure (e.g., pesticide applications) control chemical toxicity, water chemistry methods are necessary to predict risk, particularly to human health and wildlife (EPA, 1996). Chemical analysis provides the most complete information for determining excessive levels of nutrients, inorganics, metals, and other toxic compounds introduced into streams.

Agricultural and urban runoff may cause a variety of water quality problems. Runoff from these land uses could cause enrichment in streams through the addition of nutrients and particulate organics (Lovejoy et al., 1997). In urban areas, high levels of organics may be contributed by sewage treatment plants while lawn and garden fertilizers contribute to elevate nutrient levels. In agricultural areas, the holding or grazing of livestock near streams may contribute to excessive organic loads. According to Puckett (1995), agricultural practices rank first in contributing nutrients into streams, often from commercial fertilizer applications. Agriculture accounts for 65% and 66%, respectively, of total national phosphorus and nitrogen discharges (Lovejoy et al., 1997). Pesticides from runoff events may also enter waterways, but the effects of these chemicals on water quality are not well understood. These unknown effects are from the use of more biodegradable compounds like organophosphates that are difficult to detect and have replaced chlorinated-hydrocarbon pesticides on agricultural lands (Lenat and Crawford, 1994).

All land disturbing activities may result in the addition of sediment to streams (Lenat and Crawford, 1994) and the debilitating effects of sediment on the invertebrate fauna of streams has been known for some time (Chutter, 1969). In turn, if sediment affects aquatic invertebrates, it also affects the survival of fish. The fish not only lose a major food source but also lose reproduction habitat. Fine sediment introduced into streams damages aquatic habitat by reducing oxygen transport in spawning gravels, by inhibiting the removal of waste, and by forming a barrier to emerging fry (Meehan, 1979). Land use activities resulting in sedimentation of aquatic systems are among the most serious and widespread of human impacts on the quality of running waters (Cordon and Kelley, 1961). Clear cutting and forest harvesting are controversial practices and many accusations are made on the effects from these activities. Examples of timber harvesting activities include building of roads, loss of vegetation that protects soils against erosion, and compaction of soil with heavy equipment (Binkley and Brown, 1993). A second contributor to sediment in streams is agricultural production; crop farmers till the earth making the soil loose and more susceptible to erosion from rainfall events. Also, cattle production may influence the introduction of sediment into streams, either by destroying stable banks as cattle enter and exit the water, or by compacting the soil and decreasing infiltration rates. Urban areas are also a concern; storm water runoff and its influence upon the erosion deposition characteristics within a receiving stream may modify the stream's physical habitat (Pedersen and Perkins, 1986). Perkins (1982) suggested that physical changes in the urban stream environment may be the principal factors in controlling the nature of the stream biota. Physical changes in the urban stream environment that negatively influence stream biota are urban development and road construction. Urban development and road construction activities can deliver large amounts of sediment into a stream over a short period of time causing degradation to aquatic habitat and a loss of species diversity.

Other water quality criteria for determining the conditions for stream health are *in situ* water quality parameters. These include pH, water temperature, electrical conductivity, and dissolved oxygen (DO). Aquatic organisms have different levels of response to each of these. Most pollution tolerant fish species can survive in water with dissolved oxygen as low as 3.0 mg/L, but these low oxygen levels are stressful to the fish. To maintain reproduction and healthy fish, DO levels of greater than 5.0 mg/L are desirable (L. Wilson, personal communication, University of Tennessee, March,1999).

Physical Parameters

Data collected from physical monitoring of a stream are complementary to the biological and chemical parameters. The physical parameters provide information about the conditions of the biotic habitat. Biotic habitat sampling is used to document information about the quality and quantity of habitat available for fish and macroinvertebrates (Simanson et al., 1994). In turn, the land use activities around streams affect the habitat quality and quantity available to biota.

Due to growing populations and a demand for more land, stream buffer zones are being destroyed. This allows more runoff to reach the streams more quickly. The lack of riparian buffer zones comes from the farmer needing more land for cattle to graze, or to plant crops. Also, urban areas are expanding and encroaching on the rural areas causing a need for more residential housing, resulting in a loss of vegetation and buffer strips along streams. The sediment from urban development and road construction, once in the stream, can have direct effects on the aquatic organisms, or on the organisms' habitat.

There are few studies comparing land use impacts on water quality and biotic health in the same watershed. This study was designed to provide comparisons of biological and chemical water quality constituents for different land uses in the Sweetwater Creek watershed. As the research progressed, physical parameters were incorporated into the study to help explain the condition of available stream habitat for the biota. The first objective of this study was to use physical, chemical, and biological components to compare the impacts of different land uses on stream health. The second objective was to determine if chemical and biological results are related to each other within the different land uses. The results from these data will be used as a baseline to evaluate the stream health in different reaches of Sweetwater Creek.

Chapter 2

Site Description

The Sweetwater Creek watershed was the site of this investigation into the relationship between land use and water quality. This watershed is a 61.9 km^2 (23.9 mi^2) part of the larger Sweetwater Hydrological Unit (HU), which drains 161 km^2 (62.0 mi^2) into the lower Tennessee River (Figure 1). The watershed has previously been used in a study of land use impacts on chemical water quality; the subwatersheds used in this work were identical to those used in the previous study. Each of the five subwatersheds were characterized by a different land use pattern, with wooded, urban, mixed, agricultural and rural land use patterns represented.

All of the subwatersheds, except the wooded, are located along the main drainage of Sweetwater Creek. The wooded subwatershed is located on a small tributary to the main stem of Sweetwater Creek (Figure 1). The urban subwatershed is located at the downstream edge of the city of Sweetwater (Figure 1). The mixed subwatershed sampling site is located south of the city of Sweetwater at the upstream edge of the city (Figure 1). The agricultural subwatershed is also on the main stem of Sweetwater Creek and is in series with the mixed and urban subwatersheds. The rural subwatershed is located adjacent to the agricultural subwatershed and the tributary from the rural subwatershed enters the main stem of Sweetwater Creek approximately 30 m (100 ft) above the agricultural sampling site. These two subwatersheds make up the headwater drainage area for the Sweetwater watershed (Figure 2). An impoundment is located on the main stem of Sweetwater Creek in the rural subwatershed. It is privately owned and is used for recreation. A second impoundment is located in the agricultural subwatershed but it does not hold water.

Wooded Subwatershed

The wooded subwatershed consists of 2.0 km^2 (0.75 mi^2) that is 3% of the total Sweetwater Creek project drainage area making it the smallest of the five drainage areas. It is a spring-fed tributary to Sweetwater Creek and was the only sampling site not on Sweetwater Creek. The ground cover in the subwatershed consists of loblolly pines (*Pinus taeda)*, fescue (*Festuca sp.)*, and multiflora rose (*Rosa multiflora)*. Stream flow is slow, supporting no riffles, only small pools and glides. The average flow rate is 0.1 m^3/s (4.3 ft^3/s) (Richard Roy, former Research Associate, University of Tennessee, 1998). Stream width varies from 0.9 - 1.8 m (3-6 ft) and the stream length is relatively straight, with a few bends. The bottom substrate is

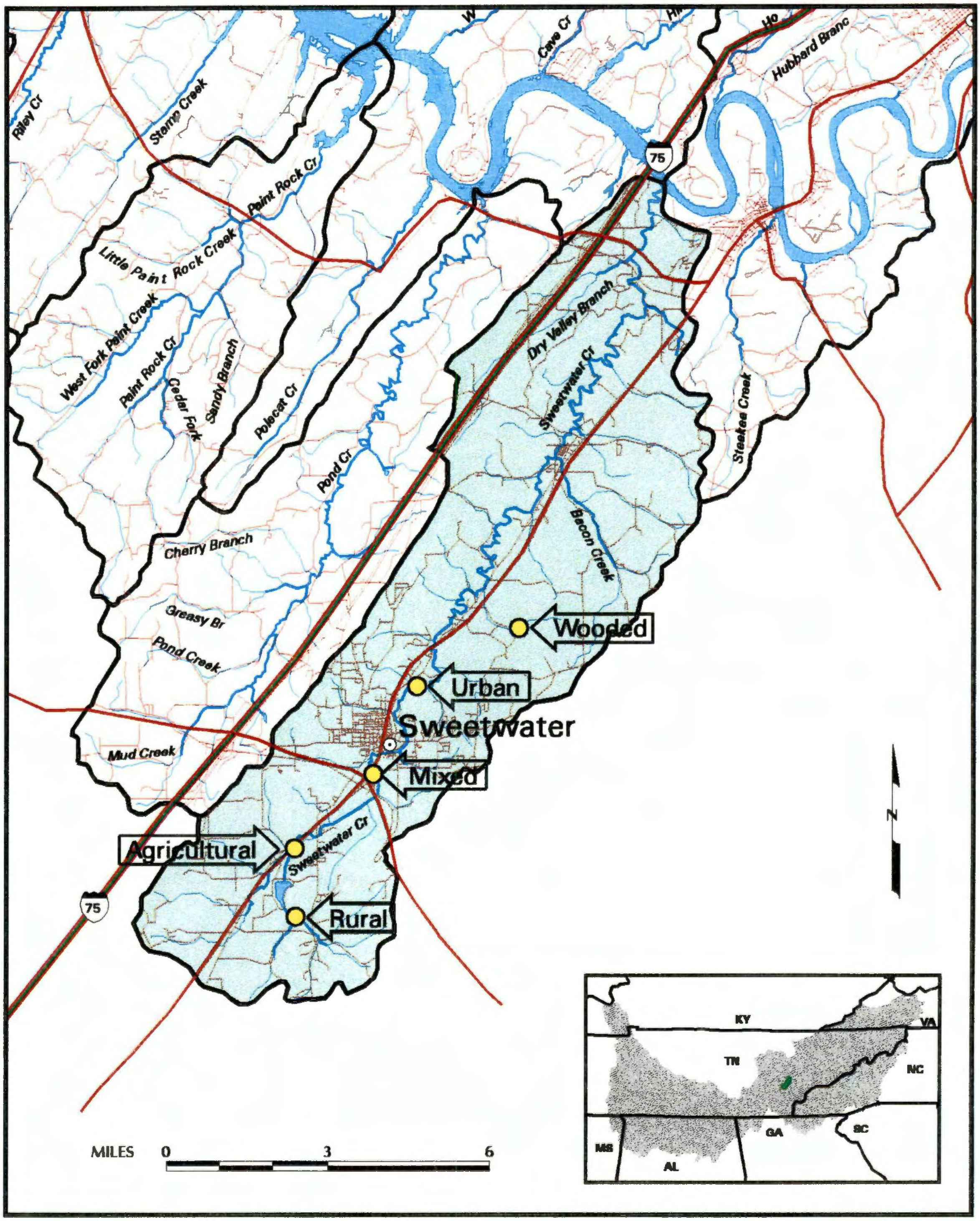


Figure 1. Map showing location of the Sweetwater Creek Watershed and subwatershed sample sites.

Figure 2. Map showing Sweetwater Creek watershed divided into five subwatersheds by land use.

dominated by sand with few to no pebbles. The banks are vegetated, but toe erosion is undercutting banks. Eight to nine-year old pines planted by Bowater Land Management are approximately 15 m (50 ft) from the stream banks. The area between the pines and the stream banks consists of thick fescue and multiflora rose. Since Bowater Land Management harvests the forest and herbicides are used, no trees are planted within 15 m (50 ft) of the tributary. However, the drainage area is dominated by loblolly pines. The sampling site for the wooded land use begins approximately 1.8 km (1.1 miles) from the confluence of the tributary with Sweetwater Creek.

Urban Subwatershed

The watershed drainage area of the urban subwatershed is 60.0 km^2 (23.0 mi^2). Approximately 16.0 km^2 (6.0 mi^2) or 26% of the urban subwatershed is comprised of impervious structures and manicured grass lots. A frequently used railroad track runs along the stream adjacent to the sampling site. This drainage area receives impacts from the municipal sewage treatment plant, the Farmer's Co-op, a hosiery factory, and Langdale Forest Products Corporation. Langdale is a wood treatment facility producing products for several uses, including telephone poles and structural timbers. The town has historically been home to several industries. The urban area receives the largest amount of stream flow of any of the sampling sites. Average stream velocity is slow with some riffles and shallow pools. The stream meanders through the urbanized area of Sweetwater, but in some places has been channelized to prevent flooding. Stream velocity increases slightly in these channelized reaches. The average flow rate is 2.4 m^3/s (84.3 ft^3/s) (Richard Roy, former Research Associate, University of Tennessee, 1998). The stream substrate is sandy but scoured in many places, revealing a hard clay streambed. Areas of the stream reach show signs of degraded substrate and have vertical banks. Also, the lack of a sufficient riparian buffer zone and vegetated banks allows the shear stress of the water to cut away the stream banks.

Mixed Subwatershed

The mixed subwatershed is comprised of a combination of several land uses that are well distributed between urbanized, agricultural, rural, and forested areas. The mixed subwatershed area is 9.6 km^2 (3.7 mi^2) or 16% of the total Sweetwater Creek project drainage area. The sampling site was located just above the town of Sweetwater (Figure 1). The mixed watershed drains 44.0 km^2 (17 mi^2) from the sampling site to the headwaters of Sweetwater Creek watershed. The stream velocity is slow and the average flow rate is 0.8 m^3/s (29.0 ft^3/s) (Richard Roy, former research Associate, University of Tennessee, 1998). The stream flow in the mixed subwatershed may be influenced by Sweetwater City potable water withdrawal since it is located approximately 3 m (10 ft) above the sampling site. However, the flow is sufficient to support a few riffles and shallow pools. The stream substrate in this reach is mostly sand, but large rocks are found sparsely spaced. The banks appear to be more stable than the downstream urban reach and support a riparian zone, an average of 3.7 m (12 ft) wide.

Agricultural Subwatershed

The agricultural subwatershed supports mostly crop land and pasture for cattle. The agricultural subwatershed is 24.3 km^2 (9.4 mi^2) or 39% of the total Sweetwater Creek project drainage area. The drainage for the watershed is 34.4 km^2 (13.3 mi^2) since the rural subwatershed is also included in the watershed drainage (Figure 2). The average stream flow is 0.8 m^3/s (27.4 ft^3/s) (Richard Roy, former Research Associate, University of Tennessee, 1998), and the reach supports more riffles, runs, and shallow pools than the other four subwatershed reaches. The stream substrate is mostly sand with a few large rocks. The stream banks are stable, supporting a riparian zone averaging 2.4 m (8 ft) wide. The sampling site is located below the confluence with the tributary of the rural subwatershed (Figure 1). Also, upstream from the sample site is an impoundment that alters stream flow by providing storage that traps sediment due to the decrease in stream velocity.

Rural Subwatershed

The rural subwatershed consists mostly of single residential dwellings on small rural lots. The drainage area is 10.1 km^2 (3.9 mi^2) or 16% of the Sweetwater Creek project drainage area. Peak flow is 0.1 m^3/s (3.2 ft^3/s) (Richard Roy, former Research Associate, University of Tennessee, 1998). The stream is relatively straight and it supports few riffles and few pools. The stream is mostly a run contained by vertical banks with a single row of trees on each side. Pasture is adjacent to both stream banks and cattle have access to the stream.

Chapter 3

Methods

Site Selection

In the initial selection of sample site locations for the water chemistry analysis, efforts were made to account for cumulative land use effects from each subwatershed drainage area (Brian Staley, personal communication, University of Tennessee, 1998). To obtain assessments of cumulative effects of nonpoint and point source pollutants, sample sites were chosen near the lower reach of each subwatershed. In the site selection for biotic sampling, the reach for fish sampling began at the same point where water chemistry samples were taken and continued upstream until available habitats were depleted. Due to the edge effect, it was important to proceed upstream and sample all available habitats due to fish migrating up stream away from the disturbance created when entering the stream. If sampling efforts had not proceeded up stream to undisturbed habitat areas, the sampling effort may not have been representative of the sampling site. However, it was still possible for the fish to move from one subwatershed to the next subwatershed reach. The edge effect was not a concern in macroinvertebrate sampling because the macroinvertebrates do not migrate in response to disturbance as fish do. The macroinvertebrates were sampled in the riffle closest to the fish and water quality sampling sites.

Sampling Season

For fish, the most desirable sampling period is spring to summer (March-September). Therefore spring and early summer were chosen for sampling in this project. One fish sample was collected in June, 1998. Fall and winter sampling were avoided due to young of the year (YOY) fish complicating the identification of species. Also, young of the year (YOY) were omitted from sampling because they were not old enough to reflect the aquatic conditions (TVA, 1995). Since YOY tend to complicate sampling due to their small size and uncertainty of identification, these fish were not considered in the Index of Biotic Integrity (IBI) analysis. However, the YOY were noted during sampling to confirm reproduction in the stream reaches. A concern of sampling fish too early in the spring or too late in the fall is low water temperatures. When water temperatures are low, fish hide in thick underbrush and can be difficult to capture using electrofishing techniques (Charles Saylor, personal communication, TVA, March, 1999).

The optimum biological sampling season for macroinvertebrates corresponds to recruitment cycles of the invertebrates (Plafkin et al., 1989). The macroinvertebrates, during these cycles, are in a size range (later instars) that will be retained during sieving. Also, identification of the invertebrates is easier during later stages of development. Reproduction of aquatic insects occurs in spring and fall of the year, which makes spring (May) and early fall (September) the most desirable sampling times. Three samples were collected for this project; two were taken in October and one in May. The optimum sample month, September, was missed due to the starting date of the research project, but October is still within the optimum sampling period for aquatic macroinvertebrate.

Fish Sampling

Three habitat types in each stream reach were chosen for quantitative fish sampling: riffles, runs, and pools. The riffles and runs were sampled with a generator-powered backpack electrofishing unit and a 3.0-m (10-ft) seine. A 27.9 m^2 (300 ft^2) area was sampled. A seine was positioned 9.1 m (30 ft) downstream of the backpack shocker. The operator of the electrofishing unit sampled the width of the seine thoroughly until he/she reached the lead line of the seine. During the sampling effort, a person followed the electrofishing operator and assisted in capturing fish caught in rock crevices, brush piles, or those that may have drifted outside of the seine area. The majority of the fish that tried to escape the electric field fled downstream into the seine and those that were stunned drifted into the seine. When the probes of the shocker reached the lead line, the seine was lifted from the water. The fish species were sorted, the number of species were recorded, and anomalies were noted. One voucher of each specimen was kept and all others released. Dr. David Etnier, an ichthyologist at the University of Tennessee, clarified any uncertainty of species identification. The third fish habitat type, pools, was sampled by two people pulling the seine, also known as seine hauls. Again, the fish were counted by species. Efforts were made to make all sampling attempts consistent and to sample each habitat with the same effort. This was achieved by three sampling efforts in each habitat. If no new species were identified, the habitat was considered depleted.

Qualitative sampling was conducted in areas where a good representation of fish habitat existed along the stream banks but were not sampled in the quantitative samples. Due to the stream channel being too wide and seine width too narrow, the additional qualitative samples were needed to effectively sample all available fish habitats. This required two people, one to operate the backpack shocker and the other to dip the fish. The sampling period was five minutes and was conducted along the stream bank in areas that best represented fish habitat that characterized the subwatershed sampling reach.

In streams that were less than 1.5 m (5 ft) wide, the sampling technique consisted only of using the backpack shocker and a person sampling with a dip net. The dip net was 0.3 m (1 ft) wide so the sampling effort proceeded upstream until 27.9 m^2 (300 ft^2) were sampled. The number of fish collected for each effort was recorded by species and anomalies were noted.

Before any calculations could be made to determine the Index of Biotic Integrity, the fish species were separated and counted, trophic levels were determined, and anomalies were noted. The book *Fisheries of Tennessee* by Etnier and Starnes (1993) was used to determine which species were tolerant or intolerant to pollution and the trophic guilds of each fish species.

Index of Biotic Integrity

The standard for the Index of Biotic Integrity is an "excellent" fish community (Karr and Dudley, 1981) comparable to the best local situations without the influence of humans (Miller et al., 1988). Karr and Dudley (1981) described biotic integrity as "the ability to support and maintain a balanced, integrated, adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of natural habitat of the region." Today, the Index of Biotic Integrity is a widely used method for determining changes in stream health.

To evaluate ecological conditions the index is divided into three groups that consist of a total of 12 metrics, (Table 1). The three groups are species richness and composition, trophic composition, and fish abundance and condition. The scoring criteria for the metrics are divided into three categories; five, three, and one where: (5), is approximately the values expected at the site; (3), deviates; and (1), strongly deviates from the fish species expected to be present in the stream (Karr et al., 1986). The scores are totaled and assigned to a classification for the condition of the stream (Table 2). The maximum possible IBI score is 60 and the minimum score is 0 for no fish.

Benthic Macroinvertebrate Sampling

Aquatic insects were sampled using quantitative and qualitative sampling procedures. The quantitative method required the use of a 0.3-m (1-ft) Surber sampler to obtain benthic macroinvertebrate in riffles. Three Surber samples were taken in the same riffle within each subwatershed. An imaginary grid was placed over the riffle and by using a random numbers table a square in the grid was chosen. The Surber was placed in the plot and all substrate within the surber frame was removed to a depth of approximately 10–12 cm (4-5 in.). All of the larger substrate was washed individually in front of the net to remove aquatic organisms clinging to the surface. All of the contents were caught in a funnel shaped net attached to the Surber. The contents, including the detritus, were transferred into 946-ml (1-qt) collection jars containing a solution of 10 percent formalin. Each jar was labeled with date, subwatershed site, and Surber sample number. All 15 samples were brought back to the lab for separation. A 946-ml (1-qt) sample was subdivided several times depending on the size of the Surber collection. These subsamples were divided to prevent overloading of the white enamel picking pan. Each

Table 1. The twelve metrics used in calculating the Index of Biotic Integrity (modified from Karr et al., 1986).

Metric Number	Description
Species Composition	
Metric 1.	Number of native species
Metric 2.	Number of darter species
Metric 3.	Number of sunfish species(excluding *Micropterus* sp.)
Metric 4.	Number of sucker species
Metric 5.	Number of intolerant species
Metric 6.	Proportion of individuals as tolerant species
Trophic Composition	
Metric 7.	Proportion of individuals as omnivores
Metric 8.	Proportion of individuals as specialized insectivorous minnows and darters
Metric 9.	Proportion of individuals as piscivores
Fish Abundance and Condition	
Metric 10.	Catch rate
Metric 11.	Proportion of individuals as hybrids
Metric 12.	Proportion of individuals with disease, tumors, fin damage, and other anomalies.

Table 2. The Index of Biotic Integrity as defined by Karr et al. (1986).

Class	Attributes	IBI Range
Excellent	Comparable to the best situation without influence of man; all regionally expected species for the habitat and stream size, including the most tolerant forms, are present with full array of age and sex classes; balanced trophic structure.	58-60
Good	Species richness somewhat below expectations, especially due to loss of most intolerant forms; some species with less than optimal abundances or size distribution; trophic structure shows some sign of distress.	48-52
Fair	Signs of additional deterioration include fewer intolerant forms, more skewed trophic structure (e.g., increasing frequency of omnivores); older age classes of top predators may be rare.	40-44
Poor	Dominated by omnivores, pollution-tolerant forms, and habitat generalist; few top carnivores; growth rates and condition factors commonly depressed; hybrids and diseased fish often present.	28-35
Very Poor	Few fish present, mostly introduced or very tolerant forms; hybrids common; disease, parasites, fin damage, and other anomalies regular.	12-23
No Fish	Repetitive sampling fails to turn up any fish.	0

sample was subdivided several times depending on the size of the Surber collection. These subsamples were divided to prevent overloading of the white enamel picking pan. Each subsample was rinsed in tap water to remove sediment particles and formalin. The subsample was placed in a white enamel pan with 2.5 cm (1 in.) of water and the contents were spread evenly across the pan. The use of a lighted magnifying lens ensured the extraction of each benthic organism from the gravel, sand, leaves, and detritus. The organisms gathered from each Surber sample were placed in a vial labeled with the date, subwatershed sampling site, and Surber sample. The last step was to identify each organism to the taxonomic level of genera. Steve Fraley, a benthic taxonomist with Tennessee Valley Authority clarified any uncertainties of identification.

In addition to the quantitative samples, qualitative samples were also taken at the same time. The qualitative sampling method consisted of a kick net, forceps, and a white enamel pan. For the qualitative sampling, additional macroinvertebrate habitats were sampled. Riffles, root wads, vegetation, and sediment were sampled by kicking into the net. The contents were placed in a white enamel pan in small portions and the organisms were removed with forceps. All aquatic organisms collected were placed in a collection jar with 10 percent formalin. Submerged wood, leaf packs, and rocks were hand picked with forceps. The aquatic organisms were identified in the field since the level of identification was only to the family taxonomic level.

Benthic Macroinvertebrate Analysis

Qualitative collections were identified to the family taxonomic level. This was done in the field, unless uncertainty about a family identification arose. In addition to noting the family, different genera identified in the same family were also noted. The density of each family per m^2 was estimated; the family was considered rare if less than 10 specimens were found, common if the density was between 10 and 100, and abundant if the number of family specimens was greater than 100. The number of EPT taxa and families were summed and scored. The EPT score reflected the stream condition (Table 3).

The quantitative assessment consisted of identifying each aquatic organism to the genus taxonomic level. The average mean abundance per 0.3 m^2 of each genus collected was then calculated. Other calculated quantitative measurements were taxa diversity per 0.3 m^2, the total EPT taxa per 0.3 m^2, and the total number of organisms collected per 0.3 m^2. Three primary means were used to determine the impairment of the benthic community: (1) total number of (EPT); (2) total number of taxa; and (3) total number of pollution tolerant taxa.

Table 3. Benthic scoring system values as modified from Plafkin et al., (1989).

Condition	Total EPT Taxa	Total Taxa
Excellent (no Impact)	>21	>46
Good (Slight Impact)	15-21	31-46
Fair (Moderate Impact)	7-14	15-30
Poor (Severe Impact)	<7	<15

Habitat Assessment

Habitat evaluation was an important consideration when determining the integrity of the aquatic ecosystem. The first step was to determine which stream classification best fit Sweetwater Creek. The Sweetwater Creek watershed has a low to moderate gradient landscape with velocities rarely greater than 0.3 m/s (1 ft/s), except during storm events. The substrates of the creek are of fine sediment or infrequent aggregations of coarser (gravel or larger) sediment particles along stream reaches. The assessment of each subwatershed was evaluated using the "Habitat Assessment Field Data Sheet: Glide/Pool Prevalence", originally described by Plafkin et al., (1989). The habitat assessment was modified by the EPA (1991) to apply to wadeable glide and pool streams. These sheets were completed after fish were collected for each subwatershed. This provided an opportunity to become more familiar with each subwatershed in respect to bottom substrate, channel morphology, and bank stability. This information provided insight into which aquatic organisms should be present and possible anthropogenic impacts on the stream.

Habitat Analysis

The "Habitat Assessment Field Data Sheet: Glide/Pool Prevalence" used in this study consisted of 10 metrics considered to be significant in determining aquatic biological habitat (Table 4). Each metric was rated as either optimal, sub-optimal, marginal, or poor. The 10 metrics were described by conditions based on characteristics of the stream. Metrics 8 – 10 were divided into right and left banks, with each bank receiving a score. A total was obtained from each subwatershed and compared between different land uses by individual metrics as well as the total. The rating for each metric was analyzed individually to determine the areas of habitat weakness in each subwatershed.

Sediment Core Samples

Sediment samples were taken with a sediment core sampler in deposition areas at the end of a run or at the beginning of a pool area. One sample was taken in each subwatershed stream reach. The samples were placed in plastic bags and taken to the soils lab where wet sieve and

Table 4. The Habitat Assessment Field Data Sheet for glide/pool prevalence modified from Plafkin et al. (1989).

Condition/Parameter	**Condition**			
Habitat Parameters	Optimal 20 - 16	Sub-optimal 15 – 11	Marginal 10 – 6	Poor 5 - 0
1. Bottom substrate and available cover	Greater than 50% mix of snags, submerged logs, undercut banks, or other stable habitat & a stage to allow full colonization potential (i.e., logs not new fall and not transient).	30-50% mix of stable habitat, well-suited for full colonization potential; adequate habitat for maintenance of populations; presence of additional substrate in the form of new fall, but not prepared for colonization.	10-30% mix of stable habitat; habitat availability less than desirable; substrate frequently disturbed or removed.	Less than 10% stable habitat, lack of habitat is obvious; substrate unstable or lacking
2. Pool substrate	Mixture of substrate materials, with gravel and firm sand prevalent, root mats and submerged vegetation common.	Mixture of soft sand, mud, or clay; mud may be dominant, some root mats and submerged vegetation present.	All mud or clay or sand bottom; little or no root mat, no submerged vegetation.	Hard-pan clay or bedrock; no root mat or vegetation.
3. Pool variability	Even mix of large-shallow, large-deep, small-deep pools present.	Majority of pools large-deep; very few shallow.	Shallow pools much more prevalent than deep pools.	Majority of pools small-shallow or pools absent.

Table 4. (continued)

Condition/Parameter	**Condition**			
Habitat Parameters	Optimal 20 - 16	Sub-optimal 15 – 11	Marginal 10 – 6	Poor 5 - 0
4. Channel Alteration	Channelization or dredging absent or minimal; stream with normal, sinuous pattern.	Some channelization present, usually in areas of bridge abutments; evidence of past channelization, i.e., dredging may be present, but recent channelization is not present.	New embankments present on both banks; channelization may be extensive, usually in urban areas or drainage areas of agricultural lands; and >80% of stream reach channelized and disrupted.	Extensive channelization; banks shored with gabion or cement, heavily urbanized areas; instream habitat greatly altered or removed entirely.
5. Sediment deposition	Less than 20% of bottom affected; minor accumulation of fine and coarse material at snags and submerged vegetation; little or no enlargements of islands or point bars.	20-50% affected; moderate accumulation; substantial sediment movement only during major storm events, some new increase in bar formation.	50-80% affected; major deposition; pools shallow, heavily silted; embankments may be present on both banks; frequent and substantial sediment movement during storm events.	Channelized; mud, silt, and/or sand braided or nonbraided channels; pools almost absent due to deposition.
6. Channel sinuosity	The bends in the stream increase the stream length 3 to 4 times longer than if it was in a straight line.	The bends in the stream increase the stream length 2 to 3 times longer than if it was in a straight line.	The bends in the stream increase the stream length 2 to 1 times longer than if it was in a straight line.	Channel straight, waterway has been channelized for a long distance.
7. Channel flow	Water reaches base of both lower banks and minimal amount of channel substrate is exposed.	Water fills> 75% of the available channel or <25% of channel substrate is exposed.	Water fills 25 – 75% of the available channel and/or riffle substrates are mostly exposed.	Very little water in channel and mostly present as standing pools.

Table 4.(continued)

Condition/Parameter	**Condition**			
Habitat Parameters	Optimal 20 - 16	Sub-optimal 15 – 11	Marginal 10 – 6	Poor 5 - 0
8. Bank vegetation(LB) Bank vegetation (RB)	More than 90% of the stream bank surfaces covered by native vegetation, including trees, understory shrubs, or non-woody macrophytes; vegetative disruption minimal or not evident, almost all plants allowed to grow naturally.	70 – 90% of the stream bank surfaces covered by native vegetation, but one class of plants not well represented; disruption is evident but not affecting full plant growth potential to any great extent, more than one-half of the potential plant stubble height remaining.	50 – 70% of the stream bank covered by vegetation; disruption obvious; patches of bare soil or closely cropped vegetation common; less than one-half of the potential plant stubble height remaining.	Less than 50% of the stream bank surfaces covered by vegetation; disruption of the stream bank vegetation is very high; vegetation has been removed to 5.1 cm (2 in.) or less in average stubble height.
9. Bank stability (LB) Bank stability (RB)	Banks stable; evidence of erosion or bank failure absent or minimal; little potential for future problems. <5% of bank affected.	Moderately stable; infrequent, small areas of erosion mostly healed over; 5 – 30% of bank in reach of erosion.	Moderately unstable; 30 – 60% of bank in reach has areas of erosion; high erosion potential during floods.	Unstable; many eroded areas; "raw" areas frequent along straight sections and bends; obvious bank sloughing; 60 – 100% of bank has erosional scars.
10. Riparian vegetative zone (LB) Riparian vegetative zone (RB)	Width of riparian zone >18 meters; human activities (i.e., parking lots, roadbeds, clear-cuts, lawns, or crops) have not impacted zone.	Width of riparian zone 12 – 18 meters; human activities have impacted zone only minimally.	Width of riparian zone 6 – 12 meters; human activities have impacted a great deal.	Width of riparian zone <6 meters; little or no riparian vegetation due to human activities.

hydrometer analyses were conducted using methods 15-5 and 15-2.2 described in "Methods of Soil Analyses" (Klute, 1986).

Water quality constituents

The following methods for evaluating water quality are described in the "Standard Procedures For The Examination Of Water And Wastewater" by the American Public Health Association et al., (1992). The water samples were taken from grab samples that were processed and refrigerated within six hours of collection. The grab samples were collected weekly at each subwatershed sample site. For the analysis of ions such as NO_3, SO_4, and Cl, method 4110B - ion chromatography with chemical suppression of eluent conductivity was used. The machine used to analyze the ions was a Dionex, DX-100. The biological oxygen demand (BOD) method used was 5210 B – 5-Day BOD test. Total suspended solids were analyzed by following the 2540-D method; total suspended solids were dried at 103-105 °C.

The general *in situ* water quality parameters for aquatic life, pH, temperature, and electrical conductivity were all tested in low and high stream flows. These parameters were collected with the Oyster meter multiple sampler Model 341450; Waltham, MA. Dissolved oxygen (DO) readings were collected with a Hana dissolved oxygen meter Model HI 9142; Woonsocket, RI.

Chapter 4

Results and Discussion

The results from each subwatershed are reported and discussed by land use. In each section the biological and chemical data are reported first for comparison. Physical parameters are reported and discussed for insight into effects caused by each land use.

Wooded Subwatershed

This small watershed is forested, but the stand consists only of loblolly pines. This uniformity of only coniferous trees lacks many characteristics of a mixed deciduous forest, therefore eliminating this forested stand as an ideal control site. Also, the stream receives little benefit from the trees since the forest begins approximately 15.2 m (50 ft) from the stream banks. In an ideal forest setting mixed hardwoods along the stream banks provide an environment supporting non-impaired streams and are often used as reference sites (Lenat and Crawford, 1994). The streamside forest typically functions as a filter by removing sediment, but in this subwatershed the trees were too far removed from the stream to benefit the small tributary.

The biological data collected in this wooded subwatershed stream indicated poor biological conditions related to the IBI. Only two fish species were collected during sampling efforts and catch rates for these species were low, three fish per 27.9 m^2 (300 ft^2) (Table 5). Sampling efforts were consistent, but due to the small size of the stream the sampling reach consisted of three, 30.5-m (100-ft) stream reaches. The lower 15.2 m (50 ft) of the first reach produced all the fish collected, which contributed to an IBI score of 22, a stream health classification of "very poor" (Table 6). Other factors that contributed to the low stream rating were Metrics 1 through 6, species composition, all received scores of 1 indicating the fish collection strongly deviated from that expected in the stream. Also, Metrics 8-10 scored 1 and Metric 11, percent of lithophilic spawners, scored 3. The only metrics that received values expected at the site, a score of 5, were Metrics 7 and 12, dealing with trophic composition and fish abundance. However, there were concerns about the accuracy of the IBI rating for this subwatershed due to its small area. Many streams less than 3.0 km^2 (1.2 mi^2) are not factored into plots of total number of fish species as a function of watershed area (Fausch et al., 1984). Therefore, if the drainage area of a watershed is less than 3.0 km^2 (1.2 mi^2), the IBI metrics may not be good indicators of stream health. According to Charlie Saylor (personal communication, TVA, 1999) with the Tennessee Valley Authority assessment team, many habitat variables are introduced, or are lacking, in a small watershed, making it difficult to standardize the watershed to a set of metrics.

Table 5. Species collected from the wooded subwatershed, June 1, 1998.

Species Name	Count
Blacknose Dace / *Rhinichthys atratulus*	7
Creek Chub / *Semotilus atromaculatus*	1

Table 6. Analysis of the modified IBI for the wooded subwatershed, June 1, 1998.

Metrics	Scoring Criteria			Obs	Score
1. Number of native fish species	<5	5-9	>9	2	1
2. Number of riffle species	<2	2	>2	0	1
3. Number of pool species	<3	3-5	>5	1	1
4. Percent of 2 dominant species	>84.4%	68.7%-84.4%	<68.7%	100%	1
5. Number of headwater intolerant species	<2	2	>2	0	1
6. Percent tolerant species	>40.0%	20.0%-40.0%	<20.0%	50%	1
7. Percent omnivores & stonerollers	>50.0%	25.0%-50.0%	<25.0%	0%	5
8. Percent specialized insectivores	<10.9%	10.9%-21.8%	>21.8%	0%	1
9. Percent piscivores	<1.5%	1.5%-3.0%	>3.0%	0%	1
10. Catch rate per 27.9 m^2 (300 ft^2)	<35	35-69	>69	3	1
11. Percent lithophilic spawners	<25.0%	25.0%-50.0%	>50.0%	50%	3
12. Percent anomalies	>5.0%	2.0%-5.0%	<2.0%	0%	5
IBI Rating: Very Poor			IBI Score	22	

The benthic macroinvertebrate sampling in the wooded subwatershed was comprised of three sampling efforts, two fall samples and one spring sample. The fall samples consisted of qualitative and quantitative samples, but only quantitative samples were collected in the spring. The total number of organisms collected on October 11, 1997, was 242 (Table 7), with a mean abundance of 74.7 organisms per 0.3 m^2 (1 ft^2), 25 total taxa, and nine EPT taxa (Table 7). Pollution tolerant organisms comprised 15% of the total sample size. Only 6% of the organisms collected from the sample were pollution tolerant. All remaining organisms were categorized as "other", which made up 79% of the total sample size. The second fall sample was collected October 15, 1998. The total sample size was 169 organisms, which was 30% smaller than the previous fall sample. The mean abundance was 56.3 organisms per 0.3 m^2 (1 ft^2), 24 total taxa, and six EPT taxa (Table 7) were collected. The percent of pollution intolerant organisms was 9%, of pollution tolerant organisms was 30%, and all other organisms comprised 61% of the sample size (Figure 3).

The qualitative measures for the wooded subwatershed for October 11, 1997, gave an EPT taxa count of three, a rating of poor, and a total taxa score of 16 which was a rating of fair (Table 6). The elevated total taxa count was attributed to organisms that did not represent either the pollution tolerant organisms or the pollution intolerant organisms. Total EPT taxa for October 15, 1998, were three, the same as for the previous fall. The total taxa collected were 15, a stream rating of fair (Table 6).

The water quality constituents for the wooded land use had concentrations below EPA drinking water standards for all ions tested (EPA, 1994). The only water quality parameter that did not meet EPA standards was fecal coliforms, and they were compared to EPA recreational standards (Table 8). The average fecal coliform counts in the wooded subwatershed was 260 CFUs/100 mL. Other water quality constituents such as the total suspended solids (TSS) for this sample site were relatively high (780 mg/L) considering the size of the stream, but were within EPA standards. The increased sediment can probably be attributed to the forestry activities in the watershed. The last timber harvest occurred approximately 10 years ago (Ray Miles, personal communication, Bowater Land Management, 1998).

All *in situ* water quality parameters (Table 9) were within the fish and aquatic life criteria suggested by the State of Tennessee (TDEC, 1995). These parameters were collected during high and low flows to compare elevated or decreased values. Water temperatures in the wooded subwatershed were 16.3 °C during high flow and 17.5 °C during low flow. The dissolved oxygen was 8.1 mg/L during high and low flows which was sufficient to support fish and benthic reproduction and to provide a stress free environment for fish and benthics.

Table 7. Wooded subwatershed quantitative (mean number per m^2) and qualitative macroinvertebrate sample data for October 11, 1997; May 28, 1998; and October 15, 1998.

Taxa	October 11, 1997		May 28, 1998	October 15, 1998	
	Quant. / 0.3 m^2	Qual.	Quant. / 0.3 m^2	Quant. / 0.3 m^2	Qual.
Amphipoda:	0.0	X	0.3	2.3	X
Annelida:					
Oligochaeta	0.0	X	0.0	6.3	X
Coleoptera:					
Elmidae		X			X
Stenelmis sp.	0.0		0.0	0.0	
Optiservus sp.	0.3		0.3	0.0	
Decapoda:					
Cambaridae	8.7	X	0.3	0.0	X
Diptera:					
Chironomidae		X			X
Chironominae	10.0		0.7	6.33	
Orthocladinae	0.7		1.7	1.0	
Tanypodinae	1.0		1.0	0.7	
Tabanidae					
Tabanus sp.	0.0		0.0	1.0	
Tipulidae		X			
Hexatoma sp.	0.3		3.7	0.0	
Limnophila sp.	0.3		0.7	0.0	
Pseudolimnophila sp.	0.0		0.3	0.3	
Tipula sp.	0.3		0.0	1.3	
Ephemeroptera:					
Baetidae		X			X
Baetis sp.	0.3		0.3	0.3	
Heptageniidae					
Stenonema sp.	0.3		0.0	0.0	
Isonichidae					
Isonychia sp.	0.3		0.0	0.0	
Leptophlebiidae		X			
Paraleptophlebia sp.	1.7		0.0	1.7	
Gastropoda:					
Pleuroceridae	38.7	X	0.0	31.3	X
Heteroptera:					
Corixidae	0.0		0.0	0.0	X
Gerridae		X			X
Gerris sp.	0.3		0.0	0.0	
Veliidae	0.0	X	0.0	0.0	X
Isopoda:					
Asellidae	0.0	X	0.0	0.0	X
Odonata:					
Aeshnidae		X			X
Boyeria sp.	1.7		0.0	0.0	
Calopterygidae	0.0	X	0.0	0.0	X

Table 7. (continued)

Taxa	October 11, 1997		May 28, 1998	October 15, 1998	
	Quant. / 0.3 m^2	Qual.	Quant. / 0.3 m^2	Quant. / 0.3 m^2	Qual.
Pelecypoda:					
Corbiculidae		X			
Corbicula fluminea	6.7		0.0	0.3	
Plecoptera:					
Nemouridae					
Amphinemura sp.	0.0		1.0	0.0	
Perlidae					
Acroneuria sp.	0.0		0.7	0.0	
Trichoptera:					
Hydropsychidae		X			X
Cheumatopsyche sp.	0.7		0.0	0.0	
Diplectrona sp.	0.3		2.0	1.7	
Hydropsyche sp.	0.3		0.0	0.0	
Limnephillidae					
Pycnopsyche sp.	0.7		0.3	0.3	
Molannidae					X
Molanna sp.	0.0		0.0	0.7	
Psychomyiidae					
Psychomyia sp.	0.3		0.0	0.0	
Rhyacophilidae					
Rhyacophila sp.	0.0		0.0	0.3	

October 11, 1997		**May 28, 1998**		**October 15, 1998**	
Mean Abundance / 0.3 m^2	74.7	Mean Abundance / 0.3 m^2	13.3	Mean Abundance / 0.3 m^2	56.3
Total Sample Size	242	Total Sample Size	42	Total Sample Size	169
Total Taxa	25	Total Taxa	14	Total Taxa	24
Total EPT Taxa	9	Total EPT Taxa	5	Total EPT Taxa	6

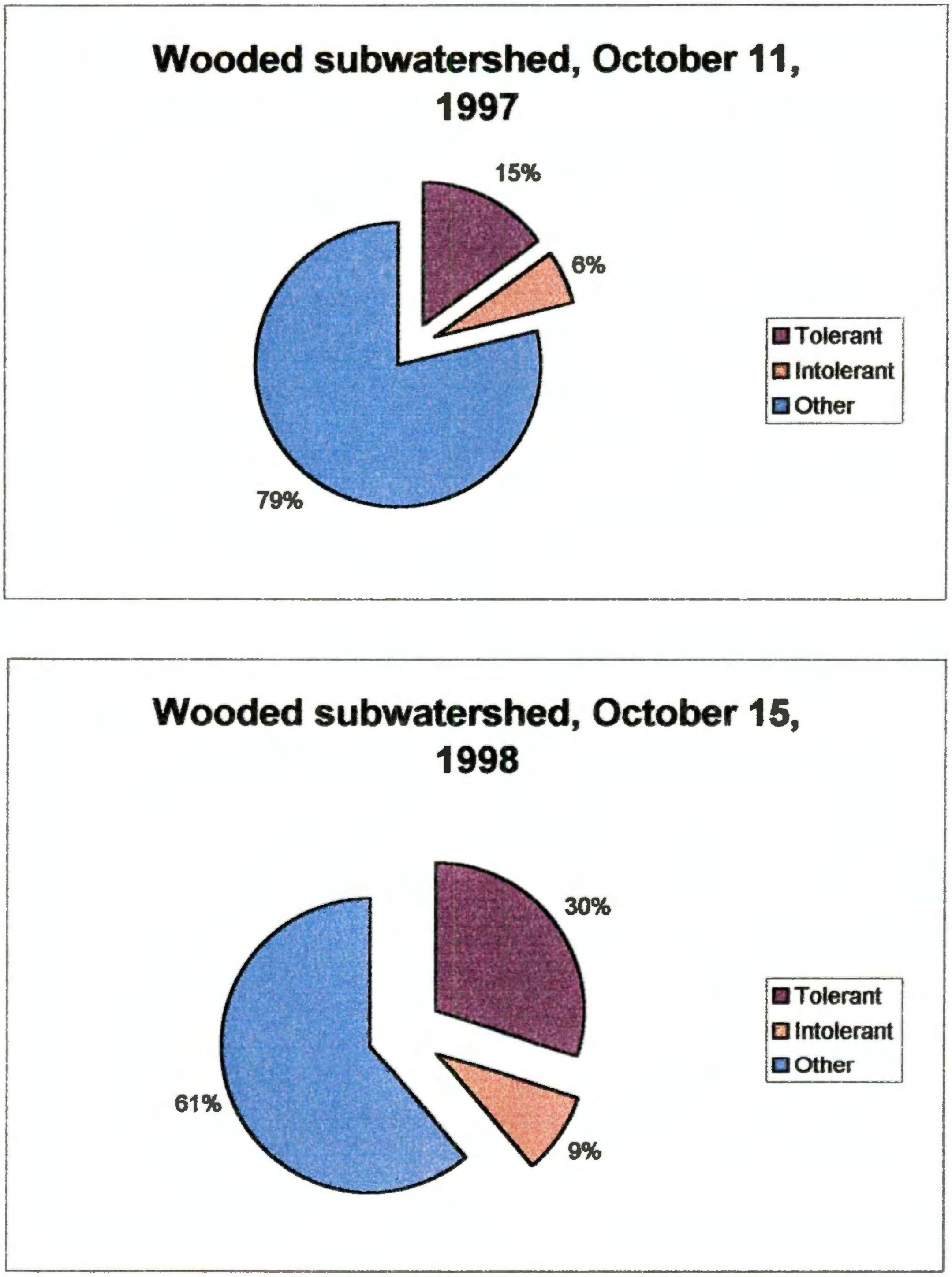


Figure 3. Percent of pollution tolerant compared to pollution intolerant, and other organisms for sampling in the wooded stream reach on October 11, 1997, and October 15, 1998.

Table 8. Water quality constituents for weekly grab samples at the wooded subwatershed sampling sites, April 17, 1997 to September 30, 1998.

	Cl (mg/L)	NO_3 (mg/L)	SO_4 (mg/L)	BOD_5 (mg/L)	TSS (mg/L)	NH_3 (mg/L)	TKN (mg/L)	Coliforms * (CFUs)	COD (mg/L)
Max.	6.0	4.2	10.5	6.0	6440.0	1.0	5.0	700	8.0
Min.	1.6	0.2	1.4	0.3	110.0	0.0	0.0	0	0.0
Avg.	2.8	0.7	2.9	2.3	800.0	0.3	2.2	260	1.5
Std. Dev.	0.8	0.5	1.5	1.5	1140.0	0.5	1.6	220	1.7
CV %	30.6	71.4	51.7	65.2	145.8	166.7	72.7	84.6	113.3

* Colony forming units per 100 mL

Table 9. General water quality results tested in situ for temperature (°C), pH, dissolved oxygen (mg/L), and conductivity (S/cm) for all subwatersheds.

Parameters	Wooded Subwatershed		Urban Subwatershed		Mixed Subwatershed		Agricultural Subwatershed		Rural Subwatershed	
	High flow 6/11/98	Low flow 8/31/98	High flow 6/11/98	Low flow 8/31/98	High flow 6/11/98	Low flow 8/31/98	High flow 6/11/98	Low flow 8/31/98	High flow 6/11/98	Low flow 8/31/98
Stage (m)	0.7	0.3	1.4	0.7	1.3	0.5	1.0	0.2	0.6	0.3
Flow m^3/s	0.4	0.1	5.0	1.4	2.0	0.1	1.7	0.5	0.2	0.1
Temperature (°C)	16.3	17.5	19.7	21.8	19.3	21.8	19.9	23.9	18.4	17.0
pH	7.5	7.6	7.2	7.9	6.8	7.3	7.2	8.3	7.1	7.3
DO (mg/L)	8.1	8.1	7.2	7.5	7.0	8.3	8.0	8.0	8.6	9.7
Electrical Conductivity (S/cm)	240	290	160	240	180	210	140	240	170	220

The habitat assessment score for the wooded subwatershed was 107 out of a possible total of 200 points. The habitat assessment value was reduced due to unstable bottom substrate, insufficient pool substrate characterization and variability, lack of channel sinuosity, and a narrow riparian vegetative zone. Since the stream substrate was evaluated as being homogeneous, a sediment core sample was taken at the lower end of a run to classify the substrate. The sediment core sample was taken where the run diffused into a pool since most depositional activity occurred as the water velocity slowed into a pool. Analyses of the core samples indicated 71% of the substrate consisted of sand, 20% of silt, and 9% of clay. During the habitat field evaluation no small pebbles or rocks were found in the stream.

Urban Subwatershed

Fish collected in the urban subwatershed were sampled by electroshocking in nine runs, seining in five pools, and electroshocking for the two qualitative samples. Riffle habitat for this watershed was severely lacking and only one riffle habitat was sampled. The low abundance and diversity of habitats resulted in a quick depletion of habitat areas to be sampled. Due to poor habitat availability, more than three samples were taken for the sampling effort. The highest catch rate per sampling effort was from the pool areas. This high catch rate was attributed to eight young of the year (YOY) skip-jack herring. However, the greatest species diversity was found in the runs. The 16 sampling efforts produced eight adult fish and ten YOY. Only four species, blue gill, stone roller, banded sculpin, and YOY skip-jack herring were collected in the urban subwatershed stream reach (Table 10).

Table 10. Species collected from the urban subwatershed, June 3, 1998.

Species Name	Count
Bluegill / *Lepomis macrochirus*	1
Central Stoneroller / *Campostoma anomalum*	3
Banded Sculpin / *Cottus carolinae*	1
Skip-jack Herring / *Alosa chrysochloris*	12 (YOY)

The IBI metrics and scoring criteria vary according to the watershed size, therefore the metrics and scoring criteria for the urban subwatershed differ from those of the wooded subwatershed due to the subwatershed drainage area. For Metrics 8 and 9, no scoring criteria were available since these metrics were calculated from other metrics. The IBI score for the urban subwatershed on June 3, 1998, was 20, a stream health value of "very poor" (Table 11). The poor IBI rating was attributed to metrics that strongly deviated from species expected to be present. The first group of metrics, species composition, received values of 1. Metric 2 showed the absence of darters, which are sensitive to degraded stream conditions. The low values of Metric 3 and 4 showed a lack of sunfish and sucker species, respectively. However, Metric 6 received a value of 5 for percent pollution intolerant species. The second group, trophic composition, also scored all 1's. Metric 8, a trophic composition metric, varies with the size of the stream, but the specialized insectivore abundance is inversely related to environmental degradation (Karr et al., 1986). The two metrics that make up the trophic composition metrics, Metric 8 and 9, tend to evaluate the shift toward a more generalized foraging population. Specialized insectivore and piscivores are not foraging generalists and have a specialized diet, so as degradation of their habitat increases, the insectivores and piscivores are eliminated from the stream (Plafkin et al., 1989). Since no specialized foraging fish in the wooded stream reach were collected, 1 was scored for both metrics. The last group of metrics, fish abundance, received a 5 since no hybrid fish were collected during the sampling effort. However, Metric 12 was low due to the number of individual specimens with black spot.

Table 11. Analysis of the modified IBI for the urban subwatershed, June 3, 1998

Metrics	Scoring Criteria			Obs	Score
1. Number of native fish species	<11	11-20	>20	4	1
2. Number of darter species	<2	4	>4	0	1
3. Number of sunfish species	<2	2	>2	1	1
4. Number of sucker species	<2	2	>2	0	1
5. Number of intolerant species	<2	2	>2	0	1
6. Percent tolerant species	>33.0%	16.5%-33.0%	<16.5%	0.0%	5
7. Percent omnivores & stonerollers	>39.5%	19.7%-39.5%	<19.7%	50.0%	1
8. Percent specialized insectivores				0.0%	1
9. Percent piscivores				0.0%	1
10. Catch rate per 27.9 m^2 (300 ft^2)	<21	21-43	>43	0	1
11. Percent hybrids	>1%	Tr.-1%	0%	0.0%	5
12. Percent anomalies	>5.0%	2.0%-5.0%	<2.0%	33.3%	1
IBI Rating: Very poor			IBI Score	20	

Benthic macroinvertebrate sampling in the urban subwatershed consisted of three sampling efforts, two in the fall and one in the spring. Sampling on October 11, 1997, yielded a mean abundance of 87.3 organisms per 0.3 m^2. A total of 262 specimens were collected; included in the total were 19 taxa and three EPT taxa (Table 12). For May 28, 1998, a lower

Table 12. Urban subwatershed quantitative (mean number per m^2) and qualitative macroinvertebrate sample data for October 11, 1997; May 28, 1998; and October 15, 1998.

Taxa	October 11, 1997		May 28, 1998	October 15, 1998	
	Quant. / 0.3 m^2	Qual.	Quant. / 0.3 m^2	Quant.	Qual. / 0.3 m^2
Amphipoda:	0.0	X	1.7	0.0	X
Anglidae					
Ferrisia sp.	0.0		0.7	6.3	
Annelida:					
Oligochaeta	0.0	X	3.3	3.7	X
Coleoptera:					
Chrysomelidae	0.0		0.3	0.0	
Elmidae		X			
Optiservus sp.	6.7		0.0	49.3	
Stenelmis sp.	0.0		4.0	2.0	
Psephenidae	0.0	X	0.0	0.0	
Decapoda:					
Cambaridae	0.3		1.7	0.0	X
Diptera:					
Chironomidae		X			X
Chironominae	0.3		2.0	2.0	
Orthocladinae	0.0		2.0	2.3	
Tanypodinae	2.7		0.7	0.3	
Simulidae	0.0	X	0.3	0.0	
Tipulidae		X			X
Anocha sp.	0.0		0.0	1.0	
Ephemeroptera:					
Baetidae		X			X
Baetis sp.1	0.0		0.0	0.3	
Baetis sp. 2	0.0		0.0	0.7	
Heptageniidae		X			X
Stenonema sp.	4.7		0.3	5.7	
Gastropoda:					
Pleuroceridae	20.3	X	0.0	51.7	X
Heteroptera:					
Corixidae	0.0	X	0.0	0.0	X
Gerridae					
Gerris sp.	0.3		0.0	0.0	
Veliidae	0.0		0.0	0.0	X
Isopoda:					
Asellidae	0.7	X	5.7	0.0	X
Odonata:					
Aeshnidae	0.0	X	0.0	0.0	X
Calopterygidae	0.0	X	0.0	0.0	X
Pelecypoda:					
Corbiculidae		X			X
Corbicula fluminea	47.3		0.0	67.0	

Table 12. (continued)

Taxa	October 11, 1997 Quant. / 0.3 m^2	October 11, 1997 Qual.	May 28, 1998 Quant. / 0.3 m^2	October 15, 1998 Quant. / 0.3 m^2	October 15, 1998 Qual.
Trichoptera:					
Hydropsychidae					X
Cheumatopsyche sp.	4.0		0.3	10.0	
Hydropsyche sp.	0.0		0.3	0.0	
Leptoceridae	0.0		0.0	0.0	X

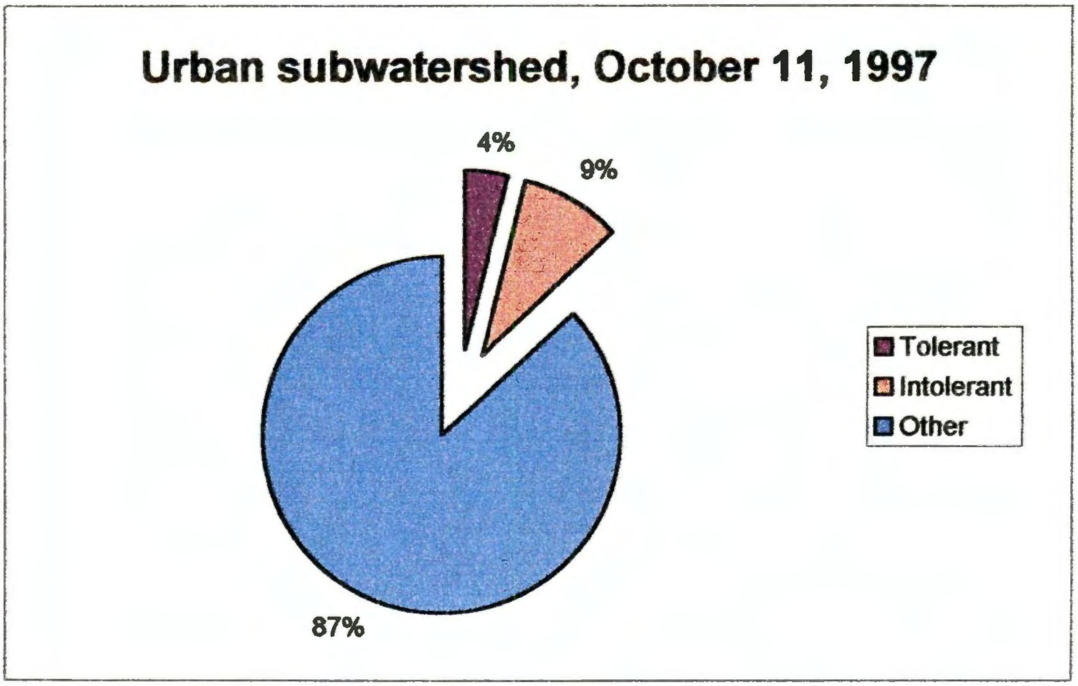
October 11, 1997		**May 28, 1998**		**October 15, 1998**	
Mean Abundance / 0.3 m^2	87.3	Mean Abundance / 0.3 m^2	24.3	Mean Abundance / 0.3 m^2	202.3
Total Sample Size	262	Total Sample Size	73	Total Sample Size	607
Total Taxa	19	Total Taxa	11	Total Taxa	22
Total EPT Taxa	3	Total EPT Taxa	3	Total EPT Taxa	5

mean abundance of 24.3 organisms per 0.3 m^2 was collected. The number of specimens collected was 73, total number of taxa was 11, and three EPT taxa were collected (Table 12). The last sample date was October 15, 1998, when a total of 607 organisms was collected. This was an increase of 2.3 times in the number of organisms collected when compared to the first fall sample taken in 1997. A mean abundance of 202.3 organisms per 0.3 m^2 was collected; included in this total were 22 taxa and five EPT taxa (Table 12). Even though the total number of organisms collected was 2.3 times greater for the fall sample in 1998, the diversity only increased by three taxa and the EPT increased by two when compared to the fall 1997 sample. The EPT taxa did make up for two of the three additional taxa diversity organisms. The increase in total specimens collected in the fall of 1998 was attributed to three taxa families, Corbiculidae, Pleuroceridae, and Elmidae. Corbiculidae, an introduced bivalve, and Pleuroceridae, a snail, were both pollution tolerant organisms. The fall sample of 1997 and the spring sample of 1998 produced the same aquatic families, but the mean abundance was not as great as in the fall 1998 sample. The percentage of pollution tolerant organisms and pollution intolerant organisms sampled October 11, 1997, was 4% and 9%, respectively. For October 15, 1998, the percentages were 4% pollution tolerant and 8% pollution intolerant organisms (Figure 4). A large percentage of organisms were Corbiculidae, Pleuricidae, and Elmidae for the fall samples of 1997 and 1998. These families are not referenced as pollution tolerant organisms but they are opportunists. Corbiculidae is an introduced species that has been very successful in colonizing streams in East Tennessee. If native mussels have been extirpated, Corbiculidae is usually the last species to be eradicated from the stream.

Analysis of the qualitative samples taken October 11, 1997, resulted in a low score of three EPT taxa and the same score was determined in the spring of 1998. The qualitative sample of fall 1998 only yielded two additional EPT organisms bringing the total to five. The taxa diversity for fall of 1997 and fall of 1998 scored fair (Table 12). However, this taxa diversity came from a diverse sample of pollution tolerant organisms, or from organisms not listed as pollution tolerant or intolerant. All three sample sites produced results reflecting poor stream health and a severely impacted stream.

Analysis of the fecal coliform for the urban subwatershed produced average fecal counts of 6230 CFUs/100 mL exceeding EPA recreational water quality standards (Table 13). The concentrations of average chloride at the urban site were 11.2 mg/L. Chloride, along with the average values for the other water quality constituents were within drinking water standards (EPA, 1994).

The *in situ* water quality parameters for high and low flows were all within the criteria for fish and aquatic life as suggested by the State of Tennessee (TDEC, 1995). The DO for the site



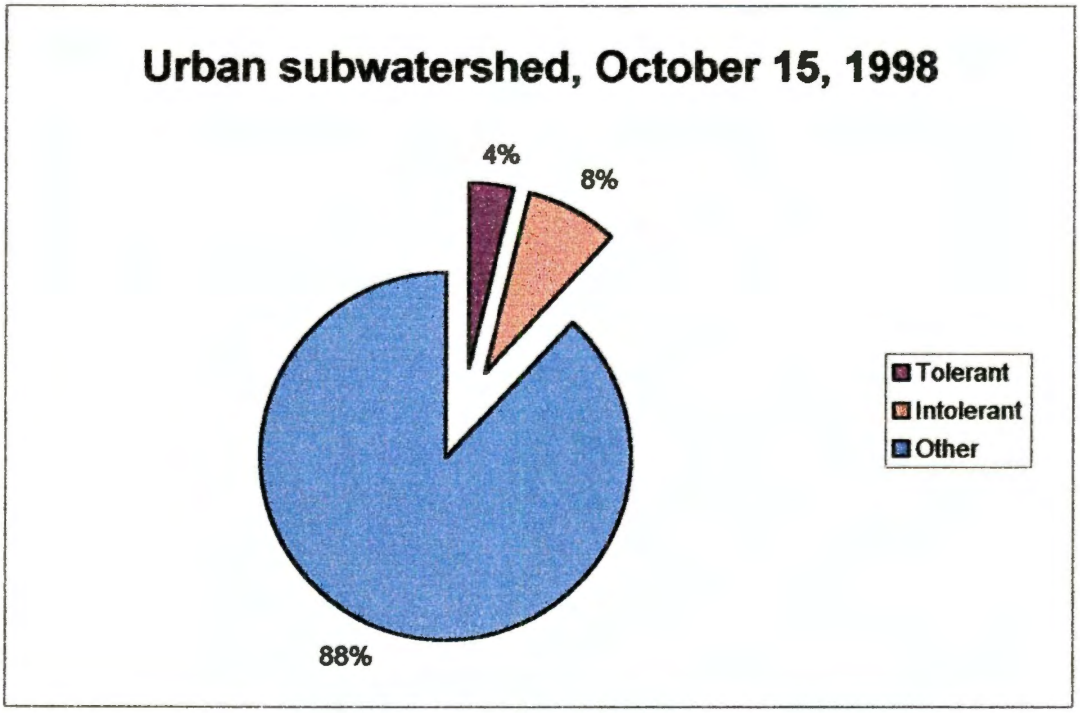


Figure 4. Percent of pollution tolerant compared to pollution intolerant, and other organisms for sampling in the urban stream reach on October 11, 1997, and October 15, 1998.

Table 13. Water quality constituents for weekly grab sample at the urban subwatershed sampling site, April 17, 1997 to September 30, 1998.

	Cl (mg/L)	NO_3 (mg/L)	SO_4 (mg/L)	BOD_5 (mg/L)	TSS (mg/L)	NH_3 (mg/L)	TKN (mg/L)	Coliforms * (CFUs)	COD (mg/L)
Max.	31.7	5.3	15.7	12.0	7700.0	1.2	11.0	13,000	19.0
Min.	3.5	0.2	1.5	1.9	270.0	0.0	0.0	0	0.0
Avg.	11.2	0.9	6.8	5.8	990.0	0.4	4.2	6200	8.8
Std. Dev.	6.6	0.7	2.8	2.9	1400.0	0.4	2.9	3500	5.8
CV %	58.9	76.9	41.2	50.0	142.0	100.0	69.0	56.5	65.8

*Colony forming units per 100 mL

was within acceptable limits of 7.2 mg/L at high flow and 7.5 mg/L at low flow (Table 9). Water temperature increased from 19.7 °C to 21.8 °C as expected during low flow in the summer months. The pH was 7.2 mg/L at high flow and 7.5 mg/L during low flow. All of these parameters were acceptable to support aquatic life.

The habitat assessment score for the urban subwatershed was 99 out of a possible 200 points. The habitat parameters showing the most degradation were bottom substrate, pool substrate, pool variability, channel alteration, channel sinuosity, and riparian vegetation. The lack of these habitat conditions reduced spawning, refuge, and food sources for aquatic organisms. The sediment core sample taken from this site contained 68% sand, 22% silt, and 10% clay. The substrate for this site was relatively homogenous; rocks and pebbles were scarce.

Mixed Subwatershed

The fish sampling for the mixed subwatershed consisted of 39 efforts. The only habitats sampled during electrofishing efforts were runs; no riffle habitats were available for sampling. The sampling efforts were comprised of 20 electrofishing efforts and 19 seine hauls. Fourteen species were collected and young of the year were noted (Table 14).

Table 14. Species collected from the mixed subwatershed, June 3, 1998.

Species Name	Count
Banded Sculpin / *Cottus carolinae*	14
Bluegill / *Lepomis macrochirus*	32
Bluntnose minnow / *Pimephales notatus*	1
Central Stoneroller / *Campostoma anomalum*	2
Common carp / *Cyprinus carpio*	3
Gizzard Shad / *Dorosoma cepedianum*	1
Golden redhorse / *Moxostoma erythrurum*	1
Green sunfish / *Lepomis cyanellus*	1
Largemouth bass / *Micropterus salmoides*	3
Northern hog sucker / *Hypentelium nigricans*	14
Snubnose darter / *Etheostoma simoterum*	1
Spotted sucker / *Minytrema melanops*	3
Striped shiner / *Luxilus chrysocephalus*	1
Western mosquitofish / *Gambushia affinis*	45

Metrics 8 and 9 were calculated based on subwatershed size and ecoregion as in the urban subwatershed. The IBI score for the mixed subwatershed was a 32, a stream health rating of poor (Table 15). Species composition scores were low (1) due to the lack of darter species collected; *Etheostoma simoterum* was the only darter collected. According to Charlie Saylor (aquatic biologist, TVA, 1999) this particular darter species is somewhat tolerant to pollution and has been collected in impacted streams. The lack of intolerant species also decreased the IBI score. Since a high percentage of the sample, 41.8%, was comprised of pollution tolerant species, Metric 6 received a low score. The trophic composition of the sample was the second weak area; the percent of specialized insectivores (0.8%) and piscivores (2.5%) each scored a 1. These two metrics, 8 and 9, were adjusted according to stream size and drainage area. The last penalty came from Metric 10, the catch rate per 27.9 m^2 (300 ft^2), eight different samples yielded

Table 15. Analysis of the modified IBI for the mixed subwatershed, June 3, 1998

Metrics	Scoring Criteria			Obs	Score
1. Number of native fish species	<10	10-18	>18	13	3
2. Number of darter species	<2	2-3	>3	1	1
3. Number of sunfish species	<2	2	>2	2	3
4. Number of sucker species	<2	2	>2	3	5
5. Number of intolerant species	<2	2	>2	0	1
6. Percent tolerant species	>34.4%	17.2%-34.4%	<17.2%	41.8%	1
7. Percent omnivores & stonerollers	>41.6%	20.8%-41.6%	<20.8%	6.6%	5
8. Percent specialized insectivores				0.8%	1
9. Percent piscivores				2.5%	1
10. Catch rate per 27.9 m^2 (300 ft^2)	<23	23-46	>46	3	1
11. Percent hybrids	>1%	Tr.-1%	0%	0.0%	5
12. Percent anomalies	>5.0%	2.0%-5.0%	<2.0%	1.6%	5
IBI Rating: Poor			IBI Score	32	

no fish. The metrics that scored the best were the number of sucker species (3), the percent of omnivores and stonerollers (6.6%), hybrids (0), and percent anomalies (1.6%). Also, three different sucker species were collected (Table 14). The low value for percent omnivores and stonerollers was considered good because omnivores and stonerollers are forage opportunists.

Table 16. Mixed subwatershed quantitative (mean number per square meter) and qualitative macroinvertebrate sample data for October 11, 1997; May 28, 1998; and October 15, 1998.

Taxa	October 11, 1997		May 28, 1998	October 15, 1998	
	Quant. / 0.3 m²	Qual.	Quant. / 0.3 m²	Quant. / 0.3 m²	Qual.
Amphipoda:					
Anglidae					X
Ferrisia sp.	34.0		0.7	2.3	
Annelida:					
Oligochaeta	0.0		1.7	2.7	
Planaridae	0.0		0.0	2.3	
Coleoptera:					
Elmidae		X			X
Stenelmis sp.	20.0		14.0	0.0	
Optiservus sp.	91.7		0.0	59.7	
Decapoda:					
Cambaridae	0.0	X	0.3	0.0	
Diptera:					
Chironomidae		X			X
Chironominae	3.3		4.0	1.7	
Orthocladinae	0.3		3.3	1.3	
Tanypodinae	0.0		1.0	0.0	
Simulidae	1.3	X	0.0	1.7	X
Tabanidae					
Tabanus sp.	0.3		0.0	0.0	
Tipulidae		X			
Hexatoma sp.	6.0		0.0	5.3	
Limnophila sp.	0.0		0.3	0.0	
Pseudolimnophila sp.	0.0		0.0	0.0	
Tipula sp.	1.0		0.0	0.3	X
Ephemeroptera:					
Baetidae		X			X
Baetis sp.1	0.0		0.0	7.7	
Baetis sp.2	19.0		7.3	2.3	
Heptageniidae		X			X
Stenonema sp.	15.7		0.3	27.0	
Isonichidae		X			X
Isonychia sp.	0.3		0.0	1.7	
Leptophlebiidae					
Paraleptophlebia sp.	0.0		0.0	0.0	
Gastropoda:					
Pleuroceridae		X			X
Elimia sp.	50.3		0.0	8.3	
Heteroptera:					
Corixidae					X
Gerridae					
Gerris sp.	0.7		0.0	0.0	

Table 16 (continued)

Taxa	October 11, 1997		May 28, 1998	October 15, 1998	
	Quant. 0.3 / m²	Qual.	Quant. 0.3 / m²	Quant. 0.3 / m²	Qual.
Isopoda:					
Asellidae	0.0	X	0.7	0.3	X
Megaloptera:					
Sialidae	0.0	X	0.0	0.0	
Odonata:					
Calopterygidae	0.0	X	0.0	0.0	X
Coenagrionidae	0.0		0.0	0.0	X
Pelecypoda:					
Corbiculidae					
Corbicula fluminea	27.3	X	6.3	4.7	X
Plecoptera:					
Nemouridae					
Amphinemura sp.	0.0		0.3	0.0	
Trichoptera:					
Hydropsychidae		X			X
Cheumatopsyche sp.	7.7		4.0	10.0	
Hydropsyche sp.	1.7		2.0	5.3	
Limnephillidae	0.0	X	0.0	0.0	
Philopotamidae					
Chimarra sp.	0.0		1.3	4.7	
Rhyacophilidae					
Rhyacophila sp.	0.7		0.0	0.0	

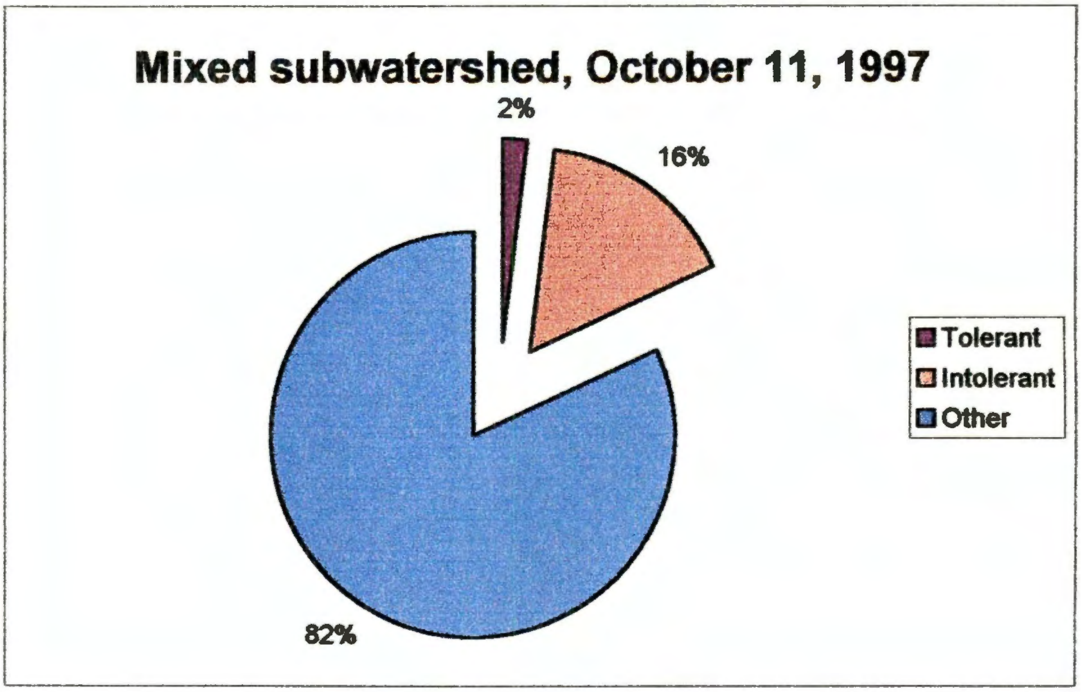
October 11, 1997		**May 28, 1998**		**October 15, 1998**	
Mean Abundance / 0.3 m²	281.7	Mean Abundance / 0.3 m²	47.7	Mean Abundance / 0.3 m²	137.0
Total Sample Size	845	Total Sample Size	143	Total Sample Size	411
Total Taxa	23	Total Taxa	16	Total Taxa	22
Total EPT Taxa	6	Total EPT Taxa	6	Total EPT Taxa	7

The benthic macroinvertebrate sampling in the mixed subwatershed consisted of three quantitative sampling efforts (Table 16). For the first sample on October 11, 1997, 845 benthic specimens were collected, comprised of 23 taxa and six EPT taxa. The mean abundance per 0.3 m^2 collected was 281.7 organisms. The spring sample collected on May 28, 1998, produced a mean abundance per 0.3 m^2 of 47.7 organisms. The total number of organisms collected was 143, taxa diversity was 16, and total EPT was six. The last sample was collected on October 5, 1998, yielding 411 organisms; included in this total were 22 taxa and seven EPT taxa. The mean abundance per 0.3 m^2 for the fall sample of 1998 was 137.0 organisms. The last sample, fall 1998, scored a fair for EPT taxa and taxa diversity collected. The percentage of pollution intolerant organisms was 42%, pollution tolerant organisms was 7% and the remaining percentage was made up of other organisms (Figure 5). The qualitative sampling results for the fall 1997 sample yielded a total of six EPT taxa and 23 taxa. In the fall of 1998, seven EPT taxa were collected with a total taxa diversity of 22. The score resulted in a ranking for stream health as fair, meaning the stream was moderately impacted (Table 3).

Average fecal coliform counts were 870 CFUs/100 mL, exceeding EPA water recreational standards of 200 CFUs/100 mL. All other water quality constituents analyzed for the mixed subwatershed were within EPA's drinking water standards (Table 17). The mixed subwatershed carried an average sediment load of 911 mg/L.

The *in situ* water quality parameters; water temperature, pH, DO, and conductivity were within the State of Tennessee fish and aquatic life criteria. These parameters were monitored at high and low flows with little variability (Table 9). The DO was 7.0 mg/L at high flow and 8.3 mg/L at low flow.

The habitat score for the mixed subwatershed was 132 of a possible 200. Factors lowering the score were pool substrates, no root mat, and submerged vegetation. Pool variability was marginal since the existing pools were shallow. The channel sinuosity of the mixed subwatershed was marginal since the bends in the stream only increased the stream length 2 to 1 times longer than if it were straight. Another suboptimal stream characteristic was bank stability with 5% – 30% of the bank reach eroded. Channel flow, bank vegetative protection, and available cover were all optimal stream characteristics in the mixed subwatershed. The sediment core sample taken from the site was comprised of 68% sand, 24% silt, and 8% clay. Approximately 20% – 50% of the stream reach was affected by sediment deposition. However, substantial sediment movement occurred, mostly during high storm events, and sediment was introduced to the stream from runoff and bank instability.



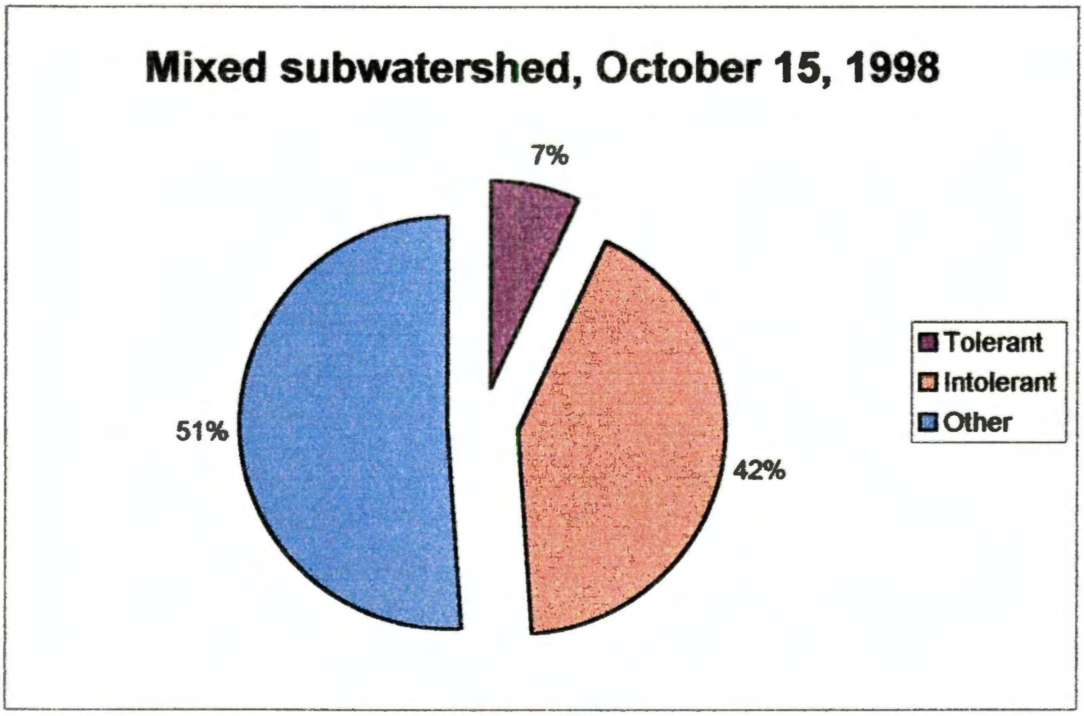


Figure 5. Percent of pollution tolerant compared to pollution intolerant, and other organisms for sampling in the mixed stream reach on October 11, 1997, and October 15, 1998.

Table 17. Water chemistry parameters for weekly grab samples at the mixed subwatershed sampling site, April 17, 1997 to September 30, 1998.

	Cl (mg/L)	NO_3 (mg/L)	SO_4 (mg/L)	BOD_5 (mg/L)	TSS (mg/L)	NH_3 (mg/L)	TKN (mg/L)	Coliforms * (CFUs)	COD (mg/L)
Max.	6.8	3.5	11.0	13.0	7500.0	1.0	9.0	1900	16.0
Min.	2.2	0.2	2.0	0.0	190.0	0.0	0.0	0	2.2
Avg.	3.9	0.7	3.8	5.1	900.0	0.4	3.5	870	6.6
Std. Dev	1.0	0.6	1.7	3.2	1450.0	0.4	2.4	540	5.1
CV %	25.6	85.7	44.7	62.7	159.0	100	68.6	62.0	77.3

*Colony forming units per 100 mL

Agricultural Subwatershed

Fish sampling in the agricultural subwatershed was comprised of nine electrofishing efforts, nine seine hauls, and two qualitative samples. All three habitat types were available for sampling, but not enough riffle habitats were available for depletion. Five riffles were sampled and four runs were sampled by electrofishing. The riffle habitats were the most productive, producing eight different species. Twelve species were collected from all sampling efforts (Table 18). After depletion, the seine was pulled up the stream channel; an *Alosa chrysochloris* (gizzard shad) and a live mussel were collected in the seine.

Table18. Species collected from the agricultural subwatershed, June 3, 1998.

Species Name	Count
Banded Sculpin / *Cottus carolinae*	80
Blacknose dace / *Rhinichthys atratulus*	3
Bluegill / *Lepomis macrochirus*	30
Central stoneroller / *Campostoma anomalum*	10
Creek chub / *Semotilus atromaculatus*	1
Flame chub / *Hemitremia flammea*	3
Golden redhorse / *Moxostoma erythrurum*	1
Green sunfish / *Lepomis cyanellus*	20
Largemouth bass / *Micropterus salmoides*	2
Northern hog sucker / *Hypentelium nigricans*	9
Snubnose darter / *Etheostoma simoterum*	27
Yellow bullhead / *Ameiurus natalis*	2

Metrics 8 and 9 of the agricultural subwatershed were calculated based on the subwatershed drainage area and ecoregion that were calculated from other metrics. The IBI score for the agricultural subwatershed was 38, a "poor/fair" rating for stream health (Table 19). A "poor/fair" rating occurs when a score falls between IBI ranges. The IBI range for a poor rating is 28 – 35 and for a fair rating is 40 – 44 (for an explanation of the attributes for each rating refer to Table 2). Species composition, Metric 2, lacked multiple darter species in the sample and received a score of 1. The only darter species found in the upper Sweetwater watershed during the 1998 sampling was *Etheostoma simoterum.* Also, the percentage of pollution tolerant organisms was considered to strongly deviate from the species that were expected in the stream. The second group of metrics, trophic composition, lacked specialized insectivores and piscivores and also received a score of 1. The last group, fish abundance and anomalies, scored 5 for

Table 19. Analysis of the modified IBI for the agricultural subwatershed, June 3, 1998

Metrics	Scoring Criteria			Obs	Score
1. Number of native fish species	<8	8-14	>14	12	3
2. Number of darter species	<2	2	>2	1	1
3. Number of sunfish species	<1	1	>1	2	5
4. Number of sucker species	<1	1	>1	2	5
5. Number of intolerant species	<2	2	>2	0	1
6. Percent tolerant species	37.1%	18.6%-37.1%	<187.6%	12.2%	5
7. Percent omnivores & stonerollers	>45.7%	22.8%-45.7%	<22.8%	6.4%	5
8. Percent specialized insectivores				14.4%	1
9. Percent piscivores				1.1%	1
10. Catch rate per 27.9 m^2 (300 ft^2)	<27	27-55	>55	10	1
11. Percent hybrids	>1%	Tr.-1%	0%	0.0%	5
12. Percent anomalies	>5.0%	2.0%-5.0%	<2.0%	0.0%	5
IBI Rating: Poor/Fair			IBI Score	38	

Metrics 11 and 12. None of the fish collected were hybrids nor were plagued with disease. The catch rate per 27.9 m^2 (300 ft^2) was 10, scoring a 1. For the number of sampling efforts, fish abundance was low.

Benthic macroinvertebrates sampled in the agricultural subwatershed did not score as well as the fish. Again, three samples were taken in the subwatershed. For October 11, 1997, a total of 279 organisms were collected with a mean abundance of 93. A total of 19 different taxa and four EPT organisms were collected (Table 20). A total of 106 organisms were collected May 22, 1998 at the agricultural subwatershed site. The mean abundance was 35.3; a total of 14 taxa and six EPT was collected. On October 15, 1998, a total of 668 organisms were collected; included in the total were 24 taxa and six EPT taxa. The sample yielded a mean abundance of 222 organisms per 0.3 m^2. The sample size collected in the fall of 1998 was 42% larger than was collected in the fall of 1997. The taxa diversity increased by five genera and the EPT increased by two genera. Despite a 42% increase in sample size, the proportion of added diversity and EPT diversity was trivial. Elmidae, Pleuroceridae, Corbiculidae, and Hydropsychidae dominated the mean abundance in the fall of 1997 sample; Hydropsychidae is a pollution intolerant organism. Elmidae, Chironomidae, Corbiculidae, and Hydropsychidae dominated the mean abundance for fall 1998 (Table 20). The percentage of pollution tolerant organisms collected in the fall of 1997 was 11%, and 15% of the species collected were pollution intolerant (Figure 6).

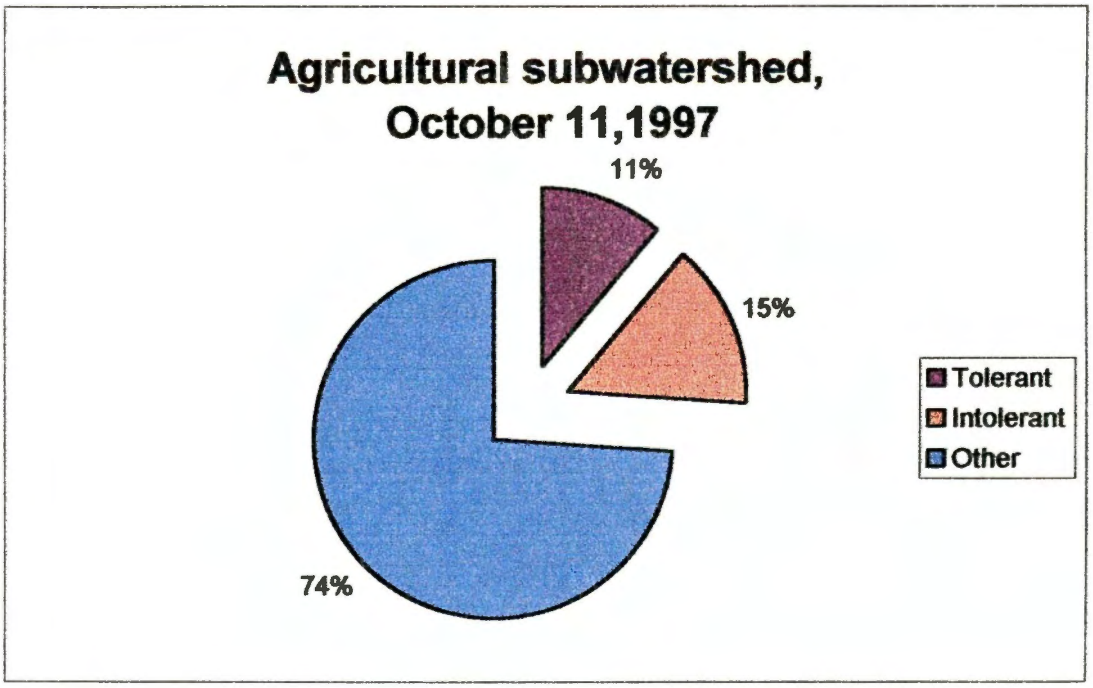
Table 20. Agricultural subwatershed quantitative (mean number per square meter) and qualitative macroinvertebrate sample data for October 11, 1997; May 28, 1998; and October 15, 1998.

Taxa	October 11, 1997		May 28, 1998	October 15, 1998	
	Quant. / 0.3 m^2	Qual.	Quant. / 0.3 m^2	Quant. / 0.3 m^2	Qual.
Amphipoda:	0.0		0.0	0.0	X
Anglidae		X			X
Ferrisia sp.	1.0		0.0	1.3	
Annelida:					
Oligochaeta	0.0	X	1.3	2.0	X
Coleoptera:					
Elmidae		X			X
Stenelmis sp.	11.0		9.7	16.0	
Optiservus sp.	22.0		0.0	1.0	
Decapoda:					
Cambaridae	0.0		0.7	0.0	X
Diptera:					
Chironomidae		X			X
Chironominae	1.7		4.0	18.0	
Orthocladinae	0.7		1.7	1.3	
Simulidae	9.0	X	1.0	10.0	X
Stratiomyidae					
Odontomyia sp.	0.0		0.3	0.0	
Tabanidae		X			
Tabanus sp.	0.0		0.0	0.0	
Tipulidae					X
Hexatoma sp.	0.0		0.0	1.0	
Tipula sp.	0.0		0.0	0.7	
Ephemeroptera:					
Baetidae		X			X
Baetis sp.1	2.0		2.0	4.3	
Baetis sp.2	0.0		0.0	0.3	
Heptageniidae		X			X
Stenonema sp.	0.0		0.0	0.3	
Gastropoda:					
Pleuroceridae		X			X
Elimia sp.	19.7		0.0	65.3	
Heteroptera:					
Gerridae	0.0	X	0.0	0.0	X
Veliidae		X			X
Rhagovelia sp.	0.0		0.0	0.7	
Isopoda:					
Asellidae	0.0	X	0.0	7.7	X
Odonata:					
Aeshnidae	0.0	X	0.0	0.0	X
Calopterygidae	0.0	X	0.0	0.0	X

Table 20. (continued)

Taxa	October 11, 1997		May 28, 1998	October 15, 1998	
	Quant. / 0.3 m^2	Qual.	Quant. / 0.3 m^2	Quant. / 0.3 m^2	Qual.
Pelecypoda:					
Corbiculidae		X			X
Corbicula fluminea	14.7		0.3	18.0	
Plecoptera:					
Nemouridae					
Amphinemura sp.	0.0		0.3	0.0	
Perlidae					
Perlesta sp.	0.0		0.3	0.0	
Trichoptera:					
Brachycentridae	0.0		0.0	0.0	X
Hydropsychidae		X			X
Cheumatopsyche sp.	9.7		8.7	7.7	
Hydropsyche sp.	1.7		4.7	67.0	
Psychomyiidae					
Psychomyia sp.	0.0		0.3	0.0	

October 11, 1997		**May 28, 1998**		**October 15, 1998**	
Mean Abundance / 0.3 m^2	93.0	Mean Abundance / 0.3 m^2	35.3	Mean Abundance / 0.3 m^2	222.7
Total Sample Size	279	Total Sample Size	106	Total Sample Size	668
Total Taxa	19	Total Taxa	14	Total Taxa	24
Total EPT Taxa	4	Total EPT Taxa	6	Total EPT Taxa	6



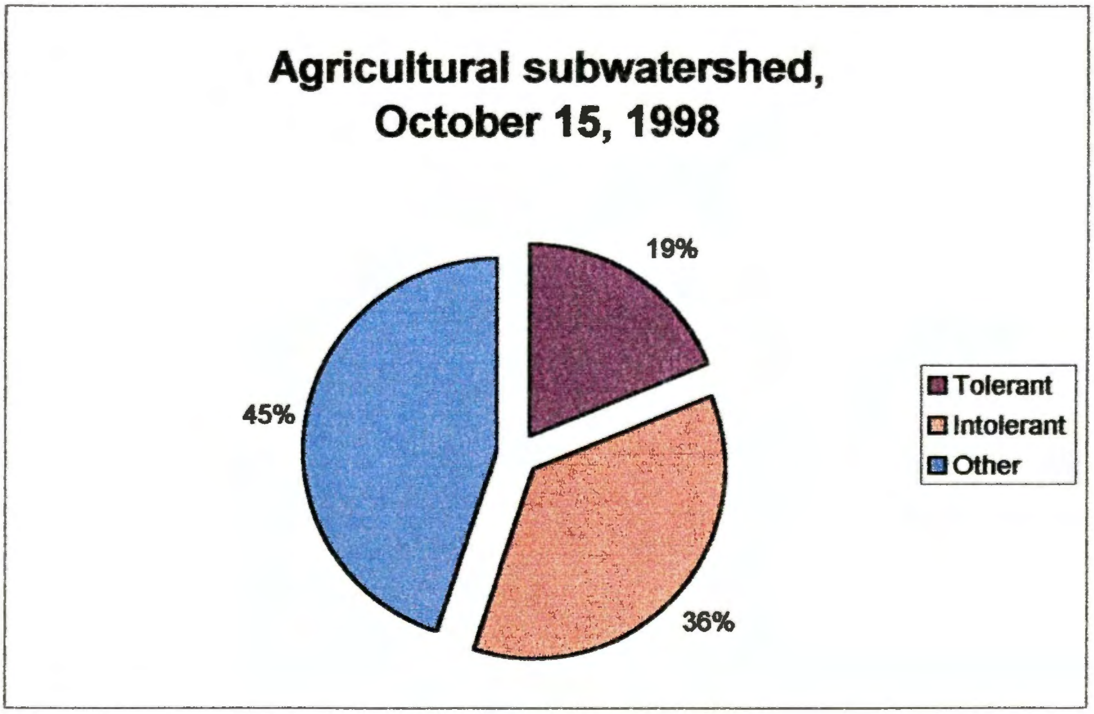


Figure 6. Percent of pollution tolerant compared to pollution intolerant, and other organisms for sampling in the agricultural stream reach on October 11, 1997, and October 15, 1998.

The remaining 74% were organisms that were not recognized for pollution sensitivity. Pollution tolerant organisms in the fall of 1998 comprised 19% of the total sample. Pollution intolerant organisms made up 36% of the total sample and 45% were other organisms. In both samples the percent of intolerant organisms exceeded the percentage of tolerant organisms. The pollution intolerant species were from three families, Baetidae, Heptageniidae, and Hydropsychidae, and from five genera.

Qualitative analysis for the fall sample of 1997 produced a stream health rating of poor. The total EPT collected in 1997 was four and the number of EPT taxa collected in the qualitative sample for fall 1998 was six. This was close to a rating of fair. If taxa diversity were taken into account, the overall score would give a stream health rating of fair, indicating the stream was moderately impacted. This rating correlated with the fish rating for 1998, both fish and benthics indicated the stream health was poor/fair. The majority of the taxa diversity for the agricultural subwatershed came from the qualitative analysis. A total of six organisms were added to the genera diversity in the fall of 1998. For the fall of 1997, eight additional genera were collected in the qualitative sample.

The water quality constituents for the agricultural subwatershed were within EPA drinking water standards with the exception of fecal coliforms (Table 21). The average for the total fecal coliforms was 300 CFUs/100 mL, which was not within EPA recreational water standards. Average concentrations of TSS were 500 mg/L, which was considered to be a relatively low concentratios compared to TSS found in other Tennessee Valley streams that often exceed 10,000 mg/L (Jack Tuberville, 1999,TVA biologist).

In situ water quality parameters for high and low flows met fish and other aquatic organisms criteria set by the State of Tennessee Water Quality Standards (TDEC, 1995) for aquatic life. Dissolved oxygen levels did not vary from 8.0 mg/L at low flow to high flow conditions. The largest fluctuation from high flow to low flow was for pH levels and conductivity. The pH ranged from 7.2 mg/L at high flow to 8.3 mg/L at low flow and conductivity at high flow was 140 S/cm and low flow was 240 S/cm. The pH was greater during low flow, possibly due to the dilution effect occurring at high flows.

The habitat assessment score for the agricultural subwatershed was 137 of a possible 200 points, the best of all the subwatersheds. The pool substrate and variability were rated as marginal. Channel sinuosity was also rated as marginal since the stream meandered very little. It appeared that landowners channelized the stream to prevent the stream from moving across their pastures or crop fields. The only habitat parameter with optimal conditions was channel flow. All other measured parameters were suboptimal, (for a list of habitat parameters, refer to Table 4). The stream substrate particle size analysis revealed 71.4% of the substrate as sand, 20.5% as silt, and 8.9% as clay.

Table 21. Water chemistry parameters for weekly grab samples at the agricultural subwatershed sampling site, April 17, 1997 to September 30, 1998.

	Cl (mg/L)	NO_3 (mg/L)	SO_4 (mg/L)	BOD_5 (mg/L)	TSS (mg/L)	NH_3 (mg/L)	TKN (mg/L)	Coliforms * (CFUs)	COD (mg/L)
Max.	6.7	2.0	8.3	5.0	930.0	1.0	8.0	1200	15.0
Min.	1.0	0.2	1.0	0.0	130.0	0.0	1.0	100	0.0
Avg.	3.3	0.5	3.0	1.8	500.0	0.4	3.0	300	5.6
Std. Dev.	0.7	0.3	1.2	1.2	200.0	0.4	2.0	350	5.0
CV %	21.2	60.0	40.0	66.7	40.4	100	66.7	120	89.3

* Colony forming units per 100 mL

Rural Subwatershed

Fish sampling in the rural subwatershed consisted of five efforts. Since the width of the stream averaged 0.9 m (3 ft), 30.4-m (100-ft) stream reaches were sampled. The sampling effort produced eight different fish species (Table 22). Young of the year *Micropterus salmoides* (largemouth bass) were collected but not used to calculate the metrics. This was because a stocked pond was upstream of the sampling efforts and the landowner had stocked the pond with largemouth bass. The bass probably escaped through the overflow valve.

Table 22. Species collected from the rural subwatershed, June 1, 1998.

Species Name	Counts
American brook lamprey / *Lampetra appendix*	5
Banded sculpin / *Cottus carolinae*	103
Blacknose dace / *Rhinichthys atratulus*	10
Bluegill / *Lepomis macrochirus*	73
Central stoneroller / *Campostoma anomalum*	16
Green sunfish / *Lepomis cyanellus*	10
Hybrid sunfish / Hybrid *Lepomis spp.*	1
Yellow bullhead / *Ameiurus natalis*	1

The IBI score for the rural subwatershed was 32, corresponding to a stream health rating of poor (Table 23). The stream was dominated by pollution tolerant and forage generalist fish. For the species composition, Metric 2 strongly deviated from the expected species numbers. This metric was an evaluation of riffle species and only one was collected. Metric 5 also strongly deviated from the diversity of headwater intolerant species expected in the subwatershed. Again, only one species was collected. Trophic composition, percent of specialized insectivores and piscivores, strongly deviated from the expected species in the subwatershed. The last group, fish abundance, rated poorly in the percent of lithophilic spawners; only 4.6% were lithophilic spawners. Of the 12 metrics, three received a rating of 5, the percent of tolerant organisms, the percent omnivores and stonerollers, and the percent diseased fish.

Benthic macroinvertebrate sampling in the rural subwatershed consisted of three samples. The samples were taken on October 11, 1997, May 28, 1998, and October 15, 1998 in the same riffle for each sampling effort. In the fall of 1997, there were 306 specimens collected with a mean abundance per 0.3 m^2 of 102.7 organisms. Taxon diversity was 25 and nine

Table 23. Analysis of the modified IBI for the rural subwatershed, June 3, 1998

Metrics	Scoring Criteria			Obs	Score
1. Number of native fish species	<5	5-9	>9	7	3
2. Number of riffle species	<2	2	>2	1	1
3. Number of pool species	<3	3-5	>5	4	3
4. Number of 2 dominant species	>84.4%	68.7%-84.4%	<68.7%	80.4%	3
5. Number of headwater intolerant species	<2	2	>2	1	1
6. Percent tolerant species	>40.0%	20.0%-40.0%	<20.0%	5.0%	5
7. Percent omnivores & stonerollers	>50.0%	25.0%-50.0%	<25.0%	7.8%	5
8. Percent specialized insectivores	<10.9%	10.9%-21.8%	>21.8%	0.0%	1
9. Percent piscivores	<1.5%	1.5%-3.0%	>3.0%	0.0%	1
10. Catch rate per 27.9 m^2 (300 ft^2)	<35	35-69	>69	66	3
11. Percent lithophilic spawners	<25.0%	25.0%-50.0%	>50.0%	4.6%	1
12. Percent anomalies	>5.0%	2.0%-5.0%	<2.0%	0.5%	5
IBI Rating: Poor			IBI Score	32	

EPT were collected. The percentage of pollution tolerant organisms was 19%, and 49% of the organisms collected were pollution intolerant (Figure 7). The fall sample of 1998 had a mean abundance of 519.7 organisms per 0.3 m^2 from a total of 1,559 specimens collected. The total taxa collected were 24 and 10 EPT taxa were collected. The percentage of pollution tolerant organisms was 4%, and 58% of the organisms were pollution intolerant. In both samples, pollution intolerant organisms dominated the sample. The sample collected in the fall of 1997 was comprised of 32 Hydropsychide per 0.3 m^2 and 15.3 Baetidae per 0.3 m^2 (Table 24). Chironomidae was the most abundant pollution tolerant organism in the sample, comprising 10.4% of the organisms collected. For the fall of 1998 sample, the mean abundance of Hydropsychidae was 341.0 organisms per 0.3 m^2. The pollution tolerant organisms Chironomidae made up 13.4% of the sample. The high abundance values indicated possible enrichment (Lenat and Crawford, 1994).

The qualitative collection for October 11, 1997, rated fair for stream health with a total of nine EPT taxa. The fall of 1998 sample also was rated as fair with a collection of 10 EPT taxa. The number of specimens collected from the fall of 1997 sample to fall of 1998 sample increased 196%.

The water quality constituents (Table 25) for the rural subwatershed were within EPA drinking water standards, except fecal coliform. The average fecal coliforms was 670 CFUs/100 mL and was not within EPA recreational standards. The average concentration of TSS in the

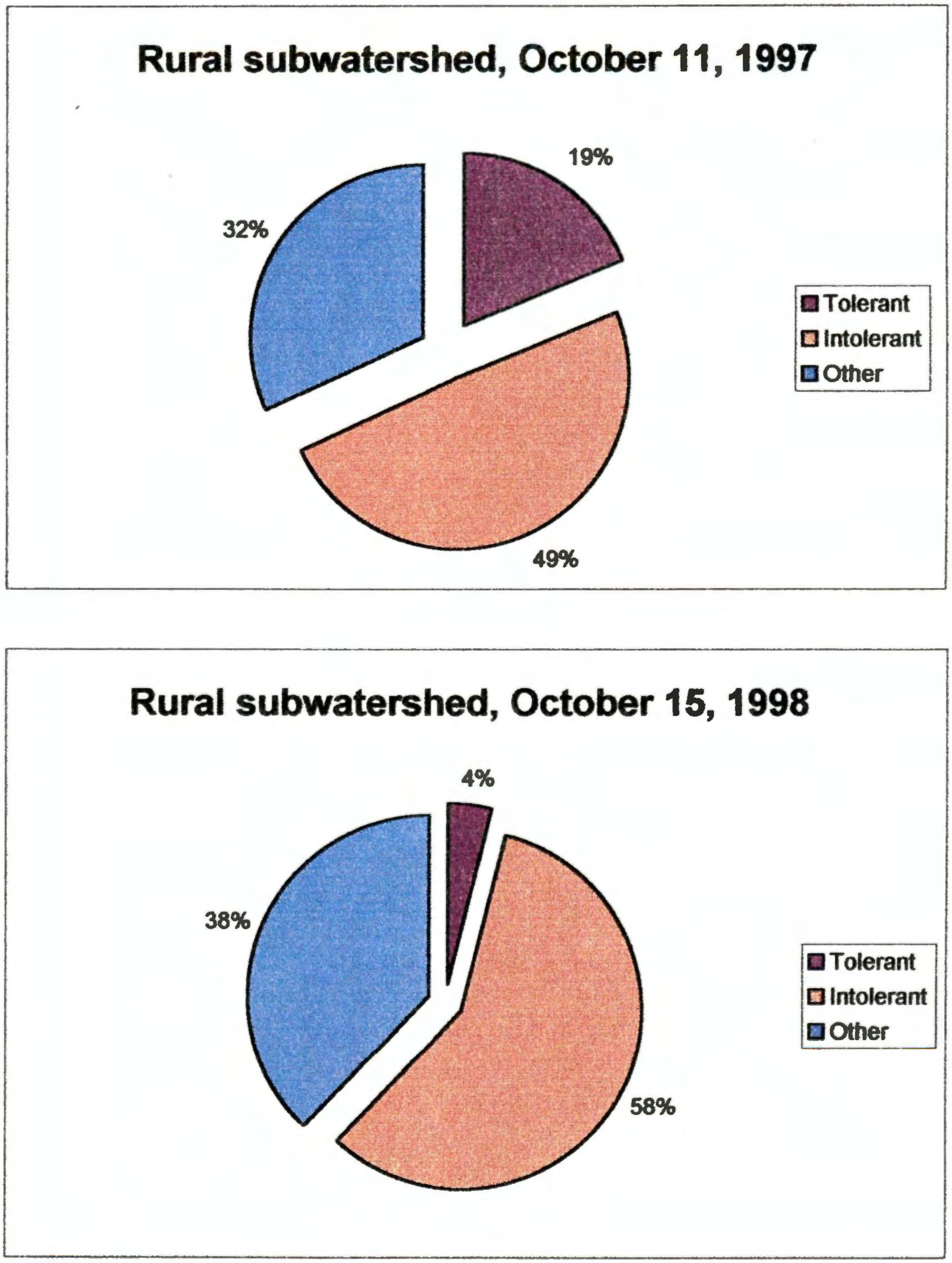


Figure 7. Percent of pollution tolerant compared to pollution intolerant, and other organisms for sampling in the rural stream reach on October 11, 1997, and October 15, 1998.

Table 24. Rural subwatershed quantitative (mean number per m^2) and qualitative macroinvertebrate sample data for October 11, 1997; May 28, 1998; and October 15, 1998.

Taxa	October 11, 1997		May 28, 1998	October 15, 1998	
	Quant. / 0.3 m^2	Qual.	Quant. / 0.3 m^2	Quant. / 0.3 m^2	Qual.
Amphipoda:	0.0		0.0	0.0	X
Annelida:					
Oligochaeta	0.0	X	0.7	4.7	X
Planaridae	0.0		0.0	0.3	
Coleoptera:					
Elmidae		X			X
Stenelmis sp.	1.3		51.7	8.7	
Optiservus sp.	9.3		0.0	119.3	
Decapoda:					
Cambaridae	1.3	X	0.7	0.0	X
Diptera:					
Athericidae					
Atherix sp.	0.3		0.0	0.0	
Chironomidae		X			X
Chironominae	8.7		3.3	4.7	
Orthocladinae	0.0		4.0	0.0	
Tanypodinae	1.7		1.7	8.7	
Simulidae	10.0	X	26.3	0.3	X
Tabanus sp.					
Tipulidae		X			X
Hexatoma sp.	0.7		1.3	0.3	
Tipula sp.	0.0		0.7	0.0	
Ephemeroptera:					
Baetidae		X			X
Baetis sp.1	13.3		2.3	5.3	
Baetis sp.2	2.0		0.0	1.0	
Ephemerellidae					X
Ephemerella sp.	0.0		4.7	0.0	
Heptageniidae					
Stenonema sp.	0.3		0.0	0.7	
Isonichidae					
Isonychia sp.	0.3		0.0	1.3	
Gastropoda:					
Pleuroceridae		X			X
Elimia sp.	19.7		0.0	22.3	

Table 24. (continued)

Taxa	October 11, 1997		May 28, 1998	October 15, 1998	
	Quant. 0.3 / m^2	Qual.	Quant. 0.3 / m^2	Quant. 0.3 / m^2	Qual.
Heteroptera:					
Gerridae		X			X
Gerris sp.	0.7		0.0	0.0	
Veliidae		X			X
Rhagovelia sp.	0.0		0.7	0.0	
Isopoda:					
Asellidae	1.3	X	0.0	0.0	X
Odonata:					
Aeshnidae	0.0	X	0.0	0.0	X
Calopterygidae	0.0	X	0.0	0.0	X
Pelecypoda:					
Corbiculidae		X			
Corbicula fluminea	0.3		0.0	0.0	
Plecoptera:					
Nemouridae					
Amphinemura sp.	0.0		2.3	0.0	
Perlidae					X
Perlesta sp.	0.0		0.3	0.0	
Trichoptera:					
Glossosomatidae		X			X
Glossosoma sp.	2.0		0.3	0.7	
Hydropsychidae		X			X
Cheumatopsyche sp.	26.7		22.0	291.3	
Diplectrona sp.	0.0		1.7	49.7	
Hydropsyche sp.	5.3		7.7	0.0	
Limnephillidae	0.0	X	0.0	0.0	X
Philopotamidae		X			
Chimarra sp.	0.3		0.0	0.0	

October 11, 1997		**May 28, 1998**		**October 15, 1998**	
Mean Abundance / 0.3 m^2	102.7	Mean Abundance / 0.3 m^2	132.0	Mean Abundance / 0.3 m^2	519.7
Total Sample Size	306	Total Sample Size	396	Total Sample Size	1,559
Total Taxa	25	Total Taxa	19	Total Taxa	24
Total EPT Taxa	9	Total EPT Taxa	8	Total EPT Taxa	10

Table 25. Water chemistry parameters for the weekly grab samples at the rural subwatershed sampling site, April 17, 1997 to September 30, 1998.

	Cl (mg/L)	NO_3 (mg/L)	SO_4 (mg/L)	BOD_5 (mg/L)	TSS (mg/L)	NH_3 (mg/L)	TKN (mg/L)	Coliforms * (CFUs)	COD (mg/L)
Max.	13.5	2.8	7.6	12.0	7200.0	1.0	9.0	1900	4.0
Min.	1.6	0.1	1.0	0.7	60.0	0.0	0.0	0	0.0
Avg.	2.8	0.5	2.3	4.9	800.0	0.3	3.7	670	5.1
Std. Dev.	1.4	0.4	1.1	2.9	1300.0	0.4	2.4	520	1.4
CV %	50.0	80.0	47.8	59.2	164.8	133.3	64.9	77.6	27.5

*Colony forming units per 100 mL

rural subwatershed was 798.0 mg/L which was relatively high for the small stream. This could be due to hobby farms and the lack of riparian zones. The riparian zones along the stream consisted of a single row of trees and pasture. The average fecal coliform count was 670 CFUs/100 mL. These elevated fecal counts could be from failing septic tanks leaching into the creek or from cattle not fenced out of the creek at the sample site.

The rural watershed *in situ* water quality parameters were within the state of Tennessee Water Quality Standards for fish and aquatic life (TDEC, 1995). The DO was 9.7 mg/L at low flow and 8.6 mg/L at high flow. A small cascade and the pond overflow may have increased the oxygenation in the water.

The habitat assessment for the rural stream reach was 119 of a possible 200 points. The habitat in the stream reach suffered from poor pool variability, marginal channel sinuosity, poor riparian vegetative zones, and channel alteration. Channel flow status was the only habitat parameter that was rated optimal. The sediment core sample revealed 9% of the stream substrate as sand, 62% as silt, and 29% as clay. The rural subwatershed substrate had the largest percentage of clay and silt. This sample area was in an area where the cattle have access to the stream. Excessive bank sloughing could have contributed to the silt loads.

Discussion of Results

Biological

Comparisons were made among subwatersheds in regards to stream health and biotic community structure within the sampled stream reaches. However, it should be noted that the IBI scoring criteria for the urban, mixed, and agricultural subwatersheds were different than for the smaller watershed drainage areas (wooded and rural). The wooded and rural subwatersheds were analyzed using the headwater IBI criteria since their drainage areas were less than 13.0 km^2 (5 mi^2). The remaining subwatersheds used metrics adjusted to analyze drainage areas larger than 13.0 km^2 (5 mi^2). This made the comparison of the metrics among the subwatersheds difficult, but the IBI score yielded subwatershed scores that were easily compared since the IBI scores represent overall stream health. An analysis of correlation was run comparing EPT and IBI results. The correlation gave a r^2 of 0.72, suggesting that 72% of the variability in the IBI can be explained by the EPT results.

Fish

The IBI scores indicated that the fish communities in all of the subwatersheds were poor, except for the agricultural subwatershed, which was poor/ fair (Figure 8). Although, the stream health was unacceptable in all subwatersheds, the best of the unacceptable was the agricultural subwatershed. The agricultural subwatershed stream reach was not as dominated by pollution tolerant fish (12.2%) as the mixed subwatershed (41.8%). Also, in the agricultural subwatershed, two sunfish species and two sucker species were collected. In the larger subwatersheds, two sunfish species and three sucker species were collected in the mixed subwatershed, and in the urban subwatershed one sunfish species and no sucker species were collected. The number of sunfish and sucker species either remained the same or decreased as the subwatershed drainage area increased. According to Fausch et al., (1984) as the watershed drainage area increases, the number of sunfish and sucker species should also increase. This indicated that the mixed and urban subwatersheds suffered from degraded stream conditions that reflected a decline in fish diversity.

Comparison of IBI metrics among the different stream reaches was difficult due to the differences in the drainage areas and this difficulty was magnified due to few species being collected. However, anomalies increased in a downstream direction. In the agricultural subwatershed 0.0% anomalies were recorded, but in the mixed subwatershed 1.6% anomalies were noted and in the urban subwatershed it increased to 33.3%. A high percentage of anomalies may frequently occur below point sources (e.g., sewage overflow, wastewater discharges), or where chronic inorganic and organic nutrients are concentrated in the stream (e.g., herbicides, fertilizer) (Holdeman, 1993). Percent of pollution tolerant species also increased in a downstream direction, which could be a cumulative effect. The rural subwatershed had the lowest percentage of pollution tolerant species of 5%, agricultural had 12.2%, mixed 41.8%, and urban 0%. The urban subwatershed had 0% pollution tolerant fish because of a low catch rate, a total of five fish were collected. The fish collected were not considered to be pollution tolerant or pollution intolerant fish.

The stream health in the rural and wooded subwatersheds was poor, but the wooded IBI score was 22, whereas the rural subwatershed was 32. Even though the rural and wooded subwatersheds had poor stream health their IBI's were quite different. The catch rate for the rural subwatershed was 66 fish per 27.9 m^2 (300 ft^2) and the wooded subwatershed was 3 fish per 27.9 m^2 (300 ft^2). This could indicate that fish avoided the tributary due to poor conditions, or the conditions in the main stem at the confluence of the tributary and Sweetwater Creek were poor, causing fish to avoid that stream reach. Only two fish species were collected in the wooded subwatershed and eight were collected in the rural subwatershed. Pollution tolerant fish

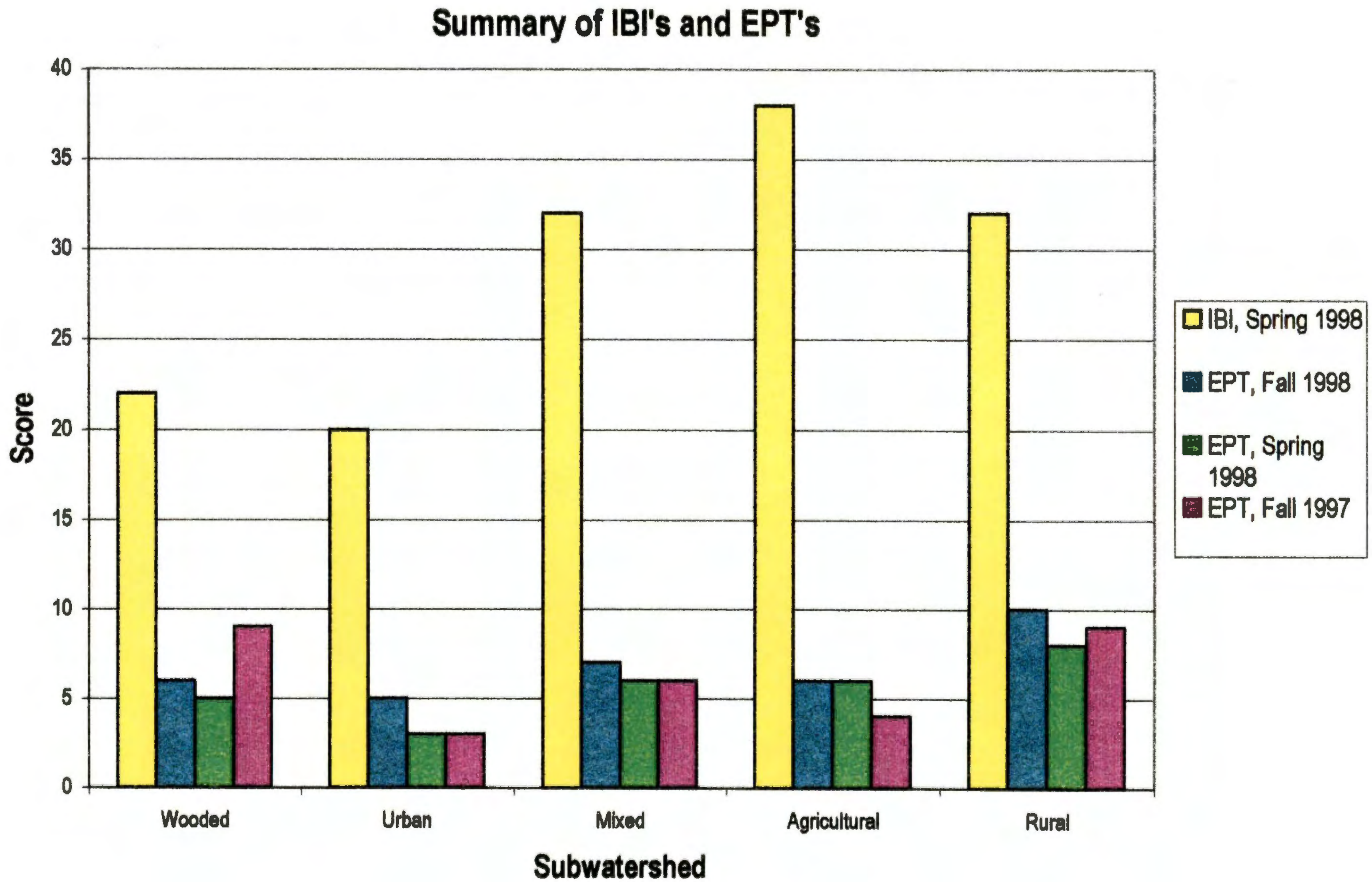


Figure 8. Summary of June 1998 IBI scores and EPT scores from October 15, 1998, May 28, 1998, and October 11, 1997, data collected at all subwatershed sampling sites.

dominated the wooded subwatershed (50.0%), and only 5.0% pollution tolerant fish were collected in the rural subwatershed. The 50% of pollution tolerant species in the wooded subwatershed was derived from only two species, one species being tolerant to pollution. The metrics for the wooded subwatershed may not represent the nature of the stream, since stream characteristics in drainage areas less than 3.0 km^2 (1.2 mi^2) are variable (Fausch et al., 1984). The eight species in the rural subwatershed were dominated by moderately pollution tolerant fish, generally indicating that conditions could have degraded enough to limit pollution intolerant fish, but had not reached a point where pollution tolerant fish dominated (Holdeman, 1993).

Macroinvertebrates

In the spring of 1997, EPT differences among the subwatersheds were not significant, but the fewest EPT were collected in the urban subwatershed (Figure 8). The rural subwatershed was the only subwatershed with fair stream health according to the EPT rating. Due to the small range in EPT values, macroinvertebrate abundance had a strong influence on the stream rating. The number of organisms collected at the rural subwatershed was four times larger than that at the agricultural subwatershed and five times greater than in the most impacted subwatershed, the urban land use. The greater abundance of macroinvertebrates may possibly be attributed to better habitat, such as substrate size or organic matter and nutrients entering the stream from cows pastured adjacent to the stream. The total number of macroinvertebrates for the urban subwatershed was 73; the wooded subwatershed was the only subwatershed with a smaller collection of macroinvertebrate (42). Both subwatersheds, wooded and urban, were dominated by the pollution tolerant Diptera. The increase in Diptera could possibly be attributed to an increase in soft substrate due to sedimentation. The EPT ratings, like the fish rating, seemed to go against ecological principles. It was expected, that the diversity of aquatic species would increase as the drainage area increased. Chronic localized effects (e.g., wastewater treatment and runoff from development) should also be considered as factors that could keep species richness and abundance low. Even in the better-rated rural subwatershed, localized conditions such as nutrient enrichment from animal waste was needed by macroinvertebrate as food, but an excessive amount could possibly be harmful to their habitat. It should be noted that the short life cycle of the macroinvertebrates involves aquatic and terrestrial distribution strategies; the macroinvertebrates, especially pollution intolerant EPT, avoid chronically impacted streams. The ability of the macroinvertebrate to fly to favorable stream conditions for reproduction could affect the EPT score negatively in degraded streams.

Water Quality Constituents

Weekly grab samples were taken for water quality analysis and water quality constituents were compared to EPA drinking water standards, except for the fecal coliforms which were compared to EPA recreational water standards of 200 CFUs/mL. Using these guidelines, water quality parameters for all five subwatersheds, except fecal coliform counts, were within EPA standards during this study.

Total Suspended Solids

Cumulative concentrations of TSS from each land use increased as anthropogenic activities increased. The average TSS concentration in the urban subwatershed was the highest at 1000 mg/L and the mixed subwatershed followed closely at 900 mg/L (Figure 9). Both of these subwatersheds were influenced by anthropogenic activities, such as development, that could have increased runoff into the stream causing the elevated concentrations of TSS. However, concentrations in the wooded subwatershed had an average TSS concentration of 780 mg/L with a maximum concentration of 6500 mg/L, a heavy concentration of TSS for a drainage area of 2.0 km^2 (0.75 mi^2). Little human activity occurred in the wooded subwatershed except during tree harvesting periods. The pine forest had been selectively harvested every 10 to 12 years with thinning occurring more often, which could have increased the concentrations of TSS since sediment still remains in the stream. The rural subwatershed also carried high maximum concentrations of TSS of 7200 mg/L. Hobby farms and rural development may have impacted the rural subwatershed, possibly increasing runoff to the stream and elevating concentrations of TSS. The agricultural subwatershed had the lowest average TSS concentration (500 mg/L) and the lowest maximum TSS concentration (930 mg/L). From a land use survey, the agricultural subwatershed had the least amount of development and lowest number of people as compared to the urban, mixed, and rural subwatersheds. Comparing average TSS concentrations to maximum TSS concentrations; the wooded, urban, and mixed subwatersheds increased eight times, the agricultural subwatershed increased two times, and the rural subwatershed increased nine times, supporting the idea that anthropogenic activities influenced runoff from the different land uses (Figure 9).

Fecal Coliform

The maximum fecal coliform count of 13,000 CFUs/100 mL occurred in the urban subwatershed which had an average count of 6230 CFUs/100 mL (Figure 10). The elevated fecal coliform counts in the urban subwatershed could have been from sewage overflow in wet weather periods when the sewage treatment plant could not handle increased sewage flows.

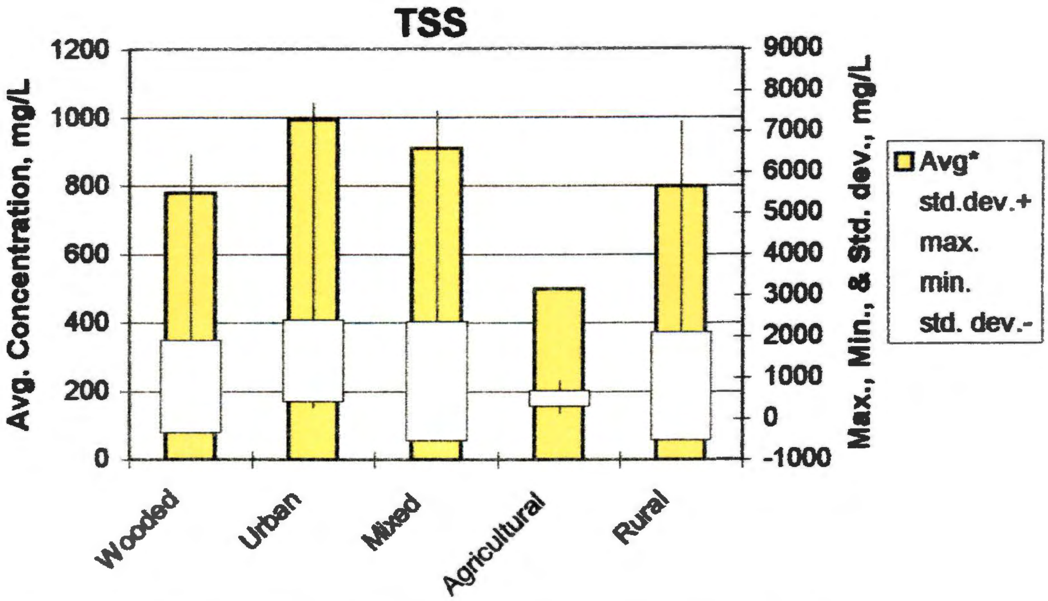


Figure 9. A comparison of weekly grab samples for TSS among the five subwatersheds based on average, maximum, and minimum concentrations from April 17, 1997 to October 30, 1997.

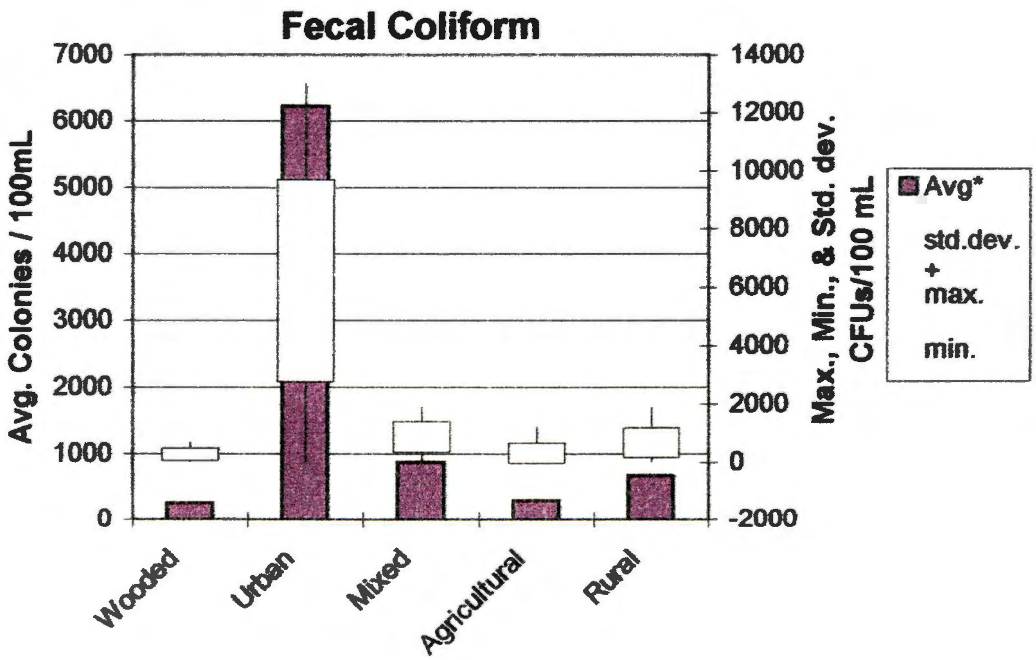


Figure 10. A comparison of weekly grab samples for fecal coliforms among the five subwatersheds based on average, maximum, and minimum concentrations from April 17, 1997 to October 30, 1997.

* Maximum values are represented by the lines extending upward, minimum values are represented by the lines extending downward, and the standard deviation is represented by the box.

Also, failing leach fields may have kept the average fecal coliform counts elevated in the urban subwatershed. Fecal coliform counts (260 CFUs/100 mL) in the wooded subwatershed may have been from area wildlife. The local area counts of fecal coliform followed the human population pattern with higher fecal coliform counts found near higher populations of people. The averages for fecal coliform counts from the highest populated areas to the least populated were 6230 CFUs/100 mL in the urban subwatershed, 870 CFUs/100 mL in th mixed, 670 CFUs/100 mL in the rural, 300 CFUs/100 mL in the agricultural, and 260 CFUs/100 mL in the wooded subwatershed.

Chloride

The average concentration of chloride was elevated in the urban subwatershed when compared to the other land uses (Figure 11). The elevated concentrations of chloride may have been due to the wastewater treatment plant. Also, increased levels of chloride in the winter months could have been from salt on the roads, especially in the urban and mixed subwatersheds where more people and roads exist. The excess chloride in the winter months could elevate the average chloride concentrations for the urban, mixed, and possibly the rural subwatersheds. This could be why the mixed subwatershed was the second highest in chloride levels of 3.9 mg/L.

Nitrate

The average nitrate concentrations for the subwatersheds varied only slightly from 0.5 mg/L to 0.9 mg/L. These values were low for all subwatersheds (Figure 12). For the subwatersheds located on the main stem of Sweetwater Creek, urban, mixed, agricultural, and rural, an increased nitrate concentration progressed downstream from the headwaters. The progression downstream evolves from low concentrations of homes and businesses to the dense population of the city limits that follows the stream. This could increase nitrate concentrations from fertilizers used on lawns and runoff from impervious surfaces that may cause nitrification to occur in the stream.

BOD_5

Five-day biological oxygen demand was the lowest in the wooded and agricultural subwatersheds with levels at 2.3 mg/L and 1.8 mg/L, respectively (Figure 13). The agricultural subwatershed was three times lower than the urban subwatershed with BOD_5 levels of 5.8 mg/L. The BOD_5 levels in the urban subwatershed could have been elevated due to the additional nutrients in the stream

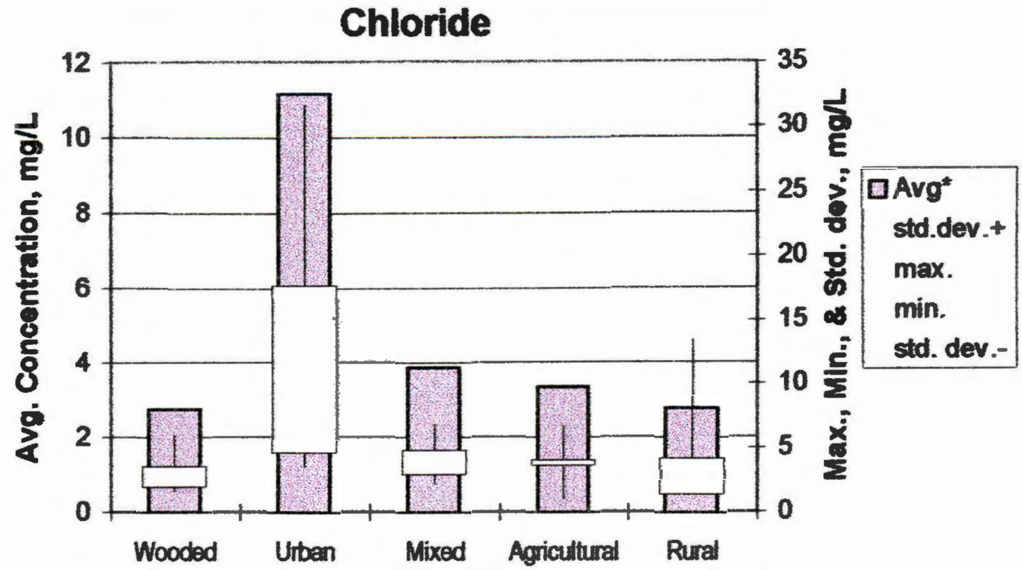


Figure 11. A comparison of weekly grab samples for chloride among the five subwatersheds based on average, maximum, and minimum concentrations from April 17, 1997 to October 30, 1997.

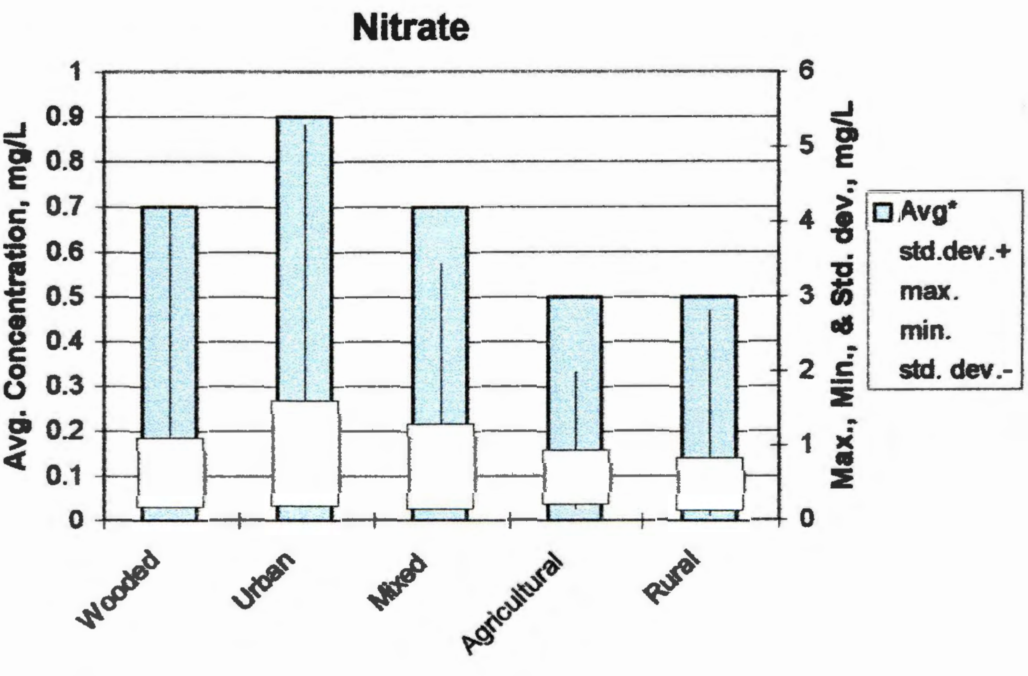


Figure 12. A comparison of weekly grab samples for nitrate among the five subwatersheds based on average, maximum, and minimum concentrations from April 17, 1997 to October 30, 1997.

*Maximum values are represented by the lines extending upward, minimum values are represented by the lines extending downward, and the standard deviation is represented by the box.

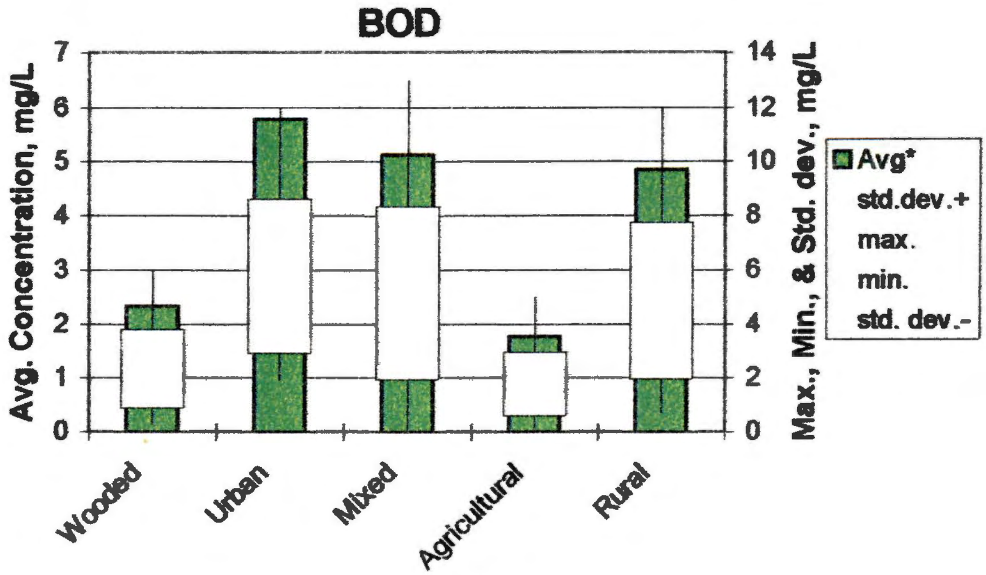


Figure 13. A comparison of weekly grab samples for BOD among the five subwatersheds based on average, maximum, and minimum concentrations from April 17, 1997 to October 30, 1997.

* Maximum values are represented by the lines extending upward, minimum values are represented by the lines extending downward, and the standard deviation is represented by the box.

from wastewater and fertilizer from lawns, or possibly from runoff from the local Farmer's CO-OP. The average BOD_5 levels in the urban, mixed, and rural subwatersheds varied only slightly (4.9 – 5.8 mg/L). The common factor among these three subwatersheds was that human activity impacted the stream in some way and the stream lost buffering capacity because vegetated riparian zones decreased in the downstream direction.

Other Water Quality Parameters

Other water quality constituents were analyzed in the five subwatersheds. Ammonia varied from 0.3 mg/L to 0.4 mg/L among the five subwatersheds (Figure 14). These values were insignificant and constant, therefore they probably had little or no negative affects on the water quality. Also, sulfate was analyzed and the concentrations varied slightly between the five subwatersheds (2.3 - 6.8 mg/mL).

Water temperatures tested *in situ* for each of the five subwatersheds were within the State of Tennessee criteria for aquatic life. Temperatures taken at low flows were up to 5 °C warmer than high flow water temperatures for all subwatersheds, except for the rural subwatershed. This was expected since low flows occurred in the summer. The rural subwatershed water temperature was cooler at low flow (17.0 °C) and warmer at high flow (18.4 °C). Since the rural stream reach is spring fed, the proximity of the sampling site to the spring probably explains the anomaly.

Dissolved oxygen levels for all five subwatersheds were sufficient to support healthy aquatic life (Figure 15). The DO ranged from 7.0 mg/L to 8.6 mg/L at low flow and 7.2 mg/L to 9.7 mg/L at high flows, which are typical of an ephemeral stream with some stream gradient. The DO oxygen concentrations varied 3 mg/L from high flows to low flows, but even the low DO concentration (7.0 mg/L) provided good conditions for fish and other aquatic organisms.

Physical Parameters

All five subwatershed stream reaches lacked adequate substrate; the wooded, urban, mixed, and agricultural stream reach yielded no substrate larger than a quarter, thus providing little habitat for spawning fish and foraging macroinvertebrates. The wooded stream reach consisted only of sand and silt but the mixed and agricultural stream reaches did support a few small gravel bars. The rural stream reach also supported gravel bars but they were comprised of larger substrate and small grapefruit size rocks. The lack of adequate substrate size may be caused by sediment from the different land uses that has covered much of the gravel and small rocks.

The wooded stream reach probably received large amounts of runoff and sediment after Bowater Land Management harvested the trees, since the existing riparian zone was too narrow

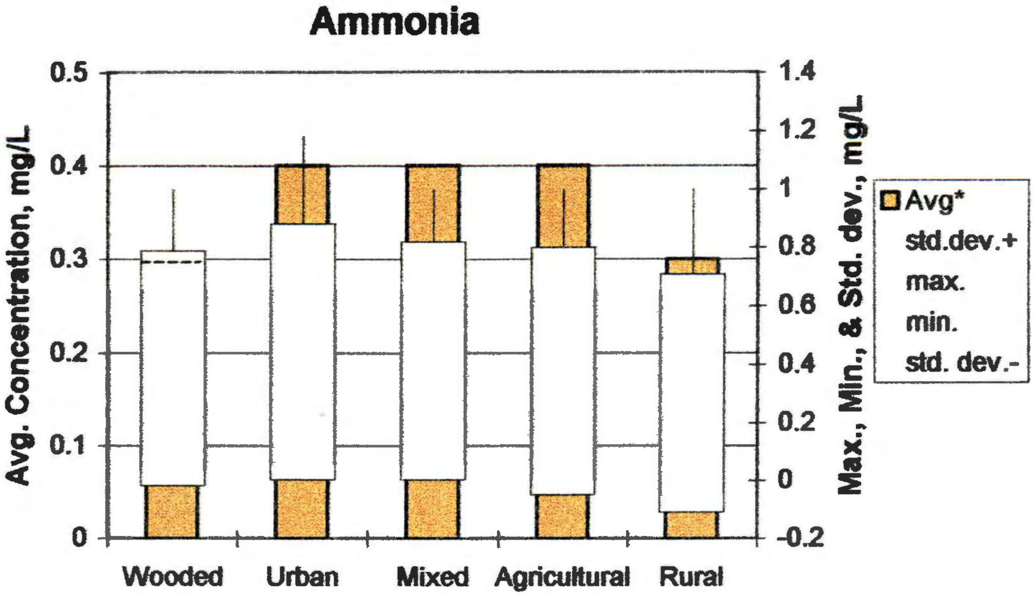


Figure 14. A comparison of weekly grab samples for ammonia among the five subwatersheds based on average, maximum, and minimum concentrations from April 17, 1997 to October 30, 1997.

*Maximum values are represented by the lines extending upward, minimum values are represented by the lines extending downward, and the standard deviation is represented by the box.

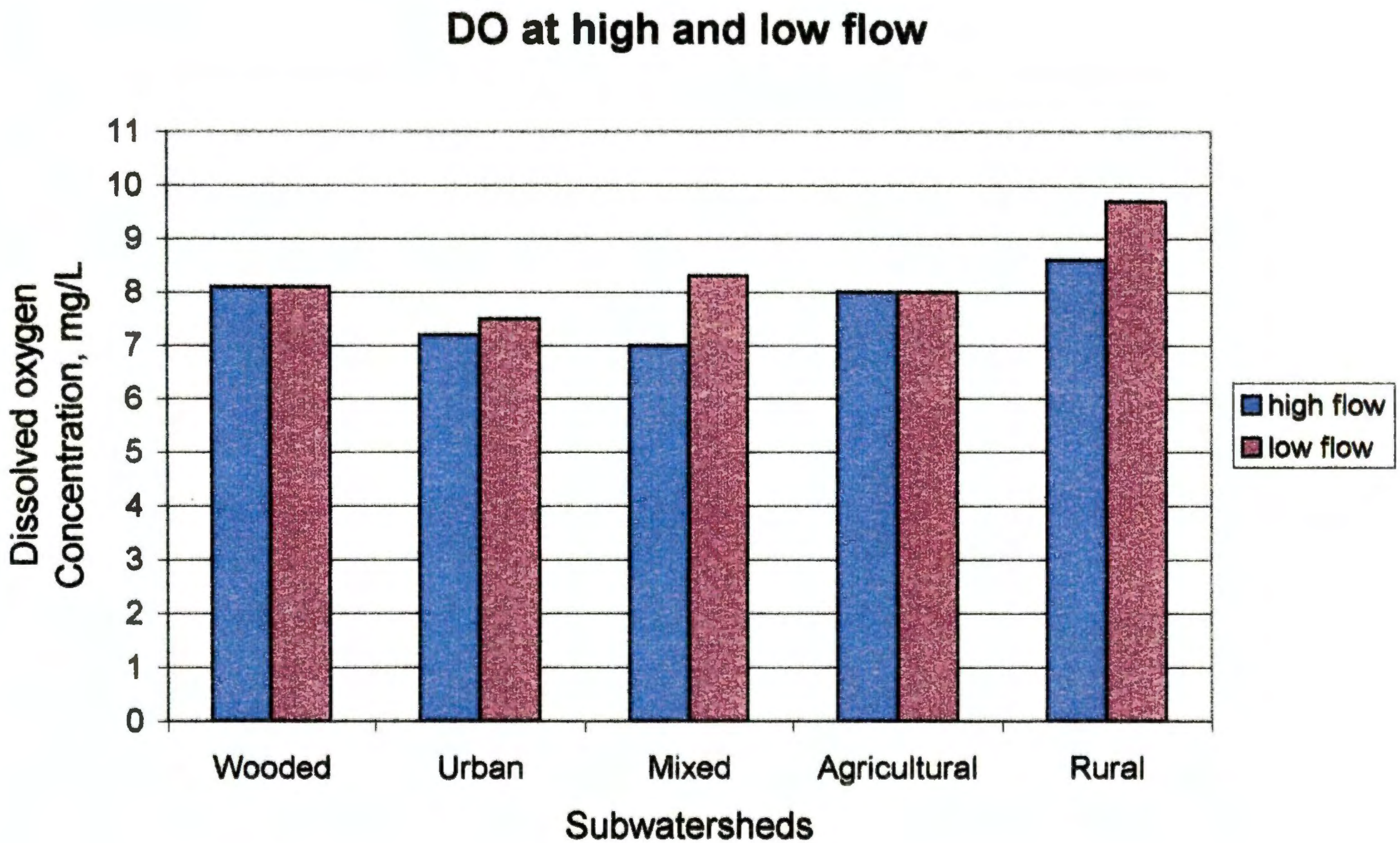


Figure 15. A comparison of dissolved oxygen concentrations among the five subwatersheds samples for low flow on in situ water August 31, 1998 and high flow on June 11, 1998.

to provide buffering. Even though the trees were only harvested every 10 to 12 years, with periodic thinning the amount of sediment was so significant that after eight to nine years of recovery time the stream was still dominated by sediment 10.2 – 12.7 cm (4 – 5 in.) deep.

In the urban stream reach, the small gravel substrate was localized in riffles and some runs. The slower moving water, pool areas near stream banks and in some runs was dominated by fine sediment. The sediment in the urban stream may have moved down stream from upper stream reaches, but urban runoff may have also contributed. Since the urban area consisted of many impervious structures and few vegetated riparian zones exist along the stream, the runoff had a direct route to the stream. Runoff from the business operations such as large 0.5 km^2 (0.3 mi^2) gravel lots and the storage of granular farm supplies (e.g., lime, fertilizer, and sand) located adjacent to the stream could have had significant impacts. In the urban stream reach, areas of the stream were channelized, leaving a hard clay pan for the stream bottom and creating a radical change from soft substrate to no substrate. No substrate or excess sediment both create poor habitat for aquatic life in the urban subwatershed. The urban community may have channelized the stream to prevent flooding and moved it to a location where urban development could continue to grow.

The runoff from the mixed subwatershed differed from runoff from the urban subwatershed only in that the mixed subwatershed had less impervious structures and less concentration of businesses. It also had narrow 0.3 – 1.5 m (1 - 5 ft) vegetated riparian zones. The runoff from the mixed subwatershed introduced significant amounts of sediment, probably due to development. Residential building may have been the most concentrated in the mixed subwatershed.

In the rural subwatershed, the stream appeared to have been channelized to prevent the stream from meandering across pasturelands. Channelized areas tend to scour the stream bottom and create excessive shear stress on the banks, causing bank sloughing. Also, downstream reaches receive peak flows of water during rain events and as the water slows in the meanders the scoured substrate is deposited, causing excessive sediment deposition in the lower stream reaches. Due to the rural subwatershed being channelized, it received poor ratings for channel sinuosity. Channel sinuosity creates a range of aquatic habitats and foraging opportunities for the aquatic life.

The agricultural subwatershed received the best overall habitat score. It was lacking in pool variability, pool substrate characterization, and channel sinuosity. The pool areas were more variable than in the other four subwatersheds, but the majority of the pools were not large and deep. This may be due to the agricultural stream reach being wide and shallow. The stream appears to have been channelized in certain reaches, which explained the lack of channel sinuosity. The marginal pool substrate characterization indicated a homogenous substrate with little root mat or submerged vegetation. The absence of submerged vegetation may have been due to the stream canopy shading aquatic vegetation. The agricultural subwatershed was the only sampled reach with suboptimal to optimal vegetated riparian zones ranging from 6 – 12 meters (20 – 39 ft). The banks were 70 – 90% protected by vegetation, resulting in banks that were moderately stable. The improved riparian zone conditions may be from efforts from different state and federal agencies to educate farmers on the benefits of fencing cattle out of the streams and leaving riparian buffer zones between the stream and farm operations.

Biological, Chemical, and Physical

Comparison among the watersheds was viewed by a holistic approach. Comparisons were made between biological and chemical results, but the chemical and biological conditions did not indicate the same conditions for each of the subwatersheds. A reason for the difference in the comparison could be that the fish and macroinvertebrates may have moved from impacted stream reaches to less impacted stream reaches; hence the higher (38) IBI score for the agricultural stream reach as compared to the lower (22) IBI score in the urban stream reach. However, in all subwatersheds water quality constituents, except fecal coliform, appeared to be good. This difference could reside in the idea that the chemical constituents, even though within EPA standards, may not be a good representation of water conditions that are tolerated by aquatic life. In the urban subwatershed, some chemical constituents were elevated compared to the other subwatersheds, chronic poor water quality may have deteriorated fish health in this stream reach since anomalies were common at 33.3%. The average levels of fecal coliform and chloride in the urban area could be two factors that caused the most stress on the fish and macroinvertebrates because these levels were elevated significantly when compared to the other subwatersheds. This may suggest it is important for water standards to incorporate responses from aquatic life. Also, the low IBI score (22) in the urban reach could be reflective of development and an area with a high population density, since the stream rating was higher in the agricultural stream reach (38), an area with a low population density.

In all of the subwatershed stream reaches, except agricultural, physical parameters were less than optimal. Three negative conditions existed in each subwatershed at different magnitudes, excess sediment, lack of vegetated riparian zone, and degraded channel conditions. Excess sediment seemed to follow the same pattern as the biological and water quality constituents, in areas of increased development, concentrations of TSS increased. In developed areas the average TSS was 1000 mg/L and in the least developed agricultural area the average TSS concentrations was 500 mg/L. The TSS concentrations could possibly be reflective of the poor conditions recorded for the habitat assessment in each subwatershed.

It may be possible that the most significant habitat condition to establish would be vegetated riparian zones. The buffering capacity of the riparian zones reduce sediment movement into the stream, which could improve habitat conditions such as, pool variability, bank stability, pool substrate, bank vegetation, and sediment deposition in the stream. The width of the vegetated riparian zone was possibly reflective of two conditions; stream health and development. The agricultural stream reach was rated as having the widest vegetated riparian zone (6-12 m) and stream health of fair, whereas the urban stream reach was rated as having the narrowest vegetated riparian zone (0-1 m) and a stream health of poor.

It appeared that the vegetated riparian zones affected the aquatic habitat indirectly since it possibly filtered sediment before it reached the stream and protected it from covering spawning and foraging habitats. Excessive sediment was a problem in certain stream reaches but a lack of substrate was a problem in other stream reaches, providing no aquatic habitat. Scoured stream beds seemed to be more prevalent in the urban stream reach where the stream had been channelized to prevent flooding and possibly to encourage development. In developed areas more impervious surfaces created from roads, buildings, and parking lots increased runoff. The runoff to the stream increased peak flow rates and caused the velocity to increase, creating a flume effect in the channelized stream reaches. This created scouring of substrate and shear stress on the banks causing sloughing that was deposited as sediment downstream. Vegetated riparian zones reduce runoff and improve infiltration rates to prevent elevated peak flows.

Chapter 5
Conclusions

Analysis of taxa from each of the five subwatersheds indicated that the fish and macroinvertebrate communities in all subwatersheds were moderately to severely impacted. However, water quality constituents were within EPA water quality standards, except for fecal coliform counts. The results of this study lead to the following conclusions:

- EPA water quality standards are not an adequate measure of stream health
  - All water quality results met EPA drinking water standards, except for fecal coliform counts
  - Biotic indices indicated all stream reaches were degraded
    - Wooded and urban stream reaches had IBI ratings of very poor (<23)
    - The mixed and rural stream reaches had IBI ratings of poor (28-35)
    - The agricultural stream reach had an IBI rating of poor/fair (38)
  - EPT ratings supported the IBI ratings

- Physical habitat degradation had a strong influence on IBI and EPT scores
  - Poor habitat conditions were found in all stream reaches

- Increased development and increased population density decreased stream health
  - Fecal coliform counts decreased with decreased population densities
    - Urban stream reaches averaged 6200 CFUs/100 mL
    - Mixed stream reaches averaged 870 CFUs/100 mL
    - Rural stream reaches averaged 670 CFUs/100 mL
    - Agricultural stream reaches averaged 500 CFUs/100 mL
  - IBI scores generally improved with decreased development and population density
    - IBI rating for the urban subwatershed was very poor (22)
    - IBI rating for mixed and rural stream reach was poor (32)
    - IBI rating for the agricultural stream reach was poor/fair (38)
    - Wooded stream reach was an, exception due to poor habitat, IBI rating very poor (20)

- It was difficult to compare biotic and water quality constituents
  - Water chemistry samples were not integrated over time, whereas effects on biological communities, by nature, always are integrated over time
  - Fish and macroinvertebrates move to less impacted areas and respond to cumulative water quality conditions.
  - Interpretation of the IBI metrics and scoring criteria among the five subwatersheds was challenging since they were adjusted according to the drainage area being analyzed.

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Vita

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