MICHAEL DUANE MERRILL
Local and Watershed Influences on Stream Fish Biotic Integrity in the Upper Oconee Watershed, Georgia, USA
(Under the Direction of ELIZABETH A. KRAMER)

This thesis examined the influences of both watershed and local environmental variables on fish diversity, richness, abundance, and an Index of Biotic Integrity (IBI) in the upper Oconee watershed. Local geomorphology, such as, the presence of riffles and bedrock, and lower percent sand in the channel bed were found to increase fish diversity, richness, and IBI values at sampled sites. Stream size, no matter the method of measurement (e.g. watershed area or field-based channel dimensions), was the strongest correlate (positive) to fish diversity, richness and IBI scores. Stream size residual analysis revealed that sites with higher percent development in the watershed and those with close downstream impoundments had lower diversity, richness and IBI scores.

Stream habitat loss and fragmentation due to impoundments were analyzed in the study watershed using geographic information system (GIS) techniques. Analyses indicated a highly fragmented system with 5,468 impoundments having inundated 8% of the 10,575 km stream length (1:24,000 scale). These ranged in size from less than 0.1 ha to 7,058 ha. Cumulatively, the small impoundments have inundated 47% of the impounded stream length with the majority occurring on headwater streams. Consequently, 46% of the 6,167 headwater streams have been impounded. Using the analysis results, implications for aquatic conservation in the watershed are discussed.

INDEX WORDS: aquatic conservation, Index of Biotic Integrity, fish communities, impoundments, dams, land use, watershed assessment, GIS, geomorphology, stream size, stream habitat loss, fragmentation

LOCAL AND WATERSHED INFLUENCES ON STREAM FISH BIOTIC

INTEGRITY IN THE UPPER OCONEE WATERSHED, GEORGIA, USA

by

MICHAEL DUANE MERRILL

B.S., Cornell Univerity, 1995

A Thesis Submitted to the Graduate Faculty

of The University of Georgia in Partial Fulfillment

of the

Requirements for the Degree

MASTER OF SCIENCE

ATHENS, GEORGIA

2001

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MICHAEL DUANE MERRILL

Approved:

Major Professor:	Elizabeth A. Kramer
Committee:	Mary C. Freeman David S. Leigh

Electronic Version Approved:

Gordhan L. Patel
Dean of the Graduate School
The University of Georgia
August 2001

ACKNOWLEDGEMENTS

My thesis project developed out of a wonderful collaboration with another masters student and friend, Lee Hartle. Lee gladly shared his knowledge of the diverse fishes of the southeast with me, as well as his highly contagious love for the beauty of streams and the organisms which live in them. Thanks Lee.

Of course, I want to thank my committee for their guidance. Liz kept me thinking about the big picture and of the implications for conservation. David taught me how to understand the physical aspects and dynamic nature of the stream channel. Even when she was swamped with projects, Mary took time out to discuss ideas and always inspired more with her creativity and knowledge. Bud gave me the chance to learn many more skills, yet more importantly, reminded me that work can and should be enjoyable.

I have been fortunate enough to get to know many intelligent and fun people at the Institute of Ecology. Special thanks go out to our field crew, John Ruiz and Jon Ray, the GIS and Freeman labs, many of the Etowah EPA group, and the North Carrell folks.

Finally, and most importantly, this work could not have been done without those people closest to me. Even from far away places my family has always been an integral part of my life. This experience has been no different and I feel truly blessed to have such a close and loving family. My loving partner, Mandy, has truly made this endeavor possible through her love and tireless support. I am incredibly happy to know that this has been only the beginning of the many wonderful advertures we will have together!

TABLE OF CONTENTS

LIST OF TABLES

Page

LIST OF FIGURES

Page

General Introduction

Effective stream conservation requires that we identify streams that serve as high quality habitat and continue to sustain functioning natural processes. In addition to identifying and protecting high quality streams, it is necessary to identify those impaired or threatened waterbodies in need of restoration. Therefore, for stream conservation to move forward appropriate assessment methods must be used to measure the health and integrity of our streams and watersheds. Biological measures are now being used in conjunction with long-utilized physical and chemical measures to assess stream health and integrity (Karr and Chu 2000). Also, watershed assessments have been recognized as important components to evaluating the integrity of streams (e.g. Weaver and Garman 1994; Richards et al. 1996; Allan and Johnson 1997; Lammert and Allan 1999; Wang et al. 2000).

Biological-based, multimetric techniques, such as the Index of Biotic Integrity (IBI) have been developed and successfully applied as stream assessment tools in many regions of the world. Multimetrics rely on a composite score based on community-level trophic, composition, and condition information and have incorporated a variety of taxa, such as fish, aquatic insects, periphyton, and amphibians (e.g. Karr et al. 1986; Allan 1995; Brooks et al. 1998). In the U.S.A., IBI methods have become widespread in use and are likely to increase due to their acceptance by many state and federal regulatory agencies. Because of their effectiveness, their widespread use, and their increasing regulatory leverage, IBI techniques are becoming important conservation tools.

In order to form a complete picture of stream health and integrity we must also consider the hydrologic and geomorphic factors which can influence the biological measures and community structure (Poff and Ward 1989; Karr and Chu 2000; Newson and Newson 2000). In other words, we must be able to separate those ‘natural’ or physical characteristics that drive normal differences in the biological makeup of a stream from those anthropogenic activities which may alter and degrade the system (Schlosser 1990; Angermeir and Winston 1999). It also has been recognized that the assessment of stream integrity requires a multi-scale approach utilizing spatial information from local conditions to the regional setting (e.g. Osborne and Wiley 1992; Habersack 2000; Marsh-Matthews and Matthews 2000; Newson and Newson 2000; Allan and Johnson 1997; Wiley et al. 1997) and over multiple time-scales (Harding et al. 1998; Ward 1998).

This study has focused on stream assessment methods utilizing a fish-based IBI as well as the community fish metrics of diversity, richness, and abundance. The benefits of sampling fish as indicators of biological integrity are well established and include: fish have relatively long lives which integrate seasonal and annual effects, ease of identification, sensitivity to a variety of stressors, societal value (aesthetic and economic), and are relatively inexpensive to monitor (Fausch et al. 1990; Karr et al. 1986). However, the main reason this study used a fish-based IBI was because the Georgia Department of Natural Resources (GA-DNR) had recently developed protocols for collecting and analyzing fish communities to assess integrity of Georgia Piedmont streams. This protocol may allow stream segments to be listed as impaired (under Section 303(d) of the Water Pollution Control Act of 1972 (‘Clean Water Act’)) if found to have a poor and degraded fish community (i.e. low IBI) (Shaner 2001).

In order to explore and test the influences on the fish community metrics (IBI, diversity, etc), natural and anthropogenic characteristics at the local and watershed scales were assessed for streams of the upper Oconee watershed, located in the Georgia Piedmont physiographic region.

The upper Oconee watershed is a part of the Altamaha River drainage which has been nationally recognized as a critical watershed in need of protection because of its unique flora and fauna (Masters et al. 1998). Georgia and especially the Atlanta and Athens areas, have some of the fastest growing human populations according to the 2000 census. The growth in these urban areas that are located in the headwaters of the Altamaha River will continue to exert pressure on the water resources of the Altamaha River. Due of the interconnected nature of stream systems, assessments of the upper Oconee watershed is undoubtedly necessary if conservation of the Atlamaha River is to fully succeed.

The work for this study was done in collaboration with another master of science student, Lee M. Hartle (Institute of Ecology, University of Georgia). His interest in the upper Oconee watershed is focused on the distribution of fishes of the upper Oconee River including the status and ecology of the Altamaha shiner (*Cyprinella xaenura*). The Altamaha shiner which is endemic to the upper Altamaha drainage (Gibbs 1957; Page and Burr 1991) and is of particular interest because it is considered a species of special concern (former Candidate 2 species) by the U.S. Fish and Wildlife Service, and is state listed as endangered (GA-DNR 1999).

In the planning stages of the project it was apparent that artificial impoundments could have a huge impact on the distribution of fishes and the integrity of the streams. Two large reservoirs within the upper Oconee are dominant features in the stream network and actually the dam of the lower reservoir defines the outlet of the study watershed (Sinclair dam). For this reason streams were selected in relationship to these large impoundments (see Chapter 1). Furthermore, as the project progressed and GIS data were analyzed it became apparent that many other impoundments existed and techniques were needed to assess the impact of these impoundments.

It has been recognized that direct loss, indirect degradation, and fragmentation of natural stream habitats are major ecological impacts of dams and their impoundments (e.g. Ward and Stanford, 1989; Dynesius and Nilsson 1994; Collier et al. 2000). With over 75,000 large dams and an estimated 2.5 million smaller dams in the U.S.A. (ICOLD 1998; Benke 1990; Masters et al. 1998) the cumulative impacts to our stream systems must be examined in order to make more informed decisions regarding rehabilitating existing impoundments and building more impoundments.

The working hypothesis is that, not only do fish communities respond to local physical and habitat variations, but also they respond to watershed scale changes in land use, road densities, and artificial impoundments. Therefore, in order to fully understand the health and condition of the streams using fish community information, the local and watershed characteristics must be quantified and considered.

Chapter 1 details the methods used to sample for stream fish, local geomorphic-habitat sampling, and those variables assessed using geographic information systems (GIS). Local and watershed physical characteristics were tested for their influence on fish metrics and IBI scores. The analysis also examined anthropogenic factors which may degrade stream quality as reflected by the fish-based assessments. These factors included, land use in the watershed and in riparian buffers, road density, and artificial impoundments.

Chapter 2 uses the upper Oconee watershed as a case study to further explore and discuss methods to assess the cumulative loss and fragmentation of stream habitat. The chapter highlights many of the potential cumulative impacts to the stream network from the many impoundments of various sizes and types. Also, the same methods employed in Chapter 2 to assess the entire watershed were used to quantify the amount of habitat loss and fragmentation for the streams sampled over the course of the project.

In the final section of the thesis I draw some conclusions by synthesizing the results of both chapters. Based on these conclusions I discuss conservation implications as well as future applications to aquatic research and planning.

CHAPTER 1

LOCAL AND WATERSHED INFLUENCES ON STREAM FISH BIOTIC INTEGRITY IN THE UPPER OCONEE WATERSHED, GEORGIA, USA

Introduction

In order to protect and restore the health and integrity of our vital freshwater ecosystems in the face of increasing water use and development pressure, it is crucial that we identify streams with high ecological integrity (to protect) as well as identify streams with impaired integrity (to restore). Currently, physical and chemical measures, long utilized as stand-alone measures for assessing stream ecological integrity, are being used in conjunction with biological-based measures (Karr and Chu 2000). This is an important shift because it means that we are directly incorporating biology into the way we evaluate the health and integrity of streams.

In order to form a more complete picture of stream health and integrity, purely biological based measures must also consider the hydrologic and geomorphic factors which can influence the biological measures and community structure (Poff and Ward 1989, Karr and Chu 2000, Newson and Newson 2000). In other words, we must be able to separate those ‘natural’ or physical characteristics that drive normal differences in the biological makeup of a stream from those anthropogenic activities which may alter and degrade the system (Schlosser 1990). It also has been recognized that the assessment of stream integrity requires a multi-scale approach utilizing spatial information from the local conditions to the regional setting (e.g. Osborne and Wiley 1992, Habersack 2000, Marsh-Matthews and Matthews 2000, Newson and Newson 2000, Allan and Johnson 1997, Harding et al. 1998, Ward 1998, Wiley et al. 1997).

This study focused on the use of a fish-based index of biotic integrity (IBI), a multimetric approach to analyze the integrity of streams. Although aquatic IBIs have been developed in many regions using a variety of taxonomic groups (e.g. periphyton, aquatic insects, amphibians) some of the first work in developing multimetric indices was with fish communities (Karr et al. 1986). The benefits of sampling fish as indicators of biological integrity have been elucidated quite well and championed by other researchers. These benefits include: relatively long lives which integrate seasonal and annual effects, ease of identification, sensitivity to a variety of stressors, societal value (aesthetic and economic), and can be inexpensively sampled relative to other taxa (Fausch et al. 1990, Karr et al. 1986). However, the main reason this study used a fish IBI (versus a macroinvertebrate index, e.g. EPT) was that stream evaluations using IBI methods are becoming more and more widespread in their use among state and federal agencies which have the regulatory power to aid in restoration of degraded sites and protection of healthy streams (Karr and Chu 2000). In fact, Georgia Department of Natural Resources (GA-DNR 2000) has recently developed and proposed protocols for collecting and analyzing the fish communities of Georgia's Piedmont streams. This protocol may allow stream segments to be listed as impaired (under Section 303(d) of the Water Pollution Control Act of 1972 ('Clean Water Act')) if found to have a poor and degraded fish community (i.e. low IBI) (Shaner 2001). Furthermore, the fish IBI is already being used to assess streams in the Piedmont region of Georgia, and its use will only expand in the future due to a mandated application if one is to acquire a fish collecting permit for water quality monitoring (Shaner 2001). Fish IBI's are being developed for other physiographic provinces of Georgia (e.g. coastal plain, ridge and valley) and therefore will become a stream assessment tool statewide.

With this expanding use of the fish IBI in Georgia comes the need for more information regarding the local and watershed physical characteristics which influence the IBI. For instance, much discussion and research has been devoted to examining the relative importance of local, watershed and broad scale influences in ecological assessments of streams and even more so for fish community dynamics (e.g. Osborne and Wiley 1992, Wiley et al. 1997, Cooper et al. 1998, Lammert and Allan 1999). Regional patterns often define what component species may actually occur (e.g. zoo-geographical constraints), define the overall hydrologic regime through climate and geology (e.g. Habersack 2000), and determine the types and frequencies of natural disturbances which may possibly occur (e.g. Montgomery 1999). The River Continuum Concept (RCC) in stream ecology gives a useful illustration of the natural differences and changes within a watershed when comparing the headwaters to the larger streams and rivers (Vannote et al. 1980). Therefore, the network position, or the placement along the RCC within the watershed will dictate much of the biology and species present. However, local scale physical and biological factors such as the pool to riffle ratio, depth variability, water velocity variability, large woody debris, and introduced species, etc. are thought to affect local population and community dynamics (Gorman and Karr 1978, Leftwich et al. 1997, Marsh-Matthews and Matthews 2000, Willis and Magnuson 2000).

The GA-DNR IBI used for this study was developed specifically for the Piedmont region in order to eliminate the broad scale differences found in other physiographic regions where climate and geology differ (GA-DNR 2000). Presumably these broad scale differences will not influence the IBI in our study because we are examining only one catchment and it is located entirely within the Piedmont physiographic province (Figure 1-1). However, streams within the study area do vary in their sub-watershed and local characteristics.

Once the natural influences on fish community patterns were analyzed, anthropogenic influences could then be examined to better understand why streams were more or less degraded as measured by the IBI. In this way stressors (causes of degradation) could be indentified and once identified solutions could be implemented to alleviate the impact on the streams. Many studies have shown changes in land use within the watershed have been associated with changes in the fish communities (e.g. Rowe et al. 1999, Wang et al 2000, Finkenbine et al. 2000). Generally, decreases in natural land cover (in GA Piedmont these are forests and wetlands) and increases in developed areas (e.g. commercial, residential) (e.g. Lammert and Allan 1999, Rothrock et al. 1998).

In order to understand the fish IBI more fully two of the component metrics were also analyzed with respect to the environmental variables. These metrics were richness (number of native fish species) and abundance (number of fish per length sampled). Also, diversity, as measured by the Shannon-Weiner index (Pielou 1975) was analyzed.

The schematic diagram (Figure 1-2) shows the local and watershed characteristics that we examined regarding their influence on the fish communities within the study watershed. Disentangling how these local and watershed scale factors influence the fish IBI developed by GA-DNR will help improve the index and perhaps help predict how it will respond in unsampled streams (Schlosser 1990, Karr et al. 1986).

Study Area

The upper Oconee watershed encompasses an area of 7,500 km^2 in the east-central portion of the state fully within the Piedmont physiographic region (Figure 1-1). After flowing through 2 large reservoirs (~125 km^2) the upper Oconee continues southeasterly to meet up with the Ocmulgee River to form the Altamaha River which eventually drains into the Atlantic Ocean. The Piedmont is characterized by rolling hills ranging from 152 m (500 ft) to 457 m (1,500 ft) above sea level. The warm and moist temperate climate has an average annual temperature ranging from 15.0° to 17.8° C and average annual rainfall from 112 cm to 142 cm. The area has predominantly igneous and metamorphic rocks of the Appalachian Mountain system with resistant outcrops of granite and gneiss apparent in the landscape (Burke, 1996, Trimble, 1970).

Methods

Site Selection Methods

Given the time frame (summer 2000) and scope (7,500km^2 watershed) of the sampling within the watershed we had a goal of 45 sampling sites. The criteria for site selection were accessibility (road crossings), watershed size class, sub-basin representation, network location relative to the two main reservoirs in the watershed (Lake Sinclair and Lake Oconee), and consideration of recent and historic sampling locations.

1 - Limited amounts of public lands within the watershed and accessibility requirements meant reliance on bridge right-of-ways to access the streams. The potential access points were enumerated by intersecting the roads database with the stream

database in a geographic information system (GIS) (see Appendix F for GIS metadata). The analysis showed 3,825 road crossings in the entire watershed (Figure 1-3). Sixty-five of these were crossing ponds, reservoirs, or wetlands (as found in the polygonal hydrography database) and were not considered, thus leaving 3,760 road-stream crossings available for selection.

2 – We stratified our sampling over four different watershed size classes in order to sample a variety of stream sizes. We used a lower size limit of 15km^2 based on the smallest watershed size of historical fish sampling points where *Cyprinella xaenura*, (Atlamaha Shiner), a species of interest for the concurrent study (Hartle 2000), were found. We then calculated the watershed size necessary to double the two-year recurrence interval flood discharge (Q_2) based on the discharge yield curves for rural watersheds of Georgia, Region 2 (Figure 1-4, Stamey and Hess 1993). The doubling was again calculated twice more, yielding four size classes. We used Q_2 as a close approximation of the theoretical bankfull event because it has been shown that many geomorphic (habitat forming) features in the streams are controlled by the one to two year flood, or the bankfull flood in many fluvial systems (Williams 1978, Leigh et al. 2001). The discharge yield curve and a +/- 25% discharge range resulted in the watershed size classes of 15 km^2 (range 9 – 22), 50 km^2 (range 32 – 72), 150 km^2 (range 96 – 215), and 400 km^2 (range 252 – 573).

Using 30 meter resolution digital elevation models (DEM) and previously available watershed boundaries (USGS 12-digit HUC) we calculated the watershed area of all the road-stream intersections. In this way, we enumerated the number of potential sampling locations that fell in each size class for the entire watershed (Figure 1-3).

3 - The last criteria for site selection were 400 km^2 sub-basins and location relative to the large river sections and the two large impoundments in the watershed. The entire study watershed had nine sub-basins in the largest size category of 400 km^2 (Figure 1-3). In addition to these sub-basins we also considered three additional categories relative to the their sub-basin setting. These were 1) direct tributaries (< 400 km^2) to the larger rivers (> 400km^2) and, 2) direct tributaries to Sinclair Reservoir and, 3) direct tributaries to Oconee Reservoir.

We did not locate any sampling sites in sub-basins where recent (1993 - 1999) collections by the Georgia Department of Natural Resources (GA-DNR) were located. These included the southernmost sub-basins of Murder Creek, Big Cedar Creek and Shoulderbone Creek and in direct tributaries to Little River (> 400 km^2) and Sinclair Reservoir. The locations of the 83 recent GA-DNR samples in the watershed are shown in Figure 1-5 for reference.

The total number of road-stream intersections falling in each of the 32 selection strata (4 size classes X 8 sub-basins) was 415 (Table 1-1). We then randomly selected available sampling sites within each of the 32 strata.

Figure 1-5 shows the final sites that were sampled and their site numbers. Three potential sites were not included because the streams were completely dry at the time visited. A total of 42 sites were sampled directly for this study. These sites were labeled with the field number LMH2000-# (initials of Lee M. Hartle, the graduate student with whom I collaborated). The site location information is in Appendix A.

Seven more sites that were sampled during the same time period (summer 2000) as part of a study by the U.S. Geological Survey (Freeman 2000) were included in the analysis. All seven USGS sites were selected based on locations in the GA Piedmont relative to municipal water withdrawals (Freeman 2000). These sites were categorized according their sub-basin and size along with our sampling sites. Two of the USGS sites were larger than our size classes (i.e. 600 and 1,011 km^2), yet were included in the analyses (Table 1-2). All the USGS sites were labeled as USGS2000-#. Their site location information is also in Appendix A.

Fish Sampling Methods

The 42 stream reaches were sampled for fishes between June 15, 2000 and August 8, 2000. The length of each sampled reach was determined by the stream's watershed size class: 15 km^2, 150 meters; 50 km^2, 200 m; 150 km^2, 250 m; 400 km^2, 300 m. These lengths were set so that each stream within a size class would have an equal distance sampled. We increased the distance sampled for the larger watershed size class streams to increase the chances that the reaches included a series of geomorphic features (e.g. pools and riffles) (Karr et al. 1986).

The USGS study followed the GA-DNR protocol for determining sampling length. This method called for a sample length of 35 times the average wetted width and a maximum of 500 meters. During site reconnaissance the wetted width was measured and averaged at multiple random locations (GA-DNR 2000).

As described above our method to determine the sample length differed from the GA-DNR protocol. Therefore, in order to make comparisons, we calculated the length-to-average-width ratio (LTOWRATIO) for each site. For further comparison we kept and analyzed the fish data separately at one site (USGS2000-16) for what would have been our sampling length (250m). In this instance, the GA-DNR protocol called for a longer stream reach than the method we employed would have (i.e. 391m). However, at many of our 42 sites the sampling length was longer than 35 times wetted width (Table 1-3).

If possible, the stream was sampled upstream from the road (bridge or culvert) we used for access and far enough away as to avoid geomorphic effects from the structures. Also, reaches with major tributaries (relative to the stream size) were avoided so that discharge did not increase substantially along the sampled length.

A backpack electro-shocker was used with a seine (8 x 6 feet, 1/8th inch mesh size) and dip nets (1/8th inch mesh size) to sample the stream segments. Most of the streams were completely wadable while those with deeper pools were shocked from the sides with dip netters capturing stunned fish. Seine hauls were used primarily in shallow, slow moving, channel margin habitat or used as a block net while larger pools were dip netted. Generally, the sampling proceeded in the downstream direction. At least four people were present for all sampling: one person with the electro-shocker, at least one person with a dip net and two people maneuvering the seine net. The entire stream reach and all habitats were sampled with one pass. All fish were kept, except for the largest specimens which were measured and identified in the field. The collected fish were preserved in 10% formalin in the field and later soaked in water and stored in 70% ethanol for long-term storage at the Georgia Museum of Natural History.

In the lab, fish were identified to species with the exception of the *Gambusia* species (*G. holbrooki* and *G. affinis*) which were only identified to Genus at the 42 sites. The USGS study identified *Gambusia* to species, yet for the analyses we considered them as one *Gambusia* species. For each site, all individuals 25 mm or greater (standard length) of a species were weighed at the same time and measured to the nearest 0.01 gram. Only those individuals 25 mm or greater (standard length) were used in the calculation of the Index of Biotic Integrity (IBI) (GA-DNR 2000).

Calculations of Fish Metrics

We utilized the IBI developed by GA-DNR for the Georgia Piedmont (Appalachicola and Atlantic-slope Drainages). Thirteen metrics comprised the IBI which had been revised from the methods Karr et al. (1986) outlined for stream fishes (Table 1-4). The first twelve metrics were scored 1, 3, or 5, and summed, thereby yielding scores ranging from 12 to 60. The last metric was used only to adjust the score downward by 4 points if the threshold for percent fish showing external anomalies was surpassed. The sites sampled were ranked into integrity classes from Excellent to Very Poor based on the IBI Score (Table 1-5). Impairment status was also evaluated for the sites based on IBI Scores (Impaired or Non-impaired). All fish data were entered into a database (FileMaker Pro 5 v.3) and checked for errors by multiple readers. Many of the IBI metrics were calculated and scored (1, 3, or 5) automatically using database scripts. However, many of the scores had to be visually interpreted by consulting the maximum species richness (MSR) graphs developed by GA-DNR. The graphs were scanned and included in Appendix H for reference (with permission from GA-DNR).

Two metrics from the IBI, native species richness and numeric abundances per 200 meters of sampled reach, were used in the analyses as well. Additionally, diversity as calculated by the Shannon-Weiner index (H') using the following formula from Pielou

(1975): $H' = -\Sigma^{S}_{i=1}(p_i \log p_i)$; where S is the number of species at the site, and p_i is the proportional abundance of the *i*th species.

Geomorhphic/Habitat Sampling Methods

We measured a number of geomorphic and habitat attributes for each of the 42 stream reaches we sampled. The length and starting point of the sampled reach was identical to the reach length sampled for fish (i.e. dependent upon watershed size class: 15 km^2, 150 meters; 50 km^2, 200 m; 150 km^2, 250 m; 400 km^2, 300 m).

A modified version of the Wolman (1954) pebble count procedure was used (Leigh et al. 2001). Each stream reach was sampled using a random starting point with five parallel transects systematically located as a function of the wetted stream width. The transects were placed at the 10^{th}, 30^{th}, 50^{th}, 70^{th}, and 90^{th} percentiles across the wetted stream width and sampled at 20 points along each transect, except the 50^{th} percentile which had 21 sampling points. The sampling points were evenly spaced along each transect by a distance of the reach length divided by 20. By staggering each transect starting point by a distance of the reach length divided by 100, a zig-zag sampling pattern resulted (Figure 1-6).

For each of the 101 sample points we measured water depth (m), habitat unit type (pool, run, riffle), and presence or absence of: bedrock, fines (silt or clay), woody debris or snags, and emergent vegetation. Also, at each point the modal stream bed sediment size class was visually estimated (or measured if unsure). The phi scale was used which is the $-\log_2$ of the intermediate axis length in millimeters. The mid-point of the size range was transformed for phi size class for the analyses. Anything larger than 256 mm was recorded as –8.5 phi and bedrock was recorded as –10.5 phi (Table 1-6). The observer was the same for all the streams sampled which allowed for consistent size class identification. The water width (m) was measured 11 times at a distance of the reach length divided by 10.

We used a survey level and stadia rod to measure the slope as a proxy for energy grade line (EGL) of the reach, which was generally measured using the elevations of riffles divided by the distance between riffles. If riffles were not present in the reach, runs were used instead. Two stream cross sections were surveyed perpendicular to the flow with a level, tape, and stadia rod unless the cross section was too large to use this method effectively, in which case a total-station was used. Measurements for the cross-sections were taken at points where the slope of the bed or bank changed, thus, the number of measured points varied for each cross-section. The cross-sections were continued past levees (if present) until the slope flattened or started up the valley floor.

Calculation of Watershed Environmental Variables

Stream Size (GIS)

In order to stratify the sites by size, watershed area was calculated in a GIS. The relationship between watershed area and discharge has been established with regional curves (Stamey and Hess 1993). Another way we quantified stream size was by counting the number of first order streams upstream from each of our sites, known as link number (LINK-ORD). We also measured the mapped distance along the main channel to the headwaters for each site (DIST-UPST) and illustrated this measure in the longitudinal profiles (Appendix C).

Sub-basin Setting

As part of the site selection criteria (see above), the sub-basin and the stream's network setting were considered. The sites were then grouped into three sub-basin setting categories (Figure 1-5): 1) those streams within a 400 km^2 sub-basin (SUBBAS), 2) those streams that directly drain into a larger river (TRIS), and 3) those streams that drain directly into the Oconee Reservoir (TRIR). Also, for each stream sampled the next size stream size class downstream was determined (DSIZECAT).

Ruggedness and Elevation

Nine metrics were used that quantified the steepness or ruggedness of the watershed of each site and three metrics were used to summarize elevation. These are described in Appendix B. The elevation for each site was used to create the longitudinal profiles for the sampled streams (Appendix C).

Land Cover

The percent land cover (from MRLC dataset, see Appendix F) for seven classes (Table 1-7) were summarized over three categories: stream segment riparian (-SEG), watershed riparian (-WRIP) and watershed (-WSHED). The segment of stream in which the sample was located was buffered by 100 meters on either side of the stream (-SEG). Likewise, all streams in the watershed were buffered and summarized by land cover percentages (-WRIP). Finally, the entire watershed for each sample site was used to summarize land cover for each site (-WSHED).

Roads

Two metrics quantifying the amount of roads were used; road length density (km/km^2) and road-stream intersection density ($\#/km^2$). See Appendix B.

Impoundments

Many variables were derived regarding the effects of fragmentation and loss due to impoundments (ponds, reservoirs, dams). Nine of them were examined in relation to the fish metrics for this first chapter. Please refer to Chapter Two which examined the methods used to derive these variables (also described in Appendix B).

Calculation of Local Environmental Variables

Slope

In addition to the energy grade line (EGL) which was measured in the field, four different slope measurements were calculated using GIS methods. These measurements were especially useful because they could be taken for all sampling sites as well as for any other location within the watershed. These methods used digital elevation models (DEM), digital raster graphics (DRG, scanned 1:24,000 scale USGS 7.5 minute topographic maps) and the streams database to obtain stream lengths (Appendix B).

A watershed longitudinal profile was constructed for each sampled stream (Appendix C). The segment slope (DEMSLOPE) was graphed simultaneously with the profile to illustrate the variability in the segment slope as the stream descends from the headwaters.

Channel Dimensions

Cross-sectional survey points were imported and analyzed using ArcView and ArcInfo (ESRI) software. Once the cross-sections were drawn the decision was made as to the bankfull elevations, or where the water elevation would be just before overtopping the current channel. The determination of this elevation was straightforward for the majority of cross-sections, however, if a channel bench or levee was present then the following rules were applied. The top of the channel bench was used as the bankfull elevation if the bench was wider than the depth of the thalweg. A bench of this size showed that the stream was actively creating a new floodplain in the old channel (Leigh et al. 2001). If the bench was of borderline width or had a slope that was in doubt, then an average for that cross-section was calculated using the bench and the normal channel elevation (i.e. a minimum and maximum elevation). If a levee was present, then the elevation of the lowest point behind the levee was used as the channel full elevation. At this elevation the back levee will most likely begin to flood with even a small breach just upstream. Once the back levee area is flooded the energy working the stream will not increase due to energy dissipation over the floodplain.

Once the bankfull elevations were determined, the cross-sectional area, wetted perimeter, hydraulic radius (area / wetted perimeter), and average depth (area / wetted width) were calculated. For all the channel dimensions, the average of the two cross-sections from the stream reach was used.

Discharge for the bankfull (QBKF) event was then calculated by multiplying the average cross-sectional area by mean velocity as calculated from the Manning equation (see Appendix G for formula). The determination of the roughness coefficient (n) for use in the Manning equation was estimated with an equation for ‘base n’ (Limerinos (1970) equation (Appendix G)). Adjustments were then made to this ‘base n’ which incorporated factors such as channel irregularity and sinuosity. These methods are outlined in Arcement and Schneider (1989).

The discharge capacity of the bankfull channel was evaluated with a ratio of the bankfull discharge (QBKF) to the estimated discharge for the two-year recurrence interval flood (Stamey and Hess 1993). If this ratio (QBKF/Q2) was greater than one then the two-year flood was likely to stay within the channel, thereby indicating an entrenced channel. If the ratio was less than one then the channel bed may be aggraded. Finally, if the QBKF/Q2 was approximately one, then the channel bankfull may have been experiencing flooding at a typical ‘bankfull’ interval (i.e. two-year recurrence interval).

Water width and depth were directly measured in the field and summary statistics were generated for the entire reach as well as for each habitat unit type (pool, riffle, runs). To quantify water depth variability throughout the stream reach, four trend statistics were calculated. The difference in depth between each adjacent sampling point was quantified and the average, standard deviation, coefficient of variation and maximum difference were calculated (TREND-D-AVG, TREND-D-STD, TREND-D-CV, TREND-D-MAX).

The water width and depth measured while in the field were referred to as ‘baseflow’ conditions. However, care was taken when analyzing these measurements because based on hydrographs from six USGS gaging stations throughout the watershed (see Table 2-15) most of the sampling was considered at or below mean daily flow conditions. In fact, drought conditions were declared in most of the upper Oconee watershed in the summer of 2000 (Minor 2001). Therefore, the ‘baseflow’ dimensions measured in the field may actually be closer to drought conditions at some sites. As mentioned earlier, three sites that were originally selected could not be sampled due to completely dry channels.

Transport Capacity

Stream power is a measure of the rate of potential energy per unit length for a particular stream reach. This can be thought of as a way to measure the competence of a stream section to move the available sediments and water through the reach (Knighton 1998). Two bankfull stream power values were calculated; STRMPOWF utilized the field-based energy grade line (EGL) while the second utilized the MAPSLOPE value. Unit stream power was calculated by dividing the STRMPOWF and STRMPOWM by the bankfull width (WWBKF).

Another method used to evaluate the transport capacity was to compare DEM-derived slopes at the stream reach relative to the slope just upstream (DEMSLOPE-UDEM) and in the entire watershed (DEMSLOPE-REL). It was hypothesized that if the slope of the upstream segment was steep relative to the sampled reach, the reach sampled may have increased sediment supply. Conversely, if the upstream segment was flat, the sediment may have been settled out, thus limiting the sample reach sediment supply.

A stream power threshold was determined in order to estimate the necessary power to move the available sediments at the reach (Bagnold 1980). The critical stream power threshold was calculated using the formula offered by Bagnold (1980) (Appendix G). Once this critical threshold was estimated, it was divided into the stream power calculated from the field (STRMPOWF) resulting in a ratio describing the transport capacity of the stream relative to what it would take to move the available bed sediments (critical threshold).

Channel Bed Sediments

Many statistics summarizing the size of channel bed sediments were initially calculated and considered for the analyses. The percent of sand, fines, sand plus fines, and bedrock were calculated for the entire reach and within the three habitat types, if present. Phi-based sediment size statistics were summarized (average, minimum, maximum, 95th, 50th, 5th percentiles, standard deviation, coefficient of variation) including bedrock as –10.5 phi and excluding the points where bedrock was encountered. Presence or absence of bedrock was also used as categorical variable (Appendix C).

Habitat

The percent coverage of the three habitat units (pool, riffle, run) was calculated using the 101 point counts from the channel transects. Presence or absence of any riffle habitat at each site was also considered. The riffle to pool ratio used a combined figure of riffle and run habitats to compare with the amount of pool habitat. The percentage of points where woody debris or snags were encountered was also calculated (see Appendix B).

Data Analysis Methods

In order to pare down the list of local and watershed environmental variables to be tested for their relationship to the biotic indices, normality and correlations among the variables were tested. The analyses were conducted within each of the eleven variable groups (stream size, sub-basin setting, ruggedness and elevation, land cover, roads, impoundments, slopes, channel dimensions, channel bed sediments, transport capacity habitat) in order to retain variables for further testing from each group.

First, the distributions of the continuous type environmental variables were tested for normality using the Shapiro-Wilk W-test, (using values greater than or equal to 0.05). In Appendix B, the W-test value is given for all the variables. Certain variables were successfully normalized or showed improved W-values using a log (L), square root (SR), or arc-sine square-root (ASR) transformation.

If multiple environmental variables were normally distributed within each of the eleven groups, then correlation analysis was conducted among the same-group variables. Unless otherwise noted non-parametric correlation analysis (Spearman's rho) was used for the testing because some of the variables were borderline normal (as indicated by the Shapiro-Wilk test). If the correlations were high (generally, $> |0.75|$) and significant ($p \leq 0.05$) among the variables in a similar group then only one was used to test the relationship to the biological variables (IBI, impaired, diversity, richness, abundance).

The relationship between each remaining environmental variable was then tested against each of the biotic variables (IBI, impaired, diversity, richness, abundance). The methods used to explore the variable-biotic metric relationship depended on the type of independent (environmental variables) and dependent data (fish metrics). For the continuous environmental variables and continuous fish metrics, correlation analysis was conducted initially and then simple linear regressions were calculated for those with the highest significant correlations (Spearman's rho). Means testing was used in the case of a categorical variable and a continuous fish metric. T-tests were used for comparisons of two means and one-way ANOVA's used for more than two categories. Contingency tables were analyzed (Pearson Chi-square statistic reported) when both independent and dependent data were categorical. Finally, logistic regression was applied in the case of a continuous variable and the impairment status (a categorical fish metric).

The last statistical analysis utilized the variable that performed the best in the bivariate analyses described above in a regression model with the fish metrics. Using the residuals from these models, the remaining variables were then related to the residuals in regressions and the strength and significance was reported.

Results

Fish Sampling Results

Forty-nine species of fish were identified out of the 20,562 individual fish sampled (> 25 mm SL) at the 49 sites. Table 1-8 shows the list of species and the number of sites at which the species was found. The complete species list for each sample site is shown in Appendix A.

The summary statistics for the IBI score, richness, diversity, and abundance are shown in Table 1-9. The IBI scoring resulted in 14 sites identified as impaired (8 Poor, 6 Very Poor) and 35 sites as non-impaired (2 Excellent, 11 Good, 22 Fair). Figure 1-7 shows the map with the IBI categories (Excellent – Very Poor) of the sampled sites.

Fish Sampling Length to Width Ratio

In order to compare the sample sites with the 35 times wetted width the GA-DNR protocols called for we calculated the length to width ratio (LTOWRATIO) at each of the 49 sites (USGS2000-13 was excluded because width was not measured).

For the 42 LMH2000 sites, the LTOWRATIO range was from 14.0 to 88.1 with mean 35.4 (std.dev. = 14.4). The average and standard deviations were calculated for each size class (Table 1-3) and all the means were compared using t-tests. None were significantly different at the 0.05 level. The summary statistics for the six USGS sites are also given in Table 1-3. Seventeen of our 42 sites equaled or surpassed the GA-DNR recommended sampling length (35 times stream width).

The different sampling lengths at site USGS2000-16 (Mulberry River) yielded differences in the calculated fish metrics. We compared the fish metrics from 250 meters (what would have been our sample reach at that site) to the 391 meters (based on GA-DNR protocol of 35 times wetted width). The added 141 meters sampled changed the IBI score from 40 (Fair) to 48 (Good). The increase in the IBI was driven by the collection of four newly encountered species: 2 *Esox americanus*, 1 *Ictualurus punctatus*, 1 *Lepomis microlophus*, and 3 *Moxostoma collapsum*. This increased richness from 18 to 22 species (metric increased from 3 to 5). The number of native sunfish metric went up from 3 to 5 because of the increase from 3 to 4 species. The number native suckers and number intolerant species metrics both went up from 3 to 5 due to the three *M. collapsum* individuals. Diversity increased from 2.18 to 2.26. The impairment status remained the same (non-impaired) and the abundance per 200 meters went down from 576 to 424, yet did not change the metric (metric 11). The fish species and metrics reported in the Appendix A for site USGS2000-16 reflect the full collection over the 391 meters.

Watershed Environmental Variable Results

Stream Size (GIS)

The watershed size of the streams sampled ranged from 12.8 km^2 to 1,010.7 km^2. Table 1-2 shows the number of sites falling into each watershed size class category.

The four original continuous variables describing stream size using GIS methods (WSHEDAREA, LINK-ORD, DIST-UPST, SIZECLASS) were all highly correlated ($p < 0.0001$ and Spearman $r \geq 0.9$ for all combinations). LINK-ORD was the only size variable with a normal distribution. However, the stratification for site selection was based on watershed size, therefore it was kept in the analyses. Also, DIST-UPST was kept in order to compare the different methods of stream size estimation using GIS and their relationship to the fish metrics.

Spearman correlation analysis revealed the significant and positive relationship between WSHEDAREA, LINK-ORD, and DIST-UPST to IBI score, diversity, and richness (Table 1-10). Logistic regression of impairment status also gave significant results (Table 1-11). Contingency table analysis and means testing (Table 1-12 and Table 1-13, respectively) showed the smaller size classes (SIZECLASS) had a higher probability of being impaired and significantly lower richness, diversity, and IBI scores.

Simple linear regression was used to fit models relating the distance to the upstream headwaters (DIST-UPST) to IBI score, richness, and diversity (Figure 1-8). All three models were significant and the residuals were normally distributed (Shapiro Wilks W-test, 0.05 level). Residual analyses were conducted using variables which were not highly correlated with DIST-UPST (Table 1-14).

Sub-basin Setting

The stratification by sub-basin and network setting resulted in 29 sample sites in sub-basins > 400km2 (SUBBAS), 14 direct tributaries to large rivers (TRIS), and 6 tributaries flowing directly into Oconee Reservoir (TRIR). The size class downstream of each site (DSIZECAT) was measured and resulted in the following: 13 sites = 50km2; 9 sites = 150 km2; 9 sites = 400 km2; 13 sites = >400km2; and 5 sites with the reservoir directly downstream.

Downstream size class and the sub-basin setting showed significant results using the means testing (Table 1-13) and contingency table analyses (Table 1-12) for IBI score, diversity, richness, and impairment status.

In the residual analysis, those sites within a 400 km^2 sub-basin had significantly higher IBI scores, richness and diversity than those sites flowing directly into large rivers (TRIS) and into the large reservoirs (TRIR) (Table 1-15). Downstream size class was significantly correlated to DIST-UPST (Table 1-14) and was not used in residual analysis.

Ruggedness and Elevation

From the eleven variables considered in the ruggedness and elevation group, only drainage density (DRAINDENSITY) and Melton’s ruggedness index (MELTONSRUG) (log transformed) were normally distributed. These two variables were correlated ($r = 0.39$, $p = 0.006$) because Melton’s index was calculated partly using drainage density. Therefore, only Melton’s ruggedness index was considered in further analyses. The index ranged from 0.0059 to 0.0296 (mean 0.0144, and median 0.0130 (st.dev. = 0.0056).

Melton's ruggedness index was significantly correlated to IBI scores, richness, and diversity (Table 1-10). Also, the index produced a significant logistic regression model of impairment status (Table 1-11). However, no residual analysis was conducted because the ruggedness index was correlated with DIST-UPST (Table 1-14).

Land Cover

None of the variables summarizing the 100 m buffer of each stream segment sampled (-SEG) were normally distributed. Most of the segment buffers were highly forested (median = 92.2 % forested) according to the land cover dataset evaluated (Appendix F), causing the distributions of forest and the other land cover classes to be highly skewed.

When analyzing the land cover classes for the riparian areas (-WRIP) within the entire watershed only forest, developed areas (arc sine square root transformation), and pasture were normally distributed. However, forest and pasture were highly correlated ($r = -0.90$, $p < 0.0001$), therefore the latter was excluded from any further analysis. Developed (DEV-WRIP) and forest (FOREST-WRIP) classes did not correlate ($r = -0.10$, $p = 0.53$), therefore both variables were kept.

The variables summarizing the percent land cover for the entire watershed showed similar patterns of normality and correlation as the riparian area analysis. Again, pasture, agriculture and forest were highly correlated (all $|r| > 0.90$, $p < 0.0001$). Of these, the forest (FOREST-WSHED) land cover class was kept for further analysis. The developed land cover class (arc sine square root transformation) was also used because it was not correlated with forest cover ($r = 0.003$, $p = 0.99$).

In summary, only four land cover variables remained after analyzing the twenty-one possible variables for normality and correlation. These were FOREST-WRIP, DEV-WRIP, FOREST-WSHED, and DEV-WSHED. Although, the correlations between FOREST-WSHED and FOREST-WRIP and between DEV-WRIP and DEV-WSHED were quite high and significant ($r = 0.85$, $p < 0.0001$ and $r = 0.82$, $p < 0.0001$, respectively) all four variables were kept in the interest of comparing watershed and riparian land cover classes with the fish metrics. Figure 1-9 and Figure 1-10 show the percent land cover class over the entire watershed and within the riparian buffers, respectively. Both graphs are sorted by the FOREST-WSHED. Table 1-16 shows the summary statistics for the four land cover variables used in further analyses.

Of the four variables tested against IBI score, richness, and diversity only the percent of developed land within the watershed (DEV-WSHED) was significantly correlated to IBI score (Table 1-10). However, percent developed in the watershed and in the riparian areas resulted in significant logistic regression models of impairment status (Table 1-11).

The residual analysis showed that development in the watershed was negatively related to IBI score and diversity values (Table 1-15).

Roads

The density of roads in the watersheds was used in further analyses because it and the density of road-stream intersections in the watershed were correlated ($r = 0.73$, $p < 0.0001$). The road densities ranged from 0.77 km/km^2 to 2.82 km/km^2, averaging 1.77 km/km^2 (stand. dev. = 0.46).

Road density (RD-DENSE-L) did not significantly correlate with any of the fish metrics (Table 1-10 and Table 1-11). However, in the residual analysis, road density showed a significant relationship to diversity residuals with diversity increasing as road density increased (Table 1-15).

Impoundments

Nine indices were used to describe the habitat loss and fragmentation due to impoundments. Of these, five were eliminated from further analyses due to non-normal distributions (FRAG-DOWN, FRAG-UP, IMP-DENSEAREA, IMP-WSHEDRATIO, IMP-LOSS). Total fragmentation (FRAG-TOT) had a borderline non-normal distribution ($W < 0.0466$) and was kept in the analysis. Correlation analyses among the remaining variables of impoundment density (IMP-DENSE; log transformation), percent of first order streams fragmented (ORD1-LOSS), and distance downstream to an impoundment (IMP-DWNDIST) showed only one significant correlation between the IMP-DENSE and ORD1-LOSS ($r = 0.60$, $p < 0.0001$). All four variables are summarized in Table 1-17.

None of the impoundment-based variables produced significant logistic regression models of impairment status (Table 1-11). Total fragmentation (FRAG-TOT) was correlated with IBI score, diversity, and richness (Table 1-10). However the variable was also correlated with DIST-UPST (Table 1-14), therefore it was not used in the stream size residual analysis. Impoundment density was the only variable to correlate with fish abundance (Table 1-10). The percentage of 1st order streams (Strahler 1957) fragmented (ORD1-LOSS) had marginal significance in correlating with richness and did not yield significant results in the residual analyses (Tables 1-10, 1-15). The distance downstream to an impoundment (IMP-DWNDIST) was correlated to IBI score and diversity (Table 1-10) and was significantly related to these metrics in the residual analysis (Table 1-15).

Local Environmental Variable Results

Slope

Of the five slope variables measured three showed normal distributions after log transformations: EGL, MAPSLOPE, DEMSLOPE. EGL and MAPSLOPE showed some correlation of 0.34 ($p = 0.03$), as did DEMSLOPE and MAPSLOPE ($r = 0.37$, $p = 0.01$). However, EGL and DEMSLOPE show no significant correlation ($r = -0.02$, $p = 0.90$). The summary statistics for the three slope variables are shown in Table 1-18.

EGL did not significantly relate to any of the fish metrics (Tables 1-19 and 1-20) nor was the variable significant in the stream size residual analysis (Table 1-24). MAPSLOPE did correlate with diversity and richness, yet was also correlated with DIST-UPST (Table 1-23). The slope of the stream segment based on the DEM (DEMSLOPE) was negatively correlated with fish richness (Table 1-23). Because DEMSLOPE was only marginally correlated with DIST-UPST (Table 1-23) it was used in the residual analysis and was found to produce a marginally significant model of richness stream size residuals (Table 1-24).

Channel Dimensions

Of the fifty channel dimension variables, only six variables were used in further analyses with the biotic metrics. These variables included the average depth (DBASE) and width (WWBASE) at ‘baseflow’ and average discharge (QBKF), depth (DBKF), and width (WWBKF) at bankfull as calculated from the cross-sections measured in the field. Also, the ratio of discharge at bankfull to the two-year recurrence interval discharge as calculated from regional discharge yield curves (QBKF/Q2). Although, most of the variables were correlated with one another (Table 1-25) none were |r| > 0.9, and all were kept for further analyses.

Summary statistics are given for the channel dimensions in Table 1-26. All sites, except site USGS2000-13 were used for the average channel width at baseflow (WWBASE) (n = 48). The bankfull estimates and baseflow depth measurements were taken from 41 sites. Appendix D shows both cross-sections for each of the 41 sites and marks the elevation used for the bankfull calculations.

Many of the channel dimensions were significantly correlated with the fish metrics (Tables 1-19 and 1-20). Generally, the larger channels had higher fish richness, IBI scores, diversity, and were less likely to be impaired. However, all were highly correlated with DIST-UPST and dependent on the watershed size, thus were not tested in the residual analysis (Table 1-23).

Transport Capacity

Of the nine variables used to describe the transport capacity of the streams, five were normally distributed (USTRMPOWM, USTRMPOWF, STRMPOWM, STRMPOWF, BAGRATIO). Only three variables were kept for the remaining analyses due to high correlations with the other variables. These were the unit stream power as calculated from mapslope (USTRMPOWM), unit stream power as calculated from EGL (USTRMPOWF), and the Bagnold ratio of stream power to critical stream power (BAGRATIO) (Table 1-27).

None of the three variables describing transport capacity were significantly related to the fish metrics (Tables 1-19 and 1-20) nor the stream size residuals (Table 1-24).

Channel Bed Sediments

Most of the 51 continuous variables summarizing the channel bed sediments were not normally distributed despite efforts to transform the variables (only 6 out of 49 had $W > 0.05$). Many of the phi-based variables were highly skewed because most of the sites had channel bed sediments that were comprised of primarily particles less than 2 mm (sand; -0.5 phi). For example, approximately 88% of the sites (36 out of 41) had more than 50% sand or fines encountered on the channel transects (Figure 1-11). Also, because all of the habitat units did not occur at many of the sites (see Figure 1-12), many sediment variables summarized for the habitat units (e.g. %SANDPOOL, AVGRUN-PHIBR) were skewed.

Percent sand (%SAND) was normally distributed without transformation, whereas percent fines (%FINES) and percent < 2 mm (%LT2MM) needed arc-sine square-root transformations. Percent particles < 2 mm was significantly correlated with percent sand ($r = 0.70$, $p < 0.0001$) and consequently, was dropped from further analysis.

Three variables quantifying the variability of sediment size were normally distributed, yet only one was not highly correlated with percent sand. However, both the standard deviation of phi sizes including bedrock (STDPHIBR) and not including bedrock (STDPHI) significantly correlated with the percentage of sand ($r = -0.59$, $p < 0.0001$ and $r = -0.62$, $p < 0.0001$, respectively) and were dropped. The one variable quantifying sediment size variability that was kept was the coefficient of variation of the phi sizes including bedrock (CVPHIBR). The values ranged from –2.19 phi to –0.55 phi, with a mean –1.12 (stand. dev. = 0.48).

The presence or absence of bedrock was also considered (BEDROCK-P/A). Bedrock was present at twenty-two sites (Figure 1-11).

Percent sand (%SAND), percent fines (%FINES), coefficient of variation of the phi sizes including bedrock (CVPHIBR), and the presence or absence of bedrock (BEDROCK-P/A) were the channel bed sediments variables used for testing against the fish metrics. Percent fines did not relate significantly to any of the fish metrics (Tables 1-19 and 1-20). Percent sand was marginally correlated with fish diversity (Table 1-19) and in the residual analysis it remained negatively and significantly related to diversity and had a marginally negative significance in relation to richness (Table 1-24). Variation in sediment size (CVPHIBR) was correlated with IBI scores and richness, yet it was highly correlated to DIST-UPST and was not used in the residual analysis (Table 1-23). The presence of bedrock led to higher IBI scores and higher diversity values (Table 24). These relationships remained significant in the residual analyses (Table 1-24).

Habitat

The percentage of points encountered along the transects for the three habitat units at the 41 sites are shown in Figure 1-12. However, none of the distributions of the habitat types were normally distributed. Instead, the presence or absence of pools (POOL-P/A) and riffles (RIFFLE-P/A) were used in further analyses. Use of both variables was supported by finding no significant relationship of presence/absence of pools to the presence/absence of riffles based on the likelihood ratio chi-square test using the contingency table (Table 1-28). Riffles were found at 15 sites and pools were found at 29 sites.

Percent observations of woody debris (%WOODYD) along the channel transects proved to be normally distributed using the using the arc-sine square-root transformation. The percent woody debris at the 41 sites varied from 1.0% to 39.6% with mean 14.1 (stand. dev. = 8.9).

Higher percentages of woody debris were correlated with higher fish richness values, yet was not significant in the stream size residual analysis (Tables 1-22 and 1-24). The presence of pools yielded marginally significant diversity values (Table 1-22), yet did not result in significant relationships in the residual analyses (Table 1-24). Conversely, presence of riffles originally did not yield any significant relationships to fish metrics (Tables 1-21 and 1-22), yet was significant in the IBI residual analysis (Table 1-24).

Discussion

Streams in the upper Oconee watershed were sampled for fish in order to measure fish diversity, native richness and abundance and, ultimately, used to calculate a fish-based Index of Biotic Integrity (IBI). These were analyzed with respect to a suite of watershed and local environmental variables which took into account both natural and anthropogenic factors.

It was evident from the analyses that stream size was a dominant factor in determining fish community patterns in the upper Oconee watershed. The results indicated that as the stream size increased, whether measured using GIS methods (watershed area, distance upstream, or number of 1st order links) or in the field (width, depth, discharge), the diversity and richness of fish increased as well (Figure 1-8). These relationships of fish community structure to longitudinal patterns are well established in the literature (e.g. Marsh-Matthews and Matthews 2000, Schleiger 2000, Angermeir and Winston 1999, Richards et al. 1996, Osborne and Wiley 1992, Barila et al. 1981). For example, in an early study Sheldon (1968) showed the ‘longitudinal succession’ (i.e. stream size) in one stream system where increased number of species was found as the stream size increased.

Interestingly, the effect of stream size was similar and also significant in determining IBI scores and impairment status. For example, the watershed size classes had significantly higher scores (Table 1-13) and had a low probability of impairment (Table 1-12).   Many of the channel width and depth variables also were significantly related to IBI score and impairment status. These channel dimensions increased positively and predictably as the distance from the headwaters increased (Table 1-23). The maximum watershed size to have an impaired status was 56.4 km^2 (LMH2000-37). The average watershed size of the impaired streams was 29.8 km^2, whereas, the average watershed size sampled was 128.9 km^2.

One can interpret this relationship of IBI scores to stream size a number of ways. One way to interpret this is that the larger streams are more resistant to the effects of land use change, road densities, impoundments and other anthropogenic impacts on streams due to increase habitat diversity and areas of refugia within the larger channel. Alternatively, the larger streams may recover faster (i.e. more resilient) from disturbance effects. However, many studies have found small stream fauna to be regularly exposed to natural disturbances (e.g. extreme variations in flow) and hence more resilient than large river fish communities (Schlosser 1990, Labbe and Fausch 2000, Osborne and Wiley

1992). Another possibility is that the IBI itself is not adequately accounting for natural stream size fish community gradients in order to effectively detect degraded stream reaches at a wide range of stream sizes.

If the latter is true, then the explanation may lie in the streams sizes GA-DNR sampled in originally developing the IBI. The Mean Species Richness (MSR) plots (Appendix H) for the Piedmont Atlantic slope drainages show they sampled approximately 10 sites that had watershed areas over 100 km^2. These few sites may not have captured the range of conditions (degraded to intact) in order to build robust regional models for streams over a certain size. The lines that include 95 percent and 5 percent of the sites are fit by eye and then the area is trisected to rate the metric 1, 3, or 5 (Karr et al. 1986, GA-DNR 2000). Therefore, if both very poor and excellent sites are not sampled in large streams while building the IBI, the MSR plots will not reflect the full range of conditions.

On the other hand, the IBI seemed quite effective in describing and discriminating integrity classes in our two smallest size classes (15 km^2 and 50 km^2). These size classes more closely reflect the stream sizes that the GA-DNR sampled and developed the IBI based on the full spectrum of conditions (see Appendix H).

The differences in methods in determining sampling lengths between our study and GA-DNR protocol must also be considered when evaluating the GA-DNR IBI. The GA-DNR protocol varied the length sampled based on the wetted width at the time of sampling (35 x wetted width), whereas, the method we employed used a set distance based on the size class of the stream. Originally, we decided against using the GA-DNR protocol primarily for two reasons. First, the time and effort necessary to sample over

300 meters required more people than the four person crew we had available. Secondly, using wetted width may have under-sampled locations because of the drought conditions occurring during our study period. For instance, a stream may be only 5 meters across during extremely low drought flows whereas, ‘normal’ (i.e. non-drought years) baseflow widths might be 7 meters. For the same site, this would mean sampling 70 meters less (245m → 175m), perhaps missing a few riffle/pool sequences. The results may therefore vary from year to year simply because of the differences in sampling lengths due to the variable wetted width. Ideally, the same riffle and pools would be sampled from year to year to consistently measure the same habitat (Karr et al. 1986).

The comparison of sampling methods at site USGS2000-13 suggested at the larger sites we may have sampled too short a distance. By using the last 250 meters (out of the full 390 m) the results would have undercounted the number of species, yielded a lower diversity score and an IBI rating of FAIR instead of GOOD. This was quite a dramatic difference, yet inconclusive because if we had used the first 250 meters of the sample then we would have included all the species from the entire 390 meters and yielded similar diversity and IBI ratings.

The analyses relating the length to width ratio (LTOWRATIO) showed that as the ratio went up (i.e. > 35) diversity went down and the likelihood of being impaired went up (see Tables 1-19 and 1-20). Even in the residual analysis (using stream size) the diversity went down as the ratio increased (Table 1-24). Driving this trend are the lowest diversity streams were smaller streams which tended (although not significantly) to be sampled at higher length to width ratios than the larger streams. Obviously, the further you go in a stream the more likely you are to come across new species, yet when is it too far to go? As discussed above even though the larger streams were under-sampled when comparing LTOWRATIO (Table 1-3), it appears that the large streams are being sampled at distances that almost guarantees that they will not score poor or very poor. Alternatively, the MSR plots need to be revisited and adjusted so as to allow for low scores. Nonetheless, the issue of sampling lengths needs more attention, especially at larger sized streams.

As mentioned earlier, stream size as measured from a GIS (e.g. DIST-UPST, WSHEDAREA) related to many of the local environmental variables (see correlations in Table 1-23). Many useful physical relationships for the upper Oconee watershed can be modeled from these data. For example, a simple linear relationship was found between the bankfull width (WWBKF) and the log watershed area (WWBKF = -1.066 + 8.973 * $\log_{10}$WSHEDAREA; r2 = 0.66, $p < 0.0001$; n = 41). Hydraulic geometry relationships like these are well established in the literature (Dunne and Leopold 1978).

Also of note, was the finding that the variation in channel bed sediment size increased (as measured by CVPHIBR) as stream size increased (Table 1-23). This variation in sediment sizes may be one important factor influencing fish community diversity. Indeed, Gorman and Karr (1978) showed that the habitat diversity, in part relating to stream bed sediment size, tended to increase in the downstream direction and this feature helped drive the increased species richness and diversity.

Another channel dimension metric used in the analyses was the ratio of the bankfull flow as modeled from the cross-sections (Appendix D) to the two-year discharge (Figure 1-4; QBKF/Q2). The ratio should give an idea of how entrenched or aggraded a channel may be. For example, if the ratio is greater than one then the two year discharge may not overtop the banks because it is entrenched. Conversely, if the ratio is less than one then the floodplain may get inundated more often, perhaps due to a stream bed that is unusually aggraded. This entrenchment ratio did not yield any significant relationships with the fish metrics, perhaps indicating that in-stream fish habitat is less dependent on the cross-sectional characteristics (i.e. entrenchment) than on the channel bed sediments and habitat units within the channel itself. This result was also found in a similar study in the Georgia Piedmont (Leigh et al. 2001).

We did find, however, that QBKF/Q2 ratio had an influence on the percentage of sand found at a site, perhaps due to the added energy of the flood in channels that are entrenched. In fact, the data show a significant decrease in the amount of sand as the streams become more and more entrenched ((R^2 = 0.13, F>0.0217). The ratio also shows a negative relationship to watershed area (R^2 = 0.17, F>0.006), meaning that the larger streams still may be flooded by the two-year flood and the smaller streams may be somewhat more entrenched. These relationships seem to support the findings of Ruhlman and Nutter (1999). In a study in the upper Oconee watershed, they found that many smaller streams have already cut down into the historic sediments in their beds deposited from the poor farming practices. However, they go on to surmise that the 'pulse' of sediment is still working its way down through the system, thus causing channel beds to be aggraded. One must also consider the alterations to the flooding regime caused by the many artificial impoundments within the watershed (see Chapter 2). Many small ponds and flood control dams have been constructed (i.e. NRCS watershed dams) which eliminate the large floods and perhaps may slow the recovery process in the larger streams. The larger floods would tend to flush out the sediments and return the channel to a less aggraded state.

Stream slope or gradient is another local geomorphic measure that has been shown to have a strong relationship to fish community metrics and was expected based on other similar studies in the Georgia Piedmont (Leigh et al. 2001, Walters et al. 2001). However, for our study sites, the EGL (field-based slope) did not correlate significantly with any of the fish metrics (Tables 1-19 and 1-20). Even after the effect of stream size was factored out, EGL did not significantly relate to the residuals of the fish IBI, diversity or richness (Table 1-24). The slope as measured from topographic maps (MAPSLOPE) and digital elevation models (DEMSLOPE) were not useful in describing the fish metrics. In some cases MAPSLOPE did correlate slightly, yet this was attributed to its correlation with stream size as measured by GIS. It is interesting to note that MAPSLOPE was correlated significantly with EGL ($r = 0.34$, $p = 0.03$) while DEMSLOPE was not ($p = 0.90$) showing that digital elevation models (DEM) in a GIS still do not have high enough resolution to approximate local slope with any accuracy.

Energy grade line (EGL) is a large controlling factor for local channel bed conditions and transport capacity (see formula for Stream Power, Appendix G). A high slope environment generally results in larger stream bed sediment particles (Knighton 1999, Hoey and Bluck 1999, Gomez 1991). Our analysis showed a significant relationship was found between EGL and percent sand ($\%SAND = 7.354 – 17.50 * \log_{10}EGL$; $F=0.0183$; $n = 41$). However, the explanatory power was low ($R^2 = 0.13$). The transport capacity measures showed the streams had more than enough competence to move the sediments (i.e. high BAGRATIO). However, the channel transects revealed a dominant sand and fines component that made up the bed sediments in the upper Oconee watershed. In fact, 88% of the sites had more than 50% sand along the transects (Figure 1-11). One explanation for this lack of significance in the relationship between transport capacity and sediment size is that the upper Oconee system is so dominated by sand that no matter the transport capacity or EGL there is always a supply of small sediments (Ruhlman and Nutter 1999, Trimble 1970). In other words, even if the sediments are mobile and shift during high flows, a constant supply is coming from remobilized upstream sediment continuously 'recharging' the sand and fines. Indeed, Trimble (1970) showed the erosive agricultural practices of the late 19th and early 20th century have left a legacy of much sediment in the rivers of the Georgia Piedmont.

Even with this ubiquitous sand component in the streams, slightly more sand at a site did prove to decrease fish community diversity and richness (Tables 1-19, and 1-24). Generally, clean, large sediments (pebble and cobble sized) provide better spawning sites and feeding habitats for many species of fish (e.g. Waters 1995). Contrary to what most studies have found (e.g. Newcombe and Jenson 1996, Warren et al 2000), we did not detect any relationship with the percentage of fines, yet we did not measure turbidity or suspended sediments for the sites which may be a more appropriate measure affecting fish communities (Schleiger 2000, Waters 1995).

The presence of bedrock correlated with higher IBI scores and diversity for the initial analyses and for the analysis of stream size residuals. Bedrock outcrops may be areas where fines and sands do not deposit, thus improving stream bed habitat quality. In fact, the average percent sand at sites with bedrock present is significantly lower than sites without bedrock (48 % and 63 %; $p = 0.029$, $df = 39$). We found bedrock at over half the sites (22 out of 41) we sampled. A 1956 geologic study of the Oconee River showed bedrock outcrops played an extremely important role in dictating the stream courses and profiles within the Georgia Piedmont (Woodruff and Parizek 1956). Also, bedrock outcrops may be fairly common in the Piedmont as evidenced by the high density of historic hydropowered mills once built all over the Piedmont (Doyon 1983).

Habitat, as measured by percent woody debris and presence or absence of riffle and pool habitat, influenced the fish metrics in a number of ways. Riffle habitat is generally thought to be high in fish richness, especially for small-bodied fishes (Warren et al. 2000). We did not find evidence of increased richness, yet did find that riffles tended to increase IBI scores (Table 1-24). The presence of pool habitat did have a marginally significant positive effect on diversity as shown by the means testing and residual analysis (Tables 1-22 and 1-24). Pool habitat, especially deep pool habitat, is important refugia in times of drought or low flow (Labbe and Fausch 2000, Schlosser 1990). Woody debris has also been shown to correlate with higher species richness due to the added habitat heterogeneity and cover offered by large woody debris (e.g. Gorman and Karr 1978, Stauffer et al. 2000, Harding et al. 1998). In our analyses, the initial correlation results showed a significant and positive relationship with richness. However, this may have been due to the slight correlation with stream size. Thus, in the residual analysis, woody debris did not correlate with any of the fish metrics.

We found the IBI, diversity and richness responded to the different positions in the network as measured by the sub-basin setting category (SUBBAS-C) and downstream size category (DSIZECAT). Osborne and Wiley (1992) found evidence to suggest that the streams with large downstream confluences, usually denoted as DLINK, were associated with higher fish richness. They went on to hypothesize that this increased richness was due, in part, to the larger population pool and the relatively more stable habitat of larger streams as compared to smaller streams. Our initial analysis supported this and showed larger downstream sizes (DSIZECAT) were associated with higher diversity, richness, and IBI scores (Tables 1-12 and 1-13). Yet this measure did not remain significantly related to the fish metrics in the residual analysis because of the positive correlation with stream size (Table 1-14). Larger streams will have larger downstream links, and therefore, caution must be used when solely looking at the downstream size (e.g. DSIZECAT, or DLINK) because of this correlation.

As an alternative to measuring the size class of the downstream confluence, the downstream setting was used also (SUBBAS-C). As compared with tributary streams flowing into the mainstem of larger rivers (TRIS) or directly into the large reservoirs (TRIR), the streams within the 400 km^2 watersheds (SUB-BAS) tended data to have more fish species, higher diversity, and higher integrity as measured by the IBI (Tables 1-12, 1-13, and 1-15). This may be a result of the populations of small stream fish essentially being isolated from other populations by reservoirs or large rivers (Winston 1991). Local extirpations of small stream fish populations perhaps cannot be easily recolonized because the large rivers and reservoirs may effectively form a barrier (Winston 1991, Wilde and Ostrand 1999). Also, predation pressure from large river species or species that proliferate in reservoirs may change the community structure for these smaller streams that flow directly into larger water bodies (Willis and Magnuson 2000, Schrank 2001). For example, *L. osseus*, generally considered a medium to large river or lake species (Page and Burr 1991), was found in a relatively small stream (61.5 km^2 - site

LMH2000-37), perhaps because it was only 5 km upstream from the impounded waters of Oconee Reservoir, a source population. The results of this analysis suggest that the downstream setting (e.g. sub-basin, river, reservoir) may be an important factor in the local fish community structure, yet more research is needed in order to test this relationship.

Land cover uses such as row crop agriculture, residential and commercial development, have been implicated in degrading water quality and causing the decline of natural fish communities through their contributions to non-point source pollution (e.g. Schleiger 2000, Lammert and Allan 1999, Rothrock et al. 1998, Allan and Johnson 1997). Our results confirmed this for the upper Oconee watershed. Even with only a maximum of 10% development within the watershed, a negative effect on stream integrity and diversity was detected in our dataset (Tables 1-10, 1-11 and 1-15). This relationship seemed to be stronger using the entire watershed values (-WSHED) rather than the riparian zone (-WRIP) or the stream segment nearest upstream from the site (-SEG). However, it must be noted that the land cover dataset used for this study was an older dataset derived from satellite imagery dating between 1989 and 1993. Recent land cover may correlate more strongly and also reveal relationships with the riparian land cover (Leigh et al. 2001). Also, past land uses have been shown to continue to affect stream systems long after they have been converted to more natural vegetation (Harding et al. 1998). Indeed, the watershed of the upper Oconee was intensively farmed during the cotton era in the late 1800’s and early 1900’s and the legacy of this era may still be apparent in the stream system (Trimble 1970, Ruhlman and Nutter 1999).

As with developed land uses, roads and road construction have been found to be detrimental to streams and to aquatic communities (Jones et al. 2000, Warren and Pardew 1998, Weaver and Garman 1994). Studies have cited roads as sources of pollution and erosion as well as potential barriers to movement (Warren and Pardew 1998). However, our data showed an increase in road density to be associated with increased diversity (Table 1-15). The explanatory power was low, yet it was significant. The roads database is relatively current, yet new residential development roads may be missing and could influence the results in some cases. The type of road and position in the stream network may also influence the effect on the stream system (Warren and Pardew 1998, Jones et al. 2000) and perhaps, incorporating the type and network position may shed more light on the results we found.

Impoundments are another way in which human development can affect the fish communities in the streams. Recently, Schrank et al. (2001) showed that the density of impoundments negatively impacted a small stream dwelling fish species. Winston et al. (1991) and Wilde and Ostrand (1999) showed the upstream extirpation of a fish species due to fragmentation by a larger reservoir. Our study also shows an impact on fish communities. The four impoundment variables analyzed in this study showed correlations with the fish community metrics. For example, as the percentage of stream remaining connected (FRAG-TOT) increased, the IBI and diversity increased (marginally significant, Table 1-10). The distance downstream to an impoundment (IMP-DWNDIST) affected the diversity after watershed size was factored in, as shown by the residual analysis (Table 1-19). The techniques for measuring and quantifying the cumulative impacts from impoundments are addressed in Chapter 2 of this thesis.

The results of our sampling efforts and scoring of the stream integrity showed the overall status of the upper Oconee was to be fair. Indeed, almost half of the streams scored fair in using the IBI rating. However, there are at least two relatively intact sub-watersheds. Many streams of the North Oconee River and the Little River were shown to have good to excellent stream integrity in many of the streams within the sub-watershed. These sub-watersheds have not seen extensive residential or commercial development to date and consequently may be in good condition. Also, these sub-watersheds were shown to have fewer impoundments and higher stream connectivity (less fragmentation) than other sub-watersheds (see Chapter 2 also). Therefore, efforts should be made to maintain stream habitat by limiting the deleterious effects of residential development and impoundments. In addition, many sub-watersheds in the upper Oconee watershed appeared to be in need of restoration efforts. For example, many of the direct tributaries to the Oconee reservoir and the regulated (via hydroelectric dams) portion of the Oconee River score very poor or poor in the IBI assessments. It will be important to understand how we can restore these streams that may be isolated due to the impoundment and unstable flow conditions caused by the regulated river.

Summary

This study examined the influences of both watershed and local environmental variables on fish diversity, richness, abundance, and an Index of Biotic Integrity (IBI) developed by the GA-DNR. The IBI is being used to assess streams throughout the Georgia Piedmont. In order to properly assess the health of a stream, it is crucial to separate natural variation in fish communities due to watershed or local conditions from anthropogenic disturbances such as land cover and impoundments.

We found that a number of watershed and local variables influenced fish community structure and integrity (as measured by the IBI). For example, the presence of riffles, bedrock, and lower percent sand at a site increased diversity, richness, and IBI values. However, the strongest influence came from stream size. As the stream size increased, no matter the method of measurement (GIS-based watershed area, distance upstream to the headwaters, or field-based channel dimensions), diversity and richness increased and the IBI (score and impairment status) improved. The influence of stream size must be considered more fully in the future use of the IBI, especially for larger streams. These results indicate the importance of factoring the stream size and also the natural variation in the local geomorphic/habitat characteristics when attempting to assess the integrity of the streams. We found that many of these factors were adequately incorporated into the IBI developed for the Georgia Piedmont by the GA-DNR. However, more data from large streams should probably be analyzed in order to better assess stream impairment.

Anthropogenic impacts on the fish communities were detected in the upper Oconee study. As residential and commercial development increased in the entire watershed the IBI and fish metrics decreased. This same relationship held when assessing the riparian (100 m buffer) areas throughout the watershed above the sites sampled. We found no or very slight improvement in the fish community metrics as road density increased. The cause for this relationship is not known and needs further exploration. The proliferation of impoundments may also be degrading the fish communities in the streams. We found that as the distance downstream to an impoundment decreased many of the fish metrics decreased also. Therefore, in order to better protect and restore streams in the upper Oconee watershed, conservation efforts must be implemented that limit the impacts of development and impoundments on stream integrity.

CHAPTER 1 TABLES AND FIGURES

Table 1-1. Watershed size classes and sub-basin distribution of road-stream intersections. The 'Other' class contains those intersections not falling in the 15, 50, 150, or 400 km^2 size classes (e.g. < $9km^2$ or > $573km^2$).

Watershed Size Class (km2)	Sub-Basins									Large River Tribs	Reservoir Tribs		Total
	APA	HLC	LIT	MOC	MUL	NOC	BCC	MUR	SHB	TRIS	OCOR	SINR	
15	26	25	19	17	26	22	5	22	9	88	28	24	311
50	10	3	10	14	3	7	10	4	7	22	15	7	112
150	8	8	7	9	5	6	2	4	1	9	1	0	60
400	8	4	1	4	4	6	4	4	1	0	0	0	36
Other	278	153	235	248	261	247	90	138	79	928	342	242	3241
Total	330	193	272	292	299	288	111	172	97	1047	386	273	3760

____ not considered for site selection due to recent collections by GA-DNR

Table 1-2. Watershed size classes and sub-basin distribution of the sites sampled for this study (LMH2000) and for USGS 2000 data.

Watershed Size Class (km2)	APA	HLC	LIT	MOC	MUL	NOC	TRIS	OCOR	Total
15	1	1	2	1	2	3	5	1	16
50	1	1	1	2	1	1	3	5	15
150	1	2	1	1	0	1	4	0	10
400	1	1	1	1	1	1	0	0	6
Other	0	0	0	0	0	0	2	0	2
Total	4	5	5	5	4	6	14	6	49

Table 1-3. Summary statistics for LTOWRATIO for the size classes of the 42 LMH2000 and for six USGS sites (USGS2000-13 not included).

Size Class	N	Mean	Maximum	Minimum	Std Dev
15	13	36.7	66.1	25.2	11.6
50	15	40.7	88.1	22.1	16.7
150	9	28.9	49.4	17.4	11.8
400	5	27.8	42.4	14.0	13.2
USGS Sites	6	34.6	38.8	21.6	6.6

Table 1-4. IBI Metrics and Calculations (developed by GA-DNR for Apalachicola and Atlantic Drainages of the GA Piedmont).

Metric	Watershed Size	Scoring Criteria		
(*group*)	**(mile^2)**	**5**	**3**	**1**
Species Richness and Composition				
1. Total number of native fish species	All	Consult graph		
2. Total number of benthic invertivore species	All	Consult graph		
3. Total number of native sunfish species	All	Consult graph		
4. Total number of native cyprinid species	All	Consult graph		
5. Total number of native sucker species	All	Consult graph		
6a. Total number of intolerant species	> 20	Consult graph		
6b. Total number of sensitive species	< 20	Consult graph		
Trophic Composition and Dynamics				
7. Evenness	All	≥ 70%	70–58%	≤ 58%
8a. Proportion of omnivores	< 20	< 14%	≥14-28%	≥ 28%
8b. Proportion of sunfish	> 20	< 26%	≥ 26-46%	≥ 46%
9. Proportion of insectivorous cyprinids	All	> 54%	≤ 54-33%	≤ 33%
Fish Abundance and Condition				
10a. Proportion of top carnivores	> 10	> 3.5%	≤ 3.5-2%	≤ 2%
10b. Proportion of pioneer species	< 10	< 42%	≥ 42-69%	≥ 69%
11. Individuals collected per 200 meters	> 10	> 700	≤ 700-350	≤ 350
12a. Proportion of simple lithophilic spawners	> 10	> 54%	≤ 54-30%	≤ 30
12b. Number of native simple lithophilic spawners	< 10	Consult graph		
13. Proportion of fish with external anomalies	All	> 1.2% - subtract 4 points from total score		

Table 1-5. IBI Integrity and Impairment Classes

IBI Score	60-52	50-44	42-34	32-26	24-8
Integrity Class	Excellent	Good	Fair	Poor	Very Poor
Impairment	Not Impaired			Impaired	

Table 1-6. Stream bed sediment size range and phi size used in analyses.

Name	mm (range)	phi
Fine	estimated	-0.5
Sand	1/16 - 2	-0.5
Granules	2 - 4	-1.5
Pebble	4 - 8	-2.5
	8 - 16	-3.5
	16 – 32	-4.5
	32 – 64	-5.5
Cobble	64 – 128	-6.5
	128 – 256	-7.5
Boulder	> 256	-8.5
Bedrock		-10.5

Table 1-7. MRLC land cover classes comprising the categories for this study.

Variable Categories	Original MRLC class (class number)
FOREST	deciduous forest (41); evergreen forest (42): mixed forest (43); forested wetland (91); emergent wetland (92)
AG	pasture (81); row crop (85)
DEV	low intensity residential (21); high intensity residential (22); commercial/industrial (23); bare rock (31); quarry/mine (32); transitional barren (33)
PAST	pasture (81)
CROP	row crop (82)
HRES	high intensity residential (22); commercial/industrial (23)
LRES	low intensity residential (21)

Table 1-8. List of the species collected and the number of sites at which each was found. List arranged in alphabetical order by genus and species.

Common Name*	Latin Name*	Number Sites
Snail bullhead	*Ameiurus brunneus (Jordan)*	28
White catfish	*Ameiurus catus (Linnaeus)*	2
Yellow bullhead	*Ameiurus natalis (Lesueur)*	7
Brown bullhead	*Ameiurus nebulosus (Lesueuer)*	4
Flat bullhead	*Ameiurus platycephalus (Girard)*	8
Pirate perch	*Aphredoderus savanus (Gilliams)*	9
Bluefin stoneroller	*Campostoma pauciradii (Burr and Cashner)*	6
Ocmulgee shiner	*Cyprinella callisema (Jordon)*	15
Altamaha shiner	*Cyprinella xaenura (Jordan)*	24
Common carp	*Cyprinus carpio (Linnaeus)*	1
Gizzard shad	*Dorosoma cepedianum (Lesueur)*	2
Creek chubsucker	*Erimyzon oblongus (Mitchill)*	11
Redfin pickerel	*Esox americana (Gmelin)*	12
Chain pickerel	*Esox niger (Lesueur)*	7
Christmas darter	*Etheostoma hopkinsi (Fowler)*	13
Turquoise darter	*Etheostoma inscriptum (Jordan and Brayton)*	27
Tessellated darter	*Etheostoma olmstedi (Storer)*	6
Mosquitofish	*Gambusia holbrooki (Girard)*	3
Mosquitofish	*Gambusia species***	19
Eastern silvery minnow	*Hybognathus regius (Girard)*	2
Rosyface chub	*Hybopsis rubrifrons (Jordan)*	30
Northern hogsucker	*Hypentelium nigricans (Lesueur)*	16
Channel catfish	*Ictalurus punctatus (Rafinesque)*	6
Brook silverside	*Labidesthes sicculus (Cope)*	1
Longnose gar	*Lepisosteus osseus (Linnaeus)*	2
Redbreast sunfish	*Lepomis auritus (Linnaeus)*	42
Green sunfish	*Lepomis cyanellus (Rafinesque)*	19
Warmouth	*Lepomis gulosus (Cuvier)*	17
Bluegill	*Lepomis macrochirus (Rafinesque)*	34
Redear sunfish	*Lepomis microlophus (Gunther)*	8
Bandfin shiner	*Luxilus zonistius (Jordan)*	2
Redeye bass	*Micropterus coosae (Hubbs and Bailey)*	15
Largemouth bass	*Micropterus salmoides (Lacepede)*	21
Spotted sucker	*Minytrema melanops (Rafinesque)*	8
V-lip redhorse	*Moxostoma collapsum (Cope)*	22
Bluehead chub	*Nocomis leptocephalus (Girard)*	41
Golden shiner	*Notemigonus crysoleucas (Mitchill)*	4
Dusky shiner	*Notropis cumminsae (Myers)*	3
Spottail shiner	*Notropis hudsonius (Clinton)*	29
Longnose shiner	*Notropis longirostris (Hay)*	1
Yellowfin shiner	*Notropis lutipinnis (Jordan and Brayton)*	37
Coastal shiner	*Notropis petersoni (Fowler)*	8
Tadpole madtom	*Noturus gyrinus (Mitchill)*	8
Margined madtom	*Noturus insignis (Richardson)*	26
Yellow perch	*Perca flavescens (Mitchill)*	3
Blackbanded darter	*Percina nigrofasciata (Agassiz)*	25
Black crappie	*Pomoxis nigromaculatus (Lesueur)*	6
Striped jumprock	*Scartomyzon rupiscartes (Jordan & Jenkins)*	37
Smallfin redhorse	*Scartomyzon sp. cf. lachneri (Robins & Raney)*	9
Creek chub	*Semotilus atromaculatus (Mitchill)*	19

* Names from Warren. Jr. et al. 2000
** USGS identified all *Gambusia* species, LMH identified only as *Gambusia* species, *G. holbrooki* and *G. affinis* are thought to occur in the watershed

Table 1-9. Summary statistics for fish metrics at 49 sites.

Biotic Metric	Maximum	Minimum	Mean	Std.Dev.
IBI Score	54	16	36.9	8.7
Native Richness	28	5	15.0	5.0
Diversity (No.)	0.89	2.49	1.82	0.44
Abundance / 200m	1012.7	41	372.0	186.5
Biomass (kg) / 200m	7.86	0.20	1.61	1.22

Table 1-10. Spearman rank correlations of watershed environmental variables to IBI score, diversity, richness, and abundance.

Watershed Environmental Variable	N	Spearman Rho IBI Score	p-value	Spearman Rho Diversity	p-value	Spearman Rho Number Natives	p-value	Spearman Rho Abundance/200m	p-value
WSHEDAREA	49	**0.34**	**0.0178**	**0.52**	**0.0001**	**0.67**	**<.0001**	0.00	0.999
LINK-ORD	49	**0.29**	**0.0457**	**0.49**	**0.0004**	**0.60**	**<.0001**	-0.05	0.71
DIST-UPST	49	**0.47**	**0.0007**	**0.55**	**<.0001**	**0.70**	**<.0001**	0.03	0.843
MELTONSRUG	49	**-0.57**	**<.0001**	**-0.55**	**<.0001**	**-0.62**	**<.0001**	-0.21	0.147
FOREST-WSHED	49	0.06	0.6979	0.18	0.2205	0.10	0.5134	0.19	0.188
DEV-WSHED	49	**-0.33**	**0.0209**	-0.23	0.1111	-0.20	0.1668	-0.05	0.731
FOREST-WRIP	49	0.02	0.9028	0.07	0.6213	0.08	0.5826	0.23	0.106
DEV-WRIP	49	-0.13	0.3768	-0.05	0.7474	0.00	0.9813	-0.10	0.494
RD-DENSE-L	49	0.14	0.3496	0.19	0.1798	-0.02	0.8914	-0.05	0.7123
FRAG-TOT	49	**0.26**	**0.0750**	**0.25**	**0.0818**	**0.37**	**0.0099**	0.02	0.868
IMP-DENSE	49	-0.17	0.2307	-0.08	0.5723	0.00	0.9875	**-0.28**	**0.048**
ORD1-LOSS	49	0.06	0.6751	0.10	0.4927	**0.25**	**0.0826**	-0.15	0.318
IMP-DWNDIST	49	**0.27**	**0.0615**	**0.27**	**0.0602**	0.12	0.4181	-0.08	0.606

Table 1-11. Logistic regressions of impairment by continuous watershed environmental variables.

Watershed Environmental Variable	n	Chi Square	Prob >ChiSq	RSquare (U) [1]	Direction [2]
WSHEDAREA	49	**13.12**	**0.0003**	**0.2238**	+
LINK-ORD	49	**8.91**	**0.0028**	**0.1519**	+
DIST-UPST	49	**16.80**	**<.0001**	**0.2865**	+
MELTONSRUG	49	**30.66**	**<.0001**	**0.5229**	+
FOREST-WSHED	49	0.27	0.6016		
DEV-WSHED	49	**10.11**	**0.0015**	**0.1724**	**-**
FOREST-WRIP	49	0.51	0.4763		
DEV-WRIP	49	**5.94**	**0.0148**	**0.1013**	**-**
RD-DENSE-L	49	0.58	0.6983		
FRAG-TOT	49	1.92	0.1656		
IMP-DENSE	49	1.25	0.2643		
ORD1-LOSS	49	0.20	0.6562		
IMP-DWNDIST	49	1.05	0.3062		

1. RSquare = -logLikelihood of the Model / -logLikelihood of the Total
2. Direction ;
+ denotes that as the variable increases the probability the site is impaired decreases
- denotes that as the variable increases the probability the site is impaired increases

Table 1-12. Contigency table and test statistics for impairment status by categorical watershed environmental variables.

Variables	class	n	Impaired	Non-Impaired	RSquare (U)	Likelihood Ratio Prob> Chi-Square	Pearson Prob> Chi-Square
SIZE CLASS	15	16	8	9	**0.2773**	**0.0027**	**0.0192**
	50	15	6	9			
	150	10	0	10			
	400	6	0	6			
	> 400	2	0	2			
SUB BAS-C	SUBBAS	31	4	27	**0.2231**	**0.0014**	**0.0011**
	TRIS	6	5	7			
	TRIR	12	5	1			
DSIZE CAT	50	13	6	7	**0.2040**	**0.0176**	**0.0156**
	150	9	1	8			
	400	9	1	8			
	> 400	13	2	11			
	Reservoir	5	4	1			

Table 1-13. Means testing for categorical watershed environmental variables using F-test for IBI score, diversity, richness, and abundance. Significant (0.05) and marginally significant (0.10) values in boldface.

Watershed Variables	class	n	IBI Score mean	IBI Score Prob>F	Diversity mean	Diversity Prob>F	Richness mean	Richness Prob>F	Abundance mean	Abundance Prob>F
SIZE CLASS	15	16	33.69	**0.0426**	1.588	**0.0060**	11.38	**< 0.0001**	348.8	0.5937
	50	15	34.60		1.736		13.93		394.8	
	150	10	40.60		2.114		18.80		318.8	
	400	6	44.00		2.014		19.83		468.2	
	> 400	2	41.00		2.310		19.00		363.8	
SUB BAS-C	SUBBAS	31	40.13	**0.0008**	1.974	**0.0041**	16.68	**0.0071**	399.9	0.3902
	TRIS	6	28.00		1.510		11.67		312.3	
	TRIR	12	33.17		1.588		12.42		329.7	
DSIZE CAT	50	13	34.54	**0.0778**	1.619	**0.0255**	11.54	**0.0002**	330.1	0.5990
	150	9	38.89		1.894		15.22		454.3	
	400	9	39.89		2.111		19.22		338.8	
	> 400	13	39.23		1.908		16.54		388.1	
	Reservoir	5	28.40		1.480		12.20		350.80	

Table 1-14. Correlation and F-statistic for watershed environmental variables related to DIST-UPST. In boldface are those variables not highly correlated with DIST-UPST.

DIST-UPST Vs.	Spearman Rho	p-value	DIST-UPST vs.	F-Ratio	Prob>F
MELTONSRUG	-0.77	<.0001	SIZECLASS	98.2	<.0001
FOREST-WSHED	**0.15**	**0.2898**	SUBBAS-C	**1.2**	**0.2093**
DEV-WSHED	**-0.06**	**0.6868**	DSIZECAT	15.3	<.0001
FOREST-WRIP	**0.08**	**0.6037**			
DEV-WRIP	**0.13**	**0.3585**			
RD-DENSE-L	**-0.07**	**0.6093**			
FRAG-TOT	0.40	0.0041			
IMP-DENSE	**-0.09**	**0.5198**			
ORD1-LOSS	**0.10**	**0.4777**			
IMP-DWNDIST	**-0.11**	**0.4680**			

Table 1-15. One-Way ANOVA for watershed environmental variable versus residual from stream size (DIST-UPST). The significant (0.05) and marginally significant (0.10) are in boldface and the R^2 and direction are given. For the significant categorical variables, the means and standard errors for each category are shown.

Watershed Environmental Variable	n	IBI Score R^2 (direction)	F > value	Diversity R^2 (direction)	F > value	Number Natives R^2 (direction)	F > value
FOREST-WSHED	49	-	0.9440	-	0.6417	-	0.7974
DEV-WSHED	49	**0.14 (-)**	**0.0076**	**0.08 (-)**	**0.0495**	-	0.1590
FOREST-WRIP	49	-	0.7219	-	0.7951	-	0.8116
DEV-WRIP	49	-	0.0514	-	0.1678	-	0.4443
RD-DENSE-L	49	-	0.3213	**0.09 (+)**	**0.0335**	-	0.9890
IMP-DENSE	49	-	0.2556	-	0.9836	-	0.6420
ORD1-LOSS	49	-	0.8772	-	0.8390	-	0.1912
IMP-DWNDIST	49	**0.09 (+)**	**0.0373**	**0.16 (+)**	**0.0048**	-	0.1407
SUBBAS-C	49	**0.20**	**0.0058**	**0.16**	**0.0204**	**0.14**	**0.0292**
SUBBA-C	n	Mean	St.Er.	Mean	St.Er.	Mean	St.Er.
SUBBAS	31	2.49	1.27	0.108	0.061	1.08	0.65
TRIS	6	-6.77	2.90	-0.179	0.140	-1.57	1.48
TRIR	12	-3.05	2.05	-0.190	0.099	-2.01	1.04

Table 1-16. Land cover classes in the watershed and in the riparian buffer (100 m).

Land cover variable	N	Maximum (%)	Minimum (%)	Mean (%)	Std.Dev. (%)
FOREST-WSHED	49	91.3	38.6	66.0	12.1
DEV-WSHED	49	10.7	0.2	3.6	2.2
FOREST-WRIP	49	97.8	53.6	79.5	8.4
DEV-WRIP	49	6.7	0.1	2.0	1.4

Table 1-17. Summary statistics for impoundment variables used for further analyses.

Variable	N	Maximum	Minimum	Mean	Std.Dev.
FRAG-TOT (%)	49	75.5	5.7	41.7	20.1
IMP-DENSE (no./km^2)	49	1.08	0.06	0.57	0.29
IMP-DWNDIST (km)	49	114.3	0.7	32.4	26.4
ORD1-LOSS (%)	49	100.0	5.3	58.2	27.0

Table 1-18. Summary statistics for slope variables (untransformed).

Slope variable	N	Maximum	Minimum	Mean	Median	Std.Dev.	Skewness
EGL	41	0.0319	0.0001	0.0034	0.0019	0.0052	4.44
MAPSLOPE	49	0.0131	0.0005	0.0029	0.0022	0.0025	2.31
SEGDEM	49	0.0083	0.0002	0.0025	0.0019	0.44	1.20

Table 1-19. Spearman rank correlations of continuous local environmental variables to for IBI score, diversity, richness, and abundance.

Local Environmental Variable	n	Spearman Rho IBI Score	p-value	Spearman Rho Diversity	p-value	Spearman Rho Number Natives	p-value	Spearman Rho Abundance/200m	p-value
EGL	41	-0.14	0.3974	-0.02	0.9190	-0.07	0.6779	0.05	0.762
MAPSLOPE	49	-0.14	0.3246	**-0.25**	**0.0804**	**-0.43**	**0.0023**	0.06	0.687
DEMSLOPE	49	-0.16	0.2836	-0.19	0.1919	**-0.45**	**0.0013**	0.04	0.799
QBKF	41	0.15	0.3547	**0.29**	**0.0686**	**0.39**	**0.0110**	0.03	0.862
WWBKF	48	**0.35**	**0.0231**	**0.53**	**0.0003**	**0.59**	**<.0001**	0.04	0.827
WWBASE	41	**0.36**	**0.0122**	**0.50**	**0.0003**	**0.42**	**0.0027**	-0.02	0.891
DBKF	41	0.17	0.2906	0.19	0.2411	**0.39**	**0.0120**	-0.01	0.953
DBASE	41	**0.27**	**0.0845**	**0.57**	**<.0001**	**0.52**	**0.0005**	-0.25	0.109
QBKF/Q2	41	-0.04	0.8064	-0.10	0.5296	-0.14	0.3920	0.13	0.404
%SAND	41	-0.18	0.2500	**-0.27**	**0.0877**	-0.12	0.4717	-0.06	0.717
%FINES	41	0.03	0.8398	0.13	0.4310	0.19	0.2385	-0.05	0.739
CVPHIBR	41	**-0.38**	**0.0148**	-0.26	0.1027	**-0.54**	**0.0003**	0.05	0.77
BAGRATIO	41	-0.13	0.4307	0.02	0.9233	0.19	0.2255	0.06	0.697
U-STRMPOWM	41	0.24	0.1342	-0.20	0.2091	-0.20	0.2138	0.15	0.363
U-STRMPOWF	41	-0.03	0.8589	0.04	0.8212	0.06	0.7223	0.08	0.622
LTOWRATIO	49	-0.12	0.4047	**-0.40**	**0.0050**	-0.09	0.5297	0.15	0.293
%WOODYD	41	0.16	0.3184	0.17	0.2933	**0.36**	**0.0205**	-0.03	0.853

Table 1-20. Logistic regressions of impairment status by continuous local environmental variables.

Local Environmental Variable	n	Chi Square	Prob >ChiSq	RSquare (U) [1]	Direction [2]
EGL	41	0.01	0.9080		
MAPSLOPE	49	3.15	0.0760		
DEMSLOPE	49	1.32	0.2497		
QBKF	41	1.13	0.2885		
WWBKF	48	**6.48**	**0.0109**	**0.1307**	+
WWBASE	41	**15.25**	**<.0001**	**0.2631**	+
DBKF	41	1.50	0.2214		
DBASE	41	**6.72**	**0.0095**	**0.1356**	+
QBKF/Q2	41	0.81	0.3686		
%SAND	41	0.11	0.7423		
%FINES	41	0.00	0.9446		
CVPHIBR	41	2.00	0.1571		
BAGRATIO	41	0.01	0.9098		
U-STRMPOWM	41	0.03	0.8595		
U-STRMPOWF	41	0.00	0.9754		
LTOWRATIO	49	**9.89**	**0.0021**	**0.1707**	**-**
%WOODYD	41	0.72	0.3951		

1. RSquare = -logLikelihood of the Model / -logLikelihood of the Total
2. Direction ;
+ denotes that as the variable increases the probability the site is impaired decreases
- denotes that as the variable increases the probability the site is impaired increases

Table 1-21. Contigency table and test statistics for impairment status by categorical local environmental variables.

Variables	P/A	n	Impaired	Non-Impaired	RSquare (U)	Likelihood Ratio Prob> Chi-Square	Pearson Prob> Chi-Square
POOL	Absent	12	4	8	0.0027	0.7148	0.7129
	Present	29	8	21			
RIFFLE	Absent	26	9	17	0.0205	0.3129	0.3218
	Present	15	3	12			
BED ROCK	Absent	19	7	12	0.0198	0.3218	0.3219
	Present	22	5	17			

Table 1-22. Means testing for categorical local environmental variables using F-test for IBI score, diversity, richness, and abundance. Significant (0.05) and marginally significant (0.10) values in boldface.

Local Variables	P/A	n	IBI Score mean	IBI Score Prob>|t|	Diversity mean	Diversity Prob>|t|	Richness mean	Richness Prob>|t|	Abundance mean	Abundance Prob>|t|
POOL	Absent	12	33.92	0.1403	**1.614**	**0.0695**	13.17	0.1517	375.48	0.8550
	Present	29	38.45		**1.888**		15.55		387.91	
RIFFLE	Absent	26	35.62	0.157	1.763	0.394	14.62	0.6823	365.66	0.4267
	Present	15	39.73		1.887		15.27		416.54	
BED ROCK	Absent	19	**33.84**	**0.027**	**1.658**	**0.042**	14.05	0.3289	355.03	0.3775
	Present	22	**39.95**		**1.938**		15.55		409.53	

Table 1-23. Correlation and F-statistic for local environmental variables related to DIST-UPST. In boldface are those variables not highly correlated with DIST-UPST.

DIST-UPST vs.	Spearman Rho	p-value	DIST-UPST vs.	F-Ratio	Prob>F
EGL	**-0.32**	**0.0438**	POOL-P/A	**0.3**	**0.6075**
MAPSLOPE	-0.64	<.0001	RIFFLE-P/A	**0.8**	**0.3767**
DEMSLOPE	**-0.34**	**0.0173**	BEDROCK-P/A	**0.2**	**0.6751**
QBKF	0.41	0.0075			
WWBKF	0.74	<.0001			
WWBASE	0.69	<.0001			
DBKF	0.45	0.0030			
DBASE	0.53	0.0003			
QBKF/Q2	-0.42	0.0058			
%SAND	**0.27**	**0.0918**			
% FINES	**-0.03**	**0.8432**			
CVPHIBR	-0.41	0.0073			
BAGRATIO	**0.20**	**0.2177**			
U-STRMPOWM	**-0.27**	**0.0923**			
U-STRMPOWF	**-0.15**	**0.3342**			
LTOWRATIO	**-0.32**	**0.0254**			
%WOODYD	**0.32**	**0.0432**			

Table 1-24. One-Way ANOVA for local environmental variable versus residual from stream size (DIST-UPST). The significant (0.05) and marginally significant (0.10) are in boldface and the R^2 and direction are given. For the significant categorical variables, the means and standard errors for each category are shown.

Local Envionmental Variable	n	IBI Score R^2 (direction)	F > value	Diversity R^2 (direction)	F > value	Number Natives R^2 (direction)	F > value
EGL	41	-	0.6457	-	0.4007	-	0.3164
DEMSLOPE	49	-	0.9456	-	0.8277	**0.07 (-)**	**0.0593**
%SAND	41	-	0.0738	**0.23 (-)**	**0.0015**	**0.09 (-)**	**0.0591**
%FINES	41	-	0.7454	-	0.0699	-	0.2308
BAGRATIO	41	-	0.2019	-	0.8410	-	0.5545
U-STRMPOWM	41	-	0.7624	-	0.8222	-	0.8895
U-STRMPOWF	41	-	0.8671	-	0.6102	-	0.5407
%WOODYD	41	-	0.7792	-	0.8074	-	0.1063
LTOWRATIO	49	-	0.4162	**0.08 (-)**	**0.0457**	-	0.6590
POOL-P/A	41	-	0.1680	**0.08 (-)**	**0.0748**	-	0.1573
RIFFLE-P/A	41	**0.10 (+)**	**0.0470**	-	0.2118	-	0.1262
BEDROCK-P/A	41	**0.12 (+)**	**0.0252**	**0.11 (+)**	**0.0358**	-	0.3637
POOL-P/A	N	Mean	St.Er.	Mean	St.Er.	Mean	St.Er.
Absent	12	-	-	-0.16	0.11	-	-
Present	29	-	-	0.07	0.07	-	-
RIFFLE-P/A							
Absent	26	-1.43	1.53	-	-	-	-
Present	15	3.76	2.02	-	-	-	-
BEDROCK-P/A							
Absent	19	-2.55	1.77	-0.63	0.08	-	-
Present	22	3.07	1.64	0.12	0.08	-	-

Table 1-25. Correlation table for channel dimension variables.

Variable	by Variable	Spearman r	Prob>|r|
DBASE	DBKF	0.21	0.1945
QBKF/Q2	DBKF	0.32	0.0427
QBKF/Q2	DBASE	0.31	0.0502
WWBKF	DBKF	0.56	< 0.0001
WWBKF	DBASE	0.38	0.0130
WWBKF	QBKF/Q2	0.12	0.4721
WWBASE	DBKF	0.35	0.0263
WWBASE	DBASE	0.76	< 0.0001
WWBASE	QBKF/Q2	0.36	0.0208
WWBASE	WWBKF	0.61	< 0.0001
QBKF	DBKF	0.76	< 0.0001
QBKF	DBASE	0.21	0.1922
QBKF	QBKF/Q2	0.54	0.0003
QBKF	WWBKF	0.68	< 0.0001
QBKF	WWBASE	0.35	0.0233
QBKF, WWBASE, WWBKF = log transformation; DBASE, QBKF/Q2 = square root transformation			

Table 1-26. Summary statistics for channel dimensions (Q2YR is given for reference).

Variable	N	Maximum	Minimum	Mean	Std.Dev.
WWBASE (m)	48	23.2	2.3	7.2	4.5
DBASE (m)	41	0.60	0.08	0.22	0.11
WWBKF (m)	41	30.6	8.3	14.6	5.1
DBKF (m)	41	2.7	0.5	1.4	0.5
QBKF (m^3/sec)	41	74.7	2.4	25.7	18.6
Q2YR (m^3/sec)	41	129.9	13.9	43.4	4.9
QBKF/Q2 (ratio)	41	2.41	0.06	0.74	0.57

Table 1-27. Summary statistics for transport variables.

Variable	N	Maximum	Minimum	Mean	Std.Dev.
BAGRATIO* (ratio)	41	23,657	13	3,738	4,808
USTRMPOWF* (watts/m)	41	684.3	0.2	75.9	136.2
USTRMPOWM (watts/m)	41	106.3	13.5	55.2	21.2
* Log transformation were used to normalize the distributions					

Table 1-28. Contingency table and test statistics for presence/absence of pools and riffles.

	Pool absent	Pool present	Total
Riffle absent	9	17	26
Riffle present	3	12	15
Total	12	29	41

Pearson ChiSquare = 0.981
Prob>ChiSq = 0.3129
d.f. = 1, 39

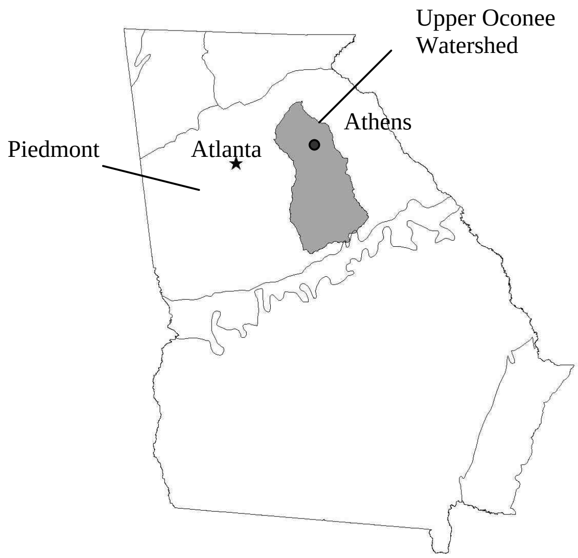


Figure 1-1. Upper Oconee watershed in the Georgia Piedmont.

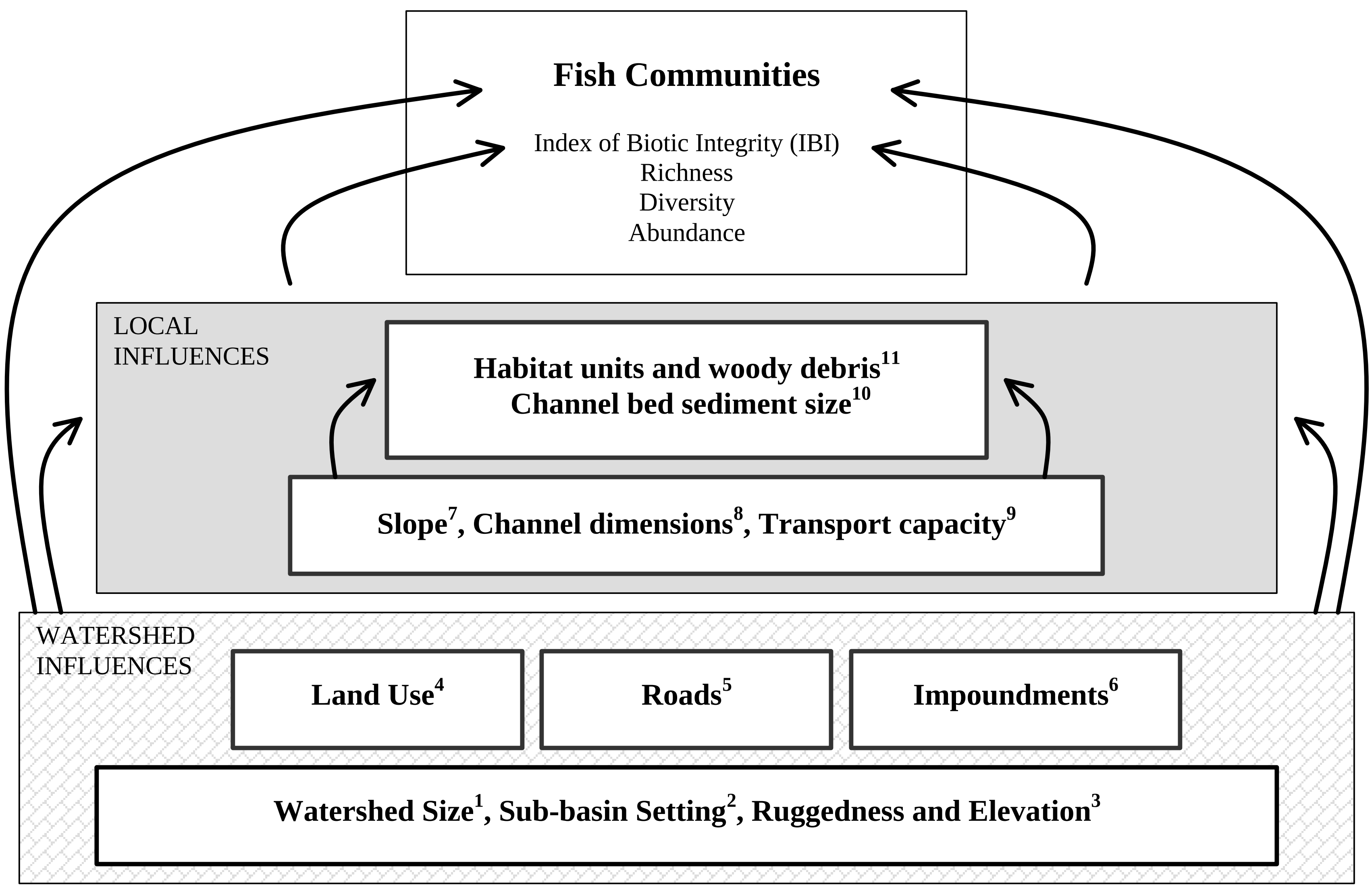


Figure 1-2. Schematic of local and watershed influences on stream fish metrics considered in this study.

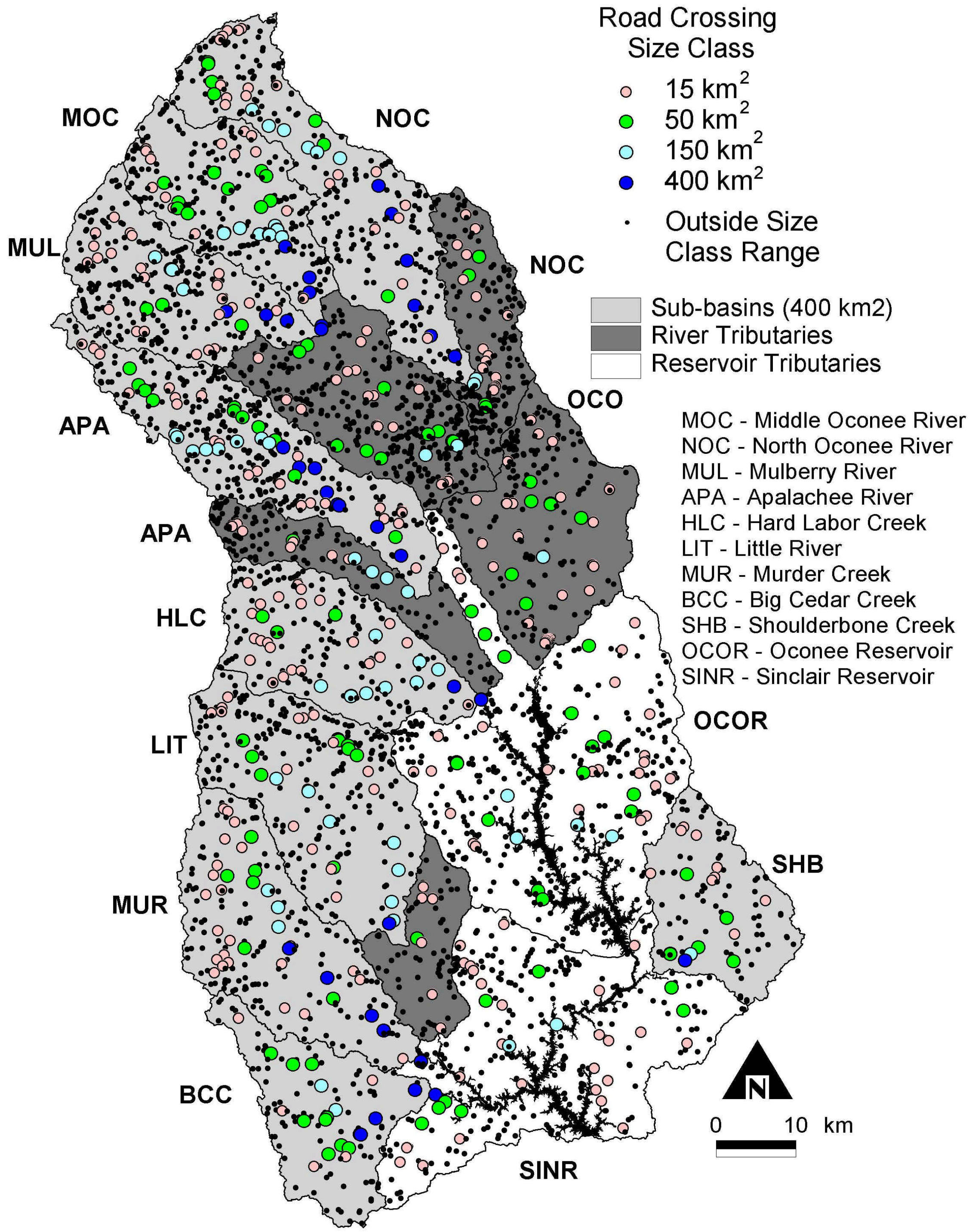


Figure 1-3. Road-stream intersections, watershed area size classes and the sub-basin categories used for site selection stratification.

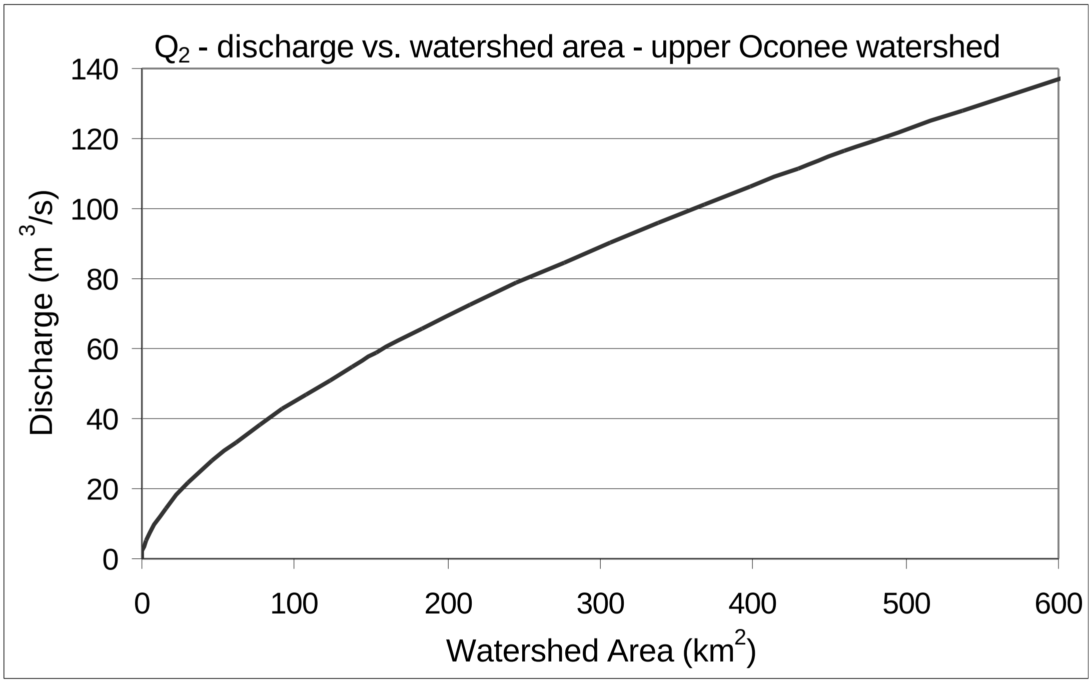


Figure 1-4. Two-year recurrence interval discharge (Q_2) (Georgia Region 2; Stamey and Hess, 1993; Q_2 (cfs) = 182 * Area (mile^2)$^{0.622}$).

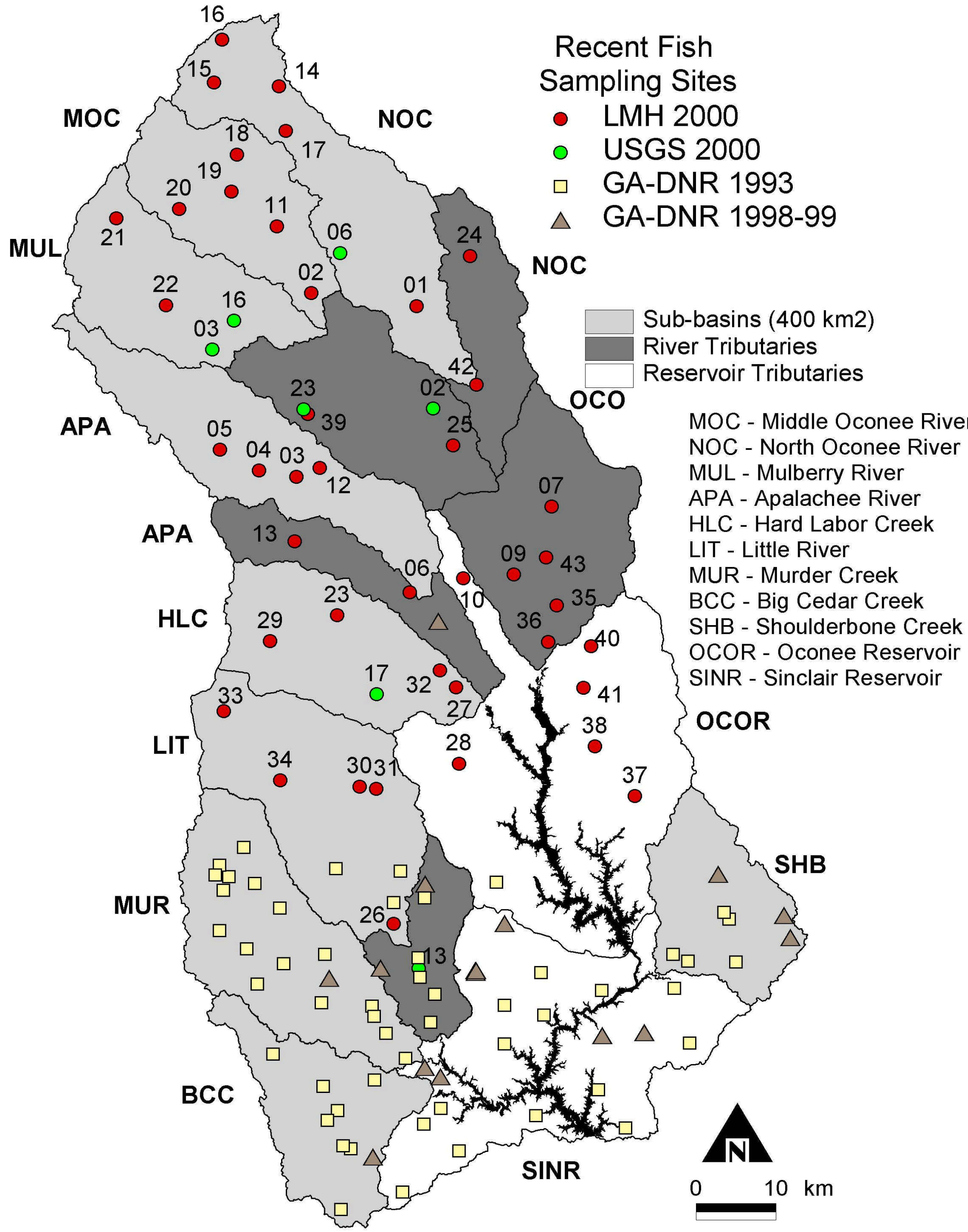


Figure 1-5. Sub-basins, recent GA-DNR sites, and sampling sites used in this study (only LMH and USGS were used in analyses presented here).

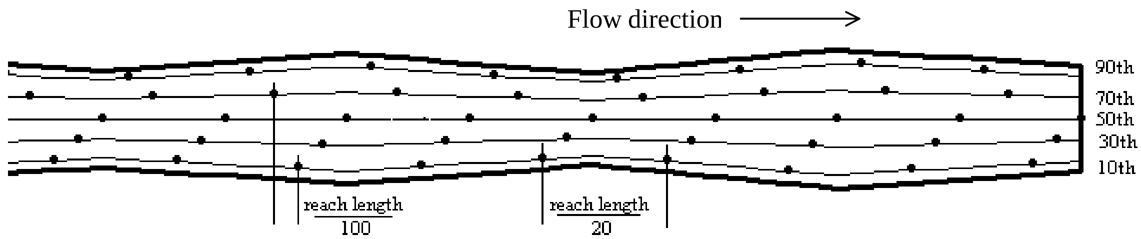


Figure 1-6. Planimetric schematic showing the five transects and sampling points for a portion of an example stream reach.

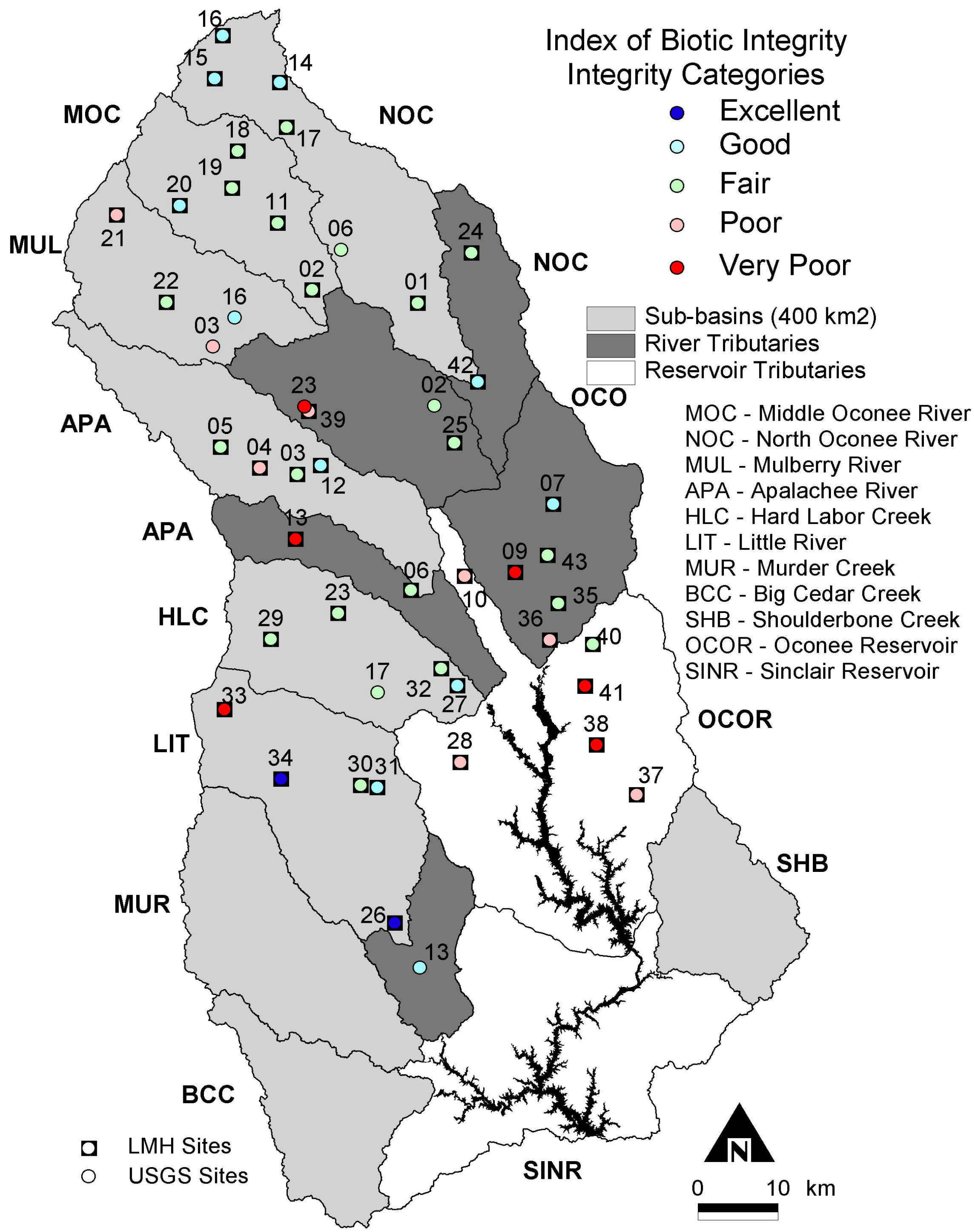
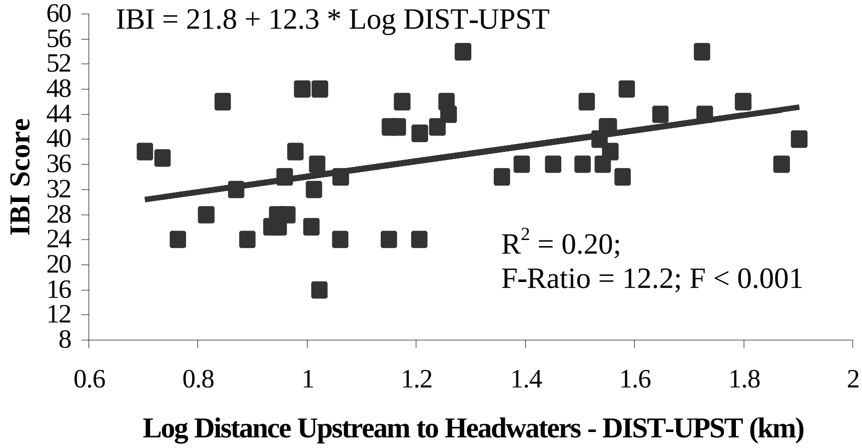
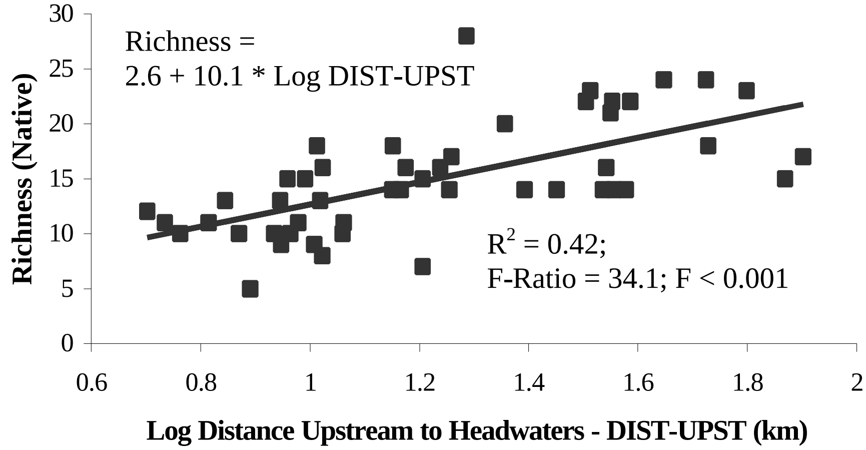


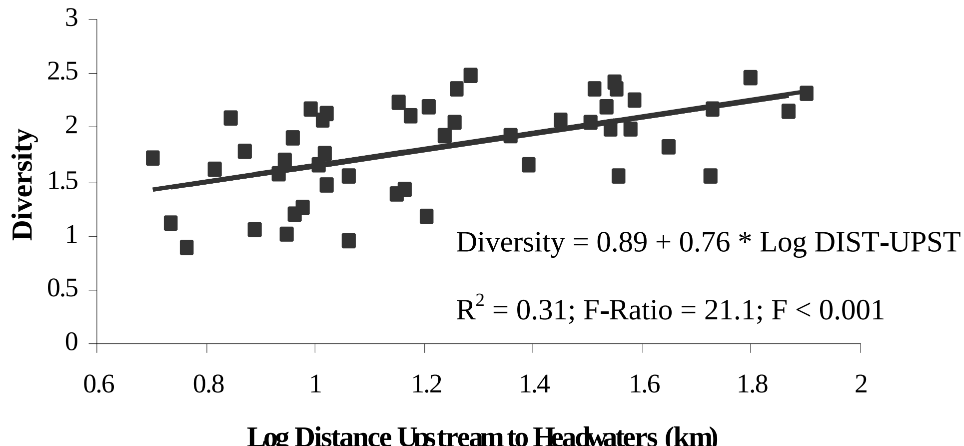
Figure 1-7. IBI integrity categories and site numbers for the 49 sites sampled in 2000.



(a)



(b)



(c)

Figure 1-8. Distance upstream versus IBI score (a), richness (b), and diversity (c).

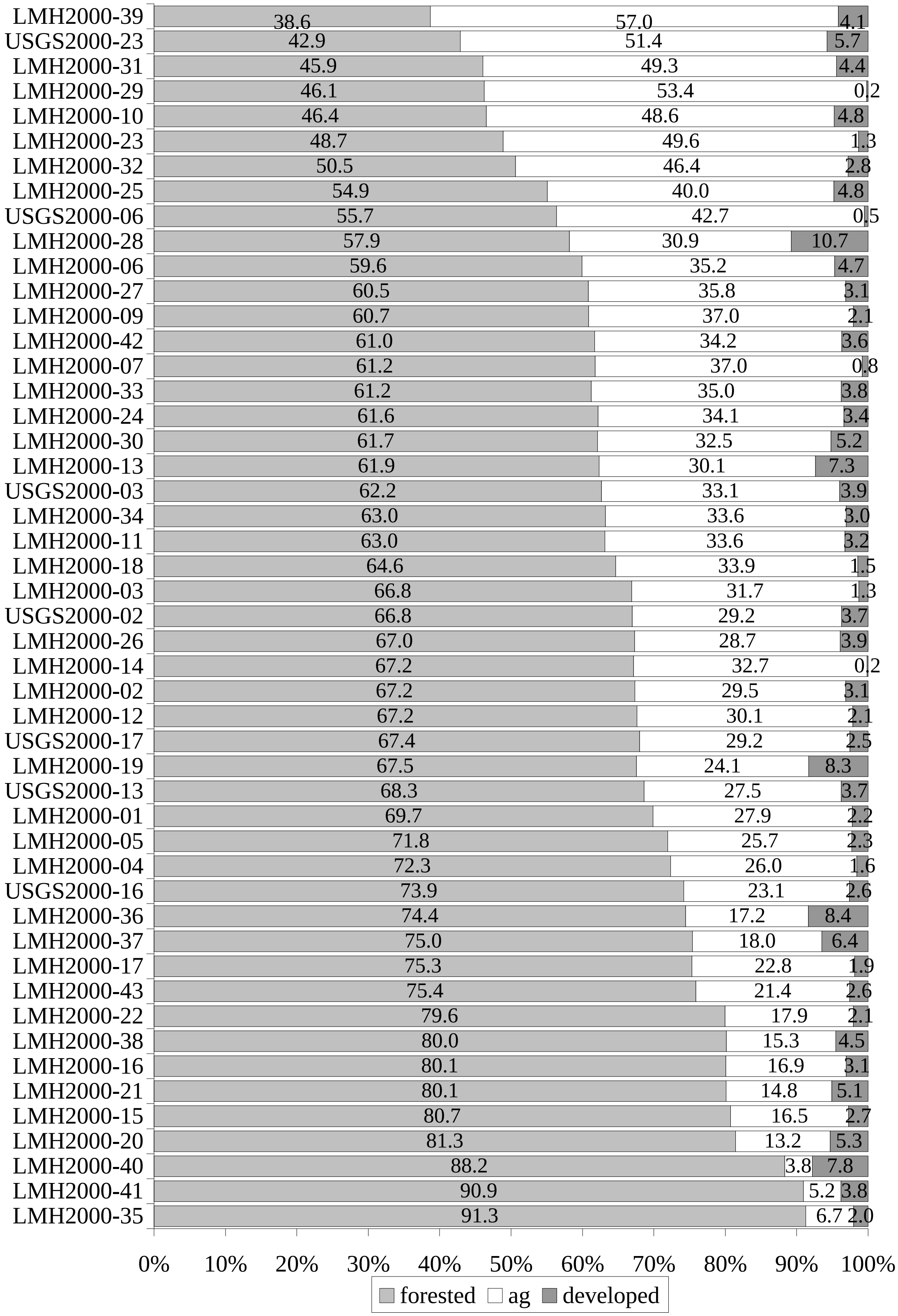


Figure 1-9. Percent land cover class in the watershed [-WSHED] (sorted by forest cover).

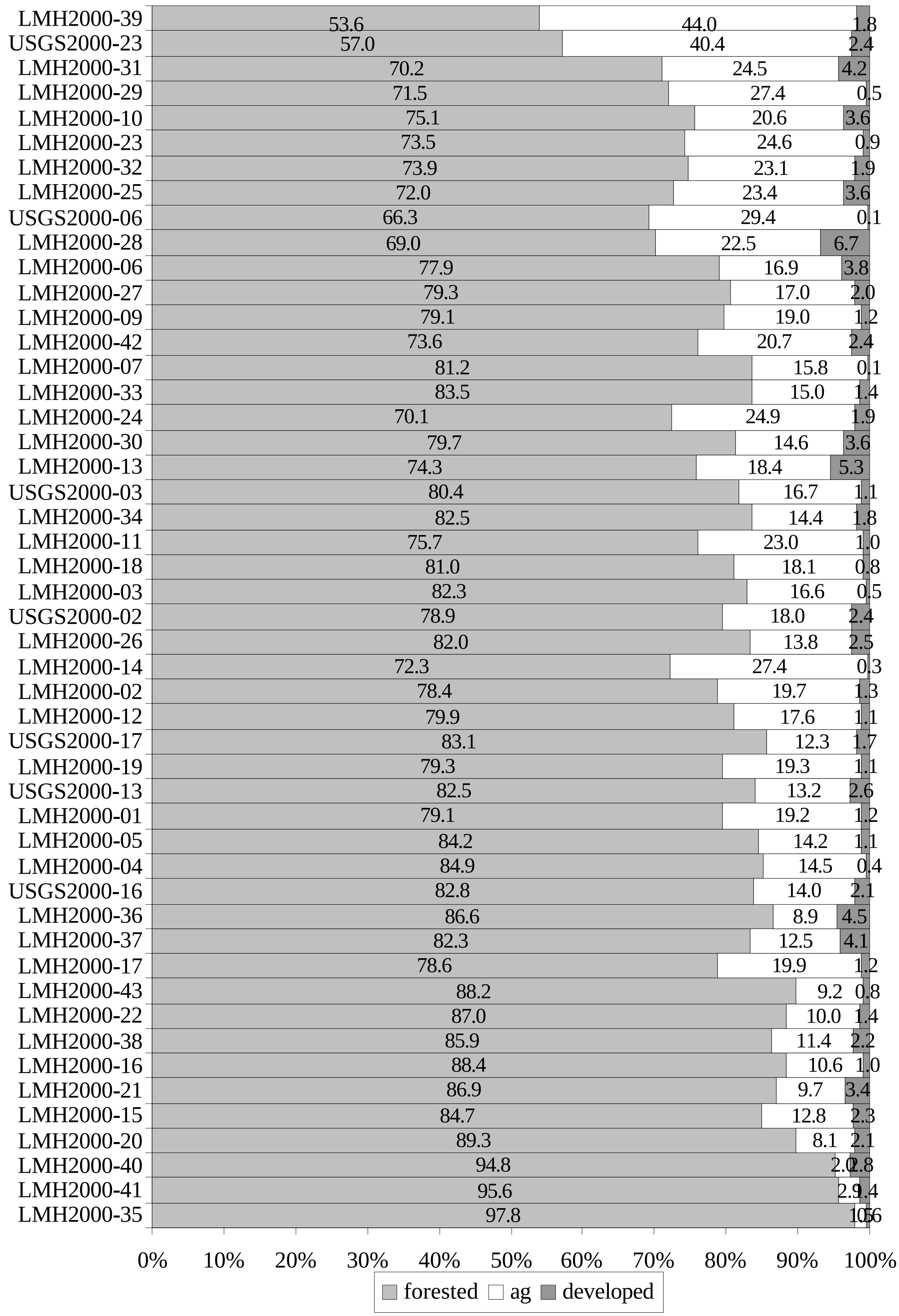


Figure 1-10. Percent land cover class in the riparian buffer (100 m) throughout the watershed [-WRIP] (sorted by forest cover in watershed, FOREST-WSHED, Figure 1-9).

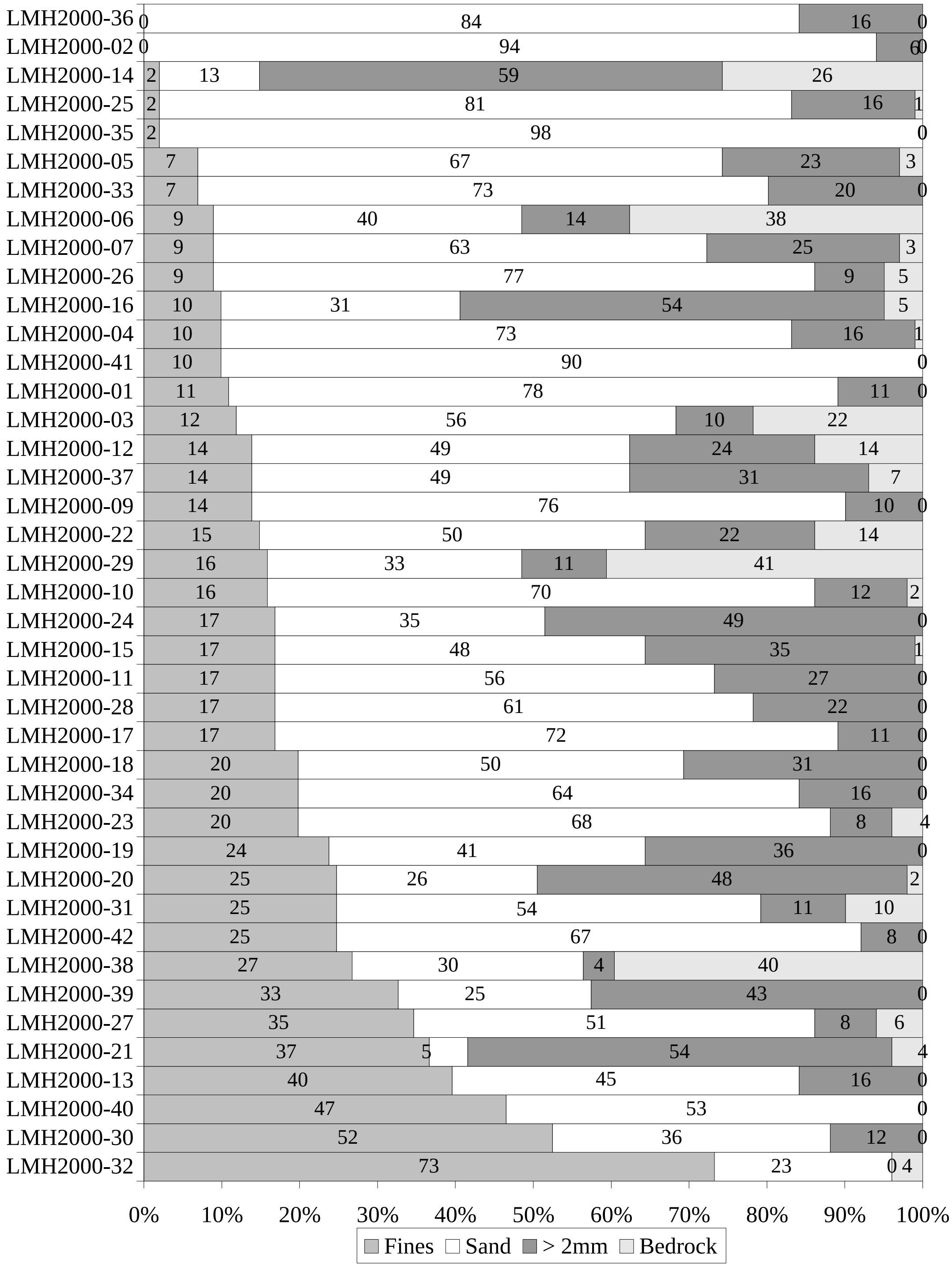


Figure 1-11. Percent channel sediment classes (sorted by fines, then sand) along the channel transects.

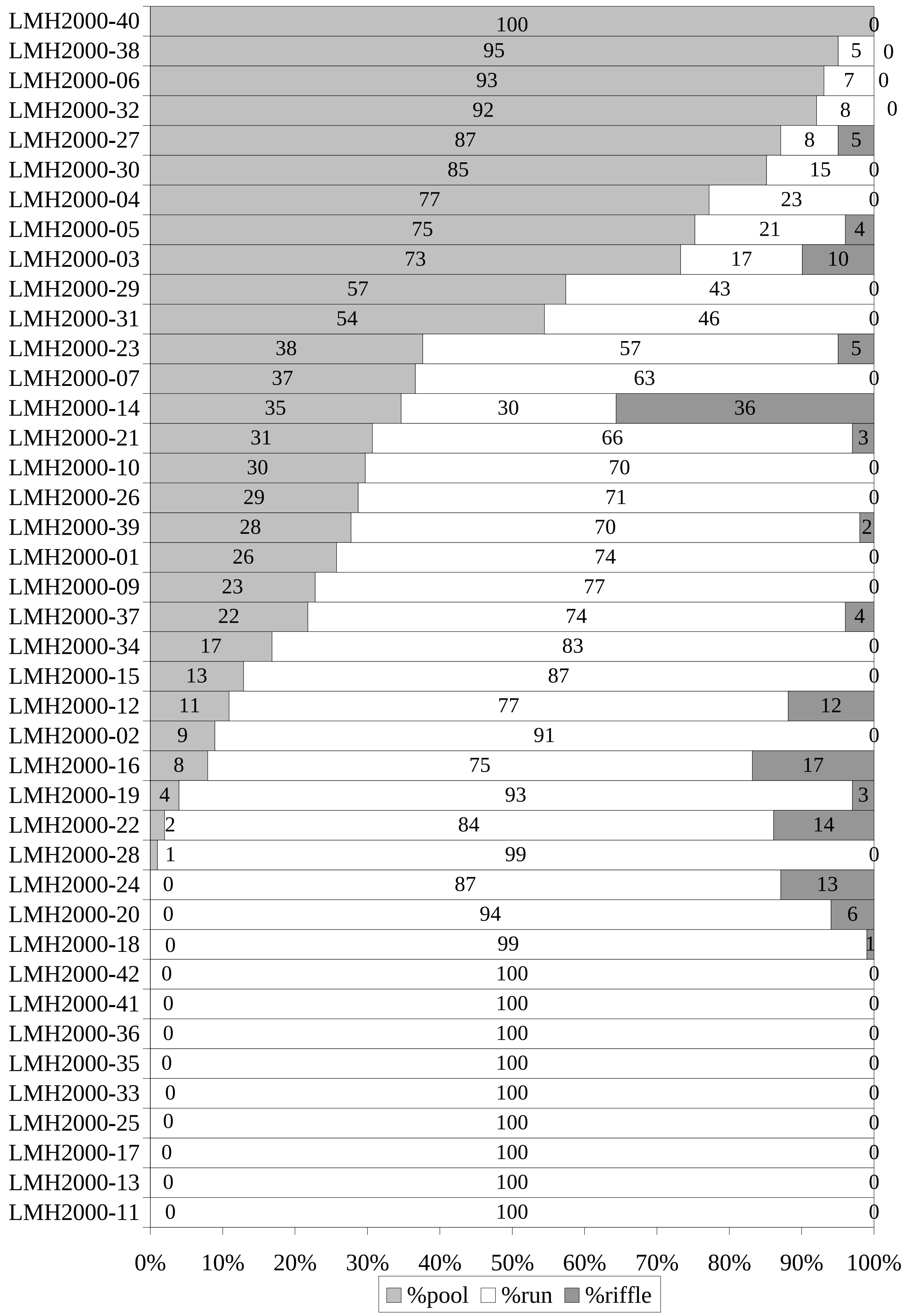


Figure 1-12. Percent habitat unit along the channel transects (sorted by pool, run, riffle).

CHAPTER 2

STREAM LOSS AND FRAGMENTATION DUE TO IMPOUNDMENTS IN THE UPPER OCONEE WATERSHED, GEORGIA, USA

Introduction

In much of the world, dams and their impoundments have been and will continue to be constructed and maintained in order to provide societal benefits such as, municipal drinking water, energy, flood control, irrigation, livestock watering, and recreation. However, it has been recognized that direst loss, indirect degradation, and fragmentation of natural stream habitats are major ecological impacts of dams and their impoundments (e.g. Ward and Stanford, 1989, Dynesius and Nilsson 1994, Collier et al. 2000). In the United States and especially in the southeast, freshwater ecosystems and their extremely diverse flora and fauna have been identified as highly imperiled and in great need of conservation and restoration (Benke 1990, Masters et al. 1998). With over 75,000 large dams and an estimated 2.5 million smaller dams in the U.S.A. (ICOLD 1998, Benke 1990, Masters et al. 1998) we must look at the cumulative impacts to our stream systems in order to make more informed decisions regarding rehabilitating existing impoundments and building more impoundments.

The most direct form of habitat loss results when stream habitats are inundated by impoundments. These stream segments are transformed from lotic to lentic habitats with shifts in the biological communities responding accordingly (Bonner and Wilder 2000, Penáz 1999). Shoal habitat, for example, in the Georgia Piedmont has mostly disappeared due to inundation of reservoirs (Wharton, 1998). In addition, many impoundment projects establish sport fisheries based on introduced and/or stocked fishes. These introductions, usually piscivorous fish species, can change the biological communities considerably and exacerbate the effects of habitat loss on native species (Whittier and Kincaid 1999, Shrank et al. 2001).

Other forms of habitat loss are due to habitat degradation in the form of flow modifications, changes in sediment supply, nutrient cycling, and temperature regimes downstream of dams (Collier et al. 2000). Ward and Stanford (1995) described the multiple ways impoundments cause disruptions to the natural longitudinal gradients found in stream systems. Downstream habit loss is dependent on the type and operation of the dam controlling the impoundment (e.g. hydropower, flood control, recreation, water supply, etc.). For example, a hydropower facility can result in dramatic changes in water discharge over short periods of time, thereby causing dangerous and unstable conditions for stream fauna and flora (Bain et al. 1988, Poff and Ward, 1989, Penáz et al. 1999). Flooding, often key in maintaining riparian wetlands and other ephemeral habitats, is intentionally prevented with flood control dams, but floods can also be reduced from many other types of impoundments (e.g. hydropower dams, water supply reservoirs, farm ponds, etc.) (Hirsch et al. 1990, Schoof and Gander 1982).

De-watering of stream reaches can degrade habitat by eliminating vital edge and shallow water habitats (Bain et al. 1988, Travnichek et al. 1995). This can occur when water is withdrawn for municipalities, industry, and agriculture (Hirsch et al., 1990). Also, the loss of water in a drainage basin can be caused by increased evaporative losses from open water impoundments (Gan et al. 1991, Morton 1983b). The overall loss of water in the streams degrades habitat and exacerbates the effects of drought on in-stream fauna (Bain et al. 1988, Travnichek et al. 1995). Unfortunately, the cumulative effect of increased evaporative losses has rarely been considered in assessing the impacts of many impoundments on in-stream biota. We will use regional estimates of evaporation and evapotranspiration to show the potential impacts of converting vegetative land cover to open water.

With increased water residence time in the system due to reservoirs and impoundments nutrient cycling may be drastically changed thereby affecting the delivery rates and timing to receiving estuaries (Vörösmarty and Sahagian 2000). Dramatic changes in downstream water temperature can ensue depending on the depth of release waters. For example, one of the southern-most cold-water trout fisheries is below Lake Lanier reservoir due to the cold, hypolimnetic discharges (Collier et al. 2000).

Another mechanism of indirect habitat loss occurs when impoundments trap sediment, thereby, starving downstream locations of sediment inputs causing incision or other geomorphic changes which can adversely affect stream biota (Shields et al. 2000). These indirect habitat losses can often affect as much or more length of stream than the length directly inundated (Shankman 1999, Shield et al. 2000).

Fragmentation due to impoundments also impacts a variety of taxonomic groups in both upstream and downstream stream segments. The most obvious impacts of fragmentation result in the blocking or slowing of migrations of diadromous aquatic species (Pringle et al. 2000). Freshwater shrimp (Benstead et al. 1999), salmon (Collier et al. 2000), and American eel (Smogor et al. 1995) are examples of aquatic species which have been negatively impacted by these migration barriers. Other groups, such as freshwater mussels depend on fish hosts to disperse and are, therefore, negatively affected by impoundments and other barriers (Vaughn and Taylor, 1999, Metcalfe-Smith 2000). Longitudinal continuity created by the natural dispersal and recolonization of riparian vegetation can be disrupted by impoundments and their dams (Jansson et al. 2000). The seeds may eventually settle out like sediment in the slower impoundment waters resulting in different riparian vegetation upstream and downstream of an impoundment (Andersson et al. 2000). Upstream isolation and extirpation of fish species also have been documented (Winston et al. 1991, Schrank et al. 2001). This local extirpation occurs when a disturbance (natural or anthropogenic) event results in the elimination of a local population and natural recolonization cannot occur because the population has been cutoff by the impoundment (Sheldon 1987). These examples show that fragmentation can occur regionally (by large, mainstem dams) and locally (by smaller, tributary dams).

In spite of our knowledge of these negative impacts on stream habitat, we continue to build and maintain dams because of the societal benefits derived from these structures. In the Piedmont region of the southeastern United States, where this study is focused, impounding and controlling flowing waters has been a human activity for thousands of years (e.g. Native American fish weirs and irrigation diversions) (Doyon 1983).

However, dam building activities in the last 150 years has been extremely intense in contrast to the small-scale nature of earlier human water engineering, (Doyon 1983, Collier et al. 2000, Shankman 1999, Pringle et al. 2000). For example, European colonists in the 1800’s built grist and saw mills on streams resulting in an estimated 950 small hydropowered mills in the Georgia Piedmont (Doyon 1983). Some of these mill dams still form small impoundments and many have been retrofit or rebuilt to expand their impoundment capacity. Starting in the early 1930's, farm ponds and small sediment retention reservoirs have been encouraged, financed and built by the Natural Resources Conservation Service (NRCS, formerly the Soil Conservation Service, SCS). Many of these were initially built in order to intercept the soil being eroded off the uplands due to erosive farming practices (Trimble 1970). These ponds formed effective sediment traps and likely prevented eroding sediments from moving further downstream. NRCS has also built and continues to maintain many 'watershed' dams which aim to control flooding (NRCS 2000). Another federal agency, the Army Corps of Engineers has been regulating, building, and operating the large dams used for navigation, water supply, flood control and hydropower for over a hundred years. Private companies and utilities also build large impoundments and dams for hydropower and cooling water for coal or nuclear powered facilities. Many dams also continue to be built because local and state governments are constructing reservoirs to ensure a stable water source to supply current and future growth for commercial, industrial and municipal uses (Sutherland 2001).

In order to make wise management decisions regarding our natural resources the benefits derived from impounding our streams and rivers must also be evaluated considering the trade offs, namely, the negative cumulative impacts to our natural systems. To examine these cumulative impacts, this study has focused on the Piedmont region in Georgia and more specifically on the upper Oconee watershed (Figure 2-1).

Like most other rivers in the Piedmont, the Oconee River has both large reservoirs and many small impoundments. For example, Sinclair and Oconee Reservoirs, filled in 1953 and 1980 respectively, provide electicity via hydroelectric power generation, a cooling water source for a coal powered facility, and are extensively used for recreational fishing and boating. Yet these reservoirs have drastically changed long sections of the free-flowing river into still waters, and regulated the river downstream from the dams. In addition to these large reservoirs, increasing water demands in the watershed and throughout Georgia will certainly put more pressure on the streams of the upper Oconee watershed (Sutherland 2001). The 1990 census estimated 265,000 residents living in and around the 56 municipalities (GA-DNR-EPD 1998) that are within the watershed. Many municipalities, including Athens, directly use the rivers in the watershed as a water supply and for waste assimilation. More development pressure is also occurring because the suburbs of Atlanta and Gainseville are just to the west and north, respectively, and based on the 2000 Census, these areas are some of the fastest growing in the state (Athens Daily Banner Herald, March 22, 2001).

Impoundment projects are continuing within the watershed. For example, Bear Creek Reservoir, a large four county 222 hectare water supply impoundment, has been built and is projected to be completed by July 2001. Other regional reservoirs have been proposed for the watershed. These proposed projects have been identified for Hard Labor Creek, Apalachee River, and the North Oconee River (GA-DNR-EPD 2001). Also, continued farm and recreational pond construction adds to the thousands already existing in the watershed.

Evaluating cumulative impacts of multiple impoundments across a watershed is key to understanding the conservation implications when considering a new dam project or when re-assessing an existing impoundment. However, cumulative effects are difficult to quantify and, to date, have not been adequately evaluated with respect to impoundments ranging from large reservoirs to small farm ponds. To quantify the cumulative impacts in a watershed or for a particular impoundment project a number of questions can be posed; What types and numbers of dams and impoundments are present? How much area and length of stream have they inundated? For each stream segment what is the upstream and downstream distance to an impoundment or dam? Where do the impoundments occur in the stream network? How many stream kilometers (pre and post-impoundments) are connected?

Through stream network analysis using geographic information systems (GIS) in the upper Oconee watershed, this study attempts to answer these questions by analyzing the cumulative impacts with regard to habitat loss and fragmentation for an entire watershed.

Study Area

The upper Oconee watershed lies entirely within the Georgia Piedmont physiographic region (Figure 2-1) and encompasses an area of 7,500 km^2 in the east-central portion of the state. The watershed is one entire U.S.Geological Survey (USGS) 8-digit hydrologic unit (HUC) with its outlet defined by Georgia Power Company's Sinclair hydroelectric dam finished in 1953. After flowing through two large reservoirs (Oconee and Sinclair), which cover 125 km^2, the upper Oconee continues southeasterly to meet up with the Ocmulgee River to form the unique Altamaha River ecosystem which eventually drains into the Atlantic Ocean. Much of the land area in the watershed is devoted to beef, dairy, and chicken production as well as significant acreage devoted to forestry production (Fisher et al. 2000). Historically, most of the watershed was farmed extensively for cotton until the decline of cotton farming in the early 1900's (Trimble 1970).

Methods

The primary tool used for analyses was a geographic information systems (GIS). Three GIS datasets were used for assessing stream habitat loss and fragmentation. These datasets included: EPA inventory of dams (1:100,000 scale), linear hydrography (streams and rivers, 1:24,000 scale), and polygonal hydrography (ponds, reservoirs, wetlands, 1:24,000 scale) (see Appendix F for metadata). The hydrography datasets for the entire Oconee River basin were complete because the datasets were part of a USGS-NHD (National Hydrography Dataset) pilot project to produce a fully networked hydrography dataset at the 1:24,000 scale. Black and white aerial photos (1:12,000 scale) were sampled and used to verify the maps of the ponds and reservoirs (GA-GIS Clearinghouse).

In order to gain more insight into the characteristics of the dams within the watershed, the information in the EPA inventory of dams database was examined. This database was incomplete, yet had useful information such as type, owner, year of construction, and size about the larger dams in the watershed.

The NHD Prototype hydrography datasets incorporated artificial centerlines to bisect the 'in-stream' polygon features (wetlands, ponds, reservoirs, and double-lined rivers). The data sets were first evaluated for network errors (e.g. dangling arcs, arcs needing flipping, and identification of stream cutoffs and multi-channel sections). Then the information in the linear hydrography was merged (i.e. streams) with the information in the polygonal hydrography (i.e. ponds, reservoirs) so that each stream segment was characterized by the direction of flow, length, type (artificial centerline or stream), and impoundment presence and its area.

Because there are very few natural lakes in the Piedmont region of Georgia (Wharton 1998) we assumed every water body (not designated as a wetland) in the database was an artificially created impoundment. With this information, the number of impoundments found within the watershed and the amount of land and stream length inundated by impoundments were quantified. Additionally, a distinction was made between 'off-stream' and 'in-stream' impoundments. Off-stream impoundments were those that did not connect or intersect with a line from the streams database, whereas in-stream impoundments were at the start of or were within the stream network (Figure 2-2 shows examples of these categories). It should be noted that, for all of the analyses we used the predicted area and location of Bear Creek Reservoir, a water supply reservoir beginning operation in July 2001.

Using automated scripts in a GIS (ArcInfo 8.0) we identified upstream and downstream segments for every stream segment and polygon in the database. In this manner, for every line segment we quantified the upstream distances to headwater streams and dams, as well as the downstream distances to the watershed outlet (Sinclair dam) and the first downstream impoundment. Also, we used Shreve (1967) magnitude analysis to quantify where in the network streams and impoundments were located. Magnitude analysis results in a link number which is the number of headwater streams upstream for each segment in the network (Shreve 1967). Figure 2-2 shows example impoundments and labels the stream segments with their link or number.

The fragmentation indices were calculated for each stream segment based on the length of stream connected to a segment pre and post-impoundment. Fragmentation was calculated as the percent stream length remaining connected for upstream, downstream, and total. The upstream length, or the "arbolate sum" is the sum of the lengths of all the streams upstream (including lengths of tribuaties) from the stream arc under consideration (U.S. E.P.A. 1982). The downstream length is the length along the main flow path to the designated outlet, in this case, Wallace dam, the outlet of the upper Oconee watershed. Figure 2-3 illustrates the fragmentation from two impoundments on an example stream segment.

Many of the fragmentation and habitat loss statistics were summarized for the 108 USGS 12-digit HUCs which comprise the upper Oconee watershed (8-digit HUC). These units averaged 71 km^2. The percent stream length inundated by impoundments and the number of dams per 12-digit HUC were calculated.

The methods outlined here could be used with any scale data (e.g. 1:100,000 or 1:5,000), yet the results may be dependent upon the scale used. For example, using 1:100,000 scale hydrography, the number of impoundments decrease (due to minimum mapping unit and resolution), as would the length of stream examined. In fact, the length of streams within the watershed using 1:100,000 scale data (using National Hydrography Dataset (NHD) 1:100,000 scale data from the USGS) is approximately 6,500 km; only sixty-one percent of the 1:24,000 scale data. Conversely, using a stream network including unmapped drainage lines and ephemeral streams (i.e. derived from a 30 meter digital elevation model (DEM)) closer to 15,000 km of streams were found, and perhaps more in-stream impoundments (i.e. those ponds with small streams flowing from them) would also become apparent. However, it was decided that the 1:24,000 scale information should be used because data are available state-wide and therefore, can be transferred to other regions. Figure 2-4 shows a portion of a 1:24,000 topographic map (USGS 7.5 minute map) comparing the differences in stream length at various scales.

For the summer of 2000 (corresponding to the period of study discussed in Chapter 1), six USGS real-time stream gaging station stage and discharge records were downloaded from the USGS website (http://ga.water.usgs.gov/rt-cgi/gen_tbl_pg). These were used to qualitatively compare stream discharges for those streams below hydro-electric dams and those not influenced by hydro-electric dams. The 15 or 30 minute recording intervals were used in the analysis. These data are still considered in pre-release format, therefore, I used these data only for qualitative assessments. The locations and gaging station numbers are shown in Figure 2-5. Five hydropower dams operate within the watershed (North High Shoals dam has a series of three dams associated with the hydropower operations). Wallace dam, which controls the level of the Oconee Reservoir, was not examined because the backwaters of Sinclair Reservoir reach the dam with no free flowing river remaining. Also, the operations of Sinclair dam were not monitored because the downstream releases are outside the study area.

As a final discussion point on the effects of impoundments on habitat loss and fragmentation possible changes to the hydrologic budget regarding evaporative losses were examined. Morton (1983a and 1983b) published small scale maps of estimated annual open water evaporation, areal evapotranspiration, and the difference was considered the net reservoir eveaporation. Using these evaporation rates and the surface area of the impoundments (see below), the changes to the hydrologic budget were calculated and used as a starting point for discussion.

Results

The EPA dam database contained 276 dam locations within the watershed. This is an incomplete database as we demonstrated with the analysis of the 1:24,000 hydrography. This is due to the many small dams missing and a few major recent dams and impoundments. However, the database did give an indication of the variety of dam types within the watershed (Table 2-1).

The number of impoundments in the polygonal hydrography (1:24,000 scale) database in the watershed was 5,468. These covered 178 km^2 or 2.3% or the land area of the entire watershed. The number of in-stream impoundments (those polygons that intersect the stream network) was 3,489. The size of the impoundments ranged from 0.01 ha to 7,058 ha (Lake Oconee Reservoir). Figure 2-6 shows the size class frequency for both in-stream and off-stream impoundments. Figure 2-7 is a point map of all impoundments representing their surface area.

Based on the 1:24,000 scale data, we found 18,747 line segments with a total length of 10,490 km in the upper Oconee watershed network. Of these line segments, 4,636 totaled 846 km (8%) of inundated streams. The two largest reservoirs (Sinclair and Oconee) covered 71% of the inundated area and 53% of the stream length lost to impoundments. In contrast to these large reservoirs, the smaller reservoirs cover 29% of the area and 47% of the inundated length.

The magnitude analysis revealed the presence of 6,167 headwater streams (link-1 or 1st order) which accounted for over 57% of the total stream length. Therefore, the highest link number, the outlet of the watershed (Sinclair dam), had a link number of 6,167. The link numbers for all the in-stream impoundments were calculated and we found that most (3,147) were on link-1 (i.e. 1^{st} order) streams. Nearly half (2,840) of the 6,167 link-1 streams had one or more impoundments. Figure 2-8 shows the link number and surface area of each individual impoundment. Figure 2-9 shows the cumulative length of stream located in the network at each link number. Figure 2-9 also shows the cumulative length of stream inundated by impoundments at each link number. For example, Sinclair dam had a link number of 6,167 and inundated 194 km of river length. Similarly, the 1,161 impoundments located on link-1 streams inundated a total of 182 km of stream. All the dam (in-stream impoundments) locations were mapped as points and color and size coded by their link number (Figure 2-10).

The stream network analysis revealed that 5,050 of the stream segments (27%) had no dam at any distance upstream. These segments accounted for 4,510 km, or 43%, of the total length of streams. However, the maximum link number with no upstream dam was link-19.

The analysis of the downstream distance to an impoundment showed that the maximum distance downstream to an impoundment was 124 km. Table 2-2 shows the number, lengths and percentages for four downstream distance classes (< 1 km, 1 – 5 km, 5 – 15 km, > 15 km) and Figure 2-11 displays these downstream distance classes. For example, 7% of the stream length had a downstream impoundment within one kilometer.

The fragmentation analysis allowed us to compare all stream segments regarding their cumulative upstream, downstream and total stream length remaining connected as a percentage of pre-impoundment conditions (Table 2-3). The cumulative impact of the 3,489 in-stream impoundments resulted in a stream system that had 51% of the overall stream length having 0 to 25% of the pre-impoundment stream length remaining connected. Figure 2-12 shows the total fragmentation for all the stream segments within the watershed.

We summarized the percent stream length inundated within each of the 108 USGS 12-digit HUCs (Figure 2-13). The lowest percentage was 0.3% while the largest was 65.4%. The units incorporating Oconee and Sinclair Reservoirs had the highest percentages. The number of impoundments (both off-stream and in-stream) in a unit was also calculated and ranged from 4 to 82 (Figure 2-14).

The anlaysis of the gaging station data revealed altered hydrographs downstream of all three hydroelectric dams that we examined (Barnett Shoals dam, North High Shoals dam, and Tallassee Shoals dam (Figure 2-15). The gage downstream of Barnett Shoals dam was located 19 kilometers downstream and was assumed to affect the hydrograph the next 8 kilometers to where the river flows into the Oconee Reservoir. Similarly, North High Shoals dam likely altered the flow well past the gage (~7 kilometers downstream) and possibly the entire length extending to the backwaters of Sinclair Reservoir (~35 km). A larger tributary flows into the Apalachee River at 15 km downstream from the dam and may act to decrease the flow changes caused by the hydro-peaking. For the time period examined, the Middle Oconee River hydrograph 15 km downstream of Tallassee Shoals dam (gage 02217500) showed only slight alterations when compared to the upstream gaging station (gage 02217475) (Figure 2-15b and 2-15a, resp.). This may be because of the dam's relatively small capacity relative to the discharge of the Middle Oconee River.

Using Morton's (1983b) map of net annual reservoir evaporation as a reference, a value of 500 mm / year was multiplied by the 178 km^2 of impounded waters to estimate the potential cumulative change in evaporative losses from the watershed. The difference between the areal evapotranspiration (prior to being replaced by open water) and the open water evaporation, or the net annual reservoir evaporation was found to be 89 million m^3/year, equivalent to 100 cfs, 2.83 m^3s, or 64.2 million gallons / day (MGD).

Discussion

Stream habitat loss, degradation and fragmentation due to impoundments have been identified as major contributing factors leading to the decline of freshwater biota (Pringle et al. 2000, Warren et al. 2000, Vaughn and Taylor 1999, Richter et al. 1997). The loss of free-flowing streams has been documented throughout many parts of the world including the southeastern United States (Shankman 1999, Soballe et al. 1992, Dynesius and Nilsson 1994, Collier et al. 2000). However, the scale of these assessments has been very broad due to limited datasets and thus, focused mainly on the largest reservoirs and dams and overlooking the thousands of smaller impoundments in the watersheds. Also, because reservoir or dam projects generally are only evaluated individually, the cumulative effects have generally not been assessed. The methods presented here represent an effort to assess the cumulative impacts of the thousands of impoundments using large-scale datasets (e.g. 1:24,000 scale or larger).

The results of the upper Oconee watershed analyses illustrated that even if an impoundment does not have an apparently large impact on an individual basis, the cumulative impact of the thousands (i.e. 5,468) of impoundments in the watershed can result in a considerable amount of habitat loss and fragmentation within the upper Oconee watershed. Ostensibly every stream in the watershed has been affected by impoundments because all streams are upstream of at least one impoundment, Sinclair Reservoir, and 73% of the stream segments are downstream from some dam. Moreover, every USGS 12-digit HUC (approximately 71 km^2 units) region has multiple (and as many as 82) impoundments within its boundaries.

Of course, the two largest impoundments, Sinclair and Oconee Reservoirs, have had an enormous impact on stream habitat, yet surprisingly small impoundments also have had considerable cumulative impacts on habitat loss and fragmentation in the watershed. The vast majority of impoundments are smaller than ten hectares (99%, see Figure 2-6). These account for over 40% of the stream length that has been inundated thus far. Many of these impoundments are located high up in the network (e.g. link-1) and, therefore, are fragmenting the upstream length of many streams. However, many of these small impoundments were also found further down in the network (e.g. link-20), thereby cutting off many streams from the downstream network.

Although, three of the hydropower dams in the watershed have relatively small impoundments (approximately 1 - 5 km upstream all together), examination of the hydrographs downstream from these dams showed evidence of hydrologic alterations. Altered flow regimes were found to affect between 41 and 77 km of river downstream, therefore most of the habitat degradation occurred downstream. Hydrologic alterations have been shown to have profound impacts on the biota (e.g. Penáz et al 1999, Van Steeter and Pitlick 1998). For example, Bain et al. (1988) found that the flow fluctuations caused decreases in many of the small-bodied fishes requiring shallow stable river margins. Habitat quality can be degraded over a considerable downstream distance because of channel incision, unstable bed sediments and/or bed armoring, which occurs due to the high energy releases and a limited sediment supply downstream (Collier et al. 2000, Shields et al. 2000, Robinson et al. 1998). The examination of hydrographs in the upper Oconee showed that another 0.5 - 0.7% of the total stream length in the watershed was affected by flow alterations. More investigation into these hydrological alterations is needed in order to identify the actual biological impacts to the downstream ecosystems.

Understanding the change to the hydrologic budget of the upper Oconee watershed due large areas (cumulatively) being converted to open water is important because of the possible impacts of stream de-watering at critical times of the year. The analysis of the net evaporative loss using regional estimates from Morton (1983a,b) showed that more water is lost to the atmosphere currently from open water impoundments than from the vegetation the impounded waters have replaced through inundation. Average monthly stream flow below the outlet of the watershed (at Milledgeville, GA USGS gage 02223000) ranges from 1,497 cfs (September) to 6,452 cfs (March). Considering the annual evaporation estimates (100 cfs) between 1.5% and 6.7% of the flow is being evaporated from artificial impoundments. Because Morton’s (1983a,b) evaporation estimates were annual, this is likely underestimating the percent evaporated during the driest months when evaporative losses are the highest. Therefore, evaporation from impoundments may be adding to the diminished flows in times of drought. As discussed above, flow alteration (de-watering) has also been shown to negatively affects stream biota (e.g. Travnichek et al. 1995).

Estimating open water evaporation and evapotranspiration from vegetated land surfaces is a very complex modeling problem, thus the estimates discussed and presented here are only a first step. For example, Morton’s estimates (1983a, 1983b) of open water evaporation generally were referring to larger reservoirs and because approximately 29% of the inundated areas in the upper Oconee watershed are from smaller impoundments Morton’s estimates may not be completely reliable for this area. Generalizations may be more difficult for small impoundments because of the high amount of variation in the key factors controlling evaporation. Factors such as, the humidity over the surrounding land areas, water depth, pond width, source water temperature, shoreline shading, and wind speed will vary greatly depending on the type, use and location of the impoundment (Dunne and Leopold 1978, Morton 1983a, Chiew and McMahon 1991). Furthermore, different land cover types (e.g. pasture versus forested wetland) will have differing evapotranspiration rates and therefore the type and amount of vegetation that was inundated is also an important factor when considering net change in water losses (Gan et al. 1991, Roberts and Roberts 1992). Therefore, in order to estimate changes in the hydrologic budget more accurately, future research must consider and incorporate the water loss from the thousands of small impoundments.

The upper Oconee watershed analyses showed that the headwater streams (link-1) have been greatly altered by impoundments with almost half of these streams being impounded one or more times. Considering the scale of the data used (1:24,000) in these analyses we are mostly likely underestimating both the number of headwater streams and the number of ponds connecting to the stream network (see Figure 2-4). What are the ramifications of having so many small streams either inundated or cutoff from the rest of the stream network? To date, no research has been done on the broad scale effect of thousands of artificial impoundments located on the small streams in the watershed.

Impounding these small streams no doubt changes the physical, chemical and biological make-up and alters how nutrients and organic matter are processed and delivered to the downstream system. Below I discuss these possible alterations due to small impoundments on headwater streams.

Meyer and Wallace (2001) argue that the small headwater streams are the real workhorses of the stream network. These small streams hold the diverse life that transform leaves and other coarse particulate organic matter (CPOM) into life-sustaining nutrients and fine organic particulate matter (FPOM) downstream (Allan 1995). According to the River Continuum Concept (RCC), headwater streams are normally dominated by CPOM composed of leaves and woody debris and further downstream the FPOM increases and changes in the biota follows (Vannote et al. 1980). However, ponds will settle out CPOM and may increase the production of algae and change the food base drastically downstream to more macroinvertebrate filter feeders which use FPOM rather than the shredders associated with CPOM (Mackay and Waters 1986). These shifts in invertebrate community structure at impoundment outlets have been studied more often at natural lake-outlets (Richardson and Mackay 1991) and more research is needed to be able to better understand the differences and similarities at outlets to artificial impoundments.

It is well established that nutrient transport and retention in lentic systems is very different from lotic systems (Horne and Goldman 1994, Allan 1995). This is in part due to the increased hydraulic residence time in the impoundments with sediment and CPOM settling out in the stagnant water column (Horne and Goldman 1994). The residence time is dependent on the ratio of inflow to storage volume and this may be high in small ponds with small volumes (Dunne and Leopold 1978). However, sedimentation still occurs within the small impoundments and acts to immobilize some nutrients, like phosphorus, and eliminate them from the downstream system (Conley et al. 2000). Other nutrients, like dissolved silica, are taken up in diatoms and settle out in standing waters, thereby eliminating this vital nutrient from further uptake (Horne and Goldman 1994). This may be adversely affecting downstream systems and ultimately may be limiting marine systems that require the delivery from freshwater systems (Ittekkot 2000). Given the numbers of small artificial impoundments, further analyses is needed to understand the cumulative effects on nutrient transport and retention in the freshwaters system.

The flow variation and its associated affects on habitat in small streams are thought to regulate biotic community structure in headwater streams (Schlosser 1982, Allan 1995). This flow variation is regulated by small impoundments and therefore may be shifting the biological community structure. Thousands of farm ponds and other small impoundments may lower the maximum discharge by storing much of the initial runoff from rain events (Schoof and Gander 1982, Hirsch et al. 1990, Poff and Ward 1989). Also, depending on how much water is released at the outlet of the pond, base flow may be cutoff entirely if all water is stored or it may be augmented due to a constant release from the pond (Richardson and Mackay 1991).

Impoundments on small streams also will shift the fish communities with formerly no or few predacious fish species to a system that is dominated by them as a result of stocking efforts and supplemental feeding efforts (Noble 1988, ULI 1992). The presence of fishes, like the bluegill, catfish, and bass drastically alter the food web and can exclude, through predation, many small-bodied fishes associated with these streams

(Schrank 2001). Also, amphibian species that are usually found in these headwater streams will be preyed upon and likely will be excluded from these altered systems (Baker and Halliday 1999, Moncello and Wright 1999).

Drought and other natural disturbances often affect small streams, yet in the absence of barriers populations in the stream rebound quickly through colonization (Peterson and Bayley 1993, Schlosser 1990). Fragmentation effects from small impoundments will be dramatic in the upstream reaches because as local extirpations occur there will be no population source for recolonization due to the presence of the impoundment (Winston et al. 1991, Wilde and Ostrand 1999).

Small streams generally have cooler waters originating from springs or seeps and are generally more shaded. Therefore, these small streams may act to moderate the temperatures in the larger rivers (Meyer and Wallace 2001). Artificial ponds located on headwaters may be warm at all depths because they may rarely be thermally stratified due to the shallow waters (Clark 1988). Consequently, the water released downstream will generally reach higher temperatures than the streams they replaced (Clark 1988, Horne and Goldman 1994) and these temperature differences may in turn shift growth rates and community composition downstream (Schlosser 1982, Richardson and Mackay 1991).

In the upper Oconee watershed small impoundments have directly inundated more than 390 km of stream. However, if we conservatively figure that 100 meters downstream of the dam is altered, then in headwater streams alone, another 200 to 300 kilometers has been altered by these small impoundments. Given the changes described above, more research is necessary to understand how these changes in the headwater streams due to impoundments will alter watershed-wide biological, physical and chemical processes (Vörösmarty and Sahgian 2000, St. Louis et al. 2000).

The techniques and findings regarding habitat loss and fragmentation due to impoundments have conservation planning and water resources management applications. With the methods presented here the sub-watersheds least impacted by impoundments may be identified as priorities for conservation. Conversely, highly impacted watersheds can be evaluated for restoration by examining the impoundments in terms of the present day benefits (e.g. flood control, sediment retention) and costs (e.g. stream length inundated, link # position, etc). Many states have begun to remove outdated, unsafe, and environmentally harmful dams as a method to restore streams (Graf 1996). Given the extent of fragmentation and loss of free-flowing streams in the upper Oconee, removing dams and impoundments should be encouraged as a viable option in stream restoration activities.

Alternative reservoir placement options could be evaluated relative to habitat loss and fragmentation. Applying these techniques will allow planners to make informed decisions before taking action on specific placement of an impoundment. For example, should a reservoir be deemed necessary, placement strategies might consider how heavily the sub-watershed is already affected by existing impoundments. Another consideration is whether to build multiple small impoundments on the headwaters or fewer larger impoundments further down in the watershed. Once an impoundment is sited these techniques can also aid in stream mitigation. Mitigation sites could be found that have similar network settings and lengths affected. Alternatively, as mentioned earlier, sites for restoration of highly impounded stream reaches could be identified as mitigation opportunities for dam removal.

More informed decisions can be made when considering whether to rehabilitate or re-license a project using the analyses presented here. There is ample opportunity for incorporating the analysis of cumulative impacts into the management and planning of impoundments in the U.S. For example, many existing large dams have mandated re-evaluations regarding their original purpose, safe function, environmental impacts and continuing benefits (e.g. Federal Energy Regulatory Commission, FERC). Also, as smaller dams age, their structural integrity must be assessed and decisions must be made whether to rehabilitate the structure (NRCS 2000) or perhaps, safely dismantle it. In fact, the Natural Resource Conservation Service (NRCS) is currently looking to fund the rehabilitation of approximately 2,200 watershed dams across the country at considerable expense (NRCS 2000). This is an opportunity for NRCS to assess the cumulative impacts of their multiple impoundments. Assessments should be conducted to determine whether the dams are serving their intended purpose (e.g. flood control, sediment traps) and attempts should be made understand the cumulative ecological impact of the many dams in a particular watershed.

Small impoundments, like farm ponds, recreation ponds, and amenity ponds continue to be built. Little to no regulation of small impoundments is mandated by law and requirements instituted for larger dams, such as a minimum flow (Travnichek et al. 1995), do not occur for small ponds. Perhaps it is time to consider regulations that consider the effects on the streams below these small impoundments which can have large cumulative impacts downstream.

The methods presented here show promise in the effort to assess cumulative impacts. These techniques have highlighted the fragmented nature of the streams within the upper Oconee watershed and resulted in methods to compare stream segments, impoundments and sub-basins. However, many questions remain and further research is needed to assess the biological effects of the fragmentation and loss. Future research projects might consider questions such as: Are there fragmentation and habitat loss thresholds at which the system ceases to function? Do impoundment waters themselves act as barriers to certain riverine species? How far downstream does a small impoundment affect the stream system? How does nutrient and carbon cycling within the system change when a large portion of the streams are impounded and water residence time increases?

CHAPTER 2 TABLES AND FIGURES

Table 2-1. Types of dams in the Upper Oconee watershed. The source is the EPA inventory of dams database (1:100,000 scale) *(incomplete database)*.

Hydroelectric	7
Irrigation	10
Recreation	172
Flood Control	35
Fire/Farm Pond	38
Tailings	2
Water Supply	7
Other	5
Total	276

Table 2-2. Downstream distance (classes) to an impoundment for each stream segment.

Distance Class (km)	Count (no.)	Count (%)	Length (km)	Length (%)
Impoundment	4,636	25	846	8
<1	2,188	12	695	7
1 - 5	2,059	11	1,667	16
5 - 15	2,542	13	1,898	18
15 - 30	3,155	17	2,346	22
30 - 60	3,279	17	2,370	23
60 - 124	888	5	668	6

Table 2-3. Length of stream in upstream, downstream and total fragmentation index classes. Fragmentation index equals the percent length remaining connected post-impoundments.

Fragmentation Class	Upstream km (%)	Downstream km (%)	Total km (%)
Impoundments		846 (8)	
0 – 25%	1,929 (18)	6,163 (59)	5,335 (51)
25 – 50%	314 (3)	2,472 (24)	2,669 (25)
50 – 75%	546 (5)	1,009 (10)	1,542 (15)
75 – 100%	6,856 (66)	0 (0)	98 (1)
Maximum	100 %	70 %	87 %

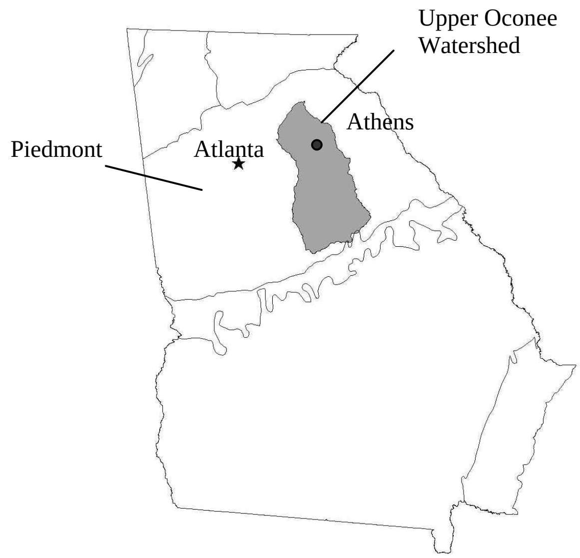


Figure 2-1. Upper Oconee watershed in the Georgia Piedmont.

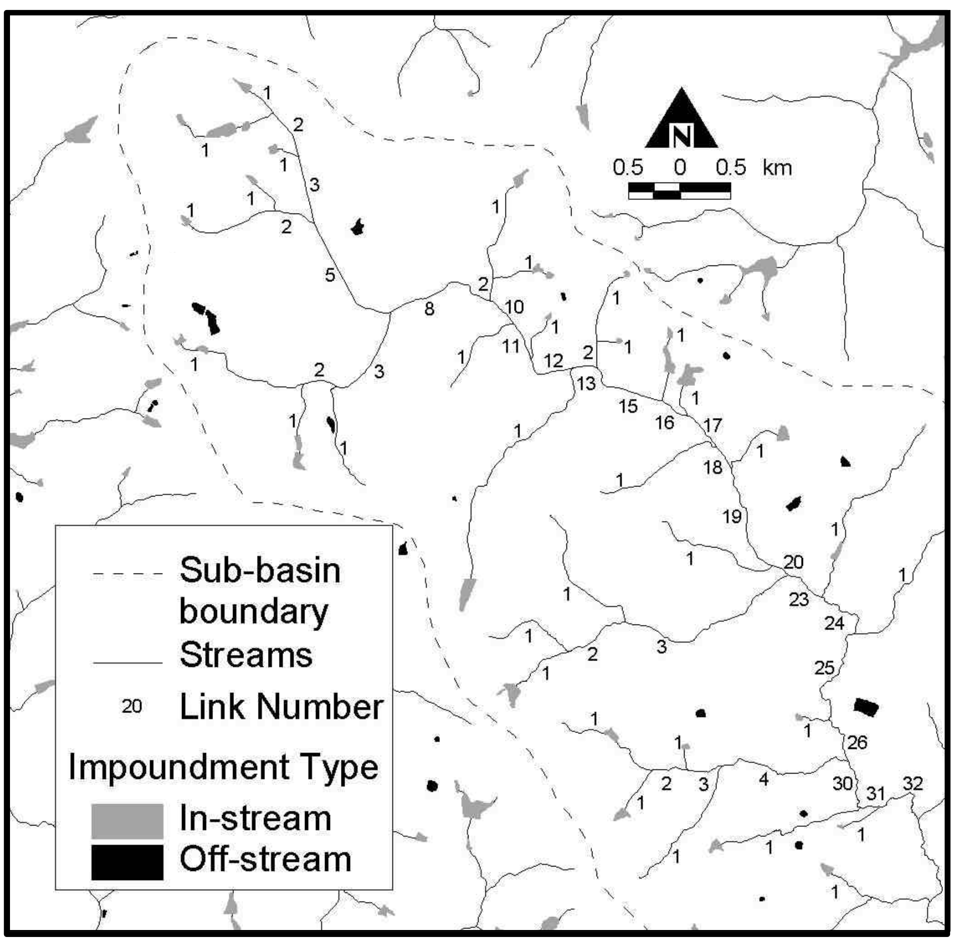


Figure 2-2. Link number and impoundment type for example sub-basin.

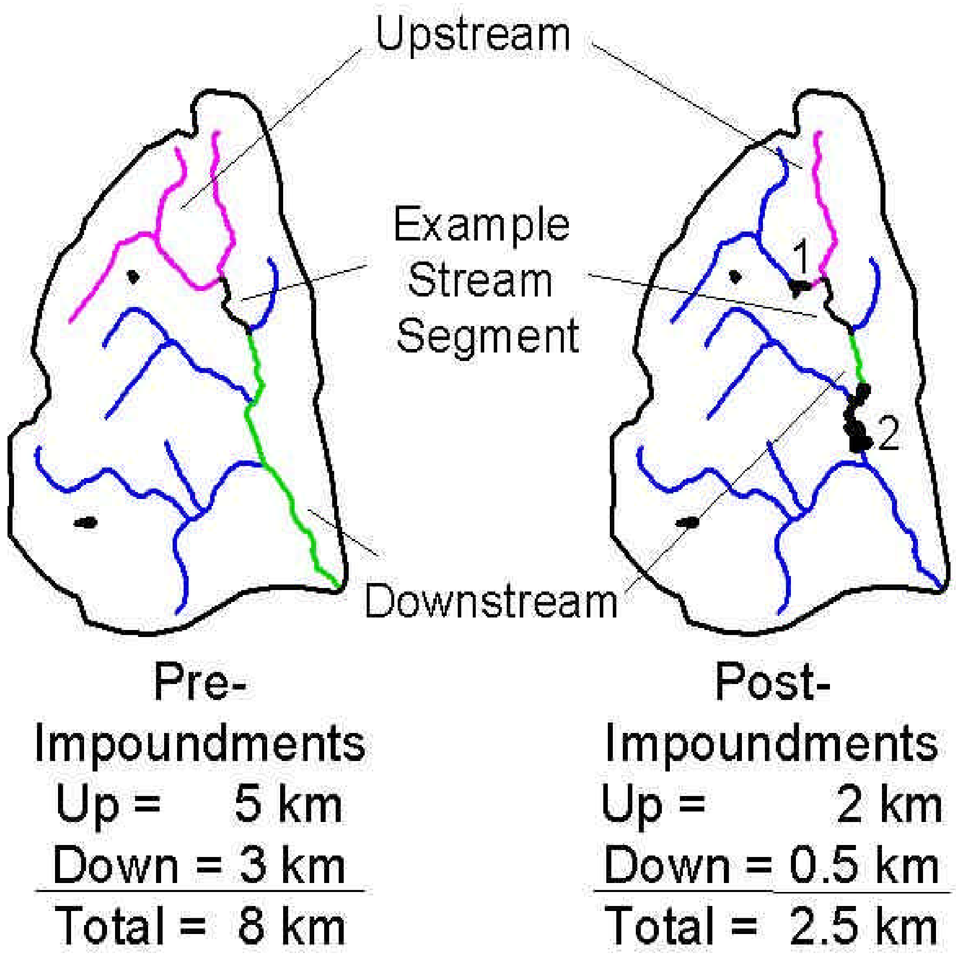


Figure 2-3. Example fragmentation from two in-stream impoundments; labeled 1 (link-2) and 2 (link-6). For this stream segment total fragmentation is 31% (2.5 / 8 km), downstream fragmentation is 16 % (0.5 / 3 km), and upstream fragmentation is 40 % (2 / 5 km)

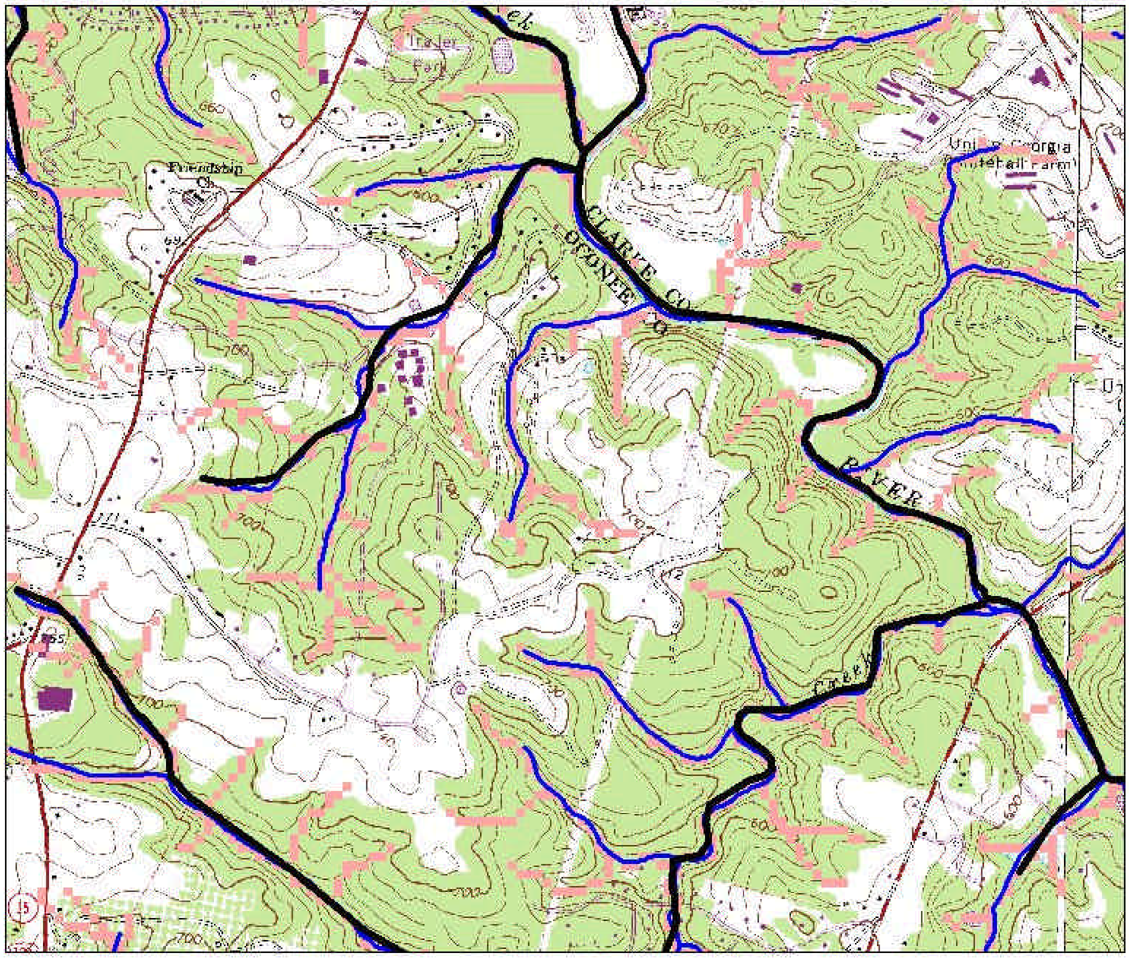


Figure 2-4. Scale differences when measuring length. Black lines (▬) are 1:100,000 scale; Blue lines (▬) are 1:24,000 scale 'blue lines' from the USGS topographic map displayed beneath the lines; Light red lines (▬▬▬▬) are the drainage network derived from 30 meter resolution digital elevation model (DEM). The analyses were done using the blue lines (1:24,000).

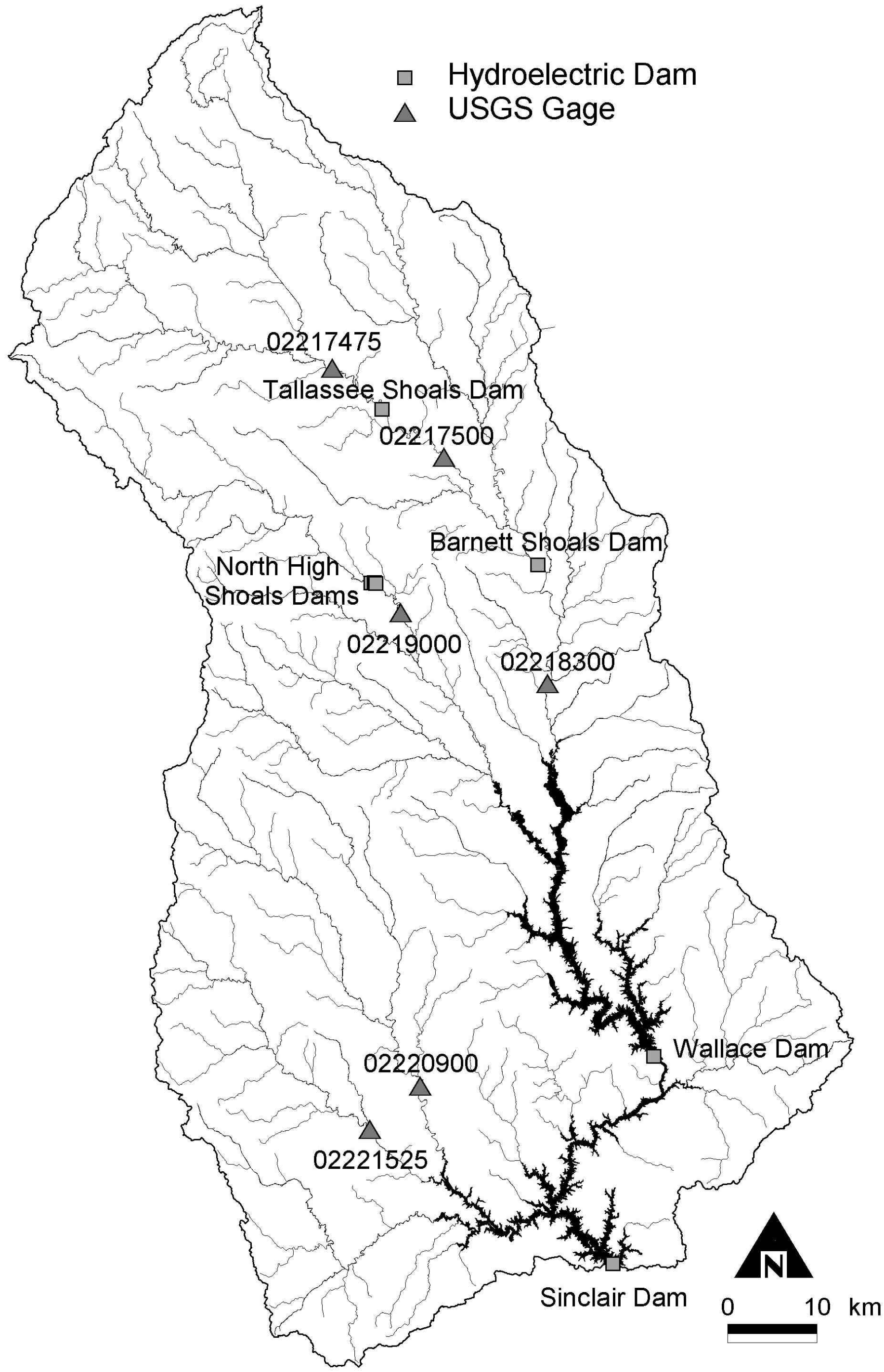


Figure 2-5. Locations of hydroelectric dams and USGS gaging stations monitored from June 10th to August 12th, 2000 (see Figure 2-15).

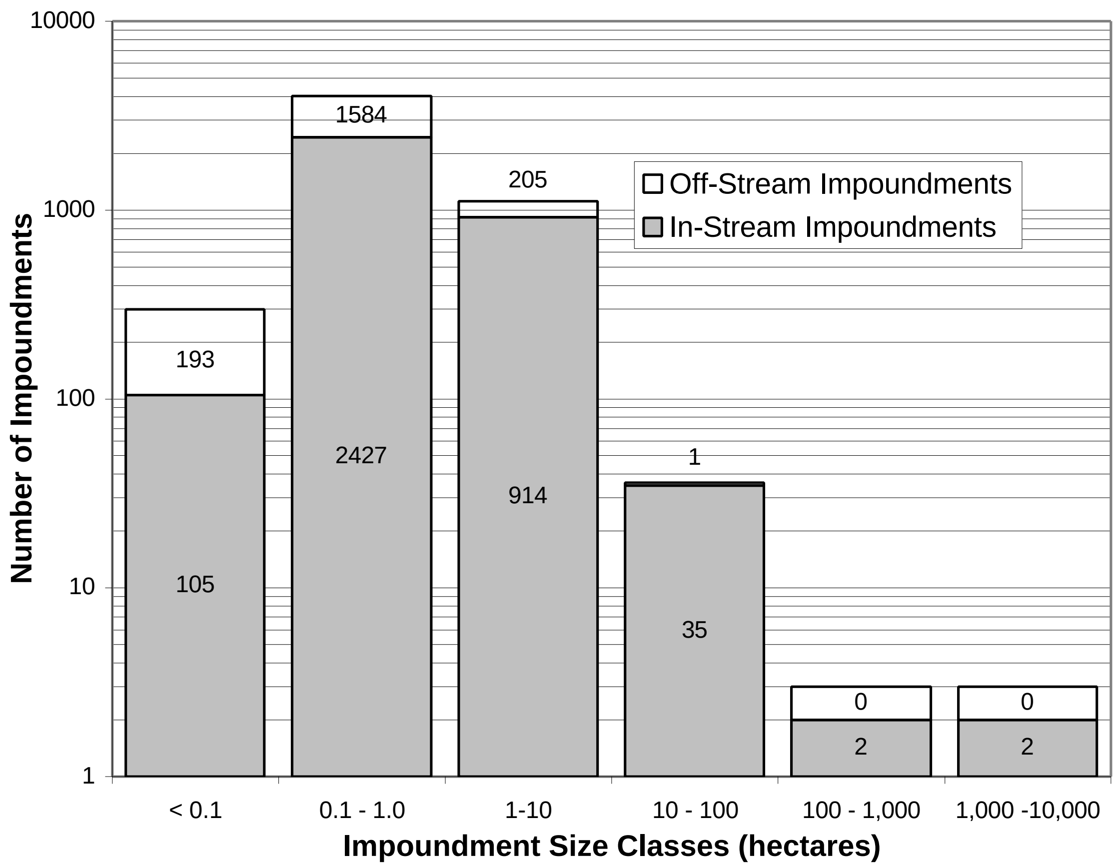


Figure 2-6. Off-stream and in-stream impoundment size class frequency.

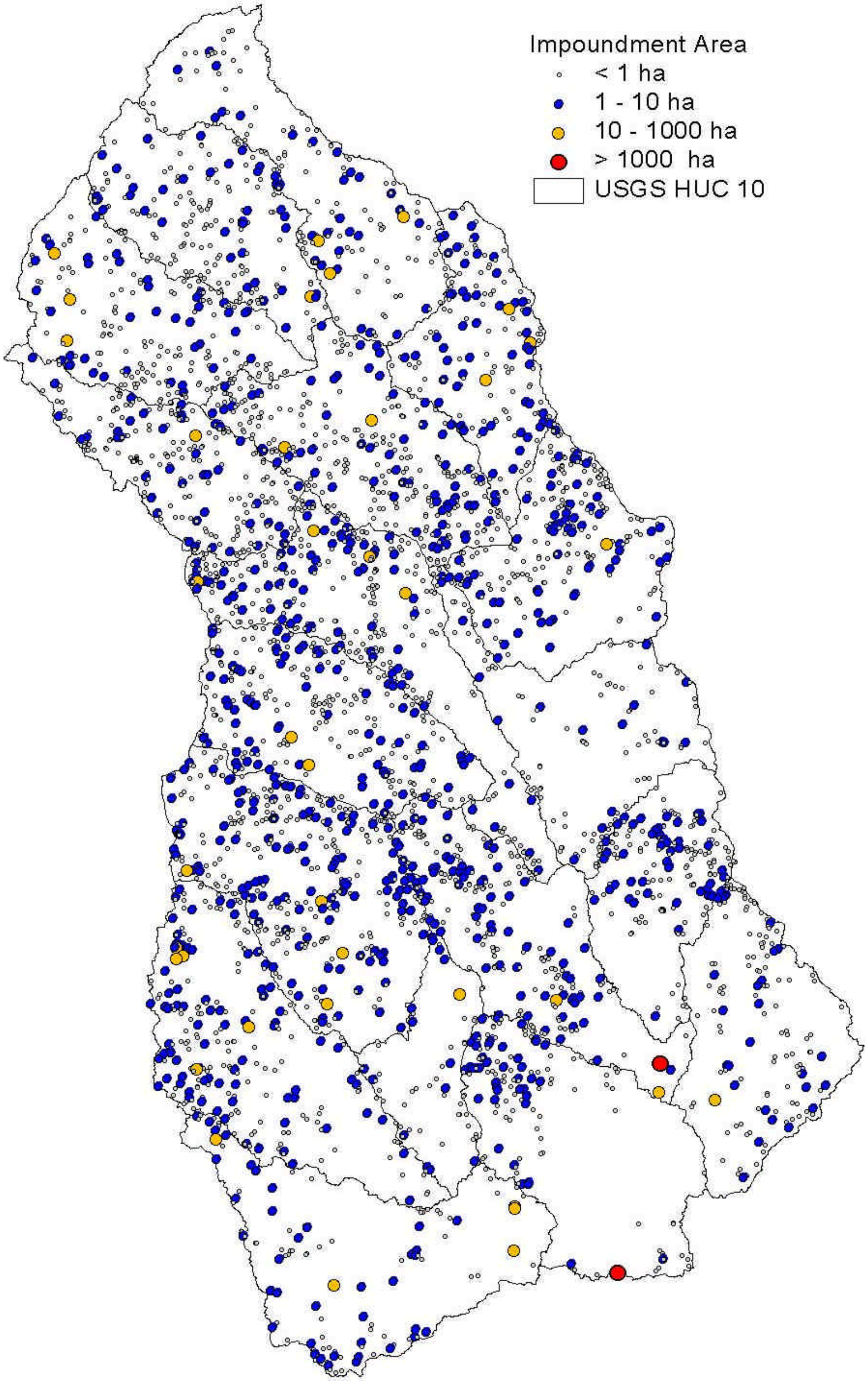


Figure 2-7. Surface area of all impoundments in the Upper Oconee watershed. For off-stream impoundments the point represents the centroid of the polygon. For in-stream impoundments the point is the location of the dam.

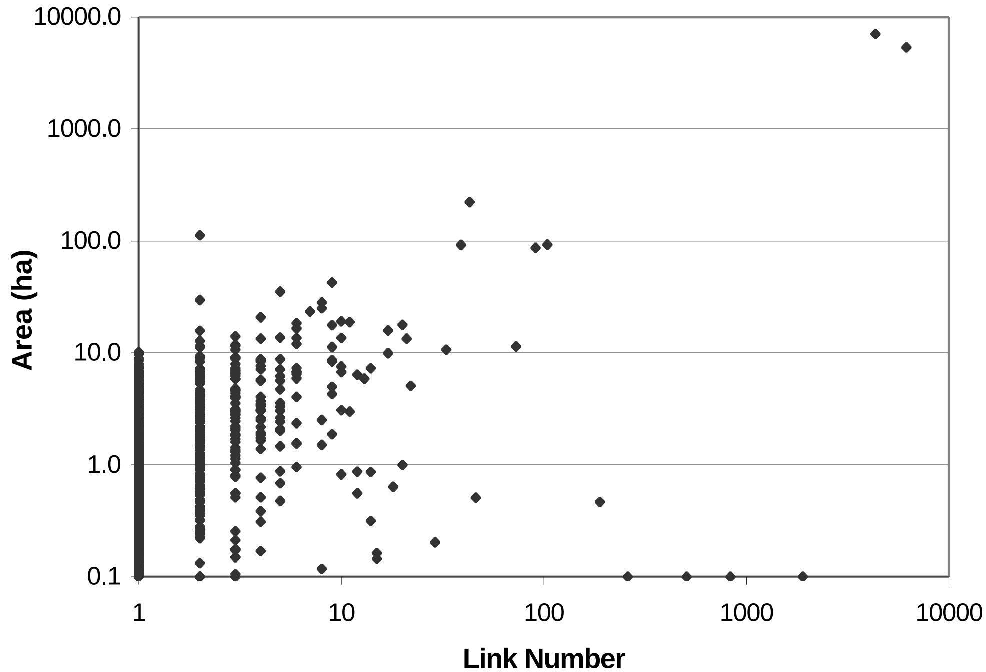


Figure 2-8. Individual (in-stream) impoundment link number and area inundated.

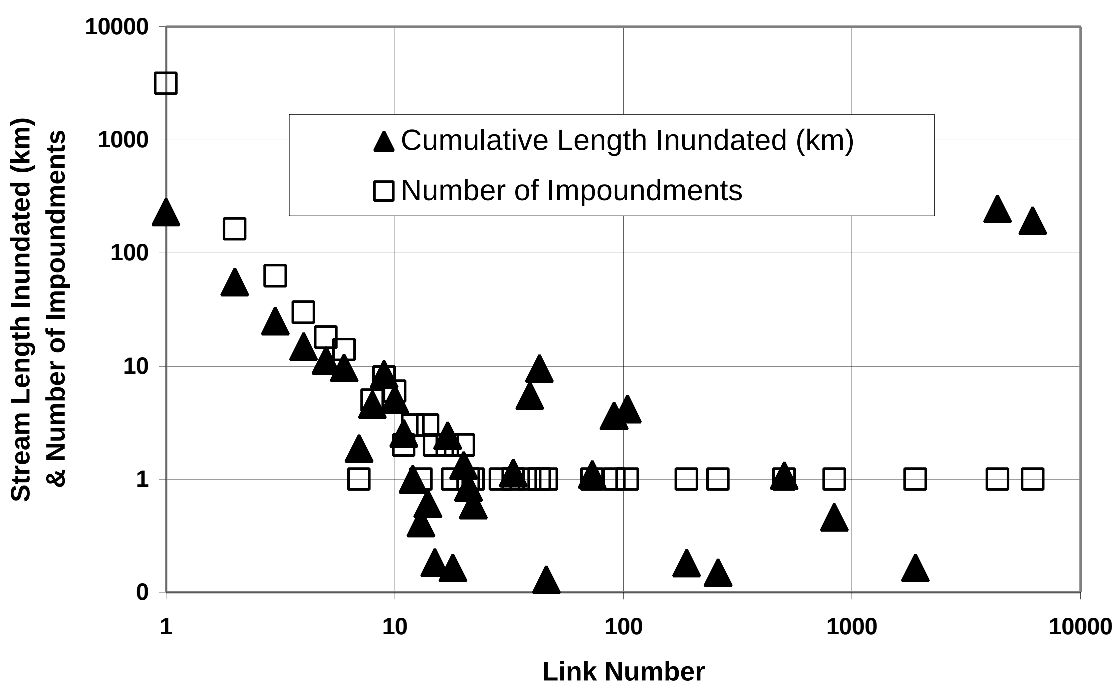


Figure 2-9. Total stream length inundated by impoundments for each link-number class.

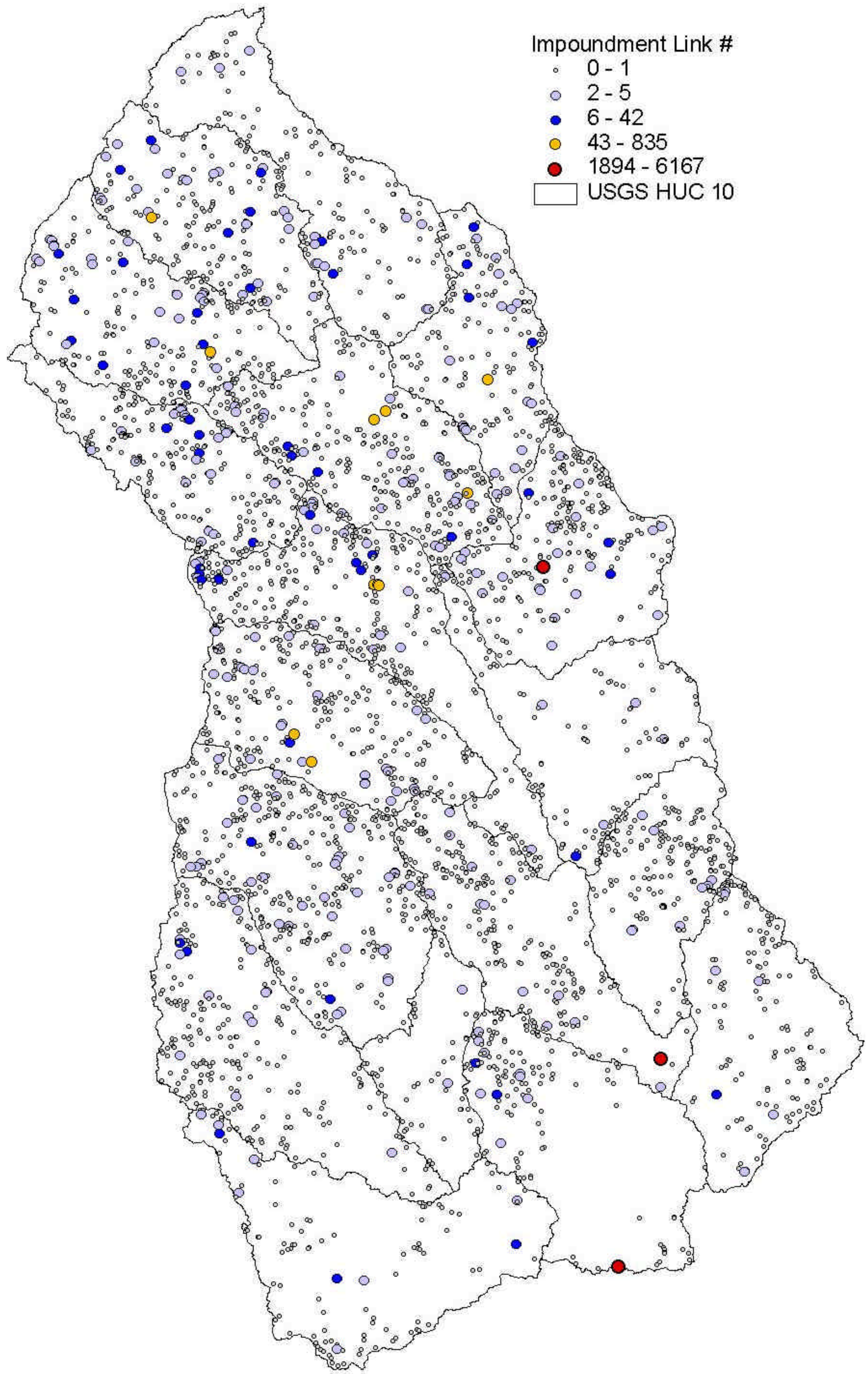


Figure 2-10. Dam locations and link numbers.

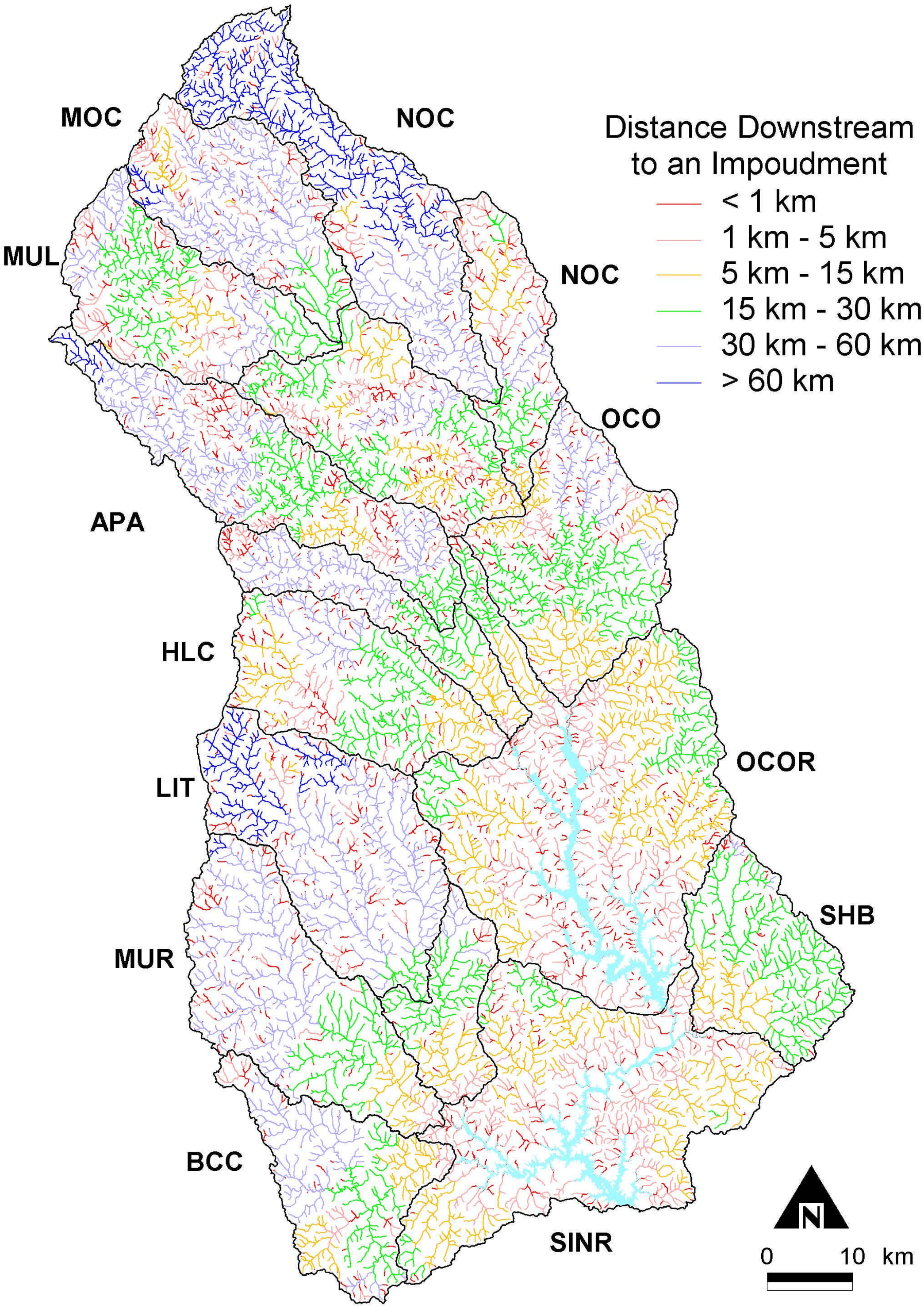


Figure 2-11. Downstream distance to impoundment waters (classes) for all stream segments.

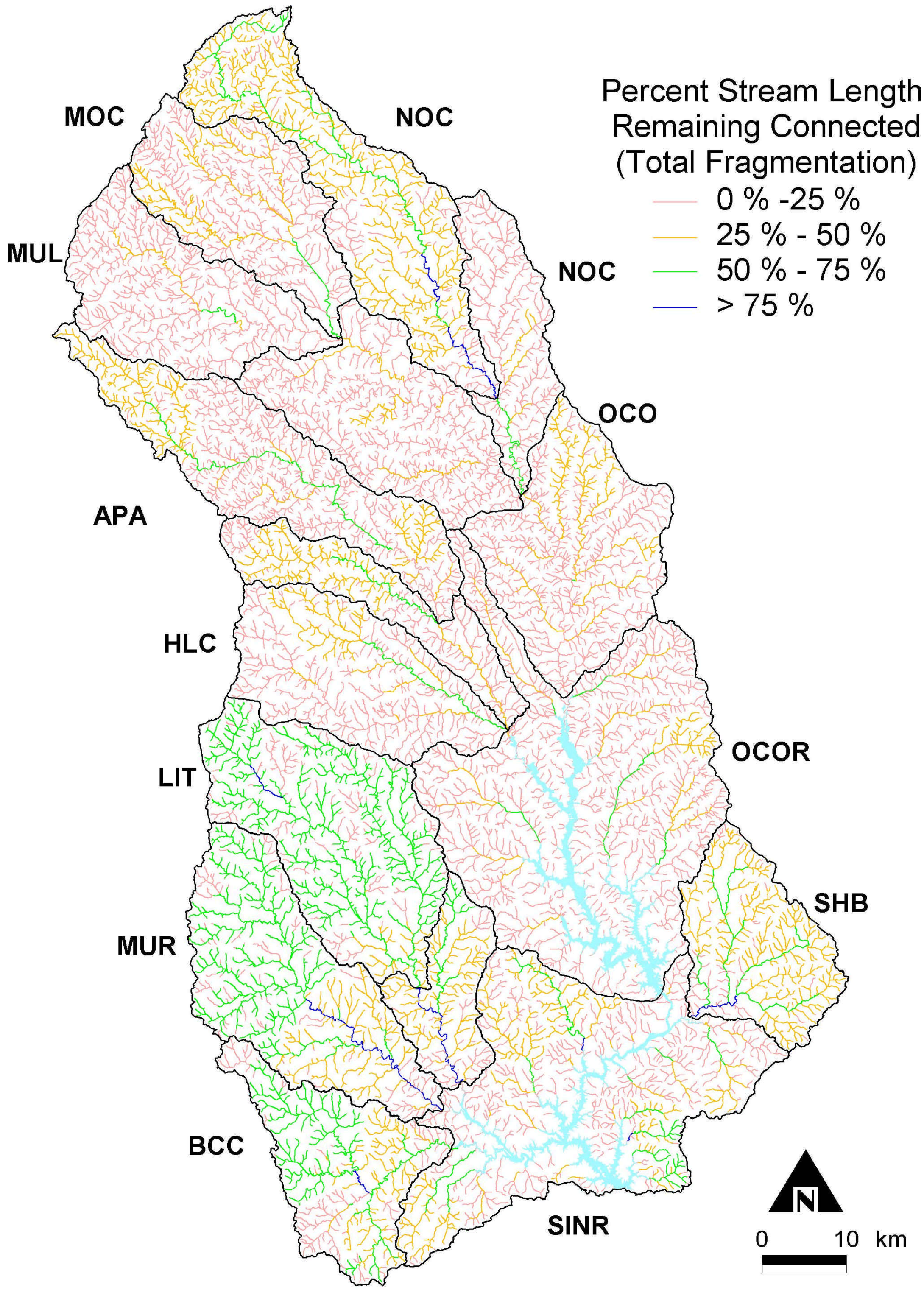


Figure 2-12. Total fragmentation index, the percent remaining connected upstream and downstream post-impoundments.

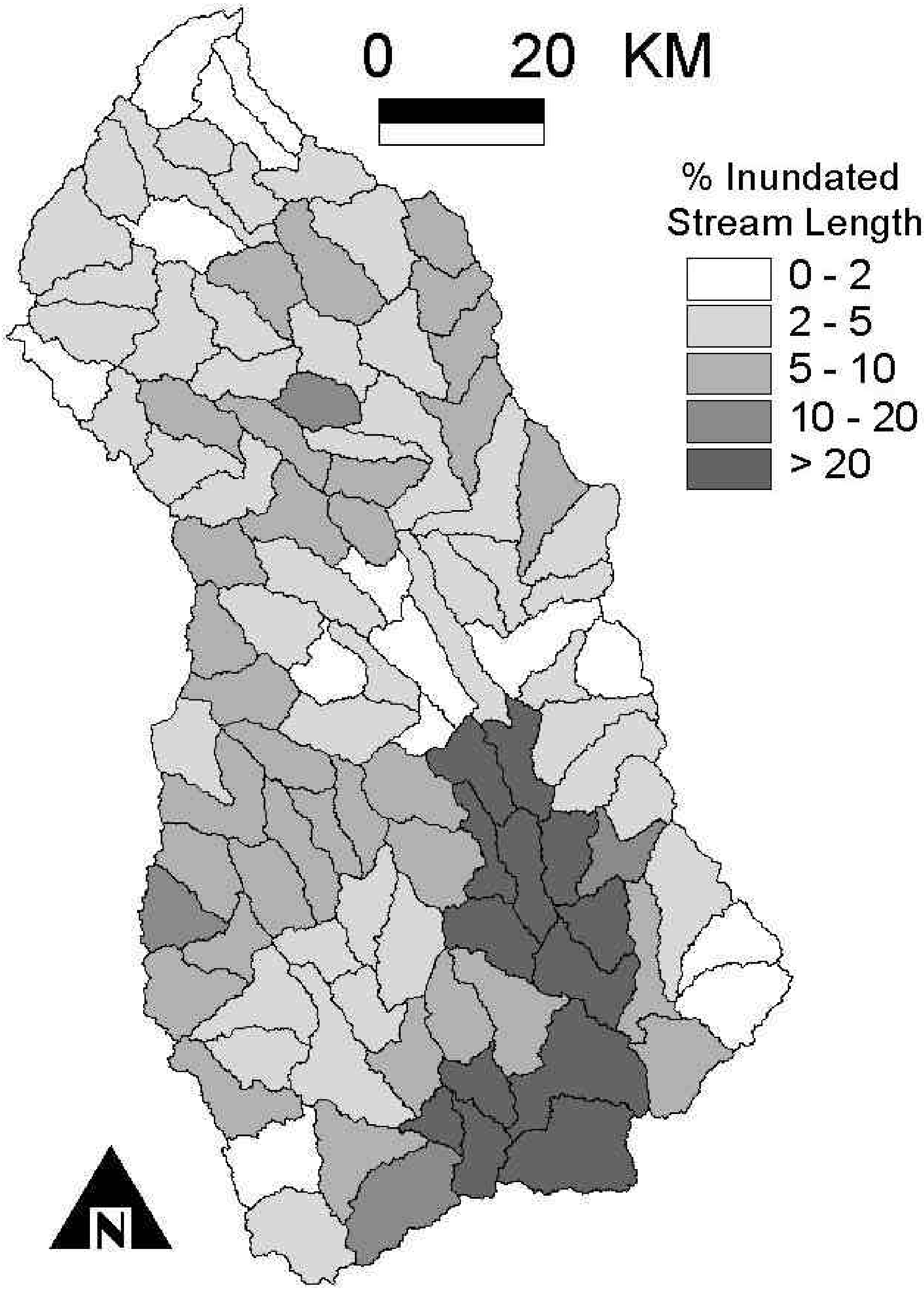


Figure 2-13. Percent of stream length inundated within USGS 12-digit HUCs.

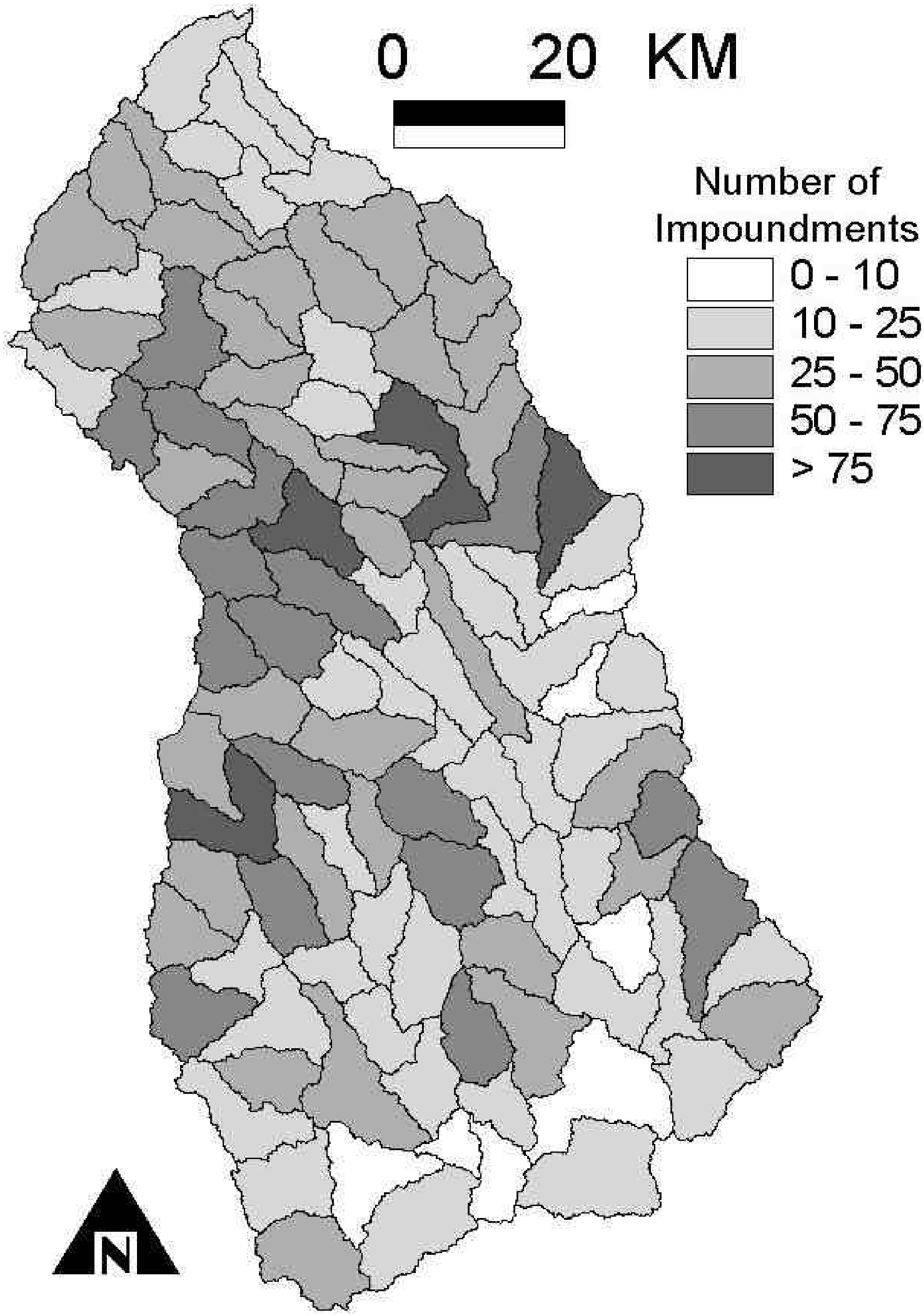


Figure 2-14. Number of impoundments (off-stream and in-stream) within USGS 12-digit HUCs.

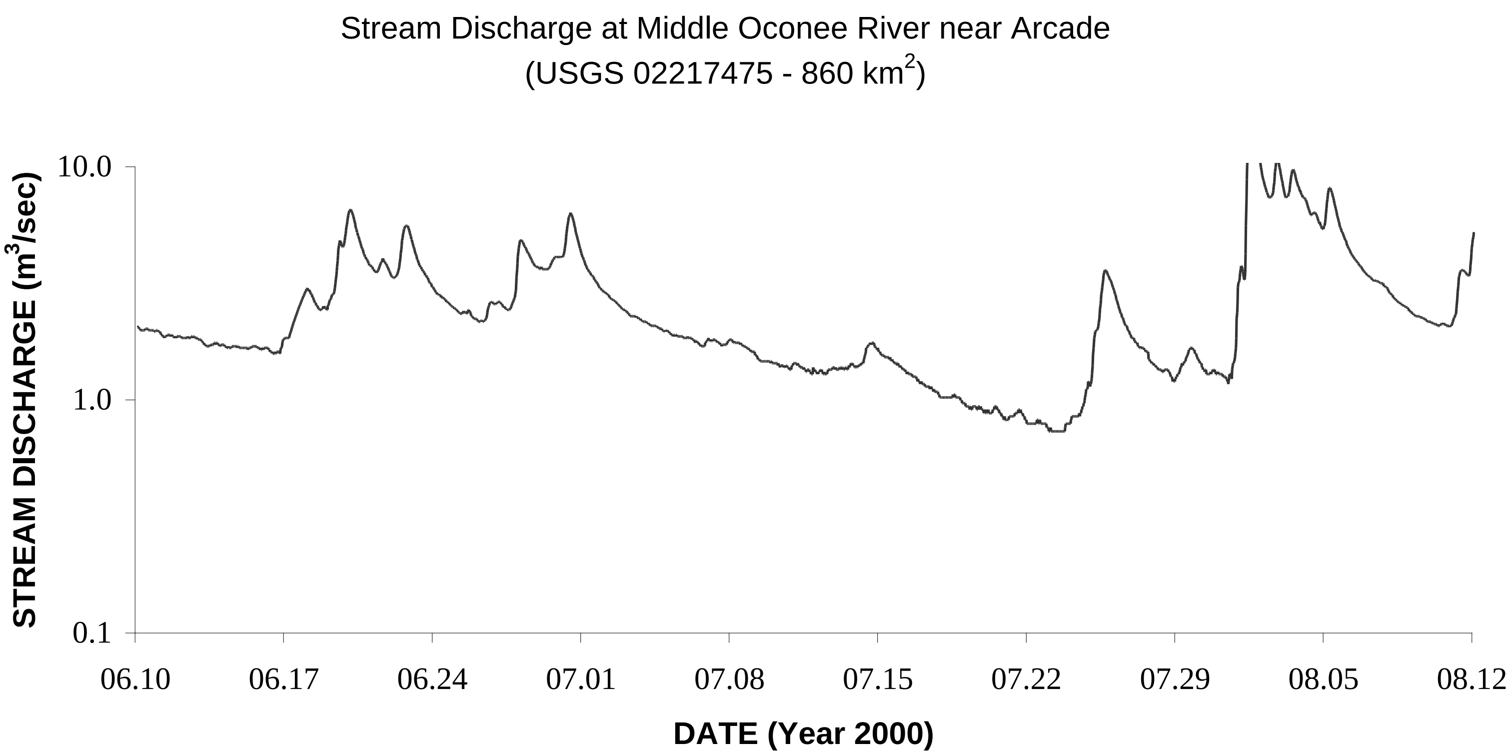


Figure 2-15a. Stream discharge at Middle Oconee River above Tallassee Shoals Hydroelectric Dam.

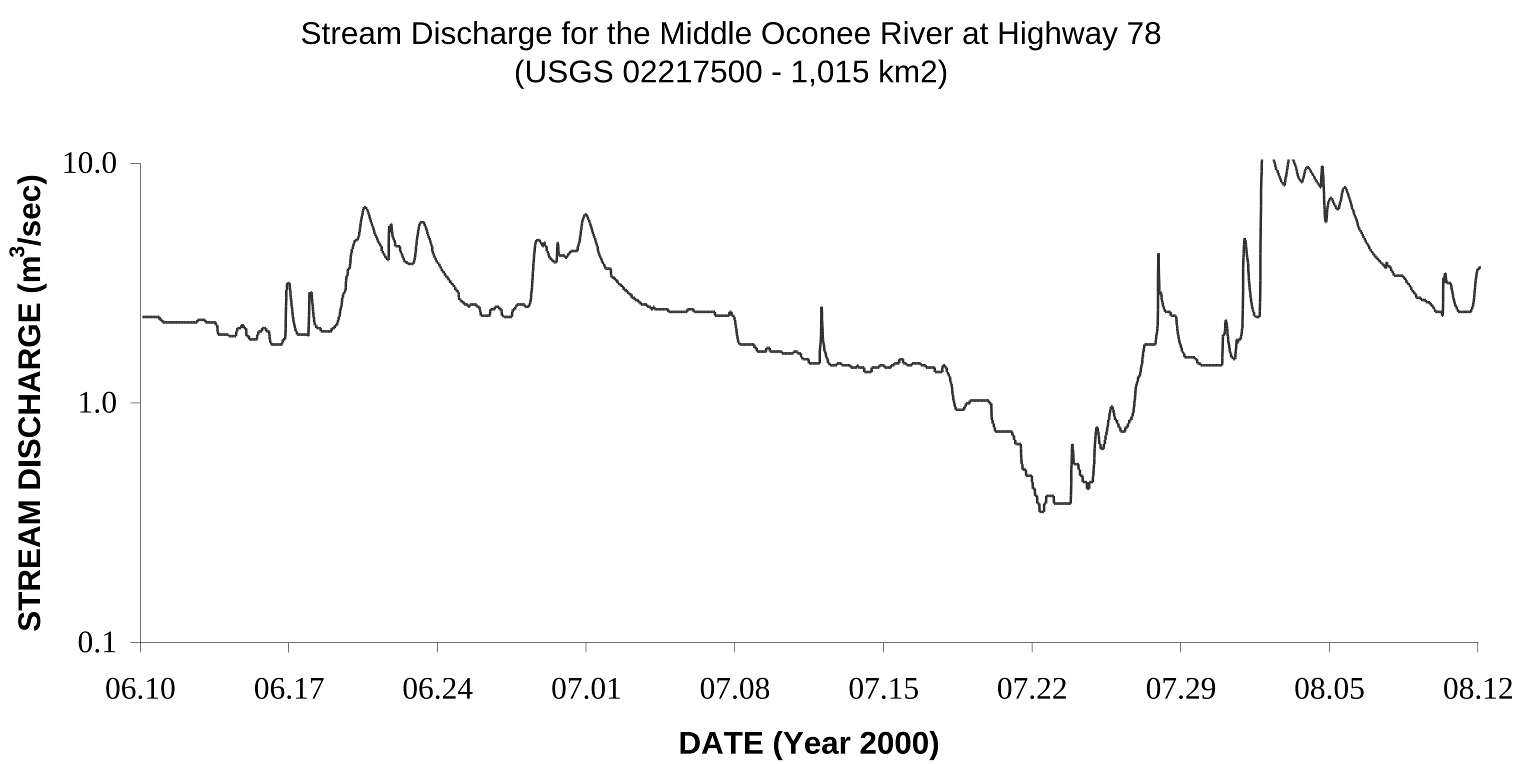


Figure 2-15b. Stream discharge at Middle Oconee River below Tallassee Shoals Hydroelectric Dam.

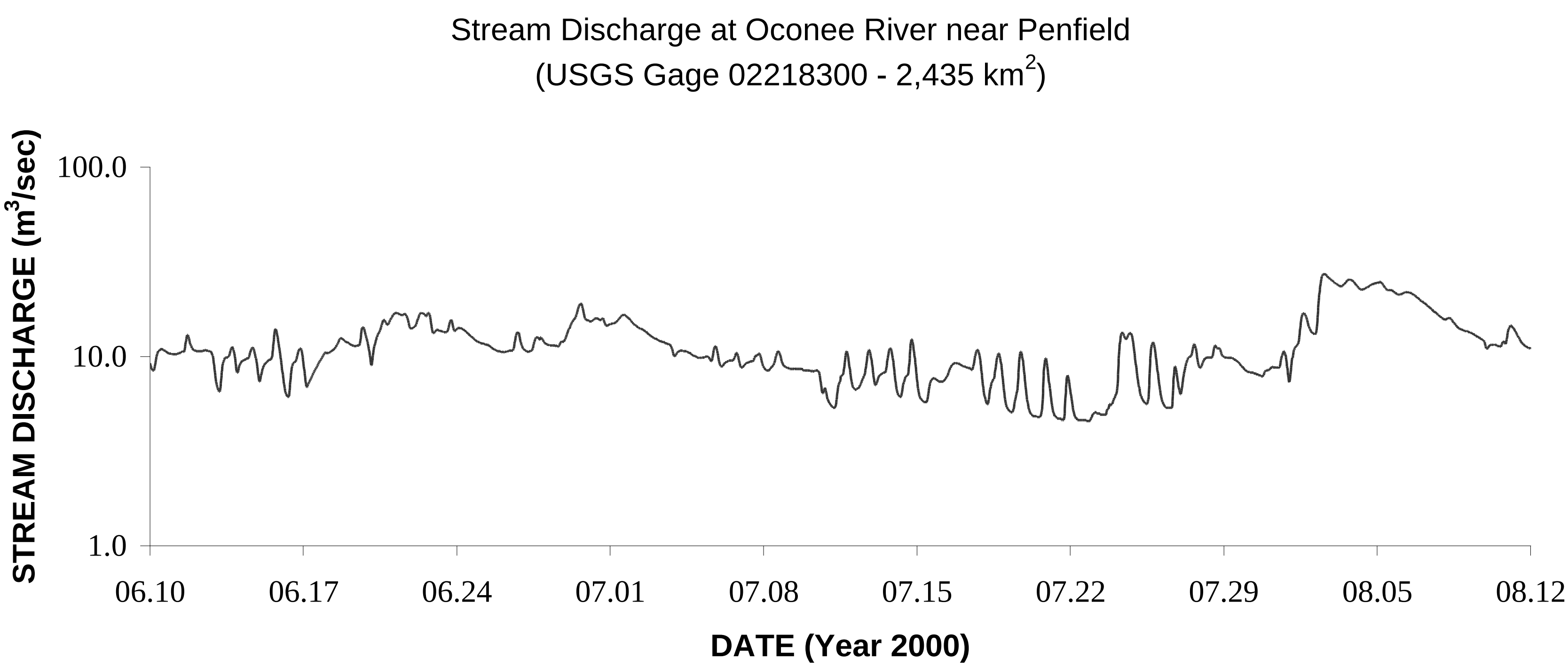


Figure 2-15c. Stream discharge at Oconee River below Barnett Shoals Hydroelectric Dam.

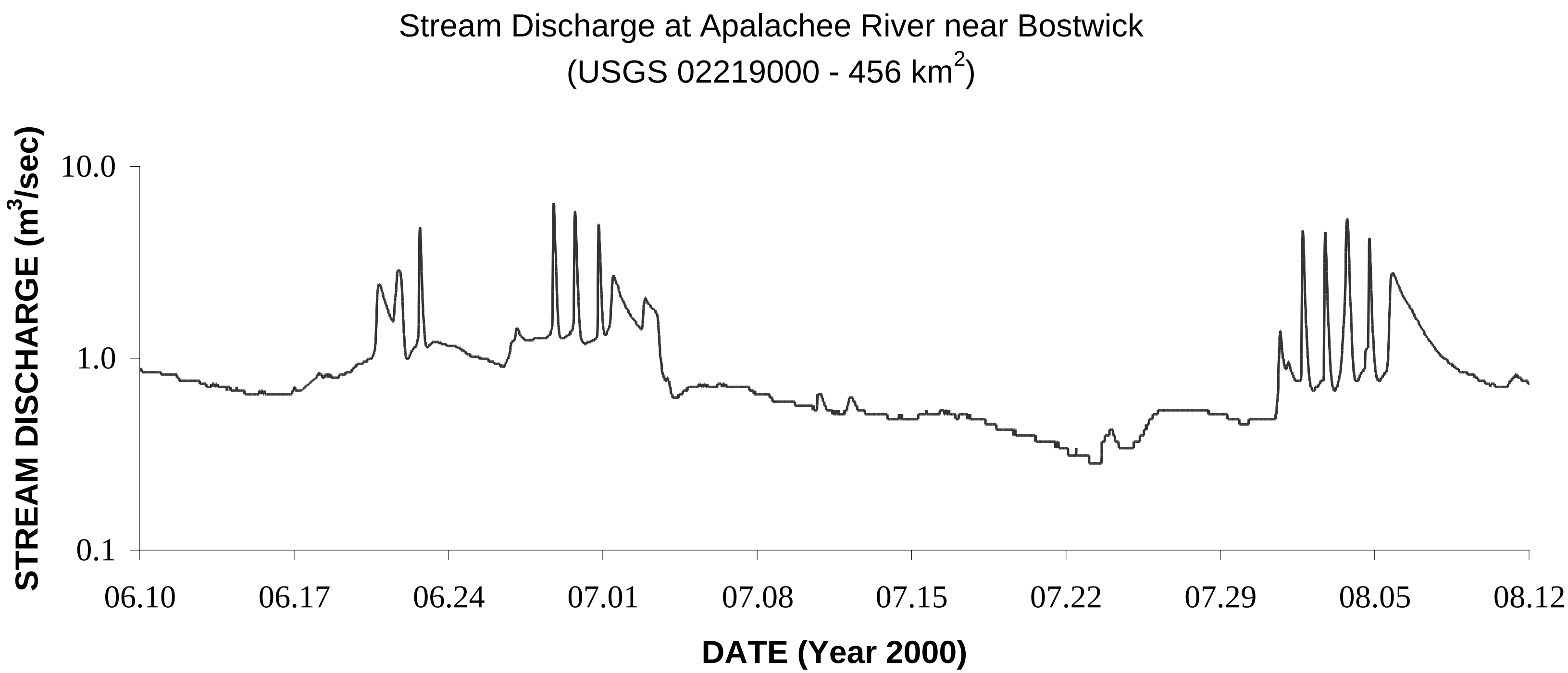


Figure 2-15d. Stream discharge at Apalachee River below North High Shoals Hydroelectric Dam.

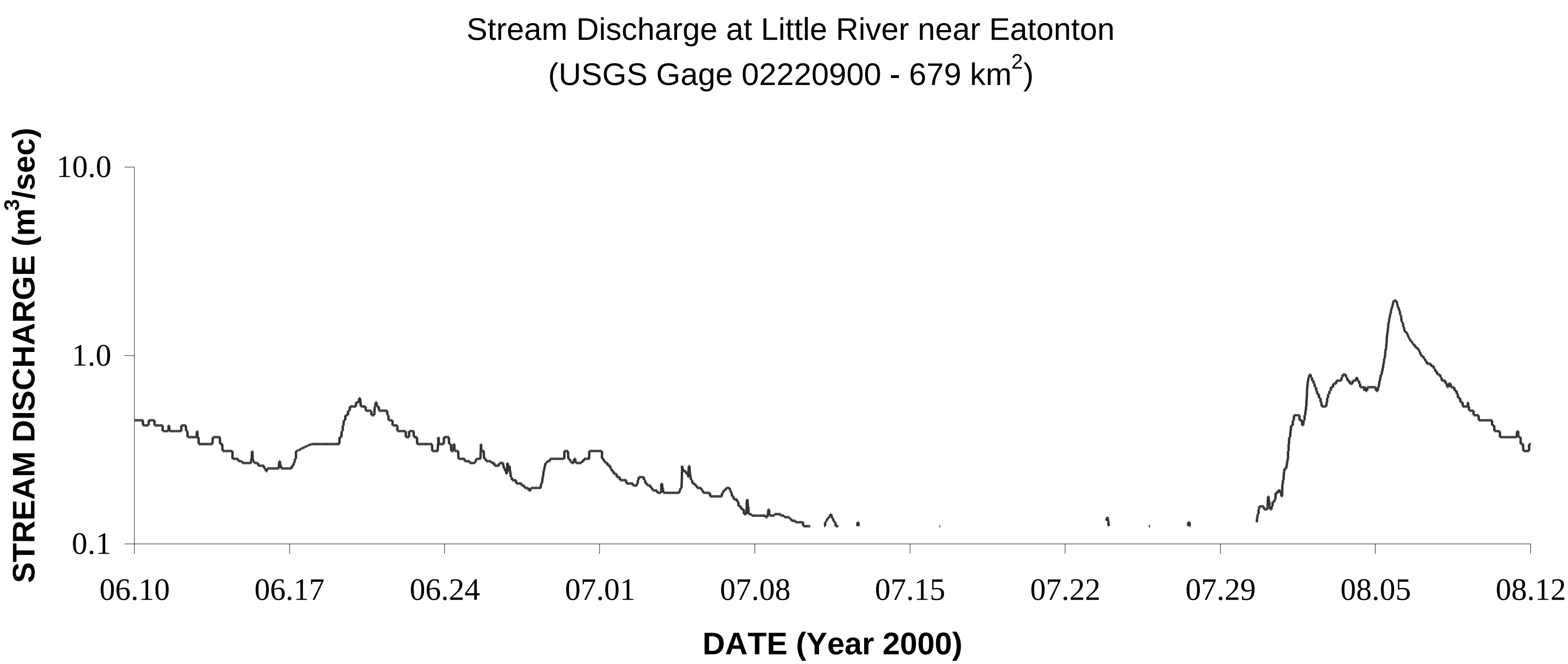


Figure 2-15e. Stream discharge at Little River near Eatonton. (No hydroelectric dam upstream)

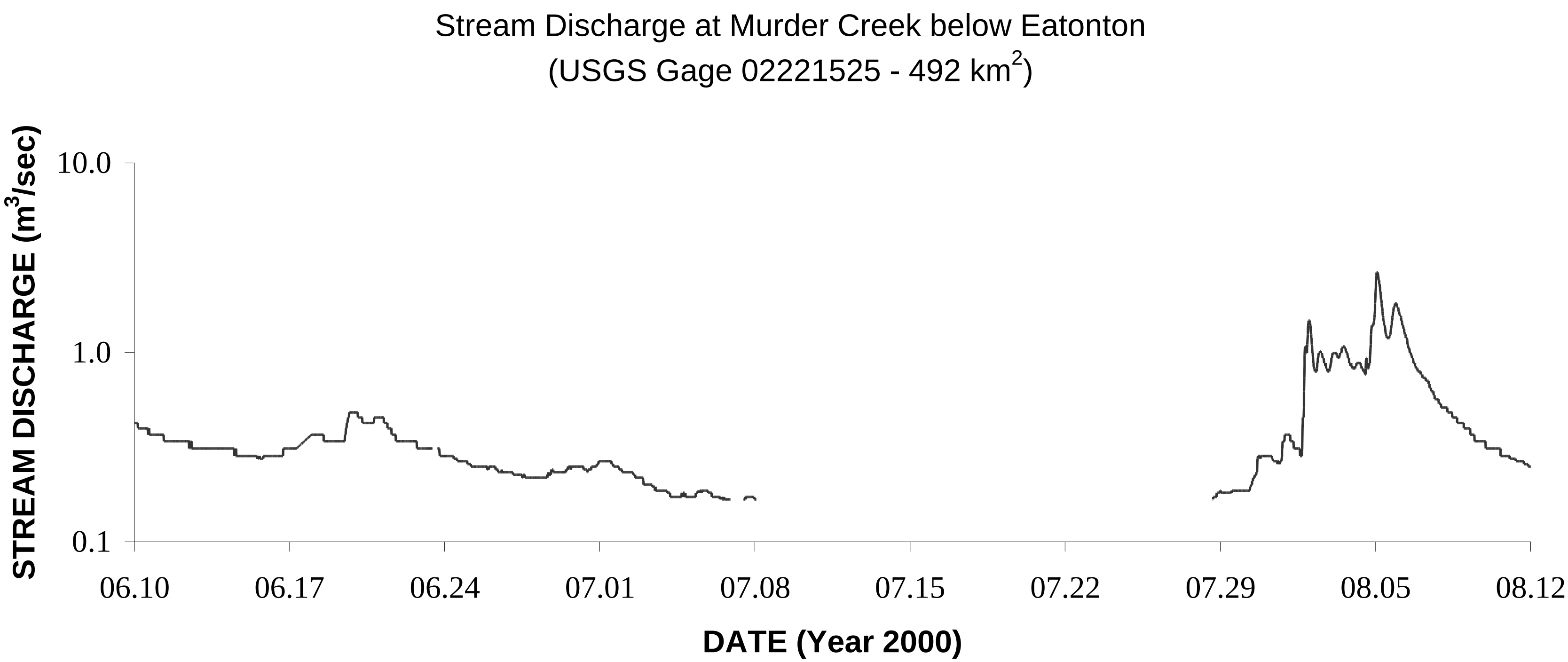


Figure 2-15f. Stream discharge at Murder Creek below Eatonton. (No hydroelectric dam upstream).

CONCLUSIONS AND CONSERVATION IMPLICATIONS

The results from the analyses conducted in the upper Oconee watershed showed that a number of local and watershed geomorphic characteristics significantly influenced the fish community structure in the streams we sampled and analyzed. These characteristics must be accounted for when using the fish-based metrics, such as the Index of Biotic Integrity (IBI) to assess the condition of streams.

The analyses showed the stream size, whether it was measured using GIS assessments or directly from local channel dimensions, was shown to be a major factor determining fish diversity and richness. As stream size increased the richness and diversity increased as well. This confirmed many past studies on the longitudinal changes of fish communities (e.g. Sheldon 1968; Barila et al. 1981; Osborne and Wiley 1992; Richards et al. 1996; Angermeir and Winston 1999; Marsh-Matthews and Matthews 2000; Schleiger 2000). However, even though the IBI considered watershed size for many of the metrics using the Mean-Species-Richness (MSR) plots, IBI showed a significant relationship to stream size. No stream with a watershed size over 56.4 km^2 was considered impaired. Furthermore, the impaired streams averaged 29.8 km^2, well below the average of all the sampled streams (128.9 km^2).

It was hypothesized that the IBI was developed primarily using smaller streams (less than 10% of the streams sampled by the GA-DNR in the Atlantic slope were over 100 km^2) and therefore the few sites may not have captured the full spectrum of conditions (degraded to un-impacted) at the larger streams. The construction of the MSR plots and delineating the 95th and 5th percentile thus may be difficult for the large streams. Conversely, the IBI scoring was able to discriminate the impairment status (excellent to very poor) at small stream sizes (15 km^2 and 50 km^2). As expected, the GA-DNR sampled hundreds of smaller streams, thus making it possible to construct complete MSR plots. Hopefully, the IBI development, especially for larger streams, can evolve and improve for the larger streams by incorporating more data from this study and other similar studies. In order for conservation actions to be implemented properly it is imperative that measures used are sensitive enough to detect degraded and or high quality conditions at all stream sizes.

Once stream size was identified as a major physical factor it was then used to model richness, diversity, and IBI score. The stream size measure used was the distance from the sampling site upstream to the headwaters along the mainstem channel. This was highly correlated with the other GIS-based measures of stream size (watershed area, link magnitude). Using the residuals from the models we were able to explore the other influences on the fish diversity, richness, and IBI.

In the analysis of local geomorphic characteristics the channel dimensions (e.g. width, depth) were also strongly controlling the fish metrics. Of course, these local channel dimensions are highly correlated with stream size using the GIS-based measures. In fact, models were built which related watershed area to local stream channel dimensions. Knowing these physical relationships will help improve the assessment techniques in the upper Oconee watershed by allowing us to reliably estimate local channel dimensions using inexpensive GIS tools.

Some of the local variables did not correlate with stream size and showed significantly improved fish community metrics. For example, the presence of bedrock at over half the sites generally improved conditions as measured by the fish metrics. The same was true for the presence of pool and riffle habitat. Many sites were dominated by run habitat with little diversity in depth apparent at the site. Despite the almost ubiquitous presence of large amount of sand sized (< 2mm) sediment in the system, lower percentages of sand did result in higher richness and diversity measures. The amount of sand at a site may be mostly controlled by transport capacity in the streams (Knighton 1999). However, the supply of sediments can eventually be limited by better land use and buffer policies in the watershed (Trimble 1970; Jones et al. 1999; Crosbie and Chow-Fraser 1999; Jakeman el al. 1999; Jones et al. 1999; Perry et al. 1999). More research is necessary to assess whether biological measures such as the IBI should be adjusted to account for natural conditions due to the presence of physical controls, like bedrock.

Watershed-wide anthropogenic factors were shown to influence fish community structure. For example, increased residential and commercial development was found to negatively impact fish diversity and lower IBI scores. Our results support other work done in the Georgia Piedmont in the early 1990's showing that increased residential development caused IBI scores to decrease (Schleiger 2000). These results can lead to improved conservation strategies within the watershed by focusing efforts on proper land use planning strategies.

For our study sites, measures of habitat loss and fragmentation due to impoundments were also shown to negatively affect stream fish communities. The total fragmentation measured in the stream network had a marginal influence on IBI, diversity, and richness.

Also for the sampled sites, as the distance downstream to an impoundment decreased biotic measures revealed more degraded conditions. This was confirmed by the analysis of the categories of sub-basin setting. Those smaller tributaries directly flowing into reservoirs had lower integrity than those sites embedded within a larger watershed usually unobstructed by impoundments within that sub-basin. These results add to the growing evidence that the cumulative effects of impoundments are not just limited to the loss of stream habitat through direct inundation, but also include fragmentation and habitat degradation (Pringle et al. 2000; Winston et al. 1991; Vaughn and Taylor 1999; Schrank 2001).

In light of these results, the highly fragmented nature of the upper Oconee watershed is particularly alarming. We were able to identify over 5,489 impoundments using publicly available GIS datasets. Of these, over 3,400 were found to be located on mapped streams (1:24,000 scale). These have inundated eight percent of the entire stream system. The majority of these impoundments were small (< 1 ha), yet cumulatively they had as much impact as the two largest reservoirs.

The results of this work have shown that almost half of the headwater streams have been impounded in the upper Oconee watershed. We must begin to recognize the critical ecosystem functions played by these headwater streams (Meyer and Wallace 2001). It also should be recognized that the problem of lost headwater streams may be even more extensive than even this study has suggested. For example, this study has relied on stream data that may represent only 70% of the actual stream channels in the upper Oconee watershed. As a first step towards stream conservation state, federal and local government agencies and organizations must use the most complete datasets available in order to gain a better understanding of the cumulative impacts of the more than one hundred thousand artificial impoundments estimated to have been built in Georgia.

Other possible consequences of impoundment construction were discussed in light of the extensive construction of impoundments in the watershed. There is evidence that net evaporative losses can be considerable when vegetation is removed and is replaced by open water (Morton 1983a, 1983b). The demands on water resources are increasing as people move to the state and the recent drought conditions have highlighted and created more interest in this water demand (Sutherland 2001). A critical eye must be focused on the overall water budget and how cumulative evaporative water loss may be impacting our water supplies. In many cases water conservation strategies can solve water demands (e.g. Baer 2001). Also, retrofitting or changing the primary use of existing impoundments may also alleviate the need for building new impoundments. By limiting the building of new impoundments and making efficient use of existing ones, the impacts on stream habitat (e.g. inundation, fragmentation) and water supply (e.g. evaporative loss) will not be increased.

In some senses, the conservation implications of the analysis of impoundments and the relationship to stream condition are clear; we need to work to minimize the amount of impounded waters, especially in areas where lakes and ponds do not naturally occur such as the Georgia Piedmont. However, because there are societal benefits derived from impounding free-flowing streams (e.g. water supply, recreation, flood control) we must be able to identify particularly detrimental types and locations of impoundments in order to maximize the benefit of dam removal and construction.

The techniques developed to examine the consequences to stream habitats due to the proliferation impoundments for this study will be useful for management, conservation, and research applications. Water supply managers can evaluate reservoir placement alternatives with respect to the fragmentation indices and length and area inundated. Multiple small impoundments may inundate more area than one large impoundment, yet larger streams would most likely be directly inundated by the larger impoundment. Researchers need to look at the cumulative impacts along fragmentation gradients and can use these techniques to help stratify sampling locations. Perhaps fragmentation thresholds exist so that where large enough watersheds are left un-impounded aquatic species can still persist. Conservation efforts can be focused to protect areas least impacted by impoundments and to restore streams highly impacted. This study showed evidence that efforts should be focused on protecting the North Oconee River and Little River sub-basins because streams were in relatively good condition (based on the fish metrics) and because they were also the least impounded.

This research was able to show that residential and urban development and artificial impoundments negatively affected stream integrity as measured by sampling fish community characteristics. It is recommended that water quality parameters, such as TSS, DO, temperature, and conductivity be measured in future analysis. Also, more in-depth analysis of the fish community structure and fish distribution in the watershed should be conducted. These types of analyses would help us to more fully understand the mechanisms involved in the relationships we have highlighted in this study.

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APPENDICES

APPENDIX A. SITE LOCATION INFORMATION, FISH LISTS AND IBI METRICS

Sorted by Field Number

Fish List Information

OCO native
- 1 = native to the Oconee River watershed*
- 0 = non-native to the Oconee River watershed*
  - * includes Upper & Lower Oconee watersheds

pollut tol (Pollution Tolerance)
- INT = intolerant
- HWINT = headwater intolerant
- TOL = tolerant
- PIO = pioneer

spp. cat (Species Category)
- MN = cyprinid species
- SU = sucker species
- SF = sunfish species
- BI = benthic insectivore species

breed guild (Breeding Guild)
- SL = simple lithophile

feed guild (Feeding Guild)
- IN = insectivore/invertivore
- HB = herbivore
- OM = omnivore
- GE = generalist
- CR = top carnivore

coll = number individuals collected

rel = number individuals released

wt (gm) = weight for all individuals > 25 mm Standard Length (grams)

< 25 mm = number individuals < 25 mm (SL)

YOY YOY = unidentified young of the year (those < 25 mm SL)

sp. = < 25 mm SL and were only identified to Genus
these were not used in the total or native species counts

APPENDIX A. Site locations, fish lists, and IBI information.

LMH2000-01

North Oconee River
June 15, 2000

Collectors
Lee M. Hartle, Michael D. Merrill, John C. Ruiz, Jonathan D. Ray

Locality
North Oconee River @ New Kings Bridge Road bridge crossing; (upstream)

County Clarke **Lat** 34.06744 **Long** -83.46302

Total # Fish (> 25mm)	Total # Fish (inclu. YOY)	Total # species	Diversity H’
217	258	18	-2.31

Index of Biotic Integrity

	Calculation	Metric
# Native species (1)	17	3
# Benthic Invertivore (2)	1	1
# Native Sunfish (3)	2	1
# Native Cyprinid (4)	8	5
# Native Sucker (5)	3	5
# Intolerant (6 a-b)	5	5
Evenness (7)	80.1	5
% Sunfish or Omniv. (8 a-b)	25	5
% Insectivorous Cyprinids (9)	136	5
% Top Carn or Pioneer (10 a-b)	3.0	1
Number / 200m (11)	143.3	1
% Simple Lithophilic (12 a-b)	75	3

IBI Category Fair **IBI Score** 40

Fish List

Genus	Species	OCO native	pollut tol	spp. cat	breed guild	feed guild	# coll	# rel	wt (gm)	# < 25 mm
Ameiurus	*brunneus*	1				OM	1		37.8	
Cyprinella	*callisema*	1	INT	MN		IN	45		30.4	3
Cyprinella	*xaenura*	1	INT	MN		IN	48		82.3	
Esox	*niger*	1				CR	2		4.7	
Hybognathus	*regius*	1	INT	MN		HB	11		29.3	4
Hybopsis	*rubrifrons*	1		MN	SL	IN	12		21.7	
Hypentelium	*nigricans*	1	INT	SU	SL	IN	6		134.0	
Lepomis	*auritus*	1		SF		IN	24		212.7	
Lepomis	*cyanellus*	0	TOL			IN	1		40.2	
Lepomis	*gulosus*	1		SF		CR	1		1.4	
Moxostoma	*collapsum*	1	INT	SU	SL	IN	3	3	550.0	
Nocomis	*leptocephalus*	1	PIO	MN		OM	8		66.5	4
Notemigonus	*crysoleucas*	1	TOL			OM	1		0.8	
Notropis	*hudsonius*	1		MN	SL	IN	21		65.7	15
Notropis	*lutipinnis*	1	PIO	MN	SL	IN	4		3.7	
Notropis	*petersoni*	1		MN	SL	IN	6		3.0	
Percina	*nigrofasciata*	1		BI	SL	IN	19		12.7	5
Scartomyzon	*rupiscartes*	1		SU	SL	IN	1		7.1	
YOY	*YOY*	1							82.3	10

Site Information

Watershed Area (km2)	Log Watershed Area (mi2)	Length Sampled (m)	Length to Avg. Width Ratio
463.9	2.25	300	19.9

APPENDIX A. Site locations, fish lists, and IBI information.

LMH2000-02

Middle Oconee River
June 16, 2000

Collectors
Lee M. Hartle, Michael D. Merrill, John C. Ruiz, Jonathan D. Ray, Byron J. Freeman

Locality
Middle Oconee River @ Galilee Church Road bridge crossing (upstream)

County Jackson **Lat** 34.07902 **Long** -83.60578

Total # Fish (> 25mm)	Total # Fish (inclu. YOY)	Total # species	Diversity H’
244	310	14	-1.98

Index of Biotic Integrity

	Calculation	Metric
# Native species (1)	14	3
# Benthic Invertivore (2)	3	3
# Native Sunfish (3)	2	1
# Native Cyprinid (4)	4	3
# Native Sucker (5)	2	3
# Intolerant (6 a-b)	3	3
Evenness (7)	75.0	5
% Sunfish or Omniv. (8 a-b)	26	5
% Insectivorous Cyprinids (9)	149	5
% Top Carn or Pioneer (10 a-b)	1.0	1
Number / 200m (11)	162.7	1
% Simple Lithophilic (12 a-b)	65	1

IBI Category Fair **IBI Score** 34

Fish List

Genus	Species	OCO native	pollut tol	spp. cat	breed guild	feed guild	# coll	# rel	wt (gm)	# < 25 mm
Ameiurus	*brunneus*	1				OM	8		151.8	
Ameiurus	*platycephalus*	1				GE	1		2.7	
Cyprinella	*callisema*	1	INT	MN		IN	94		100.9	2
Cyprinella	*xaenura*	1	INT	MN		IN	31		94.4	
Esox	*niger*	1				CR	1		3.7	
Etheostoma	*inscriptum*	1	HWINT	BI	SL	IN	2		3.6	
Hypentelium	*nigricans*	1	INT	SU	SL	IN	7		90.6	
Lepomis	*auritus*	1		SF		IN	25		269.2	
Lepomis	*macrochirus*	1		SF		IN	1		14.7	
Nocomis	*leptocephalus*	1	PIO	MN		OM	14		227.9	
Notropis	*hudsonius*	1		MN	SL	IN	24		94.8	
Noturus	*insignis*	1	HWINT	BI		IN	4		8.7	
Percina	*nigrofasciata*	1		BI	SL	IN	25		49.6	3
Scartomyzon	*rupiscartes*	1		SU	SL	IN	7		106.1	
YOY	*YOY*	1							0.0	61

Site Information

Watershed Area (km2)	Log Watershed Area (mi2)	Length Sampled (m)	Length to Avg. Width Ratio
361.6	2.14	300	21.3

APPENDIX A. Site locations, fish lists, and IBI information.

LMH2000-03

Shoal Creek
June 20, 2000

Collectors
Lee M. Hartle, Michael D. Merrill, John C. Ruiz, Jonathan D. Ray

Locality
Shoal Creek (Tributary to Apalachee River) @ Bradley Gin Rd. N. of US 78 @ Serenity Creek Farm; (upstream).

County Walton **Lat** 33.87238 **Long** -83.61912

Total # Fish (> 25mm)	Total # Fish (inclu. YOY)	Total # species	Diversity H'
354	405	16	-2.19

Index of Biotic Integrity

	Calculation	Metric
# Native species (1)	15	3
# Benthic Invertivore (2)	4	4
# Native Sunfish (3)	3	3
# Native Cyprinid (4)	5	5
# Native Sucker (5)	1	1
# Intolerant (6 a-b)	3	3
Evenness (7)	79.0	5
% Sunfish or Omniv. (8 a-b)	40	5
% Insectivorous Cyprinids (9)	174	3
% Top Carn or Pioneer (10 a-b)	3.0	1
Number / 200m (11)	352.0	3
% Simple Lithophilic (12 a-b)	239	5

IBI Category	Fair	IBI Score	41

Fish List

	Genus	Species	OCO native	pollut tol	spp. cat	breed guild	feed guild	# coll	# rel	wt (gm)	# < 25 mm
1	*Ameiurus*	*brunneus*	1				OM	8		156.7	
	Cyprinella	*xaenura*	1	INT	MN		IN	34		150.5	
	Etheostoma	*inscriptum*	1	HWINT	BI	SL	IN	40		54.8	1
	Hybopsis	*rubrifrons*	1		MN	SL	IN	44		98.9	4
5	*Lepomis*	*auritus*	1		SF		IN	13		163.5	
	Lepomis	*cyanellus*	0	TOL			IN	2		56.1	
	Lepomis	*gulosus*	1		SF		CR	2		21.9	
	Lepomis	*macrochirus*	1		SF		IN	18		314.0	
	Lepomis	*sp.*	1		SF					0.0	1
10	*Micropterus*	*salmoides*	1				CR	1		86.0	
	Nocomis	*leptocephalus*	1	PIO	MN		OM	32		233.2	32
	Notropis	*hudsonius*	1		MN	SL	IN	3		8.0	8
	Notropis	*lutipinnis*	1	PIO	MN	SL	IN	93		143.4	3
	Noturus	*gyrinus*	1		BI		IN	2		17.7	
15	*Noturus*	*insignis*	1	HWINT	BI		IN	3		37.6	
	Percina	*nigrofasciata*	1		BI	SL	IN	54		102.6	1
	Scartomyzon	*rupiscartes*	1		SU	SL	IN	5		66.5	1
20											
25											

Site Information

Watershed Area (km2)	Log Watershed Area (mi2)	Length Sampled (m)	Length to Avg. Width Ratio
46.7	1.26	200	26.7

LMH2000-04

Shoal Creek
June 22, 2000

Collectors
Lee M. Hartle, Michael D. Merrill, John C. Ruiz, Jonathan D. Ray

Locality
Shoal Creek @ Gratis Road bridge crossing; (upstream)

County Walton **Lat** 33.87811 **Long** -83.66996

Total # Fish (> 25mm)	Total # Fish (inclu. YOY)	Total # species	Diversity H’
293	302	11	-1.57

Index of Biotic Integrity

	Calculation	Metric
# Native species (1)	10	3
# Benthic Invertivore (2)	2	3
# Native Sunfish (3)	1	1
# Native Cyprinid (4)	3	3
# Native Sucker (5)	1	3
# Intolerant (6 a-b)	1	1
Evenness (7)	65.4	3
% Sunfish or Omniv. (8 a-b)	72	3
% Insectivorous Cyprinids (9)	163	5
% Top Carn or Pioneer (10 a-b)	208.0	1
Number / 200m (11)	366.7	3
% Simple Lithophilic (12 a-b)	184	3

IBI Category Poor **IBI Score** 32

Fish List

Genus	Species	OCO native	pollut tol	spp. cat	breed guild	feed guild	# coll	# rel	wt (gm)	# < 25 mm
Ameiurus	*brunneus*	1				OM	1		64.6	
Etheostoma	*inscriptum*	1	HWINT	BI	SL	IN	5		8.4	3
Hybopsis	*rubrifrons*	1		MN	SL	IN	27		59.5	1
Lepomis	*auritus*	1		SF		IN	18		161.1	
Lepomis	*cyanellus*	0	TOL			IN	17		176.0	
Micropterus	*salmoides*	1				CR	1		8.1	
Nocomis	*leptocephalus*	1	PIO	MN		OM	71		469.7	
Notropis	*lutipinnis*	1	PIO	MN	SL	IN	136		265.0	3
Percina	*nigrofasciata*	1		BI	SL	IN	13		50.6	
Scartomyzon	*rupiscartes*	1		SU	SL	IN	3		58.4	2
Semotilus	*atromaculatus*	1	TOL/PI			GE	1		5.1	

Site Information

Watershed Area (km2)	Log Watershed Area (mi2)	Length Sampled (m)	Length to Avg. Width Ratio
16.8	0.81	150	26.3

APPENDIX A. Site locations, fish lists, and IBI information.

LMH2000-05

Apalachee River
June 22, 2000

Collectors
Lee M. Hartle, Michael D. Merrill, John C. Ruiz, Jonathan D. Ray

Locality
Apalachee River @ Route 11 bridge; S of Bethlehem; (upstream)

County Walton **Lat** 33.90026 **Long** -83.72329

Total # Fish (> 25mm)	Total # Fish (inclu. YOY)	Total # species	Diversity H'
267	314	17	-1.99

Index of Biotic Integrity

	Calculation	Metric
# Native species (1)	16	3
# Benthic Invertivore (2)	3	3
# Native Sunfish (3)	3	3
# Native Cyprinid (4)	5	3
# Native Sucker (5)	2	3
# Intolerant (6 a-b)	2	3
Evenness (7)	70.3	5
% Sunfish or Omniv. (8 a-b)	27	5
% Insectivorous Cyprinids (9)	143	3
% Top Carn or Pioneer (10 a-b)	2.0	1
Number / 200m (11)	210.4	1
% Simple Lithophilic (12 a-b)	134	3

IBI Category Fair **IBI Score** 36

Fish List

Genus	Species	OCO native	pollut tol	spp. cat	breed guild	feed guild	# coll	# rel	wt (gm)	# < 25 mm
Ameiurus	*brunneus*	1				OM	1		24.2	
Ameiurus	*natalis*	1	TOL			GE	1		67.7	
Cyprinella	*xaenura*	1	INT	MN		IN	68		112.3	
Etheostoma	*inscriptum*	1	HWINT	BI	SL	IN	20		32.9	
Gambusia	*species*	1	TOL			OM	1		0.2	
Hybopsis	*rubrifrons*	1		MN	SL	IN	3		6.5	
Lepomis	*auritus*	1		SF		IN	19		278.7	
Lepomis	*cyanellus*	0	TOL			IN	2		46.5	
Lepomis	*gulosus*	1		SF		CR	1	1	5.8	
Lepomis	*macrochirus*	1		SF		IN	6		96.8	
Moxostoma	*collapsum*	1	INT	SU	SL	IN	1	1	0.4	
Nocomis	*leptocephalus*	1	PIO	MN		OM	32		163.5	29
Notropis	*hudsonius*	1		MN	SL	IN	1		4.6	
Notropis	*lutipinnis*	1	PIO	MN	SL	IN	71		88.1	18
Noturus	*insignis*	1	HWINT	BI		IN	1		10.7	
Percina	*nigrofasciata*	1		BI	SL	IN	35		57.2	
Scartomyzon	*rupiscartes*	1		SU	SL	IN	2		27.8	

Site Information

Watershed Area (km2)	Log Watershed Area (mi2)	Length Sampled (m)	Length to Avg. Width Ratio
138.7	1.73	250	19.8

APPENDIX A. Site locations, fish lists, and IBI information.

LMH2000-06

Jack's Creek
June 23, 2000

Collectors
Lee M. Hartle, Michael D. Merrill, John C. Ruiz, Jonathan D. Ray

Locality
Jack's Creek @ Wagnon Mill Road - bridge is gone; (upstream)

County Morgan **Lat** 33.74573 **Long** -83.46285

Total # Fish (> 25mm)	Total # Fish (inclu. YOY)	Total # species	Diversity H'
262	329	15	-2.20

Index of Biotic Integrity

	Calculation	Metric
# Native species (1)	14	3
# Benthic Invertivore (2)	2	3
# Native Sunfish (3)	2	1
# Native Cyprinid (4)	5	3
# Native Sucker (5)	2	3
# Intolerant (6 a-b)	5	5
Evenness (7)	81.2	5
% Sunfish or Omniv. (8 a-b)	41	5
% Insectivorous Cyprinids (9)	122	3
% Top Carn or Pioneer (10 a-b)	14.0	5
Number / 200m (11)	207.2	1
% Simple Lithophilic (12 a-b)	112	3

IBI Category Fair **IBI Score** 40

Fish List

Genus	Species	OCO native	pollut tol	spp. cat	breed guild	feed guild	# coll	# rel	wt (gm)	# < 25 mm
Cyprinella	*callisema*	1	INT	MN		IN	12		12.0	
Cyprinella	*xaenura*	1	INT	MN		IN	53		84.8	10
Etheostoma	*inscriptum*	1	HWINT	BI	SL	IN	19		20.0	1
Hybopsis	*rubrifrons*	1		MN	SL	IN	4		0.0	4
Lepomis	*auritus*	1		SF		IN	37		399.9	
Lepomis	*cyanellus*	0	TOL			IN	3		67.3	
Lepomis	*macrochirus*	1		SF		IN	4		399.9	
Micropterus	*coosae*	1	HWINT			CR	13		226.0	2
Micropterus	*salmoides*	1				CR	1		13.2	
Minytrema	*melanops*	1	INT	SU	SL	IN	1		105.8	
Moxostoma	*collapsum*	1	INT	SU	SL	IN		1	0.0	
Nocomis	*leptocephalus*	1	PIO	MN		OM	21		53.0	9
Notropis	*hudsonius*	1		MN	SL	IN	53		15.8	21
Percina	*nigrofasciata*	1		BI	SL	IN	34		76.5	
Scartomyzon	*sp cf. lachneri*	1	INT	SU	SL	IN	6		69.9	2
YOY	*YOY*	1							0.0	18

Site Information

Watershed Area (km2)	Log Watershed Area (mi2)	Length Sampled (m)	Length to Avg. Width Ratio
150.6	1.76	250	17.4

APPENDIX A. Site locations, fish lists, and IBI information.

LMH2000-07

Big Creek
June 27, 2000

Collectors
Lee M. Hartle, Michael D. Merrill, John C. Ruiz, Jonathan D. Ray

Locality
Big Creek @ Bob Godfrey Rd bridge crossing; (downstream)

County Oglethorpe **Lat** 33.84554 **Long** -83.27503

Total # Fish (> 25mm)	Total # Fish (inclu. YOY)	Total # species	Diversity H'
487	630	16	-2.10

Index of Biotic Integrity

	Calculation	Metric
# Native species (1)	16	3
# Benthic Invertivore (2)	2	3
# Native Sunfish (3)	3	5
# Native Cyprinid (4)	4	3
# Native Sucker (5)	3	5
# Intolerant (6 a-b)	2	3
Evenness (7)	75.8	5
% Sunfish or Omniv. (8 a-b)	34	5
% Insectivorous Cyprinids (9)	256	3
% Top Carn or Pioneer (10 a-b)	15.0	3
Number / 200m (11)	473.0	3
% Simple Lithophilic (12 a-b)	351	5

IBI Category Good **IBI Score** 46

Fish List

Genus	Species	OCO native	pollut tol	spp. cat	breed guild	feed guild	# coll	# rel	wt (gm)	# < 25 mm
Ameiurus	*brunneus*	1				OM	1		55.0	
Etheostoma	*inscriptum*	1	HWINT	BI	SL	IN	29		29.1	
Gambusia	*species*	1	TOL			OM	1		1.3	9
Hybopsis	*rubrifrons*	1		MN	SL	IN	82		196.2	
Hypentelium	*nigricans*	1	INT	SU	SL	IN	26		113.4	
Lepomis	*auritus*	1		SF		IN	21		320.1	
Lepomis	*macrochirus*	1		SF		IN	9		54.6	
Lepomis	*microlophus*	1		SF		IN	4		19.7	
Micropterus	*coosae*	1	HWINT			CR	15		114.6	1
Moxostoma	*collapsum*	1	INT	SU	SL	IN	2	1	1.0	0
Nocomis	*leptocephalus*	1	PIO	MN		OM	72		275.6	
Notropis	*hudsonius*	1		MN	SL	IN	10		4.1	
Notropis	*lutipinnis*	1	PIO	MN	SL	IN	164		285.0	
Noturus	*sp.*	1		BI		IN			0.0	1
Percina	*nigrofasciata*	1		BI	SL	IN	27		47.5	
Scartomyzon	*rupiscartes*	1		SU	SL	IN	10		53.1	1
Scartomyzon	*sp.*	1		SU					0.0	24
Semotilus	*atromaculatus*	1	TOL/PI			GE	13		7.2	
YOY	*YOY*	1							0.0	107

Site Information

Watershed Area (km2)	Log Watershed Area (mi2)	Length Sampled (m)	Length to Avg. Width Ratio
65.6	1.40	200	34.6

APPENDIX A. Site locations, fish lists, and IBI information.

LMH2000-09

Rose Creek
June 28, 2000

Collectors
Lee M. Hartle, Michael D. Merrill, John C. Ruiz, Jonathan D. Ray

Locality
Rose Creek @ Antioch Church Road bridge crossing; (upstream)

County Oconee **Lat** 33.76828 **Long** -83.32391

Total # Fish (> 25mm)	Total # Fish (inclu. YOY)	Total # species	Diversity H'
280	329	10	-0.95

Index of Biotic Integrity

	Calculation	Metric
# Native species (1)	10	1
# Benthic Invertivore (2)	2	3
# Native Sunfish (3)	2	1
# Native Cyprinid (4)	2	1
# Native Sucker (5)	1	1
# Intolerant (6 a-b)	1	1
Evenness (7)	41.4	1
% Sunfish or Omniv. (8 a-b)	77	3
% Insectivorous Cyprinids (9)	184	5
% Top Carn or Pioneer (10 a-b)	0.0	1
Number / 200m (11)	274.0	1
% Simple Lithophilic (12 a-b)	189	5

IBI Category Very Poor **IBI Score** 24

Fish List

	Genus	Species	OCO native	pollut tol	spp. cat	breed guild	feed guild	# coll	# rel	wt (gm)	# < 25 mm
1	*Ameiurus*	*platycephalus*	1				GE	1		21.9	1
	Etheostoma	*hopkinsi*	1		BI	SL	IN	2		4.6	
	Gambusia	*species*	1	TOL			OM	1		1.2	
	Lepomis	*auritus*	1		SF		IN	1		15.0	
5	*Lepomis*	*macrochirus*	1		SF		IN	5		6.2	
	Nocomis	*leptocephalus*	1	PIO	MN		OM	76		166.5	23
	Notropis	*lutipinnis*	1	PIO	MN	SL	IN	184		217.1	20
	Noturus	*insignis*	1	HWINT	BI		IN	2		24.1	
	Scartomyzon	*rupiscartes*	1		SU	SL	IN	3		1.0	1
10	*Semotilus*	*atromaculatus*	1	TOL/PI			GE	5		6.0	4

Site Information

Watershed Area (km2)	Log Watershed Area (mi2)	Length Sampled (m)	Length to Avg. Width Ratio
42.0	1.21	200	42.1

APPENDIX A. Site locations, fish lists, and IBI information.

LMH2000-10

Greenbrier Creek
June 28, 2000

Collectors
Lee M. Hartle, Michael D. Merrill, John C. Ruiz, Jonathan D. Ray

Locality
Greenbrier Creek @ Marshall Store Road bridge crossing (upstream)

County Oconee **Lat** 33.76288 **Long** -83.39180

Total # Fish (> 25mm)	Total # Fish (inclu. YOY)	Total # species	Diversity H'
92	92	9	-1.66

Index of Biotic Integrity

	Calculation	Metric
# Native species (1)	9	1
# Benthic Invertivore (2)	1	1
# Native Sunfish (3)	3	5
# Native Cyprinid (4)	2	1
# Native Sucker (5)	2	5
# Intolerant (6 a-b)	0	1
Evenness (7)	75.6	1
% Sunfish or Omniv. (8 a-b)	9	5
% Insectivorous Cyprinids (9)	43	3
% Top Carn or Pioneer (10 a-b)	50.0	3
Number / 200m (11)	120.0	1
% Simple Lithophilic (12 a-b)	47	1

IBI Category Poor **IBI Score** 28

Fish List

	Genus	Species	OCO native	pollut tol	spp. cat	breed guild	feed guild	# coll	# rel	wt (gm)	# < 25 mm
1	*Erimyzon*	*oblongus*	1		SU		IN	5		125.2	
	Etheostoma	*hopkinsi*	1		BI	SL	IN	2		4.1	
	Lepomis	*auritus*	1		SF		IN	6		114.1	
	Lepomis	*gulosus*	1		SF		CR	8		57.0	
5	*Lepomis*	*macrochirus*	1		SF		IN	17		111.0	
	Nocomis	*leptocephalus*	1	PIO	MN		OM	7		103.9	
	Notemigonus	*crysoleucas*	1	TOL			OM	2		11.4	
	Notropis	*lutipinnis*	1	PIO	MN	SL	IN	43		88.9	
	Scartomyzon	*rupiscartes*	1		SU	SL	IN	2		49.1	
10											
15											
20											
25											

Site Information

Watershed Area (km2)	Log Watershed Area (mi2)	Length Sampled (m)	Length to Avg. Width Ratio
22.7	0.94	150	46.6

APPENDIX A. Site locations, fish lists, and IBI information.

LMH2000-11

Middle Oconee River
June 30, 2000

Collectors
Lee M. Hartle, Michael D. Merrill, John C. Ruiz, Jonathan D. Ray, Adam Paul Davis

Locality
Middle Oconee River @ SR 129 @ Pendergrass Flea Market: (upstream)

County Jackson **Lat** 34.15294 **Long** -83.65426

Total # Fish (> 25mm)	Total # Fish (inclu. YOY)	Total # species	Diversity H’
427	428	15	-2.06

Index of Biotic Integrity

	Calculation	Metric
# Native species (1)	14	3
# Benthic Invertivore (2)	3	3
# Native Sunfish (3)	1	1
# Native Cyprinid (4)	5	3
# Native Sucker (5)	3	5
# Intolerant (6 a-b)	3	3
Evenness (7)	76.2	5
% Sunfish or Omniv. (8 a-b)	37	5
% Insectivorous Cyprinids (9)	172	3
% Top Carn or Pioneer (10 a-b)	2.0	1
Number / 200m (11)	340.0	1
% Simple Lithophilic (12 a-b)	213	3

IBI Category	Fair	IBI Score	36

Fish List

	Genus	Species	OCO native	pollut tol	spp. cat	breed guild	feed guild	# coll	# rel	wt (gm)	# < 25 mm
1	*Ameiurus*	*brunneus*	1				OM	2		26.9	
	Cyprinella	*xaenura*	1	INT	MN		IN	35		102.3	
	Esox	*niger*	1				CR	2		17.7	
	Etheostoma	*inscriptum*	1	HWINT	BI	SL	IN	19		24.1	
5	*Hybopsis*	*rubrifrons*	1		MN	SL	IN	17		34.2	
	Hypentelium	*nigricans*	1	INT	SU	SL	IN	23		514.5	1
	Lepomis	*auritus*	1		SF		IN	35		168.6	
	Lepomis	*cyanellus*	0	TOL			IN	2		55.0	
	Moxostoma	*collapsum*	1	INT	SU	SL	IN	2		22.0	
10	*Nocomis*	*leptocephalus*	1	PIO	MN		OM	136		828.6	
	Notropis	*hudsonius*	1		MN	SL	IN	23		49.7	
	Notropis	*lutipinnis*	1	PIO	MN	SL	IN	97		148.4	
	Noturus	*insignis*	1	HWINT	BI		IN	2		5.8	
	Percina	*nigrofasciata*	1		BI	SL	IN	17		36.3	
15	*Scartomyzon*	*rupiscartes*	1		SU	SL	IN	15		189.1	
20											
25											

Site Information

Watershed Area (km2)	Log Watershed Area (mi2)	Length Sampled (m)	Length to Avg. Width Ratio
159.3	1.79	250	25.0

APPENDIX A. Site locations, fish lists, and IBI information.

LMH2000-12

Apalachee River
July 05, 2000

Collectors
Lee M. Hartle, Michael D. Merrill, John C. Ruiz, Jonathan D. Ray

Locality
Apalachee River @ SR78/10 bridge crossing (downstream)

County Oconee **Lat** 33.88272 **Long** -83.58814

Total # Fish (> 25mm)	Total # Fish (inclu. YOY)	Total # species	Diversity H'
785	799	19	-2.17

Index of Biotic Integrity

	Calculation	Metric
# Native species (1)	18	3
# Benthic Invertivore (2)	3	3
# Native Sunfish (3)	4	5
# Native Cyprinid (4)	5	3
# Native Sucker (5)	3	5
# Intolerant (6 a-b)	2	3
Evenness (7)	73.6	5
% Sunfish or Omniv. (8 a-b)	80	5
% Insectivorous Cyprinids (9)	267	3
% Top Carn or Pioneer (10 a-b)	2.0	1
Number / 200m (11)	516.0	3
% Simple Lithophilic (12 a-b)	481	5

IBI Category	Good	IBI Score	44

Fish List

Genus	Species	OCO native	pollut tol	spp. cat	breed guild	feed guild	# coll	# rel	wt (gm)	# < 25 mm
Ameiurus	*brunneus*	1				OM	9		228.7	2
Cyprinella	*xaenura*	1	INT	MN		IN	109		196.8	
Erimyzon	*oblongus*	1		SU		IN	1		42.4	
Etheostoma	*inscriptum*	1	HWINT	BI	SL	IN	115		233.0	
Gambusia	*species*	1	TOL			OM	9		4.0	7
Hybopsis	*rubrifrons*	1		MN	SL	IN	11		32.6	
Lepomis	*auritus*	1		SF		IN	46		447.2	
Lepomis	*cyanellus*	0	TOL			IN	2		98.5	
Lepomis	*gulosus*	1		SF		CR	1		51.0	
Lepomis	*macrochirus*	1		SF		IN	31		164.2	
Lepomis	*microlophus*	1		SF		IN	2		8.5	
Micropterus	*salmoides*	1				CR	1		25.5	
Moxostoma	*collapsum*	1	INT	SU	SL	IN	10	4	1468.	
Nocomis	*leptocephalus*	1	PIO	MN		OM	85		190.8	
Notropis	*hudsonius*	1		MN	SL	IN	130		109.5	
Notropis	*lutipinnis*	1	PIO	MN	SL	IN	17		30.2	4
Noturus	*insignis*	1	HWINT	BI		IN	8		45.6	
Percina	*nigrofasciata*	1		BI	SL	IN	192		405.8	
Scartomyzon	*rupiscartes*	1		SU	SL	IN	2		40.1	
YOY	*YOY*	1							0.0	1

Site Information

Watershed Area (km2)	Log Watershed Area (mi2)	Length Sampled (m)	Length to Avg. Width Ratio
321.5	2.09	300	14.0

LMH2000-13

Jack's Creek
July 05, 2000

Collectors
Lee M. Hartle, Michael D. Merrill, John C. Ruiz, Jonathan D. Ray

Locality
Jack's Creek @ Bearden Road (brige out); (upstream)

County Walton **Lat** 33.79963 **Long** -83.61963

Total # Fish (> 25mm)	Total # Fish (inclu. YOY)	Total # species	Diversity H'
42	42	8	-1.47

Index of Biotic Integrity	Calculation	Metric
# Native species (1)	8	1
# Benthic Invertivore (2)	0	1
# Native Sunfish (3)	1	1
# Native Cyprinid (4)	2	1
# Native Sucker (5)	2	3
# Intolerant (6 a-b)	0	1
Evenness (7)	70.7	1
% Sunfish or Omniv. (8 a-b)	21	1
% Insectivorous Cyprinids (9)	4	1
% Top Carn or Pioneer (10 a-b)	1.0	3
Number / 200m (11)	41.0	1
% Simple Lithophilic (12 a-b)	6	1

IBI Category Very Poor **IBI Score** 16

Fish List

Genus	Species	OCO native	pollut tol	spp. cat	breed guild	feed guild	# coll	# rel	wt (gm)	# < 25 mm
Ameiurus	*brunneus*	1				OM	1		47.0	
Erimyzon	*oblongus*	1		SU		IN	2		0.8	
Esox	*niger*	1				CR	1		4.6	
Gambusia	*species*	1	TOL			OM	1		0.2	
Lepomis	*auritus*	1		SF		IN	21		538.2	
Nocomis	*leptocephalus*	1	PIO	MN		OM	10		83.3	
Notropis	*petersoni*	1		MN	SL	IN	4		6.3	
Scartomyzon	*rupiscartes*	1		SU	SL	IN	2		30.7	

Site Information

Watershed Area (km2)	Log Watershed Area (mi2)	Length Sampled (m)	Length to Avg. Width Ratio
55.5	1.33	200	31.3

APPENDIX A. Site locations, fish lists, and IBI information.

LMH2000-14

Candler Creek
July 06, 2000

Collectors
Lee M. Hartle, Michael D. Merrill, John C. Ruiz, Jonathan D. Ray

Locality
Candler Creek @ SR 52 bridge crossing; started ca 35m upstream and sampled ca. 115 downstream of bridge.

County Hall **Lat** 34.31034 **Long** -83.65627

Total # Fish (> 25mm)	Total # Fish (inclu. YOY)	Total # species	Diversity H'
414	434	14	-2.08

Index of Biotic Integrity	Calculation	Metric
# Native species (1)	13	3
# Benthic Invertivore (2)	2	3
# Native Sunfish (3)	2	3
# Native Cyprinid (4)	5	5
# Native Sucker (5)	2	5
# Intolerant (6 a-b)	5	5
Evenness (7)	78.8	5
% Sunfish or Omniv. (8 a-b)	68	3
% Insectivorous Cyprinids (9)	117	1
% Top Carn or Pioneer (10 a-b)	91.0	5
Number / 200m (11)	549.3	3
% Simple Lithophilic (12 a-b)	268	5

IBI Category Good **IBI Score** 46

Fish List

Genus	Species	OCO native	pollut tol	spp. cat	breed guild	feed guild	# coll	# rel	wt (gm)	# < 25 mm
Ameiurus	*brunneus*	1				OM	6		193.6	
Cyprinella	*xaenura*	1	INT	MN		IN	10		36.6	
Etheostoma	*inscriptum*	1	HWINT	BI	SL	IN	138		195.2	10
Hybopsis	*rubrifrons*	1		MN	SL	IN	35		99.8	
Hypentelium	*nigricans*	1	INT	SU	SL	IN	12		54.1	
Lepomis	*auritus*	1		SF		IN	48		309.0	
Lepomis	*cyanellus*	0	TOL			IN	2		18.2	
Lepomis	*macrochirus*	1		SF		IN	8		226.5	
Micropterus	*coosae*	1	HWINT			CR	9		216.3	
Micropterus	*sp.*	1		SF					0.0	1
Nocomis	*leptocephalus*	1	PIO	MN		OM	62		502.9	6
Notropis	*hudsonius*	1		MN	SL	IN	43		39.1	
Notropis	*lutipinnis*	1	PIO	MN	SL	IN	29		59.9	2
Noturus	*insignis*	1	HWINT	BI		IN	1		21.9	
Scartomyzon	*rupiscartes*	1		SU	SL	IN	11		72.1	1

Site Information

Watershed Area (km2)	Log Watershed Area (mi2)	Length Sampled (m)	Length to Avg. Width Ratio
18.2	0.85	150	35.6

APPENDIX A. Site locations, fish lists, and IBI information.

LMH2000-15

North Oconee River
July 06, 2000

Collectors
Lee M. Hartle, Michael D. Merrill, John C. Ruiz, Jonathan D. Ray

Locality
North Oconee River @ Joe Chandler Road bridge crossing (upstream)

County Hall **Lat** 34.31268 **Long** -83.74436

Total # Fish (> 25mm)	Total # Fish (inclu. YOY)	Total # species	Diversity H'
597	774	16	-2.05

Index of Biotic Integrity

	Calculation	Metric
# Native species (1)	14	3
# Benthic Invertivore (2)	2	3
# Native Sunfish (3)	2	3
# Native Cyprinid (4)	5	5
# Native Sucker (5)	2	5
# Intolerant (6 a-b)	5	5
Evenness (7)	74.0	5
% Sunfish or Omniv. (8 a-b)	83	5
% Insectivorous Cyprinids (9)	295	3
% Top Carn or Pioneer (10 a-b)	3.0	1
Number / 200m (11)	594.0	3
% Simple Lithophilic (12 a-b)	398	5

IBI Category	Good	IBI Score	46

Fish List

Genus	Species	OCO native	pollut tol	spp. cat	breed guild	feed guild	# coll	# rel	wt (gm)	# < 25 mm
Ameiurus	*brunneus*	1				OM	1		65.2	
Ameiurus	*sp.*	1							0.0	3
Cyprinella	*xaenura*	1	INT	MN		IN	94		126.9	
Etheostoma	*inscriptum*	1	HWINT	BI	SL	IN	146		115.3	67
Hybopsis	*rubrifrons*	1		MN	SL	IN	122		184.1	59
Hypentelium	*nigricans*	1	INT	SU	SL	IN	34		384.5	
Lepomis	*auritus*	1		SF		IN	6		49.9	
Lepomis	*cyanellus*	0	TOL			IN	1		5.3	
Lepomis	*macrochirus*	1		SF		IN	9		40.1	
Luxilus	*zonistius*	0		MN	SL	IN	1		3.0	
Micropterus	*coosae*	1	HWINT			CR	3		154.0	
Moxostoma	*sp.*	1							0.0	6
Nocomis	*leptocephalus*	1	PIO	MN		OM	82		353.6	7
Notropis	*hudsonius*	1		MN	SL	IN	36		59.9	13
Notropis	*lutipinnis*	1	PIO	MN	SL	IN	42		102.6	
Noturus	*insignis*	1	HWINT	BI		IN	2		5.4	
Scartomyzon	*rupiscartes*	1		SU	SL	IN	17		173.1	22
Semotilus	*atromaculatus*	1	TOL/PI			GE	1		5.8	

Site Information

Watershed Area (km2)	Log Watershed Area (mi2)	Length Sampled (m)	Length to Avg. Width Ratio
43.9	1.23	200	32.3

APPENDIX A. Site locations, fish lists, and IBI information.

LMH2000-16

North Oconee River
July 06, 2000

Collectors
Lee M. Hartle, Michael D. Merrill, John C. Ruiz, Jonathan D. Ray

Locality
North Oconee River @ Greenway Road bridge crossing (upstream)

County Hall **Lat** 34.36119 **Long** -83.73529

Total # Fish (> 25mm)	Total # Fish (inclu. YOY)	Total # species	Diversity H'
328	374	16	-2.18

Index of Biotic Integrity

	Calculation	Metric
# Native species (1)	15	5
# Benthic Invertivore (2)	2	3
# Native Sunfish (3)	2	3
# Native Cyprinid (4)	5	5
# Native Sucker (5)	2	5
# Intolerant (6 a-b)	4	5
Evenness (7)	78.5	5
% Sunfish or Omniv. (8 a-b)	57	3
% Insectivorous Cyprinids (9)	142	3
% Top Carn or Pioneer (10 a-b)	150.0	3
Number / 200m (11)	422.7	3
% Simple Lithophilic (12 a-b)	237	5

IBI Category Good **IBI Score** 48

Fish List

	Genus	Species	OCO native	pollut tol	spp. cat	breed guild	feed guild	# coll	# rel	wt (gm)	# < 25 mm
1	*Ameiurus*	*brunneus*	1				OM	7		133.7	
	Campostoma	*pauciradii*	1	PIO	MN		OM	25		11.1	
	Etheostoma	*inscriptum*	1	HWINT	BI	SL	IN	57		93.8	11
	Hybopsis	*rubrifrons*	1		MN	SL	IN	32		72.0	19
5	*Hypentelium*	*nigricans*	1	INT	SU	SL	IN	23		462.0	
	Lepomis	*auritus*	1		SF		IN	3		68.8	
	Lepomis	*macrochirus*	1		SF		IN	3		56.7	
	Lepomis	*sp.*	1		SF					0.0	1
	Luxilus	*zonistius*	0		MN	SL	IN	10		40.7	4
10	*Micropterus*	*coosae*	1	HWINT			CR	11		367.2	4
	Micropterus	*salmoides*	1				CR	2		15.8	
	Nocomis	*leptocephalus*	1	PIO	MN		OM	25		118.6	4
	Notropis	*hudsonius*	1		MN	SL	IN	1		3.6	
	Notropis	*lutipinnis*	1	PIO	MN	SL	IN	99		170.7	2
15	*Noturus*	*insignis*	1	HWINT	BI		IN	4		27.2	1
	Scartomyzon	*rupiscartes*	1		SU	SL	IN	25		350.6	
	Semotilus	*atromaculatus*	1	TOL/PI			GE	1		0.3	
20											
25											

Site Information

Watershed Area (km2)	Log Watershed Area (mi2)	Length Sampled (m)	Length to Avg. Width Ratio
17.0	0.82	150	37.0

APPENDIX A. Site locations, fish lists, and IBI information.

LMH2000-17

North Oconee River
July 07, 2000

Collectors
Lee M. Hartle, Michael D. Merrill, John C. Ruiz, Jonathan D. Ray

Locality
North Oconee River @ Diamond Hill Church Road; ca 40m upstream of bridge

County Jackson **Lat** 34.26038 **Long** -83.64563

Total # Fish (> 25mm)	Total # Fish (inclu. YOY)	Total # species	Diversity H'
388	407	23	-2.36

Index of Biotic Integrity

	Calculation	Metric
# Native species (1)	22	5
# Benthic Invertivore (2)	3	3
# Native Sunfish (3)	2	1
# Native Cyprinid (4)	6	5
# Native Sucker (5)	4	5
# Intolerant (6 a-b)	3	3
Evenness (7)	75.4	5
% Sunfish or Omniv. (8 a-b)	41	5
% Insectivorous Cyprinids (9)	185	3
% Top Carn or Pioneer (10 a-b)	2.0	1
Number / 200m (11)	293.6	1
% Simple Lithophilic (12 a-b)	218	5

IBI Category Fair **IBI Score** 42

Fish List

	Genus	Species	OCO native	pollut tol	spp. cat	breed guild	feed guild	# coll	# rel	wt (gm)	# < 25 mm
1	*Ameiurus*	*brunneus*	1				OM	2		50.1	
	Ameiurus	*natalis*	1	TOL			GE	1		8.9	
	Ameiurus	*platycephalus*	1				GE	2		32.3	
	Campostoma	*pauciradii*	1	PIO	MN		OM	2		0.6	
5	*Cyprinella*	*xaenura*	1	INT	MN		IN	39		86.1	
	Erimyzon	*oblongus*	1		SU		IN	1		21.0	
	Etheostoma	*inscriptum*	1	HWINT	BI	SL	IN	2		0.5	
	Gambusia	*species*	1	TOL			OM	1		0.9	1
	Hybopsis	*rubrifrons*	1		MN	SL	IN	23		41.8	
10	*Hypentelium*	*nigricans*	1	INT	SU	SL	IN	9		152.2	
	Lepomis	*auritus*	1		SF		IN	32		297.3	
	Lepomis	*cyanellus*	0	TOL			IN	9		85.0	
	Lepomis	*macrochirus*	1		SF		IN	9		33.6	
	Micropterus	*salmoides*	1				CR	1		0.9	
15	*Moxostoma*	*collapsum*	1	INT	SU	SL	IN	5	1	35.4	
	Nocomis	*leptocephalus*	1	PIO	MN		OM	59		963.9	3
	Notropis	*hudsonius*	1		MN	SL	IN	107		73.9	8
	Notropis	*lutipinnis*	1	PIO	MN	SL	IN	16		43.9	
	Noturus	*insignis*	1	HWINT	BI		IN	1		8.6	
20	*Percina*	*nigrofasciata*	1		BI	SL	IN	17		44.0	2
	Pomoxis	*nigromaculatus*	1				CR	1		13.0	
	Scartomyzon	*rupiscartes*	1		SU	SL	IN	38		524.7	5
	Semotilus	*atromaculatus*	1	TOL/PI			GE	10		48.4	
25											

Site Information

Watershed Area (km2)	Log Watershed Area (mi2)	Length Sampled (m)	Length to Avg. Width Ratio
135.3	1.72	250	28.5

APPENDIX A. Site locations, fish lists, and IBI information.

LMH2000-18

Pond Fork
July 07, 2000

Collectors
Lee M. Hartle, Michael D. Merrill, John C. Ruiz, Jonathan D. Ray

Locality
Pond Fork @ Mangum Mill Road (? or Three Bridges Rd?) bridge crossing; 1st bridge N of Hall/Jackson county line (upstream)

County Hall **Lat** 34.23253 **Long** -83.71116

Total # Fish (> 25mm)	Total # Fish (inclu. YOY)	Total # species	Diversity H'
318	342	11	-1.12

Index of Biotic Integrity

	Calculation	Metric
# Native species (1)	11	3
# Benthic Invertivore (2)	1	1
# Native Sunfish (3)	2	2
# Native Cyprinid (4)	4	5
# Native Sucker (5)	2	5
# Intolerant (6 a-b)	2	3
Evenness (7)	46.5	1
% Sunfish or Omniv. (8 a-b)	29	5
% Insectivorous Cyprinids (9)	254	5
% Top Carn or Pioneer (10 a-b)	271.0	1
Number / 200m (11)	402.7	3
% Simple Lithophilic (12 a-b)	264	3

IBI Category Fair **IBI Score** 37

Fish List

Genus	Species	OCO native	pollut tol	spp. cat	breed guild	feed guild	# coll	# rel	wt (gm)	# < 25 mm
Ameiurus	*brunneus*	1				OM	2		3.7	
Campostoma	*pauciradii*	1	PIO	MN		OM	2		5.0	
Etheostoma	*inscriptum*	1	HWINT	BI	SL	IN	4		8.3	
Hybopsis	*rubrifrons*	1		MN	SL	IN	26		43.3	3
Hypentelium	*nigricans*	1	INT	SU	SL	IN	4		14.5	
Lepomis	*auritus*	1		SF		IN	7		4.6	
Lepomis	*macrochirus*	1		SF		IN	2		61.3	
Nocomis	*leptocephalus*	1	PIO	MN		OM	25		129.1	7
Notropis	*lutipinnis*	1	PIO	MN	SL	IN	228		236.4	12
Scartomyzon	*rupiscartes*	1		SU	SL	IN	2		22.9	2
Semotilus	*atromaculatus*	1	TOL/PI			GE	16		32.6	

Site Information	Watershed Area (km2)	Log Watershed Area (mi2)	Length Sampled (m)	Length to Avg. Width Ratio
	13.7	0.72	150	35.2

APPENDIX A. Site locations, fish lists, and IBI information.

LMH2000-19

Allen Creek
July 12, 2000

Collectors
Lee M. Hartle, Michael D. Merrill, John C. Ruiz, Jonathan D. Ray

Locality
Allen Creek @ SR346 (Fork Church Road); ca. 170m downstream of SR129/11

County Jackson **Lat** 34.19047 **Long** -83.71674

Total # Fish (> 25mm)	Total # Fish (inclu. YOY)	Total # species	Diversity H'
755	1,030	16	-1.93

Index of Biotic Integrity	Calculation	Metric
# Native species (1)	16	5
# Benthic Invertivore (2)	3	5
# Native Sunfish (3)	2	1
# Native Cyprinid (4)	6	5
# Native Sucker (5)	2	3
# Intolerant (6 a-b)	4	5
Evenness (7)	69.5	3
% Sunfish or Omniv. (8 a-b)	223	1
% Insectivorous Cyprinids (9)	371	3
% Top Carn or Pioneer (10 a-b)	1.0	1
Number / 200m (11)	739.0	5
% Simple Lithophilic (12 a-b)	456	5
IBI Category	Fair	
IBI Score		42

Fish List

Genus	Species	OCO native	pollut tol	spp. cat	breed guild	feed guild	# coll	# rel	wt (gm)	# < 25 mm
Ameiurus	*brunneus*	1				OM	1		18.5	1
Campostoma	*pauciradii*	1	PIO	MN		OM	27		49.6	6
Cyprinella	*xaenura*	1	INT	MN		IN	22		48.9	
Etheostoma	*inscriptum*	1	HWINT	BI	SL	IN	29		35.0	2
Hybopsis	*rubrifrons*	1		MN	SL	IN	22		66.1	5
Hypentelium	*nigricans*	1	INT	SU	SL	IN	6		51.9	
Lepomis	*auritus*	1		SF		IN	23		141.0	
Lepomis	*macrochirus*	1		SF		IN	11		61.8	
Micropterus	*salmoides*	1				CR	1		26.7	
Nocomis	*leptocephalus*	1	PIO	MN		OM	195		412.9	125
Notropis	*hudsonius*	1		MN	SL	IN	270		105.6	41
Notropis	*lutipinnis*	1	PIO	MN	SL	IN	57		85.2	82
Noturus	*insignis*	1	HWINT	BI		IN	3		6.5	1
Percina	*nigrofasciata*	1		BI	SL	IN	2		5.0	
Scartomyzon	*rupiscartes*	1		SU	SL	IN	70		307.1	12
Semotilus	*atromaculatus*	1	TOL/PI			GE	16		18.6	

Site Information	Watershed Area (km2)	Log Watershed Area (mi2)	Length Sampled (m)	Length to Avg. Width Ratio
	48.8	1.28	200	33.7

APPENDIX A. Site locations, fish lists, and IBI information.

LMH2000-20

Walnut Creek
July 12, 2000

Collectors
Lee M. Hartle, Michael D. Merrill, John C. Ruiz, Jonathan D. Ray

Locality
Walnut Creek @ SR 211 bridge crossing (upstream)

County Hall **Lat** 34.17005 **Long** -83.78765

Total # Fish (> 25mm)	Total # Fish (inclu. YOY)	Total # species	Diversity H'
573	608	18	-2.11

Index of Biotic Integrity	Calculation	Metric
# Native species (1)	17	5
# Benthic Invertivore (2)	3	5
# Native Sunfish (3)	2	1
# Native Cyprinid (4)	7	5
# Native Sucker (5)	3	5
# Intolerant (6 a-b)	5	5
Evenness (7)	73.0	5
% Sunfish or Omniv. (8 a-b)	158	3
% Insectivorous Cyprinids (9)	288	3
% Top Carn or Pioneer (10 a-b)	0.0	1
Number / 200m (11)	569.0	3
% Simple Lithophilic (12 a-b)	287	3

IBI Category	IBI Score
Good	44

Fish List

Genus	Species	OCO native	pollut tol	spp. cat	breed guild	feed guild	# coll	# rel	wt (gm)	# < 25 mm
Ameiurus	*brunneus*	1				OM	2		55.1	2
Campostoma	*pauciradii*	1	PIO	MN		OM	8		13.3	
Cyprinella	*xaenura*	1	INT	MN		IN	95		94.0	1
Etheostoma	*inscriptum*	1	HWINT	BI	SL	IN	69		65.6	11
Hybopsis	*rubrifrons*	1		MN	SL	IN	81		100.0	11
Hypentelium	*nigricans*	1	INT	SU	SL	IN	5		76.4	
Lepomis	*auritus*	1		SF		IN	13		121.5	
Lepomis	*cyanellus*	0	TOL			IN	2		9.6	
Lepomis	*macrochirus*	1		SF		IN	10		43.0	
Moxostoma	*collapsum*	1	INT	SU	SL	IN	5		5.0	
Nocomis	*leptocephalus*	1	PIO	MN		OM	148		238.6	
Notropis	*cummingsae*	1	CHA,	MN	SL	IN	1		0.3	
Notropis	*hudsonius*	1	[illegible]	MN	SL	IN	19		19.8	8
Notropis	*lutipinnis*	1	PIO	MN	SL	IN	92		106.3	
Noturus	*insignis*	1	HWINT	BI		IN	6		29.5	
Percina	*nigrofasciata*	1		BI	SL	IN	3		5.9	
Scartomyzon	*rupiscartes*	1		SU	SL	IN	12		30.5	2
Semotilus	*atromaculatus*	1	TOL/PI			GE	2		0.9	

Site Information

Watershed Area (km2)	Log Watershed Area (mi2)	Length Sampled (m)	Length to Avg. Width Ratio
42.3	1.21	200	31.5

APPENDIX A. Site locations, fish lists, and IBI information.

LMH2000-21

Mulberry River
July 12, 2000

Collectors
Lee M. Hartle, Michael D. Merrill, John C. Ruiz, Jonathan D. Ray

Locality
Mulberry River @ Cash Road bridge crossing (downstream)

County Hall **Lat** 34.15697 **Long** -83.87152

Total # Fish (> 25mm)	Total # Fish (inclu. YOY)	Total # species	Diversity H’
196	439.1	10	-1.79

Index of Biotic Integrity	Calculation	Metric
# Native species (1)	10	3
# Benthic Invertivore (2)	1	1
# Native Sunfish (3)	2	3
# Native Cyprinid (4)	3	3
# Native Sucker (5)	1	3
# Intolerant (6 a-b)	1	1
Evenness (7)	77.6	5
% Sunfish or Omniv. (8 a-b)	46	3
% Insectivorous Cyprinids (9)	107	5
% Top Carn or Pioneer (10 a-b)	124.0	3
Number / 200m (11)	244.0	1
% Simple Lithophilic (12 a-b)	115	1

IBI Category		IBI Score	
	Poor		32

Fish List

	Genus	Species	OCO native	pollut tol	spp. cat	breed guild	feed guild	# coll	# rel	wt (gm)	# < 25 mm
1	*Ameiurus*	*brunneus*	1				OM	9		386.6	2
	Ameiurus	*platycephalus*	1				GE	1		19.6	1
	Campostoma	*pauciradii*	1	PIO	MN		OM			1.3	5
	Hybopsis	*rubrifrons*	1		MN	SL	IN	33		53.4	148
5	*Lepomis*	*auritus*	1		SF		IN	15		145.4	
	Lepomis	*macrochirus*	1		SF		IN	3		37.3	
	Nocomis	*leptocephalus*	1	PIO	MN		OM	37		87.6	87
	Notropis	*lutipinnis*	1	PIO	MN	SL	IN	74		47.1	0.1
	Noturus	*insignis*	1	HWINT	BI		IN	3		24.2	
10	*Scartomyzon*	*rupiscartes*	1		SU	SL	IN	8		64.3	
	Semotilus	*atromaculatus*	1	TOL/PI			GE	13		23.8	
15											
20											
25											

Site Information	Watershed Area (km2)	Log Watershed Area (mi2)	Length Sampled (m)	Length to Avg. Width Ratio
	17.5	0.83	150	27.2

APPENDIX A. Site locations, fish lists, and IBI information.

LMH2000-22

Little Mulberry
July 13, 2000

Collectors
Lee M. Hartle, Michael D. Merrill, John C. Ruiz, Jonathan D. Ray

Locality
Little Mulberry River @ Boss Hardy Road bridge crossing; (downstream)

County Barrow **Lat** 34.06108 **Long** -83.80376

Total # Fish (> 25mm)	Total # Fish (inclu. YOY)	Total # species	Diversity H’
283	326	18	-2.23

Index of Biotic Integrity

	Calculation	Metric
# Native species (1)	18	5
# Benthic Invertivore (2)	3	5
# Native Sunfish (3)	2	3
# Native Cyprinid (4)	6	5
# Native Sucker (5)	3	5
# Intolerant (6 a-b)	6	5
Evenness (7)	77.2	5
% Sunfish or Omniv. (8 a-b)	92	1
% Insectivorous Cyprinids (9)	107	3
% Top Carn or Pioneer (10 a-b)	2.0	1
Number / 200m (11)	281.0	1
% Simple Lithophilic (12 a-b)	134	3

IBI Category Fair **IBI Score** 42

Fish List

Genus	Species	OCO native	pollut tol	spp. cat	breed guild	feed guild	# coll	# rel	wt (gm)	# < 25 mm
Ameiurus	*brunneus*	1				OM	6		102.3	1
Cyprinella	*callisema*	1	INT	MN		IN	3		2.9	
Cyprinella	*xaenura*	1	INT	MN		IN	19		59.6	1
Etheostoma	*inscriptum*	1	HWINT	BI	SL	IN	7		89.8	2
Hybopsis	*rubrifrons*	1		MN	SL	IN	13		29.9	5
Hypentelium	*nigricans*	1	INT	SU	SL	IN	8		102.7	
Lepomis	*auritus*	1		SF		IN	11		92.5	
Lepomis	*macrochirus*	1		SF		IN	15		92.4	
Micropterus	*salmoides*	1				CR	1		5.2	
Moxostoma	*sp.*	1								2
Nocomis	*leptocephalus*	1	PIO	MN		OM	86		536.3	13
Notropis	*hudsonius*	1		MN	SL	IN	12		17.9	5
Notropis	*lutipinnis*	1	PIO	MN	SL	IN	60		73.3	14
Noturus	*insignis*	1	HWINT	BI		IN	5		20.4	
Percina	*nigrofasciata*	1		BI	SL	IN	4		6.1	
Pomoxis	*nigromaculatus*	1				CR	1		17.5	
Scartomyzon	*rupiscartes*	1		SU	SL	IN	27		205.1	
Scartomyzon	*sp cf. lachneri*	1	INT	SU	SL	IN	3		58.1	
Semotilus	*atromaculatus*	1	TOL/PI			GE	2		13.0	

Site Information

Watershed Area (km2)	Log Watershed Area (mi2)	Length Sampled (m)	Length to Avg. Width Ratio
40.4	1.19	200	31.7

APPENDIX A. Site locations, fish lists, and IBI information.

LMH2000-23

Big Sandy Creek
July 15, 2000

Collectors
Lee M. Hartle, Michael D. Merrill, John C. Ruiz, Jonathan D. Ray, Amanda M. Brown, R. Dale McPherson, Robert M. Halleux

Locality
Big Sandy Creek @ Sandy Creek Road (upstream)

County Morgan **Lat** 33.71640 **Long** -83.55975

Total # Fish (> 25mm)	Total # Fish (inclu. YOY)	Total # species	Diversity H'
536	542	14	-1.43

Index of Biotic Integrity	Calculation	Metric
# Native species (1)	14	3
# Benthic Invertivore (2)	3	5
# Native Sunfish (3)	2	3
# Native Cyprinid (4)	5	5
# Native Sucker (5)	1	1
# Intolerant (6 a-b)	4	5
Evenness (7)	54.0	1
% Sunfish or Omniv. (8 a-b)	97	3
% Insectivorous Cyprinids (9)	374	5
% Top Carn or Pioneer (10 a-b)	12.0	3
Number / 200m (11)	535.0	3
% Simple Lithophilic (12 a-b)	395	5
IBI Category: Fair	IBI Score	42

Fish List

	Genus	Species	OCO native	pollut tol	spp. cat	breed guild	feed guild	# coll	# rel	wt (gm)	# < 25 mm
1	*Cyprinella*	*callisema*	1	INT	MN		IN	1		0.8	
	Esox	*americanus*	1				CR	9		78.4	
	Etheostoma	*inscriptum*	1	HWINT	BI	SL	IN	4		3.7	
	Hybopsis	*rubrifrons*	1		MN	SL	IN	58		79.6	
5	*Lepomis*	*auritus*	1		SF		IN	25		231.2	
	Lepomis	*macrochirus*	1		SF		IN	3		120.1	
	Micropterus	*coosae*	1	HWINT			CR	3		84.8	
	Micropterus	*sp.*	1		SF					251.2	5
	Nocomis	*leptocephalus*	1	PIO	MN		OM	97		224.5	
10	*Notropis*	*hudsonius*	1		MN	SL	IN	9		20.9	
	Notropis	*lutipinnis*	1	PIO	MN	SL	IN	306		247.7	1
	Noturus	*insignis*	1	HWINT	BI		IN	2		14.8	
	Percina	*nigrofasciata*	1		BI	SL	IN	8		23.3	
	Scartomyzon	*rupiscartes*	1		SU	SL	IN	10		201.9	
15	*Semotilus*	*atromaculatus*	1	TOL/PI			GE	1		4.9	

Site Information	Watershed Area (km2)	Log Watershed Area (mi2)	Length Sampled (m)	Length to Avg. Width Ratio
	39.8	1.19	200	34.4

LMH2000-24

Hardeman Creek
July 17, 2000

Collectors
Lee M. Hartle, Michael D. Merrill, John C. Ruiz, Jonathan D. Ray, R. Dale McPherson

Locality
Hardeman Creek @ Tal Phillips Road crossing; (downstream)

County Jackson **Lat** 34.12497 **Long** -83.39263

Total # Fish (> 25mm)	Total # Fish (inclu. YOY)	Total # species	Diversity H'
351	399	12	-1.27

Index of Biotic Integrity

	Calculation	Metric
# Native species (1)	11	3
# Benthic Invertivore (2)	2	3
# Native Sunfish (3)	2	3
# Native Cyprinid (4)	3	3
# Native Sucker (5)	2	5
# Intolerant (6 a-b)	3	5
Evenness (7)	51.1	1
% Sunfish or Omniv. (8 a-b)	67	3
% Insectivorous Cyprinids (9)	228	5
% Top Carn or Pioneer (10 a-b)	298.0	1
Number / 200m (11)	450.7	3
% Simple Lithophilic (12 a-b)	237	3

IBI Category Fair **IBI Score** 38

Fish List

Genus	Species	OCO native	pollut tol	spp. cat	breed guild	feed guild	# coll	# rel	wt (gm)	# < 25 mm
Ameiurus	*natalis*	1	TOL			GE	1		29.5	
Etheostoma	*inscriptum*	1	HWINT	BI	SL	IN	1		2.8	
Hybopsis	*rubrifrons*	1		MN	SL	IN	7		21.3	
Lepomis	*auritus*	1		SF		IN	6		75.8	
Lepomis	*cyanellus*	0	TOL			IN	2		21.6	
Lepomis	*macrochirus*	1		SF		IN	17		60.1	1
Moxostoma	*collapsum*	1	INT	SU	SL	IN	1		0.9	
Nocomis	*leptocephalus*	1	PIO	MN		OM	67		241.2	17
Notropis	*lutipinnis*	1	PIO	MN	SL	IN	221		296.7	28
Noturus	*insignis*	1	HWINT	BI		IN	11		90.9	1
Scartomyzon	*rupiscartes*	1		SU	SL	IN	7		34.3	
Semotilus	*atromaculatus*	1	TOL/PI			GE	10		14.6	1

Site Information

Watershed Area (km2)	Log Watershed Area (mi2)	Length Sampled (m)	Length to Avg. Width Ratio
16.3	0.80	150	28.3

APPENDIX A. Site locations, fish lists, and IBI information.

LMH2000-25

Barber Creek
July 18, 2000

Collectors
Lee M. Hartle, Michael D. Merrill, John C. Ruiz, Jonathan D. Ray

Locality
Barber Creek above confluence with McNutt Creek; upstream of new Hwy 441S

County Oconee **Lat** 33.91163 **Long** -83.40930

Total # Fish (> 25mm)	Total # Fish (inclu. YOY)	Total # species	Diversity H'
685	769.2	14	-1.55

Index of Biotic Integrity	Calculation	Metric
# Native species (1)	14	3
# Benthic Invertivore (2)	3	3
# Native Sunfish (3)	2	1
# Native Cyprinid (4)	5	3
# Native Sucker (5)	2	3
# Intolerant (6 a-b)	2	3
Evenness (7)	58.6	3
% Sunfish or Omniv. (8 a-b)	11	5
% Insectivorous Cyprinids (9)	422	5
% Top Carn or Pioneer (10 a-b)	0.0	1
Number / 200m (11)	546.4	3
% Simple Lithophilic (12 a-b)	441	5
IBI Category	Fair	
IBI Score	38	

Fish List

Genus	Species	OCO native	pollut tol	spp. cat	breed guild	feed guild	# coll	# rel	wt (gm)	# < 25 mm
Ameiurus	*brunneus*	1				OM	3		53.4	10
Cyprinella	*xaenura*	1	INT	MN		IN	14		21.2	2
Etheostoma	*inscriptum*	1	HWINT	BI	SL	IN	14		16.1	4
Gambusia	*species*	1	TOL			OM			0.0	4
Hybopsis	*rubrifrons*	1		MN	SL	IN	29		63.0	14
Lepomis	*auritus*	1		SF		IN	7		70.2	
Lepomis	*macrochirus*	1		SF		IN	4		35.3	
Moxostoma	*collapsum*	1	INT	SU	SL	IN	5		5.3	
Nocomis	*leptocephalus*	1	PIO	MN		OM	201		573.4	0.1
Notropis	*hudsonius*	1		MN	SL	IN	61		14.2	46
Notropis	*lutipinnis*	1	PIO	MN	SL	IN	318		388.2	0.1
Noturus	*insignis*	1	HWINT	BI		IN	13		68.0	4
Percina	*nigrofasciata*	1		BI	SL	IN	8		24.6	
Scartomyzon	*rupiscartes*	1		SU	SL	IN	6		2.7	
Semotilus	*atromaculatus*	1	TOL/PI			GE	2		9.7	

Site Information	Watershed Area (km2)	Log Watershed Area (mi2)	Length Sampled (m)	Length to Avg. Width Ratio
	109.6	1.63	250	48.4

APPENDIX A. Site locations, fish lists, and IBI information.

LMH2000-26

Little River
July 19, 2000

Collectors
Lee M. Hartle, Michael D. Merrill, John C. Ruiz, Jonathan D. Ray

Locality
Little River @ Glades Rd. bridge; (downstream)
utm17(nad83)

County Putnam **Lat** 33.37259 **Long** -83.47418

Total # Fish (> 25mm)	Total # Fish (inclu. YOY)	Total # species	Diversity H'
1,520	1,712	24	-2.43

Index of Biotic Integrity	Calculation	Metric
# Native species (1)	24	5
# Benthic Invertivore (2)	4	5
# Native Sunfish (3)	4	5
# Native Cyprinid (4)	8	5
# Native Sucker (5)	4	5
# Intolerant (6 a-b)	5	5
Evenness (7)	76.4	5
% Sunfish or Omniv. (8 a-b)	84	5
% Insectivorous Cyprinids (9)	1072	5
% Top Carn or Pioneer (10 a-b)	17.0	1
Number / 200m (11)	1012.7	5
% Simple Lithophilic (12 a-b)	720	3

IBI Category Excellent **IBI Score** 54

Fish List

Genus	Species	OCO native	pollut tol	spp. cat	breed guild	feed guild	# coll	# rel	wt (gm)	# < 25 mm
Ameiurus	*brunneus*	1				OM	2		22.4	1
Cyprinella	*callisema*	1	INT	MN		IN	401		293.2	2
Cyprinella	*xaenura*	1	INT	MN		IN	165		228.7	63
Etheostoma	*inscriptum*	1	HWINT	BI	SL	IN	80		23.6	13
Etheostoma	*olmstedi*	1		BI		IN	52		29.8	
Gambusia	*species*	1	TOL			OM	1		0.4	8
Hybopsis	*rubrifrons*	1		MN	SL	IN	208		150.2	16
Ictalurus	*punctatus*	1				GE	1		4.8	
Lepomis	*auritus*	1		SF		IN	75		466.2	2
Lepomis	*gulosus*	1		SF		CR	1		7.1	
Lepomis	*macrochirus*	1		SF		IN	6		23.1	
Lepomis	*microlophus*	1		SF		IN	2		6.1	
Micropterus	*coosae*	1	HWINT			CR	16		680.0	
Minytrema	*melanops*	1	INT	SU	SL	IN	17		154.0	1
Moxostoma	*collapsum*	1	INT	SU	SL	IN	29	5	1540.	
Nocomis	*leptocephalus*	1	PIO	MN		OM	76		127.8	11
Notropis	*cummingsae*	1		MN	SL	IN	61		27.5	3
Notropis	*hudsonius*	1		MN	SL	IN	106		103.3	4
Notropis	*lutipinnis*	1	PIO	MN	SL	IN	126		153.7	56
Notropis	*petersoni*	1		MN	SL	IN	5		4.4	
Noturus	*insignis*	1	HWINT	BI		IN	2		12.9	
Percina	*nigrofasciata*	1		BI	SL	IN	53		57.9	5
Scartomyzon	*rupiscartes*	1		SU	SL	IN	19		136.9	
Scartomyzon	*sp cf. lachneri*	1	INT	SU	SL	IN	11		59.1	
Catostomidae sp.		1		SU					0.0	7

Site Information

Watershed Area (km2)	Log Watershed Area (mi2)	Length Sampled (m)	Length to Avg. Width Ratio
354.2	2.14	300	41.6

APPENDIX A. Site locations, fish lists, and IBI information.

LMH2000-27

Hard Labor Creek
July 20, 2000

Collectors
Lee M. Hartle, Michael D. Merrill, John C. Ruiz, Jonathan D. Ray

Locality
Hard Labor Creek @ Lower Apalachee Road bridge crossing (upstream)
utm17(nad83) 277612.72,3724846.70

County Morgan **Lat** 33.640240 **Long** -83.397810

Total # Fish (> 25mm)	Total # Fish (inclu. YOY)	Total # species	Diversity H'
828	956	26	-1.82

Index of Biotic Integrity

	Calculation	Metric
# Native species (1)	24	5
# Benthic Invertivore (2)	3	3
# Native Sunfish (3)	4	5
# Native Cyprinid (4)	6	5
# Native Sucker (5)	3	5
# Intolerant (6 a-b)	6	5
Evenness (7)	55.9	1
% Sunfish or Omniv. (8 a-b)	109	5
% Insectivorous Cyprinids (9)	566	5
% Top Carn or Pioneer (10 a-b)	15.0	1
Number / 200m (11)	550.0	3
% Simple Lithophilic (12 a-b)	237	1
IBI Category	Good	
IBI Score	44	

Fish List

	Genus	Species	OCO native	pollut tol	spp. cat	breed guild	feed guild	# coll	# rel	wt (gm)	# < 25 mm
1	*Ameiurus*	*brunneus*	1				OM	5		34.9	
	Cyprinella	*callisema*	1	INT	MN		IN	403		392.3	41
	Cyprinella	*xaenura*	1	INT	MN		IN	16		27.9	6
	Dorosoma	*cepedianum*	1				OM	1		34.1	
5	*Etheostoma*	*olmstedi*	1		BI		IN	17		6.7	7
	Gambusia	*species*	1	TOL			OM	1		0.3	15
	Hybognathus	*regius*	1	INT	MN		HB	1		8.1	
	Ictalurus	*punctatus*	1				GE	5		234.1	
	Lepomis	*auritus*	1		SF		IN	97		610.4	1
10	*Lepomis*	*cyanellus*	0	TOL			IN	1		9.4	
	Lepomis	*gulosus*	1		SF		CR	1		17.4	
	Lepomis	*macrochirus*	1		SF		IN	10		70.0	2
	Lepomis	*microlophus*	1		SF		IN	1		4.7	
	Micropterus	*coosae*	1	HWINT			CR	6		49.3	
15	*Micropterus*	*salmoides*	1				CR	1		1.1	
	Minytrema	*melanops*	1	INT	SU	SL	IN	1	1	219.4	
	Moxostoma	*collapsum*	1	INT	SU	SL	IN	8	1	1467.	
	Nocomis	*leptocephalus*	1	PIO	MN		OM	16		25.9	8
	Notropis	*hudsonius*	1		MN	SL	IN	125		153.8	10
20	*Notropis*	*lutipinnis*	1	PIO	MN	SL	IN	22		7.4	29
	Noturus	*insignis*	1	HWINT	BI		IN	1		0.3	
	Percina	*nigrofasciata*	1		BI	SL	IN	62		97.7	
	Pomoxis	*nigromaculatus*	1				CR	6		335.7	
	Scartomyzon	*sp cf. lachneri*	1	INT	SU	SL	IN	17		1719.	
25	*Cyprinidae*	*sp.*	1		MN					0.0	9
	Labidesthes	*sicculus*	1				IN	1		0.2	
	Perca	*flavescens*	0				CR	1		92.3	

Site Information

Watershed Area (km2)	Log Watershed Area (mi2)	Length Sampled (m)	Length to Avg. Width Ratio
400.4	2.19	300	42.4

APPENDIX A. Site locations, fish lists, and IBI information.

LMH2000-28 North Sugar Creek July 20, 2000

Collectors
Lee M. Hartle, Michael D. Merrill, John C. Ruiz, Jonathan D. Ray

Locality
North Sugar Creek @ Barrow's Grove Road (underneath I-20); (upstream)
utm17(nad83) 277976.70,3715321.44

County Morgan **Lat** 33.554480 **Long** -83.391520

Total # Fish (> 25mm)	Total # Fish (inclu. YOY)	Total # species	Diversity H'
524	799	9	-1.01

Index of Biotic Integrity	Calculation	Metric
# Native species (1)	9	1
# Benthic Invertivore (2)	0	1
# Native Sunfish (3)	2	3
# Native Cyprinid (4)	3	3
# Native Sucker (5)	2	5
# Intolerant (6 a-b)	1	1
Evenness (7)	45.9	1
% Sunfish or Omniv. (8 a-b)	297	1
% Insectivorous Cyprinids (9)	188	3
% Top Carn or Pioneer (10 a-b)	0.0	1
Number / 200m (11)	520.0	3
% Simple Lithophilic (12 a-b)	219	3

IBI Category Poor **IBI Score** 26

Fish List

Genus	Species	OCO native	pollut tol	spp. cat	breed guild	feed guild	# coll	# rel	wt (gm)	# < 25 mm
Ameiurus	*natalis*	1	TOL			GE	2		10.6	5
Hybopsis	*rubrifrons*	1		MN	SL	IN	5		8.1	
Lepomis	*auritus*	1		SF		IN	3		45.2	
Lepomis	*macrochirus*	1		SF		IN	1		9.2	2
Moxostoma	*collapsum*	1	INT	SU	SL	IN	4		5.7	
Nocomis	*leptocephalus*	1	PIO	MN		OM	297		421.7	107
Notropis	*lutipinnis*	1	PIO	MN	SL	IN	183		250.4	161
Scartomyzon	*rupiscartes*	1		SU	SL	IN	27		43.6	
Semotilus	*atromaculatus*	1	TOL/PI			GE	2		1.4	

Site Information	Watershed Area (km2)	Log Watershed Area (mi2)	Length Sampled (m)	Length to Avg. Width Ratio
	36.1	1.14	200	54.2

APPENDIX A. Site locations, fish lists, and IBI information.

LMH2000-29

Reedy Creek
July 21, 2000

Collectors
Lee M. Hartle, Michael D. Merrill, John C. Ruiz, Jonathan D. Ray

Locality
Reedy Creek @ Mt. Paran Church Road (downstream)
utm17(nad83) 254457.18,3730578.30

County Walton **Lat** 33.686790 **Long** -83.648840

Total # Fish (> 25mm)	Total # Fish (inclu. YOY)	Total # species	Diversity H'
404	509	13	-1.72

Index of Biotic Integrity

	Calculation	Metric
# Native species (1)	12	3
# Benthic Invertivore (2)	2	3
# Native Sunfish (3)	3	5
# Native Cyprinid (4)	3	3
# Native Sucker (5)	1	3
# Intolerant (6 a-b)	0	1
Evenness (7)	67.1	3
% Sunfish or Omniv. (8 a-b)	109	3
% Insectivorous Cyprinids (9)	221	5
% Top Carn or Pioneer (10 a-b)	234.0	3
Number / 200m (11)	514.7	3
% Simple Lithophilic (12 a-b)	234	3

IBI Category Fair **IBI Score** 38

Fish List

Genus	Species	OCO native	pollut tol	spp. cat	breed guild	feed guild	# coll	# rel	wt (gm)	# < 25 mm
Ameiurus	*brunneus*	1				OM	1		13.7	2
Gambusia	*species*	1	TOL			OM			0.0	1
Hybopsis	*rubrifrons*	1		MN	SL	IN	109		135.3	
Lepomis	*auritus*	1		SF		IN	27		172.0	
Lepomis	*cyanellus*	0	TOL			IN	4		6.1	
Lepomis	*macrochirus*	1		SF		IN	6		71.5	
Lepomis	*microlophus*	1		SF		IN	5		8.7	
Micropterus	*salmoides*	1				CR	1		0.0	
Nocomis	*leptocephalus*	1	PIO	MN		OM	108		404.9	95
Notropis	*lutipinnis*	1	PIO	MN	SL	IN	112		126.0	
Noturus	*gyrinus*	1		BI		IN	4		5.4	2
Percina	*nigrofasciata*	1		BI	SL	IN	11		8.9	2
Scartomyzon	*rupiscartes*	1		SU	SL	IN	2		24.0	
Semotilus	*atromaculatus*	1	TOL/PI			GE	14		35.9	3

Site Information

Watershed Area (km2)	Log Watershed Area (mi2)	Length Sampled (m)	Length to Avg. Width Ratio
14.0	0.73	150	30.1

APPENDIX A. Site locations, fish lists, and IBI information.

LMH2000-30

Big Indian Creek
July 25, 2000

Collectors
Lee M. Hartle, Michael D. Merrill, John C. Ruiz, Silas E. Mathes

Locality
Big Indian Creek @ SR83 (Robert Hillsman Br.) bridge crossing (upstream)
utm17(nad83) 265574.00,3712440.83

County Morgan **Lat** 33.525870 **Long** -83.524250

Total # Fish (> 25mm)	Total # Fish (inclu. YOY)	Total # species	Diversity H’
311	319	20	-1.93

Index of Biotic Integrity

	Calculation	Metric
# Native species (1)	20	5
# Benthic Invertivore (2)	4	5
# Native Sunfish (3)	4	5
# Native Cyprinid (4)	4	3
# Native Sucker (5)	3	5
# Intolerant (6 a-b)	0	3
Evenness (7)	64.4	3
% Sunfish or Omniv. (8 a-b)	204	1
% Insectivorous Cyprinids (9)	61	1
% Top Carn or Pioneer (10 a-b)	3.0	1
Number / 200m (11)	310.0	1
% Simple Lithophilic (12 a-b)	80	1

IBI Category Fair **IBI Score** 34

Fish List

Genus	Species	OCO native	pollut tol	spp. cat	breed guild	feed guild	# coll	# rel	wt (gm)	# < 25 mm
Ameiurus	*brunneus*	1				OM	4		56.5	
Ameiurus	*natalis*	1	TOL			GE	1		32.9	
Ameiurus	*platycephalus*	1				GE	15		213.5	
Etheostoma	*inscriptum*	1	HWINT	BI	SL	IN	4		3.3	
Etheostoma	*olmstedi*	1		BI		IN	1		0.4	
Hybopsis	*rubrifrons*	1		MN	SL	IN	18		24.8	
Lepomis	*auritus*	1		SF		IN	127		1747.	1
Lepomis	*gulosus*	1		SF		CR	1		23.4	
Lepomis	*macrochirus*	1		SF		IN	67	1	534.1	3
Lepomis	*microlophus*	1		SF		IN	8		164.0	
Micropterus	*coosae*	1	HWINT			CR	1		116.4	
Micropterus	*salmoides*	1				CR	1		3.4	
Minytrema	*melanops*	1	INT	SU	SL	IN	2		220.7	
Moxostoma	*collapsum*	1	INT	SU	SL	IN	1		3.4	
Notropis	*hudsonius*	1		MN	SL	IN	13		57.9	
Notropis	*lutipinnis*	1	PIO	MN	SL	IN	1		3.5	
Notropis	*petersoni*	1		MN	SL	IN	29		52.1	4
Noturus	*insignis*	1	HWINT	BI		IN	4		60.6	
Percina	*nigrofasciata*	1		BI	SL	IN	10		17.5	
Scartomyzon	*sp cf. lachneri*	1	INT	SU	SL	IN	2		5.0	

Site Information

Watershed Area (km2)	Log Watershed Area (mi2)	Length Sampled (m)	Length to Avg. Width Ratio
76.2	1.47	200	47.2

APPENDIX A. Site locations, fish lists, and IBI information.

LMH2000-31

Little Indian Creek
July 25, 2000

Collectors
Lee M. Hartle, Michael D. Merrill, John C. Ruiz, Silas E. Mathes

Locality
Little Indian Creek @ Indian Creek Road bridge crossing (upstream)
utm17(nad83) 267667.83,3712166.37

County Morgan **Lat** 33.523860 **Long** -83.501650

Total # Fish (> 25mm)	Total # Fish (inclu. YOY)	Total # species	Diversity H’
175	201	16	-2.13

Index of Biotic Integrity	Calculation	Metric
# Native species (1)	16	5
# Benthic Invertivore (2)	3	5
# Native Sunfish (3)	2	3
# Native Cyprinid (4)	4	5
# Native Sucker (5)	2	5
# Intolerant (6 a-b)	0	1
Evenness (7)	76.7	5
% Sunfish or Omniv. (8 a-b)	21	5
% Insectivorous Cyprinids (9)	59	3
% Top Carn or Pioneer (10 a-b)	58.0	5
Number / 200m (11)	229.3	1
% Simple Lithophilic (12 a-b)	83	5
IBI Category	Good	
IBI Score	48	

Fish List

Genus	Species	OCO native	pollut tol	spp. cat	breed guild	feed guild	# coll	# rel	wt (gm)	# < 25 mm
Ameiurus	*nebulosus*	1	TOL			OM	2		21.4	
Erimyzon	*oblongus*	1		SU		IN	1		23.6	1
Esox	*americanus*	1				CR	5		148.6	
Etheostoma	*hopkinsi*	1		BI	SL	IN	10		4.4	1
Gambusia	*species*	1	TOL			OM	1		0.6	
Lepomis	*auritus*	1		SF		IN	46		521.1	
Lepomis	*macrochirus*	1		SF		IN	13		135.9	
Micropterus	*salmoides*	1				CR	1		13.9	
Nocomis	*leptocephalus*	1	PIO	MN		OM	18		151.3	16
Notropis	*hudsonius*	1		MN	SL	IN	18		23.2	
Notropis	*lutipinnis*	1	PIO	MN	SL	IN	40		53.9	7
Notropis	*petersoni*	1		MN	SL	IN	1		1.3	
Noturus	*gyrinus*	1		BI		IN	3		3.4	
Percina	*nigrofasciata*	1		BI	SL	IN	1		3.2	
Scartomyzon	*rupiscartes*	1		SU	SL	IN	13		352.5	
Aphredoderus	*sayanus*	1				IN	2		1.2	1

Site Information

Watershed Area (km2)	Log Watershed Area (mi2)	Length Sampled (m)	Length to Avg. Width Ratio
12.8	0.69	150	46.7

LMH2000-32

Big Sandy Creek
July 26, 2000

Collectors
Lee M. Hartle, Michael D. Merrill, John C. Ruiz, R. Dale McPherson

Locality
Big Sandy Creek @ Sandy Creek Road (upstream)
utm17(nad83) 275595.81,3726946.51

County Morgan **Lat** 33.658740 **Long** -83.420070

Total # Fish (> 25mm)	Total # Fish (inclu. YOY)	Total # species	Diversity H'
284	356	23	-2.42

Index of Biotic Integrity

	Calculation	Metric
# Native species (1)	21	5
# Benthic Invertivore (2)	3	3
# Native Sunfish (3)	3	3
# Native Cyprinid (4)	6	3
# Native Sucker (5)	3	5
# Intolerant (6 a-b)	4	5
Evenness (7)	77.2	5
% Sunfish or Omniv. (8 a-b)	89	3
% Insectivorous Cyprinids (9)	110	3
% Top Carn or Pioneer (10 a-b)	13.0	5
Number / 200m (11)	218.4	1
% Simple Lithophilic (12 a-b)	70	1

IBI Category Fair **IBI Score** 42

Fish List

Genus	Species	OCO native	pollut tol	spp. cat	breed guild	feed guild	# coll	# rel	wt (gm)	# < 25 mm
Ameiurus	*brunneus*	1				OM	5		211.9	
Cyprinella	*callisema*	1	INT	MN		IN	65		62.1	
Cyprinella	*xaenura*	1	INT	MN		IN	1		3.0	
Esox	*americanus*	1				CR	2		8.0	
Etheostoma	*olmstedi*	1		BI		IN	16		5.7	9
Gambusia	*species*	1	TOL			OM	4		3.5	7
Lepomis	*auritus*	1		SF		IN	68		709.4	
Lepomis	*cyanellus*	0	TOL			IN	3		31.5	
Lepomis	*gulosus*	1		SF		CR	2		8.4	
Lepomis	*macrochirus*	1		SF		IN	16		137.1	3
Micropterus	*coosae*	1	HWINT			CR	4		175.4	
Moxostoma	*collapsum*	1	INT	SU	SL	IN	5		0.0	
Nocomis	*leptocephalus*	1	PIO	MN		OM	19		11.1	25
Notropis	*hudsonius*	1		MN	SL	IN	30		46.3	2
Notropis	*lutipinnis*	1	PIO	MN	SL	IN	10		14.5	23
Notropis	*petersoni*	1		MN	SL	IN	4		10.2	3
Noturus	*insignis*	1	HWINT	BI		IN	1		13.7	
Percina	*nigrofasciata*	1		BI	SL	IN	9		14.8	
Pomoxis	*nigromaculatus*	1				CR	1		40.1	
Scartomyzon	*rupiscartes*	1		SU	SL	IN	7		113.2	
Scartomyzon	*sp cf. lachneri*	1	INT	SU	SL	IN	5		33.3	
Aphredoderus	*sayanus*	1				IN	3		25.3	
Perca	*flavescens*	0				CR	4		51.0	

Site Information

Watershed Area (km2)	Log Watershed Area (mi2)	Length Sampled (m)	Length to Avg. Width Ratio
170.6	1.82	250	22.6

APPENDIX A. Site locations, fish lists, and IBI information.

LMH2000-33

Little River
July 28, 2000

Collectors
Lee M. Hartle, Michael D. Merrill, John C. Ruiz, Jonathan D. Ray

Locality
Little River @ State Highway 278 (upstream) (S of I-20)
utm17(nad83) 48640.12,3721866.71

County Newton **Lat** 33.606940 **Long** -83.709070

Total # Fish (> 25mm)	Total # Fish (inclu. YOY)	Total # species	Diversity H'
361	362	10	-0.89

Index of Biotic Integrity	Calculation	Metric
# Native species (1)	10	3
# Benthic Invertivore (2)	1	1
# Native Sunfish (3)	1	1
# Native Cyprinid (4)	4	3
# Native Sucker (5)	1	3
# Intolerant (6 a-b)	0	1
Evenness (7)	38.8	1
% Sunfish or Omniv. (8 a-b)	187	1
% Insectivorous Cyprinids (9)	165	3
% Top Carn or Pioneer (10 a-b)	349.0	1
Number / 200m (11)	478.7	3
% Simple Lithophilic (12 a-b)	170	3
IBI Category	Very Poor	
IBI Score	24	

Fish List

Genus	Species	OCO native	pollut tol	spp. cat	breed guild	feed guild	# coll	# rel	wt (gm)	# < 25 mm
Esox	*americanus*	1				CR	1		9.1	
Etheostoma	*hopkinsi*	1		BI	SL	IN	3		4.3	
Gambusia	*species*	1	TOL			OM	1		0.9	1
Hybopsis	*rubrifrons*	1		MN	SL	IN	2		0.7	
Lepomis	*auritus*	1		SF		IN	2		28.5	
Nocomis	*leptocephalus*	1	PIO	MN		OM	186		112.2	
Notropis	*hudsonius*	1		MN	SL	IN	1		0.5	
Notropis	*lutipinnis*	1	PIO	MN	SL	IN	162		128.8	
Scartomyzon	*rupiscartes*	1		SU	SL	IN	2		1.3	
Semotilus	*atromaculatus*	1	TOL/PI			GE	1		2.3	

Site Information

Watershed Area (km2)	Log Watershed Area (mi2)	Length Sampled (m)	Length to Avg. Width Ratio
17.1	0.82	150	43.9

APPENDIX A. Site locations, fish lists, and IBI information.

LMH2000-34

Little River
July 28, 2000

Collectors
Lee M. Hartle, Michael D. Merrill, John C. Ruiz, Jonathan D. Ray

Locality
Little River @ W.W. West Memorial bridge crossing (downstream)
utm17(nad83) 255683.92,3713224.70

County Morgan **Lat** 33.530720 **Long** -83.630860

Total # Fish (> 25mm)	Total # Fish (inclu. YOY)	Total # species	Diversity H'
484	583	28	-2.49

Index of Biotic Integrity	Calculation	Metric
# Native species (1)	28	5
# Benthic Invertivore (2)	5	5
# Native Sunfish (3)	3	3
# Native Cyprinid (4)	8	5
# Native Sucker (5)	5	5
# Intolerant (6 a-b)	5	5
Evenness (7)	74.7	5
% Sunfish or Omniv. (8 a-b)	76	5
% Insectivorous Cyprinids (9)	265	5
% Top Carn or Pioneer (10 a-b)	13.0	3
Number / 200m (11)	360.8	3
% Simple Lithophilic (12 a-b)	290	5

IBI Category Excellent **IBI Score** 54

Fish List

Genus	Species	OCO native	pollut tol	spp. cat	breed guild	feed guild	# coll	# rel	wt (gm)	# < 25 mm
Ameiurus	*brunneus*	1				OM	1		0.3	
Ameiurus	*platycephalus*	1				GE	1		0.4	
Cyprinella	*callisema*	1	INT	MN		IN	34		28.2	
Cyprinella	*xaenura*	1	INT	MN		IN	4		6.6	
Erimyzon	*oblongus*	1		SU		IN	1		11.9	
Esox	*americanus*	1				CR	5		38.0	
Etheostoma	*hopkinsi*	1		BI	SL	IN	2		1.0	
Etheostoma	*inscriptum*	1	HWINT	BI	SL	IN	21		13.0	1
Gambusia	*species*	1	TOL			OM	33		26.1	44
Hybopsis	*rubrifrons*	1		MN	SL	IN	51		24.3	
Ictalurus	*punctatus*	1				GE	1		5.4	
Lepomis	*auritus*	1		SF		IN	51		688.7	
Lepomis	*gulosus*	1		SF		CR	5		16.7	16
Lepomis	*macrochirus*	1		SF		IN	20		243.3	
Micropterus	*salmoides*	1				CR	3		160.7	
Minytrema	*melanops*	1	INT	SU	SL	IN	8		455.8	
Moxostoma	*collapsum*	1	INT	SU	SL	IN	3		22.5	
Nocomis	*leptocephalus*	1	PIO	MN		OM	29		82.6	7
Notropis	*cummingsae*	1		MN	SL	IN	4		2.5	
Notropis	*hudsonius*	1		MN	SL	IN	14		26.4	
Notropis	*lutipinnis*	1	PIO	MN	SL	IN	143		172.3	31
Notropis	*petersoni*	1		MN	SL	IN	15		16.9	
Noturus	*gyrinus*	1		BI		IN	1		1.2	
Noturus	*insignis*	1	HWINT	BI		IN	2		4.3	
Percina	*nigrofasciata*	1		BI	SL	IN	26		33.8	
Scartomyzon	*rupiscartes*	1		SU	SL	IN	2		43.8	
Scartomyzon	*sp cf. lachneri*	1	INT	SU	SL	IN	1		134.1	
Aphredoderus	*sayanus*	1				IN	3		12.6	

Site Information

Watershed Area (km2)	Log Watershed Area (mi2)	Length Sampled (m)	Length to Avg. Width Ratio
137.7	1.73	250	49.4

APPENDIX A. Site locations, fish lists, and IBI information.

LMH2000-35

Sandy Creek
August 01, 2000

Collectors
Lee M. Hartle, Michael D. Merrill, John C. Ruiz, Jonathan D. Ray

Locality
Sandy Creek (above small tributary)@ East of Forest Service Road 1234B (off of Scull Shoals Road)
utm17(nad83) 290168.87,3735050.88

County Greene **Lat** 33.734760 **Long** -83.264940

Total # Fish (> 25mm)	Total # Fish (inclu. YOY)	Total # species	Diversity H'
418	487.1	11	-1.55

Index of Biotic Integrity

	Calculation	Metric
# Native species (1)	11	3
# Benthic Invertivore (2)	2	3
# Native Sunfish (3)	1	1
# Native Cyprinid (4)	3	3
# Native Sucker (5)	2	5
# Intolerant (6 a-b)	1	1
Evenness (7)	64.6	3
% Sunfish or Omniv. (8 a-b)	93	3
% Insectivorous Cyprinids (9)	224	3
% Top Carn or Pioneer (10 a-b)	273.0	3
Number / 200m (11)	502.7	3
% Simple Lithophilic (12 a-b)	301	3

IBI Category	Fair	IBI Score	34

Fish List

Genus	Species	OCO native	pollut tol	spp. cat	breed guild	feed guild	# coll	# rel	wt (gm)	# < 25 mm
Erimyzon	*oblongus*	1		SU		IN	8		16.1	
Esox	*americanus*	1				CR	3		18.3	
Etheostoma	*hopkinsi*	1		BI	SL	IN	42		15.6	6
Etheostoma	*inscriptum*	1	HWINT	BI	SL	IN	32		10.6	
Gambusia	*species*	1	TOL			OM	41		25.4	62
Hybopsis	*rubrifrons*	1		MN	SL	IN	3		5.8	
Lepomis	*auritus*	1		SF		IN	12		31.8	
Nocomis	*leptocephalus*	1	PIO	MN		OM	52		142.9	1
Notropis	*lutipinnis*	1	PIO	MN	SL	IN	221		226.8	0.1
Scartomyzon	*rupiscartes*	1		SU	SL	IN	3		2.8	
Aphredoderus	*sayanus*	1				IN	1		1.6	

Site Information

Watershed Area (km2)	Log Watershed Area (mi2)	Length Sampled (m)	Length to Avg. Width Ratio
25.2	0.99	150	29.0

APPENDIX A. Site locations, fish lists, and IBI information.

LMH2000-36

Harris Creek
August 01, 2000

Collectors
Lee M. Hartle, Michael D. Merrill, John C. Ruiz, Jonathan D. Ray

Locality
Harris Creek @ SR15 bridge crossing (upstream)
utm17(nad83) 289078.32,3730504.34

County Greene **Lat** 33.693570 **Long** -83.275620

Total # Fish (> 25mm)	Total # Fish (inclu. YOY)	Total # species	Diversity H'
588	609	10	-1.19

Index of Biotic Integrity

	Calculation	Metric
# Native species (1)	10	3
# Benthic Invertivore (2)	3	5
# Native Sunfish (3)	1	1
# Native Cyprinid (4)	2	1
# Native Sucker (5)	2	5
# Intolerant (6 a-b)	1	1
Evenness (7)	51.7	1
% Sunfish or Omniv. (8 a-b)	193	1
% Insectivorous Cyprinids (9)	304	3
% Top Carn or Pioneer (10 a-b)	548.0	1
Number / 200m (11)	537.0	3
% Simple Lithophilic (12 a-b)	329	3

IBI Category Poor **IBI Score** 28

Fish List

Genus	Species	OCO native	pollut tol	spp. cat	breed guild	feed guild	# coll	# rel	wt (gm)	# < 25 mm
Erimyzon	*oblongus*	1		SU		IN	1		1.4	
Esox	*americanus*	1				CR	1		9.8	
Etheostoma	*hopkinsi*	1		BI	SL	IN	20		8.5	13
Etheostoma	*inscriptum*	1	HWINT	BI	SL	IN	4		2.3	
Lepomis	*auritus*	1		SF		IN	12		0.0	
Nocomis	*leptocephalus*	1	PIO	MN		OM	193		343.5	
Notropis	*lutipinnis*	1	PIO	MN	SL	IN	304		271.4	
Noturus	*gyrinus*	1		BI		IN	1		4.4	
Scartomyzon	*rupiscartes*	1		SU	SL	IN	1		0.4	
Semotilus	*atromaculatus*	1	TOL/PI			GE	51		56.4	8

Site Information

Watershed Area (km2)	Log Watershed Area (mi2)	Length Sampled (m)	Length to Avg. Width Ratio
16.6	0.81	200	66.1

APPENDIX A. Site locations, fish lists, and IBI information.

LMH2000-37

Beaverdam Creek
August 02, 2000

Collectors
Lee M. Hartle, Michael D. Merrill, John C. Ruiz, Jonathan D. Ray

Locality
Beaverdam Creek @ Old Sparta Road bridge crossing; (downstream)
utm17(nad83) 299918.90,3711251.84

County Greene **Lat** 33.522140 **Long** -83.154410

Total # Fish (> 25mm)	Total # Fish (inclu. YOY)	Total # species	Diversity H'
217	219	19	-2.06

Index of Biotic Integrity

	Calculation	Metric
# Native species (1)	18	5
# Benthic Invertivore (2)	3	5
# Native Sunfish (3)	3	3
# Native Cyprinid (4)	4	3
# Native Sucker (5)	1	1
# Intolerant (6 a-b)	0	1
Evenness (7)	70.1	5
% Sunfish or Omniv. (8 a-b)	117	1
% Insectivorous Cyprinids (9)	42	1
% Top Carn or Pioneer (10 a-b)	11.0	5
Number / 200m (11)	213.0	1
% Simple Lithophilic (12 a-b)	51	1

IBI Category	Poor	IBI Score	32

Fish List

Genus	Species	OCO native	pollut tol	spp. cat	breed guild	feed guild	# coll	# rel	wt (gm)	# < 25 mm
Ameiurus	*brunneus*	1				OM	3		38.8	
Ameiurus	*natalis*	1	TOL			GE	1		13.8	
Esox	*niger*	1				CR	3		10.0	
Etheostoma	*hopkinsi*	1		BI	SL	IN	1		1.2	
Hybopsis	*rubrifrons*	1		MN	SL	IN	1		2.7	
Lepisosteus	*osseus*	1	TOL			CR		1	0.0	
Lepomis	*auritus*	1		SF		IN	42		293.6	
Lepomis	*cyanellus*	0	TOL			IN	1		9.4	
Lepomis	*gulosus*	1		SF		CR	5		98.1	
Lepomis	*macrochirus*	1		SF		IN	70		402.1	
Micropterus	*salmoides*	1				CR	2		13.0	
Nocomis	*leptocephalus*	1	PIO	MN		OM	30		89.0	2
Notropis	*hudsonius*	1		MN	SL	IN	13		54.6	
Notropis	*lutipinnis*	1	PIO	MN	SL	IN	28		37.2	
Noturus	*gyrinus*	1		BI		IN	5		19.8	
Percina	*nigrofasciata*	1		BI	SL	IN	4		17.3	
Scartomyzon	*rupiscartes*	1		SU	SL	IN	4		78.5	
Semotilus	*atromaculatus*	1	TOL/PI			GE	1		3.8	
Aphredoderus	*sayanus*	1				IN	2		8.8	

Site Information

Watershed Area (km2)	Log Watershed Area (mi2)	Length Sampled (m)	Length to Avg. Width Ratio
56.4	1.34	200	61.5

APPENDIX A. Site locations, fish lists, and IBI information.

LMH2000-38

Richland Creek
August 02, 2000

Collectors
Lee M. Hartle, Michael D. Merrill, John C. Ruiz, Jonathan D. Ray

Locality
Richland Creek @ SR 278/12 bridge crossing (upstream)
utm17(nad83) 294893.59,3717453.76

County Greene **Lat** 33.577080 **Long** -83.209910

Total # Fish (> 25mm)	Total # Fish (inclu. YOY)	Total # species	Diversity H'
306	343	14	-1.38

Index of Biotic Integrity	Calculation	Metric
# Native species (1)	14	3
# Benthic Invertivore (2)	2	3
# Native Sunfish (3)	2	1
# Native Cyprinid (4)	3	1
# Native Sucker (5)	1	1
# Intolerant (6 a-b)	2	3
Evenness (7)	52.5	1
% Sunfish or Omniv. (8 a-b)	35	5
% Insectivorous Cyprinids (9)	19	1
% Top Carn or Pioneer (10 a-b)	8.0	3
Number / 200m (11)	285.0	1
% Simple Lithophilic (12 a-b)	27	1
IBI Category	Very Poor	
IBI Score	24	

Fish List

	Genus	Species	OCO native	pollut tol	spp. cat	breed guild	feed guild	# coll	# rel	wt (gm)	# < 25 mm
1	*Ameiurus*	*brunneus*	1				OM	1		13.9	
	Cyprinella	*xaenura*	1	INT	MN		IN	1		0.1	
	Erimyzon	*oblongus*	1		SU		IN	5		13.3	
	Etheostoma	*hopkinsi*	1		BI	SL	IN	9		2.7	16
5	*Gambusia*	*species*	1	TOL			OM	18		19.2	16
	Lepomis	*auritus*	1		SF		IN	202		577.7	
	Lepomis	*gulosus*	1		SF		CR			0.8	3
	Lepomis	*macrochirus*	1		SF		IN	1		18.3	
	Micropterus	*coosae*	1	HWINT			CR	6		113.3	
10	*Micropterus*	*salmoides*	1				CR	2		1.4	
	Nocomis	*leptocephalus*	1	PIO	MN		OM	13		57.8	2
	Notemigonus	*crysoleucas*	1	TOL			OM	3		24.8	
	Notropis	*hudsonius*	1		MN	SL	IN	18		10.3	
	Noturus	*gyrinus*	1		BI		IN	6		23.8	
15	*Aphredoderus*	*sayanus*	1				IN	21		40.2	

Site Information	Watershed Area (km2)	Log Watershed Area (mi2)	Length Sampled (m)	Length to Avg. Width Ratio
	50.0	1.29	200	38.6

APPENDIX A. Site locations, fish lists, and IBI information.

LMH2000-39

Barber Creek
August 03, 2000

Collectors
Lee M. Hartle, Michael D. Merrill, John C. Ruiz, Jonathan D. Ray

Locality
Barber Creek @ Robertson Creek Road bridge crossing (upstream)
utm17(nad83) 259154.56,3758918.75

County Barrow **Lat** 33.943210 **Long** -83.605950

Total # Fish (> 25mm)	Total # Fish (inclu. YOY)	Total # species	Diversity H'
161	218	13	-1.69

Index of Biotic Integrity

	Calculation	Metric
# Native species (1)	13	3
# Benthic Invertivore (2)	2	3
# Native Sunfish (3)	2	3
# Native Cyprinid (4)	3	3
# Native Sucker (5)	1	3
# Intolerant (6 a-b)	1	1
Evenness (7)	66.0	3
% Sunfish or Omniv. (8 a-b)	49	1
% Insectivorous Cyprinids (9)	31	1
% Top Carn or Pioneer (10 a-b)	70.0	3
Number / 200m (11)	213.3	1
% Simple Lithophilic (12 a-b)	43	3

IBI Category Poor **IBI Score** 28

Fish List

Genus	Species	OCO native	pollut tol	spp. cat	breed guild	feed guild	# coll	# rel	wt (gm)	# < 25 mm
Ameiurus	*brunneus*	1				OM	2		34.3	
Ameiurus	*nebulosus*	1	TOL			OM	1		56.4	
Ameiurus	*platycephalus*	1				GE	3		103.2	
Etheostoma	*inscriptum*	1	HWINT	BI	SL	IN	11		20.4	
Lepomis	*auritus*	1		SF		IN	60		794.9	11
Lepomis	*gulosus*	1		SF		CR	1		3.9	
Lepomis	*macrochirus*	1		SF		IN			272.6	46
Micropterus	*salmoides*	1				CR	1		4.7	
Nocomis	*leptocephalus*	1	PIO	MN		OM	46		192.1	
Notropis	*hudsonius*	1		MN	SL	IN	7		17.4	
Notropis	*lutipinnis*	1	PIO	MN	SL	IN	24		19.5	
Noturus	*gyrinus*	1		BI		IN	2		16.1	
Pomoxis	*nigromaculatus*	1				CR	2		24.9	
Scartomyzon	*rupiscartes*	1		SU	SL	IN	1		71.9	

Site Information

Watershed Area (km2)	Log Watershed Area (mi2)	Length Sampled (m)	Length to Avg. Width Ratio
23.0	0.95	150	25.2

APPENDIX A. Site locations, fish lists, and IBI information.

LMH2000-40

Fishing Creek
August 08, 2000

Collectors
Lee M. Hartle, John C. Ruiz, Jonathan D. Ray, Tim N. Burgess, (habitat) Michael D. Merrill

Locality
Fishing Creek @ Conger Road bridge (bridge out) crossing (upstream)
utm17(nad83) 294445.62,3729931.98

County Greene **Lat** 33.642500 **Long** -83.226740

Total # Fish (> 25mm)	Total # Fish (inclu. YOY)	Total # species	Diversity H’
636	1,105	13	-1.75

Index of Biotic Integrity

	Calculation	Metric
# Native species (1)	13	3
# Benthic Invertivore (2)	3	5
# Native Sunfish (3)	2	1
# Native Cyprinid (4)	3	1
# Native Sucker (5)	2	3
# Intolerant (6 a-b)	0	1
Evenness (7)	68.3	3
% Sunfish or Omniv. (8 a-b)	52	5
% Insectivorous Cyprinids (9)	352	5
% Top Carn or Pioneer (10 a-b)	1.0	1
Number / 200m (11)	632.0	3
% Simple Lithophilic (12 a-b)	409	5

IBI Category Fair **IBI Score** 36

Fish List

Genus	Species	OCO native	pollut tol	spp. cat	breed guild	feed guild	# coll	# rel	wt (gm)	# < 25 mm
Ameiurus	*natalis*	1	TOL			GE	2		1.2	
Erimyzon	*oblongus*	1		SU		IN	19		12.6	1
Esox	*americanus*	1				CR	1		7.2	
Etheostoma	*hopkinsi*	1		BI	SL	IN	12		2.7	8
Etheostoma	*inscriptum*	1	HWINT	BI	SL	IN	3		0.4	
Etheostoma	*olmstedi*	1		BI		IN	9		3.3	
Gambusia	*species*	1	TOL			OM	2		1.6	9
Hybopsis	*rubrifrons*	1		MN	SL	IN	204		79.1	40
Lepomis	*auritus*	1		SF		IN	49		269.7	40
Lepomis	*macrochirus*	1		SF		IN	3		28.1	
Nocomis	*leptocephalus*	1	PIO	MN		OM	142		93.4	15
Notropis	*lutipinnis*	1	PIO	MN	SL	IN	148		141.2	356
Scartomyzon	*rupiscartes*	1		SU	SL	IN	42		87.1	

Site Information

Watershed Area (km2)	Log Watershed Area (mi2)	Length Sampled (m)	Length to Avg. Width Ratio
64.9	1.40	200	22.1

APPENDIX A. Site locations, fish lists, and IBI information.

LMH2000-41

Town Creek
August 08, 2000

Collectors
Lee M. Hartle, John C. Ruiz, Jonathan D. Ray, Tim N. Burgess, (habitat) Michael D. Merrill

Locality
Town Creek @ SR15 bridge crossing (upstream)
utm17(nad83) 293487.86,3724742.35

County Greene **Lat** 33.642500 **Long** -83.226740

Total # Fish (> 25mm)	Total # Fish (inclu. YOY)	Total # species	Diversity H’
104	106	7	-1.19

Index of Biotic Integrity	Calculation	Metric
# Native species (1)	7	1
# Benthic Invertivore (2)	1	1
# Native Sunfish (3)	2	3
# Native Cyprinid (4)	2	1
# Native Sucker (5)	0	1
# Intolerant (6 a-b)	0	1
Evenness (7)	61.1	3
% Sunfish or Omniv. (8 a-b)	36	1
% Insectivorous Cyprinids (9)	54	3
% Top Carn or Pioneer (10 a-b)	3.0	3
Number / 200m (11)	104.0	1
% Simple Lithophilic (12 a-b)	57	5

IBI Category Very Poor **IBI Score** 24

Fish List

Genus	Species	OCO native	pollut tol	spp. cat	breed guild	feed guild	# coll	# rel	wt (gm)	# < 25 mm
Esox	*americanus*	1				CR	3		14.7	
Etheostoma	*hopkinsi*	1		BI	SL	IN	3		3.7	
Lepomis	*auritus*	1		SF		IN	4		14.1	
Lepomis	*macrochirus*	1		SF		IN	2		18.9	
Nocomis	*leptocephalus*	1	PIO	MN		OM	36		89.2	2
Notropis	*lutipinnis*	1	PIO	MN	SL	IN	54		55.2	
Aphredoderus	*sayanus*	1				IN	2		4.8	

Site Information	Watershed Area (km2)	Log Watershed Area (mi2)	Length Sampled (m)	Length to Avg. Width Ratio
	30.6	1.07	200	88.1

APPENDIX A. Site locations, fish lists, and IBI information.

LMH2000-42

Sandy Creek
August 08, 2000

Collectors
Lee M. Hartle, John C. Ruiz, Jonathan D. Ray, R. Dale McPherson, (habitat) Michael D. Merrill

Locality
Sandy Creek @ Sandy Creek Nature Center; upstream of old 441S bridge (below pond outlet)
utm17(nad83) 280139.89,3762567.35

County Clarke **Lat** 33.642500 **Long** -83.226740

Total # Fish (> 25mm)	Total # Fish (inclu. YOY)	Total # species	Diversity H'
301	351.2	23	-2.36

Index of Biotic Integrity	Calculation	Metric
# Native species (1)	23	5
# Benthic Invertivore (2)	4	5
# Native Sunfish (3)	3	3
# Native Cyprinid (4)	7	5
# Native Sucker (5)	4	5
# Intolerant (6 a-b)	5	5
Evenness (7)	75.1	5
% Sunfish or Omniv. (8 a-b)	53	5
% Insectivorous Cyprinids (9)	118	3
% Top Carn or Pioneer (10 a-b)	5.0	1
Number / 200m (11)	240.0	1
% Simple Lithophilic (12 a-b)	100	3

IBI Category Good **IBI Score** 46

Fish List

Genus	Species	OCO native	pollut tol	spp. cat	breed guild	feed guild	# coll	# rel	wt (gm)	# < 25 mm
Ameiurus	*brunneus*	1				OM	3		33.0	0.1
Ameiurus	*platycephalus*	1				GE	1		53.6	
Cyprinella	*callisema*	1	INT	MN		IN	74		79.6	8
Cyprinella	*sp.*	1		MN					0.0	0.1
Cyprinella	*xaenura*	1	INT	MN		IN	11		20.7	9
Esox	*niger*	1				CR	1		5.9	
Etheostoma	*hopkinsi*	1		BI	SL	IN	3		1.4	
Etheostoma	*inscriptum*	1	HWINT	BI	SL	IN	8		2.2	
Gambusia	*species*	1	TOL			OM	1		1.4	9
Hybopsis	*rubrifrons*	1		MN	SL	IN	22		11.7	
Hypentelium	*nigricans*	1	INT	SU	SL	IN	8		91.0	
Lepomis	*auritus*	1		SF		IN	39		715.2	
Lepomis	*gulosus*	1		SF		CR	3		45.2	
Lepomis	*macrochirus*	1		SF		IN	11		113.4	
Lepomis	*sp.*	1		SF					0.0	14
Micropterus	*coosae*	1	HWINT			CR	1		3.5	
Minytrema	*melanops*	1	INT	SU	SL	IN	11		7.2	
Moxostoma	*collapsum*	1	INT	SU	SL	IN	3		162.5	
Nocomis	*leptocephalus*	1	PIO	MN		OM	55		28.6	6
Notropis	*hudsonius*	1		MN	SL	IN	8		10.1	1
Notropis	*lutipinnis*	1	PIO	MN	SL	IN	2		0.7	
Notropis	*petersoni*	1		MN	SL	IN	1		0.4	
Noturus	*insignis*	1	HWINT	BI		IN	1		3.0	
Percina	*nigrofasciata*	1		BI	SL	IN	33		19.3	3
Scartomyzon	*rupiscartes*	1		SU	SL	IN	1		37.1	

Site Information	Watershed Area (km2)	Log Watershed Area (mi2)	Length Sampled (m)	Length to Avg. Width Ratio
	167.0	1.81	250	23.9

APPENDIX A. Site locations, fish lists, and IBI information.

LMH2000-43

Big Creek
July 31, 2000

Collectors
Lee M. Hartle, John C. Ruiz, Jonathan D. Ray

Locality
Big Creek @ county road 86 (?) (upstream); just before confluence with Oconee River
utm17(nad83) 288847.65,3740991.23

County Oglethorpe **Lat** 33.642500 **Long** -83.226740

Total # Fish (> 25mm)	Total # Fish (inclu. YOY)	Total # species	Diversity H’
387	425	14	-1.67

Index of Biotic Integrity

	Calculation	Metric
# Native species (1)	14	3
# Benthic Invertivore (2)	2	3
# Native Sunfish (3)	1	1
# Native Cyprinid (4)	4	3
# Native Sucker (5)	3	5
# Intolerant (6 a-b)	4	5
Evenness (7)	63.1	3
% Sunfish or Omniv. (8 a-b)	10	5
% Insectivorous Cyprinids (9)	243	5
% Top Carn or Pioneer (10 a-b)	3.0	1
Number / 200m (11)	297.6	1
% Simple Lithophilic (12 a-b)	111	1

IBI Category Fair **IBI Score** 36

Fish List

Genus	Species	OCO native	pollut tol	spp. cat	breed guild	feed guild	# coll	# rel	wt (gm)	# < 25 mm
Cyprinella	*callisema*	1	INT	MN		IN	163		48.6	
Cyprinella	*xaenura*	1	INT	MN		IN	2		1.7	
Esox	*americanus*	1				CR	2		10.8	
Gambusia	*species*	1	TOL			OM	15		8.4	26
Hypentelium	*nigricans*	1	INT	SU	SL	IN	1		2.5	
Lepomis	*auritus*	1		SF		IN	10		24.8	4
Micropterus	*salmoides*	1				CR	1		2.5	
Moxostoma	*collapsum*	1	INT	SU	SL	IN	1		2.4	
Nocomis	*leptocephalus*	1	PIO	MN		OM	74		188.9	1
Notropis	*lutipinnis*	1	PIO	MN	SL	IN	78		41.7	5
Noturus	*insignis*	1	HWINT	BI		IN	8		27.8	2
Percina	*nigrofasciata*	1		BI	SL	IN	24		30.1	
Scartomyzon	*rupiscartes*	1		SU	SL	IN	7		36.9	
Aphredoderus	*sayanus*	1				IN	1		0.8	

Site Information

Watershed Area (km2)	Log Watershed Area (mi2)	Length Sampled (m)	Length to Avg. Width Ratio
152.6	1.77	250	25.0

APPENDIX A. Site locations, fish lists, and IBI information.

USGS2000-02

Middle Oconee River
June 15, 2000

Collectors
Mary C. Freeman, Richard S. Weyers, John Seginak, Paula A. Marcinek, E. Shane Hawthorne, Peter Esselman, Lee M. Hartle, MiD Merrill, John C. Ruiz, Jonathan D. Ray

Locality
Middle Oconee @ Ben Burton Park; downstream of Athens-Clarke water intake; sampled under 10 Loop & Mitchell Br Rd;
utm17(nad83) 274747 32 3759582 60

County Clarke **Lat** 33.95265 **Long** -83.43755

Total # Fish (> 25mm)	Total # Fish (inclu. YOY)	Total # species	Diversity H'
682	793	16	-2.16

Index of Biotic Integrity	Calculation	Metric
# Native species (1)	15	3
# Benthic Invertivore (2)	3	3
# Native Sunfish (3)	2	1
# Native Cyprinid (4)	6	5
# Native Sucker (5)	2	3
# Intolerant (6 a-b)	3	3
Evenness (7)	77.7	5
% Sunfish or Omniv. (8 a-b)	70	5
% Insectivorous Cyprinids (9)	318	3
% Top Carn or Pioneer (10 a-b)	0.0	1
Number / 200m (11)	272.0	1
% Simple Lithophilic (12 a-b)	232	3

IBI Category	Fair	IBI Score	36

Fish List

	Genus	Species	OCO native	pollut tol	spp. cat	breed guild	feed guild	# coll	# rel	wt (gm)	# < 25 mm
1	*Ameiurus*	*brunneus*	1				OM	35		663.8	5
	Cyprinella	*callisema*	1	INT	MN		IN	225		378.1	2
	Cyprinella	*xaenura*	1	INT	MN		IN	46		113.9	0
	Etheostoma	*inscriptum*	1	HWINT	BI	SL	IN	88		130.2	7
5	*Hybopsis*	*rubrifrons*	1		MN	SL	IN	21		53.1	0
	Ictalurus	*punctatus*	1				GE	2		8.8	3
	Lepomis	*auritus*	1		SF		IN	66		675.9	0
	Lepomis	*cyanellus*	0	TOL			IN	1		32.0	0
	Lepomis	*macrochirus*	1		SF		IN	4		60.1	0
10	*Lepomis*	*sp*	1		SF			0		0.0	82
	Moxostoma	*collapsum*	1	INT	SU	SL	IN	55		304.2	0
	Nocomis	*leptocephalus*	1	PIO	MN		OM	59		256.8	8
	Notropis	*hudsonius*	1		MN	SL	IN	23		93.5	0
	Notropis	*lutipinnis*	1	PIO	MN	SL	IN	3		3.2	0
15	*Noturus*	*insignis*	1	HWINT	BI		IN	11		38.0	0
	Percina	*nigrofasciata*	1		BI	SL	IN	42		130.0	4
	Scartomyzon	*rupiscartes*	1		SU	SL	IN	1		22.3	0

Site Information	Watershed Area (km2)	Log Watershed Area (mi2)	Length Sampled (m)	Length to Avg. Width Ratio
	1010.7	2.59	500	21.6

USGS2000-03

Cedar Creek
June 13, 2000

Collectors
Mary C. Freeman, Richard S. Weyers, John Seginak, Paula A. Marcinek, E. Shane Hawthorne

Locality
Cedar Creek below Winder Water Supply Reservoir @ N. Candler Rd (downstream); utm17(nad83) 247254.20,3766938.98

County Barrow **Lat** 34.01267 **Long** -83.73690

Total # Fish (> 25mm)	Total # Fish (inclu. YOY)	Total # species	Diversity H'
210	218	11	-1.62

Index of Biotic Integrity	Calculation	Metric
# Native species (1)	11	3
# Benthic Invertivore (2)	1	1
# Native Sunfish (3)	3	5
# Native Cyprinid (4)	3	3
# Native Sucker (5)	1	3
# Intolerant (6 a-b)	1	1
Evenness (7)	67.5	3
% Sunfish or Omniv. (8 a-b)	101	1
% Insectivorous Cyprinids (9)	23	1
% Top Carn or Pioneer (10 a-b)	116.0	3
Number / 200m (11)	250.6	1
% Simple Lithophilic (12 a-b)	35	3

IBI Category Poor **IBI Score** 28

Fish List

Genus	Species	OCO native	pollut tol	spp. cat	breed guild	feed guild	# coll	# rel	wt (gm)	# < 25 mm
Ameiurus	*nebulosus*	1	TOL			OM	1		0.6	0
Etheostoma	*inscriptum*	1	HWINT	BI	SL	IN	8		15.9	0
Gambusia	*holbrooki*	1	TOL			OM	3		2.2	7
Hybopsis	*rubrifrons*	1		MN	SL	IN	1		6.9	0
Lepomis	*auritus*	1		SF		IN	17	35	751.6	0
Lepomis	*gulosus*	1		SF		CR	8		77.9	0
Lepomis	*macrochirus*	1		SF		IN	14		86.8	0
Nocomis	*leptocephalus*	1	PIO	MN		OM	94		177.2	1
Notemigonus	*crysoleucas*	1	TOL			OM	3		12.3	0
Notropis	*lutipinnis*	1	PIO	MN	SL	IN	22		9.5	0
Scartomyzon	*rupiscartes*	1		SU	SL	IN	4		154.5	0

Site Information	Watershed Area (km2)	Log Watershed Area (mi2)	Length Sampled (m)	Length to Avg. Width Ratio
	15.7	0.78	162	38.6

APPENDIX A. Site locations, fish lists, and IBI information.

USGS2000-06

Curry Creek
June 20, 2000

Collectors
Mary C. Freeman, Richard S. Weyers, John Seginak, Paula A. Marcinek, Peter Esselman

Locality
Curry Creek below Jefferson Water Supply Reservoir upstream of SR 82/15; utm17(nad83) 263152.60,3778973.71

County Jackson **Lat** 34.12481 **Long** -83.56817

Total # Fish (> 25mm)	Total # Fish (inclu. YOY)	Total # species	Diversity H'
93	97	15	-1.90

Index of Biotic Integrity

	Calculation	Metric
# Native species (1)	15	5
# Benthic Invertivore (2)	3	3
# Native Sunfish (3)	2	3
# Native Cyprinid (4)	3	3
# Native Sucker (5)	3	5
# Intolerant (6 a-b)	2	3
Evenness (7)	70.3	1
% Sunfish or Omniv. (8 a-b)	6	5
% Insectivorous Cyprinids (9)	4	1
% Top Carn or Pioneer (10 a-b)	1.0	1
Number / 200m (11)	125.0	1
% Simple Lithophilic (12 a-b)	47	3

IBI Category Fair **IBI Score** 34

Fish List

Genus	Species	OCO native	pollut tol	spp. cat	breed guild	feed guild	# coll	# rel	wt (gm)	# < 25 mm
Ameiurus	*brunneus*	1				OM	1		8.6	1
Erimyzon	*oblongus*	1		SU		IN	1		175.5	0
Etheostoma	*hopkinsi*	1		BI	SL	IN	2		3.3	0
Etheostoma	*inscriptum*	1	HWINT	BI	SL	IN	28		33.3	0
Gambusia	*holbrooki*	1	TOL			OM	1		1.5	0
Hybopsis	*rubrifrons*	1		MN	SL	IN	3		0.7	1
Hypentelium	*nigricans*	1					1		34.2	0
Lepomis	*auritus*	1		SF		IN	16	17	540.0	2
Lepomis	*macrochirus*	1		SF		IN	3	1	88.1	0
Micropterus	*salmoides*	1				CR	1		85.0	0
Minytrema	*melanops*	1	INT	SU	SL	IN	0	1	60.0	0
Nocomis	*leptocephalus*	1	PIO	MN		OM	4		30.3	0
Notropis	*lutipinnis*	1	PIO	MN	SL	IN	1		0.2	0
Percina	*nigrofasciata*	1		BI	SL	IN	5		10.9	0
Scartomyzon	*rupiscartes*	1		SU	SL	IN	7		245.8	0

Site Information

Watershed Area (km2)	Log Watershed Area (mi2)	Length Sampled (m)	Length to Avg. Width Ratio
27.9	1.03	144	35.1

APPENDIX A. Site locations, fish lists, and IBI information.

USGS2000-13

Little River
July 10, 2000

Collectors
Richard S. Weyers, John Seginak, Peter Esselman, E. Shane Hawthorne, Paula A. Marcinek, Lee M. Hartle, Michael D. Merrill, John C. Ruiz, Jonathan D. Ray

Locality
Little River below Eatonton Water Intake @ end of service road off of Happey Royal Dr.(??)
utm17(nad83) 272947.59,3689795.94

County Putnam **Lat** 33.32340 **Long** -83.43920

Total # Fish (> 25mm)	Total # Fish (inclu. YOY)	Total # species	Diversity H’
1,158	1,160	25	-2.46

Index of Biotic Integrity

	Calculation	Metric
# Native species (1)	23	5
# Benthic Invertivore (2)	3	3
# Native Sunfish (3)	3	3
# Native Cyprinid (4)	5	3
# Native Sucker (5)	4	5
# Intolerant (6 a-b)	5	5
Evenness (7)	76.5	5
% Sunfish or Omniv. (8 a-b)	218	5
% Insectivorous Cyprinids (9)	278	1
% Top Carn or Pioneer (10 a-b)	89.0	5
Number / 200m (11)	455.6	3
% Simple Lithophilic (12 a-b)	374	3

IBI Category Good **IBI Score** 46

Fish List

Genus	Species	OCO native	pollut tol	spp. cat	breed guild	feed guild	# coll	# rel	wt (gm)	# < 25 mm
Ameiurus	*brunneus*	1				OM	65		3870.	0
Ameiurus	*catus*	1				OM	1		86.9	0
Cyprinella	*callisema*	1	INT	MN		IN	54		92.1	0
Cyprinella	*xaenura*	1	INT	MN		IN	77		199.2	0
Cyprinus	*carpio*	0	TOL			OM	1	2	0.0	0
Dorosoma	*cepedianum*	1				OM	10		1003.	0
Etheostoma	*inscriptum*	1	HWINT	BI	SL	IN	116		193.0	0
Ictalurus	*punctatus*	1				GE	7		373.0	0
Lepisosteus	*osseus*	1	TOL			CR	1	4	1500.	0
Lepomis	*auritus*	1		SF		IN	187		1925.	0
Lepomis	*macrochirus*	1		SF		IN	28		438.0	0
Lepomis	*microlophus*	1		SF		IN	3		262.0	0
Micropterus	*coosae*	1	HWINT			CR	73		1804.	0
Micropterus	*salmoides*	1				CR	1		400.0	0
Minytrema	*melanops*	1	INT	SU	SL	IN	14		740.8	0
Moxostoma	*collapsum*	1	INT	SU	SL	IN	4	1	1160.	0
Nocomis	*leptocephalus*	1	PIO	MN		OM	252		488.0	1
Notropis	*hudsonius*	1		MN	SL	IN	131		353.9	0
Notropis	*lutipinnis*	1	PIO	MN	SL	IN	16		21.5	0
Noturus	*insignis*	1	HWINT	BI		IN	3		44.5	0
Percina	*nigrofasciata*	1		BI	SL	IN	42		197.0	0
Pomoxis	*nigromaculatus*	1				CR	4		74.6	0
Scartomyzon	*rupiscartes*	1		SU	SL	IN	13		448.9	0
Scartomyzon	*sp cf. lachneri*	1	INT	SU	SL	IN	38		3846.	0
Perca	*flavescens*	0				CR	10		120.9	1

Site Information

Watershed Area (km2)	Log Watershed Area (mi2)	Length Sampled (m)	Length to Avg. Width Ratio
599.8	2.36	500	?

APPENDIX A. Site locations, fish lists, and IBI information.

USGS2000-16

Mulberry River
July 10, 2000

Collectors
Richard S. Weyers, John Seginak, Peter Esselman, E. Shane Hawthorne, Paula A. Marcinek, Lee M. Hartle, Michael D. Merrill, John C. Ruiz, Jonathan D. Ray

Locality
Mulberry River below Winder Water Supply Intake (dam) @ access road off of SR 52
utm17(nad83) 249946.51,3770527.00

County Barrow/Jackson **Lat** 34.04564 **Long** -83.70881

Total # Fish (> 25mm)	Total # Fish (inclu. YOY)	Total # species	Diversity H’
834	836	23	-2.26

Index of Biotic Integrity	Calculation	Metric
# Native species (1)	22	5
# Benthic Invertivore (2)	3	3
# Native Sunfish (3)	4	5
# Native Cyprinid (4)	6	5
# Native Sucker (5)	3	5
# Intolerant (6 a-b)	4	5
Evenness (7)	72.0	5
% Sunfish or Omniv. (8 a-b)	130	5
% Insectivorous Cyprinids (9)	318	3
% Top Carn or Pioneer (10 a-b)	15.0	1
Number / 200m (11)	424.6	3
% Simple Lithophilic (12 a-b)	323	3

IBI Category	Good	IBI Score	48

Fish List

	Genus	Species	OCO native	pollut tol	spp. cat	breed guild	feed guild	# coll	# rel	wt (gm)	# < 25 mm
1	*Ameiurus*	*brunneus*	1				OM	16		490.9	0
	Cyprinella	*callisema*	1	INT	MN		IN	209		197.0	0
	Cyprinella	*xaenura*	1	INT	MN		IN	59		165.9	0
	Esox	*americanus*	1				CR	2		5.7	0
5	*Esox*	*niger*	1				CR	2		97.1	0
	Etheostoma	*inscriptum*	1	HWINT	BI	SL	IN	188		277.8	1
	Gambusia	*holbrooki*	1	TOL			OM	3		2.4	0
	Hybopsis	*rubrifrons*	1		MN	SL	IN	6		1.8	0
	Hypentelium	*nigricans*	1	INT	SU	SL	IN	16		403.7	0
10	*Ictalurus*	*punctatus*	1				GE	1		0.2	0
	Lepomis	*auritus*	1		SF		IN	93		820.0	0
	Lepomis	*cyanellus*	0	TOL			IN	1		19.4	0
	Lepomis	*gulosus*	1		SF		CR	1		32.8	0
	Lepomis	*macrochirus*	1		SF		IN	35		191.3	0
15	*Lepomis*	*microlophus*	1		SF		IN	1		99.0	0
	Micropterus	*salmoides*	1				CR	10		601.2	0
	Moxostoma	*collapsum*	1	INT	SU	SL	IN	3		885.0	0
	Nocomis	*leptocephalus*	1	PIO	MN		OM	70		299.9	1
	Notropis	*hudsonius*	1		MN	SL	IN	43		81.8	0
20	*Notropis*	*lutipinnis*	1	PIO	MN	SL	IN	1		1.1	0
	Noturus	*insignis*	1	HWINT	BI		IN	8		48.4	0
	Percina	*nigrofasciata*	1		BI	SL	IN	31		76.6	0
	Scartomyzon	*rupiscartes*	1		SU	SL	IN	35		966.3	0
25											

Site Information	Watershed Area (km2)	Log Watershed Area (mi2)	Length Sampled (m)	Length to Avg. Width Ratio
	284.3	2.04	391	34.9

USGS2000-17

Hard Labor Creek
July 13, 2000

Collectors
Richard S. Weyers, John Seginak, Peter Esselman, E. Shane Hawthorne, Paula A. Marcinek

Locality
Hard Labor Creek below Madison Water Intake @ end of access road off of Doster Bridge Rd.
utm17(nad83) 267725.09,3723950.59

County Morgan **Lat** 33.63005 **Long** -83.50410

Total # Fish (> 25mm)	Total # Fish (inclu. YOY)	Total # species	Diversity H'
288	290	23	-2.05

Index of Biotic Integrity	Calculation	Metric
# Native species (1)	22	5
# Benthic Invertivore (2)	3	3
# Native Sunfish (3)	3	3
# Native Cyprinid (4)	6	5
# Native Sucker (5)	3	5
# Intolerant (6 a-b)	3	3
Evenness (7)	65.3	3
% Sunfish or Omniv. (8 a-b)	144	1
% Insectivorous Cyprinids (9)	46	1
% Top Carn or Pioneer (10 a-b)	9.0	3
Number / 200m (11)	473.3	3
% Simple Lithophilic (12 a-b)	75	1
IBI Category	Fair	**IBI Score** 36

Fish List

Genus	Species	OCO native	pollut tol	spp. cat	breed guild	feed guild	# coll	# rel	wt (gm)	# < 25 mm
Ameiurus	*brunneus*	1				OM	3		23.6	0
Ameiurus	*catus*	1				OM	1		22.1	0
Cyprinella	*callisema*	1	INT	MN		IN	7		6.1	0
Esox	*americanus*	1				CR	3		20.5	0
Etheostoma	*olmstedi*	1		BI		IN	7		5.7	0
Gambusia	*holbrooki*	1	TOL			OM	3		1.9	0
Hybopsis	*rubrifrons*	1		MN	SL	IN	1		2.7	0
Lepomis	*auritus*	1		SF		IN	132		874.3	0
Lepomis	*cyanellus*	0	TOL			IN	1		47.6	0
Lepomis	*gulosus*	1		SF		CR	1		14.2	0
Lepomis	*macrochirus*	1		SF		IN	11		140.0	0
Micropterus	*coosae*	1	HWINT			CR	4		45.0	0
Micropterus	*salmoides*	1				CR	1		330.0	0
Moxostoma	*collapsum*	1	INT	SU	SL	IN	5		40.8	0
Nocomis	*leptocephalus*	1	PIO	MN		OM	36		30.9	0
Notropis	*hudsonius*	1		MN	SL	IN	21		44.2	0
Notropis	*longirostris*	1		MN	SL	IN	2		0.9	0
Notropis	*lutipinnis*	1	PIO	MN	SL	IN	15		7.1	2
Noturus	*insignis*	1	HWINT	BI		IN	2		13.0	0
Percina	*nigrofasciata*	1		BI	SL	IN	23		43.3	0
Scartomyzon	*rupiscartes*	1		SU	SL	IN	3		25.3	0
Scartomyzon	*sp cf. lachneri*	1	INT	SU	SL	IN	5		6.1	0
Aphredoderus	*sayanus*	1				IN	1		6.5	0

Site Information	Watershed Area (km2)	Log Watershed Area (mi2)	Length Sampled (m)	Length to Avg. Width Ratio
	169.5	1.82	120	35.3

APPENDIX A. Site locations, fish lists, and IBI information.

USGS2000-23

Barber Creek
July 31, 2000

Collectors
Richard S. Weyers, John Seginak, Peter Esselman, E. Shane Hawthorne

Locality
Barber Creek below Statham Water Supply Reservoir @ Bethlehem Rd (downstream)
utm17(nad83) 258627.47,3759505.13

County Barrow **Lat** 33.94837 **Long** -83.61181

Total # Fish (> 25mm)	Total # Fish (inclu. YOY)	Total # species	Diversity H’
114	114	5	-1.05

Index of Biotic Integrity

	Calculation	Metric
# Native species (1)	5	1
# Benthic Invertivore (2)	0	1
# Native Sunfish (3)	2	3
# Native Cyprinid (4)	1	1
# Native Sucker (5)	0	1
# Intolerant (6 a-b)	1	1
Evenness (7)	65.5	3
% Sunfish or Omniv. (8 a-b)	14	5
% Insectivorous Cyprinids (9)	0	1
% Top Carn or Pioneer (10 a-b)	13.0	5
Number / 200m (11)	173.8	1
% Simple Lithophilic (12 a-b)	0	1

IBI Category Very Poor **IBI Score** 24

Fish List

Genus	Species	OCO native	pollut tol	spp. cat	breed guild	feed guild	# coll	# rel	wt (gm)	# < 25 mm
Ameiurus	*nebulosus*	1	TOL			OM	1		44.6	0
Lepomis	*auritus*	1		SF		IN	51		342.1	0
Lepomis	*macrochirus*	1		SF		IN	48		272.9	0
Micropterus	*coosae*	1	HWINT			CR	1		5.7	0
Nocomis	*leptocephalus*	1	PIO	MN		OM	13		142.9	0

Site Information

Watershed Area (km2)	Log Watershed Area (mi2)	Length Sampled (m)	Length to Avg. Width Ratio
16.5	0.80	130	35.1

APPENDIX B. LOCAL AND WATERSHED ENVIRONMENTAL VARIABLE DESCRIPTIONS

Listed by Analysis Scale (watershed or local) and Variable Group

Appendix B. Local and watershed variables measured and calculated for the sampled sites.

n	W test[1]	Variable	Trans-form[2]	Scale[3]	Variable Group[4]	Units of Measure	Variable Description
49	n/a	NAME			site	none	stream name
49	n/a	FIELDNUM				none	field number
49	0.2300	IBISCORE			fish metric	score	GA-DNR Index of Biotic Integrity score
49	n/a	IBICATEGOR				category	GA-DNR Index of Biotic Integrity category (Excellent to Very Poor)
49	n/a	IMPAIRED				category	Impairment category (Impaired and Non-impaired)
49	0.2121	RICHNESS				count	number native fish species
49	0.0187	DIVERSITY				none	Shannon-Weiner Diversity Index based on numbers of fish
49	0.0690	ABUND-200				no/200m	number of fish sampled per 200 meters
49	0.0003	LTOWRATIO			effort	none	length of stream sampled divided by average water width when sampled
49	n/a	SIZECLASS		Watershed Variables	size	category	size class based on Q2 doubling (15,50,150, 400, >400)
49	0.0039	WSHEDAREA	L			km2	catchment area
49	0.0847	LINK-ORD	L			count	number of headwater streams (1st order Strahler) upstream
49	0.0271	DIST-UPST	L			km	stream distance upstream to headwaters as measured on 1:24,000 scale maps
49	n/a	SUBBAS-C			subbasin setting	category	the sub-basin category; SUBBAS, TRIS, TRIR
49	n/a	DSIZECAT				category	the size class of the next size class stream downstream of the site
49	<	RELIEF-RATIO			ruggedness	none	height of the basin divided by the trunk stream length
49	0.4008	DRAIN-DENSITY				km/km2	length of mapped stream within watershed divided by watershed area
49	0.0458	REL-RELIEF	L			none	height of the basin divided by the perimeter of the basin
49	0.3797	MELTONSRUG	SR			none	drainage density / relief total
49	0.0030	RELIEFTOTAL				m	total elevation range of the watershed
49	<	WSHED10%				% by area	percent of the 100m buffer with slopes greater than 10% (calculated by DEM)
49	<	RIPWSHED10%				% by area	percent of the watershed with slopes greater than 10% (calculated by DEM)
49	<	AVGWSHEDSLP				none	average percent slope for all cells in the watershed (calculated by DEM)
49	0.0488	ELEVMIN			elevation	m	minimum elevation in watershed
49	<	ELEVMAX				m	maximum elevation in watershed
49	0.0136	ELEVMEAN				m	mean elevation in watershed
49	<	FOREST-SEG			land cover - segment	% by area	% forest classess from MRLC 1993 in 100m buffer for the stream segment
49	<	AG-SEG				% by area	% agricultural classes from MRLC 1993 in 100m buffer for the stream segment
49	<	DEV-SEG				% by area	% developed classes from MRLC 1993 in 100m buffer for the stream segment
49	<	LRES-SEG				% by area	% low density developed class (MRLC 1993) in 100m buffer for the stream segment
49	<	HRES-SEG				% by area	% high density developed class (MRLC 1993) in 100m buffer for the stream segment
49	<	PAST-SEG				% by area	% pasture class from MRLC 1993 in 100m buffer for the stream segment
49	<	CROP-SEG				% by area	% cropland class from MRLC 1993 in 100m buffer for the stream segment

Appendix B. Local and watershed variables measured and calculated for the sampled sites.

n	W test[1]	Variable	Trans-form[2]	Scale[3]	Variable Group[4]	Units of Measure	Variable Description
49	0.1453	FOREST-WRIP		Watershed Variables	land cover - riparian	% by area	% forest classes from MRLC 1993 in 100m buffer for the stream segment
49	0.1599	DEV-WRIP	ASR			% by area	% developed classes from MRLC 1993 in 100m buffer for the stream segment
49	0.7496	PAST-WRIP				% by area	% pasture class from MRLC 1993 in 100m buffer throughout the watershed
49	0.0318	AG-WRIP				% by area	% agricultural classes from MRLC 1993 in 100m buffer for the stream segment
49	<	LRES-WRIP				% by area	% low density developed class (MRLC 1993) in 100m buffer in the watershed
49	<	HRES-WRIP				% by area	% high density developed class (MRLC 1993) in 100m buffer in the watershed
49	<	CROP-WRIP				% by area	% cropland class from MRLC 1993 in 100m buffer throughout the watershed
49	0.4645	FOREST-WSHED			land cover - watershed	% by area	% forest classes from MRLC 1993 in watershed
49	0.8188	DEV-WSHED	ASR			% by area	% developed classes from MRLC 1993 in watershed
49	0.5545	PAST-WSHED				% by area	% pasture class from MRLC 1993 in the watershed
49	0.4099	AG-WSHED				% by area	% agricultural classes from MRLC 1993 in watershed
49	<	LRES-WSHED				% by area	% low density developed class from MRLC 1993 in the watershed
49	<	HRES-WSHED				% by area	% high density developed class from MRLC 1993 in the watershed
49	0.0014	CROP-WSHED				% by area	% cropland class from MRLC 1993 in the watershed
49	0.6892	RD-DENSE-L			road	km/km2	length of roads in the watershed / watershed area
49	0.2444	RD-CROSS				no/km2	number of road-stream crossings in the watershed / watershed area
49	0.0466	FRAG_TOT			impoundment - fragmentation	% by length	total percent remaining connected
49	0.0651	IMP-DENSE				no/km2	number of impoundments in the watershed (off and in-stream)
49	<	FRAG_UP				% by length	upstream percent remaining connected
49	<	FRAG_DOWN				% by length	downstream percent remaining connected
49	0.0163	IMP-DENSEAREA				ha/km2	area of impoundments in the watershed (off and in-stream)
49	<	IMP-WSHEDRATIO				% by area	ratio of impoundment watershed to total watershed (instream)
49	0.0562	IMP-DWNDIST	L			km	distance downstream to nearest impoundment
49	0.0500	ORD1-LOSS			impound - loss	% by length	percent headwaters cutoff by impoundments
49	0.0093	IMP-LOSS				% by length	percent inundated length of stream upstream

Appendix B. Local and watershed variables measured and calculated for the sampled sites.

n	W test[1]	Variable	Trans-form[2]	Scale[3]	Variable Group[4]	Units of Measure	Variable Description
41	0.9352	EGL	L	Local Variables	slope	m/m	energy grade line slope from survey data
49	0.7423	MAPSLOPE	L			m/m	slope derived from 20 ft contours from USGS topographic maps
49	0.1441	DEMSLOPE	L			m/m	(upstream node DEM elevation - downstream node DEM elevation) / segment length
49	0.0001	LOCALDEM	L			m/m	average DEM slope for three cells around actual sampling location
49	<	UDEM	L			m/m	DEMSLOPE of the first segment upstream from the sampled segment
41	0.4274	DBKF			channel dimension	m	average bankfull depth (bankfull area / bankfull width)
41	0.3638	RBKF				m	average hydraulic radius at bankfull (bankfull area / wetted perimeter)
41	0.3371	WWBKF	L			m	average water width at bankfull
41	<	XCABKF				m3	average cross sectional area at bankfull
41	0.0004	CVXCABKF				m3	coefficient of variation of cross sectional area at bankfull
41	0.0007	WPBKF				m	average wetted perimeter at bankfull
41	0.0244	VBKF				m/sec	average flow velocity at bankfull calculated with the Manning Equation
41	0.6558	QBKF	L			m3/sec	average bankfull discharge calculated from cross-sections using Glauker-Manning
41	0.0843	QBKF/Q2	SR			none	ratio of QBKF to calculated 2-yr flood discharge (Q2YR)
41	0.1947	DBASE	SR			m	average water depth during baseflow conditions
49	0.1074	WWBASE	L			m	average water width during baseflow conditions
41	<	TREND-D-AVG				m	average of the absolute value of the depth differences between adjacent counts
41	<	TREND-D-STD				m	stdev of the absolute value of the depth differences between adjacent counts
41	<	TREND-D-CV				m	cv of the absolute value of the depth differences between adjacent counts
41	<	TREND-D-MAX				m	maximum of the absolute value of the depth differences between adjacent counts
41	0.0010	STD-D				m	standard deviation of water depth measured from channel transects
41	0.0161	CV-D				m	cv of water depth measured from channel transects
41	<	MAX-D				m	maximum water depth measured from channel transects
41	<	MIN-D				m	minimum water depth measured from channel transects
41	0.0022	95%-D				m	95th percentile value of water depth observations from channel transects
41	0.0007	50%-D				m	50th percentile value of water depth observations from channel transects
41	0.0059	5%-D				m	5th percentile value of water depth observations from channel transects
41	<	MODE-D				m	mode of water depth observations from channel transects
41	0.0003	AVGPOOL-D				m	average pool depth during baseflow conditions from channel transects
41	<	STDPOOL-D				m	standard deviaton of pool depth during baseflow conditions from channel transects
41	<	CVPOOL-D				m	cv of pool depth during baseflow conditions from channel transects
41	0.0016	MAXPOOL-D				m	maximum pool depth during baseflow conditions from channel transects
41	<	MINPOOL-D				m	minimum pool depth during baseflow conditions from channel transects

Appendix B. Local and watershed variables measured and calculated for the sampled sites.

n	W test[1]	Variable	Trans-form[2]	Scale[3]	Variable Group[4]	Units of Measure	Variable Description
41	0.0007	95%POOL-D		Local Variables	channel dimension	m	95th percentile value of pool depth observations from channel transects
41	0.0002	50%POOL-D				m	50th percentile value of pool depth observations from channel transects
41	<	5%POOL-D				m	5th percentile value of pool depth observations from channel transects
41	<	MODEPOOL-D				m	mode value of pool depth observations from channel transects
41	0.0490	AVGRUN-D				m	average run depth during baseflow conditions from channel transects
41	<	STDRUN-D				m	standard deviaton of run depth during baseflow conditions from channel transects
41	<	CVRUN-D				m	cv of run depth during baseflow conditions from channel transects
41	<	MAXRUN-D				m	maximum run depth during baseflow conditions from channel transects
41	0.1633	95%RUN-D				m	95th percentile value of run depth observations from channel transects
41	0.0090	50%RUN-D				m	50th percentile value of run depth observations from channel transects
41	0.0279	5%RUN-D				m	5th percentile value of run depth observations from channel transects
41	<	MINRUN-D				m	minimum run depth during baseflow conditions from channel transects
41	<	MODERUN-D				m	mode value of run depth observations from channel transects
41	<	AVGRIFF-D				m	average riffle depth during baseflow conditions from channel transects
41	<	STDRIFF-D				m	standard deviaton of riffle depth during baseflow conditions from channel transects
41	<	CVRIFF-D				m	cv of riffle depth during baseflow conditions from channel transects
41	<	MAXRIFF-D				m	maximum riffle depth during baseflow conditions from channel transects
41	<	MINRIFF-D				m	minimum riffle depth during baseflow conditions from channel transects
41	<	95%RIFF-D				m	95th percentile value of riffle depth observations from channel transects
41	<	50%RIFF-D				m	50th percentile value of riffle depth observations from channel transects
41	<	5%RIFF-D				m	5th percentile value of riffle depth observations from channel transects
41	<	MODERIFF-D				m	mode percentile value of riffle depth observations from channel transects
41	0.8521	%SAND			channel bed sediment	% by count	percent sand observed on channel transects
41	0.1014	%FINES	ASR			% by count	percent fines observed on channel transects
41	0.5593	%LT2MM	ASR			% by count	percent fines and sand observed on channel transects (+ 1.0% for trans.)
41	<	%BEDROCK				% by count	percent bedrock noted on channel transects
41	n/a	BEDROCK-P/A				p/a	bedrock present (1) or absent (1)
41	<	%BR-POOL				% by count	percent bedrock noted on channel transects in pool habitats
41	<	%BR-RUN				% by count	percent bedrock noted on channel transects in run habitats
41	<	%BR-RIFFLE				% by count	percent bedrock noted on channel transects in riffle habitats
41	<	AVGPHIBR				phi	mean phi observed on channel transects, bedrock as -10.5 phi
41	0.0581	STDPHIBR				phi	standard deviation phi observed on channel transects, bedrock as -10.5 phi
41	0.1483	CVPHIBR				phi	cv of phi observed on channel transects, bedrock as -10.5 phi

Appendix B. Local and watershed variables measured and calculated for the sampled sites.

n	W test[1]	Variable	Trans-form[2]	Scale[3]	Variable Group[4]	Units of Measure	Variable Description
41	<	MAXPHIBR		Local Variables	channel bedsediment	phi	maximum phi value observed on channel transects, bedrock as -10.5 phi
41	<	MINPHIBR				phi	minimum phi value observed on channel transects, bedrock as -10.5 phi
41	<	95%PHIBR				phi	95th percentile phi observed on channel transects, bedrock as -10.5 phi
41	<	50%PHIBR				phi	50th percentile phi observed on channel transects, bedrock as -10.5 phi
41	<	5%PHIBR				phi	5th percentile phi observed on channel transects, bedrock as -10.5 phi
41	<	AVGPHI				phi	mean phi observed on channel transects, not including bedrock
41	0.0980	STDPHI				phi	standard deviation phi observed on channel transects, not including bedrock
41	0.0079	CVPHI				phi	cv of phi observed on channel transects, not including bedrock
41	<	MAXPHI				phi	maximum phi observed on channel transects, not including bedrock
41	<	MINPHI				phi	minimum phi observed on channel transects, not including bedrock
41	<	95%PHI				phi	95th percentile phi observed on channel transects, not including bedrock
41	<	50%PHI				phi	50th percentile phi observed on channel transects, not including bedrock
41	0.0040	5%PHI				phi	5th percentile phi observed on channel transects, not including bedrock
41	<	%SANDPOOL				% by count	percent sand noted on channel transects in pool habitats
41	<	AVGPOOL-PHIBR				phi	mean phi observed in pools on channel transects, bedrock as -10.5 phi
41	<	STDPOOL-PHIBR				phi	standard dev of phi observed in pools on channel transects, bedrock as -10.5 phi
41	<	CVPOOL-PHIBR				phi	cv of phi observed in pools on channel transects, bedrock as -10.5 phi
41	<	MAXPOOL-PHIBR				phi	maximum phi observed in pools on channel transects, bedrock as -10.5 phi
41	<	MINPOOL-PHIBR				phi	mean phi observed in pools on channel transects, bedrock as -10.5 phi
41	<	95%POOL-PHIBR				phi	mean phi observed in pools on channel transects, bedrock as -10.5 phi
41	<	50%POOL-PHIBR				phi	mean phi observed in pools on channel transects, bedrock as -10.5 phi
41	<	5%POOL-PHIBR				phi	mean phi observed in pools on channel transects, bedrock as -10.5 phi
41	0.0025	%SANDRUN				% by count	percent sand noted on channel transects in run habitats
41	<	AVGRUN-PHIBR				phi	mean phi observed on channel transects in the run habitats, bedrock as -10.5 phi
41	0.0128	STDRUN-PHIBR				phi	standard dev of phi observed in pools on channel transects, bedrock as -10.5 phi
41	0.0764	CVRUN-PHIBR				phi	cv of phi observed in runs on channel transects, bedrock as -10.5 phi
41	<	MAXRUN-PHIBR				phi	maximum phi observed in runs on channel transects, bedrock as -10.5 phi
41	<	MINRUN-PHIBR				phi	mean phi observed in runs on channel transects, bedrock as -10.5 phi
41	<	95%RUN-PHIBR				phi	mean phi observed in runs on channel transects, bedrock as -10.5 phi
41	<	50%RUN-PHIBR				phi	mean phi observed in runs on channel transects, bedrock as -10.5 phi
41	0.0001	5%RUN-PHIBR				phi	mean phi observed in runs on channel transects, bedrock as -10.5 phi
41	<	%SANDRIFF				% by count	percent sand noted on channel transects in riffle habitats
41	<	AVGRIFF-PHIBR				phi	mean phi observed on channel transects in the riffle habitats, bedrock as -10.5 phi

Appendix B. Local and watershed variables measured and calculated for the sampled sites.

n	W test[1]	Variable	Trans-form[2]	Scale[3]	Variable Group[4]	Units of Measure	Variable Description
41	<	STDRIFF-PHIBR		Local Variables	channel bed sediment	phi	standard dev of phi observed in pools on channel transects, bedrock as -10.5 phi
41	<	CVRIFF-PHIBR				phi	cv of phi observed in riffles on channel transects, bedrock as -10.5 phi
41	<	MAXRIFF-PHIBR				phi	maximum phi observed in riffles on channel transects, bedrock as -10.5 phi
41	<	MINRIFF-PHIBR				phi	mean phi observed in riffles on channel transects, bedrock as -10.5 phi
41	<	95%RIFF-PHIBR				phi	mean phi observed in riffles on channel transects, bedrock as -10.5 phi
41	<	50%RIFF-PHIBR				phi	mean phi observed in riffles on channel transects, bedrock as -10.5 phi
41	<	5%RIFF-PHIBR				phi	mean phi observed in riffles on channel transects, bedrock as -10.5 phi
41	0.4604	STRMPOWF	L		transport capacity	watts	stream power of the average bankfull flood using EGL
41	0.2713	U-STRMPOWF	L			watts/m	unit stream power of the average bankfull flood using EGL and bkf-W
41	0.7861	STRMPOWM	L			watts	stream power of the average bankfull flood using DEM slope
41	0.5129	U-STRMPOWM				watts/m	unit stream power of the average bankfull flood using EGL and bkf-W
41	<	BAGNOLDWC				none	Bagnold's critical stream power (function of AVGPHI and AVG-D-BKF)
41	0.0939	BAGRATIO	L			none	Ratio of STRMPOWF divided by BAGRNOLDWC
49	<	SEGDEM-UDEM				none	ratio of SEGMENTDEM to the Upstream segment DEM slope
49	<	SEGDEM-REL				none	ration of segment DEM to Relief Ratio
49	<	LOCDEMSEGDEM				none	local DEM slope divided by segment DEM slope
41	0.4750	%WOODYD	ASR		habitat	% by count	percent woodydebris or snag noted from point counts along channel transects
41	<	%POOL				% by count	percent points observed as pool habitat along channel transects
41	<	%RUN				% by count	percent points observed as run habitat along channel transects
41	<	%RIFFLE				% by count	percent points observed as riffle habitat along channel transects
41	n/a	RIFFLE-P/A				p/a	presence of riffle habitat (1) or absence (0)
41	n/a	POOL-P/A				p/a	presence of pool habitat (1) or absence (0)
41	<	RIFFTOPOOL				none	riffle-run counts divided by pool counts along channel transects

1 Shapiro-Wilks test for normal distribution; '<' = < 0.0001
2 Transformation was used to normalize the distribution; 'L' = Log10; 'SR' = Square Root; 'ASR' = Arc-sine square root
3 Scale of the variable (Local or Watershed)
4 Variable were grouped by type according to the schematic in Figure 1 (Chapter I)

APPENDIX C. LONGITUDINAL PROFILES OF SAMPLED STREAMS

Explanation:

These graphs show the longitudinal profile of the sampled streams and the slope of the segments as measured by the digital elevation model (DEM). The distance from the headwaters is plotted on the x-axis. The line represents the elevation as marked on the right y-axis. The triangular points represent the slope (left y-axis) of the stream segment. The elevation difference between the upstream segment start point (from–node) and the downstream segment endpoint (to-node) was summarized using the DEM. The difference was then divided by the length of the segment to calculate the segment slope.

The arrows and labels are used to identify the locations of the sites sampled for this study. Also, the arrow in bold and pointing away from the line identifies the downstream confluence. The table below identifies the figure on which the site is located.

Field Number	Figure	Field Number	Figure
LMH2000-01	C.10	LMH2000-27	C.9
LMH2000-02	C.7	LMH2000-28	C.21
LMH2000-03	C.8	LMH2000-29	C.18
LMH2000-04	C.8	LMH2000-30	C.19
LMH2000-05	C.1	LMH2000-31	C.14
LMH2000-06	C.6	LMH2000-32	C.5
LMH2000-07	C.3	LMH2000-33	C.4
LMH2000-09	C.24	LMH2000-34	C.4
LMH2000-10	C.29	LMH2000-35	C.26
LMH2000-11	C.7	LMH2000-36	C.11
LMH2000-12	C.1	LMH2000-37	C.28
LMH2000-13	C.6	LMH2000-38	C.27
LMH2000-14	C.16	LMH2000-39	C.2
LMH2000-15	C.10	LMH2000-40	C.13
LMH2000-16	C.10	LMH2000-41	C.20
LMH2000-17	C.10	LMH2000-42	C.23
LMH2000-18	C.22	LMH2000-43	C.3
LMH2000-19	C.7	USGS2000-02	C.7
LMH2000-20	C.25	USGS2000-03	C.31
LMH2000-21	C.12	USGS2000-06	C.17
LMH2000-22	C.15	USGS2000-13	C.4
LMH2000-23	C.5	USGS2000-16	C.12
LMH2000-24	C.30	USGS2000-17	C.9
LMH2000-25	C.2	USGS2000-23	C.2
LMH2000-26	C.4		

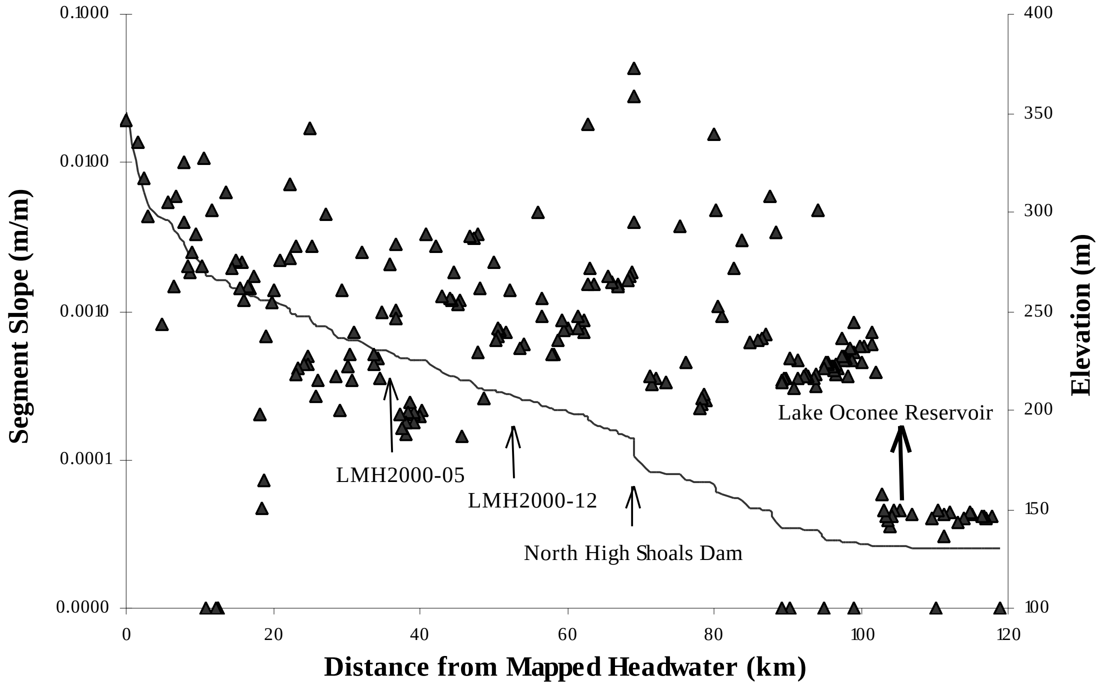


Figure C.1. Apalachee River

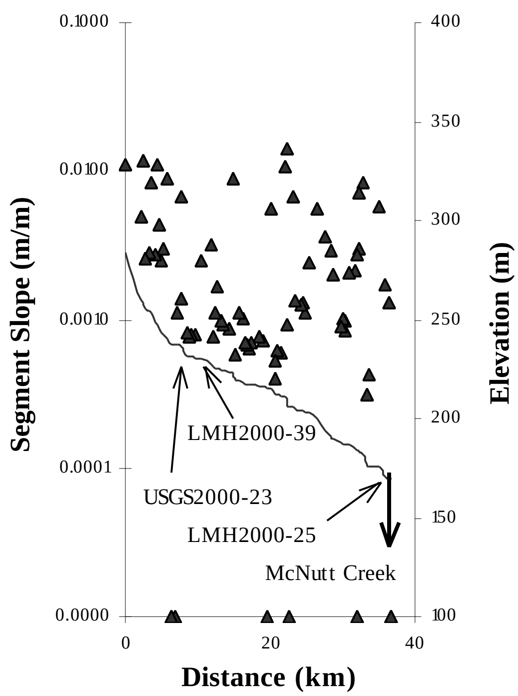


Figure C.2. Barber Creek

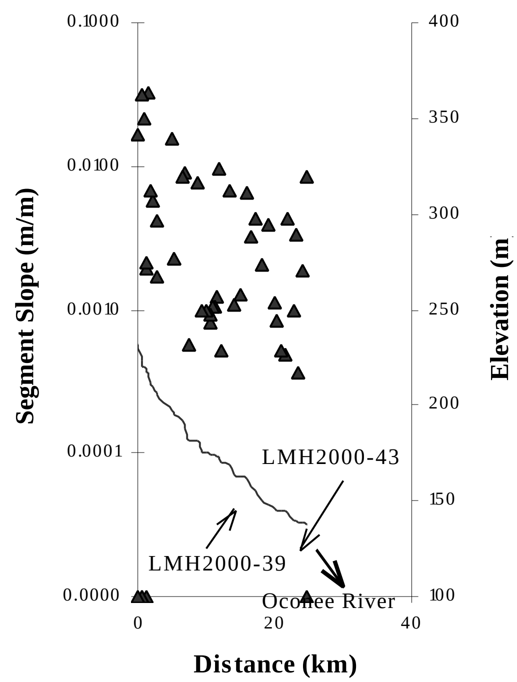


Figure C.3. Big Creek

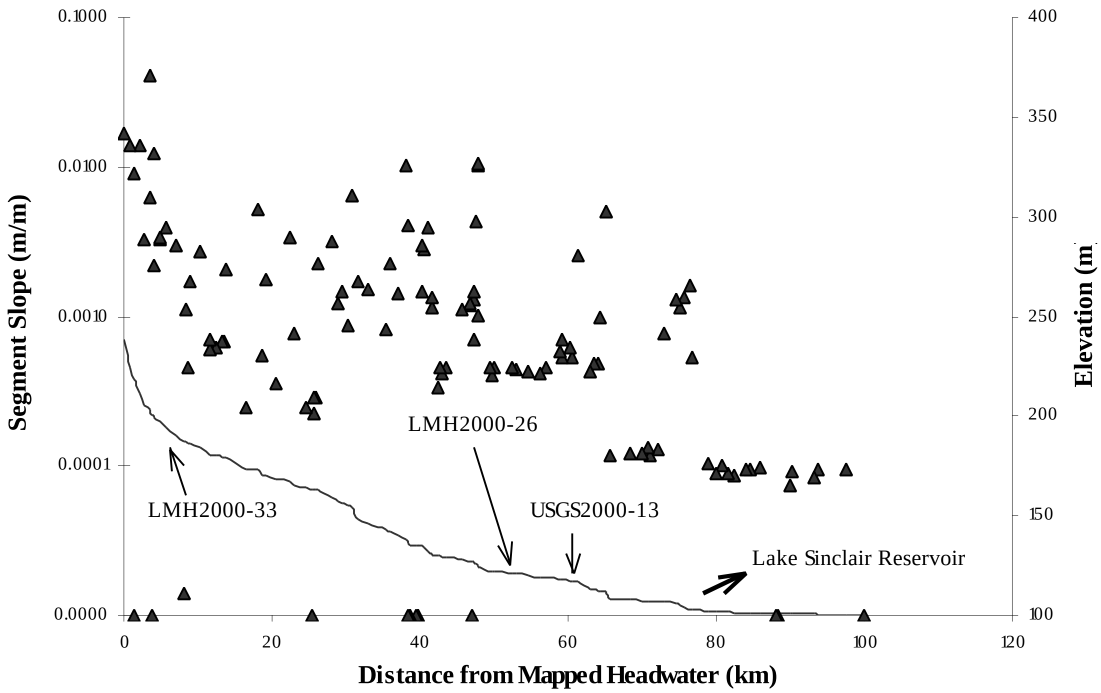


Figure C.4. Little River

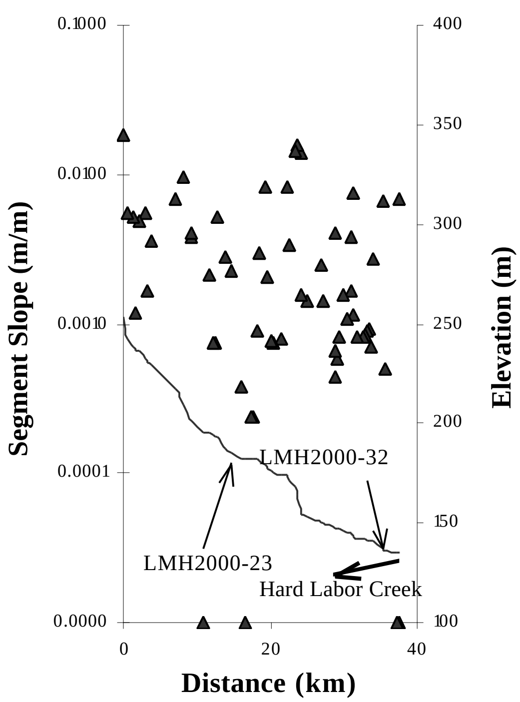


Figure C.5. Big Sandy Creek

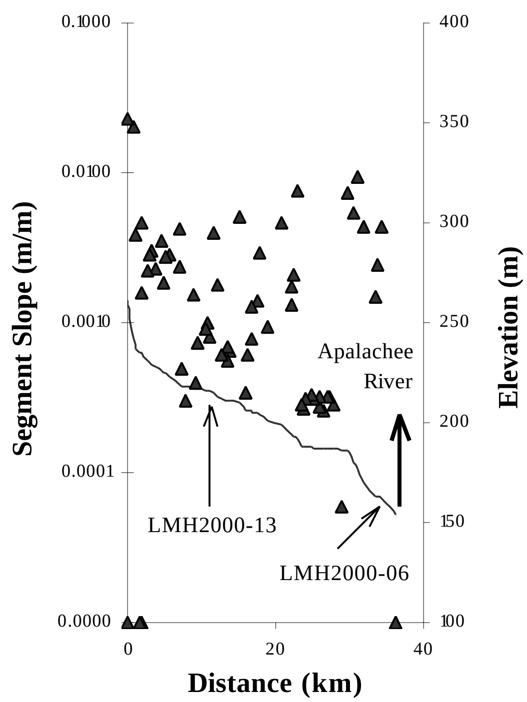


Figure C.6. Jacks Creek

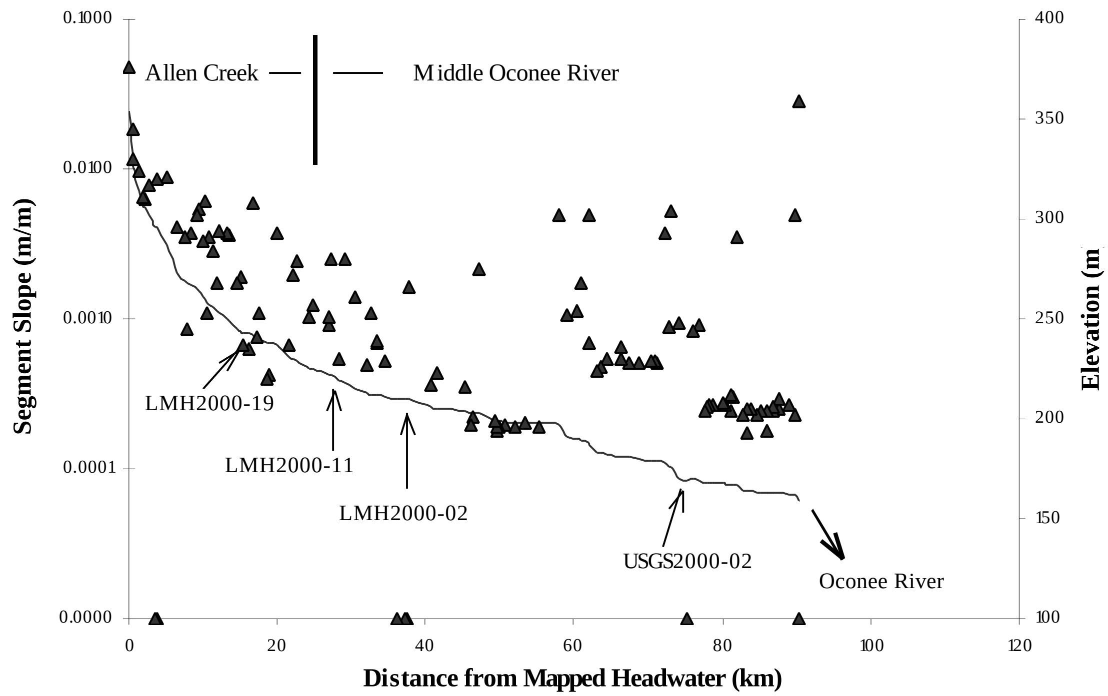


Figure C.7. Allen Creek and Middle Oconee River

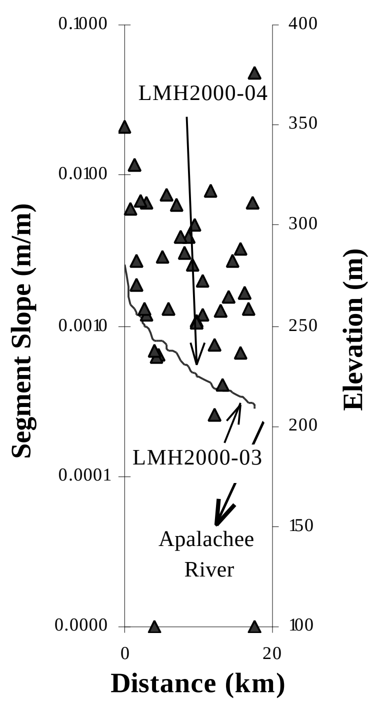


Figure C.8. Shoal Creek 2

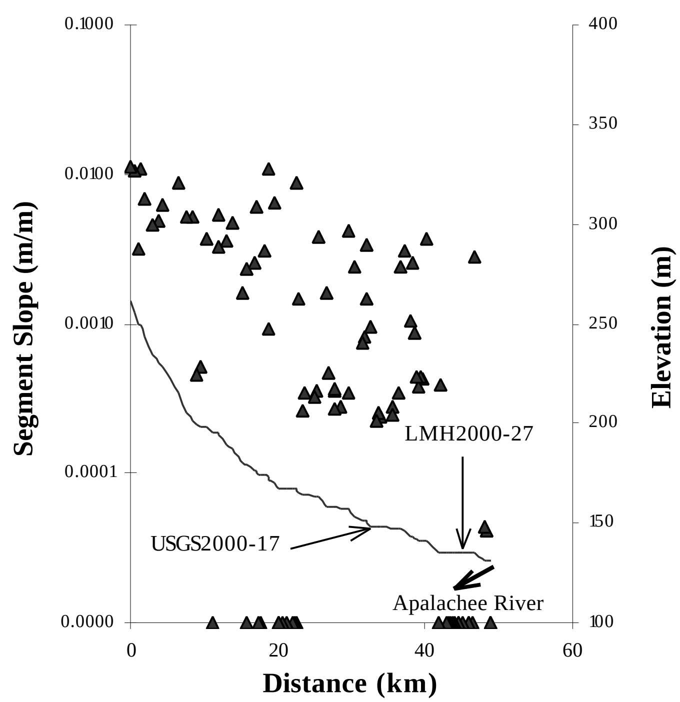


Figure C.9. Hard Labor Creek

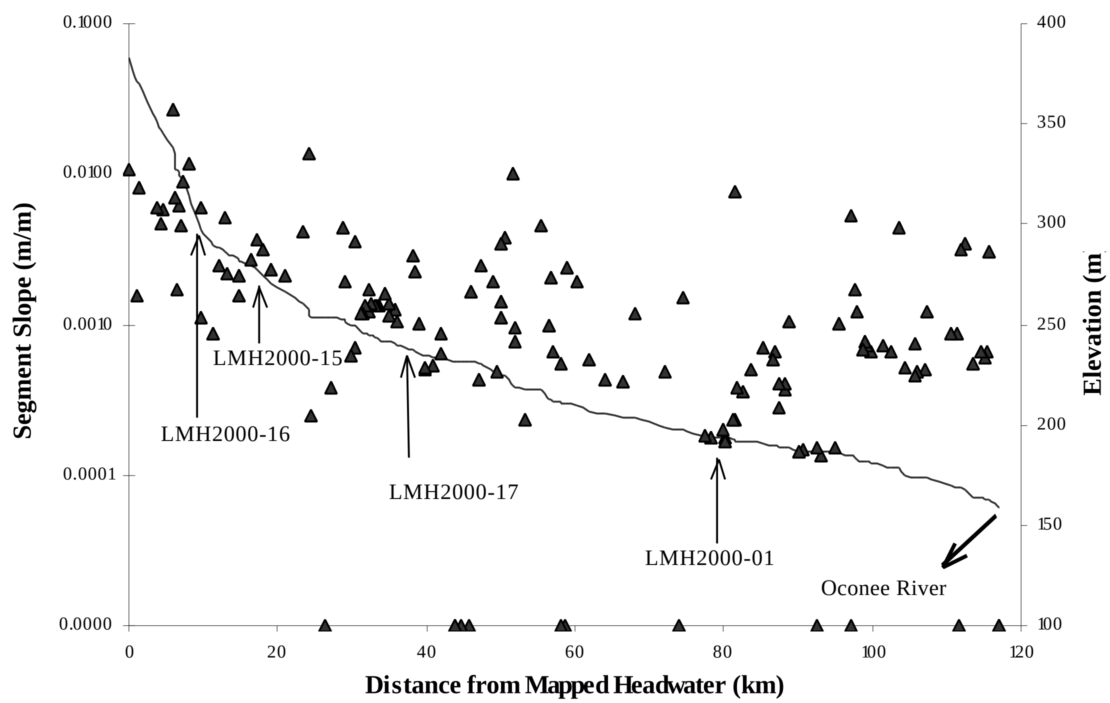


Figure C.10. North Oconee River

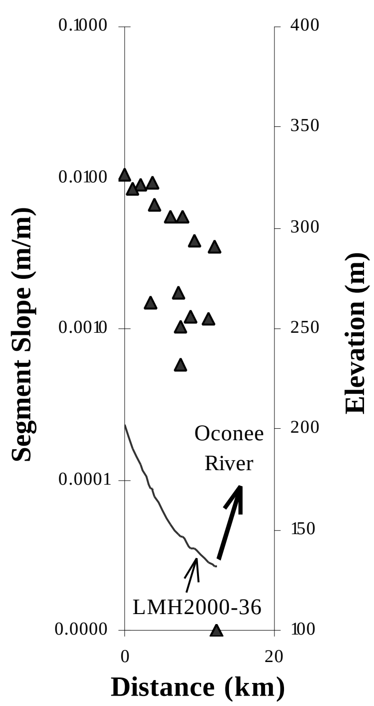


Figure C.11. Harris Creek

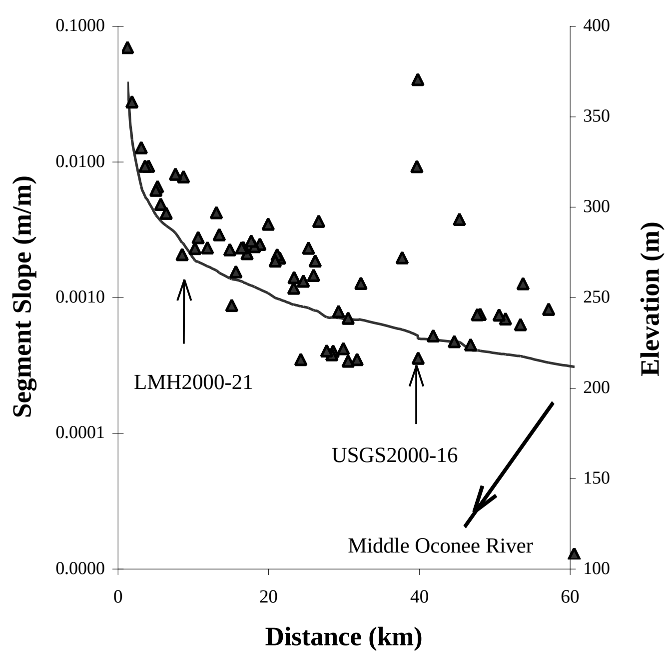


Figure C.12. Mulberry River

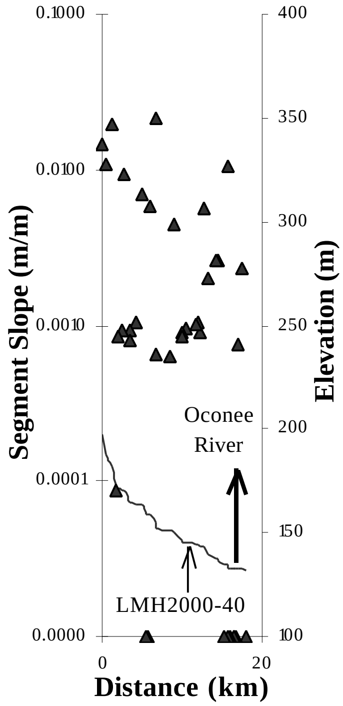


Figure C.13. Fishing Cr.

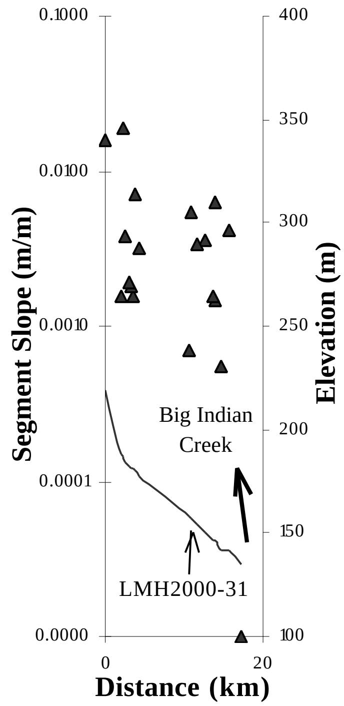


Figure C.14. Little Indian Cr.

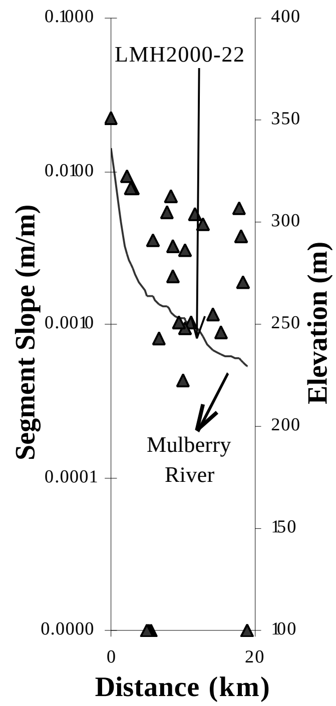


Figure C.15. Little Mulberry R.

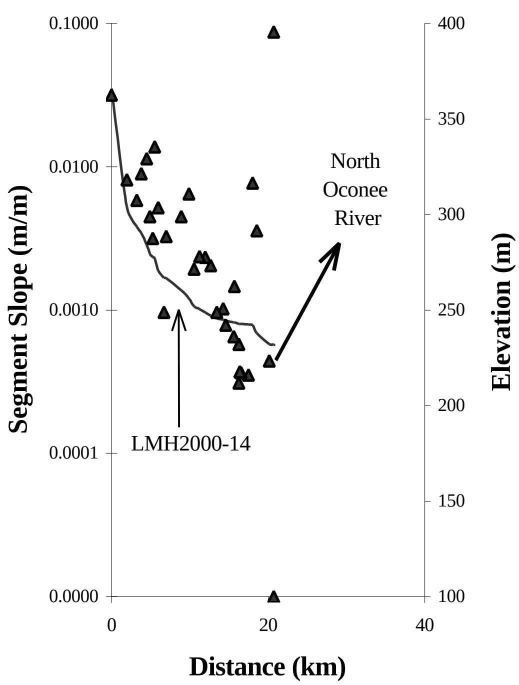


Figure C.16. Candler Creek

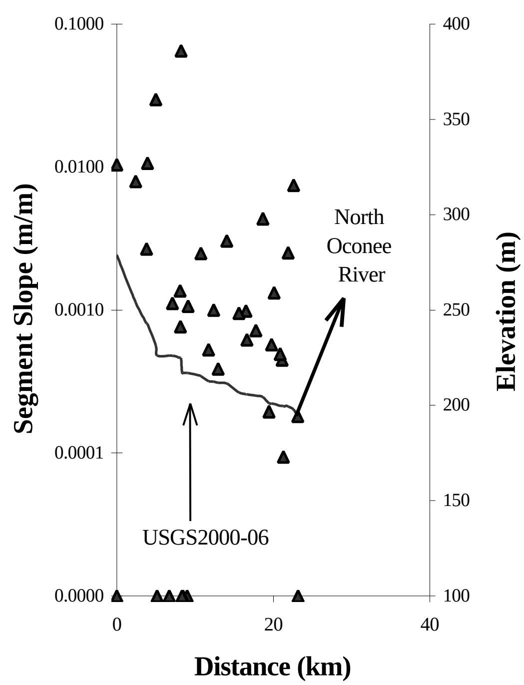


Figure C.17. Curry Creek

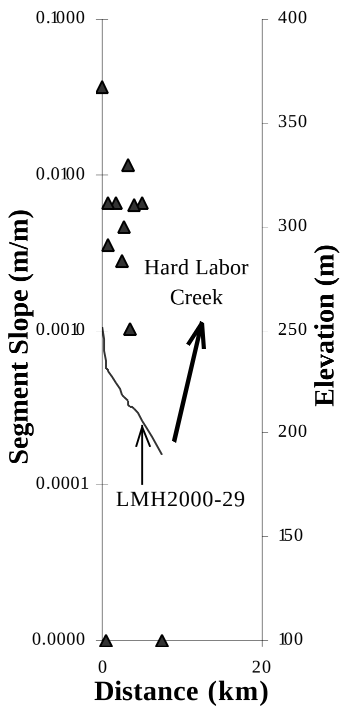


Figure C.18. Reedy Creek

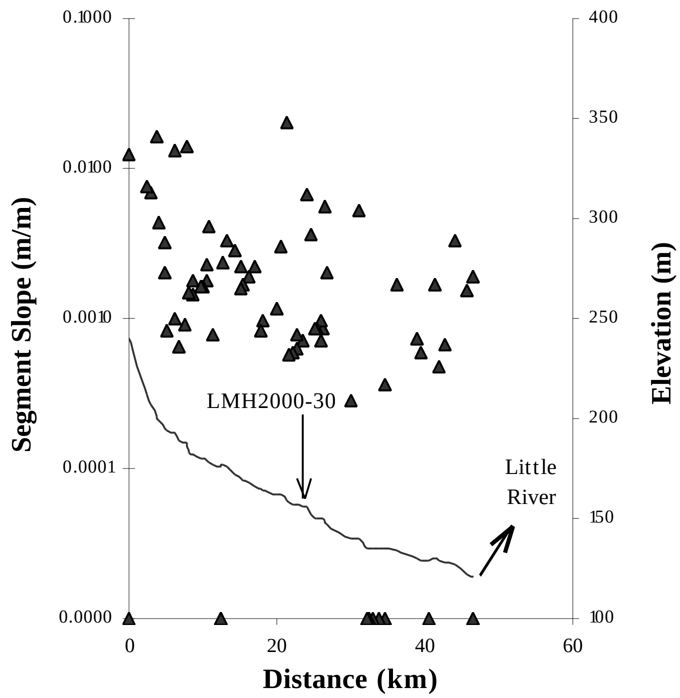


Figure C.19. Big Indian Creek

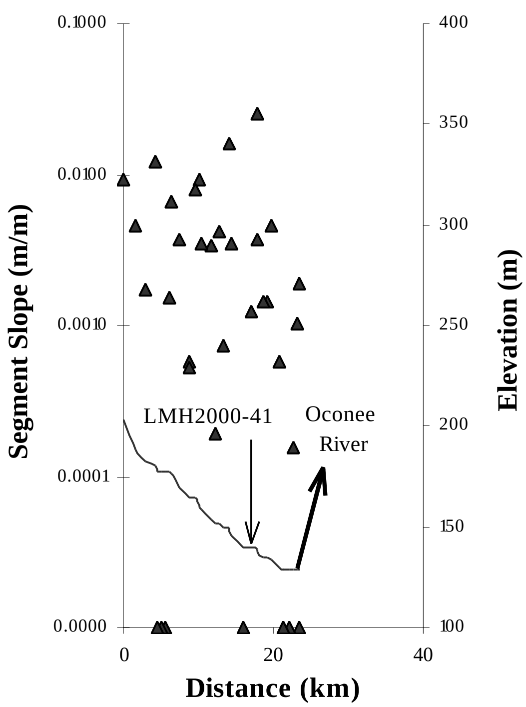


Figure C.20. Town Creek 1

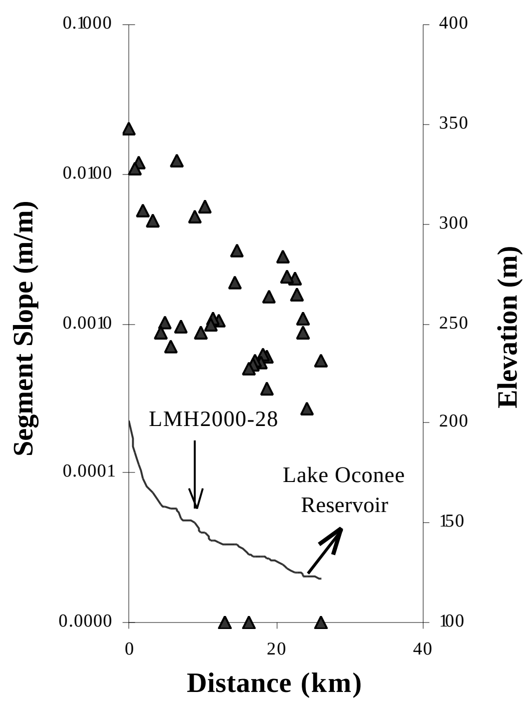


Figure C.21. Sugar Creek and North Sugar Cr.

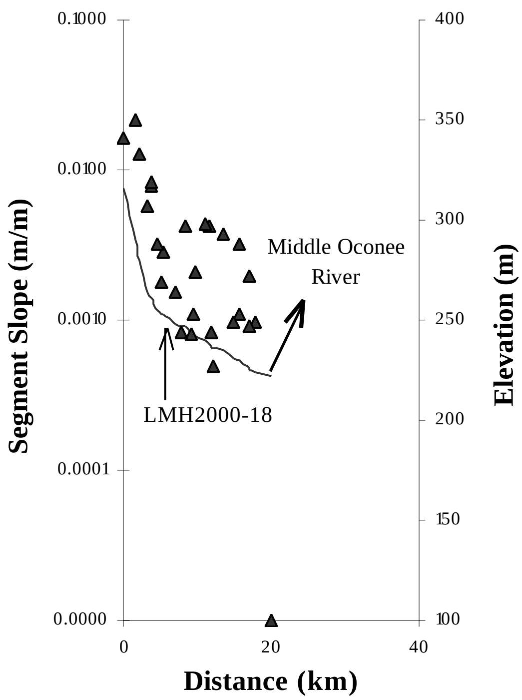


Figure C.22. Pond Fork

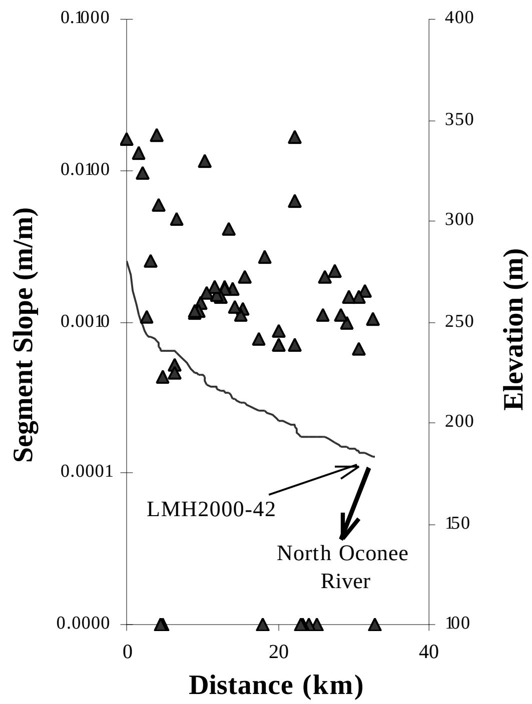


Figure C.23. Sandy Creek 1

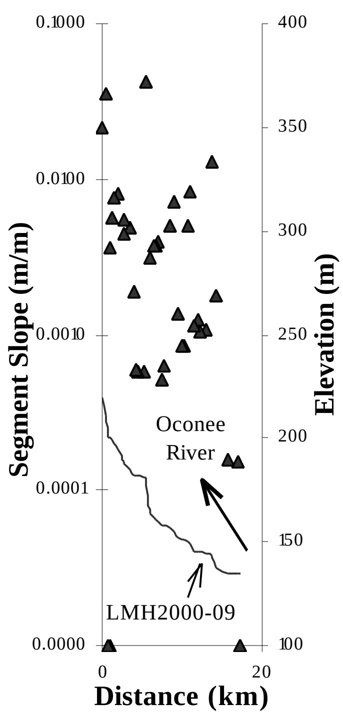


Figure C.24. Rose Creek

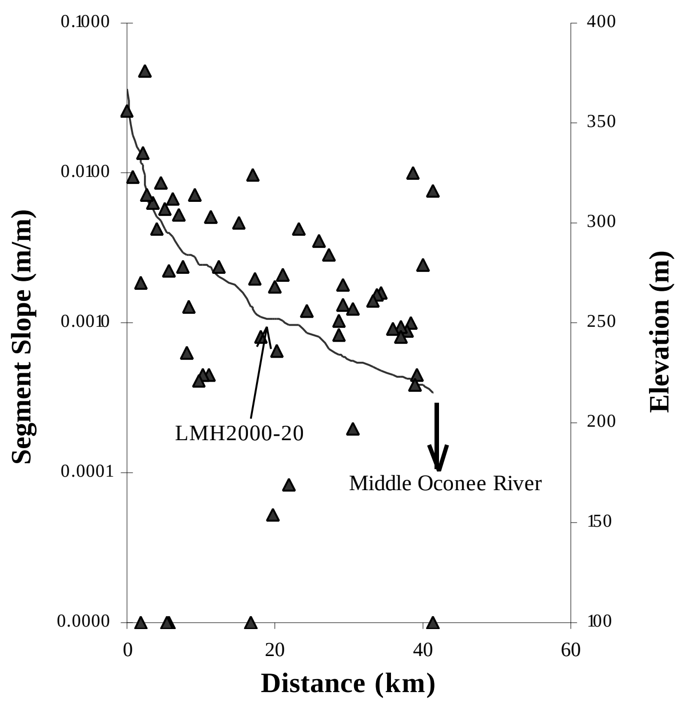


Figure C.25. Walnut Creek

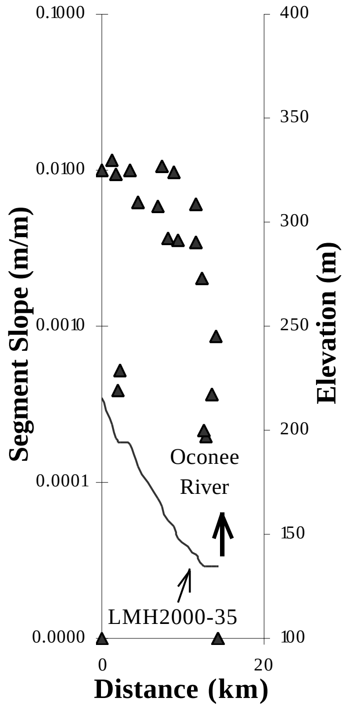


Figure C.26. Sandy Creek 2

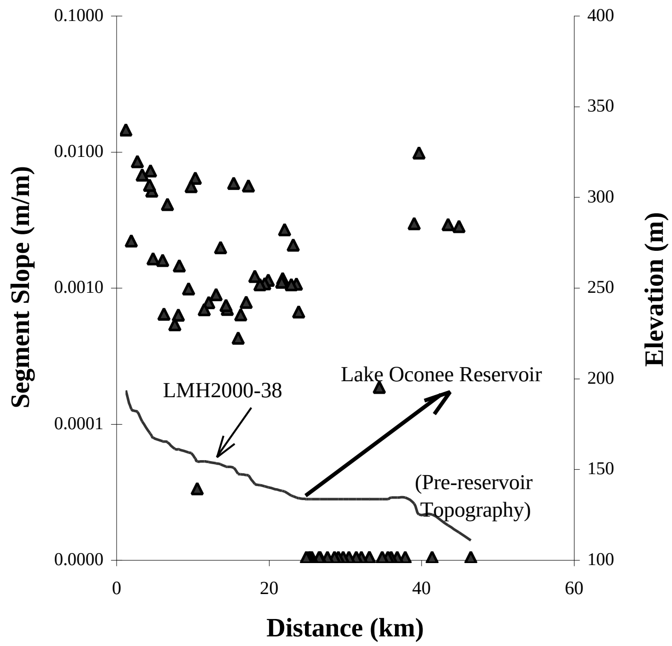


Figure C.27. Richland Creek

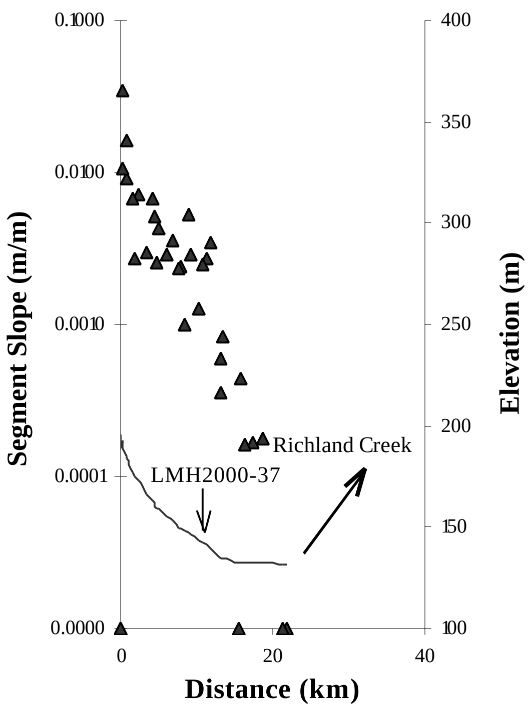


Figure C.28. Beaverdam Creek 3

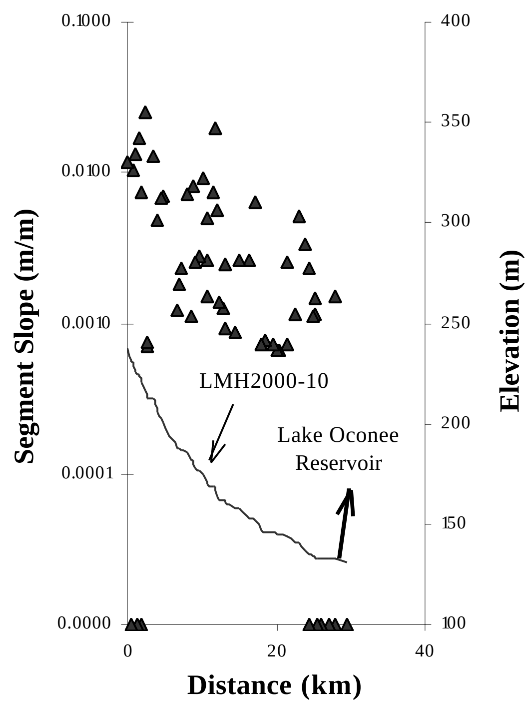


Figure C.29. Greenbrier Creek

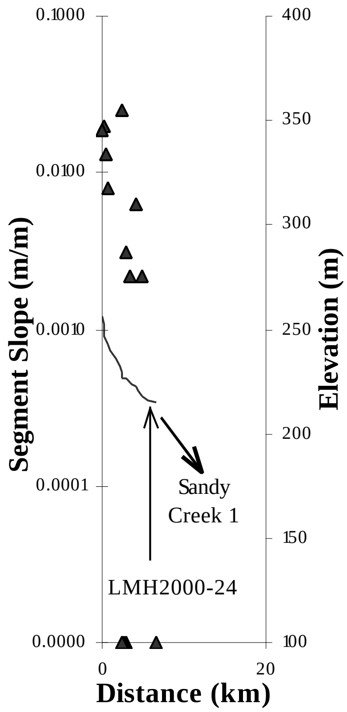


Figure C.30. Hardeman Creek

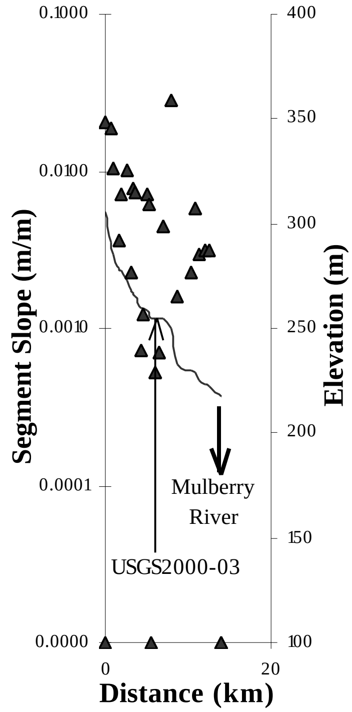
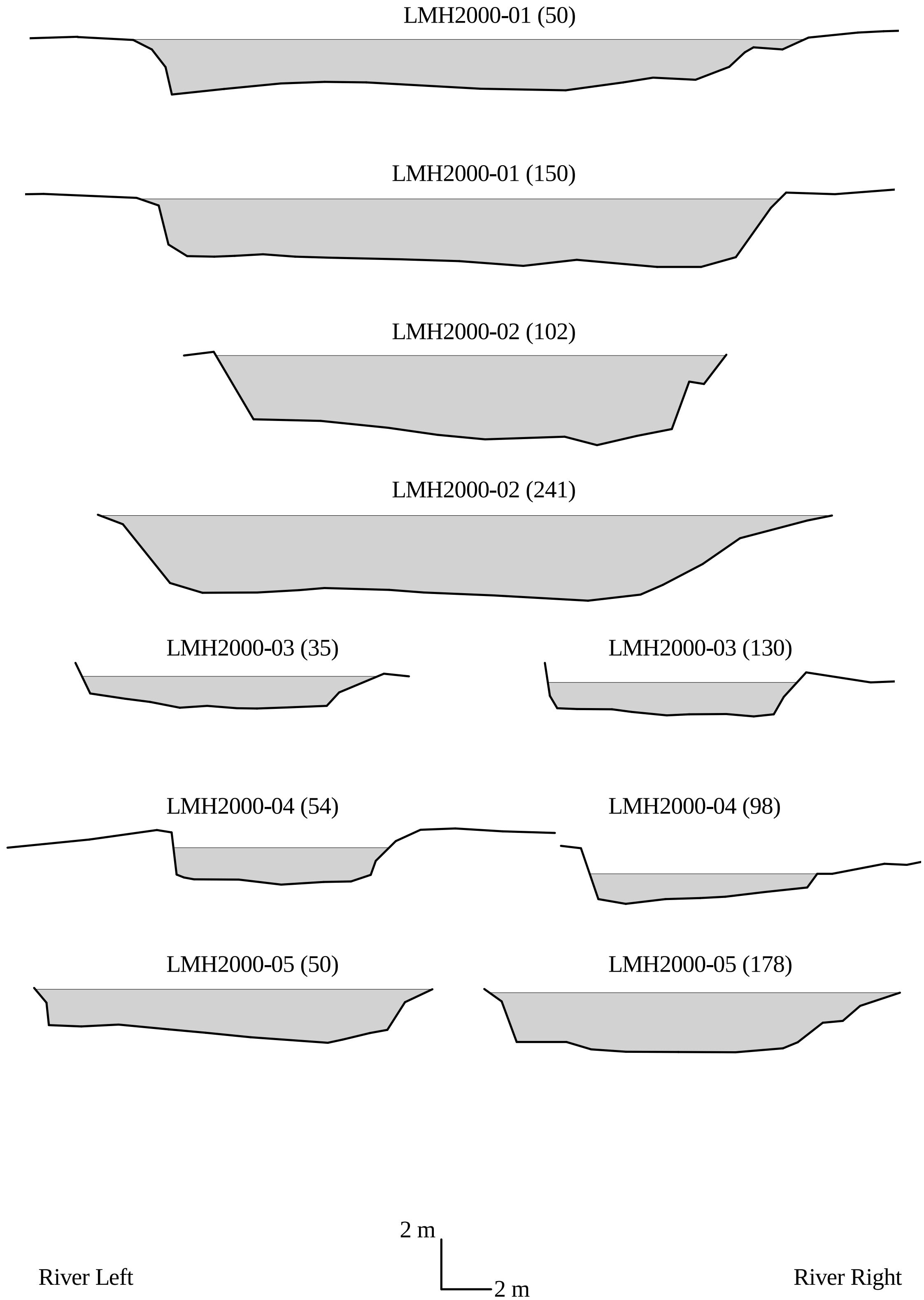


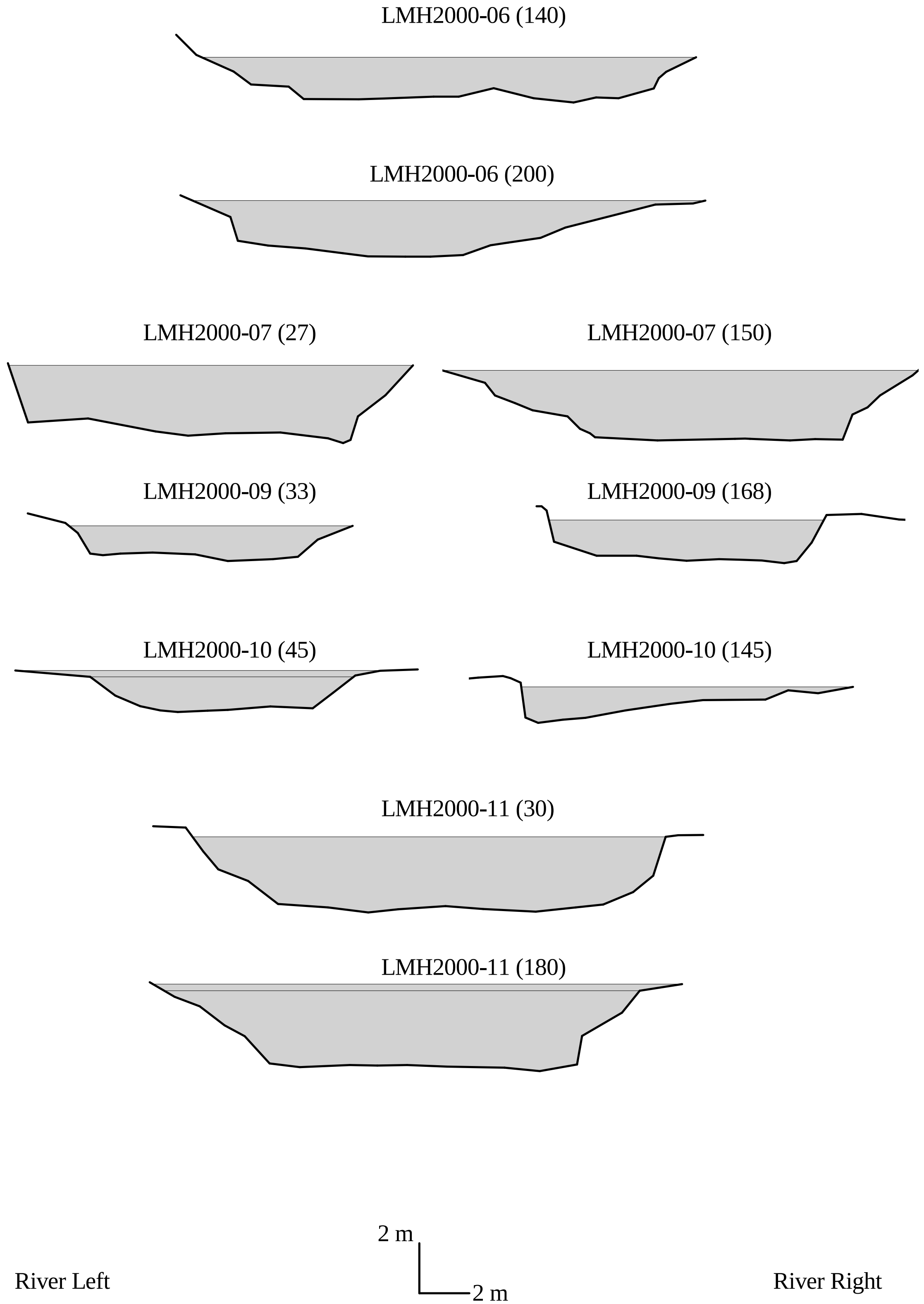
Figure C.31. Cedar Creek

APPENDIX D. CROSS-SECTIONS AND BANKFULL ELEVATIONS

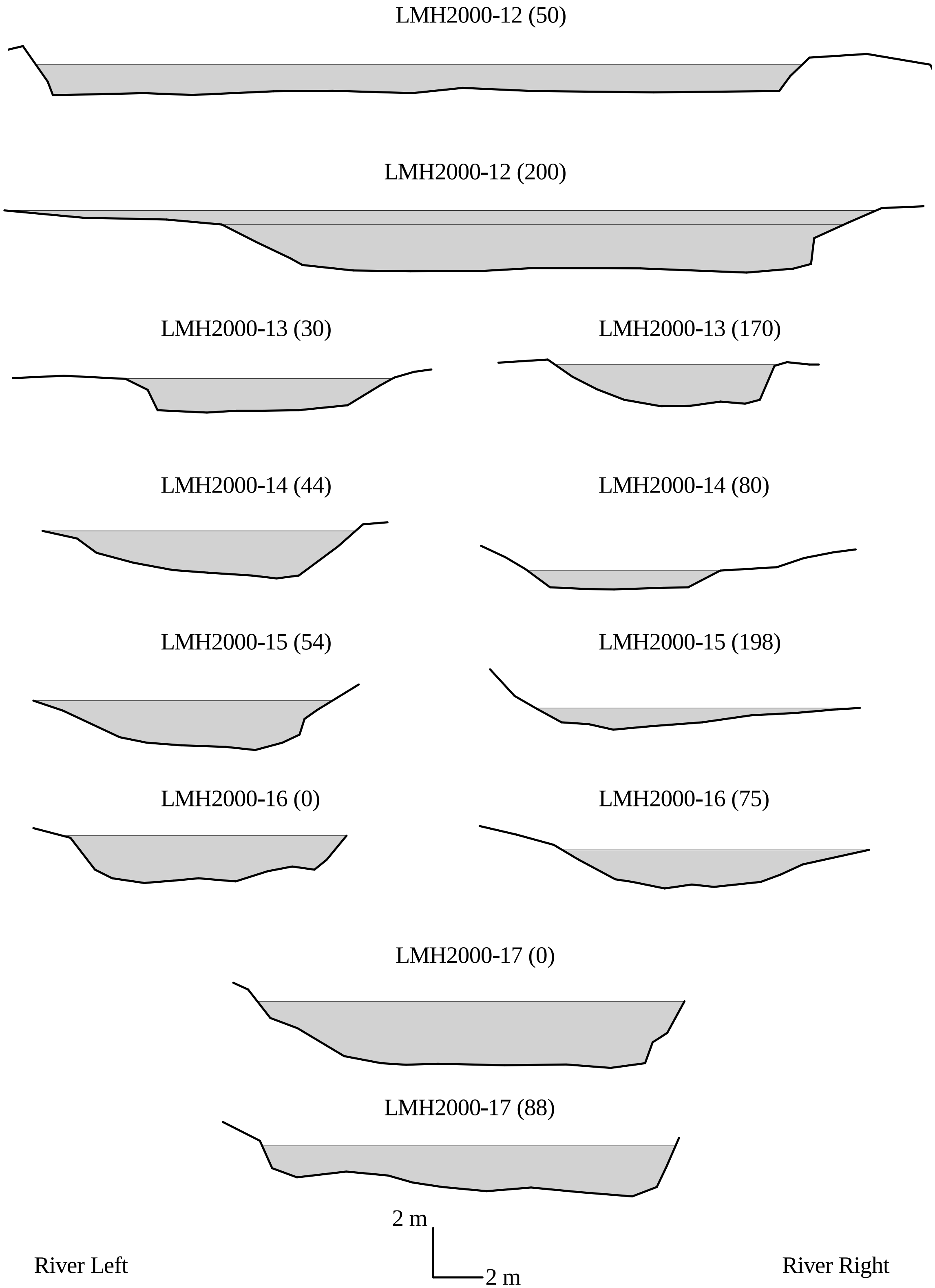
Sorted by Field Number



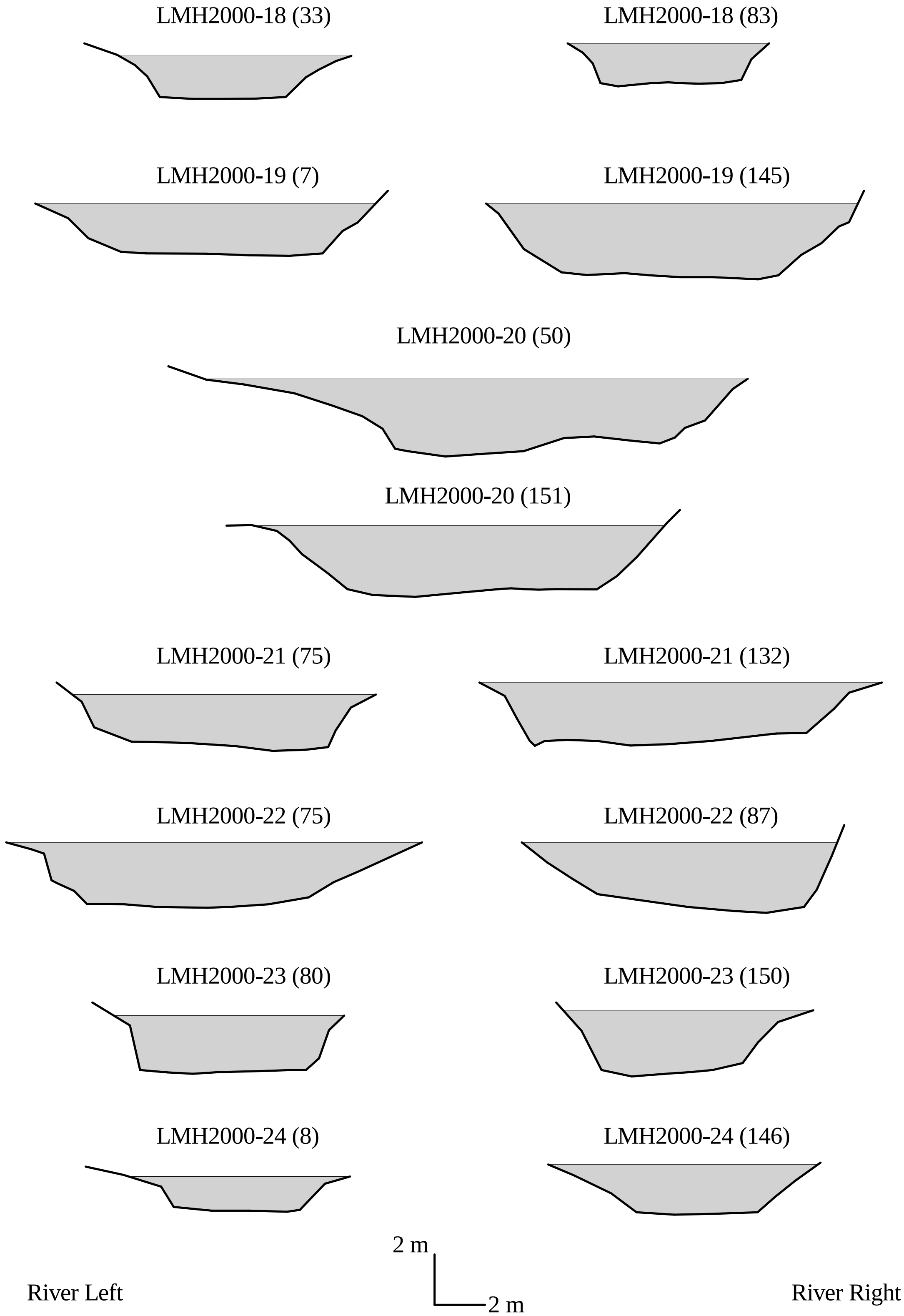
APPENDIX D. Stream cross-sections and 'bankfull' area. Width and depth are shown with no exaggeration using a scale of 1:250. Number in parentheses is distance along the transect. If two lines mark the 'bankfull' area then the average area was used in calculations.



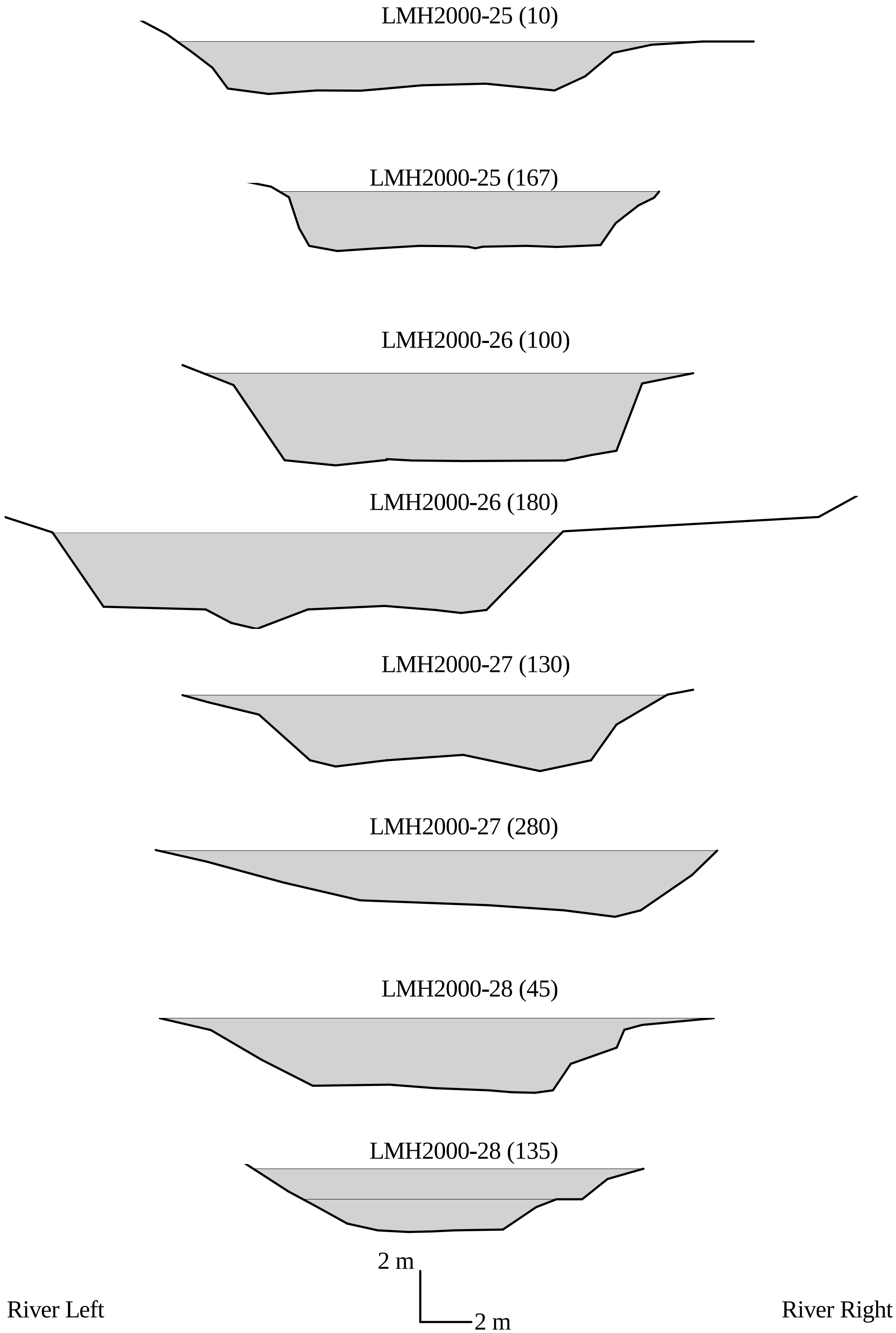
APPENDIX D. Stream cross-sections and 'bankfull' area. Width and depth are shown with no exaggeration using a scale of 1:250. Number in parentheses is distance along the transect. If two lines mark the 'bankfull' area then the average area was used in calculations.



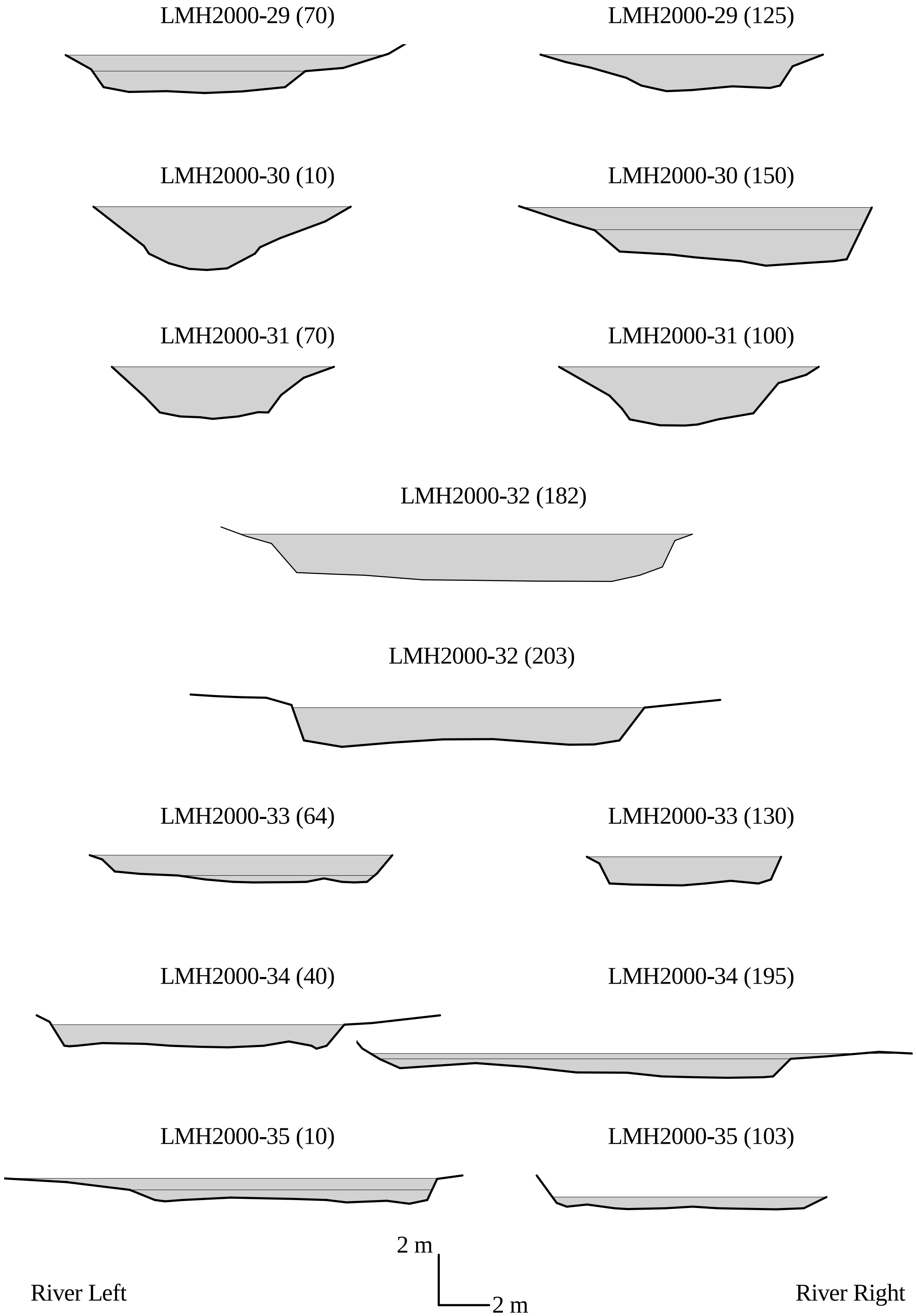
APPENDIX D. Stream cross-sections and 'bankfull' area. Width and depth are shown with no exaggeration using a scale of 1:250. Number in parentheses is distance along the transect. If two lines mark the 'bankfull' area then the average area was used in calculations.



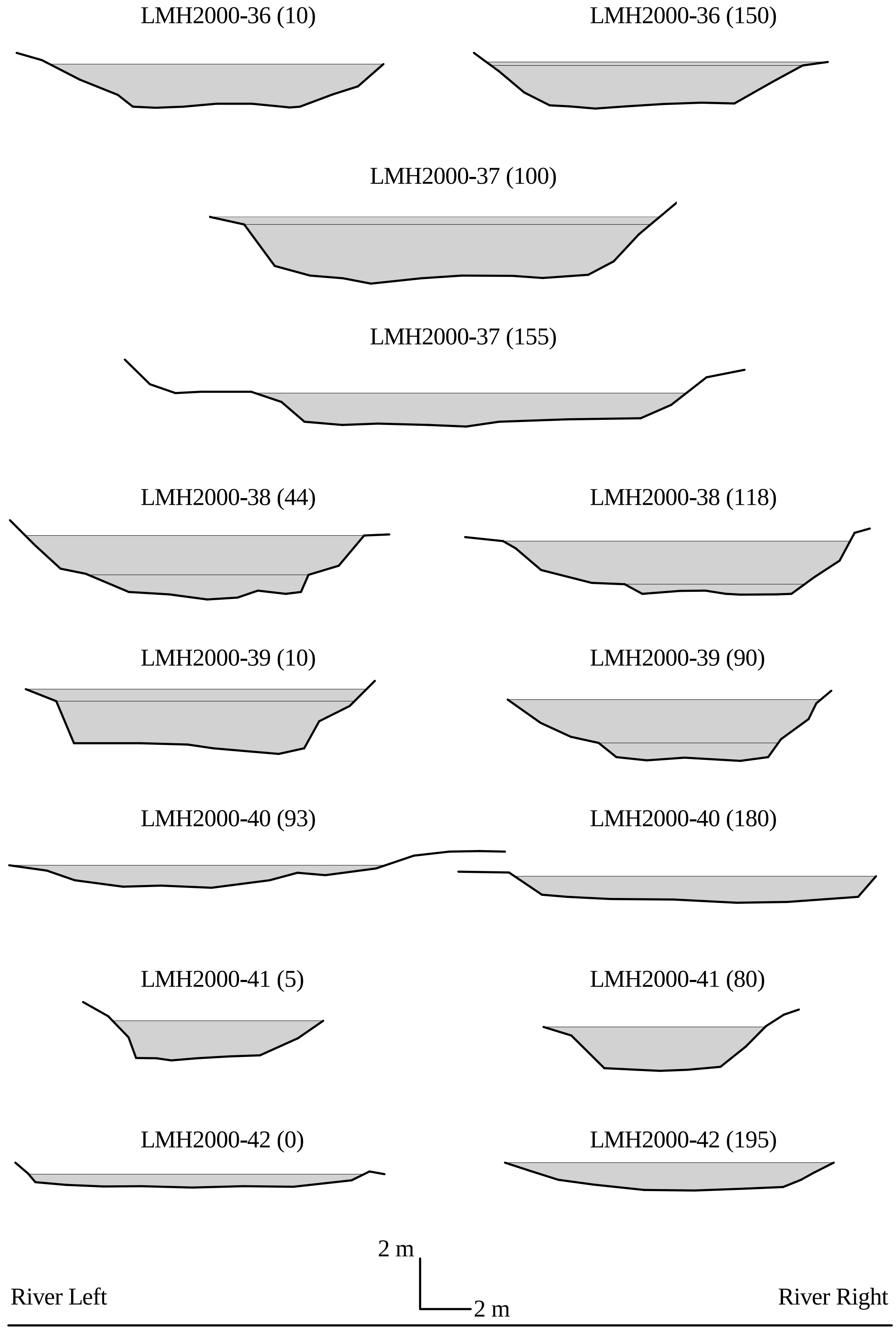
APPENDIX D. Stream cross-sections and 'bankfull' area. Width and depth are shown with no exaggeration using a scale of 1:250. Number in parentheses is distance along the transect. If two lines mark the 'bankfull' area then the average area was used in calculations.



APPENDIX D. Stream cross-sections and 'bankfull' area. Width and depth are shown with no exaggeration using a scale of 1:250. Number in parentheses is distance along the transect. If two lines mark the 'bankfull' area then the average area was used in calculations.



APPENDIX D. Stream cross-sections and 'bankfull' area. Width and depth are shown with no exaggeration using a scale of 1:250. Number in parentheses is distance along the transect. If two lines mark the 'bankfull' area then the average area was used in calculations.



APPENDIX D. Stream cross-sections and 'bankfull' area. Width and depth are shown with no exaggeration using a scale of 1:250. Number in parentheses is distance along the transect. If two lines mark the 'bankfull' area then the average area was used in calculations.

APPENDIX E. GEOMORPHIC-HABITAT SAMPLING DATA

Sorted by Field Number

APPENDIX E. Geomorphic-Habitat Sampling Data for All Sites

Variable[1]	Variable Group[2]	LMH2000-01	LMH2000-02	LMH2000-03	LMH2000-04	LMH2000-05	LMH2000-06	LMH2000-07
SIZECLASS	size	400	400	50	15	150	150	50
WSHEDAREA		463.9	361.6	46.7	16.8	138.7	150.6	65.6
LINK-ORD		361	379	80	29	152	191	73
DIST-UPST		79.8	37.9	16.1	8.6	34.9	34.4	15.0
SUBBAS-C	setting	SUBBAS	SUBBAS	SUBBAS	SUBBAS	SUBBAS	TRIS	TRIS
DSIZECAT		> 400	> 400	400	50	400	> 400	150
DRAIN-DENSITY	ruggedness and elevation	1.428	1.120	1.859	1.923	1.585	1.522	1.454
REL-RELIEF		0.00330	0.00351	0.00129	0.00079	0.00170	0.00204	0.00174
MELTONSRUG		0.00657	0.00590	0.02140	0.02693	0.01162	0.01092	0.01648
ELEVMIN		193	210	213	229	230	162	160
RD-DENSE-L	road	1.749	1.875	1.852	1.986	1.833	1.987	1.652
RD-CROSS		0.550	0.586	0.941	0.775	0.598	0.777	0.533
FRAG_TOT	impound-ment	74.8	55.5	36.0	28.5	61.5	58.6	45.3
IMP-DENSE		0.31	0.46	0.98	0.83	0.66	0.90	1.08
IMP-DWNDIST		45.5	22.6	18.9	26.4	33.3	22.1	26.9
ORD1-LOSS		34.9	54.6	52.5	31.0	43.4	62.8	72.6
EGL	slope	0.0008	0.0008	0.0053	0.0006	0.0031	0.0048	0.0009
MAPSLOPE		0.0005	0.0007	0.0016	0.0037	0.0014	0.0034	0.0006
DEMSLOPE		0.0002	0.0016	0.0016	0.0039	0.0010	0.0024	0.0013
DBKF	channel dimensions	1.92	2.57	1.06	1.05	1.69	1.36	2.15
RBKF		1.78	2.32	0.96	0.91	1.51	1.29	1.87
WWBKF		26.54	24.95	10.94	8.90	16.22	20.15	17.60
XCABKF		50.87	64.14	11.58	9.37	27.37	27.49	37.89
QBKF		37.51	56.23	25.77	5.65	35.25	34.23	33.67
QBKF/Q2		0.29	0.51	0.83	0.34	0.57	0.53	0.87
DBASE		0.38	0.27	0.32	0.19	0.41	0.60	0.17
WWBASE		15.05	14.06	7.50	5.70	12.65	14.39	5.77
N-FINAL		0.041	0.037	0.032	0.041	0.046	0.058	0.037
AVGPHIBR	channel bed sediments	-0.85	-0.67	-3.16	-0.85	-1.71	-5.24	-1.64
STDPHIBR		1.08	0.82	4.23	1.15	2.49	4.77	2.34
CVPHIBR		-1.28	-1.23	-1.34	-1.36	-1.45	-0.91	-1.43
AVGPHI		-0.85	-0.67	-1.12	-0.75	-1.44	-2.07	-1.37
STDPHI		1.08	0.82	1.89	0.62	1.98	3.10	1.77
CVPHI		-1.28	-1.23	-1.69	-0.83	-1.37	-1.50	-1.29
STRMPOWF	transport capacity	276.0	441.3	1333.7	34.2	1074.3	1597.4	290.9
U-STRMPOWF		10.4	17.7	121.9	3.8	66.2	79.3	16.5
STRMPOWM		665.0	806.0	487.0	603.0	835.0	2141.3	237.2
U-STRMPOWM		25.1	32.3	44.5	67.8	51.5	106.3	13.5
BAGNOLDWC		0.091	0.079	0.773	0.085	0.207	5.631	0.198
BAGRATIO		3041.7	5612.1	1725.6	401.7	5201.8	283.7	1469.1
%WOODYD	habitat	17.8	7.9	12.9	18.8	16.8	3.0	3.0
Residuals of DIST-UPST								
Residuals IBISCORE		-5.146	-7.172	4.391	-7.269	-4.734	-0.657	9.783
Residuals Richness		-4.777	-4.506	0.251	-1.999	-2.145	-4.081	1.574
Residuals DIVERSITY		0.015	0.105	-0.388	0.027	0.067	-0.148	-0.325

1 See Appendix B for description of each variable.

2 Also, see Figures 8 (land cover), 9 (land cover), 10 (habitat classes), 11 (sediment classes)

APPENDIX E. Geomorphic-Habitat Sampling Data for All Sites

Variable[1]	Variable Group[2]	LMH2000-09	LMH2000-10	LMH2000-11	LMH2000-12	LMH2000-13	LMH2000-14	LMH2000-15
SIZECLASS	size	50	15	150	400	50	15	50
WSHEDAREA		42.0	22.7	159.3	321.5	55.5	18.2	43.9
LINK-ORD		49	25	175	413	80	18	43
DIST-UPST		11.5	10.2	28.3	53.6	10.5	7.0	18.0
SUBBAS-C	setting	TRIS	TRIR	SUBBAS	SUBBAS	TRIS	SUBBAS	SUBBAS
DSIZECAT		> 400	50	400	> 400	150	50	150
DRAIN-DENSITY	ruggedness and elevation	1.542	1.574	1.124	1.421	1.655	1.711	1.495
REL-RELIEF		0.00122	0.00088	0.00220	0.00295	0.00165	0.00083	0.00103
MELTONSRUG		0.01635	0.02253	0.00618	0.00886	0.01967	0.01300	0.01073
ELEVMIN		146	174	219	206	217	266	272
RD-DENSE-L	road	0.917	1.309	2.420	1.887	2.819	1.680	2.500
RD-CROSS		0.238	0.440	0.458	0.675	1.262	0.714	1.298
FRAG_TOT	impound-ment	39.0	31.9	49.3	64.1	44.2	49.6	56.5
IMP-DENSE		0.50	0.79	0.43	0.71	1.08	0.11	0.16
IMP-DWNDIST		15.5	17.6	33.4	16.0	46.5	93.0	105.9
ORD1-LOSS		46.9	52.0	49.1	49.4	73.8	16.7	20.9
EGL	slope	0.0006	0.0009	0.0005	0.0033	0.0017	0.0318	0.0001
MAPSLOPE		0.0022	0.0024	0.0022	0.0010	0.0015	0.0050	0.0031
DEMSLOPE		0.0083	0.0028	0.0025	0.0014	0.0007	0.0033	0.0031
DBKF	channel dimensions	1.21	0.91	2.43	1.30	1.14	1.00	0.87
RBKF		1.08	0.85	2.14	1.24	1.03	0.87	0.83
WWBKF		11.18	12.90	19.71	30.59	10.04	10.26	12.64
XCABKF		13.52	11.70	47.82	39.69	11.39	10.27	10.99
QBKF		9.05	9.57	30.69	47.02	13.09	22.47	2.36
QBKF/Q2		0.31	0.48	0.46	0.45	0.38	1.30	0.08
DBASE		0.10	0.12	0.23	0.34	0.22	0.13	0.23
WWBASE		4.75	3.22	10.00	21.47	6.38	4.22	6.19
N-FINAL		0.037	0.036	0.040	0.050	0.036	0.080	0.047
AVGPHIBR	channel bed sediments	-0.63	-0.97	-1.11	-2.96	-0.72	-6.46	-1.78
STDPHIBR		0.43	1.63	1.18	3.81	0.57	3.34	2.00
CVPHIBR		-0.68	-1.68	-1.06	-1.29	-0.78	-0.52	-1.12
AVGPHI		-0.63	-0.78	-1.11	-1.75	-0.72	-5.06	-1.69
STDPHI		0.43	0.91	1.18	2.47	0.57	2.71	1.81
CVPHI		-0.68	-1.17	-1.06	-1.41	-0.78	-0.53	-1.07
STRMPOWF	transport capacity	51.8	87.6	154.8	1508.6	223.4	7019.0	2.5
U-STRMPOWF		4.6	6.8	7.9	49.3	22.3	684.2	0.2
STRMPOWM		632.9	461.6	1451.9	1022.2	495.2	851.0	925.6
U-STRMPOWM		56.6	35.8	73.7	33.4	49.3	83.0	73.2
BAGNOLDWC		0.070	0.094	0.120	0.658	0.076	16.150	0.203
BAGRATIO		734.9	928.8	1286.5	2292.8	2933.3	434.6	12.5
%WOODYD	habitat	9.9	11.9	16.8	20.8	24.8	28.7	7.9
Residuals of DIST-UPST								
Residuals IBISCORE		-10.814	-8.173	-3.614	0.978	-18.348	13.829	8.793
Residuals Richness		-3.271	-3.744	-3.222	-2.028	-4.888	1.904	-1.241
Residuals DIVERSITY		0.738	-0.010	-0.077	0.031	0.194	-0.553	-0.212

1 See Appendix B for description of each variable.

2 Also, see Figures 8 (land cover), 9 (land cover), 10 (habitat classes), 11 (sediment classes)

APPENDIX E. Geomorphic-Habitat Sampling Data for All Sites

Variable[1]	Variable Group[2]	LMH2000-16	LMH2000-17	LMH2000-18	LMH2000-19	LMH2000-20	LMH2000-21	LMH2000-22
SIZECLASS	size	15	150	15	50	50	15	50
WSHEDAREA		17.0	135.3	13.7	48.8	42.3	17.5	40.4
LINK-ORD		14	128	15	58	49	19	29
DIST-UPST		9.8	35.7	5.4	17.3	18.2	7.4	14.2
SUBBAS-C	setting	SUBBAS	SUBBAS	SUBBAS	SUBBAS	SUBBAS	SUBBAS	SUBBAS
DSIZECAT		50	400	50	150	150	50	150
DRAIN-DENSITY	ruggedness and elevation	1.262	1.633	1.643	1.625	1.815	1.693	1.412
REL-RELIEF		0.00073	0.00200	0.00078	0.00115	0.00124	0.00085	0.00123
MELTONSRUG		0.01110	0.00953	0.01416	0.01014	0.01253	0.01255	0.01090
ELEVMIN		297	240	251	239	253	271	238
RD-DENSE-L	road	2.764	1.922	2.338	1.998	2.316	1.926	2.187
RD-CROSS		0.884	0.761	0.509	0.656	0.876	0.401	0.941
FRAG_TOT	impound-ment	52.8	67.1	30.1	35.2	19.9	23.9	17.2
IMP-DENSE		0.12	0.24	0.44	0.31	0.26	0.06	0.32
IMP-DWNDIST		114.3	88.2	48.0	43.7	54.1	31.1	15.5
ORD1-LOSS		14.3	25.0	33.3	46.6	95.9	5.3	58.6
EGL	slope	0.0028	0.0019	0.0036	0.0005	0.0062	0.0033	0.0104
MAPSLOPE		0.0058	0.0013	0.0031	0.0025	0.0016	0.0048	0.0039
DEMSLOPE		0.0011	0.0012	0.0028	0.0060	0.0020	0.0060	0.0045
DBKF	channel dimensions	1.19	1.84	1.24	1.98	1.94	1.77	1.92
RBKF		1.10	1.63	1.06	1.73	1.78	1.54	1.69
WWBKF		11.98	17.05	8.62	14.14	18.94	14.04	14.51
XCABKF		14.28	31.31	10.69	27.95	36.71	24.80	27.83
QBKF		15.52	40.00	17.00	16.55	70.69	31.45	60.16
QBKF/Q2		0.93	0.66	1.17	0.52	2.41	1.86	2.11
DBASE		0.22	0.22	0.13	0.17	0.22	0.21	0.17
WWBASE		4.05	8.77	4.26	5.93	6.35	5.52	6.31
N-FINAL		0.049	0.037	0.038	0.042	0.045	0.049	0.051
AVGPHIBR	channel bed sediments	-3.34	-0.68	-1.53	-1.50	-2.28	-3.10	-2.79
STDPHIBR		3.02	0.56	1.82	1.66	2.19	2.66	3.73
CVPHIBR		-0.90	-0.83	-1.19	-1.11	-0.96	-0.86	-1.34
AVGPHI		-2.97	-0.68	-1.53	-1.50	-2.12	-2.79	-1.55
STDPHI		2.60	0.56	1.82	1.66	1.87	2.24	2.23
CVPHI		-0.88	-0.83	-1.19	-1.11	-0.88	-0.80	-1.44
STRMPOWF	transport capacity	421.0	737.3	606.3	85.2	4319.3	1020.5	6137.4
U-STRMPOWF		35.1	43.2	70.4	6.0	228.0	72.7	423.0
STRMPOWM		937.5	777.7	448.9	788.7	472.1	799.1	1085.2
U-STRMPOWM		78.2	45.6	52.1	55.8	24.9	56.9	74.8
BAGNOLDWC		0.933	0.077	0.167	0.171	0.362	0.780	0.589
BAGRATIO		451.2	9623.4	3623.2	498.9	11920.6	1308.7	10425.8
%WOODYD	habitat	1.0	7.9	6.9	8.9	8.9	2.0	27.7
Residuals of DIST-UPST								
Residuals IBISCORE		14.035	1.145	6.183	4.995	6.746	-0.482	6.065
Residuals Richness		2.427	3.756	1.019	0.925	1.720	-1.352	3.806
Residuals DIVERSITY		-0.537	-0.299	0.330	-0.100	-0.522	-0.238	-0.470

1 See Appendix B for description of each variable.

2 Also, see Figures 8 (land cover), 9 (land cover), 10 (habitat classes), 11 (sediment classes)

APPENDIX E. Geomorphic-Habitat Sampling Data for All Sites

Variable[1]	Variable Group[2]	LMH2000-23	LMH2000-24	LMH2000-25	LMH2000-26	LMH2000-27	LMH2000-28	LMH2000-29
SIZECLASS	size	50	15	150	400	400	50	15
WSHEDAREA		39.8	16.3	109.6	354.2	400.4	36.1	14.0
LINK-ORD		32	13	137	251	317	29	12
DIST-UPST		14.7	9.5	36.0	53.0	44.4	8.9	5.0
SUBBAS-C	setting	SUBBAS	TRIS	TRIS	SUBBAS	SUBBAS	TRIR	SUBBAS
DSIZECAT		150	50	150	> 400	400	Reservoir	50
DRAIN-DENSITY	ruggedness and elevation	1.269	1.299	1.641	1.250	1.336	1.261	1.353
REL-RELIEF		0.00111	0.00085	0.00152	0.00332	0.00416	0.00134	0.00086
MELTONSRUG		0.01526	0.01724	0.01340	0.00838	0.00937	0.01740	0.01740
ELEVMIN		185	218	171	121	134	147	199
RD-DENSE-L	road	1.286	1.330	2.070	1.419	1.378	2.138	1.740
RD-CROSS		0.502	0.491	0.930	0.449	0.462	0.775	0.641
FRAG_TOT	impound-ment	42.2	8.6	36.4	71.2	51.3	39.7	14.7
IMP-DENSE		0.55	0.61	0.83	0.59	0.63	0.80	0.71
IMP-DWNDIST		29.6	11.3	0.7	24.2	5.7	10.0	7.0
ORD1-LOSS		50.0	84.6	62.0	67.7	71.9	82.8	58.3
EGL	slope	0.0015	0.0030	0.0028	0.0014	0.0008	0.0018	0.0089
MAPSLOPE		0.0028	0.0023	0.0032	0.0007	0.0009	0.0028	0.0073
DEMSLOPE		0.0023	0.0022	0.0017	0.0005	0.0002	0.0052	0.0066
DBKF	channel dimensions	1.79	1.17	1.60	2.66	1.77	1.52	0.91
RBKF		1.42	1.03	1.47	2.27	1.65	1.32	0.83
WWBKF		9.53	9.75	17.73	19.56	20.42	15.64	10.76
XCABKF		17.09	11.36	28.29	51.95	36.08	23.84	9.75
QBKF		19.00	11.40	48.44	60.06	25.65	24.31	21.53
QBKF/Q2		0.67	0.70	0.91	0.55	0.22	0.92	1.46
DBASE		0.24	0.12	0.11	0.16	0.33	0.09	0.18
WWBASE		5.81	5.31	5.16	7.21	7.08	3.69	4.99
N-FINAL		0.037	0.055	0.033	0.037	0.044	0.043	0.042
AVGPHIBR	channel bed sediments	-1.06	-2.77	-0.87	-1.25	-1.56	-0.84	-5.18
STDPHIBR		2.02	2.73	1.20	2.35	2.84	0.94	4.79
CVPHIBR		-1.90	-0.98	-1.38	-1.88	-1.82	-1.12	-0.92
AVGPHI		-0.67	-2.77	-0.78	-0.77	-0.99	-0.84	-1.55
STDPHI		0.62	2.73	0.72	1.05	1.78	0.94	2.40
CVPHI		-0.92	-0.98	-0.92	-1.36	-1.79	-1.12	-1.55
STRMPOWF	transport capacity	276.2	333.4	1330.4	824.9	206.9	421.9	1890.2
U-STRMPOWF		29.0	34.2	75.0	42.2	10.1	27.0	175.6
STRMPOWM		763.9	372.5	1642.7	724.6	1087.3	721.2	1063.6
U-STRMPOWM		80.1	38.2	92.6	37.0	53.3	46.1	98.8
BAGNOLDWC		0.111	0.542	0.091	0.139	0.179	0.088	4.973
BAGRATIO		2489.1	614.9	14573.3	5945.0	1158.2	4788.2	380.1
%WOODYD	habitat	23.8	8.9	14.9	19.8	36.6	7.9	1.0
Residuals of DIST-UPST								
Residuals IBISCORE		5.887	4.189	-2.897	11.035	1.979	-7.434	7.580
Residuals Richness		-0.340	-1.445	-4.279	4.019	4.796	-3.135	2.346
Residuals DIVERSITY		0.346	0.360	0.520	0.647	0.315	0.598	-0.301

1 See Appendix B for description of each variable.

2 Also, see Figures 8 (land cover), 9 (land cover), 10 (habitat classes), 11 (sediment classes)

APPENDIX E. Geomorphic-Habitat Sampling Data for All Sites

Variable[1]	Variable Group[2]	LMH2000-30	LMH2000-31	LMH2000-32	LMH2000-33	LMH2000-34	LMH2000-35	LMH2000-36
SIZECLASS	size	50	15	150	15	150	15	15
WSHEDAREA		76.2	12.8	170.6	17.1	137.7	25.2	16.6
LINK-ORD		73	9	140	16	110	17	12
DIST-UPST		22.7	10.6	35.4	5.8	19.3	11.5	9.2
SUBBAS-C	setting	SUBBAS	SUBBAS	SUBBAS	SUBBAS	SUBBAS	TRIS	TRIS
DSIZECAT		150	50	400	50	400	> 400	> 400
DRAIN-DENSITY	ruggedness and elevation	1.375	1.167	1.333	1.393	1.285	1.297	1.488
REL-RELIEF		0.00169	0.00056	0.00246	0.00102	0.00267	0.00097	0.00083
MELTONSRUG		0.01441	0.01828	0.01029	0.01848	0.01267	0.01232	0.01903
ELEVMIN		157	162	139	195	169	141	141
RD-DENSE-L	road	1.726	2.218	1.328	1.912	1.794	0.825	1.502
RD-CROSS		0.788	0.938	0.486	0.526	0.690	0.198	1.205
FRAG_TOT	impound-ment	68.3	63.0	63.4	71.2	69.5	31.4	23.3
IMP-DENSE		0.89	1.02	0.63	0.64	0.62	0.16	0.24
IMP-DWNDIST		47.4	50.9	10.2	71.7	57.4	13.2	4.9
ORD1-LOSS		76.7	88.9	61.4	62.5	64.5	23.5	25.0
EGL	slope	0.0043	0.0004	0.0006	0.0034	0.0014	0.0023	0.0017
MAPSLOPE		0.0020	0.0033	0.0009	0.0043	0.0013	0.0020	0.0042
DEMSLOPE		0.0008	0.0031	0.0027	0.0033	0.0018	0.0036	0.0012
DBKF	channel dimensions	1.39	1.39	1.41	0.77	0.59	0.50	1.27
RBKF		1.22	1.20	1.29	0.61	0.58	0.46	1.19
WWBKF		11.56	9.55	15.95	8.27	15.80	13.41	13.00
XCABKF		16.11	13.26	22.57	6.40	9.40	6.69	16.54
QBKF		22.99	7.24	13.66	8.01	8.12	6.87	21.61
QBKF/Q2		0.54	0.52	0.20	0.48	0.13	0.32	1.32
DBASE		0.24	0.20	0.49	0.09	0.19	0.09	0.09
WWBASE		4.24	3.21	11.08	3.42	5.06	5.16	3.03
N-FINAL		0.048	0.037	0.041	0.043	0.040	0.041	0.033
AVGPHIBR	channel bed sediments	-0.86	-1.94	-0.90	-0.83	-0.84	-0.50	-0.70
STDPHIBR		1.05	3.29	1.96	0.73	0.92	0.00	0.50
CVPHIBR		-1.22	-1.70	-2.19	-0.89	-1.10	0.00	-0.71
AVGPHI		-0.86	-1.00	-0.50	-0.83	-0.84	-0.50	-0.70
STDPHI		1.05	1.74	0.00	0.73	0.92	0.00	0.50
CVPHI		-1.22	-1.73	0.00	-0.89	-1.10	0.00	-0.71
STRMPOWF	transport capacity	973.2	26.6	74.4	265.3	114.8	154.9	362.9
U-STRMPOWF		84.2	2.8	4.7	32.1	7.3	11.6	27.9
STRMPOWM		844.3	445.1	629.7	699.1	752.3	415.9	675.2
U-STRMPOWM		73.0	46.6	39.5	84.5	47.6	31.0	51.9
BAGNOLDWC		0.089	0.251	0.092	0.081	0.079	0.056	0.076
BAGRATIO		10901.0	105.9	807.5	3287.0	1457.5	2769.5	4796.4
%WOODYD	habitat	39.6	14.9	22.8	11.9	21.8	7.9	11.9
Residuals of DIST-UPST								
Residuals IBISCORE		-4.456	13.641	1.181	-7.169	16.416	-0.837	-5.634
Residuals Richness		3.731	3.104	2.785	-0.270	12.448	-2.290	-2.300
Residuals DIVERSITY		-0.014	-0.464	-0.358	0.574	-0.627	0.143	0.428

1 See Appendix B for description of each variable.

2 Also, see Figures 8 (land cover), 9 (land cover), 10 (habitat classes), 11 (sediment classes)

APPENDIX E. Geomorphic-Habitat Sampling Data for All Sites

Variable[1]	Variable Group[2]	LMH2000-37	LMH2000-38	LMH2000-39	LMH2000-40	LMH2000-41	LMH2000-42	LMH2000-43
SIZECLASS	size	50	50	15	50	50	150	150
WSHEDAREA		56.4	50.0	23.0	64.9	30.6	167.0	152.6
LINK-ORD		75	43	32	57	28	121	153
DIST-UPST		10.3	14.1	8.8	10.5	16.1	32.6	24.7
SUBBAS-C	setting	TRIR	TRIR	TRIS	TRIR	TRIR	TRIS	TRIS
DSIZECAT		Reservoir	Reservoir	50	Reservoir	Reservoir	> 400	> 400
DRAIN-DENSITY	ruggedness and elevation	1.561	1.477	1.691	1.524	1.555	1.320	1.479
REL-RELIEF		0.00162	0.00134	0.00098	0.00177	0.00091	0.00233	0.00248
MELTONSRUG		0.02045	0.01922	0.02748	0.01654	0.01884	0.01197	0.01157
ELEVMIN		143	149	231	145	143	184	138
RD-DENSE-L	road	1.709	1.354	1.990	0.774	0.955	1.856	1.261
RD-CROSS		0.709	0.360	1.089	0.170	0.098	0.695	0.308
FRAG_TOT	impound-ment	55.5	53.6	15.2	49.7	38.3	19.8	50.1
IMP-DENSE		1.01	0.30	1.05	0.28	0.13	0.50	0.67
IMP-DWNDIST		5.3	11.1	27.8	7.0	6.9	27.4	17.6
ORD1-LOSS		60.0	27.9	100.0	31.6	10.7	90.1	62.1
EGL	slope	0.0098	0.0038	0.0024	0.0025	0.0017	0.0005	
MAPSLOPE		0.0027	0.0020	0.0016	0.0019	0.0022	0.0011	0.0005
DEMSLOPE		0.0013	0.0007	0.0008	0.0010	0.0035	0.0016	0.0019
DBKF	channel dimensions	1.60	1.27	1.54	0.78	1.18	0.56	
RBKF		1.47	1.00	1.24	0.68	1.04	0.61	
WWBKF		16.95	10.74	11.18	13.13	8.55	14.59	
XCABKF		27.12	13.65	17.17	10.21	10.12	8.17	
QBKF		74.74	20.24	16.16	13.33	13.00	4.26	
QBKF/Q2		2.13	0.62	0.81	0.35	0.54	0.06	
DBASE		0.14	0.35	0.27	0.26	0.08	0.33	
WWBASE		3.25	5.18	5.95	9.04	2.27	10.46	
N-FINAL		0.038	0.041	0.054	0.036	0.032	0.040	
AVGPHIBR	channel bed sediments	-2.12	-4.71	-1.88	-0.50	-0.50	-0.77	
STDPHIBR		3.16	4.88	1.74	0.00	0.00	1.15	
CVPHIBR		-1.49	-1.04	-0.93	0.00	0.00	-1.50	
AVGPHI		-1.50	-0.91	-1.88	-0.50	-0.50	-0.77	
STDPHI		2.24	1.61	1.74	0.00	0.00	1.15	
CVPHI		-1.50	-1.77	-0.93	0.00	0.00	-1.50	
STRMPOWF	transport capacity	7172.6	750.6	384.3	332.4	219.3	21.5	
U-STRMPOWF		423.2	69.9	34.4	25.3	25.7	1.5	
STRMPOWM		939.4	644.4	304.8	707.1	509.8	748.7	
U-STRMPOWM		55.4	60.0	27.3	53.9	59.6	51.3	
BAGNOLDWC		0.303	3.389	0.240	0.059	0.062	0.073	
BAGRATIO		23656.8	221.5	1603.8	5642.1	3553.2	294.2	
%WOODYD	habitat	10.9	6.9	15.8	8.9	8.9	18.8	
Residuals of DIST-UPST								
Residuals IBISCORE		-2.231	-11.916	-5.404	1.692	-12.602	5.628	-2.898
Residuals Richness		5.209	-0.179	0.890	0.146	-7.743	5.153	-2.634
Residuals DIVERSITY		-0.409	0.374	-0.089	-0.093	0.613	-0.322	0.278

1 See Appendix B for description of each variable.

2 Also, see Figures 8 (land cover), 9 (land cover), 10 (habitat classes), 11 (sediment classes)

APPENDIX E. Geomorphic-Habitat Sampling Data for All Sites

Variable[1]	Variable Group[2]	USGS2000-02	USGS2000-03	USGS2000-06	USGS2000-13	USGS2000-16	USGS2000-17	USGS2000-23
SIZECLASS	size	1200	15	15	1200	400	150	15
WSHEDAREA		1010.7	15.7	27.9	599.8	284.3	169.5	16.5
LINK-ORD		953	17	21	431	259	124	22
DIST-UPST		74.1	6.5	9.1	63.0	38.6	32.0	7.8
SUBBAS-C	setting	SUBBAS	SUBBAS	SUBBAS	SUBBAS	SUBBAS	SUBBAS	TRIS
DSIZECAT		> 400	400	50	600	600	400	50
DRAIN-DENSITY	ruggedness and elevation	1.494	1.440	1.261	1.272	1.539	1.258	1.675
REL-RELIEF		0.00583	0.00084	0.00118	0.00460	0.00339	0.00228	0.00080
MELTONSRUG		0.00631	0.01941	0.01649	0.00809	0.00824	0.00997	0.02958
ELEVMIN		170	255	217	113	219	151	236
RD-DENSE-L	road	1.971	1.505	1.805	1.415	1.986	1.375	2.205
RD-CROSS		0.741	0.509	0.503	0.472	0.819	0.425	1.211
FRAG_TOT	impound-ment	6.8	17.9	28.1	75.5	5.7	18.1	15.7
IMP-DENSE		0.47	0.95	0.86	0.61	0.37	0.61	0.67
IMP-DWNDIST		24.2	39.0	60.5	15.3	35.8	18.1	28.9
ORD1-LOSS		95.6	100.0	100.0	67.5	100.0	88.7	100.0
EGL	slope							
MAPSLOPE		0.0007	0.0032	0.0131	0.0023	0.0104	0.0010	0.0075
DEMSLOPE		0.0052	0.0005	0.0011	0.0025	0.0003	0.0008	0.0067
DBKF	channel dimensions							
RBKF								
WWBKF								
XCABKF								
QBKF								
QBKF/Q2								
DBASE								
WWBASE								
N-FINAL								
AVGPHIBR	channel bed sediments							
STDPHIBR								
CVPHIBR								
AVGPHI								
STDPHI								
CVPHI								
STRMPOWF	transport capacity							
U-STRMPOWF								
STRMPOWM								
U-STRMPOWM								
BAGNOLDWC								
BAGRATIO								
%WOODYD	habitat							
Residuals of DIST-UPST								
Residuals IBISCORE		-8.749	-3.801	0.424	2.116	6.730	-4.273	-8.735
Residuals Richness		-6.450	0.209	2.748	2.263	3.414	4.235	-6.560
Residuals DIVERSITY		0.149	-0.113	-0.289	-0.213	-0.169	-0.019	0.508

1 See Appendix B for description of each variable.

2 Also, see Figures 8 (land cover), 9 (land cover), 10 (habitat classes), 11 (sediment classes)

APPENDIX F. GEOGRAPHIC INFORMATION SYSTEM (GIS) DATA SOURCES

Appendix F. Geographic Information System (GIS) Data Sources

<u>Map Projection Information:</u>

Projection:	Universal Transverse Mercator (UTM)
Zone:	17
Datum:	NAD83
Spheroid:	GRS1980
Units:	Meters
Parameters:	None

<u>Data Sources:</u>

- Streams (linear hydrography)
  - Description: Streams and polygon artificial center-lines; based on the USGS 7.5 minute topographic quadrangle 'blue lines'
  - Scale: 1:24,000
  - Source: Prototype for 1:24,000 scale National Hydrography Dataset (NHD)
  - Year: 2000 (pre-release)
  - Notes: Primarily artificial centerlines were added where ponds, wetland, reservoirs, and double-lined rivers occurred

- Reservoirs, rivers, wetlands, and ponds (polygonal hydrography)
  - Description: Polygons primarily based on the USGS 7.5 minute topographic quadrangle polygons
  - Scale: 1:24,000
  - Source: Prototype for 1:24,000 scale National Hydrography Dataset (NHD)
  - Year: 2000 (pre-release)
  - Notes: Polygons were added and cleaned based on 1993 black and white DOQQ

- Streams (linear hydrography)
  - Description: Major streams, and some polygon artificial center-lines
  - Scale: 1:100,000
  - Source: USGS and US EPA National Hydrography Dataset (NHD)
  - Year: updated 2000, based on original Reach Files 3 (RF3)
  - Notes:

- Digitial Elevation Model (DEM) – National Elevation Dataset (NED)
  - Description: Elevation grid
  - Scale: 1:24,000, 30 x 30 meter resolution
  - Source: USGS
  - Year: publication data 1999
  - Notes: Improved edge matching and standardized datasets from 7.5 minute quadrangles

Appendix F. Geographic Information System (GIS) Data Sources

- Land Cover
  - Description: Multi-Resolution Land Characteristics Consortium (MRLC) Land Cover derived from Landsat Thematic Mapper Satellite Data
  - Scale: 30 meter resolution
  - Source: USGS
  - Year: source data 1989-1993; published 1999
  - Notes:

- Roads
  - Description: Georgia DLG-F Roads and Highways
  - Scale: 1:12,000
  - Source: GA Department of Transportation (DOT)
  - Year: 1997
  - Notes: Many have been updated and photorevised using 1993 digital ortho quarter quadrangles (DOQQ's) at 1:12,000-scale.

- Hydrologic Units (HUC)
  - Description: Hydrologic units and watershed boudaries; 12-digit HUCs
  - Scale: 1:24,000
  - Source: USGS
  - Year: publication date 2000
  - Notes: The boundaries were digitized from USGS 7.5 minute topographic quadrangles

- Georgia Physiographic Provinces
  - Description: Physiographic province boundaries (Coastal plain, Piedmont, etc)
  - Scale: 1:2,000,000
  - Source: GA Deparment of Natural Resources (DNR)
  - Year: 1996
  - Notes:

- USGS Gaging Stations
  - Description: Stream gaging station location and data
  - Scale: 1:100,000
  - Source: USGS
  - Year: publication date 1998
  - Notes:

- Digital Ortho-Photo Quarter Quadrangles (DOQQ)
  - Description: Black and white aerial photos corrected for topographic distortions (ortho-rectified)
  - Scale: 1:12,000 (~1 meter resolution)
  - Source: USGS
  - Year: 1993

Appendix F. Geographic Information System (GIS) Data Sources

- County Boundaries
  - Description: Georgia County Boundaries
  - Scale: 1:31,680
  - Source: GA Department of Transportation
  - Year: 1997
  - Notes:

- USGS Digital Raster Graphics (DRG)
  - Description: scanned USGS 7.5 minute topographic quadrangles
  - Scale: 1:24,000
  - Source: USGS
  - Year: published 1993; dates of quadrangles vary
  - Notes:

- Inventory of Dams
  - Description: USEPA inventory of dam locations
  - Scale: 1:100,000
  - Source: Federal Emergency Management Agency (FEMA) and USEPA and US Army Corps of Engineers
  - Year: 1998
  - Notes: Only larger dams regulated by federal or state agencies

APPENDIX G. FORMULAS USED IN GEOMORPHIC CALCULATIONS

APPENDIX G. Formulas used in calculations.

- From Arcement and Schneider (1989)
  Base n = Manning's equation roughness coefficient:

$$\text{Base } n = \frac{0.0926 * R_{bkf}^{1/6}}{1.16 + 2 * \log (R_{bkf} / d_{84})}$$

where, R_{bkf} = hydraulic radius at bankfull; d_{84} = the 84th percentile sediment size

- Manning equation for Mean velocity at bankfull (V_{bkf}):

$$V_{bkf} = R_{bkf}^{2/3} * EGL^{1/2} / n$$

where, n = roughness coefficient (estimated above),
R_{bkf} = hydraulic radius at bankfull and EGL = energy grade line

- Stream Power = p*g*Q*S,

where, p*g = density of water*gravitational constant = 9810 (N/m^3);
Qbkf = discharge at bankfull (m^3/s);
S = Energy Grade Line for STRMPOWF
S = MAPSLOPE for STRMPOWM

- Bagnold's (1980) critical stream power:

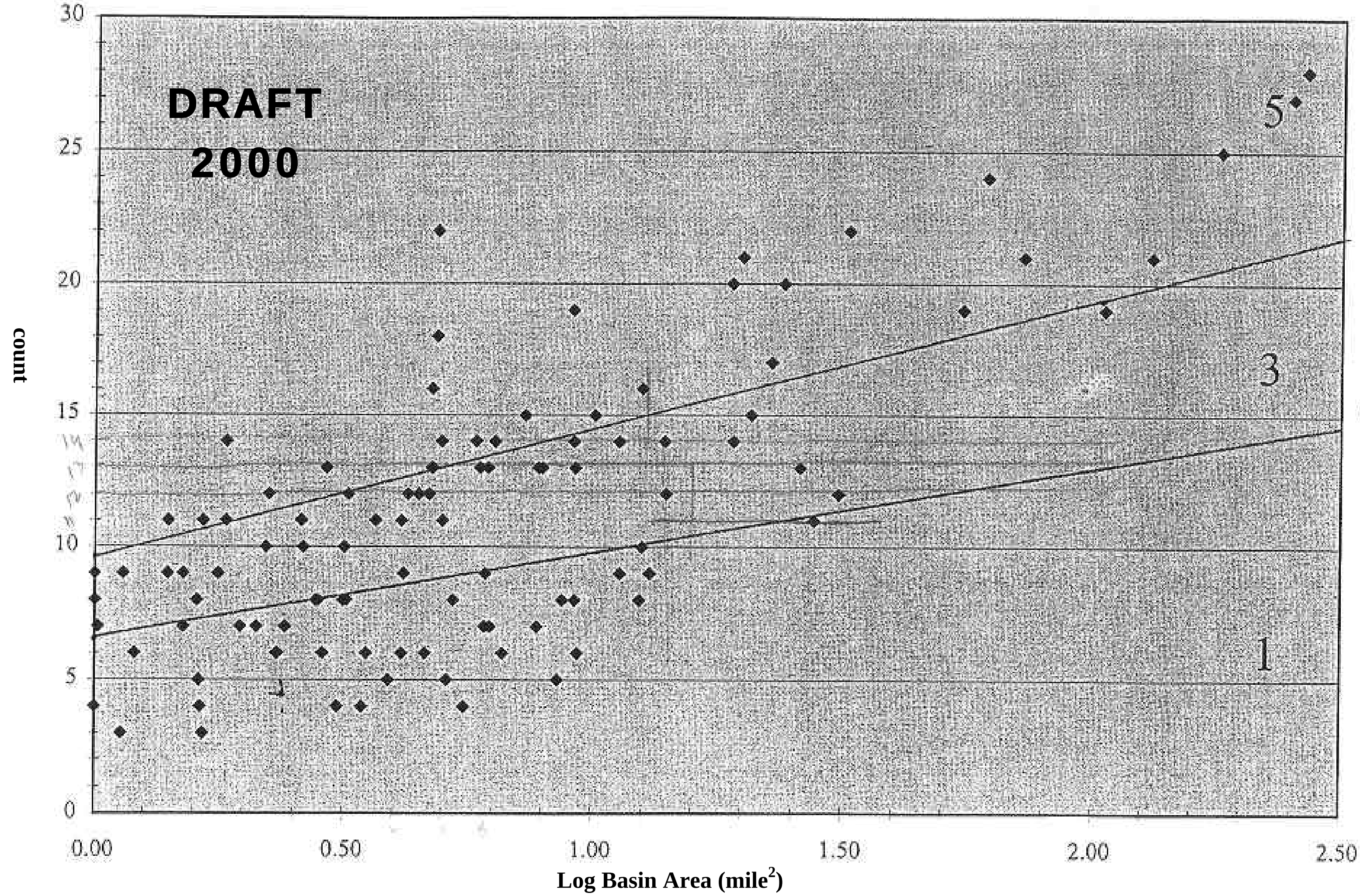
$$BAGNOLDWC = 290 * D^{3/2} * \log (12 * DBKF / D)$$

where, DBKF = average depth at bankfull (m),
D = average stream bed sediment diameter (m)

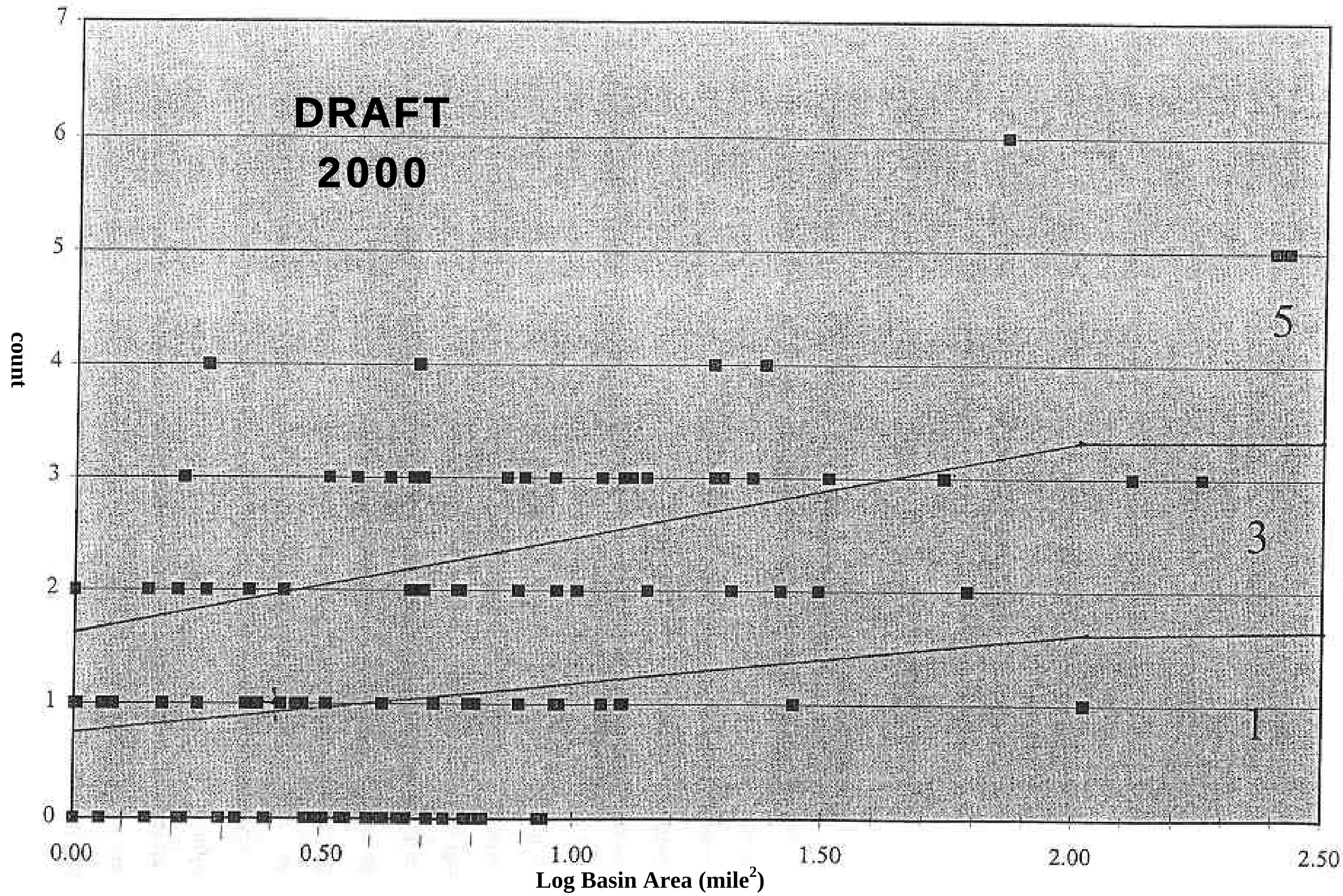
APPENDIX H. GA-DNR MEAN-SPECIES-RICHNESS PLOTS FOR IBI INTERPRETATION

Reproduced with permission from:
GA-DNR. 2000. DRAFT Standard operating procedures for conducting biomonitoring on fish communities in the Piedmont Ecoregion of Georgia. Georgia Department of Natural Resources, Wildlife Resources Division, Fisheries Section. Revised June 9, 2000.

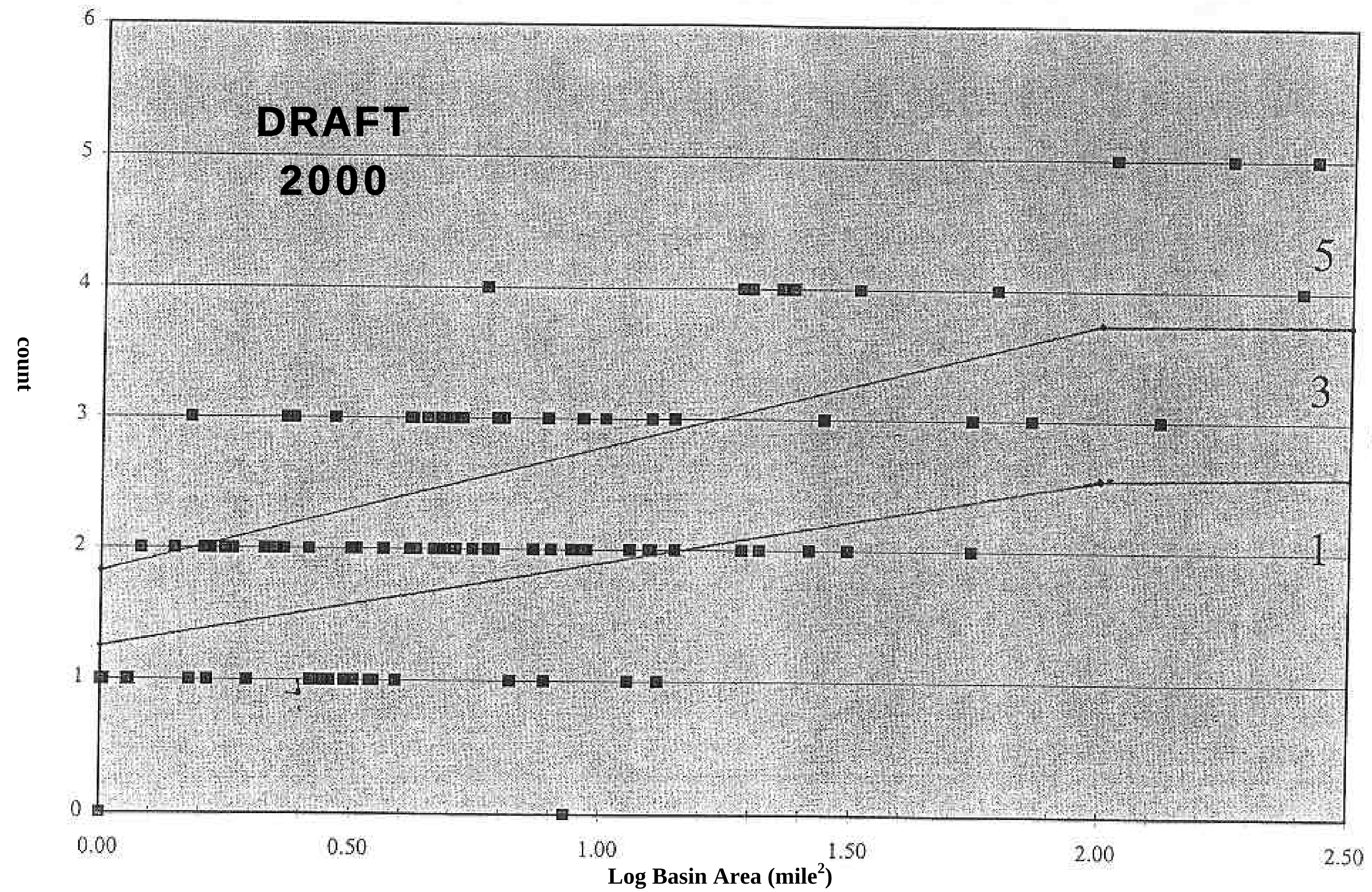
Note:
Shown here are only MSR plots for the Atlantic slope Piedmont drainages.
See GA-DNR for MSR plots forApalachicola Piedmont drainages.



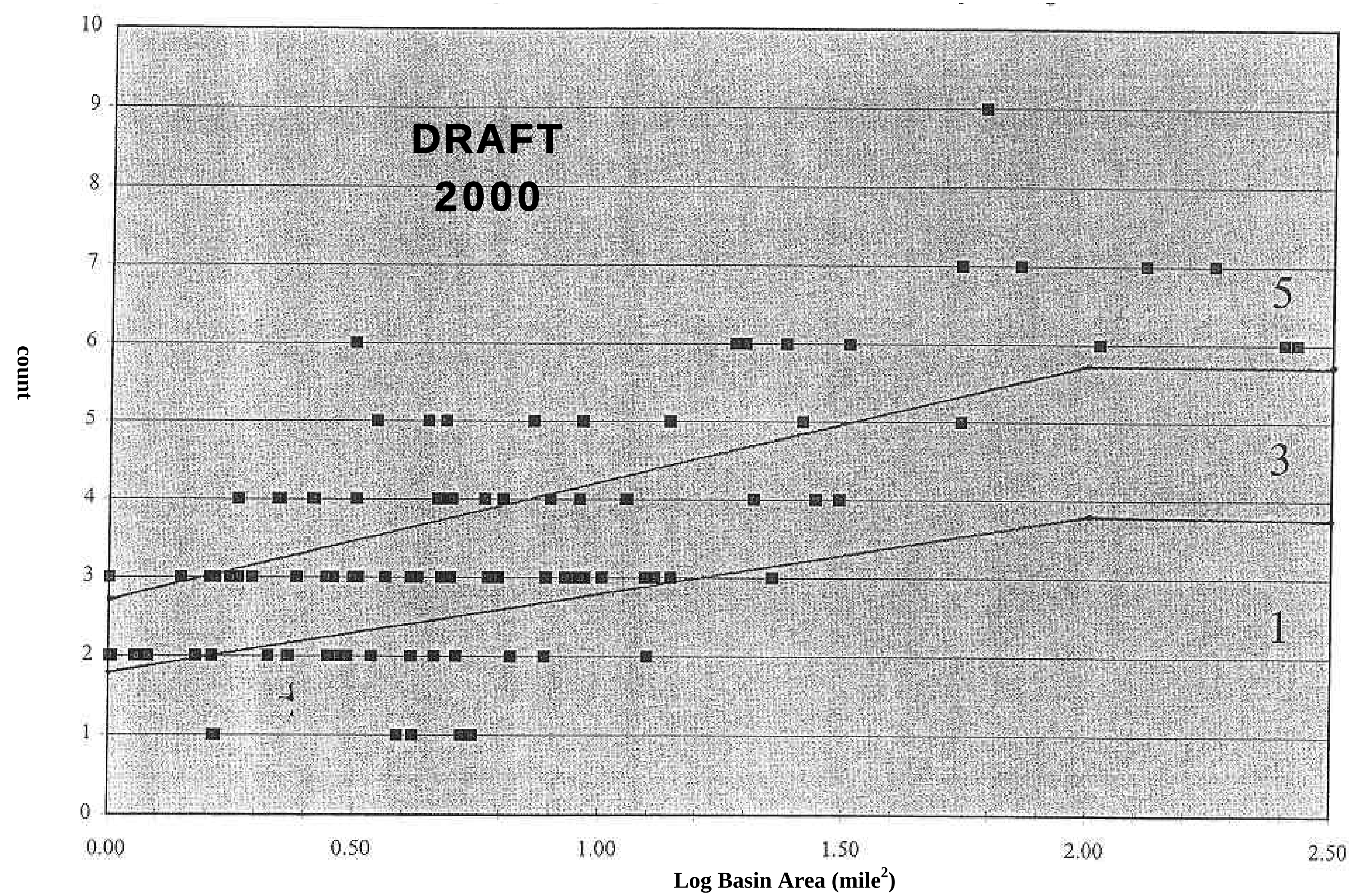
GA-DNR Index of Biotic Integrity Metric 1 plot.
Total number of native fish species vs. drainage basin area ($\log_{10}$ $mile^2$) for the Atlantic Slope drainage basins.



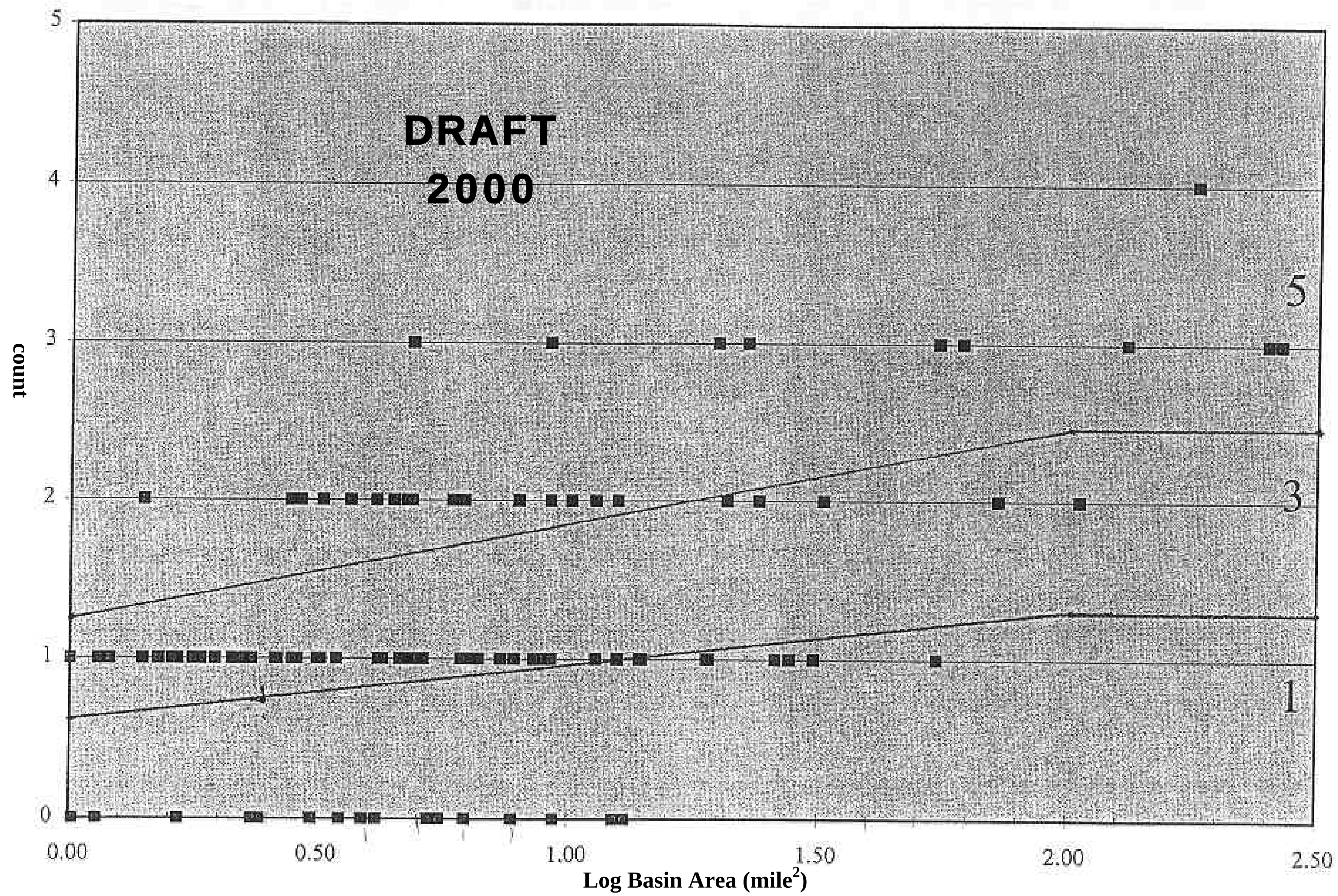
GA-DNR Index of Biotic Integrity Metric 2 plot.
Total number of benthic invirtevore species vs. drainage basin area ($\log_{10}$ mile^2) for the Atlantic Slope drainage basins.



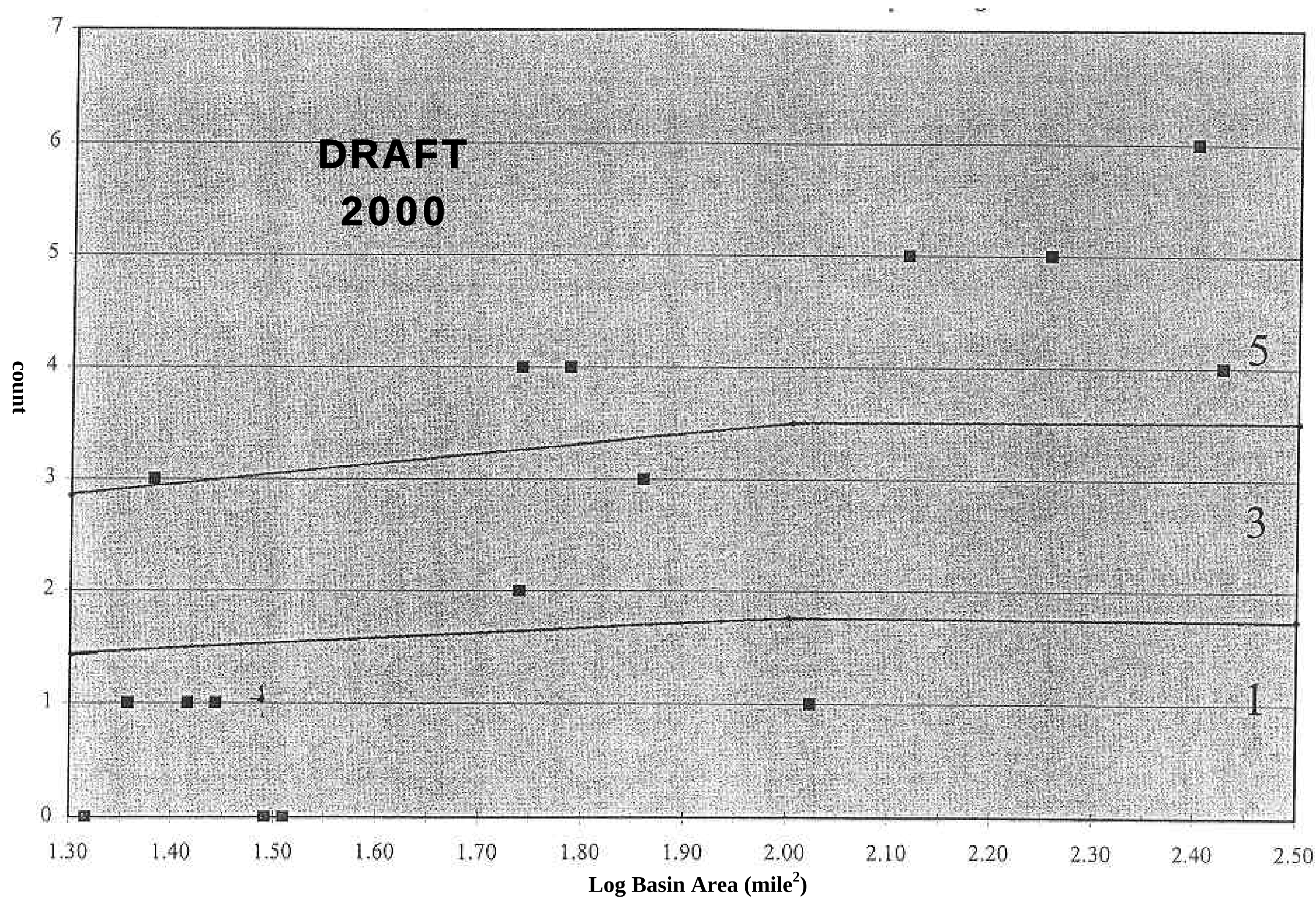
GA-DNR Index of Biotic Integrity Metric 3 plot.
Total number of native sunfish species vs. drainage basin area ($\log_{10}$ mile^2) for the Atlantic Slope drainage basins.



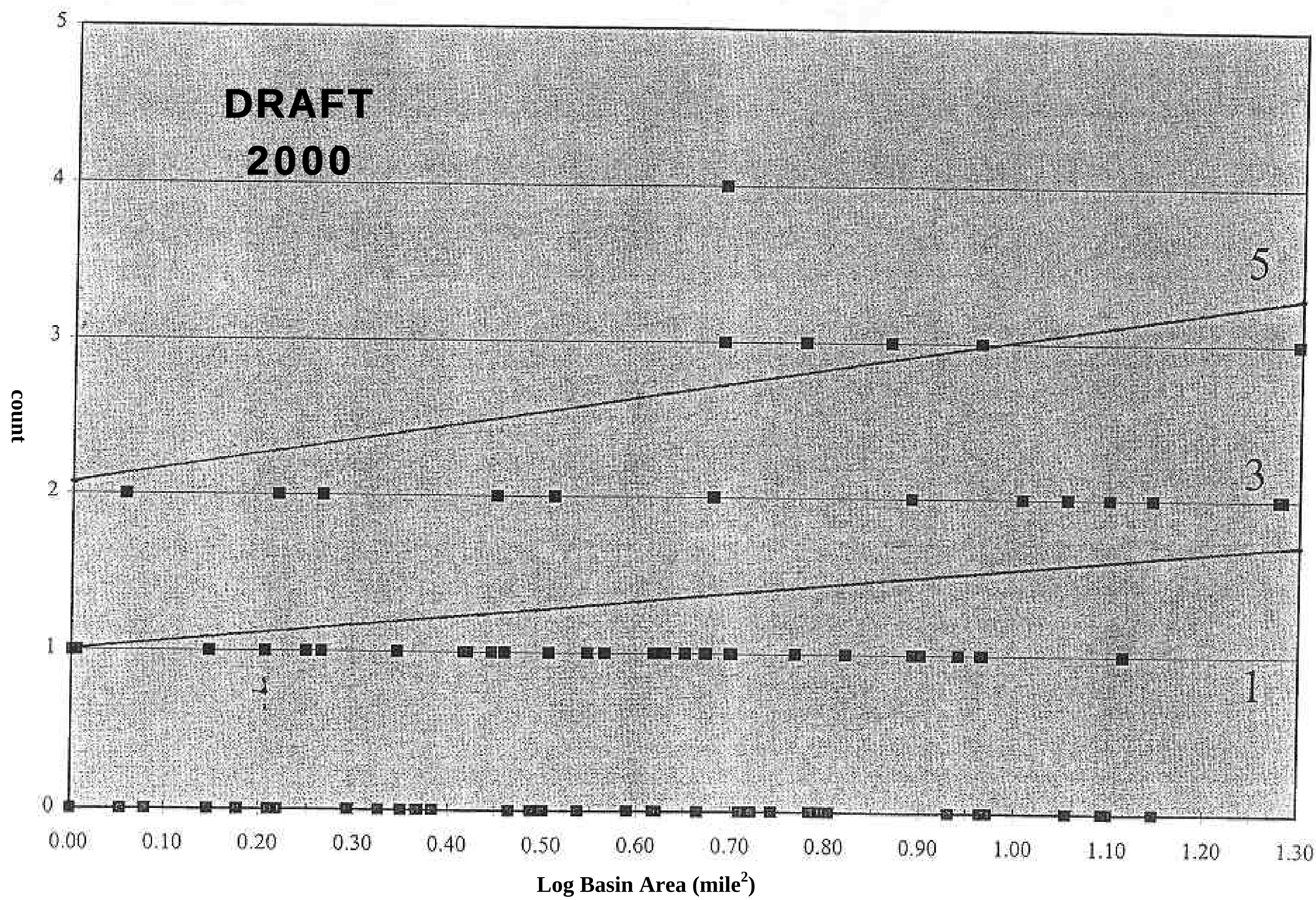
GA-DNR Index of Biotic Integrity Metric 4 plot.
Total number of native minnow species vs. drainage basin area ($\log_{10}$ mile^2) for the Atlantic Slope drainage basins.



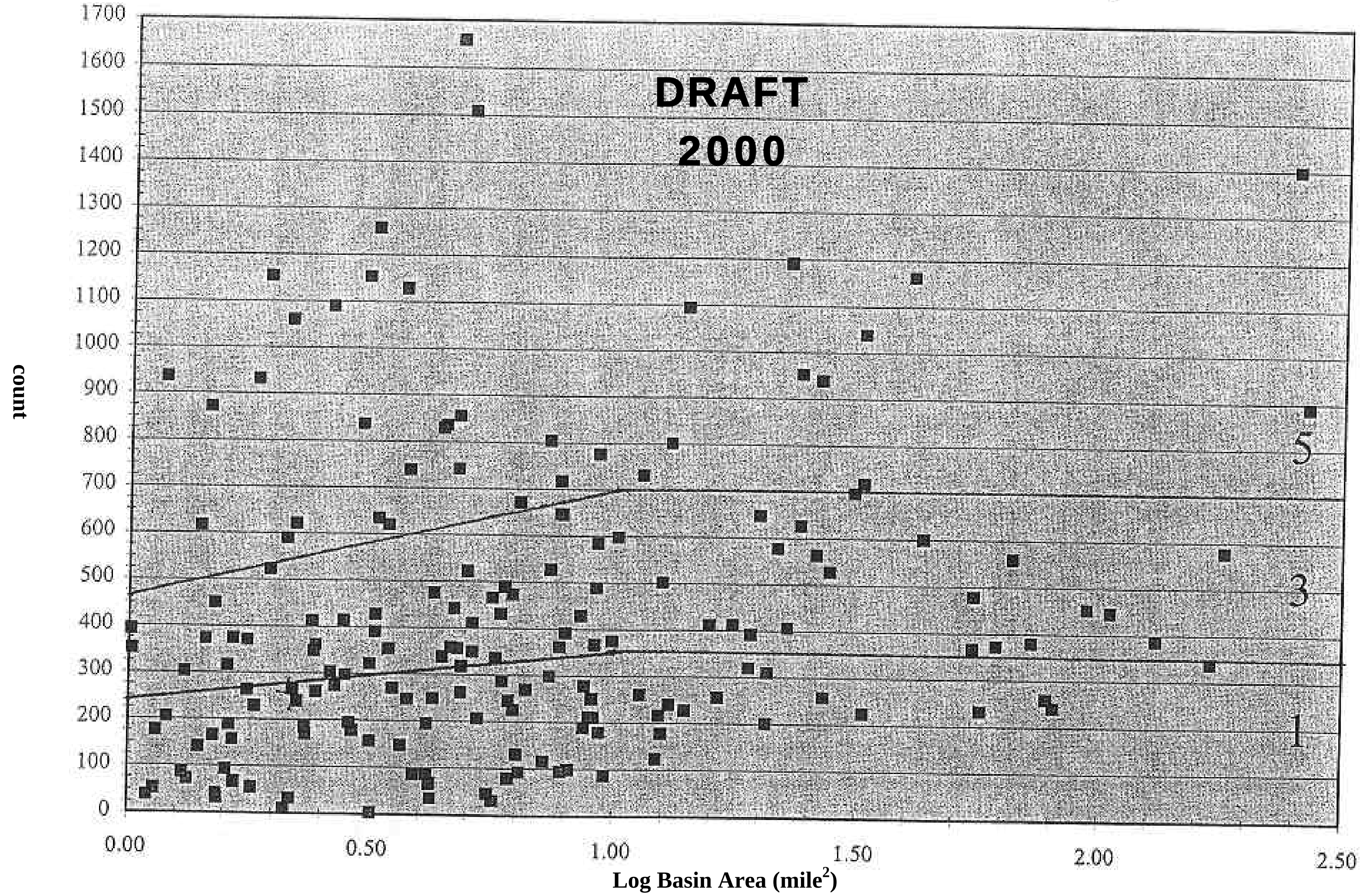
GA-DNR Index of Biotic Integrity Metric 5 plot.
Total number of native sucker species vs. drainage basin area ($\log_{10}$ mile^2) for the Atlantic Slope drainage basins.



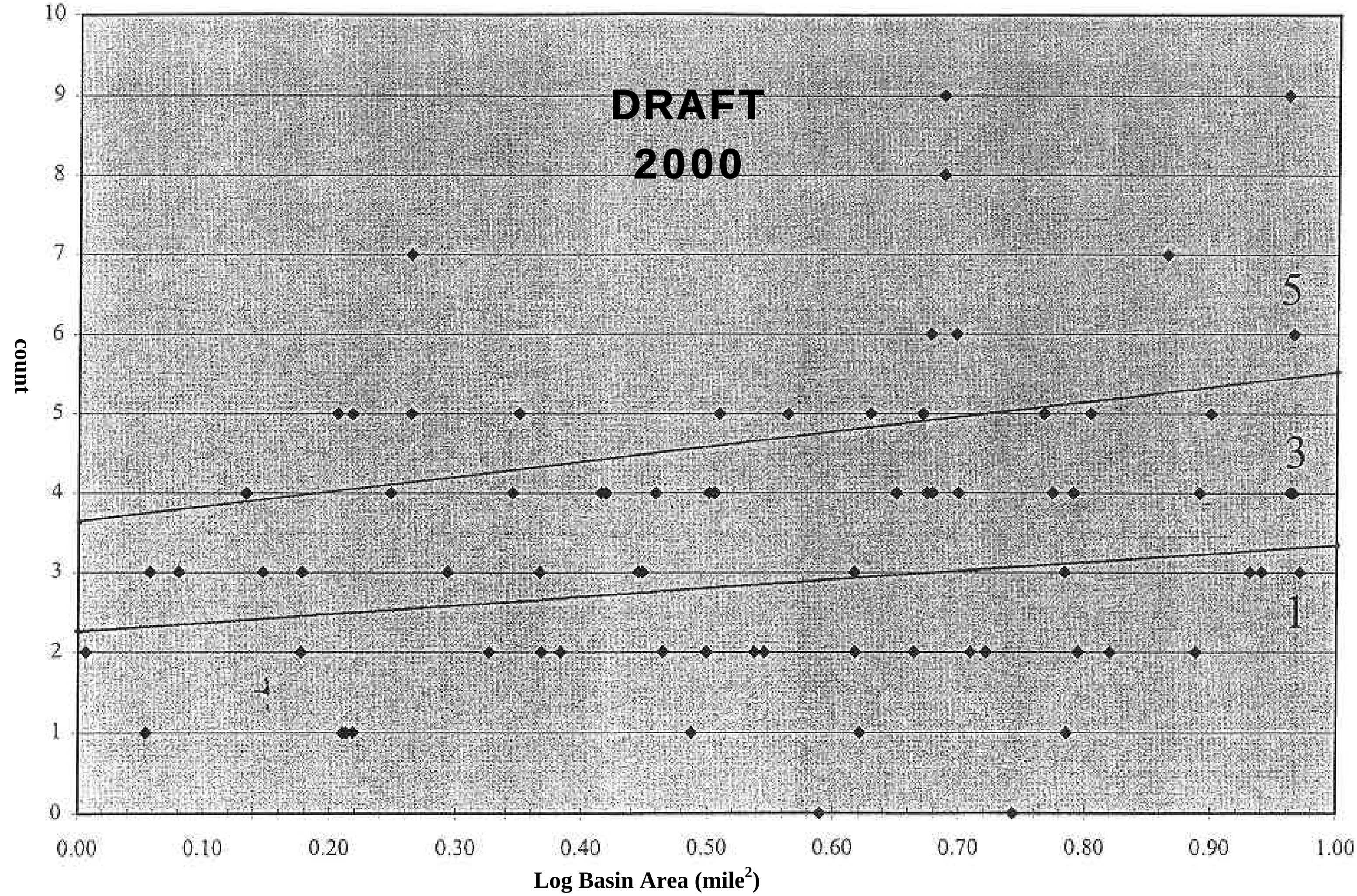
GA-DNR Index of Biotic Integrity Metric 6 plot. Greater than 20 mile^2.
Total number of intolerant species vs. drainage basin area ($\log_{10}$ mile^2) for the Atlantic Slope drainage basins.



GA-DNR Index of Biotic Integrity Metric 6 plot. Less than 20 mile^2.
Total number of sensitive species vs. drainage basin area ($\log_{10}$ mile^2) for the Atlantic Slope drainage basins.



GA-DNR Index of Biotic Integrity Metric 11 plot.
Number of individuals collected per 200 meters of electrofishing minus tolerants, exotics, and hybrids.



GA-DNR Index of Biotic Integrity Metric 12 plot. Less than 10 mile^2.
Total number of simple lithophilic spawning species vs. drainage basin area ($\log_{10}$ mile^2) for the Atlantic Slope drainage basins.