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Characterizing how fish communities and physical habitat structure are affected by urbanization in an East Tennessee watershed

Robert Lee Sain
University of Tennessee - Knoxville

To the Graduate Council:

I am submitting herewith a thesis written by Robert Lee Sain entitled "Characterizing how fish communities and physical habitat structure are affected by urbanization in an East Tennessee watershed." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Biosystems Engineering Technology.

John Schwartz, Daniel Yoder, Major Professor

We have read this thesis and recommend its acceptance:

Richard Strange, Ray Albright

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

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

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Ray Albright, _______

Accepted for the Council:

__Anne Mayhew__
Vice Chancellor and
Dean of Graduate Studies

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

Robert Lee Sain II
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Abstract:

Urbanization alters watershed hydrology, which leads to degradation of physical and biological components of urban streams. A part of this scenario is thought to be a product of increased storm water runoff due to excessive impervious surface. Impervious surface runoff increases the peak discharge in urban streams, causing a flushing or rapid flooding effect to occur. This flushing effect can overwhelm the natural pattern and profile of a stream channel, causing degradation of habitat and the fish population. This study investigates urbanization effects on habitat structure and fish communities in a rapidly urbanizing watershed in East Tennessee.

Field measures of habitat complexity and fish indices of biotic integrity (IBI) were gathered for twenty-four stream reaches in the Beaver Creek watershed, Knox County, Tennessee. Habitat inventory produced 291 Channel Geomorphic Units (CGU) with up to 20 measurements taken in each unit. Average width and depth measurements were performed on 10 different types of pools. IBI sampling produced 7185 fish, yielding 21 species of 7 families in the 24 sites. A combination of Pearson correlations, multiple and simple linear regression, and Analysis of Variance (ANOVA) means separation techniques were used to see if changes in measured habitat and fish metrics occurred in relation to increased urbanization. Potential urbanization effects on physical habitat structure and fish communities were first considered at the ($p < .10$) significance, using the Pearson correlation technique. Multiple and linear regressions were used to explain the strongest relationships found for fish and habitat, to increase in urbanization ($p < 0.05$). ANOVA means separation was used to examine and validate relationships found using the six sub-watersheds as treatments, and the four reaches within each sub-watershed as replicates.

Mosaics of urban land use varied from 1 to 54% in the watershed catchments. The statistical techniques described earlier were employed to gather relationships found between fish and habitat sites relative to an urbanization gradient. Measures of physical habitat structure were weakly correlated with percent urbanization. As percent urbanization increased, IBI scores decreased ($p = 0.0004$), and the number of darters decreased ($p = 0.0041$). Sub-watersheds significantly differed for IBI scores ($p = 0.0015$), and for curve number values ($p = 0.0048$).

Results suggest that within the range of urbanization used for this study (1 to 54% total urban and 1 to 18% commercial/ industrial) channel geomorphic units such as scour pools and riffles are not significantly altered. However, fish community assemblages did show a shift towards impairment as quantified by the IBI. This indicates that a stressor other than physical habitat degradation causes a negative effect on fish in the Beaver Creek watershed.

Table of Contents

List of Tables

List of Figures

Chapter 1: Introduction

Urbanization alters watershed land use, and in turn causes change in watershed hydrology, ultimately leading to degradation in stream ecosystems (Schmidt and Talmage 2001; Wang et al. 2001; Walters et al. 2005; Kennen et al. 2005). When rain falls on rooftops and concrete it accumulates, forms runoff, and can quickly become water that feeds directly into streams (Lee and Heaney, 2003). Impervious ground cover such as concrete have a trickle down effect on water quality, peak flows, and ground water storage released during base flow (Leopold 1968; Booth and Jackson 1997). This excess water is often due to impervious ground cover, and it creates a flashy rise in streams and may negatively impact habitat and fish communities (Schmidt and Talmage 2001). Impervious surfaces such as compacted soil, roads, sidewalks, and rooftops contribute the most to excess runoff (Arnold and Gibbons 1996). Urban areas tend to shed excess runoff efficiently via storm drains that allow water to flush rapidly into adjacent streams. Even relatively low levels of urbanization, in the range of 10 to 25%, have been found to alter hydrology, geomorphology, water quality, and stream communities (Booth and Jackson 1997; Paul and Meyer 2001).

Approximately 90,000 miles of streams and rivers in the United States have been impacted by urbanization (USEPA, 2000). In Tennessee 538,000 lake acres and more than 15,000 miles of our streams are listed as not supporting designated uses (TDEC, 2006). Furthermore, 24% of these waters are impaired due to habitat alterations, accounting for more than 4,000 miles of impairment. The primary impairments include loss of biological integrity due to siltation, the problem of pathogens and the degradation of stream banks (TDEC, 2006b). Many of the causes for habitat loss occur in urban areas. For this reason, local, state and federal government entities are interested in characterizing local impacts of urbanizing watersheds.

A study has linked change in stream geomorphology and habitat structure to increases of urbanization (Wang et al., 2001). In some urban streams, the key loss of stream habitat structure is the simplification of pool-riffle sequences, where it has been observed that glide habitat dominates (MacRae, 1996; Schwartz and Herricks 2006). Numerous studies have successfully proven that stream fishes depend on a diversity of habitat structure, such as those found in scour pools and riffles (Wichert and Rapport, 1998; Newson and Newson, 2000). For this reason it is important to monitor physical habitat such as pools in streams adjacent to or prone to future urbanization (Scholz and Booth, 2001).

Specific anthropogenic stressors causing pollution in streams are often difficult to tease out with observations (Kohler and Hubert 1993). Stream fishes are dependent on water and of other living aquatic organisms within the stream allowing fish to be a reliable indicator of stream health (Karr et al. 1986). Fish have the ability to live in all but the most polluted streams but have also been found very sensitive to environmental stressors (Karr et al. 1986). A better understanding of urban impacts to watersheds is essential if city planners and watershed managers are to meet the growing need for preservation and improvement (Arnold and Gibbons 1996). However, the key component or mechanism causing degradation is not easily identifiable to watershed managers and investigators.

Effects of urbanization on the biological integrity of watersheds have not been fully characterized in the southern Appalachian region. Beaver Creek in the Ridge and Valley Eco-region (67) was selected for this study. Objectives of this study were to address the following questions:

1. Is physical habitat structure found in ridge and valley streams altered by urbanization as a function of drainage area?

2. Does urbanization in this watershed alter fish assemblages?

In general, information derived by exploring these questions should improve our understanding of the degradation of ecosystems in urbanized watersheds of ridge and valley streams in East Tennessee.

Chapter 2: Literature Review

2.1 Watershed Management:

In East Tennessee, degraded streams are listed on the mandated EPA 303d list determined by the Tennessee Department of Environment and Conservation (TDEC). TDEC has stated that common sources of stream impairment are related to silt and sediment. Total maximum daily loads (TMDL's) are being developed to reduce and, or prevent the impact that silt and sediment have on stream ecosystems (TMDL, 2005). Watershed managers can use TMDL's to facilitate better decisions about 303d listed waters such as found in Beaver Creek watershed. A better understanding of impacts from urban land use on stream systems is crucial for protection of our water resources (Choi et al., 2003; Walters et al., 2005).

Beaver Creek and three of the tributary watersheds studied for this study are listed in the final version of the Tennessee 303d list (TDEC, 2005). These streams are listed as category 5, for one or more uses impaired. Causes of impairment for Beaver Creek watershed include habitat alteration and the loss of biological integrity (TDEC, 2005). Impairment due to habitat alteration such as tree removal can denude a stream bank and lead to excess sediment in the stream channel (see Figure 1). TDEC list streams as impaired for low biological integrity if they fall below a score of fair/ good.

Figure 1. Denuded stream bank. June 22, 2005; Site14, Hines Branch.

2.2. Geographical Information Systems and Urbanization:

An abundance of recent studies have shown degradation of fish communities as urbanization increased (Walters et al. 1995; Wang et al. 2000; Jennings and Jarnagin 2002; Angermeier et al. 2004; Kennen et al. 2005). This degree of urbanization has become less complicated to determine as effective spatial measurement tools such as Geographic Information Systems (GIS) have become easier to use. Easily accessible spatial relationships have sparked newfound interest in urbanization studies. Previous studies have drawn information from areas as large as the entire contributing watershed to as small as 50 square feet from a specific point of interest (Lammert et al. 1999). The majority of these studies, including one by Walters et al. (2005), have used entire catchments to measure percent urbanization. However, a study in Wisconsin discovered that urban measurements taken within buffer zones significantly differed in contribution of urban land use (Wang et al. 2001). McBride and Booth (2005) found that when measuring percent urbanization relative to a stream site that affects of buffered urban land did not differ for impervious surfaces.

Typical urban land uses have one key component in common: they all include some amount of impervious surface. Impervious surfaces have been loosely defined as any surface that does not allow water to infiltrate into soil (Booth and Jackson 1997), which typically includes rooftops, driveways, sidewalks, roads, and highways. The effects of impervious surfaces on stormwater differs depending if it is connected directly to other impervious surface. The degree to which impervious surface is connected may be referred to as its "effective imperviousness surface" (Booth and Jackson 1997). Commercial and Industrial urban land uses have been found to contain the highest percentage of effective impervious surface (Booth and Jackson 1997).

Pollutant loads have shown to increase as the amount of watershed impervious surface increases (Angermeier et al. 2004; Carle et al 2005). Further, at least one study found watershed imperviousness to be the primary gauge of ecosystem health (Jennings and Jarnagin 2002) (see Figure 2). A threshold of

Figure 2. Construction site runoff. April 10, 2004; Wee Williams Golf Course, Knoxville, TN.

10 to 20 percent imperviousness has been found sufficient to alter ecosystem health as measured by IBI scores (Schueler 1994; Booth and Jackson 1997; Jennings and Jarnagin 2002).

Urban effects on watersheds include increased sediment, non-point pollution, increased runoff temperature, and a change in hydrology. This change in hydrology acts as the primary delivery mechanism for sediment, excess water, and chemicals that travel with runoff (Jennings and Jarnagin 2002), as shown in Figure 2.

2.3 Fish Community Change and Habitat Alterations:

Change in physical habitat structure does not necessarily respond rapidly to human impact, so degraded habitat characteristics may not be found until long after the causal human impact has occurred. In addition, researchers have had a difficult time connecting the quality of physical habitat units to land-use change. Scholz and Booth (2001) found that only pools are suitable for monitoring habitat comparisons over time. Pools have shown some crude but consistently inverse correlations to human disturbance. For this reason it is important to use a habitat inventory procedure that captures a lot of information about pools and pool formation. Further, pool-forming properties such as woody debris are important for biological integrity in that wood formed pools can provide cover for fish (Angermeier et al., 2004). Trees and woody debris create scour pools and act to provide habitat for terrestrial and aquatic insects (Angermeier et al., 2004).

Trees within riparian areas along stream banks are often removed for urban development reasons. This removal is one example of how urbanization can alter stream physical habitat structure, which in turn can impact aquatic species diversity. The removal of stream-side vegetation such as trees can create a void in the shade canopy, enabling more sunlight to penetrate, which raises the temperature of the water. This elevated temperature can change the ecological function of a stream system (Vannote et al. 1980). Removal of trees can also reduce the possibility for beaver dam creation that further inhibits ecological functions such as wetland creation.

2.4 Utility of Habitat Inventory:

The USDA forest service standard habitat inventory procedure uses the Basin Visual Estimation Technique (BVET) for delineating fish habitat (Hankin and Reeves, 1988; Overton et. al., 1997). Delineated habitat units defined by channel geomorphic units (CGU) are used to characterize stream channel form and function. CGU's were developed by Hawkins et al. (1993) to better understand fish habitat usage, while providing a method to inventory habitat changes occurring from environmental impacts. The field observer walks upstream while delineating units, first by either fast or slow type water. Second, fast water units such as riffles, runs and glides are quickly classified, while slow water or pools are examined in greater detail. Pools act to dissipate energy in a stream channel which is facilitated by elements of roughness found in wood, rock, roots, and meander bends. For this reason the field observer looks for a defined drop in stream channel elevation, and then identifies the roughness forming structure. Weighted measurements of each and every type of pool may then be compared from one stream to another stream (Hawkins et al., 1993).

BVET type inventory procedures remain the most common methodology used for fish habitat assessment, but have limitations (Williams et al. 2004). One of the

Figure 3. Bedrock formed step-pool complex. June 21, 2005; Site 6, Cox Creek.

limitations noted by Williams et al. (2004) is that streams comprised of sand and gravel substrate often lack bed controlling structures (see Figure 3). Streams lacking structure such as bedrock and large woody debris shift easily, not allowing for formation of scour units and thus comparability of pool measurements. For this reason the CGU approach is not recommended in eco-regions where streams typically lack bed control substrate such as bedrock, boulders, or large woody debris. However, wood and bedrock-control structures that often form pools are typical of the Ridge and Valley eco-region (Etnier and Starnes 1993).

The watershed used for this study was found to be similar to other Ridge and Valley watersheds with abundant bedrock and large woody debris. Replication of site-specific criteria used to identify CGU’s was another concern raised by Williams et al. (2004). Williams et al. (2004) found there to be a wide variation in opinions between field observers when looking at the same stream. Fortunately for this study, one field observer identified all habitat units, thus reducing potential bias. CGU’s commonly found during this study included variations of riffles, runs, pools, and glides. Pools found were formed by meander bends, large woody debris, bedrock, boulders, rootwads, or by some combination of these. Pools were measured at the deepest portion and at the shallowest portion where they crested. An example of a pool formed by lateral meander scour may be viewed in Figures 4 and 5.

Physical habitat measurements are more cost-effective than chemical monitoring in that they may be quickly identified in the field and are less expensive to analyze in the office (Scholz and Booth 2001). Further, Scholz and Booth (2001) showed that physical habitat measurements can usually tell the researcher more about the potential causes of stream degradation.

The health of stream fishes is dependent upon biota facilitated by physical habitat quality. Physical habitat such as rock and large woody debris act to provide structure in streams (see Figures 6). Streams maintain a state of dynamic equilibrium, in part by scouring pools around these structures, which

Figure 4. Crest depth measurement taken at the “tail-out” portion of the thalwag. June 24, 2005; Site 11, Grassy Creek.

Figure 5. Maximum pool depth measurement taken in the thalweg. June 24, 2005; Site 11, Grassy Creek.

Figure 6. Wood-formed, mid-channel pool. June 25, 2005; Site 20, Knob Fork.

either directly or indirectly provides refuge and ecological medium to fish and other aquatic organisms (Angermeier et al. 2004).

2.5 Utility of IBI Method

The IBI is a well-documented that may be used for assessment of urbanizing watersheds USEPA (1999). The IBI developed by Karr (1981) is used to examine fish communities. The IBI method uses 12 metrics to assess biotic integrity (Karr 1986). These include 6 metrics that describe species richness and composition, 3 that relate to trophic composition, and 3 that measure fish abundance and condition. Scores of 1, 3, or 5 are possible for each metric. The six metrics used to describe species richness and compositions are good indicators of stream degradation. Metrics one through four assess species

Figure 7: Depicts the use of a backpack shocker. This device stuns fish that are either immediately netted or swept to a downstream seine net. June 22, 2005; Site 11, Williams Creek.

richness. Metrics five and six are used to determine the presence of tolerant or intolerant fish. Metrics seven through nine assess the energy base within the community food web (see Figure 7).

They help identify shifts towards more generalized foraging that typically increase in degraded streams, while metrics ten through twelve measure fish abundance and condition. The sums of the 12 metric scores result in an overall score that ranges from 12 to 60 (very poor to excellent). Metric two through five are of particular interest for studies related to urban impacts, as the fish that comprise these metrics are among the first to be decimated after perturbation (Karr 1986).

The IBI sampling method was first developed and tested in the mid-western United States, but has since undergone adjustments by local biologist in differing regions of the country. The State of Tennessee guidelines recognize adjustments developed by the Tennessee Wildlife Resource Agency (TWRA), the University of Tennessee (UT) and the Tennessee Valley Authority (TVA) (Saylor and Ahlstedt 1990).

Chapter 3: Methods

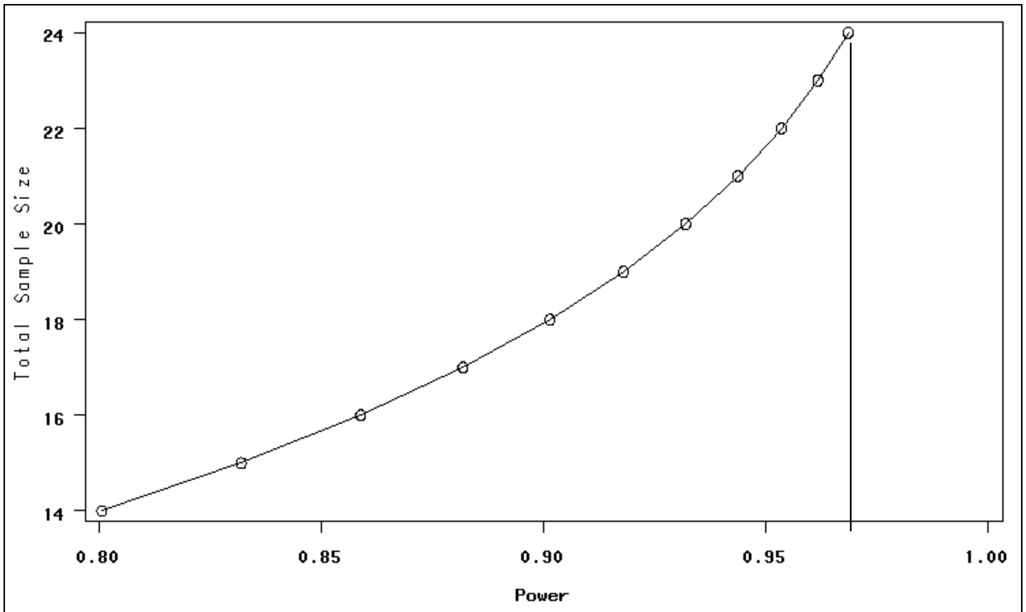
3.1 Study Design:

This study characterizes effects of urbanization on physical and fish habitat in an East Tennessee watershed. Two study questions have been drawn:

1. Is physical habitat structure found in ridge and valley streams altered by urbanization as a function of drainage area?
2. Does urbanization in this watershed alter fish assemblages?

These questions were addressed by first selecting sites that represented a range of urban land uses within six subwatersheds. Fish habitat was surveyed using both physical and visual measurements. Fish community measurements required the use of electro-shocking equipment and identification of fish species to establish IBI scores.

Statistical power calculations were performed using a significance level of 5%. These showed that with an R^2 of 40%, 24 sites were needed to provide a 97% statistical power. An R^2 of 40% was used in reference to relationships discovered in several similar studies (Walters et al., 1995; Schleiger, 2000; Wang et al., 2000; Schmidt and Talmage, 2001; Wang et al., 2001; Jennings and Jarnagin, 2002; Angermeier et al., 2004; Rashleigh, 2004; Kennen et al., 2005). The analysis established the number of sites needed for the study (see Figure 8) (SAS, 2004).



Computed N Total Alpha: .05 With an R2 of .4

Index	Nominal Power	Actual Power	N Total
1	0.800	0.801	14
2	0.900	0.901	18
3	0.965	0.969	24

Figure 8. Statistical Power Calculations performed using a significance level of 5% with an R^2 of 40%. Calculations showed that 24 sites would provide 97% statistical power.

3.2 Site Selection:

Twenty-four stream sites were found in six sub-watersheds within the Beaver Creek watershed, each with a different mosaic of land use types in its contributing area. Land use within Beaver Creek Watershed played a key role in determining suitable subwatersheds during the preliminary site selection process. The entire 90-mi^2 Beaver Creek watershed was found to be approximately 23% urban. Knowing this overall percentage allowed for visual estimation of contributing areas within subwatersheds so as to select sub-watersheds with varying degrees of urbanization relative to the overall. Fish and habitat inventory sites were selected from six sub-watersheds of Beaver Creek watershed as shown in Chapter 4. Four sites within each sub-watershed were located, and global positioning system (GPS) points were taken (see Table 1). Sites were spaced far enough apart to capture a broad range of urban effects, and were limited to 3rd order or smaller streams having less than 15 square miles of drainage area. This size restriction was put in place to make sure that each site was wadeable for both habitat inventory and for backpack electro-shocking. This not only simplified field work, but allowed researchers to use the same techniques and equipment at each site.

3.3 Land Use:

High quality 4-meter resolution aerial photography taken in August 2003 was used to delineate Beaver Creek land uses for this study. A land use database was created using 2003 aerial photographs obtained from KGIS (Knoxville, TN) and was digitized by the UT Geography Department using ArcMap, GIS software version 9.1. Land use delineation was performed by overlaying aerial photographs of Beaver Creek watershed into Arc Map, geo-rectifying the image as necessary, and drawing polygons to form a spatially correct layer. The original layer contained over two hundred classifications for land use types. Land use types were consolidated based on similarities into eleven types (see Table

Table 1. GPS locations taken for each site (Trimble GPS-132).

Site	Stream	N	W
Locations	Reaches	degrees feet	degrees feet
1	Knob 1	36 02.242	084 00.206
2	2	36 01.922	083 59.896
3	3	36 01.504	083 59.284
4	4	36 01.588	083 58.998
5	Hines1	36 04.257	083 56.724
6	2	36 04.109	083 56.559
7	3	36 04.079	083 56.312
8	4	36 03.828	083 55.562
9	Cox 1	36 04.821	083 53.997
10	2	36 04.601	083 53.811
11	3	36 04.760	083 53.238
12	4	36 05.067	083 52.548
13	Beaver 1	36 04.900	083 54.350
14	2	36 05.432	083 53.577
15	3	36 06.007	083 52.625
16	4	36 06.314	083 52.317
17	Willow 1	36 05.506	083 54.969
18	2	36 05.947	083 54.511
19	3	36 06.053	083 54.404
20	4	36 07.654	083 53.478
21	Grassy 1	35 59.649	084 04.068
22	2	35 59.094	084 03.557
23	3	35 59.171	084 03.589
24	4	35 59.466	084 02.807

2). Five of these types were considered urban and thus used for this project (see Table 2).

All spatial data and hydrologic analysis for drainage area to each site was compiled and analyzed using ArcMap 9.1 software (see Table 3). Procedures were followed as listed below.

1. Acquired Digital Elevation Model for Beaver Creek Watershed
2. Acquired 2003 Land Use data layers created by the UT Geography Department (Dr. Carol Hardin)
3. Acquired Tennessee Wildlife Resource Agency (TWRA) Streams of Tennessee layer from the state website.
4. Imported GPS location points into ArcMap and checked to make sure they made sense.
5. Performed watershed tool pre-requisites: a. filled sinks b. flow accumulation c. stream network d. flow direction.
6. Activated interactive watershed tool bar in hydrology tools.
7. Delineated each site using the watershed tool by referencing GPS points taken in the field.
8. Changed the newly delineated sub-watersheds from raster files to feature files using spatial analyst.

Table 2. Consolidated land use layers designating the urban (U) and non-urban (NU) groups.

Land Use	Urban	CN	Description
Residential (High Density)	U	85	Single family, high density (more than 6/acre) Apartment/condominium complex
Residential (Medium Density)	U	75	Single family, medium density (2-5/acre)
Residential (Low Density)	NU	68	Single family, low density (fewer than 2/acre)
Commercial	U	92	Central business district; Strip development; Shopping center; Service areas; Community complex; Water treatment plant; Institutional other; Airport; Major highway right of way
Industrial	U	88	Light industry; Heavy industry
Disturbed/Transitional	U	81	Quarry; Disturbed area without sediment control structures/practices; Disturbed area with sediment control structures/practices
Agricultural	NU	79	Cropland; Good pasture, well maintained; Fair pasture, uneven growth and condition with minimal maintenance; Heavily overgrazed pasture; Poor pasture, sparse cover, shallow soils, steep slopes, often gullies; Feedlot of loafing areas; Specialty crops; Hay land
Open Land (Good)	NU	69	Golf course; Park; Medium brush (10'-20'); High brush (greater than 20'); Shrub and brush
Woods (Thick)	NU	55	Woods (Thick)
Woods (Thin)	NU	66	Woods (Thin)
Water	NU	100	Streams and canals; Detention Ponds

Table 3. SCS Curve Numbers derivation (Chow et al. 1988).

	Hydrologic Soil Group			
Land Use	A	B	C	D
Residential (High Density)	61	75	83	87
Residential (Medium Density)	54	70	80	85
Residential (Low Density)	45	65	77	82
Commercial	89	92	94	95
Industrial	81	88	91	93
Disturbed/ Transitional	77	86	91	94
Agricultural	66	77	85	89
Open Land	30	48	65	73
Meadow	30	58	71	78
Woods (Thick Cover)	30	55	70	77
Woods (Thin Cover)	32	58	72	79
Impervious	98	98	98	98

9. Opened the updated database table from each site and exported the file into Microsoft Excel format.
10. Sorted and broke out urban and forested land uses associated with each site.
11. Compiled all urban and forested land use totals into separate Microsoft Excel spreadsheets.

3.4 SCS Curve Numbers:

The Soil Conservation Service (SCS) curve numbers were used to describe runoff potential for all land use types associated with each fish and habitat site (SCS 1986). Soils data were clipped and spatially joined for each site using ArcMap, GIS 9.1. Site percentages of land use types were summarized for each soil type and then multiplied by the corresponding curve number coefficient relative to each land use (see Tables 3 and 4). SCS Curve number coefficients were weighted to account for the mix of soil groups B, C and D soil types. Using spatially correct combinations of B, C and D soil groups, relative to total contributing area, CN values were calculated for each site (see Tables 4 and Figure 9).

3.5 Habitat Inventory:

A USDA Forest Service “Fish Habitat Standard Inventory Procedure” was performed at each site (Overton et al. 1997). Habitat Inventory was conducted starting June 1, 2005 and ending July 10, 2005. The field crew consisted of three individuals, including one who has been trained by the Forest Service to use this technique. Stream length sampled was a minimum of 30 times the average stream width, or at least 150 meters. Field equipment included a 50-meter drag chain, a two-meter measuring rod, waders, clipboard, camera and other necessary items as described in the Forest Service field manual (Overton et al. 1997). The field observers started at the downstream end of each site and proceeded up stream while dragging a fiberglass measuring chain along the deepest part of the channel or thalwag. Habitat units such as pools, glides, riffles and runs were delineated in meters, and photographed in accordance to Forest Service guidelines (see Table 5). Habitat units were also flagged to be located for later fish IBI surveys.

Table 4. Weighted Curve Numbers calculated for each site

Site	Stream Names	% Total Urban	Drain Area (sq.mi)	B Soils	C Soils	D Soils	Weighted CN
1	Beaver 1	0.14	14.16	51.75	12.65	8.19	72.6
2	Beaver 2	0.14	9.88	50.2	13.86	9.94	74.0
3	Beaver 3	0.10	8.20	50.68	13.74	9.62	74.0
4	Beaver 4	0.12	4.93	50.53	13.11	10.59	74.2
5	Cox 1	0.13	3.68	59.09	5.08	4.47	68.6
6	Cox 2	0.07	2.75	57.8	5.48	5.67	69.0
7	Cox 3	0.07	2.20	58.08	4.84	5.82	68.7
8	Cox 4	0.05	1.59	56.39	4.99	7.86	69.2
9	Grassy 1	0.16	5.79	52.72	10.18	8.34	71.2
10	Grassy 2	0.16	5.26	56.21	8.5	5.83	70.5
11	Grassy 3	0.23	2.32	53.55	9.82	9.39	72.8
12	Grassy 4	0.27	1.84	53.17	10.93	9.68	73.8
13	Hines 1	0.49	2.33	61.24	8.94	1.53	71.7
14	Hines 2	0.49	2.17	61.16	8.97	1.44	71.6
15	Hines 3	0.54	2.09	61.36	8.86	1.29	71.5
16	Hines 4	0.51	1.65	65.9	4.4	0.95	71.3
17	Knob 1	0.28	5.89	34.49	34.39	4.43	73.3
18	Knob 2	0.28	5.65	34.96	34.57	4.3	73.8
19	Knob 3	0.25	3.31	31.59	39.3	1.95	72.8
20	Knob 4	0.26	2.84	60.63	3.34	4.04	68.0
21	Willow 1	0.03	3.71	59.75	5.71	5.89	71.4
22	Willow 2	0.01	3.30	61.68	4.38	5.31	71.4
23	Willow 3	0.01	3.20	61.23	4.43	5.1	70.8
24	Willow 4	0.00	1.25	67.66	0.01	0	67.7

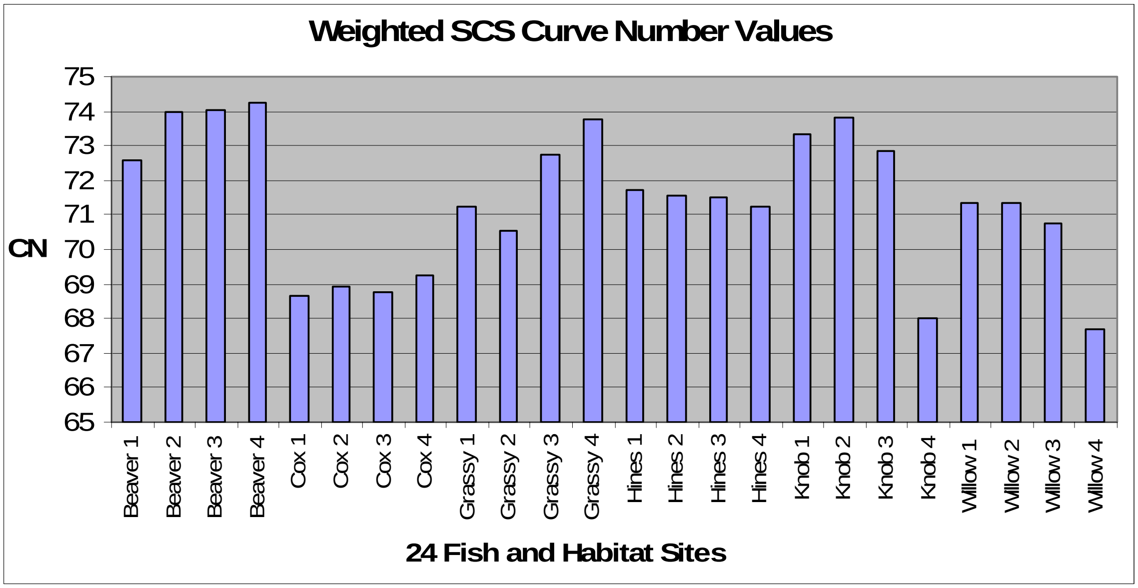


Figure 9. Sites sub-watershed, runoff potential values based on the SCS Curve Numbers. Land use coefficients used for calculation were derived from Chow et al. (1988).

Table 5. Stream habitat delineation criteria. Derived from USDA Forest Service Habitat Inventory standard protocol (Overton et al. 1997).

Habitat Inventory	Notes:
Habitat Units	Riffle: broken surface, fast water, shallow, usually wide, narrows into runs. Run: Smooth surface, fast water, trough shaped, not uniform in depth, changing slope, drops into pools. Pool: Smooth surface, slow water, deep, not uniform in depth, up wells and tails out to glides. Glide: Smooth surface, fast water, shallow, uniform in depth, changing slope, wide, changes into riffle.
Habitat Unit Dimensions (m)	Length: measured along thalwag, depicting longitudinal distance. Width: average of wetted, low-flow channel width, one to three measurements taken. Depth: average water depth, low-flow channel depth, one to three measurements taken. Maximum Depth. max depth at low flow, one measurement taken.
Large Woody Debris (m)	At least 0.1 meter in diameter, greater than 1 meter long. Length, width and % of wood submerged were measured with a measuring rod.
Wood Aggregates	At least 2 pieces intertwined within the bankfull width. Numbers of pieces were recorded.
Root Wads	Not attached to live tree stem and within the bankfull width.
Intact Riparian	Where as woody vegetation extended to at least 40 feet to the side of an adjacent stream bank.
Riparian Trees	Trees counted had to be at least 8 inches in diameter and growing immediately adjacent to the streambank.

The Forest Service habitat inventory method was originally designed to compare stream attributes to a reference stream condition. A DOS based-program called FBASE has been developed by the USDA Forest Service to compare fish habitat inventory attributes (Wollrab 1999). Key relationships found in FBASE were used for this project but analyzed using a Microsoft Access Database. This DBASE program was created to query attributes of all variables recorded from each field site into a series of tables. Variables such as length, depth, average depth, width/depth ratio, max depth, percent length, area, and volume were queried and pasted back into Excel spreadsheets. Excel spreadsheets were used to weight numerical data to the relative length or area of each electro-shocked habitat unit. Tables used for statistical comparison may be found in Appendix C. IBI data as well as raw fish data were also fit into the database. Fish data were queried based on various physical attributes. All weighted and extracted data were then sorted, organized, and prepared for copying into statistical software (SAS 2004).

3.6 Fish Sampling

Fish biotic integrity surveys were conducted at each of the twenty-four sites using techniques based on those of the Tennessee Valley Authority (TVA, 2005) (Appendix A). Site sample areas were measured to later calculate the total number of fish captured per site, or catch per unit effort as discussed below. IBI surveys were conducted during base stream flow months for East Tennessee, July 15 through August 30, 2005.

IBI's were conducted using two dipnets, a twenty-foot seine, and a Smith-Root LR-24, battery powered backpack electro-shocker. This backpack electro-shocker is unique in that it has a setup option to automatically adjust voltage, frequency and duty cycle based on the conductivity of the water. The LR-24 uses a small built-in computer to calibrate on-site how much electricity is needed to effectively shock and stun fish (Smith-Root, LR-24 Manual). Conductivity and temperature were measured separately using an YSI unit so as to justify any additional tweaking of the electrical field being used (see Figures 10 and 11). The shock-to-seine method was used in all habitat units to stun fish into a seine net; fish were retrieved from the seine, identified to species and then released. Fish that could not be identified to species in the field were sacrificed and taken to the UT Ichthyology Lab, Knoxville TN.

The IBI method uses 12 metrics to assess biotic integrity (see Figure 12). The sum of the 12 metrics score results in a range from 12 to 60, very poor to excellent (see Figure 12 and Table 6). Calculation of these scores was facilitated by recent technology developed by the TVA.

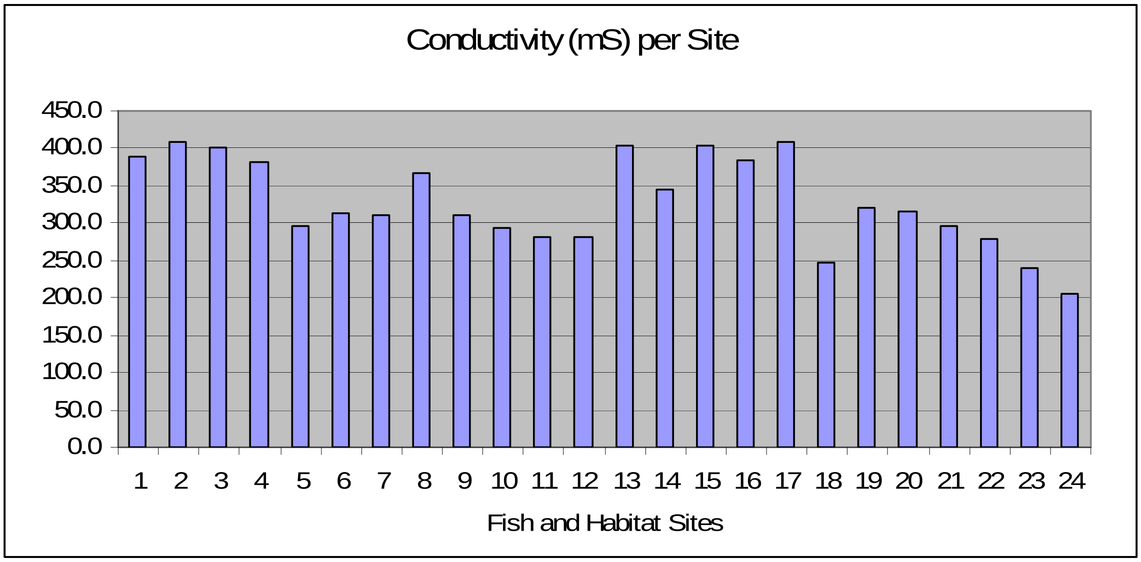


Figure 10. Chart depicting conductivity (mS) found for each fish and habitat site.

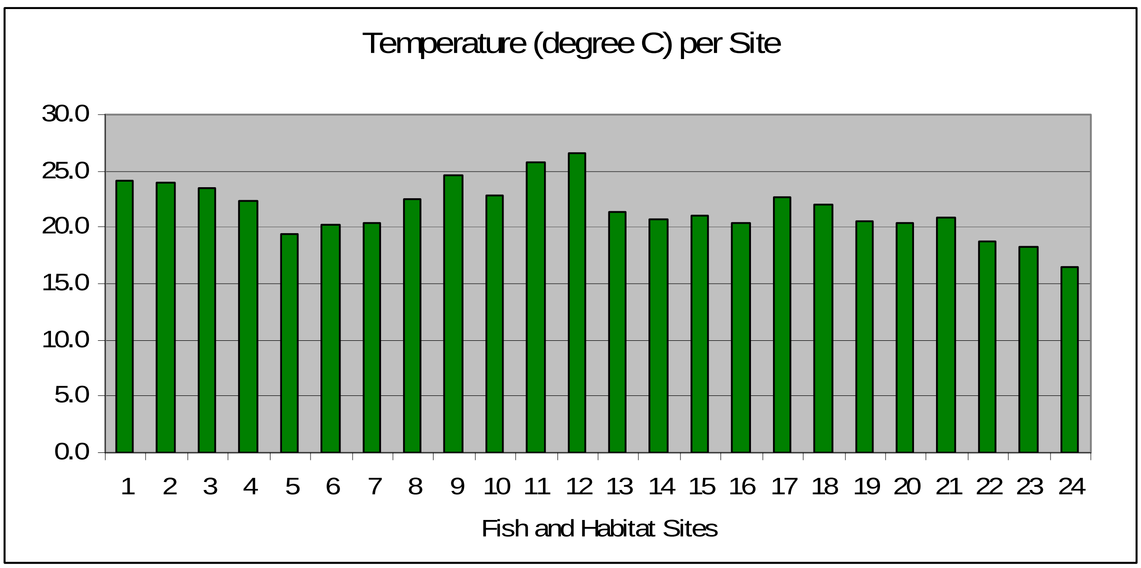


Figure 11. Chart depicting temperature (degrees C) found for each fish and habitat site.

1. Number of native species

2. Number of native darter species or (headwater streams)** Number of riffle species

3. Number of native sunfish species (less Micropterus sp.) or (headwater streams) Number of pool species

4. Number of native sucker species or (headwater streams) Percent composition by two most dominate species

5. Number of intolerant species or (headwater streams) Number of headwater intolerant species

6. Percentage of fish as tolerant species

7. Percentage of fish as omnivores and stoneroller species

8. Percentage of fish as specialized insectivores

9. Percentage of fish as piscivores

10. Catch rate (average number/300 Sq. Ft. or 5 minutes of boat shocking)

11. Percentage of fish as hybrids or (headwater streams) Percentage of fish as simple lithophilic spawners

12. Percentage of fish with disease, tumors, fin damage, and other anomalies

*Each is assigned a value as follows: 1-poor, 3-intermediate, 5-the best to be expected. The IBI for a given site is the sum of those values.

**Headwater streams include perennial streams with drainage areas of less than five to one square miles (Central Appalachian Ridges and Valleys, and Interior Plateau Eco-regions), <10 to one square miles (Blue Ridge Mountains Eco-region), or <100 to 10 square miles (Southwestern Appalachians Eco-region).

Figure 12. List of metrics used in calculating Index of Biotic Integrity*

Table 6. Index of Biotic integrity scoring classes with attribute descriptions originally developed by Karr (Karr et al. 1986).

Class	Attributes	IBI Range
Excellent	Comparable to the best situations without influence of man; all regionally expected species for the habitat and stream size, including the most intolerant forms, are present with full array of age and sex classes; balanced trophic structure.	58-60
Good	Species richness somewhat below expectation, especially due to loss of most intolerant forms; some species with less than optimal abundances or size distribution; trophic structure shows some signs of stress.	48-52
Fair	Signs of additional deterioration include fewer intolerant forms, more skewed trophic structure (e.g., increasing frequency of omnivores); older age classes of top predators may be rare.	40-44
Poor	Dominated by omnivores, pollution-tolerant forms, and habitat generalists; few top carnivores; growth rates and condition factors commonly depressed; hybrids and diseased fish often present.	28-34
Very Poor	Few fish present, mostly introduced or tolerant forms; hybrids common; disease, parasites, fin damage, and other anomalies regular.	12-22
No fish	Repetitive sampling fails to turn up any fish.	

TVA has improved IBI scoring quality and efficiency with a computer program they call the Stream Survey Recording System (see Appendix A). The Stream Survey Recording System version 2.02 (SSurvey) criteria were set using the trisection method described by Karr (1981).

The SSurvey software was used in this study to produce an IBI score for each site (TVA 2005) (see Appendix B). SSurvey contains up-to-date information for fish species and metrics. The metric scoring criteria change at various drainage area size classes. Drainage area adjustments and other programming language for SSurvey specifications may be found in (Appendix A).

3.7 Statistical Analysis:

A combination of correlation, multiple regression, simple regression, and ANOVA mean separation techniques were run with SAS for this study (SAS 2004). The Pearson correlation was used to examine over 1000 numbers representing data collected for fish and habitat attributes. Correlations had to show a 90% confidence, ($p < 0.10$), level to be considered for further statistical analysis.

Further statistical analysis was performed by first using multiple linear regressions to narrow down potential relationships to fewer and more powerful combinations. Combinations of independent variables often weeded out all but one variable, leading to a linear regression model. Multiple and linear regression models had to show 95% confidence, p< .0.05, level to be considered explanatory. Likewise, multiple and linear regressions were used to explain the strongest relationships found between fish and habitat parameters, and percent urbanization. Data such as fish abundance per 100 m^2 required a log transformation to ensure normality. Weaker and more general correlations were needed to separate differences between watersheds.

Means separation was used to compare differences among watersheds because there were four sites located in each of six sub-watersheds. Sub-watersheds were set up as treatments, with sites acting as replicates. It is important to note that the sites themselves can not be considered true replicates because they are expected to differ in drainage area, geology, aspect, and slope. However, it is commonly thought to be impossible to find two natural stream reaches that are exact replicates of one another. Replication comparison was performed using data independent of natural variability, such as the IBI score. Measured site attributes were weighted to accommodate for stream size differences and for this reason could be compared under the assumption of replication. The Tukey means separation technique was used to determine differences for variables found in the six sub-watersheds.

Chapter 4: Study Area

4.1 Watershed Overview

Beaver Creek watershed contains ninety mile^2 (233 km^2) of drainage area and is located in the ridge and valley eco-region of East Tennessee (see Figure 13). Beaver Creek watershed is part of the 628 mile^2 Lower Clinch River Watershed (TDEC, 2006b). Beaver Creek flows southwest, meandering 48 miles through northwest Knox County, Tennessee, and emptying into the Clinch River about 40 miles upstream of its confluence with the Tennessee River. This watershed is currently only 23% urban (as of August 2003), but is in the process of becoming much more urbanized in the next few years (see Figure 14).

Three of the tributary watersheds studied for this project are listed in the final version of the Tennessee 303d list (TDEC, 2005). Hines Branch, Grassy Creek, and Knob Fork are listed as category 5, designated for one or more impaired uses. The primary impairments include loss of biological integrity due to siltation and habitat loss from altered stream-side vegetation. This alteration of stream habitat structure and fish community structure may be related to current and increasing urban land use found in Beaver Creek sub-watersheds. For this reason local, state and federal government organizations are interested in a thorough assessment of impacts in this urbanizing watershed.

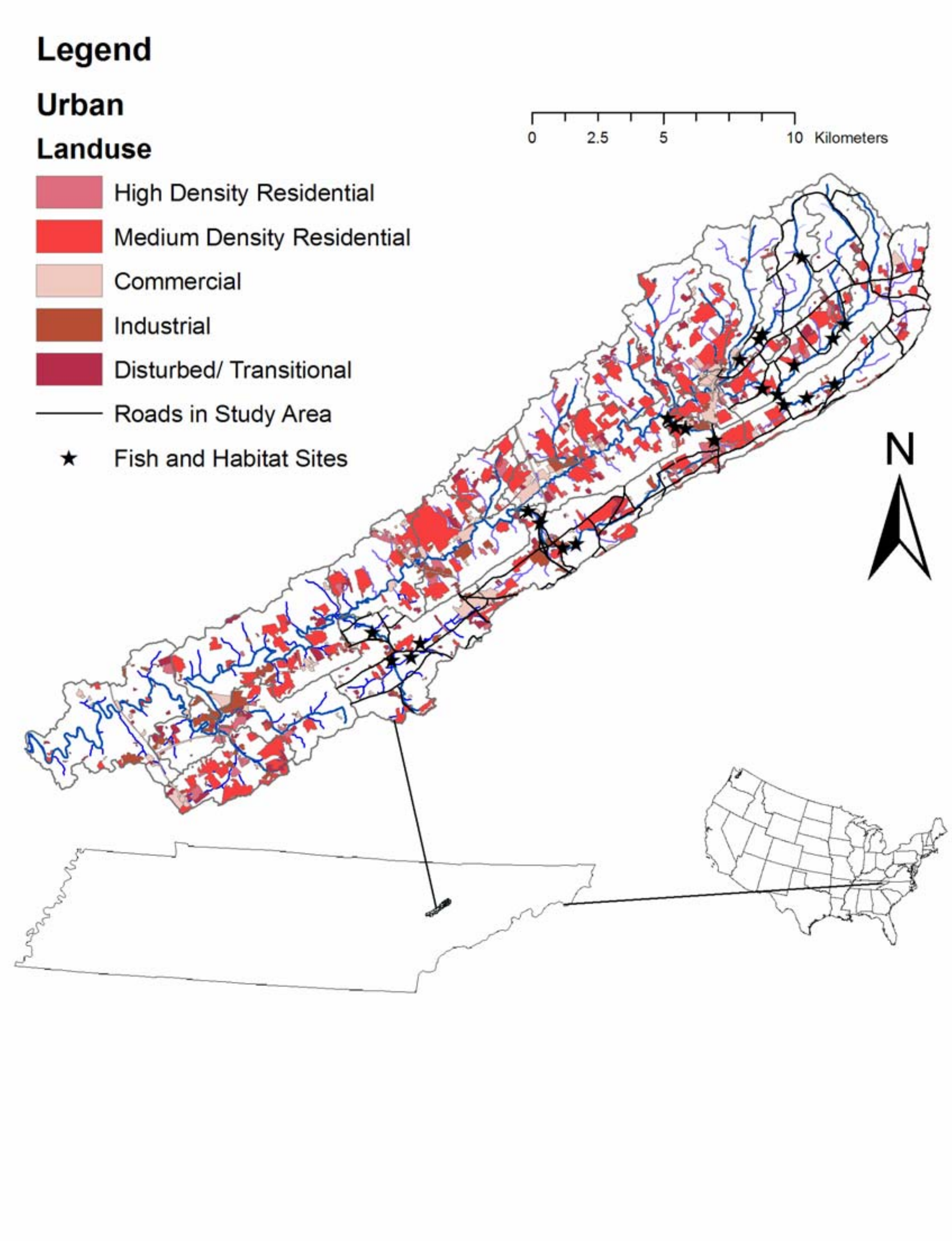


Figure 13. Beaver Creek watershed located in north Knox County, East Tennessee. Also provides a visual representation of the 23% urban land use (2003 data) found for the entire Beaver Creek watershed. The 24 fish and habitat sites are denoted by black stars.

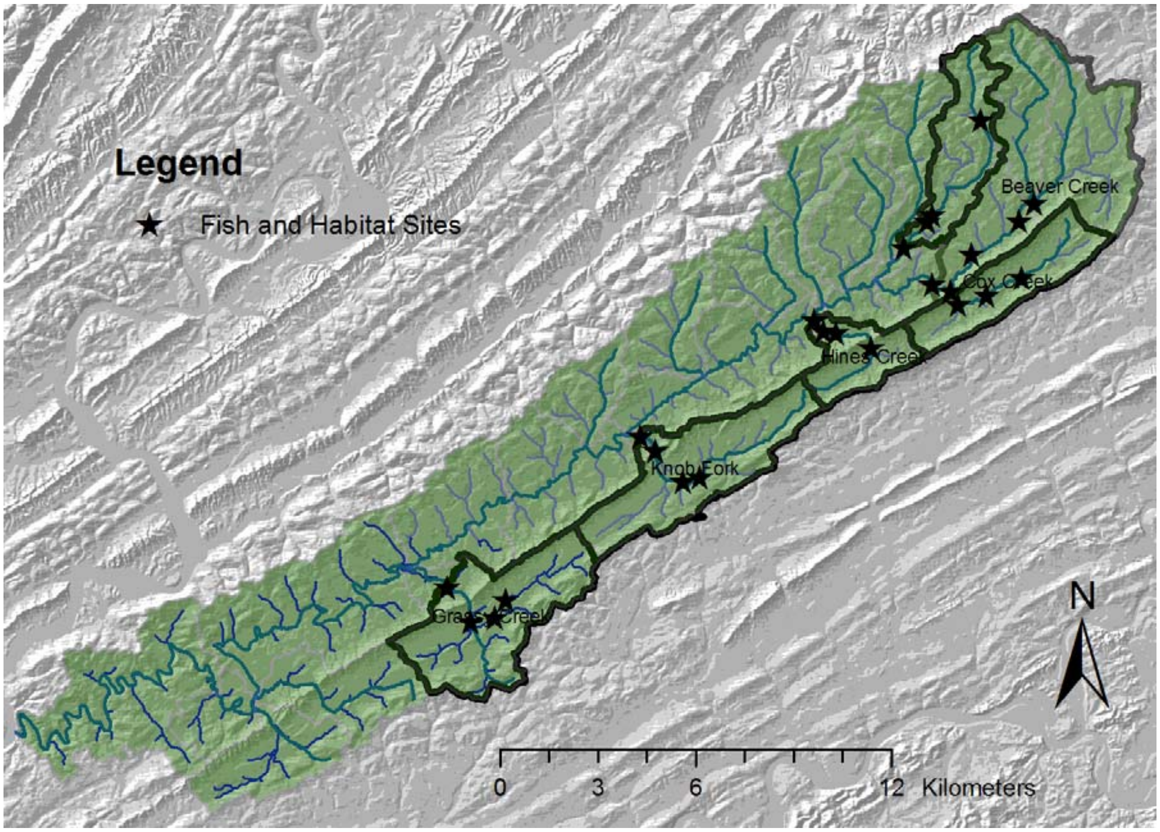


Figure 14. A visual representation of Beaver Creek watershed topography. The six sub-watersheds studied are outlined in black and 24 study sites identified with black stars.

4.2 Upper Beaver Creek Sites

Four of twenty-four sites (sites 1 through 4) are located on the main channel of Beaver Creek, starting at mile 38.5. These sites are on stream sections that may be characterized as low-gradient, with the land adjacent to them becoming low to medium density residential. The floodplain is accessible for sites one, two, and four. Both active and washed out remains of beaver dams are scattered throughout upper Beaver Creek. Beaver dams acted as a natural barrier blocking the up stream boundary for all four sites. Inundation of the floodplain near several of the beaver dams was found near each site, indicating that beavers have used the low gradient and wide floodplain to their advantage.

A brief summary of site measurements may be found in Table 7. All habitat and riparian metrics values for each site in upper Beaver Creek may be found in Appendix C. Land use composition changed for each location with respect to delineated drainage areas (see Figure 15 and Table 8).

4.3 Cox Creek Sites:

Four of twenty-four sites are located on Cox Creek (mile 0.05), a tributary to Beaver Creek. These sites (sites 5 through 8) are on stream sections that may be characterized as low-gradient, with an average slope of less than 1%. The floodplain was accessible for all sites in this stream. Washed out remains of beaver dams but no active beaver dams were found in Cox Creek. Cox Creek has been named an unofficial reference stream by the TDEC because of its pristine condition relative to others in this area.

A brief summary of site measurements may be found in Table 7. All habitat and riparian metrics values for each site in Cox Creek may be found in Appendix C. Land use composition changed for each location with respect to delineated drainage areas (see Figure 16 and Table 8).

Table 7. Summarizes parameters for each sub-watershed.

Sub-Watersheds	Average Wetted Width Range (m)	Average Water Depth Range (m)	2004 303d list (N or Y)	Number of Habitat Units
Upper Beaver	3.1 to 5.7	0.15 to 0.32	No	38
Cox	2.3 to 5.2	0.12 to 0.20	No	66
Grassy	2.6 to 2.9	0.13 to 0.20	Yes	41
Hines	2.7 to 3.4	0.15 to 0.19	Yes	71
Knob	2.0 to 4.5	0.10 to 0.26	Yes	38
Willow	2.8 to 3.4	0.12 to 0.23	No	37

Table 8. Depicts land use percentages found for the 24 fish and habitat sites.

Site	Stream Names	Contributing Area of Site (miles^2)	High Density Residential	Medium Density Residential	Commercial	Industrial	Disturbed/ Transitional	Total Urban
1.00	Beaver 1	14.16	1.02%	9.21%	1.07%	0.26%	2.00%	13.56%
2.00	Beaver 2	9.88	1.21%	8.41%	1.17%	0.19%	2.74%	13.72%
3.00	Beaver 3	8.20	0.04%	6.38%	1.35%	0.24%	2.17%	10.18%
4.00	Beaver 4	4.93	0.00%	7.47%	2.17%	0.32%	2.48%	12.44%
5.00	Cox 1	3.68	0.68%	10.64%	0.97%	0.50%	0.35%	13.13%
6.00	Cox 2	2.75	0.04%	5.31%	0.52%	0.60%	0.38%	6.85%
7.00	Cox 3	2.20	0.05%	5.07%	0.53%	0.68%	0.47%	6.74%
8.00	Cox 4	1.59	0.00%	4.44%	0.24%	0.09%	0.00%	4.78%
9.00	Grassy 1	5.79	0.68%	5.64%	4.56%	1.80%	3.44%	16.12%
10.00	Grassy 2	5.26	0.80%	4.53%	5.38%	1.46%	3.43%	15.60%
11.00	Grassy 3	2.32	1.34%	3.28%	11.38%	2.38%	4.65%	23.03%
12.00	Grassy 4	1.84	1.68%	2.47%	14.31%	2.54%	5.70%	26.70%
13.00	Hines 1	2.33	9.39%	27.66%	3.90%	6.67%	1.08%	48.71%
14.00	Hines 2	2.17	9.87%	26.42%	4.02%	7.15%	1.16%	48.62%
15.00	Hines 3	2.09	10.27%	26.20%	3.77%	7.23%	6.85%	54.32%
16.00	Hines 4	1.65	13.02%	31.58%	2.11%	4.18%	0.52%	51.41%
17.00	Knob 1	5.89	0.20%	13.88%	4.67%	5.76%	3.16%	27.67%
18.00	Knob 2	5.65	0.21%	14.03%	4.47%	5.94%	3.20%	27.85%
19.00	Knob 3	3.31	0.15%	16.04%	2.10%	2.72%	3.68%	24.70%
20.00	Knob 4	2.84	0.18%	18.07%	1.31%	1.84%	4.26%	25.65%
21.00	Willow 1	3.71	0.06%	2.18%	0.53%	0.11%	0.58%	3.46%
22.00	Willow 2	3.30	0.00%	0.41%	0.15%	0.06%	0.30%	0.92%
23.00	Willow 3	3.20	0.00%	0.42%	0.06%	0.00%	0.31%	0.79%
24.00	Willow 4	1.25	0.00%	0.26%	0.00%	0.00%	0.00%	0.26%

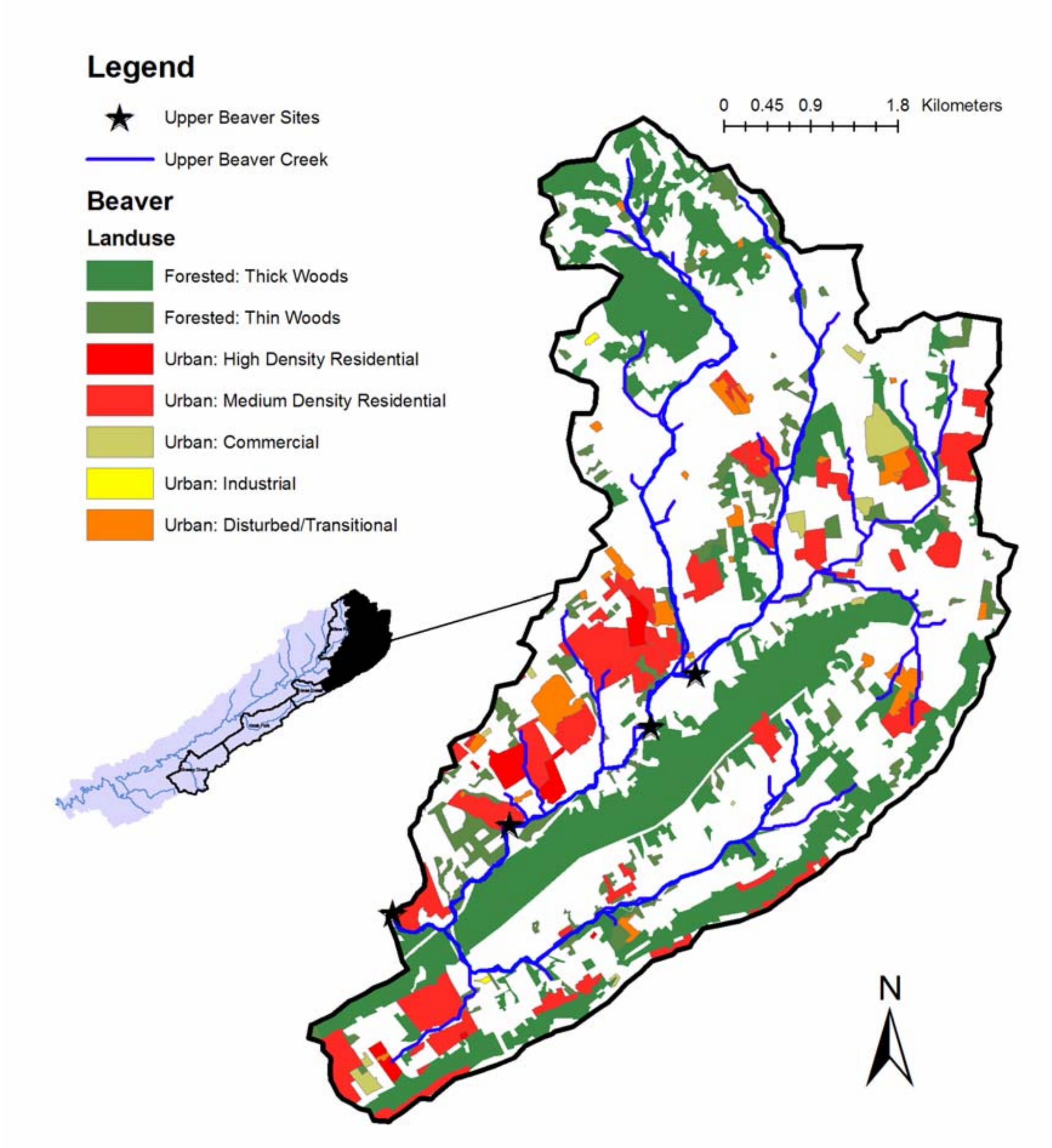


Figure 15. Forested and urban land use (in 2003) found for sites one through four in upper Beaver Creek. Site statistics may be found in tables 7 and 8.

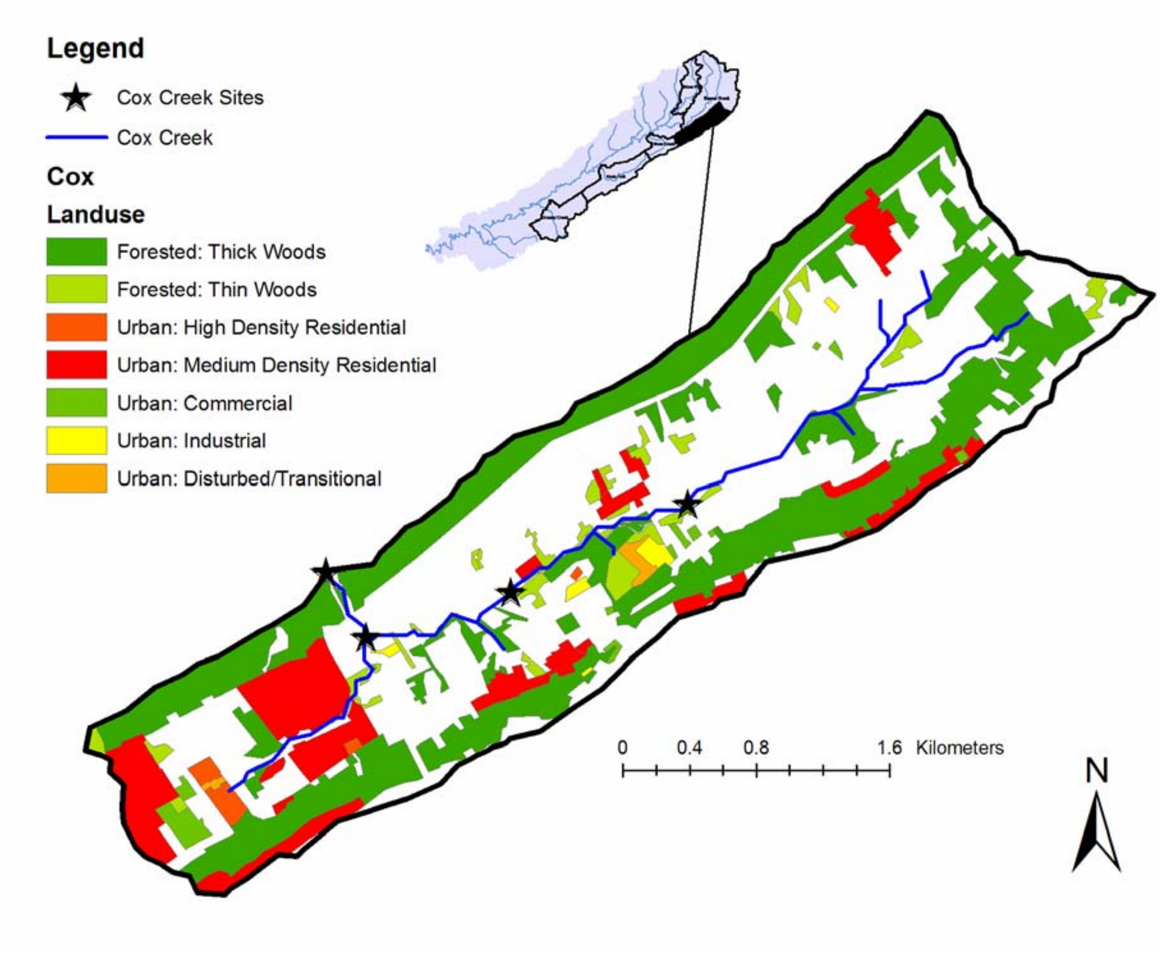


Figure 16. Forested and urban land use (in 2003) found for sites five through eight in Cox Creek. Site statistics may be found in tables 7 and 8.

4.4 Grassy Creek Sites:

Four of twenty-four sites (sites 9 through 12) are located in Grassy Creek, a tributary to Beaver Creek, starting at mile 0.5.

These sites are on stream sections that may be characterized as low-gradient, with an average slope of less than 0.5%. The floodplain was accessible to the stream for all but one of the four sites. Site 10 had stream banks that were highly incised, indicating that the stream at bankfull flow is not able to over-top and spread out into the floodplain. There were no washed out remains of beaver dams nor active beaver dams found in Grassy Creek. Grassy Creek has been listed on Tennessee’s 303d list as a category 5, not supporting due to more than one impaired uses.

A brief summary of site measurements may be found in Table 7. All habitat and riparian metrics values for each site in Grassy Creek may be found in Appendix C. Land use composition changed for each location with respect to delineated drainage areas (see Figure 17 and Table 8).

4.5 Hines Branch Sites:

Four of twenty-four sites (sites 13 through 16) are located in Hines Branch, a tributary to Beaver Creek, starting at mile 0. These sites are on stream sections that may be characterized as low-gradient with an average slope of less than

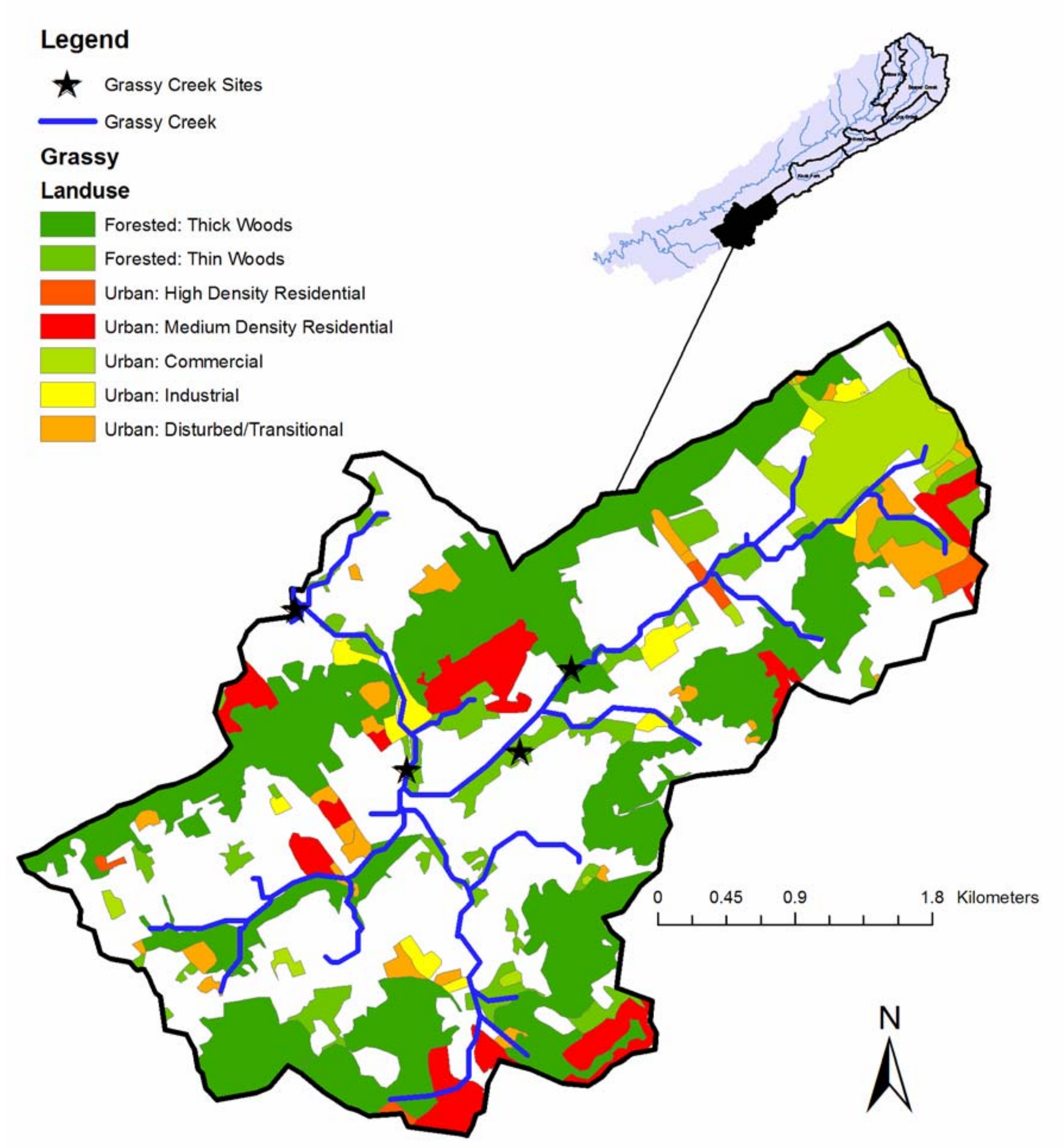


Figure 17. Forested and urban land use (in 2003) found for sites nine through twelve in Grassy Creek. Site statistics may be found in tables 7 and 8.

0.5%. The floodplain was not accessible for any of the sites measured in this stream. There were no washed out remains of beaver dams nor active beaver dams found in Hines Branch. Hines Branch has been listed on Tennessee's 303d list as a category 5, not supporting due to more than one impaired uses.

A brief summary of site measurements may be found in Table 7. All habitat and riparian metrics values for each site in Hines Branch may be found in Appendix C. Land use composition changed for each location with respect to delineated drainage areas (see Figure 18 and Table 8).

4.6 Knob Fork Sites:

Four of twenty-four sites (sites 17 through 20) are located in Knob Fork, a tributary to Beaver Creek, starting at mile 0.4.

These sites are on stream sections that may be characterized as low-gradient, with an average slope of less than 1%. The floodplain was accessible for all sites in this stream. There were no washed out remains of beaver dams nor active beaver dams found in Knob Fork.

A brief summary of site measurements may be found in Table 7. All habitat and riparian metrics values for each site in Knob Fork may be found in Appendix C.

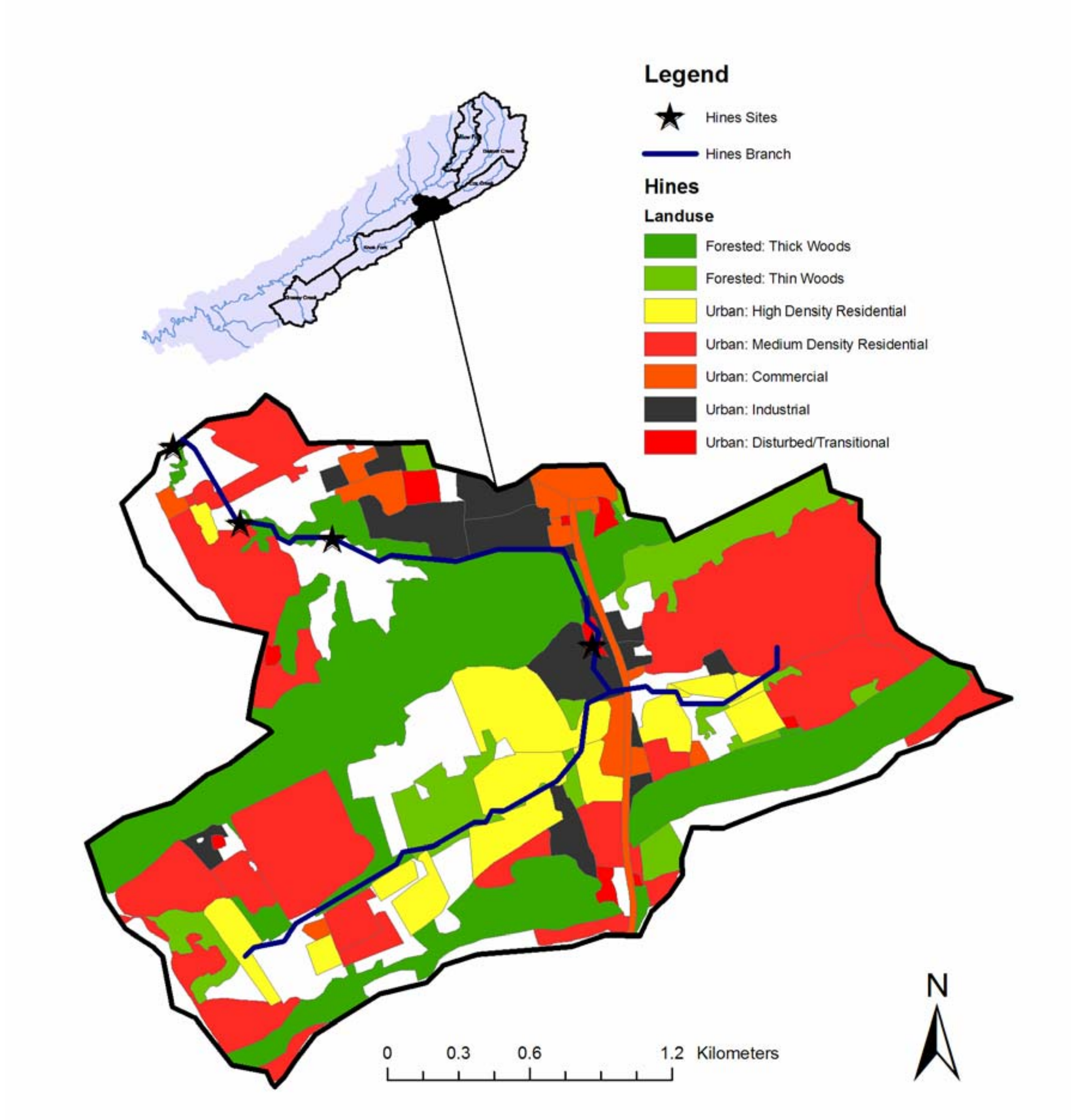


Figure 18. Forested and urban land use (in 2003) found for sites thirteen through sixteen in Hines Branch. Site statistics may be found in tables 7 and 8.

Land use composition changed for each location with respect to delineated drainage areas (see Figure 19 and Table 8).

4.7 Willow Fork Sites:

Four of twenty-four sites (sites 21 through 24) are located in Willow Fork, a tributary to Beaver Creek, starting at mile 1.1. These sites are on stream sections that may be characterized as low-gradient with an average slope of less than 1%, and one site having a slope of less than 2%. The floodplain was accessible for all sites in this stream. There were no washed out remains of beaver dams nor active beaver dams found in Willow Fork. Willow Fork has not yet been listed on the state of Tennessee's 303d list.

A brief summary of site measurements may be found in Table 7. All habitat and riparian metrics values for each site in Willow Fork may be found in Appendix C. Land use composition changed for each location with respect to delineated drainage areas (see Figure 20 and Table 8).

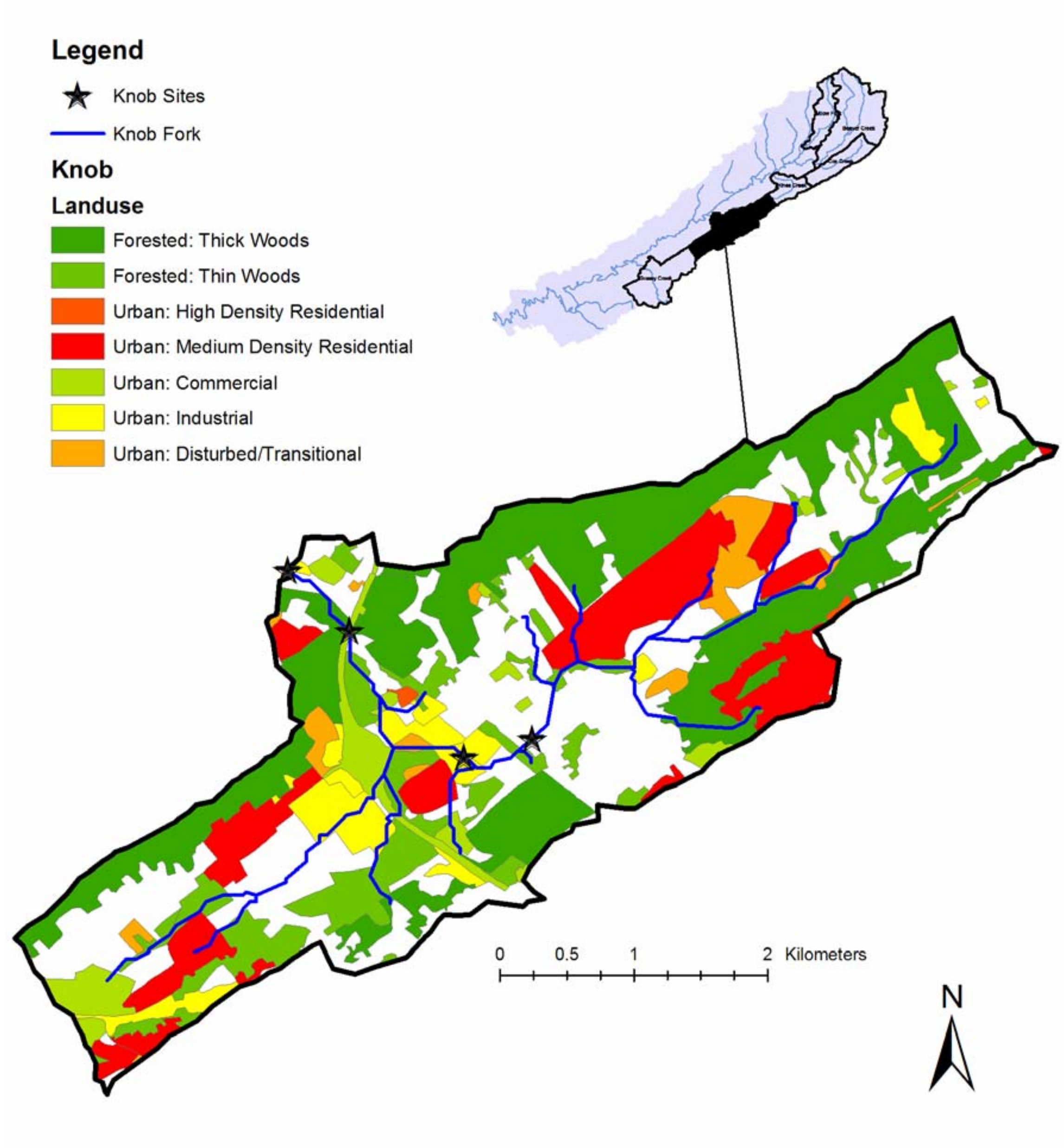


Figure 19: Forested and urban land use (in 2003) found for sites seventeen through twenty in Knob Fork. Site statistics may be found in tables 7 and 8.

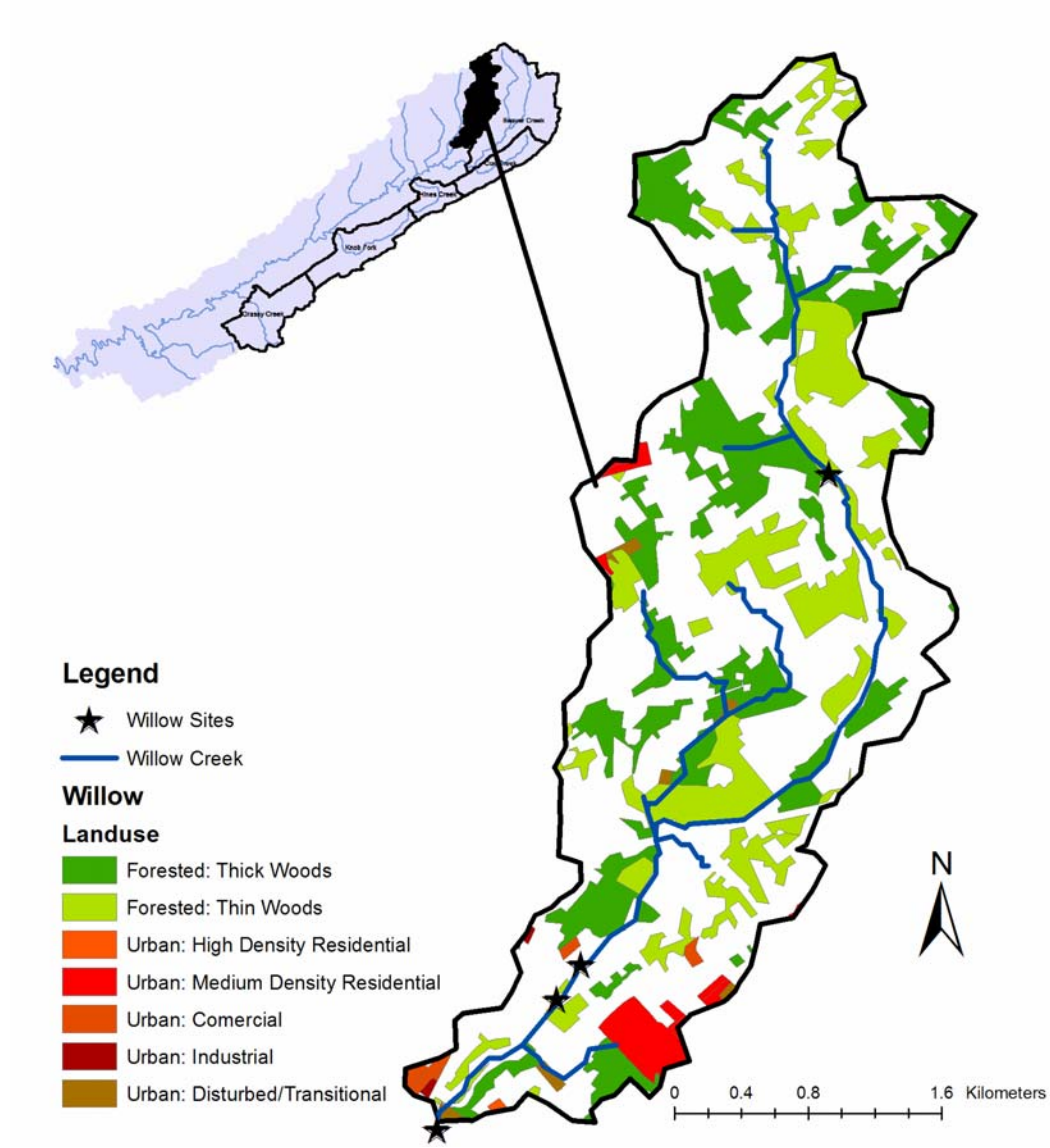


Figure 20: Forested and urban land use (in 2003) found for sites twenty-one through twenty-four in Willow Creek. Site statistics may be found in tables 7 and 8.

Chapter 5: Results

5.1 Urban:

IBI scores ranged from 28 to 50 out of a possible score range of 12 to 60. A significant correlation was found between fish IBI scores and watershed urbanization. Five different urban land uses were used to sum percent total urban land use for each of twenty four sites surveyed in Beaver Creek watershed. Total urban land use explained 29% of the variability (R^2 = 0.29) that correlated to a decline in the IBI (see Figure 21). Using multiple and simple linear regression, IBI scores were further tested to see if correlations were more strongly related to some specific urban land use or combinations of two or more of the five urban land uses (see Figure 22).

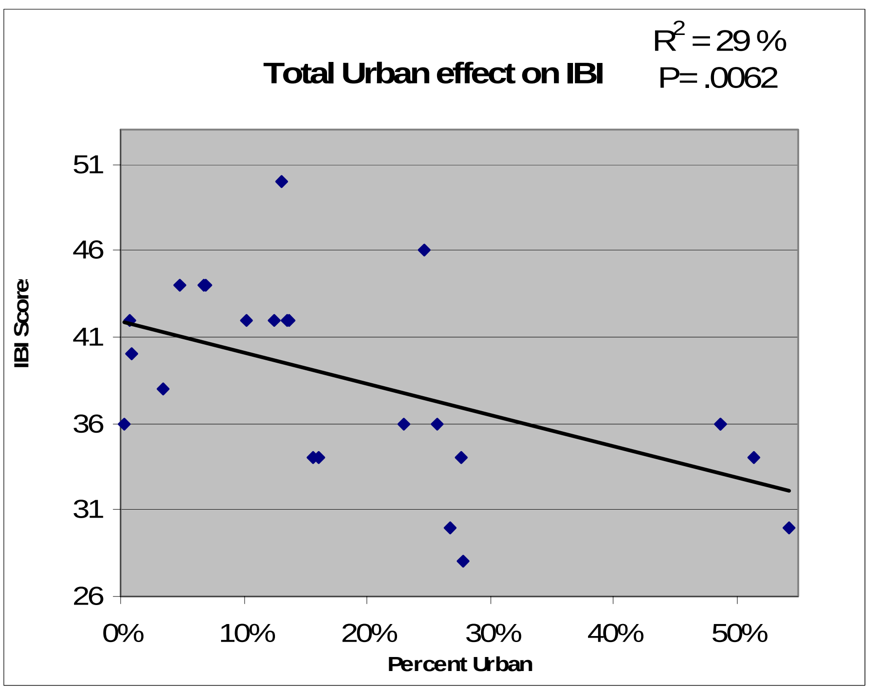


Figure 21. Simple linear regression depicting total urban land use effect on IBI Scores.

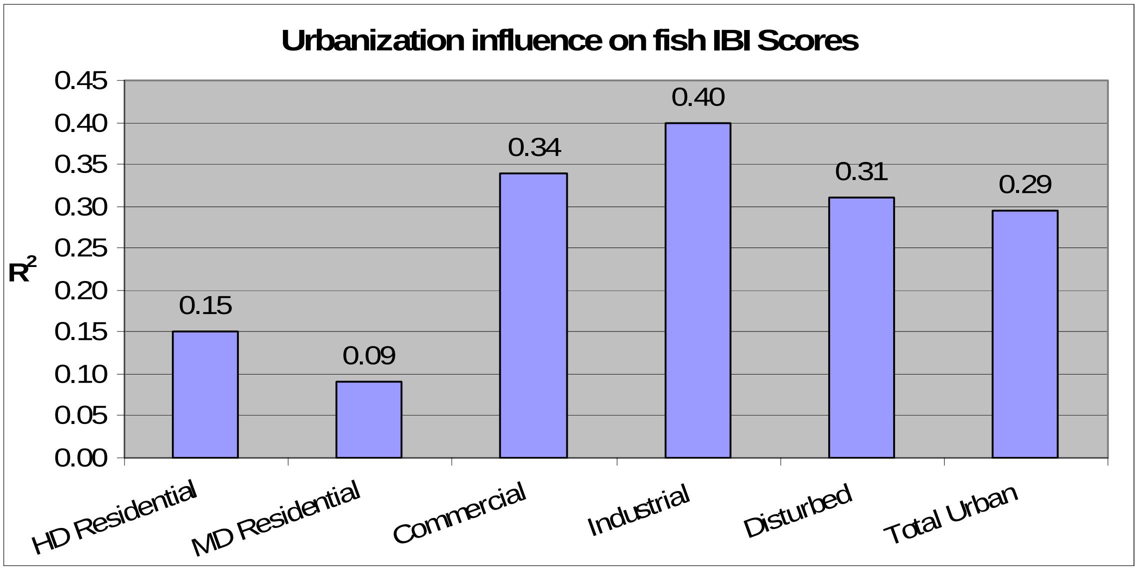


Figure 22. R^2 values found for urban land use types and P values. Industrial showing the lowest P value of 0.0010 (SAS 2004).

Commercial and Industrial land uses were more highly correlated to a decline in IBI scores. Multiple regression relating Commercial and Industrial to IBI scores showed an R^2 of 53% and a $p < 0.0004$ (see Figure 23). Therefore, the combination of Industrial and Commercial urban land use was used as the surrogate for total percent urban land use within each watershed. An analysis of variance means separation showed sites in Hines Branch to have the highest percent urban land use (see Appendix C).

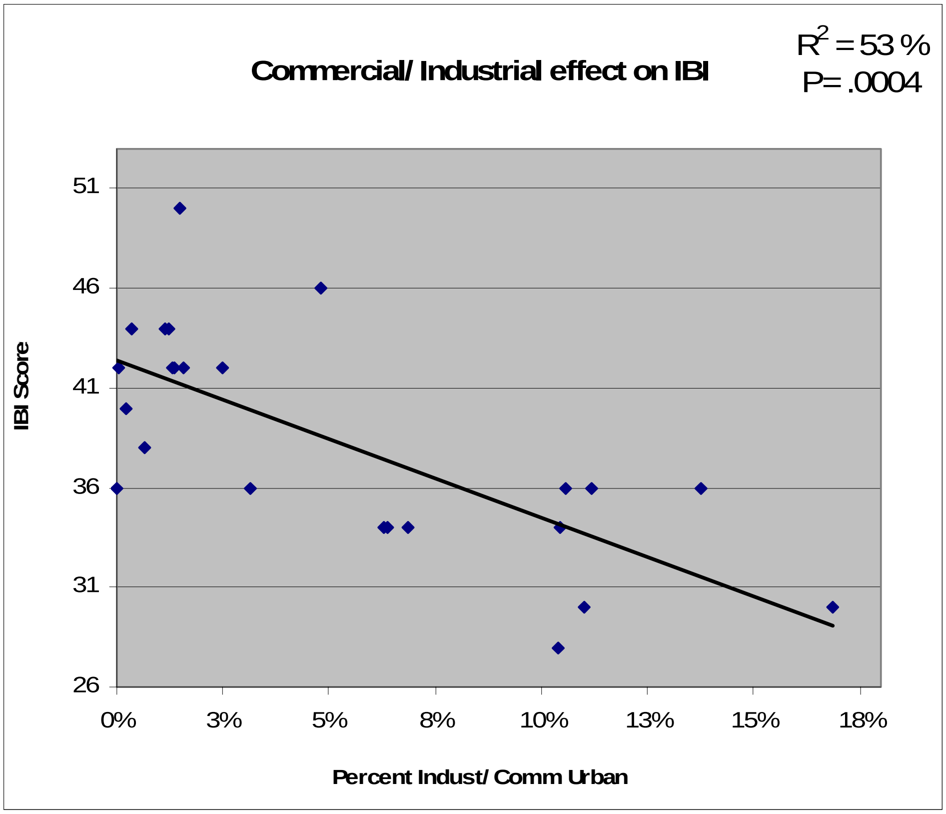


Figure 23. A multiple regression depicting Commercial and Industrial land use effects on IBI Scores.

5.2 Fish:

In 24 sites 7185 fish were shocked and identified, yielding 21 species of 7 families (see Table 9 and see Appendix C). Multiple regression using Industrial and Commercial percentages per sub-watershed showed the highest significance to decline in fish IBI scores (p= 0.0004) (see Figure 23). Families of darters, number of native fish, and the trophic guild of specialized insectivores also showed significant decline with increased percent urbanization (see Appendix D).

Table 9. Total fish collected numbered 7185 representing 21 species of 7 families. Introduced Species *.

Scientific Name	Common Name	Occurance Frequency	Total Abundance	Tolerance	Trophic Guild	Reproductive Guild
Catostomidae						
Catostomus commersonii	White sucker	18	225	tolerant	omnivore	Lithophilic
Hypentelium nigricans	Northern hog sucker	20	158	HW intol	insectivore	Lithophilic
Centrarchidae						
Ambloplites rupestris	Rock bass	8	34	intolerant	Top Carniv	
Lepomis auritus	Redbreast sunfish *	19	265	n/r	insectivore	
Lepomis cyanellus	Green sunfish	14	78	tolerant	insect	
Lepomis macrochirus	Bluegill	19	340	n/r	insect	
Micropterus puntulatus	Spotted bass	1	2	n/r	Top Carniv	
Micropterus salmoides	Largemouth bass	11	52	n/r	Top Carniv	
Cottidae						
Cottus carolinae	Banded sculpin	20	294	n/r	insect	
Cyprinidae						
Campostoma oligolepis	Largescale stoneroller	23	1354	n/r	omnivore	
Luxilus chrysocephalus	Striped shiner	23	1640	tolerant	omnivore	Lithophilic
Luxilus cocogenus	Warpaint shiner	1	1	HW intol	spec insect	Lithophilic
Lythrurus lirus	Mountain shiner	8	342	HW intol	spec insect	Lithophilic
Pimephales notatus	Bluntnose minnow	2	9	n/r	omnivore	
Rhinichthys atratulus	Blacknose dace	22	1321	n/r	insect	Lithophilic
Semotilus atromaculatus	Creek chub	23	588	tolerant	insect	
Ictaluridae						
Ameritus natalis	Yellow bullhead	6	34	tolerant	omnivore	
Percidae						
Etheostoma blennioides	Greenside darter	12	51	n/r	spec insect	Lithophilic
Etheostoma flaballare	Fantail darter	13	79	intolerant	spec insect	
Etheostoma jessiae	Blueside darter	9	39	intolerant	spec insect	Lithophilic
Etheostoma simoterum	Snubnose darter	16	147	n/r	spec insect	Lithophilic
Poeciliidae						
Gambusia affinis	Western mosquitofish *	7	132	tolerant	insectivore	

5.3 Habitat:

Pearson correlation analysis between urban land use and all other variables showed only a few potential relationships with physical habitat (see Appendix D). Potential habitat relationships with urban land area included percent run length, average steam width, crest to max depth ratio, average riffle width, percent boulders and max pool depth. Run length, average steam width, pool crest to pool max depth ratio, average riffle width and percent boulders decreased in response to increased urban land use. To narrow down the best habitat indicator, multiple regressions were run comparing the five correlated values to percent Commercial and Industrial land use. Pool crest to pool max depth ratio and average riffle width could not be used due to covariance between attributes. The remaining three (percent run length, average stream wetted width and percent boulders) showed an R^2 of 36% and a p-value of 0.0285.
Of these three, average stream wetted width (p= 0.0259) and percent boulders (p= 0.0038) also correlated with IBI scores (see Appendix D).

Several anticipated physical habitat relationships did not correlate to either percent urbanization or IBI scores, including percent riffle length, pool length, pool average and max depth, intact riparian and percent gravel (Table 10).

The number of native fish, greenside darters per 100 square meters, and percent specialized insectivores all showed positive correlations with average wetted

Table 10. Physical habitat relationships that correspond with correlations for both percent urbanization and IBI scores. Also listed are several non-significant variables that have been found to correlate with increased urbanization.

Dependent Variable	Urban P Values	Slope	IBI P Values	Slope
Index of Biotic Integrity (IBI)	0.0004	neg	1.00	N/A
Crest to Max Depth Ratio	0.0202	neg	0.266	N/A
Average Riffle Width	0.0263	neg	0.227	N/A
% Boulders per 100m2	0.0453	neg	0.0038	pos
Wood aggregates/ 100m2	0.0453	neg	0.0038	pos
% Riffle Length	0.604	N/A	0.532	N/A
% Pool Length	0.166	N/A	0.739	N/A
Average pool depth	0.594	N/A	0.982	N/A
max pool depth	0.278	N/A	0.569	N/A
% Intact Riparian	0.625	N/A	0.663	N/A
% Gravel per 100m2	0.304	N/A	0.317	N/A
Average wetted width	0.0634	neg	0.0259	pos

stream width. A negative correlation was found between percent Industrial and Commercial urban land use and average wetted stream width. The majority of these habitat variables also correlated to drainage area, indicating that many are related as a function of drainage area (discussed below). The index of biotic integrity was scored, in part, based on drainage area and therefore showed correlations independent of drainage area.

A multiple regression run using wood aggregates and percent boulders revealed a weak relationship that may connect urbanization to both fish and habitat. Wood aggregates and percent boulders had a direct positive correlation with IBI scores (p = .0038), and a direct negative correlation with percent Industrial/ Commercial urban land use (p = 0.0453).

5.4 Drainage Area:

Drainage area showed typical effects on habitat measurements relative to the size of each stream. Drainage area was not directly related to percent urbanization or IBI scores. Drainage area did correlate with fish abundances such as number of darters, as anticipated by the developers of the IBI (Karr et al. 1986) (see Figure 24).

5.5 SCS Curve Numbers:

Curve Number (CN) values, as described in Chapter 3, were used to test if the runoff potential of each sub-watershed could be linked to stream health. CN values were also used because they took into account the entirety of all the land uses found within each sub-watershed. The Pearson correlation analysis between CN values and all other variables did show some potential relationships. However, upon trying regression analysis the weighted CN values did not have enough variation in value to provide meaningful information. A less powerful analysis of variance was used to see if CN values differed by watershed (SAS 2004). Tukey means separation showed CN values to not significantly differ for one individual watersheds but Cox Creek did show the lowest average CN value (p= 0.0048). Cox Creek and all other sub-watersheds did differ significantly from upper the Beaver Creek sub-watershed (see Figure 25). Cox Creek sub-watershed showed an average CN value of 68.9 (see Table 11).

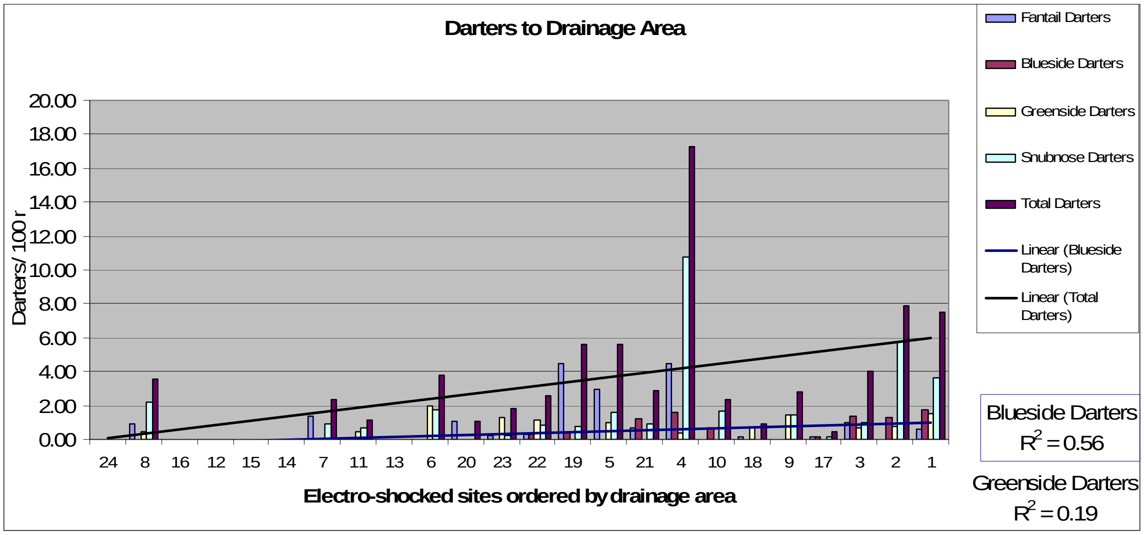


Figure 24. Drainage area influence on darter abundances. Relationship derived from 24 sites of Beaver Creek watershed, July 2005. Note: drainage areas are used to organize the field sites from left to right (low to high).

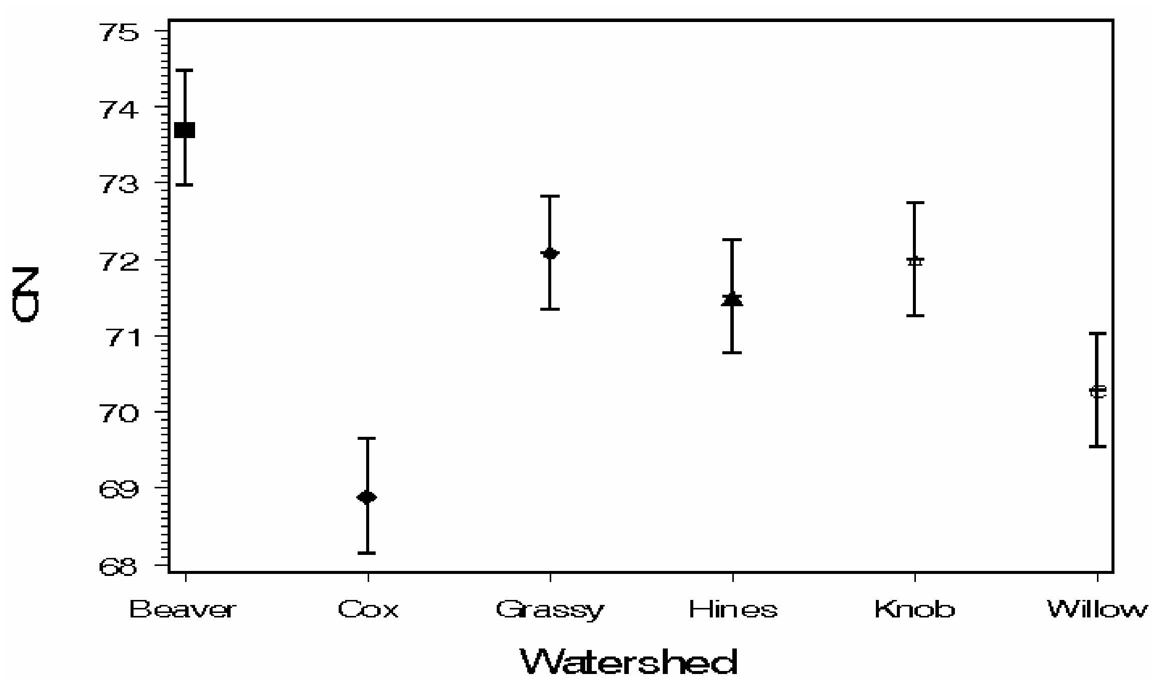


Figure 25. CN values mean differences found using six sub-watersheds as treatments.

Table 11. ANOVA, Tukey means separation results showing differences found between the six sub-watersheds.

Anova Mean Separation using Tukey (P< .05)	P Value	Mean	Trans	Significant differences found between sub-watersheds of Beaver Creek
Percent Urbanization	<0.0001	0.51	None	Hines differed having the highest urban
SCS Curve Number (CN)	0.0048	68.9	None	Cox had lowest CN values but did not differ
Index of Biotic Integrity (IBI)	0.0015	45.5	None	Cox differed having the best IBI scores
Percent Point Bar to total	0.1402	n/a	None	No differences between watersheds
Wood aggregates per 100m2	0.9923	n/a	None	No differences between watersheds
weighted wetted width	0.0013	n/a	None	No differences between watersheds
Percent Boulders	0.001	0.33	None	Cox differed having the highest percent boulders

Chapter 6: Discussion

Fish biological integrity was significantly affected by two measures of urbanization: total percent urban and percent Commercial/ Industrial. Total percent urban land use explained 29% of the variability in IBI scores (p= 0.0062), while Industrial and Commercial urban land use explained 53% of the variability in IBI scores (p = 0.0004). A threshold of approximately 10 to 15% impervious surface (Industrial and Commercial land use) was found to drop IBI scores into the poor category in Beaver Creek watershed. This finding matched results found in similar studies conducted nationwide (Walters et al. 1995; Schleiger 2000; Wang et al 2000; Schmidt and Talmage 2001; Wang et al. 2001; Jennings and Jarnagin 2002; Angermeier et al. 2004; Rashleigh 2004; Kennen et al. 2005; Snyder et al. 2005).

The combination of Industrial and Commercial urban land has shown to have the highest amount of connected impervious surface of any other urban category (Booth and Jackson 1997). Furthermore, connected imperviousness was the best single indicator of stream health for a study conducted in Wisconsin (Wang et al. 2001). Land uses with high amounts of connected impervious surface showed a similar connection for the Beaver Creek watershed, in this study. This means that connected impervious surfaces should be of primary interest to watershed managers or those involved in mitigating the effects of localized urban growth.

Connected impervious cover conversely showed the weakest relationship to measures of habitat structure in the same study by Wang et al. (2001). In comparison, habitat structure for this study showed a weak to insignificant correlation for both impervious cover (Industrial and Commercial land use) and for total urban land use (see Appendix D).

One study has shown a higher significance of urbanization effects on IBI scores when measured in close proximity (within 50 meters of either stream bank) to the stream (Wang et al. 2001). However, this study used entire catchments for each site, and found a higher correlation between percent urbanization and IBI scores than were found by Wang et al. (2001).

The strongest relationship found was with the combination of Industrial and Commercial urban land. However, the percentage Industrial and Commercial did not exceed 18% for any of the 24 catchments used for regression analysis. This left, at the very least, 82% of contributing areas out of the model. For this reason weighted SCS curve numbers were calculated for each of the 24 sites and then compared using means separation. Cox Creek differed significantly having the highest IBI scores ($p = 0.0015$). Means separation also showed Cox Creek watershed to have the lowest CN but was not statistically different than the CN for Willow Creek sub-watershed. Willow and Cox Creek sub-watersheds, together, differed significantly from upper Beaver Creek sub-watershed which showed significantly higher weighted CN's (p= 0.0048). Upper Beaver Creek sub-watershed likely showed high CN's due to its larger size, hence having more rock out-croppings and other land uses associated with D soil types.

Relationships between habitat structure and urbanization were very few, and of the few most were only weakly correlated to either urbanization, indicating no significant relationships (see Table 5.2). This lack of significant connection between urbanization and physical habitat matched findings in the study by Wang et al. (2001), but these results contradict studies that have shown significant change to occur to in-stream physical habitat structure with urbanization (Arnold and Gibbons 1996, Booth and Jackson 1997). Further investigation of physical habitat structure at the sub-watershed scale showed Cox Creek watershed to differ for percent boulders (p= .001). This difference likely occurred not as product of urbanization, but rather due to the fact that Cox Creek had some of the lowest percent urbanization values and the highest percent boulders. This further implies that no relationship was found between percent urbanization and physical habitat structures. In spite of this, fish communities calculated as part of the IBI and also separate from the IBI showed a decline in the presence of higher percent urbanization. Fish are dependent upon physical habitat to thrive, but because no specific habitat altering component was identified, there must be some other element due to urbanization that was not measured, such as sediment load, chemical runoff, from velocity or some other environmental stressor(s).

This study showed that there is a unique and largely undefined environmental stressor affecting fish communities in the urbanized areas of Beaver Creek watershed.   This validated similar results found in other studies nationwide. Why urbanization only affected aquatic biota and not physical structure is likely due to some component of urban runoff not yet explored in the Beaver Creek watershed.

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Appendices

Appendix A

Scoring Criteria for Total Number of Native Fish Species by Ecoregion and Watershed. Values Indicate X/Y Coordinates of Plots Describing the Relationship Between Maximum Expected Number of Fish Species and Drainage Area.

1 Total Number of Native Species

Ecoregion	Watershed		1	3	5	Max	Minimum Drainage Area	Maximum Number of Species	Minimum Drainage Area	Maximum Number of Species
BR	All	<1000	Varies with drainage area				1	7	1000	35
BR	All	>1000	<12	12-23	>23	35	>1000	35		
IP	All	<1000	Varies with drainage area				1	6	1000	68
IP	All	>1000	<23	23-45	>45	68	>1000	68		
RV	All	<1000	Varies with drainage area				1	3	1000	63
RV	All	>1000	<21	21-42	>42	63	>1000	63		
SA	All	<1000	Varies with drainage area				<10		Not Scored	
SA	All	>1000		Not Scored			10	9	1000	38

2 Number of Darter Species

Ecoregion	Watershed		1	3	5	Max	Minimum Drainage Area	Maximum Number of Species	Minimum Drainage Area	Maximum Number of Species
BR	All	10-1000	Varies with drainage area				10	4	1000	7
BR	All	>1000	<3	3-4	>4	7				
IP	All	5-1000	Varies with drainage area				5	5	1000	13
IP	All	>1000	<5	5-8	>8	13				
RV	CP, CN, HI	5-1000	Varies with drainage area				5	4	1000	12
RV	CP, CN, HI	>1000	<4	4-8	>8	12				
RV	HO	5-1000	Varies with drainage area				5	2	1000	11
RV	HO	>1000	<4	4-7.5	>7.5	11				
SA	All	<1000	Varies with drainage area				<10		Not scored	
SA	All	>1000		Not Scored			10	1	1000	11
2a. Number of Riffle Species										
BR	All	<10	Varies with drainage area				1	1	10	7.5
IP	All	<2	0		>0					
IP	All	2-5	Varies with drainage area				2	2	5	5
RV	All	<5	Varies with drainage area				1	1	5	5

3 Number of Sunfish Species, less Micropterus

Ecoregion	Watershed		1	3	5	Max	Minimum Drainage Area	Maximum Number of Species	Minimum Drainage Area	Maximum Number of Species
BR	All	>10	<1	1	>1	2				
IP	All	5-10	Varies with drainage area				5	4	10	6
IP	All	10-40	Varies with drainage area				10	6	40	7
IP	All	>40	<3	3-4	>4	7				
RV	CN, HI	5-40	Varies with drainage area				5	3.5	40	7
RV	CN, HI	>40	<3	3-4	>4	7				
RV	CP, HO	5-20	Varies with drainage area				5	2	20	4
RV	CP, HO	>20	<2	2	>2	4				
SA	All	>100	<2	2	>2	4				
3a. Number of Pool Species										
BR	All	<10	Varies with drainage area				1	3	10	11
IP	All	<5	Varies with drainage area				1	2	5	14
RV	All	<2	0		>0					
RV	All	2-5	Varies with drainage area				2	3	5	11
SA	All	10-100	Varies with drainage area				10	5	100	15

4 Number of Sucker Species

Ecoregion	Watershed		1	3	5	Max	Minimum Drainage Area	Maximum Number of Species	Minimum Drainage Area	Maximum Number of Species	
BR	All	10-60	<1	1	>1	2					
BR	All	60-500	Varies with drainage area				60	2	500	6	
BR	All	>500	<2	2-4	>4	6					
IP	All	5-10	Varies with drainage area				5	2	10	3	
IP	All	10-60	<2	2	>2	3					
IP	All	60-1000	Varies with drainage area				60	3	1000	12	
IP	All	>1000	4	4-8	>8	12					
RV	All	5-10	Varies with drainage area				5	2	10	3	
RV	All	10-60	<2	2	>2	3					
RV	All	60-1000	Varies with drainage area				60	3	1000	12	
RV	All	>1000	<4	4-8	>8	12					
SA	All	100-1000	Varies with drainage area				100	3	1000	4	
4a. Dominance											
BR	All	<10	Varies with drainage area				1	60	10	40	*
IP	All	<5	<60	60-80	>80	40					
RV	All	<5	Varies with drainage area				1	70	5	50	*
SA	All	10-100	Varies with drainage area				10	50	100	40	

* Trisect between these points and 100%

5 Number of Intolerant Species

Ecoregion	Watershed		1	3	5	Max	Minimum Drainage Area	Maximum Number of Species	Minimum Drainage Area	Maximum Number of Species
BR	All	10-50	Varies with drainage area				10	3	50	4
BR	All	>50	<2	2	>2	4				
IP	All	5-1000	Varies with drainage area				5	3	1000	10
IP	All	>1000	<4	4-6	>6	10				
RV	CN, HI, HO	5-1000	Varies with drainage area				5	3	1000	8
RV	CN, HI, HO	>1000	<3	3-5	>5	8				
RV	CP	5-1000	Varies with drainage area				5	3.5	1000	10
RV	CP	>1000	<4	4-6	>6	10				
SA	All	100-1000	Varies with drainage area				100	3	1000	6
5a. Number of Headwater Intolerant Species										
BR	All	<10	Varies with drainage area				1	1	10	8
IP	All	<2	0		>0					
IP	All	2-5	Varies with drainage area				2	2	5	6
RV	All	<5	Varies with drainage area				1	1	5	5.5
SA	All	10-100	Varies with drainage area				10	2	100	5

6 Percent of Individuals as Tolerant Species

Ecoregion	Watershed		1	3	5	Max	Minimum Drainage Area	Maximum Number of Species	Minimum Drainage Area	Maximum Number of Species
BR	All	<5	>40	20-40	<20	60				
BR	All	5-400	Varies with drainage area				5	60	400	30
BR	All	>400	>20	10-20	<10	30				
IP	All	<5	>40	20-40	<20	60				
IP	All	5-400	Varies with drainage area				5	60	400	30
IP	All	>400	>20	10-20	<10	30				
RV	All	<5	>40	20-40	<20	60				
RV	All	5-400	Varies with drainage area				5	60	400	30
RV	All	>400	>20	10-20	<10	30				
SA	All	10-400	Varies with drainage area				5	60	400	30
SA	All	>400	>20	10-20	<10	30				

7 Percent of Individuals as Omnivores

Ecoregion	Watershed		1	3	5	Max	Minimum Drainage Area	Maximum Number of Species	Minimum Drainage Area	Maximum Number of Species
BR	All	<5	>33	17-33	<17	50				
BR	All	5-400	Varies with drainage area				5	50	400	25
BR	All	>400	>16	9-16	<9	25				
IP	All	<5	>50	25-50	<25	75				
IP	All	5-400	Varies with drainage area				5	75	400	30
IP	All	>400	>20	10-20	<10	30				
RV	All	<5	>50	25-50	<25	75				
RV	All	5-400	Varies with drainage area				5	75	400	30
RV	All	>400	>20	10-20	<10	30				
SA	All	10-400	Varies with drainage area				5	60	400	30
SA	All	>400	>20	10-20	<10	30				

8 Percent of Individuals as Specialized Insectivores

Ecoregion	Watershed		1	3	5	Max	Minimum Drainage Area	Maximum Number of Species	Minimum Drainage Area	Maximum Number of Species
BR	All	1-10	Varies with drainage area				1	20	10	75
BR	All	>10	<25	25-50	>50	75				
IP	All	All	<22	22-44	>44	66				
RV	All	1-100	Varies with drainage area				1	15	100	75
RV	All	>100	<25	25-50	>50	75				
SA	All	10-1000	Varies with drainage area				10	35	1000	75

9 Percent of Individuals as Piscivores

Ecoregion	Watershed		1	3	5	Max	Minimum Drainage Area	Maximum Number of Species	Minimum Drainage Area	Maximum Number of Species
BR	All	<3	0		>0					
BR	All	3-10	Varies with drainage area				3	4	10	6
BR	All	>10	<2	2-4	>4	6				
IP	All	<3	0		>0					
IP	All	3-10	Varies with drainage area				3	2	10	5
IP	All	10-100	Varies with drainage area				10	5	100	6
IP	All	>100	<2	2-4	>4	6				
RV	All	<3	0		>0					
RV	All	3-10	Varies with drainage area				3	4	10	6
RV	All	>10	<2	2-4	>4	6				
SA	All	<10	Not Scored							
SA	All	>10	<2	2-4	>4	6				

10 Catch Rate (number of fish per 300 sq. ft.)

Ecoregion	Watershed		1	3	5	Max	Minimum Drainage Area	Maximum Number of Species	Minimum Drainage Area	Maximum Number of Species
BR	All	All	Varies with drainage area				1	120	5000	20
IP	All	All	Varies with drainage area				1	200	5000	20
RV	All	1-5000	Varies with drainage area				1	200	5000	20
RV	All	5000-10000	Varies with drainage area				5000	20	10000	16
SA	All	All	Varies with drainage area				10	32	1000	20

Ecoregion	Watershed		1	3	5	Max	Minimum Drainage Area	Maximum Number of Species	Minimum Drainage Area	Maximum Number of Species
11 Percent of Individuals as Hybrids										
BR	All	10-5000	>1	Tr.-1	0					
IP	All	5-5000	>1	Tr.-1	0					
RV	All	5-5000	>1	Tr.-1	0					
SA	All	100-1000	>1	Tr.-1	0					
11a. Percent Individuals Lithophylic Spawners										
BR	All	<10	<20	20-40	>40	60				
IP	All	<5		Varies with drainage area			1	45	5	70
RV	All	<5	<25	25-50	>50	75				
SA	All	10-100	<23.3	23.3-46.	>46.6	70				

12 Percent of Individuals with Anomalies

Ecoregion	Watershed		1	3	5	Max	Minimum Drainage Area	Maximum Number of Species	Minimum Drainage Area	Maximum Number of Species
All	All	All	>5	2-5	>2					

APPENDIX B

Site 1

Beaver Creek (38.5) 571-1

Central Appalachian Ridges and Valleys Clinch/Powell

Drainage Area:14.16 Knox,TN

	Scoring Criteria			Obs.	Score
Number of native fish species	<9	9-17	>17	17	3
Number of darter species	<2	2-3	>3	4	5
# sunfish species, -Micropterus	<2	2-2	>2	3	5
Number of sucker species	<2	2-2	>2	2	3
Number of intolerant species	<2	2-2	>2	3	5
Percent tolerant species	>35.2%	17.6%-35.2%	<17.6%	29.3%	3
% omnivores and stoneroller species	>42.9%	21.4%-42.9%	<21.4%	53.6%	1
Percent specialized insectivores	<16.5%	16.5%-33.0%	>33.0%	20.5%	3
Percent piscivores	<2.0%	2.0%-4.0%	>4.0%	3.4%	3
Catch rate (per 300 sq ft)	<24	24-49	>49	16	1
Percent hybrids	>1	Tr.-1	0	0.0%	5
Percent anomalies	>5.0%	2.0%-5.0%	<2.0%	1.0%	5

Done Print Rating: fair IBI Score= 42

Site 2

Beaver Creek (40.2) 567-7

Central Appalachian Ridges and Valleys Clinch/Powell

Drainage Area:9.88 Knox,TN

	Scoring Criteria			Obs.	Score
Number of native fish species	<8	8-15	>15	15	3
Number of darter species	<2	2-3	>3	3	3
# sunfish species, -Micropterus	<1	1-1	>1	2	5
Number of sucker species	<1	1-1	>1	2	5
Number of intolerant species	<2	2-2	>2	1	1
Percent tolerant species	>36.9%	18.4%-36.9%	<18.4%	32.6%	3
% omnivores and stoneroller species	>45.3%	22.7%-45.3%	<22.7%	31.4%	3
Percent specialized insectivores	<14.9%	14.9%-29.9%	>29.9%	29.6%	3
Percent piscivores	<2.0%	2.0%-4.0%	>4.0%	0.7%	1
Catch rate (per 300 sq ft)	<27	27-54	>54	67	5
Percent hybrids	>1	Tr.-1	0	0.0%	5
Percent anomalies	>5.0%	2.0%-5.0%	<2.0%	0.9%	5

Done Print Rating: fair IBI Score= 42

Site 3

Beaver Creek (41.7) 567-8

Central Appalachian Ridges and Valleys Clinch/Powell

Drainage Area:8.2 Knox,TN

	Scoring Criteria			Obs.	Score
Number of native fish species	<8	8-14	>14	16	5
Number of darter species	<2	2-2	>2	4	5
# sunfish species, -Micropterus	<1	1-1	>1	2	5
Number of sucker species	<1	1-1	>1	2	5
Number of intolerant species	<2	2-2	>2	2	3
Percent tolerant species	>37.7%	18.9%-37.7%	<18.9%	39.7%	1
% omnivores and stoneroller species	>46.6%	23.3%-46.6%	<23.3%	49.3%	1
Percent specialized insectivores	<14.1%	14.1%-28.3%	>28.3%	15.4%	3
Percent piscivores	<1.9%	1.9%-3.8%	>3.8%	4.7%	5
Catch rate (per 300 sq ft)	<28	28-57	>57	19	1
Percent hybrids	>1	Tr.-1	0	0.0%	5
Percent anomalies	>5.0%	2.0%-5.0%	<2.0%	2.3%	3

Done Print Rating: fair IBI Score= 42

Site 4

Beaver Creek (42.5) 567-9

Central Appalachian Ridges and Valleys Clinch/Powell

Drainage Area:4.93 Knox,TN

	Scoring Criteria			Obs.	Score
Number of native fish species	<6	6-11	>11	14	5
Number of riffle species	<2	2-2	>2	3	5
Number of pool species	<4	4-6	>6	8	5
Percent of 2 dominant species	>83.4%	66.8%-83.4%	<66.8%	67.7%	3
# of hw intolerant species	<2	2-3	>3	4	5
Percent tolerant species	>40.0%	20.0%-40.0%	<20.0%	19.0%	5
% omnivores and stoneroller species	>50.0%	25.0%-50.0%	<25.0%	64.5%	1
Percent specialized insectivores	<11.9%	11.9%-23.9%	>23.9%	9.0%	1
Percent piscivores	<1.6%	1.6%-3.2%	>3.2%	0.0%	1
Catch rate (per 300 sq ft)	<32	32-65	>65	65	3
Percent lithophilic spawners	<25.0%	25.0%-50.0%	>50.0%	36.1%	3
Percent anomalies	>5.0%	2.0%-5.0%	<2.0%	1.4%	5

Done Print Rating: fair IBI Score= 42

Site 5
Cox Creek (.01) 2718-2

Central Appalachian Ridges and Valleys Clinch/Powell

Drainage Area:3.69 Knox,TN

	Scoring Criteria			Obs.	Score
Number of native fish species	<5	5-9	>9	16	5
Number of riffle species	<2	2-2	>2	4	5
Number of pool species	<3	3-5	>5	9	5
Percent of 2 dominant species	>84.6%	69.2%-84.6%	<69.2%	46.3%	5
# of hw intolerant species	<2	2-2	>2	4	5
Percent tolerant species	>40.0%	20.0%-40.0%	<20.0%	13.4%	5
% omnivores and stoneroller species	>50.0%	25.0%-50.0%	<25.0%	31.5%	3
Percent specialized insectivores	<10.7%	10.7%-21.3%	>21.3%	15.1%	3
Percent piscivores	<1.4%	1.4%-2.9%	>2.9%	2.0%	3
Catch rate (per 300 sq ft)	<35	35-70	>70	23	1
Percent lithophilic spawners	<25.0%	25.0%-50.0%	>50.0%	52.8%	5
Percent anomalies	>5.0%	2.0%-5.0%	<2.0%	1.7%	5

Done Print Rating: good IBI Score= 50

Site 6
Cox Creek (.4) 2718-3

Central Appalachian Ridges and Valleys Clinch/Powell

Drainage Area:2.75 Knox,TN

	Scoring Criteria			Obs.	Score
Number of native fish species	<4	4-7	>7	13	5
Number of riffle species	<2	2-2	>2	3	5
Number of pool species	<2	2-3	>3	7	5
Percent of 2 dominant species	>85.8%	71.6%-85.8%	<71.6%	47.7%	5
# of hw intolerant species	<2	2-2	>2	3	5
Percent tolerant species	>40.0%	20.0%-40.0%	<20.0%	37.7%	3
% omnivores and stoneroller species	>50.0%	25.0%-50.0%	<25.0%	50.0%	3
Percent specialized insectivores	<9.4%	9.4%-18.8%	>18.8%	6.2%	1
Percent piscivores	0		>0	1.8%	5
Catch rate (per 300 sq ft)	<38	38-76	>76	27	1
Percent lithophilic spawners	<25.0%	25.0%-50.0%	>50.0%	47.7%	3
Percent anomalies	>5.0%	2.0%-5.0%	<2.0%	3.1%	3

Done Print Rating: fair IBI Score= 44

Site 7

Cox Creek (.9) — 2718-4

Central Appalachian Ridges and Valleys — Clinch/Powell

Drainage Area:2.2 — Knox,TN

	Scoring Criteria			Obs.	Score
Number of native fish species	<3	3-6	>6	11	5
Number of riffle species	<1	1-1	>1	3	5
Number of pool species	<2	2-2	>2	5	5
Percent of 2 dominant species	>86.7%	73.5%-86.7%	<73.5%	51.1%	5
# of hw intolerant species	<2	2-2	>2	3	5
Percent tolerant species	>40.0%	20.0%-40.0%	<20.0%	42.7%	1
% omnivores and stoneroller species	>50.0%	25.0%-50.0%	<25.0%	54.4%	1
Percent specialized insectivores	<8.4%	8.4%-16.8%	>16.8%	3.2%	1
Percent piscivores	0		>0	1.0%	5
Catch rate (per 300 sq ft)	<40	40-81	>81	26	1
Percent lithophilic spawners	<25.0%	25.0%-50.0%	>50.0%	52.8%	5
Percent anomalies	>5.0%	2.0%-5.0%	<2.0%	1.9%	5

Done Print Rating: fair IBI Score= 44

Site 8

Cox Creek (1.9) — 2718-5

Central Appalachian Ridges and Valleys — Clinch/Powell

Drainage Area:1.59 — Knox,TN

	Scoring Criteria			Obs.	Score
Number of native fish species	<3	3-4	>4	10	5
Number of riffle species	<1	1-1	>1	4	5
Number of pool species	0		>0	3	5
Percent of 2 dominant species	>88.1%	76.2%-88.1%	<76.2%	63.7%	5
# of hw intolerant species	<1	1-1	>1	2	5
Percent tolerant species	>40.0%	20.0%-40.0%	<20.0%	18.5%	5
% omnivores and stoneroller species	>50.0%	25.0%-50.0%	<25.0%	49.2%	3
Percent specialized insectivores				6.5%	1
Percent piscivores				0.0%	1
Catch rate (per 300 sq ft)	<44	44-88	>88	17	1
Percent lithophilic spawners	<25.0%	25.0%-50.0%	>50.0%	46.8%	3
Percent anomalies	>5.0%	2.0%-5.0%	<2.0%	1.6%	5

Done Print Rating: fair IBI Score= 44

Site 9

Grassy Creek (.5) 4490-2

Central Appalachian Ridges and Valleys — Ft. Loudoun/Melton Hill/Wattsb

Drainage Area:5.79 — Knox,TN

	Scoring Criteria			Obs.	Score
Number of native fish species	<7	7-12	>12	11	3
Number of darter species	<2	2-2	>2	2	3
# sunfish species, -Micropterus	<1	1-1	>1	2	5
Number of sucker species	<1	1-1	>1	2	5
Number of intolerant species	<2	2-2	>2	0	1
Percent tolerant species	>39.3%	19.7%-39.3%	<19.7%	42.2%	1
% omnivores and stoneroller species	>49.0%	24.5%-49.0%	<24.5%	43.0%	3
Percent specialized insectivores				6.3%	1
Percent piscivores				5.5%	1
Catch rate (per 300 sq ft)	<31	31-62	>62	14	1
Percent hybrids	>1	Tr.-1	0	0.0%	5
Percent anomalies	>5.0%	2.0%-5.0%	<2.0%	0.0%	5

Done Print Rating: poor IBI Score= 34

Site 10

Grassy Creek (1.1) 4490-3

Central Appalachian Ridges and Valleys — Ft. Loudoun/Melton Hill/Wattsb

Drainage Area:5.26 — Knox,TN

	Scoring Criteria			Obs.	Score
Number of native fish species	<6	6-11	>11	13	5
Number of darter species	<2	2-2	>2	2	3
# sunfish species, -Micropterus	<1	1-1	>1	3	5
Number of sucker species	<1	1-1	>1	1	3
Number of intolerant species	<2	2-2	>2	2	3
Percent tolerant species	>39.8%	19.9%-39.8%	<19.9%	48.0%	1
% omnivores and stoneroller species	>49.7%	24.8%-49.7%	<24.8%	55.1%	1
Percent specialized insectivores				5.5%	1
Percent piscivores				3.9%	1
Catch rate (per 300 sq ft)	<32	32-64	>64	12	1
Percent hybrids	>1	Tr.-1	0	0.0%	5
Percent anomalies	>5.0%	2.0%-5.0%	<2.0%	1.6%	5

Done Print Rating: poor IBI Score= 34

Site 11

Grassy Creek (1.9) 4490-4

Central Appalachian Ridges and Valleys — Ft. Loudoun/Melton Hill/Wattsb

Drainage Area:2.32 — Knox,TN

	Scoring Criteria			Obs.	Score
Number of native fish species	<4	4-6	>6	10	5
Number of riffle species	<2	2-2	>2	2	3
Number of pool species	<2	2-2	>2	5	5
Percent of 2 dominant species	>86.5%	73.0%-86.5%	<73.0%	47.1%	5
# of hw intolerant species	<2	2-2	>2	1	1
Percent tolerant species	>40.0%	20.0%-40.0%	<20.0%	27.5%	3
% omnivores and stoneroller species	>50.0%	25.0%-50.0%	<25.0%	31.4%	3
Percent specialized insectivores				4.9%	1
Percent piscivores				3.9%	1
Catch rate (per 300 sq ft)	<40	40-80	>80	7	1
Percent lithophilic spawners	<25.0%	25.0%-50.0%	>50.0%	29.4%	3
Percent anomalies	>5.0%	2.0%-5.0%	<2.0%	0.0%	5

Done Print Rating: poor/fair IBI Score= 36

Site 12

Grassy Creek (2.3) 4490-5

Central Appalachian Ridges and Valleys — Ft. Loudoun/Melton Hill/Wattsb

Drainage Area:1.84 — Knox,TN

	Scoring Criteria			Obs.	Score
Number of native fish species	<3	3-5	>5	9	5
Number of riffle species	<1	1-1	>1	0	1
Number of pool species	0		>0	7	5
Percent of 2 dominant species	>87.5%	74.9%-87.5%	<74.9%	53.3%	5
# of hw intolerant species	<1	1-1	>1	0	1
Percent tolerant species	>40.0%	20.0%-40.0%	<20.0%	56.1%	1
% omnivores and stoneroller species	>50.0%	25.0%-50.0%	<25.0%	53.3%	1
Percent specialized insectivores				0.0%	1
Percent piscivores				7.5%	1
Catch rate (per 300 sq ft)	<42	42-85	>85	9	1
Percent lithophilic spawners	<25.0%	25.0%-50.0%	>50.0%	48.6%	3
Percent anomalies	>5.0%	2.0%-5.0%	<2.0%	0.9%	5

Done Print Rating: poor IBI Score= 30

Site 13

Hines Branch (.05) 5081-2

Central Appalachian Ridges and Valleys Ft. Loudoun/Melton Hill/Wattsb

Drainage Area:2.33 Knox,TN

	Scoring Criteria			Obs.	Score
Number of native fish species	<4	4-6	>6	11	5
Number of riffle species	<2	2-2	>2	1	1
Number of pool species	<2	2-2	>2	7	5
Percent of 2 dominant species	>86.5%	73.0%-86.5%	<73.0%	61.6%	5
# of hw intolerant species	<2	2-2	>2	3	5
Percent tolerant species	>40.0%	20.0%-40.0%	<20.0%	60.2%	1
% omnivores and stoneroller species	>50.0%	25.0%-50.0%	<25.0%	48.9%	3
Percent specialized insectivores				0.4%	1
Percent piscivores				0.7%	1
Catch rate (per 300 sq ft)	<40	40-80	>80	20	1
Percent lithophilic spawners	<25.0%	25.0%-50.0%	>50.0%	67.6%	5
Percent anomalies	>5.0%	2.0%-5.0%	<2.0%	2.5%	3

Done Print Rating: poor/fair IBI Score= 36

Site 14

Hines Branch (.4) 5081-3

Central Appalachian Ridges and Valleys Ft. Loudoun/Melton Hill/Wattsb

Drainage Area:2.17 Knox,TN

	Scoring Criteria			Obs.	Score
Number of native fish species	<3	3-6	>6	6	3
Number of riffle species	<1	1-1	>1	1	3
Number of pool species	<2	2-2	>2	3	5
Percent of 2 dominant species	>86.8%	73.6%-86.8%	<73.6%	67.3%	5
# of hw intolerant species	<2	2-2	>2	0	1
Percent tolerant species	>40.0%	20.0%-40.0%	<20.0%	42.9%	1
% omnivores and stoneroller species	>50.0%	25.0%-50.0%	<25.0%	22.4%	5
Percent specialized insectivores				0.0%	1
Percent piscivores				0.0%	1
Catch rate (per 300 sq ft)	<41	41-81	>81	12	1
Percent lithophilic spawners	<25.0%	25.0%-50.0%	>50.0%	64.4%	5
Percent anomalies	>5.0%	2.0%-5.0%	<2.0%	0.0%	5

Done Print Rating: poor/fair IBI Score= 36

Site 15

Hines Branch (.9) 5081-4

Central Appalachian Ridges and Valleys — Ft. Loudoun/Melton Hill/Wattsb

Drainage Area:2.09 — Knox,TN

	Scoring Criteria			Obs.	Score
Number of native fish species	<3	3-6	>6	6	3
Number of riffle species	<1	1-1	>1	1	3
Number of pool species	<2	2-2	>2	2	3
Percent of 2 dominant species	>86.9%	73.9%-86.9%	<73.9%	57.8%	5
# of hw intolerant species	<2	2-2	>2	1	1
Percent tolerant species	>40.0%	20.0%-40.0%	<20.0%	36.6%	3
% omnivores and stoneroller species	>50.0%	25.0%-50.0%	<25.0%	46.0%	3
Percent specialized insectivores	<8.2%	8.2%-16.4%	>16.4%	0.0%	1
Percent piscivores	0		>0	0.0%	1
Catch rate (per 300 sq ft)	<41	41-82	>82	25	1
Percent lithophilic spawners	<25.0%	25.0%-50.0%	>50.0%	58.1%	5
Percent anomalies	>5.0%	2.0%-5.0%	<2.0%	12.1%	1

Done Print Rating: poor IBI Score= 30

Site 16

Hines Branch (1.9) 5081-5

Central Appalachian Ridges and Valleys — Ft. Loudoun/Melton Hill/Wattsb

Drainage Area:1.65 — Knox,TN

	Scoring Criteria			Obs.	Score
Number of native fish species	<3	3-4	>4	6	5
Number of riffle species	<1	1-1	>1	1	3
Number of pool species	0		>0	3	5
Percent of 2 dominant species	>87.9%	75.9%-87.9%	<75.9%	90.1%	1
# of hw intolerant species	<1	1-1	>1	0	1
Percent tolerant species	>40.0%	20.0%-40.0%	<20.0%	41.1%	1
% omnivores and stoneroller species	>50.0%	25.0%-50.0%	<25.0%	8.9%	5
Percent specialized insectivores				0.0%	1
Percent piscivores				0.0%	1
Catch rate (per 300 sq ft)	<44	44-87	>87	19	1
Percent lithophilic spawners	<25.0%	25.0%-50.0%	>50.0%	59.6%	5
Percent anomalies	>5.0%	2.0%-5.0%	<2.0%	0.4%	5

Done Print Rating: poor IBI Score= 34

Site 17

Knob Fork (.4) 5995-1

Central Appalachian Ridges and Valleys Ft. Loudoun/Melton Hill/Wattsb

Drainage Area:5.89 Knox,TN

	Scoring Criteria			Obs.	Score
Number of native fish species	<7	7-12	>12	12	3
Number of darter species	<2	2-2	>2	3	5
# sunfish species, -Micropterus	<1	1-1	>1	1	3
Number of sucker species	<1	1-1	>1	2	5
Number of intolerant species	<2	2-2	>2	2	3
Percent tolerant species	>39.3%	19.6%-39.3%	<19.6%	85.7%	1
% omnivores and stoneroller species	>48.9%	24.4%-48.9%	<24.4%	70.1%	1
Percent specialized insectivores				1.6%	1
Percent piscivores				0.0%	1
Catch rate (per 300 sq ft)	<31	31-62	>62	14	1
Percent hybrids	>1	Tr.-1	0	0.0%	5
Percent anomalies	>5.0%	2.0%-5.0%	<2.0%	0.0%	5

Done Print Rating: poor IBI Score= 34

Site 18

Knob Fork (.9) 5995-2

Central Appalachian Ridges and Valleys Ft. Loudoun/Melton Hill/Wattsb

Drainage Area:5.65 Knox,TN

	Scoring Criteria			Obs.	Score
Number of native fish species	<7	7-12	>12	11	3
Number of darter species	<2	2-2	>2	2	3
# sunfish species, -Micropterus	<1	1-1	>1	1	3
Number of sucker species	<1	1-1	>1	2	5
Number of intolerant species	<2	2-2	>2	1	1
Percent tolerant species	>39.4%	19.7%-39.4%	<19.7%	68.2%	1
% omnivores and stoneroller species	>49.2%	24.6%-49.2%	<24.6%	64.7%	1
Percent specialized insectivores				2.1%	1
Percent piscivores				0.0%	1
Catch rate (per 300 sq ft)	<31	31-63	>63	15	1
Percent hybrids	>1	Tr.-1	0	0.0%	5
Percent anomalies	>5.0%	2.0%-5.0%	<2.0%	4.5%	3

Done Print Rating: poor IBI Score= 28

Site 19
Knob Fork (1.9) 5995-3

Central Appalachian Ridges and Valleys — Ft. Loudoun/Melton Hill/Wattsb

Drainage Area:3.31 — Knox,TN

	Scoring Criteria			Obs.	Score
Number of native fish species	<5	5-8	>8	14	5
Number of riffle species	<2	2-2	>2	3	5
Number of pool species	<3	3-4	>4	8	5
Percent of 2 dominant species	>85.0%	70.1%-85.0%	<70.1%	57.4%	5
# of hw intolerant species	<2	2-2	>2	4	5
Percent tolerant species	>40.0%	20.0%-40.0%	<20.0%	37.7%	3
% omnivores and stoneroller species	>50.0%	25.0%-50.0%	<25.0%	26.9%	3
Percent specialized insectivores	<10.2%	10.2%-20.4%	>20.4%	6.7%	1
Percent piscivores	<1.4%	1.4%-2.8%	>2.8%	1.8%	3
Catch rate (per 300 sq ft)	<36	36-72	>72	26	1
Percent lithophilic spawners	<25.0%	25.0%-50.0%	>50.0%	62.3%	5
Percent anomalies	>5.0%	2.0%-5.0%	<2.0%	0.9%	5

Done Print Rating: fair/good IBI Score= 46

Site 20
Knob Fork (2.4) 5995-4

Central Appalachian Ridges and Valleys — Ft. Loudoun/Melton Hill/Wattsb

Drainage Area:2.84 — Knox,TN

	Scoring Criteria			Obs.	Score
Number of native fish species	<4	4-8	>8	7	3
Number of riffle species	<2	2-2	>2	2	3
Number of pool species	<2	2-4	>4	3	3
Percent of 2 dominant species	>85.7%	71.4%-85.7%	<71.4%	72.0%	3
# of hw intolerant species	<2	2-2	>2	2	3
Percent tolerant species	>40.0%	20.0%-40.0%	<20.0%	35.8%	3
% omnivores and stoneroller species	>50.0%	25.0%-50.0%	<25.0%	18.7%	5
Percent specialized insectivores				2.1%	1
Percent piscivores				0.0%	1
Catch rate (per 300 sq ft)	<38	38-75	>75	14	1
Percent lithophilic spawners	<25.0%	25.0%-50.0%	>50.0%	73.1%	5
Percent anomalies	>5.0%	2.0%-5.0%	<2.0%	0.0%	5

Done Print Rating: poor/fair IBI Score= 36

Site 21

Willow Fork (1.1) 12267-2

Central Appalachian Ridges and Valleys — Ft. Loudoun/Melton Hill/Wattsb

Drainage Area:3.71 — Knox,TN

	Scoring Criteria			Obs.	Score
Number of native fish species	<5	5-9	>9	13	5
Number of riffle species	<2	2-2	>2	3	5
Number of pool species	<3	3-5	>5	7	5
Percent of 2 dominant species	>84.6%	69.1%-84.6%	<69.1%	61.8%	5
# of hw intolerant species	<2	2-2	>2	3	5
Percent tolerant species	>40.0%	20.0%-40.0%	<20.0%	46.1%	1
% omnivores and stoneroller species	>50.0%	25.0%-50.0%	<25.0%	62.7%	1
Percent specialized insectivores	<10.7%	10.7%-21.4%	>21.4%	4.9%	1
Percent piscivores	<1.5%	1.5%-2.9%	>2.9%	0.5%	1
Catch rate (per 300 sq ft)	<35	35-70	>70	19	1
Percent lithophilic spawners	<25.0%	25.0%-50.0%	>50.0%	46.6%	3
Percent anomalies	>5.0%	2.0%-5.0%	<2.0%	0.0%	5

Done Print Rating: poor/fair IBI Score= 38

Site 22

Willow Fork (1.9) 12267-3

Central Appalachian Ridges and Valleys — Ft. Loudoun/Melton Hill/Wattsb

Drainage Area:3.3 — Knox,TN

	Scoring Criteria			Obs.	Score
Number of native fish species	<5	5-8	>8	13	5
Number of riffle species	<2	2-2	>2	4	5
Number of pool species	<3	3-4	>4	6	5
Percent of 2 dominant species	>85.1%	70.1%-85.1%	<70.1%	50.0%	5
# of hw intolerant species	<2	2-2	>2	3	5
Percent tolerant species	>40.0%	20.0%-40.0%	<20.0%	32.4%	3
% omnivores and stoneroller species	>50.0%	25.0%-50.0%	<25.0%	49.0%	3
Percent specialized insectivores				4.4%	1
Percent piscivores				0.5%	1
Catch rate (per 300 sq ft)	<36	36-72	>72	17	1
Percent lithophilic spawners	<25.0%	25.0%-50.0%	>50.0%	46.6%	3
Percent anomalies	>5.0%	2.0%-5.0%	<2.0%	4.9%	3

Done Print Rating: fair IBI Score= 40

Site 23

Willow Fork (2.1) — 12267-4

Central Appalachian Ridges and Valleys — Ft. Loudoun/Melton Hill/Wattsb

Drainage Area:3.2 — Knox,TN

	Scoring Criteria			Obs.	Score
Number of native fish species	<5	5-8	>8	12	5
Number of riffle species	<2	2-2	>2	4	5
Number of pool species	<3	3-4	>4	5	5
Percent of 2 dominant species	>85.2%	70.4%-85.2%	<70.4%	64.8%	5
# of hw intolerant species	<2	2-2	>2	3	5
Percent tolerant species	>40.0%	20.0%-40.0%	<20.0%	55.8%	1
% omnivores and stoneroller species	>50.0%	25.0%-50.0%	<25.0%	42.7%	3
Percent specialized insectivores				3.5%	1
Percent piscivores				1.0%	1
Catch rate (per 300 sq ft)	<37	37-73	>73	16	1
Percent lithophilic spawners	<25.0%	25.0%-50.0%	>50.0%	72.4%	5
Percent anomalies	>5.0%	2.0%-5.0%	<2.0%	1.5%	5

Done Print Rating: fair IBI Score= 42

Site 24

Lammie Branch (4.7) — 6065-1

Central Appalachian Ridges and Valleys — Ft. Loudoun/Melton Hill/Wattsb

Drainage Area:1.25 — Knox,TN

	Scoring Criteria			Obs.	Score
Number of native fish species	<2	2-2	>2	3	5
Number of riffle species	<1	1-1	>1	0	1
Number of pool species	0		>0	1	5
Percent of 2 dominant species	>89.1%	78.2%-89.1%	<78.2%	97.5%	1
# of hw intolerant species	<1	1-1	>1	0	1
Percent tolerant species	>40.0%	20.0%-40.0%	<20.0%	12.4%	5
% omnivores and stoneroller species	>50.0%	25.0%-50.0%	<25.0%	2.5%	5
Percent specialized insectivores				0.0%	1
Percent piscivores				0.0%	1
Catch rate (per 300 sq ft)	<47	47-94	>94	16	1
Percent lithophilic spawners	<25.0%	25.0%-50.0%	>50.0%	85.1%	5
Percent anomalies	>5.0%	2.0%-5.0%	<2.0%	0.0%	5

Done Print Rating: poor/fair IBI Score= 36

APPENDIX C

Land Use Table: Land use was broken into seven categories with five contributing to the percentage of total urban, and with two contributing to the percentage of total forested land use.

Site	Stream Names	Contributing Area of Site (miles^2)	High Density Residential	Medium Density Residential	Commercial	Industrial	Disturbed/ Transitional	Total Urban	Thick Woods	Thin Woods	Total Forested
1	Beaver 1	14.16	1.0%	9.2%	1.1%	0.3%	2.0%	13.6%	24.5%	5.0%	29.5%
2	Beaver 2	9.88	1.2%	8.4%	1.2%	0.2%	2.7%	13.7%	20.6%	5.0%	25.6%
3	Beaver 3	8.20	0.0%	6.4%	1.4%	0.2%	2.2%	10.2%	21.5%	4.8%	26.3%
4	Beaver 4	4.93	0.0%	7.5%	2.2%	0.3%	2.5%	12.4%	17.7%	5.8%	23.5%
5	Cox 1	3.68	0.7%	10.6%	1.0%	0.5%	0.3%	13.1%	33.5%	3.0%	36.5%
6	Cox 2	2.75	0.0%	5.3%	0.5%	0.6%	0.4%	6.9%	33.4%	3.3%	36.7%
7	Cox 3	2.20	0.1%	5.1%	0.5%	0.7%	0.5%	6.7%	34.7%	3.6%	38.3%
8	Cox 4	1.59	0.0%	4.4%	0.2%	0.1%	0.0%	4.8%	36.8%	2.0%	38.8%
9	Grassy 1	5.79	0.7%	5.6%	4.6%	1.8%	3.4%	16.1%	31.3%	6.7%	38.0%
10	Grassy 2	5.26	0.8%	4.5%	5.4%	1.5%	3.4%	15.6%	31.7%	6.5%	38.1%
11	Grassy 3	2.32	1.3%	3.3%	11.4%	2.4%	4.6%	23.0%	27.5%	7.8%	35.3%
12	Grassy 4	1.84	1.7%	2.5%	14.3%	2.5%	5.7%	26.7%	26.1%	7.6%	33.7%
13	Hines 1	2.33	9.4%	27.7%	3.9%	6.7%	1.1%	48.7%	28.3%	7.0%	35.4%
14	Hines 2	2.17	9.9%	26.4%	4.0%	7.2%	1.2%	48.6%	30.3%	7.6%	37.8%
15	Hines 3	2.09	10.3%	26.2%	3.8%	7.2%	6.9%	54.3%	30.6%	7.9%	38.4%
16	Hines 4	1.65	13.0%	31.6%	2.1%	4.2%	0.5%	51.4%	26.1%	9.3%	35.4%
17	Knob 1	5.89	0.2%	13.9%	4.7%	5.8%	3.2%	27.7%	31.6%	9.4%	41.0%
18	Knob 2	5.65	0.2%	14.0%	4.5%	5.9%	3.2%	27.8%	31.4%	9.6%	41.0%
19	Knob 3	3.31	0.2%	16.0%	2.1%	2.7%	3.7%	24.7%	38.6%	4.4%	42.9%
20	Knob 4	2.84	0.2%	18.1%	1.3%	1.8%	4.3%	25.7%	39.4%	3.0%	42.4%
21	Willow 1	3.71	0.1%	2.2%	0.5%	0.1%	0.6%	3.5%	19.3%	15.2%	34.5%
22	Willow 2	3.30	0.0%	0.4%	0.2%	0.1%	0.3%	0.9%	20.2%	16.3%	36.5%
23	Willow 3	3.20	0.0%	0.4%	0.1%	0.0%	0.3%	0.8%	20.3%	16.7%	36.9%
24	Willow 4	1.25	0.0%	0.3%	0.0%	0.0%	0.0%	0.3%	27.3%	14.2%	41.4%

Habitat Metrics: Shows Physical measurements taken in the field for twenty-four sites in six sub-watersheds of Beaver Creek drainage.

Site	Stream Names	Average Wetted Width m	Average Water Depth m	# of Units	% Pools	Max Pool depth m	Avg Pool area m2	Pool volume m3	% Runs	% Riffle	Avg Riffle depth m	Average Riffle Length m	% Glide
1	Beaver 1	5.66	0.32	14.00	0.49	0.82	196.76	81.36	0.11	0.37	0.25	25.28	0.03
2	Beaver 2	3.53	0.16	9.00	0.68	0.64	98.92	22.36	0.07	0.25	0.06	14.33	0.00
3	Beaver 3	4.74	0.20	5.00	0.75	0.71	129.63	30.46	0.00	0.25	0.08	34.00	0.00
4	Beaver 4	3.05	0.15	10.00	0.42	0.59	59.21	12.73	0.15	0.23	0.06	14.17	0.19
5	Cox 1	5.20	0.16	20.00	0.36	0.51	85.89	14.93	0.07	0.43	0.08	32.86	0.15
6	Cox 2	4.36	0.20	17.00	0.69	0.63	57.47	13.05	0.07	0.15	0.11	8.93	0.10
7	Cox 3	4.04	0.20	16.00	0.76	0.66	65.13	15.97	0.00	0.19	0.06	15.47	0.05
8	Cox 4	2.29	0.12	13.00	0.49	0.42	24.58	3.43	0.13	0.18	0.07	9.93	0.19
9	Grassy 1	2.86	0.18	12.00	0.55	0.69	42.58	11.57	0.10	0.26	0.10	15.33	0.09
10	Grassy 2	3.36	0.16	10.00	0.34	0.59	50.17	11.37	0.07	0.41	0.16	13.15	0.18
11	Grassy 3	2.79	0.13	7.00	0.39	0.41	58.98	8.70	0.00	0.34	0.19	28.00	0.26
12	Grassy 4	2.63	0.20	12.00	0.65	0.45	43.79	6.88	0.00	0.14	0.05	10.15	0.21
13	Hines 1	2.71	0.16	26.00	0.76	0.52	44.09	8.88	0.02	0.21	0.05	15.66	0.01
14	Hines 2	3.13	0.19	12.00	0.88	0.58	50.63	10.16	0.00	0.08	0.08	14.80	0.04
15	Hines 3	3.09	0.18	21.00	0.60	0.63	44.53	10.91	0.18	0.22	0.08	9.40	0.00
16	Hines 4	3.41	0.15	12.00	0.44	0.65	37.08	8.30	0.23	0.33	0.05	11.08	0.00
17	Knob 1	4.51	0.26	9.00	0.77	1.08	103.79	36.67	0.00	0.18	0.07	16.10	0.05
18	Knob 2	4.25	0.16	10.00	0.53	0.57	76.52	17.14	0.11	0.29	0.09	14.13	0.08
19	Knob 3	2.02	0.14	9.00	0.52	0.53	34.24	6.99	0.00	0.48	0.06	15.80	0.00
20	Knob 4	2.82	0.10	10.00	0.35	1.34	39.04	5.47	0.00	0.57	0.07	16.64	0.08
21	Willow 1	3.35	0.20	6.00	0.55	0.53	48.03	10.57	0.12	0.00			0.33
22	Willow 2	2.88	0.20	10.00	0.57	0.69	46.15	12.00	0.05	0.30	0.14	12.33	0.08
23	Willow 3	3.32	0.23	8.00	0.31	0.57	56.30	13.57	0.46	0.18	0.13	16.05	0.05
24	Willow 4	3.42	0.12	13.00	0.28	0.32	28.64	3.97	0.36	0.31	0.11	9.20	0.05

Habitat Metrics (continued): Shows Physical measurements taken in the field for twenty-four sites in six sub-watersheds of Beaver Creek drainage.

Site	Stream Names	% Bedrock	% Boulders	% Cobble	% Gravel	% Fines	% Intact Riparian	% incised bank	% point bar	Total # Single Pieces	Volume m3 LW Singles	# of Aggregate Pieces	Aggregate pieces/ 100 m2	# of Root Wads
1	Beaver 1	4%	0%	4%	43%	49%	67%	48%	20%	11	754	476	3400	15
2	Beaver 2	0%	3%	6%	48%	43%	67%	59%	25%	4	6	22	244	8
3	Beaver 3	0%	2%	8%	60%	30%	59%	63%	25%	4	8	34	680	2
4	Beaver 4	0%	2%	5%	28%	63%	0%	71%	18%		0	53	530	
5	Cox 1	16%	32%	7%	27%	20%	67%	42%	26%	3	6	153	765	12
6	Cox 2	16%	54%	8%	6%	17%	50%	52%	0%	0	1	141	829	0
7	Cox 3	46%	6%	5%	9%	34%	84%	59%	14%	4	32	191	1194	3
8	Cox 4	18%	38%	8%	15%	22%	67%	29%	6%	1	0	41	315	1
9	Grassy 1	0%	0%	0%	47%	53%	25%	79%	20%		0	16	133	
10	Grassy 2	0%	0%	1%	50%	49%	84%	85%	33%	4	13	44	440	
11	Grassy 3	9%	1%	0%	46%	44%	17%	89%	34%	7	15	36	514	
12	Grassy 4	19%	3%	12%	38%	28%	100%	73%	14%	3	5	32	267	
13	Hines 1	44%	0%	1%	0%	55%	59%	47%	21%	0	0	80	308	1
14	Hines 2	5%	3%	4%	59%	29%	34%	77%	8%		0	73	608	
15	Hines 3	1%	10%	9%	53%	27%	50%	39%	18%	5	64	73	348	4
16	Hines 4	0%	9%	13%	38%	41%	50%	40%	24%	1	0	99	825	
17	Knob 1	0%	0%	0%	48%	52%	50%	74%	18%	1	0	29	322	
18	Knob 2	8%	0%	7%	44%	41%	50%	70%	29%	3	5	59	590	
19	Knob 3	0%	1%	2%	64%	33%	25%	52%	18%	1	0	216	2400	
20	Knob 4	4%	1%	5%	64%	26%	75%	68%	50%	1	0	108	1080	
21	Willow 1	9%	18%	15%	7%	51%	50%	36%	0%	2	0	25	417	
22	Willow 2	9%	4%	9%	50%	26%	67%	75%	19%	2	1	156	1560	
23	Willow 3	5%	0%	0%	54%	41%	34%	87%	14%	2	0	56	700	
24	Willow 4	32%	21%	15%	19%	13%	100%	29%	0%	2	5	42	323	

Fish Survey Numbers: Shows fish metrics calculated from samples taken in the field for twenty-four sites in six sub-watersheds of Beaver Creek drainage. This table shows IBI Scores, SWDI Scores, and species abundance per 100 square meters.

Site	Stream Names	IBI Scores	SWDI	Blueside Darter Abundance / 100 m2	Greenside Darter Abundance / 100 m2	Snubnose Darter Abundance / 100 m2	Darter Abundance / 100 m2	% Omnivore & stoneroller species/ reach	Stoneroller Abundanc e/ 100 m2	Redbreast Abundance / 100 m2	Sculpin Abundance/ 100 m2	Blacknose Dace Abundance / 100 m2	Sucker Abundance/ 100 m2	White sucker Abundance / 100 m2
1	Beaver 1	42	2.30	1.71	1.52	3.61	6.42	0.54	14.61	1.28	2.25	2.25	5.62	1.90
2	Beaver 2	42	2.12	1.31	0.79	5.77	7.87	0.31	20.98	40.92	0.52	1.84	9.71	8.65
3	Beaver 3	42	2.35	1.35	0.68	1.01	4.05	0.49	11.31	4.05	0.34	6.25	5.91	3.71
4	Beaver 4	42	1.70	1.62	0.41	10.76	17.25	0.64	108.79	5.48	0.00	32.47	11.57	8.32
5	Cox 1	50	2.13	0.00	1.02	1.63	5.31	0.32	12.45	0.92	10.80	17.40	2.75	0.41
6	Cox 2	44	2.1	0.00	1.99	1.77	3.77	0.50	16.42	0.22	9.32	8.21	2.88	1.99
7	Cox 3	44	2	0.00	0.00	0.93	2.32	0.54	13.47	0.93	5.11	9.05	4.64	2.32
8	Cox 4	44	1.75	0.00	0.45	2.23	3.56	0.49	21.34	0.44	0.44	13.78	3.56	0.00
9	Grassy 1	34	2.29	0.00	1.41	1.41	2.81	0.43	7.02	2.46	1.05	0.00	2.11	1.41
10	Grassy 2	34	1.96	0.67	0.00	1.68	2.35	0.55	4.70	0.00	2.35	0.00	2.35	0.00
11	Grassy 3	36	2.03	0.00	0.46	0.70	1.16	0.31	3.95	1.63	0.00	1.16	1.39	0.23
12	Grassy 4	30	1.92	0.00	0.00	0.00	0.00	0.53	2.78	2.47	0.00	1.86	1.55	1.54
13	Hines 1	36	1.87	0.00	0.00	0.00	0.00	0.49	2.93	1.13	4.51	13.32	3.61	2.25
14	Hines 2	36	1.51	0.00	0.00	0.00	0.00	0.43	1.01	0.60	3.62	18.30	2.41	2.42
15	Hines 3	30	1.54	0.00	0.00	0.00	0.00	0.46	18.87	0.26	7.60	29.36	0.26	0.00
16	Hines 4	34	1.07	0.00	0.00	0.00	0.00	0.09	2.41	0.48	0.24	36.82	1.93	1.92
17	Knob 1	34	1.34	0.15	0.00	0.15	0.45	0.70	0.61	0.30	0.45	2.88	5.45	3.95
18	Knob 2	28	1.67	0.00	0.70	0.00	0.88	0.65	5.46	0.35	0.88	6.52	3.88	3.16
19	Knob 3	46	1.90	0.37	0.00	0.74	5.59	0.27	3.73	0.00	8.21	30.21	2.98	1.12
20	Knob 4	36	1.31	0.00	0.00	0.00	1.03	0.19	0.00	0.00	3.36	26.11	0.52	0.00
21	Willow 1	38	1.96	1.22	0.00	0.91	2.39	0.63	14.81	0.24	1.19	3.10	2.63	0.61
22	Willow 2	40	1.98	0.28	1.14	0.85	2.55	0.49	17.00	0.00	3.68	11.90	3.97	2.56
23	Willow 3	42	1.71	0.00	1.30	0.26	1.82	0.43	0.26	0.26	3.38	11.71	2.34	0.00
24	Willow 4	36	0.49	0.00	0.00	0.00	0.00	0.03	1.16	0.00	0.00	39.86	0.00	0.00

Fish Survey Numbers (Continued): Shows fish metrics calculated from samples taken in the field for twenty-four sites in six sub-watersheds of Beaver Creek drainage. This table shows IBI Scores, SWDI Scores, and species abundance per 100 square meters.

Site	Stream Names	IBI Scores	SWDI	Northern hogsuckers Abundance/ 100 m2	Creek Chub Abundance / 100 m2	Mountain Shiner Abundance/ 100m2	Stripe Shiner Abundance / 100m2	Western Mosquitofish Abundance/ 100 m2	Largemouth Bass Abundance/ 100 m2	Green Sunfish Abundance/ 100 m2	Bluegill Abundance / 100 m2	Redbreast Abundance / 100 m2	Rock Bass Abundance/ 100 m2
1	Beaver 1	42	2.30	4.75	14.61	6.26	15.89	0.16	0.48	0.32	3.53	1.28	1.60
2	Beaver 2	42	2.12	1.05	20.98	59.28	39.87	17.57	1.57	4.20	19.15	40.92	0.00
3	Beaver 3	42	2.35	2.19	11.31	5.91	16.71	0.00	3.04	1.52	1.86	4.05	0.00
4	Beaver 4	42	1.70	3.25	108.79	1.62	16.85	5.89	0.00	0.61	0.20	5.48	0.00
5	Cox 1	50	2.13	2.65	12.45	4.40	7.14	0.00	0.18	0.18	0.55	0.92	1.10
6	Cox 2	44	2.1	0.89	16.42	1.55	24.85	0.00	0.00	2.66	11.98	0.22	1.55
7	Cox 3	44	2	2.32	13.47	0.00	23.22	0.00	0.00	0.00	7.20	0.93	0.70
8	Cox 4	44	1.75	3.56	21.34	0.00	5.78	0.00	0.00	0.00	1.78	0.44	0.00
9	Grassy 1	34	2.29	0.70	7.02	0.00	7.02	4.56	2.46	2.11	9.48	2.46	0.00
10	Grassy 2	34	1.96	2.35	4.70	0.00	15.43	0.00	0.67	1.34	8.72	0.00	0.34
11	Grassy 3	36	2.03	1.16	3.95	0.00	3.25	0.00	0.93	0.00	7.20	1.63	0.00
12	Grassy 4	30	1.92	0.00	2.78	0.00	12.68	0.00	2.47	0.62	4.95	2.47	0.00
13	Hines 1	36	1.87	1.35	2.93	0.23	26.19	0.90	0.00	3.16	1.58	1.13	0.45
14	Hines 2	36	1.51	0.00	1.01	0.00	5.83	0.00	0.00	0.00	0.00	0.60	0.00
15	Hines 3	30	1.54	0.26	18.87	0.00	22.02	0.00	0.00	0.00	0.00	0.26	0.00
16	Hines 4	34	1.07	0.00	2.41	0.00	1.68	0.00	0.00	0.00	0.00	0.48	0.00
17	Knob 1	34	1.34	1.52	0.61	0.30	29.55	0.00	0.00	0.00	0.45	0.30	0.00
18	Knob 2	28	1.67	0.70	5.46	0.00	23.09	0.35	0.00	0.35	0.00	0.35	0.00
19	Knob 3	46	1.90	1.86	3.73	0.00	17.53	0.00	0.37	1.49	0.75	0.00	1.12
20	Knob 4	36	1.31	0.52	0.00	0.00	8.79	0.00	0.00	0.00	0.52	0.00	0.00
21	Willow 1	38	1.96	2.74	14.81	0.00	15.28	3.82	0.24	0.48	2.15	0.24	0.00
22	Willow 2	40	1.98	1.42	17.00	0.00	8.78	0.00	0.28	0.00	2.27	0.00	0.00
23	Willow 3	42	1.71	2.34	0.26	0.00	21.85	0.00	0.00	0.26	2.60	0.26	0.52
24	Willow 4	36	0.49	0.00	1.16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

APPENDIX D

Pearson Correlations used to find relationships for further statistical analysis. R values shown for values with P<.10; boxed values for P<.05 and for bolded values = P<.0001

Fish Abundance and Diversity

Variables	IBI Scores	fish / m2	native fish	anomolies	Fantail dar/ 100m2	Blueside/ 100m2	Greenside/ 100m2	Snubnose/ 100m2	Mt. Shiner/ 100m2	centrarchids/ 100m2	darters/ 100m2	cyprinids/ 100m2	suckers / 100m2	sculpins/ 100m2	% Omnivores	% Specialized insect	% Top Carnivores	S.W.D.I.
IBI Scores	1.00																	
fish / m2		1.00																
native fish	0.62	0.35	1.00															
anomolies				1.00														
Fantail dar/ 100m2	0.59	0.40	0.41		1.00													
Blueside/ 100m2		0.55	0.62			1.00												
Greenside/ 100m2	0.39		0.53				1.00											
Snubnose/ 100m2	0.38	**0.83**	0.47		0.51	0.70		1.00										
Mt. Shiner/ 100m2		0.70				0.43		0.43	1.00									
centrarchids/ 100m2		0.65				0.37		0.43	**0.93**	1.00								
darters/ 100m2	0.54	**0.78**	0.60		0.71	0.70		**0.95**			1.00							
cyprinids/ 100m2		**0.96**			0.49	0.53		**0.84**	0.51	0.42	**0.80**	1.00						
suckers / 100m2	0.37	**0.79**	0.63		0.40	0.71		**0.84**	0.54	0.50	**0.81**	**0.76**	1.00					
sculpins/ 100m2	0.45			0.42										1.00				
% Omnivores			0.43										0.42		1.00			
% Specialized insect	0.55	0.59	**0.72**			0.70	0.47	0.58	0.78	0.72	0.60	0.44	0.63			1.00		
% Top Carnivores												-0.39					1.00	
S.W.D.I.	0.38		**0.74**			0.39	0.53			0.40					0.48	0.57	0.57	1.00
Industrial urban land	-0.72		-0.44			-0.36	-0.42	-0.35			-0.44					-0.45		
total urban land	-0.54		-0.44				-0.46				-0.37					-0.36		
drainage area			0.67			**0.75**	0.44	0.43	0.50	0.45	0.43		0.57			**0.79**		0.49
lar patch/ tot forest			-0.47	0.41		-0.47	-0.45									-0.43		
SCS CN Numbers	-0.35					0.43							0.35	-0.47				
% Point Bar to tot																		
% riffle length															-0.51			
% run length																		
% pool length															0.43			
% glide length																		
avg pool depth			0.48			0.43	0.37						0.37		0.49			
avg riffle depth							0.50											
average depth			0.54			0.39	0.49						0.36		0.42	0.35		
average width			0.53				0.45									0.46		
max pool depth																		
crest to max ratio			0.36				0.49											
average riffle width			0.45			0.38	0.52									0.38		
# of riparian trees		-0.38										-0.37						
% of intact riparian					-0.37						-0.40							
# of wood pieces						0.39										0.45		
Avg wood length				0.45									-0.36					
Avg wood diameter																		
% wood submerged														-0.39				
avg wood volume						0.47										0.42		
wood agg/ 100m2	0.44				0.37													
% Boulders	0.42													0.41				
% Cobble			-0.36															
% Gravel																		
% Fines			0.36			0.46		0.41					0.49	-0.41	0.45			

Urban Indicators

Variables	Industrial urban land	total urban land	drainage area	lar patch/ tot forest	SCS CN Numbers
Industrial urban land	1.00				
total urban land	0.72	1.00			
drainage area			1.00		
lar patch/ tot forest	0.50	0.66	-0.46	1.00	
SCS CN Numbers	0.38				1.00
% Point Bar to tot					
% riffle length					
% run length	-0.37				
% pool length					
% glide length					
avg pool depth			0.71		
avg riffle depth			0.43		
average depth			0.64	-0.38	
average width	-0.38		0.57		
max pool depth		0.45			
crest to max ratio	-0.47	-0.54	0.39	-0.65	
average riffle width	-0.45	-0.35	0.56	-0.47	
# of riparian trees					-0.39
% of intact riparian					
# of wood pieces			0.57		
Avg wood length					
Avg wood diameter					
% wood submerged					
avg wood volume			0.69		
wood agg/ 100m2					
% Boulders	-0.39				-0.45
% Cobble					
% Gravel					
% Fines			0.41		0.46

Habitat Characteristics and Landscape Influences

Variables	% Point Bar to tot	% riffle length	% run length	% pool length	% glide length	avg pool depth	avg riffle depth	average depth	average width	max pool depth	crest to max ratio	average riffle width	# of riparian trees	% of intact riparian	# of wood pieces	Avg wood length	Avg wood diameter	% wood submerged	avg wood volume	wood agg/ 100m2	% Boulders	% Cobble	% Gravel	% Fines
% Point Bar to tot	1.00																							
% riffle length	**0.73**	1.00																						
% run length			1.00																					
% pool length		-0.56	-0.57	1.00																				
% glide length					1.00																			
avg pool depth					-0.35	1.00																		
avg riffle depth		0.36				0.38	1.00																	
average depth						**0.90**	0.48	1.00																
average width						0.55	0.36	0.68	1.00															
max pool depth	0.37				-0.42					1.00														
crest to max ratio	-0.46		0.51			0.48	0.43	0.56	0.35	-0.43	1.00													
average riffle width						0.61	0.42	0.66	0.84		0.51	1.00												
# of riparian trees	0.63	0.63		-0.46									1.00											
% of intact riparian														1.00										
# of wood pieces						0.39	0.67	0.36	0.44			0.45			1.00									
Avg wood length		0.45		-0.36										0.39	0.53	1.00								
Avg wood diameter									0.35			0.36		0.59	0.54	0.59	1.00							
% wood submerged														0.36			0.51	1.00						
avg wood volume						0.64	0.65	0.54	0.46		0.48	0.57			0.74	0.37			1.00					
wood agg/ 100m2																				1.00				
% Boulders	-0.53																				1.00			
% Cobble	-0.42						-0.37	-0.37		-0.36				0.45							0.44	1.00		
% Gravel	0.55	0.44														0.35					-0.59		1.00	
% Fines						0.46		0.35						-0.48		-0.38					-0.59	-0.47		1.00

Pearson Correlations that show potential relationships. R values shown for values with P<.10; boxed values for P<.05 and for bolded values = P<.0001. Note that IBI Scores correlated with several fish metrics, percent industrial/ commercial land, and two physical habitat measures. Also apparent is the relationships found for the individual fish metrics. Several of these fish metrics corresponded with drainage area, urban land use, and average wetted stream width. Average wetted stream width, in turn, may be the only potential connection found between physical habitat, fish abundance, and urbanization.

Variables	Fish Abundance and Diversity																	Urban Indicators				
	IBI Scores	fish / m2	native fish	anomolies	Fantail dar/ 100m2	Blueside/ 100m2	Greenside/ 100m2	Snubnose/ 100m2	Mt. Shiner/ 100m2	centrarchids/ 100m2	darters/ 100m2	cyprinids/ 100m2	suckers / 100m2	sculpins/ 100m2	% Omnivores	% Specialized insect	% Top Carnivores	S.W.D.I.	Industrial urban land	total urban land	drainage area	lar patch/ tot forest	SCS CN Numbers
IBI Scores	1.00																						
fish / m2		1.00																					
native fish	0.62		1.00																				
anomolies				1.00																			
Fantail dar/ 100m2					1.00																		
Blueside/ 100m2						1.00																	
Greenside/ 100m2	0.39						1.00																
Snubnose/ 100m2	0.38							1.00															
Mt. Shiner/ 100m2									1.00														
centrarchids/ 100m2										1.00													
darters/ 100m2	0.54										1.00												
cyprinids/ 100m2												1.00											
suckers / 100m2	0.37												1.00										
sculpins/ 100m2	0.45													1.00									
% Omnivores															1.00								
% Specialized insect	0.55		**0.72**			0.70	0.47	0.58	**0.78**	0.72	0.60		0.63			1.00							
% Top Carnivores																	1.00						
S.W.D.I.																		1.00					
Industrial urban land	-0.72		-0.44				-0.42				-0.44					-0.45			1.00				
total urban land																				1.00			
drainage area			0.67			**0.75**	0.44	0.43	0.50	0.45	0.43		0.57			**0.79**					1.00		
lar patch/ tot forest			-0.47	0.41		-0.47	-0.45									-0.43			0.50		-0.46	1.00	
SCS CN Numbers																							1.00
% Point Bar to tot																							
% riffle length																							
% run length																			-0.37				
% pool length																							
% glide length																							
avg pool depth																					0.71		
avg riffle depth																					0.43		
average depth																					0.64		
average width			0.53				0.45									0.46			-0.38		0.57		
max pool depth																							
crest to max ratio																			-0.47		0.39		
average riffle width																			-0.45		0.56		
# of riparian trees																							
% of intact riparian																							
# of wood pieces																					0.57		
Avg wood length																							
Avg wood diameter																							
% wood submerged																							
avg wood volume																					0.69		
wood agg/ 100m2	0.44																						
% Boulders	0.42													0.41					-0.39				
% Cobble																							
% Gravel																							
% Fines																					0.41		

VITA

Robert Lee Sain II was born in Atlanta, GA on May 21, 1973. He graduated from Bearden High School in Knoxville, TN in May of 1992, before attending Mercer University's, Stetson School of Business in Macon, GA. He returned to Tennessee and earned a Bachelor of Science degree in wildlife and fisheries from the University of Tennessee in May of 1998.

Robert pursued a career fisheries science for six years where he was able to work in Oregon, Idaho, Montana, Wyoming and Tennessee before returning to graduate school. He completed the requirements for a Master's of Science degree from the University of Tennessee in Biosystems Engineering Technology in May of 2006.