Underwater Video Mapping of the Pigeon River in Haywood County, North Carolina, and Cocke County, Tennessee

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DEDICATION

This is dedicated to my wife Misty for helping me get here.

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Anyone who has attempted to complete a dissertation understands that even though the name on it is their own, that many stood beside and provided the support necessary to achieve this life-long goal.

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ABSTRACT

The Pigeon River, which is located in western North Carolina and eastern Tennessee, is one of three major drainages of the French Broad River Basin. The river begins at the confluence of the East Fork Pigeon and the West Fork Pigeon Rivers in Haywood County, North Carolina, and flows north to northwest for approximately 70 river miles to the French Broad River in Cocke County, Tennessee. The river has had historical anthropogenic impacts to the system since the area was settled. These included forestry practices and agriculture, a paper mill in Canton, North Carolina, the Walters Dam for hydroelectric power, and more recently a change in land use patterns to development. As a result, the river's biological communities were impacted and many species were extirpated. Since the early 1990s, water quality improvements and the efforts of numerous organizations have led to the re-introduction of some of the original species native to the Pigeon River.

The current study used underwater video to record current conditions of the mainstem river bottom from the confluence of the East Fork and West Fork Pigeon Rivers to Panther Creek at PRM 47.0. Also located were tributaries that flowed into the river. The sediment deltas at the mouth of each of these were video-taped and sediment depth measurements were recorded. Turbidity levels (NTUs) were record above, in, and below each of the tributaries entering the Pigeon River.

The study also: 1) developed a continuous geo-referenced video of Pigeon River's substrate in Haywood County, North Carolina, and Cocke County, Tennessee, 2) identified tributaries impacting the Pigeon River by transporting sediment loads, 3) identified locations

suitable for future recovery efforts, and 4) created a Qualitative Habitat Evaluation Index (QHEI).

Deliverables from the study included a video record of approximately 22 river miles of the Pigeon River substrate North Carolina and 11 river miles in Tennessee, documentation of 17 flowing Pigeon River tributaries in North Carolina, the identification of fish collection sites above Canton, and the calculation of a Qualitative Habitat Evaluation Index.

PREFACE

The Pigeon River Fund (PRF) was formed in 1996 to improve surface water quality, to enhance fish and wildlife management habitats, to expand public use and access to waterways, and to increase citizens' awareness about their roles in protecting these resources. Through May 2010, a total of $3,441,947 has been awarded in grants by the fund, including $1,819,088 for projects in Haywood County

In response to a public interest in the quality of the surface waters in Haywood County, North Carolina, one organization that PRF works closely with has been Haywood Waterways Association (HWA) was formed in 1994. The group was created as a response to the Pigeon River Fund (PRF). HWA, a non-profit organization, has grown with over 200 members as of January, 2002. The purpose of HWA is to reduce nonpoint pollution in the Pigeon River Watershed through public awareness, education, and water quality monitoring.

Through their efforts the organization has been able to identify many sources of nonpoint pollution. This led to analysis of the system, as well as plans to address current and future issues. The PRF has been used to raise funds to correct sedimentation issues in several subwatersheds. The product of these efforts has been the Watershed Action Plan that was created by the Technical Advisory Committee. One key component to the work was public involvement. The goal of the plan was to outline strategies to correct past and current problems and to formulate a plan in place for future and possible problems as they are identified in the watershed.

Another component of HWA has been public education outreach through the local secondary school system with the annual *Kids in the Creek* program for all 8th grade students in the Haywood County School System. HWA leads summer youth programs and publishes information for other interested parties. Finally, the organization works with other organizations to train for erosion control measures.

Because funding is vital to the organization's purpose, HWA has been able to obtain funding of $1,409,060 since 1997, including $500,000 for the sediment removal from Lake Junaluska. The monies have benefited several local communities, towns, and organizations as well as several agencies and organizations.

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CHAPTER I

INTRODUCTION AND GENERAL INFORMATION

Project Description

The Pigeon River, which is located in western North Carolina and eastern Tennessee, is one of three major drainages of the French Broad River Basin. The river begins at the confluence of the East Fork Pigeon and the West Fork Pigeon Rivers in Haywood County, North Carolina, and flows north to northwest for approximately 70 river miles to the French Broad River in Cocke County, Tennessee. This basin is predominately "forestland" (50%) followed by "other" at 23% and "agriculture" at 17% (WAP, 2002). In recent years the trend of land use has changed with a decrease in agricultural practices at 72% and an increase of urban and build-up at 42% (WAP, 2002).

The Pigeon River has undergone numerous changes and impacts to the system during the 20th century beginning in 1908. The first impacts to the area by settlers were forestry practices and agriculture. With the use of the railroad system in Haywood County, North Carolina, large tracts of lumber were harvested, thus altering the landscape of the subwatersheds and the steep mountain terrain facilitated severe erosion of the soils, which were deposited in the river's system.

The first localized impact directly to the Pigeon River was located in Canton, North Carolina, when the Champion Fiber Company Paper Mill became operational in 1908. Though it provided economic opportunity to the community, it came with a severe environmental cost. As a result, water quality deteriorated and over time, numerous fish kills occurred, and the river's biological community was adversely affected.

Issues continued over the next 74 years until Tennessee state officials demanded improvements be made to the waters entering the state and flowing into Cocke County, Tennessee (Bartlett, 1995). It took an additional 15 years before the United States Environmental Protection Agency (EPA) assessed the mill discharge. Five years earlier in 1992, Blue Ridge Paper Inc., which bought the mill from Champion, modified their paper bleaching process, which resulted in a reduction of chemical waste products discharged into the Pigeon River, and substantially improved water quality.

Eventually in 2000, it was determined that the Pigeon River had undergone improvements to the physical habitat and water quality, and the reintroduction of native fish species into the Pigeon River became a possibility (Coombs, 2003). In 2001, eight fish species were reintroduced in Tennessee, and in 2004, ten fish species were reintroduced in North Carolina by the collaborative efforts of the Pigeon River Recovery Project.

Because of the historical impacts along with current and future anthropogenic activities, the overall health of the Pigeon River is at a critical junction. With the changes in land use patterns, such as urban and development, new impacts with an emphasis to sediment are being observed throughout each of the subwatersheds. If left unchecked, the progress made in the Pigeon River could be stopped or reversed.

The primary objective of this study was to observe and classify the stream bed substrate conditions by video recording the Pigeon River's substrate in Haywood County, North Carolina, and Cocke County, Tennessee. Secondary objectives included:

1) identification of the sections of the river that are being impacted by sediment loading,

2) determination if there is a relationship between land use practices and the sediment loads of the Pigeon River,

3) identification of additional suitable fish re-introduction and collection sites, and

4) development of habitat suitability indices to identify microhabitat preferences using the modified Qualitative Habitat Evaluation Index (QHEI).

CHAPTER II

LITERATURE REVIEW

Physical Conditions in Freshwater Systems

The primary factor affecting the structure and composition of stream faunal communities is the physical habitat (Gorman and Karr, 1978; Schlosser, 1982, 1987; Frissell et al., 1986; Angermeier, 1987; Cummins, 1988; Osborne and Wiley, 1992; Richards et al., 1993; Richards and Host, 1994; Poff and Allan, 1995). Among different aquatic ecosystems, streams and rivers are the most affected by human activities (Naiman and Turner, 2000). Land use change is the primary modification of these ecosystems (Carpenter et al., 1992; National Research Council, 1993; Vitousek, 1994; Strayer et al., 2003). The greatest impacts include watershed modifier and use and contamination of aquatic resources by anthropogenic factors (Carpenter et al., 1992). As a result of these impacts, riverine characteristics will be affected. These characteristics include timing, amount, and types of water inputs of light, organic matter, and other materials to the systems (Strayer et al., 2003).

Across North America, the freshwater fish fauna is at risk with an estimated 40% at risk on some level (Master et al., 1998). There are 115 freshwater fish species listed as endangered under the Endangered Species Act (ESA) of 1983 by United States Fish and Wildlife Service (USFWS, 2006). The highest diversity of temperate freshwater fishes in the world is found in North America. Within the Southeastern United States, there are more than 600 species, and the greatest diversity is in the Appalachian Mountains (Walsh et al., 1995), and specifically within the state of Tennessee, with 319 native and introduced species (Etnier and Starnes, 1993). Four species native to Tennessee have become extinct, and it has been stated that the number will probably increase over time (Etnier and Starnes, 1993). Due to the increased population growth of the southeastern United States and the existing aquatic biodiversity, this area has become vulnerable and will continue to be so in the future (Master et al., 1998). Nearly 350 fish species inhabit upland streams and rivers within the Appalachian Mountains. Of the 300 darter and minnow species, approximately 21% are imperiled (Walsh et al., 1995). According to Walsh et al. (1995) these species are dependent on clean substrates and can be sensitive to sedimentation. For example, in disturbed watersheds with increased fine sediments, fish assemblages are altered by the reduction of fish species that require clean gravel and cobble for spawning. Some of the factors that are influencing these pressures include, but are not limited to, rapid urbanization, little to no land management, and lack of long-term planning (Walsh et al., 1995; Warren et al., 2000).

There is an inter-connected relationship between the land-use factors which in turn affects the health of the water bodies. Land use effects include habitat degradation, fragmentation, and loss over time (Walsh et al., 1995; Master et al., 1998). These changes are the result of erosion and deposition of sediments, reservoir construction, the alteration of flows and continuity of the system, channelization, development, and pollution (Neves and Angermeier, 1990; Richter et al., 1997). Each of these changes further impacts the freshwater system by fragmentation and degradation. It is estimated that 45% of river miles in the southern Appalachian Mountains are affected by high levels of sedimentation (SAMAB, 1996).

According to Etnier (1997), the level of sediment and homogenization of the streambed is one of the primary causes of imperilment for an estimated 40% of southeastern fish. This issue is further compounded because of the benthic feeding habits of many of these fish and food choices may become unavailable to these species (USFWS, 2006) . Most of these endangered fish utilize benthic spawning (Warren et al., 2000). These silt increases have a direct impact on the decline of fish species and may pose both lethal and sub-lethal impacts (Warren et al., 2000; Sutherland et al., 2002). Silt impacts include physiological issues such as reduced growth rates, and respiratory and osmoregulatory issues. Reduced growth rates among fish are most detrimental because of the relationship of early life success (early months) to survival rates and yearly population dynamics (Helfman et al., 1997). These contributing factors are both biological and environmental.

Historical Habitat Assessments in Freshwater Systems

Researchers have focused their efforts on assessing stream habitats for evaluating river health and have utilized multiple protocols to describe these freshwater systems (Maddock, 1999). One concern that has been raised in these protocols is determining the detail level of the assessment in relation to a cost-effective assessment and determining those biologically significant factors. New technologies have been utilized to assess the habitat that have increased the rate of assessment and improve the level of details attained by the physical habitat assessment (Maddock, 1999). Roper et al. (2002) stated that previous habitat assessment protocols have come under critical debate recently due to several limitations, including variations among the data, different results and conclusions with similar protocols, and multiple sampling errors. Limitations continue with human training and the nature of the system being studied, and the difficulties of identifying the changes to stream characteristics as a result of anthropogenic activities both within and outside the study area (Bauer and Ralph, 2001).

Ever since it was determined that physical habitat shapes biological communities, researchers have tried to piece together these connections for that community. It is the holistic approach of physical habitat, biological community, chemical composition of the water and soils, flows, and energy (since moving water has the ability to do work) that shape these systems (Karr et al., 1986). Physical habitat is influenced by several parameters. These include sedimentation (erosion and deposition), particle composition, riparian zone vegetation, and along the horizontal gradient channel. Each of these affects water flows and energy. Another important parameter in shaping the communities is type of habitat available such as riffles, runs, and pools as well as their sequences (Karr et al., 1986).

The biological community may also shape itself (Karr et al., 1986). Biological factors include behaviors such as competition, predation, parasitism, health, and feeding preferences. In turn, each of these affects sustainability of the biological community.

One of the functions of these aquatic systems is to allow chemical reactions to occur (Karr et al., 1986). Chemical composition and concentrations influence water quality. Quality issues also include pH levels, temperature, and oxygen levels. Wastes from anthropogenic activities, such as the paper mill and agriculture, can shift the levels to outside normal ranges for many species.

Finally, flows and energy shape the habitat. These flow regimes influence distribution patterns of species. Previously it was thought that high flow (flooding) periods were exceedingly important, but more recent studies suggest that low flows (daily minimums) are equally important. Because much of the stream flow is from ground flows and surface runoff compared to directly entering the system through precipitation events, the quality of the water entering the system is influenced as well. This includes land use patterns, and collection and transport of pollutants such as additional sediment and chemical pollutants including nitrogen and phosphorous (Karr et al., 1986).

According to Ohio EPA (1987) one of the primary objectives of the Water Quality Act of 1965 is to restore and maintain the physical, chemical, and biological integrity of surface waters in the United States. Though the emphasis is on the biological component, this restoration and maintenance is often based upon non-biological measures such as chemical and physical water quality (Karr et al., 1986). The rationale is that once the chemical and physical parameters improve, the biological components will be restored to a higher level of integrity.

Biological integrity was first discussed in the Water Pollution Control Act of 1948 and the 1972 amendments and has continued to be used even though the term has become ambiguous. At first, it was used to describe conditions that existed prior to human civilizations, or to describe the protection and propagation of balanced, indigenous populations and systems that have been undisturbed by human activities. Few systems meet these descriptions today. Gakstatter et al. (1981) stated that this concept of biological integrity was unreachable and could not be defined or assessed as the result of the uses of surface waters over time. As a result, biological integrity has come to mean the ability of an aquatic ecosystem to support and maintain a balanced, integrated, adaptive community of organisms which have a species composition, diversity, and functional organization comparable to that of the natural habitats within a region (Karr and Dudley, 1981). Firstly, biological integrity can be quantified based upon measurable characteristics of biological community structure and function in the least impacted habitats.

Secondly, this integrity provided for the eventual development of biocriteria using the biosurvey/ecoregion approach.

It has been proposed by Cairnes (1975) and Karr et al. (1986) that those systems that can be classified as having biological integrity can either withstand or quickly recover from disturbances, both from natural processes such as episodic weather events, or human-induced conditions. The frequency, magnitude, and duration of these disturbances influence the reaction of the system. In turn, those systems that do not possess biological integrity due to degradation have had their capacity to withstand and recover from these disturbances significantly reduced. This level is not static, however, and the system can continue to be further degraded. These systems can be considered to possess this integrity when its inherent potential is realized, its condition is stable, its capacity for self-repair when perturbed is preserved, and the minimal external support for management is needed (Karr et al., 1986).

According to Karr et al. (1986), there are five major environmental factors that most affect aquatic ecosystems: biological interactions, chemical variables, energy source, flow regime, and habitat structure. Changes in the physical, chemical, and/or biological processes associated with these factors, can negatively impact the biota, and thus impact the biological integrity of the system. To succeed, the methods and monitoring efforts to identify these disturbances must assess the factors in all classes rather than one or two. Holistic approaches are more likely to succeed because the approach is driven by measured responses rather than generalized assumptions, and can provide cost-effective alternatives.

Though assessing biological criteria have formed the foundation of numerous monitoring programs and restoration efforts, there are limitations to this methodology. Biological evaluations can be used to identify general degradation groups but the determination of cause requires multiple approaches because of: 1) limitations such as evaluation accuracy of the ecoregions is limited, 2) the approach cannot be mechanistically applied and expert judgment is required, 3) natural variability is not eliminated, and 4) one set of ecoregions does not cover the entire spectrum of situations.

The systems approach to surface water habitat assessment is necessary. The traditional approach is made on subjective judgment type assumptions instead of specific values. Kaufmann et al. (1999) reviewed visual judgment methods in relation to anthropogenic disturbances to these systems and determined that the scores were imprecise and the precision of field data collected failed to provide a high degree of evaluation to the system. Lancaster (2000) reviewed the concept of ecological health of the environment with an emphasis on freshwater systems and concluded that there can be no objective definition of 'health' therefore ecosystem monitoring programs have problems including but not limited to selection of reference sites and that data can only be used for past situations. Whittier et al. (2007) reviewed the selection of reference sites for stream biological assessments and concluded that a small subset of reference sites represented least-disturbed conditions.

Prior to the 1980s, fish communities were monitored and assessed using a one or two criteria to produce an index (Karr et al., 1986). Shannon and Weaver (1949) utilized diversity indices that evaluated number of species (richness) and abundance of species (equitability). Boling et al. (1975) focused on biomass while Gammon et al. (1981) combined biomass and diversity. Limitations of these assessments included oversimplifying the fish community and failure to provide an accurate assessment of current conditions.

Index of Biotic Integrity (IBI)

The Index of Biotic Integrity (IBI) was first developed by Karr (1981) for midwestern US streams and later modified by Karr et al. (1986) in response to the Water Pollution Control Act of 1966, the Federal Water Pollution Control Amendments of 1972, and the Clean Water Act of 1977 that required states to restore and maintain the quality and biotic integrity of surface-water bodies (Karr et al., 1986). Karr and Dudley (1981) stated that the IBI is a tool for quantifying the changes in stream health as the result of habitat degradation or flow alteration and it provides agencies a reliable and cost-effective methodology for assessing water-resource quality in response to anthropogenic factors (Karr et al., 1986; Karr et al., 1987). These factors include population growth and land use change, such as urban development on forestland. Wang et al. (1997) stated that urban development will affect the aquatic community and these changes will alter fish diversity, fish trophic structure, and temporal variability of fish abundance in the stream system.

By determining fish community structure, both past and present conditions within a watershed can be assessed (Karr, 1981; Karr et al., 1986). Identifiable changes within the system include increased wastewater discharges from municipalities, channelization of the streams, and agricultural runoff (Fausch et al., 1990). Because of these changes, the relative abundance of tolerant fish species increases, populations can become fragmented, and invasive species can increase (Allan and Flecker, 1993).

This ecologically based method assesses the health of aquatic ecosystems by scoring 12 fish community metrics that are divided into categories of species richness, trophic structure, and fish abundance and condition. These metrics are used to determine changes in the community structure that would otherwise be unidentified if water chemistry parameters alone were used. Fish are important indicators of changes to stream health because their sensitivity to numerous stressors (Fausch et al., 1990) depend on suitable water-quality conditions throughout their life cycle (Gatz and Harig, 1993). Further fish can demonstrate negative effects in relation to habitat modifications and changes in their prey base (Karr, 1981) long-lived species' reproduction and life histories can be altered due to environmental changes (Karr et al., 1986), are important both economically and for the aesthetic value to humans (Fausch et al., 1990).

Throughout the history of fish surveys various techniques have been utilized by ichthyologists to collect fish species. These techniques include the use of seines of varying sizes depending on targeted species and habitat, chemical treatments to a broad area such as the use of rotenone, as well as the use of electricity to immobilize fish for collection, identification and release. Each of these techniques has their advantages and disadvantages.

Normally, where there is a decline in the physical habitat, there is a negative impact on the biological communities. The changes usually include fewer species overall, a shift towards more tolerant species, an increase in disease and physical ailments, and fewer species present (Table 1). According to Karr (1981), the parameters to assess fish communities can be divided into two groups: species composition and richness and ecological factors. The specific parameters used are listed in Table 2. However, there is some evidence that mountainous streams cannot be assessed and compared to lower elevation streams because diversity and abundances may be different in these mountainous streams. Both TVA and NCDENR have questioned these procedures and have made efforts to improve the techniques of sampling this type of stream system.

Table 1. Biotic integrity classes used in assessment of fish communities along with general descriptions of their attributes (Karr, 1981).

Class	Attributes
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.
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.
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.
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.
Very Poor	Few fish present, mostly introduced or very tolerant forms; hybrids common; disease, parasites, fin damage, and other anomalies.
No Fish	Repetitive sampling fails to turn up any fish.

Table 2. Parameters used in the assessment of fish communities (Karr, 1981).

Species Composition and Richness
Number of species
Presence of intolerant species
Species richness and composition of darters
Species richness and composition of suckers
Species richness and composition of sunfish (except green sunfish)
Proportion of green sunfish
Proportion of hybrid individuals
Ecological Factors
Number of individuals in sample
Proportion of omnivores (individuals)
Proportion of insectivorous cyprinids
Proportion of top carnivores
Proportion with disease, tumors, fin damage, and other anomalies

There are several versions of the IBI utilized throughout North America and parts of Europe. These specific versions are necessary due to the faunal differences among the different systems (Simon and Lyons, 1995). For example, the version for the central United States would fail to address species richness in streams in southeastern United States.

Benthic macroinvertebrates are small stream-inhabiting organisms that can be seen with the naked eye and spend all or part of their life cycle in or near the stream bottom (WAP, 2002). Within this group there are three insect orders that are important in assessing stream health. They are Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies), and are usually referred to as EPT indicator species. The EPT Index shows that high-quality (healthier) streams have a higher species richness compared to low-quality streams (Barbour et al., 1999). These EPT taxa are typically pollution intolerant and their numbers are greatly reduced or eliminated when pollution levels increase.

Barbour et al. (1999) stated that macroinvertebrates are useful to assess stream health due to several reasons. These include: 1) they are sensitive to long-term and episodic stressors to the systems, 2) many species spend their juvenile life cycle (prior to emergence) within a specific geographic location, and 3) they have the ability to demonstrate the effects of physical habitat alteration, effects of point and non-point pollutants, and the cumulative effects of those pollutants over time. Other reasons for assessment include localized movements compared to fish, ease of collection, and use of the index when chemical and physical measurements would fail to yield data.

Macroinvertebrate samples are collected by numerous methods such as kick nets, sweep nets, leaf pack samples, and visual collections (Barbour et al., 1999). Single habitat collections were first utilized by Platkin et al. (1989) in riffle and run habitats to standardize assessments in streams with those habitats. This habitat was selected based upon macroinvertebrate diversity and abundance in this section of the stream reach being the highest of any habitat. The concern with this single habitat sampling approach is that some streams fail to have a large percentage of cobble (30%) in the stream bed, and thus the community is inefficiently sampled. Current sampling preference is collecting from numerous habitats such as leaf packs, tree snags, and undercut banks. The percentage of each habitat sampled is based upon the percentage each habitat represents within the sampling reach.

Physical Habitat Suitability Index

The Habitat Suitability Index (HSI) is utilized by wildlife managers for policy decisions (USGS, 2009). The index model describes the relationships between environmental factors and species needs based upon identified habitat. These factors can include biota, stream flow, substrate type, canopy cover, and water quality.

Johnson (2008) developed a mathematical model that quantifies mussel habitat ranges in order to maximize habitat identification accuracy through the use of Underwater Mass Spectrometer (UWMS). Her model assesses substrate composition, depth, macrohabitat (pool, riffle, run), and embeddedness. Scores are 0–34, and are divided into ranges of optimal, sub-optimal, marginal, sub-marginal, and unsuitable.

Further, habitat units (HUs) and average habitat units (AHUs) are determined and used for the HSI. Habitat units are based upon the HSI values and the size of the habitat. These are based upon the number of HUs that are changed by management practices (USFWS, 1981).

Qualitative Habitat Evaluation Index (QHEI)

The Qualitative Habitat Evaluation Index (QHEI) was developed by Rankin (1989) to correlate stream potential to habitat integrity that would provide evidence of how habitat could affect biological expectations within a system on a macro-habitat level. This approach assesses the properties of habitat instead of individual factors. The QHEI categorizes the biotic and abiotic factors vital for habitat quality. One advantage of the QHEI is that the number of field measurements needed, as well as time necessary, is minimal. A second advantage is that it takes advantage of the field experience of field biologists who are accurate in their assessments. These measurements utilize key variables that could influence fish communities that will maximize the explanatory power of the index. The index can have acceptable reproducibility among workers. Finally, the index can be used to separate the relative effects of habitat compared to water quality on fish community structure, or be able to determine the baseline community that could be expected in a particular habitat.

The QHEI is divided into six categories which capture a specific component of habitat integrity. These categories are substrate, instream cover, channel quality, riparian erosion, pool/riffles habitat, and gradient. Substrate is divided into type and quality, while instream cover is divided into type and amount. Channel quality characters include sinuosity, development, channelization, and stability. Pool and riffle habitat characters include maximum depth, current available, pool morphology, riffle/run depth, riffle substrate stability, and riffle embeddedness. Each of the categories is scored individually and totaled for a maximum of 100 points. The maximum score represents an ideal microhabitat for targeted fish species (Ohio EPA, 1989; Rankin, 1989). From this index, those categories that could pinpoint the habitat based upon sediment only were utilized for this study. These were substrate and pool and riffle habitat characters. An example of the QHEI evaluation form is provided in Table 3.

Historical Fish Surveys in North America

Ichthyology has been studied in North America since the 18th century (Etnier and Starnes, 1993). Several North American species were described in Carolus Linnaeus' 10th edition of *Systema Naturae* (1758). This classic work laid the foundation for binomial scientific nomenclature that is being used today. Work continued into the 19th century by several French naturalists including B.G.E. Lacepede (1798-1803) in the Ohio River region (Etnier and Starnes, 1993). American naturalists began studying broadly distributed freshwater species as well. Works by Agassiz, Baird, Cope, Girard, Jordan, Kirtland and Rafinesque laid the foundation for future efforts throughout North America.

The first work specific to fishes of Tennessee River Basin was Storer (1845) that described species from the Tennessee River tributaries near Florence, Alabama. Agassiz (1854) published work from Alabama and Cope (1868a, 1868b, and 1870) produced work from collections in western Virginia. Later in the 1800s, Jordan and Evermann (1896-1900) began documenting freshwater fish and produced the *Fishes of North and Middle America*.

After Jordan moved to Stanford in the 1890s, work in the area declined but his associates focused on fishes in the Cumberland River in Kentucky and Tennessee and made collections throughout the Tennessee and Cumberland River systems (Kirsch 1892, 1893; Woolman 1892).

Work in eastern Tennessee was produced by Evermann and Hildebrand (1916). Evermann (1918) also produced a summary of regional work. Few collection efforts were undertaken during this period and of those most were limited to cosmopolitan areas. It is believed that

Table 3. Qualitative Habitat Evaluation Index form (Ohio EPA, 1989)

1. SUBSTRATE (value)				
Best type	Other	Origin	Quality Silt/Embeddedness	
Bldr/slabs (10)	Hardpan (4)	Limestone (1)	Heavy (-2)	
Boulder (9)	Detritus (3)	Tills (1)	Moderate (-1)	
Cobble (8)	Muck (2)	Wetlands (0)	Normal (0)	
Gravel (7)	Silt (2)	Hardpan (0)	Free (1)	
Sand (6)	Artificial (0)	Sandstone (0)	Extensive (-2)	
Bedrock (5)		Rip/rap (0)	Moderate (-1)	
		Lacusturine (0)	Normal (0)	
		Shale (-1)	None (1)	
		Coal fines (-2)		
2. INSTREAM COVER (value)				
Undercut banks (1)	Logs/woody debris (1)	Oxbows (1)	Root wads (1)	Boulders (1)
Root mats (1)	Shallows (1)	Overhanging vegetation (1)	Aquatic macrophytes (1)	Pool >70 cm (2)
Amount				
Extensive >75% (11)	Moderate 25-75% (7)	Sparse 5-25% (3)	Nearly absent <5% (1)	
3. CHANNEL MORPHOLOGY (value)				
Sinuosity				
High (4)	Moderate (3)	Low (2)	None (1)	
Development				
Excellent (7)	Good (5)	Fair (3)	Poor (1)	
Channelization				
None (6)	Recovered (4)	Recovering (3)	Recent (1)	
Stability				
High (3)	Moderate (2)	Low (1)		

Table 3. (Continued)

4. BANK EROSION AND RIPARIAN ZONE EROSION (value)				
None/little (3)	Moderate (2)	Heavy (1)		
Riparian Width				
Wide >50m (4)	Moderate10-50m (3)	Narrow 5-10m (2)	Very narrow <5m (1)	None (0)
Flood Plain Quality				
Forest, swamp (3)	Shrub/old field (2)	Residential park (1)	Fenced pasture (1)	Open pasture (0)
Conservation tillage (1)	Urban/industrial (0)	Mining/construction (0)		
5. POOL/GLIDE AND RIFFLE/RUN QUALITY (value)				
Maximum depth				
>1m (6)	0.7-<1m (4)	0.4-<0.7m (2)	0.2-<0.4m (1)	<0.2m (0)
Channel width				
Pool width>riffle width (2)	Pool width=riffle width (1)	Pool width<riffle width (0)		
Current velocity				
Torrential (-1)	Very fast (1)	Fast (1)	Moderate (1)	Slow (1)
Interstitial (-1)	Intermittent (-2)	Eddies (1)		
Riffle depth				
Best area >10cm (2)	Best areas 5-10cm (1)	Best areas <5cm (0)		

Table 3. (Continued)

Run depth				
Maximum >50cm (2)	Maximum <50cm (1)			
Riffle/run substrate				
Stable (2)	Moderate stable (1)	Unstable (0)		
Riffle/run embeddedness				
None (2)	Low (1)	Moderate (0)	Extensive (-1)	
6. GRADIENT (FT/MI) DRAINAGE AREA MI^2 (value)				
Very low-low (2-4)	Moderate (6-10)	High-very high (10-6)		

several species became extinct, including the harelip sucker, *Lagochila lacera* (including Tennessee individuals), as well as other unknown species (Etnier and Starnes, 1993). However, there were important works undertaken. Fowler (1923, 1936, and 1945) published survey reports of species occurring within Tennessee. Baker (1937, 1939) and Baker and Parker (1938) published works on the fishes of Reelfoot Lake, Tennessee. Kuhne (1939) published the first book of the fishes of Tennessee, *A Guide to the Fishes of Tennessee and the Mid-South*. The work included 168 species compared to the 300 species discussed by Etnier and Starnes (1993).

Beginning in the 1940s through the 1960s, work continued on describing the fish of the Tennessee region. Tennessee Valley Authority (TVA) assessed streams that would be altered by the impoundments on the Tennessee River system during the construction phase of hydroelectric dams. The main focus of these works was on smaller streams and not the larger rivers. Etnier et al. (1979) published the findings. Notable works were by Shoup and Peyton (1940) and Shoup et al. (1941) from the Cumberland Plateau in the Roaring, Obey, and Wolf rivers. Pfitzer (1954) published works on the tailwaters below reservoirs in the Tennessee River system. Work continued by TVA and at Reelfoot Lake though this time period.

From 1965–1985, Dr. David Etnier at the University of Tennessee collected fish species throughout the state and region. His approach surveyed entire river systems and later presented historical and a compositional synopsis of the collection (Etnier and Krotzer, 1990).

Numerous efforts were conducted by Etnier and students from the University of Tennessee and other institutions. Important works included Stiles and Etnier (1971) on the Conasuga River, the Wolf River in western Tennessee (Medford and Simco, 1971), Armstrong and Williams (1971) efforts in caves and springs in the southern Highland Rim area, the Big

South Fork of the Cumberland (Comiskey and Etnier, 1972), and the Elk River by Jandebeur (1972). Other system-wide surveys included the Hatchie River (Starnes, 1973), Obion River (Dickinson, 1973), Hiwassee River (Hitch and Etnier, 1974), lower Tennessee River western tributaries (Clark, 1974), Clinch River (Masnik, 1974), Forked Deer River (Boronow, 1975), and sections of Little Pigeon River (Starnes, 1977). The Tennessee River at Chattanooga was surveyed by Haines (1982), as well as Big South Fork and Sequatchie River systems by O'Bara and Estes (1984a, b).

According to Etnier and Starnes (1993), TVA began efforts in the late 1960s and early 1970s to collect information on fish distribution in the Tennessee River drainage. Surveys were conducted in the Emory, Powell, Flint, upper Little Tennessee, Sequatchie, Buffalo, Bear Creek, and Duck systems between 1968-1975 and the French Broad system by Harned (1979). This work was conducted by TVA biologists Feeman, Fitz, and Saylor.

Fish distribution surveys have not been limited to the state of Tennessee during this time. The works of Satterfield (1961), Richardson et al. (1963), Ross and Carico (1963), Richardson (1964), Crowell (1965), Wall (1968), and Sisk (1969) all focused on the Tennessee River drainage in Virginia, North Carolina, Georgia, Alabama, and Kentucky. The Mobile Basin and its tributaries have been assessed by Boschung (1961), Caldwell (1969), Barclay and Howell (1973), Dycus and Howell (1974), Mette et al. (1987), Boschung (1989), and Pierson et al. (1989). In Kentucky, surveys have been conducted by Smith and Sisk (1969) and Webb and Sisk (1975); Burr and Mayden (1979) collected species from the Mississippi River, and the upper Cumberland drainage was surveyed by Carter and Jones (1969), Harker et al. (1980), and Branson and Schuster (1982).

There have been numerous comprehensive works on the fishes in the states neighboring Tennessee. Some of the species described in these works also occur within Tennessee. Works include Pflieger (1975) in Missouri, Buchanan (1973) and Robinson and Buchanan (1988) in Arkansas, Cook (1959) in Mississippi, Smith-Vaniz (1968) and Boshung et al. (2003) in Alabama, Clay (1962, 1975) and Burr and Warren (1986) in Kentucky, Menhinick (1991) in North Carolina, and Jenkins and Burkhead (1993) in Virginia.

Because fish are sensitive indicators of water-quality conditions (Smith, 1971), they are an important assessment tool for numerous programs (Karr et al., 1986). According to Wootton (1990), the changes in water chemistry and/or physical change alterations will change the community by affecting the structure. Community changes include size components, functional groups, species diversity, and relative abundances.

Representative samples often are collected to describe fish community structure (Hocutt et al., 1974; Hocutt, 1981). The data obtained from these collections document the presence and relative abundance of species that represent the fish community that can provide insight into water quality (Plafkin et al., 1989). There are requirements for the collection of representative samples. The geomorphic channel units (pools, riffles, and runs) of the stream section are representative of the geomorphology of the stream. Each of the sampling methods for fish has specific limitations with regard to a specific environment (Backiel and Welcomme, 1980). Because these limitations are based upon selectiveness and sampling efficiency, different methods should be used to obtain an overall representation of the community.

Seining

Seining is a common fish sampling method in streams (Bagenal, 1978). One benefit of seining is that it is size selective, i.e., smaller fish are more likely to be captured than larger individuals (Wiley and Tsai, 1983). It has been suggested that electrofishing and seining would complement one another when trying to obtain a thorough representation of the fish community.

Seines are used to enclose and/or encircle the fish in order to trap them. The seine is picked up from the stream and the water exists through mesh openings leaving the fish in the seine for collection and identification purposes. The height of the seine is stretched from the stream bottom due to a bottom lead weight line and to the water's surface with a top float line. Poles are attached to each end of the seine and are handled by a two-person crew.

Seines come in a various sizes and mesh sizes, but three types are the most commonly used for sampling the fish community. These are 3 m x 1.2 m, 7.6 m to 9.1 m x 1.2 m, and 30.5 m to 61 m x 1.8 m. The first one is known as a "common sense" seine with a mesh size of 6.4 mm. The second seine will have a bag in the center of the seine, and is known as a "bag seine". As the bag seine is pulled through the water, the fish are herded to the seine's center and collected within the bag. The third type of seine is a hoop or trap net that forms a tapered funnel entrance to a box that prevents fish from swimming back out of the seine.

The fish community in a wadeable stream can be sampled with any seine type. Factors that are considered in seine selection include which geomorphic channel units are present and the level of complexity of the habitat at the sampling location.

Electrofishing

Fish can be captured by the use of electricity by generating a high voltage potential that is applied between two electrodes that are in the water. Both direct current and alternating current are used. Direct current travels from the cathode (negative) to the anode (positive) in a single direction while alternating current switches directions back and forth. Fish responses to the current are based upon the electrical current and the wave form. The fish responses to the current include avoidance, electrotaxis, electotetanus, electonarcosis, and death (Meador et al., 1993). The alternating current can injure the fish while direct current forces the fish to swim towards the anode. The advantage to direct current is less likelihood of damage to the fish.

The most influential limiting factor on the effectiveness of electrofishing is water conductivity. In low-conductivity water, the water is not conducive to the electrical current flow, and reducing the amount of electrical current traveling through the water, and ultimately the fish's body. Therefore, a higher electrical output is required to create a strong enough electrical field to stun the fish. In high-conductivity water, the electrical current flow is more concentrated. Because of this, the output must be minimized in order to reduce potential damage to the fish.

In wadeable streams, backpack or towed electrofishing gear is used to sample fish. A backpack shocker is chosen in shallow, less than 1.0 m, and small, less than 5.0 m wide, headwater streams. The towed gear is useful in wide wadeable streams, greater than 5.0 m wide, with deep pools, and greater than 1.0 m deep. One limiting factor in the use of this gear is the need for a three to six person crew. Sampling starts at the downstream boundary of the sampling reach and the crew moves upstream. As a result of this movement, the stream's turbidity increases and the visibility level decreases. Though this creates a capture issue due to decreased visibility in the water column, the downstream current forces the stunned fish to drift downstream and allows for capture. Within the sampling reach, all habitats within must be sampled. Another concern with electrofishing is human error resulting in continuous application of the current to the water. Fish may sense this constant current and simply move away from the moving electric current. Instead, the gear operator should approach with the electric current off and use the anode to sweep the habitat forcing the fish to undergo galvanotaxis.

Large unwadable streams can be sampled using electrofishing boats. Sampling equipment includes a gasoline-powered generator and an electrical output control mechanism in an aluminum boat that uses a cathode and an anode array with varying configurations such as single (stainless steel cable), circular (hollow stainless steel ball), or multiple steel cables. Though the boat crew is smaller than the backpack crew, the sampling effort success rate is highly dependent upon the boat driver skill level to maneuver the boat to allow the crew members the opportunity to capture stunned fish. The shoreline is sampled at a downstream direction because fish are oriented into the direction of flow and can swim into the electrical field or swim downstream to escape and can be encountered again. If the fish turns to escape, it has oriented its body perpendicular to the electrical field and has exposed a greater surface area to the electrical field and is more likely to become stunned. Once stunned, the fish will float in the same direction as the boat and be more likely to be collected. The Ohio Environmental Protection Agency (1987) has demonstrated that downstream sampling is more effective than sampling in an upstream orientation.

Another factor of successful electroshocking efforts is time of day. Most efforts are made during daylight hours but Loeb (1957) and Paragamian (1989) determined that night efforts in nonwadeable streams can collect more species and a larger number of individuals. It is believed that there is a reduction of gear avoidance by the fish because of diurnal movements of the fish. Issues of night time sampling include safety concerns and additional costs due to over time.

In recent years, a new technique has been utilized to aid in habitat assessment. One of these techniques utilizes an underwater video mapping system (UVMS) to document physical habitats in both marine and freshwater systems, but the system can also be utilized to identify the fish species present that could not be located by traditional techniques.

Background and Justification of UVMS

Underwater video mapping systems were first used on coral reef surveys to produce benthic habitat maps to identify human impacts vs. natural changes (Legoza, 2002). Since then the technology has been utilized in other areas such as riverine research (Fiscor, 2005; McConkey, 2010). Streambed habitat can be assessed to determine the best suitable habitat for targeted species including fish and mussels. The video can also be used to describe the biological communities. Species composition, relative abundance, and behaviors can be recorded and described. These character descriptions are based upon the distance between fish or mussels and the camera, activity levels of fish and mussels, and the turbidity levels.

Because some of the issues discussed by Roper et al. (2002) still exist, these questions have also been raised on the validity of this current technology. Rogers (2008) tested the reliability of traditional pebble count methods and video assessments on particle size, diameter size class, and percent distribution, and found no statistically significant differences among those measures. According to Rogers (2008), there are several benefits to using this method over the traditional methods. These benefits include reduced field work, less dependency on conditions (long periods of severe weather), and the ability of the researcher to analyze data in a controlled setting over time.

River Impacts

There are many stressors/drivers that impact a stream. These include agriculture, grazing, road construction, and urban development (by rill and gully erosion) as well as reduced infiltration causing higher peak flows and channel degradation (Montgomery, 1994; Swason and Dyrness, 1995). According to West (2002), nonpoint pollution (agriculture and urbanization) was responsible for 70% of water pollution in the Southeastern United States.

Agriculture has extensive impacts and can cause extensive landscape changes (Allan, 2004). The effects on streams include changes in riparian vegetation, alternation of channel morphology, degraded instream habitats, and higher sediment and nutrient loads compared to unimpacted streams (Cooper, 1993). Agricultural nutrient and sediment pollution has been identified as the leading cause of water quality degradation in the United States (Osborne and Kovacic, 1993). This process can cause higher rates of sediment production because of the increased erosive power of raindrops and sheet wash (Dunne and Leopold, 1978; Chang et al., 1982). Further, there are increased runoff rates (Chang et al., 1982) that affect stream water quality and instream habitats (US-EPA, 1994). In turn, there are increased sediment loads in the streams because of bank erosion and incision (Kuhnle et al., 2008). These increased loads are the largest pollutants by volume in the United States (US-EPA, 1994).

Urban development can also impact a stream. During the construction phase, there are additional fine sediments (Dunne and Leopold, 1978). Once construction is complete, there is increased channel erosion (Jones et al., 2000). Road construction is another stressor. There is a direct link to roads and sediment production (Jones et al., 2000).

Increases in sedimentation due to land surface disturbances affect stream ecosystems (Beschta and Jackson, 1978; Jones and Clark, 1987; McDonnell and Pickett, 1990; Walters, 1995; Delong and Brusven, 1998). More than 45% of the U.S. streams are affected (Judy et al., 1984). Sediment input includes agriculture, urban development, forest practices, mining, and road construction (Walters, 1995). According to the US-EPA (1990), the number one problem affecting water quality is increased sediment loading.

Alteration and reduction of forest cover increases sediment transport and decreases stream habitat quality as well as increasing sediment loads which alter stream morphology (Walters, 1995; Roth et al., 1996; Allan et al., 1997). Changes include stream width and local gradient, which results in bed aggradations and decreased pool and riffle areas (Coast et al., 1985). Further, as the deforested riparian patches increase, the abundances of shallow pools, and filling of riffles increases (Jones et al., 1999).

Recent studies on the effects of increased siltation and turbidity on southeastern U.S. fish assemblages have shown negative impacts (Berkman and Rabeni, 1987; Rabeni and Smale, 1995; Jones et al., 1999). When high levels of fine sediment are present, the bed features become homogenous, cover is reduced, and there is a decrease in macroinvertebrates (McIntosh et al., 2000; Suttle et al., 2004).

Johnson et al. (2001) stated that streambed substrate is a key factor of the physical habitat in lotic ecosystems and is a focus on most stream habitat survey protocols. Streambed substrate is the material that forms the surface layer of the streambed and influences habitat quality for benthic invertebrates and aquatic vertebrates. The substrate composition will affect the macroinvertebrate community including the diversity and richness levels being the highest when the substrate composition is dominated by gravel or cobble substrates with low levels of fine sediment (<2mm) (Wood and Armitage, 1997).

Streambed particle size can change in relation to changes in sediment supply in these systems (Buffington and Montogomery, 1999). Changes can occur due to anthropogenic land use activities including but not limited to forest harvesting, agriculture, and development such as roads and residences and these activities will increase erosion and the amount of sediment available to streams including an increase in the percentage of fine particles (Sidorchuk and Golosov, 2003).

Faustini and Kaufmann (2007) evaluated the United States Environmental Protection Agency's (USEPA's) Environmental Monitoring and Assessment Programs (EMAP) (Paulsen et al., 1991) to evaluate the EMAP physical habitat survey protocol for wadeable streams. Their focus was to determine the sources and relative magnitudes of bias and uncertainty in reach-scale estimates of particle size or abundance of fines sediments from the use of EMAP sampling protocol, to quantify the precision of this visual classification-based particle size metrics, to compare them to traditional pebble counts, to evaluate if these data have a high degree of accuracy and precision to address the science and to use the data for management questions at the regional scale. They concluded that there were several error sources from data collected at

1,200 sites that included classification error, binning error due to general size classifications and the effect of using bedrock as the largest size class. The classification error contributed 20% to the particle size estimates errors.

CHAPTER III

DESCRIPTION OF STUDY AREA

The study was conducted within the Pigeon River. It is one of three major drainages of the French Broad River Basin; the other two are the French Broad River and the Nolichucky River. The United States Geological Survey (USGS) and the United States Natural Resources Conservation Service (NRCS) have designated the Pigeon River and its major tributaries (East and West Forks Pigeon River, Jonathan, Richland, Cataloochee, Big Creek and one previous unmarked site) as the hydrological unit 06010106, while the North Carolina Division of Water Quality (NCDWQ) has assigned it the subbasin code of 04-03-05 (NCDWQ, 2007).

The Pigeon River is located mostly in western North Carolina, and a portion in eastern Tennessee. The river begins at the confluence of the East Fork Pigeon and the West Fork Pigeon rivers in Haywood County, North Carolina, and continues north to northwest for approximately 70 river miles to the French Broad River in Cocke County, Tennessee (Figure 1). The headwaters of the Pigeon River arise in the Pisgah National Forest 32.0 km southwest of Asheville, North Carolina (Bartlett, 1995). The Pigeon is approximately 113.0 km in length with a watershed size of 1,725 km^2. The majority of the river's length 74.6%, or 84.3 km, is in North Carolina compared to the length in Tennessee is 23.6%, or 28.7 km (Saylor et al., 1993). All specific sites will be designated in Pigeon River Miles (PRM); this is common terminology and map referencing information and will be used throughout the paper.

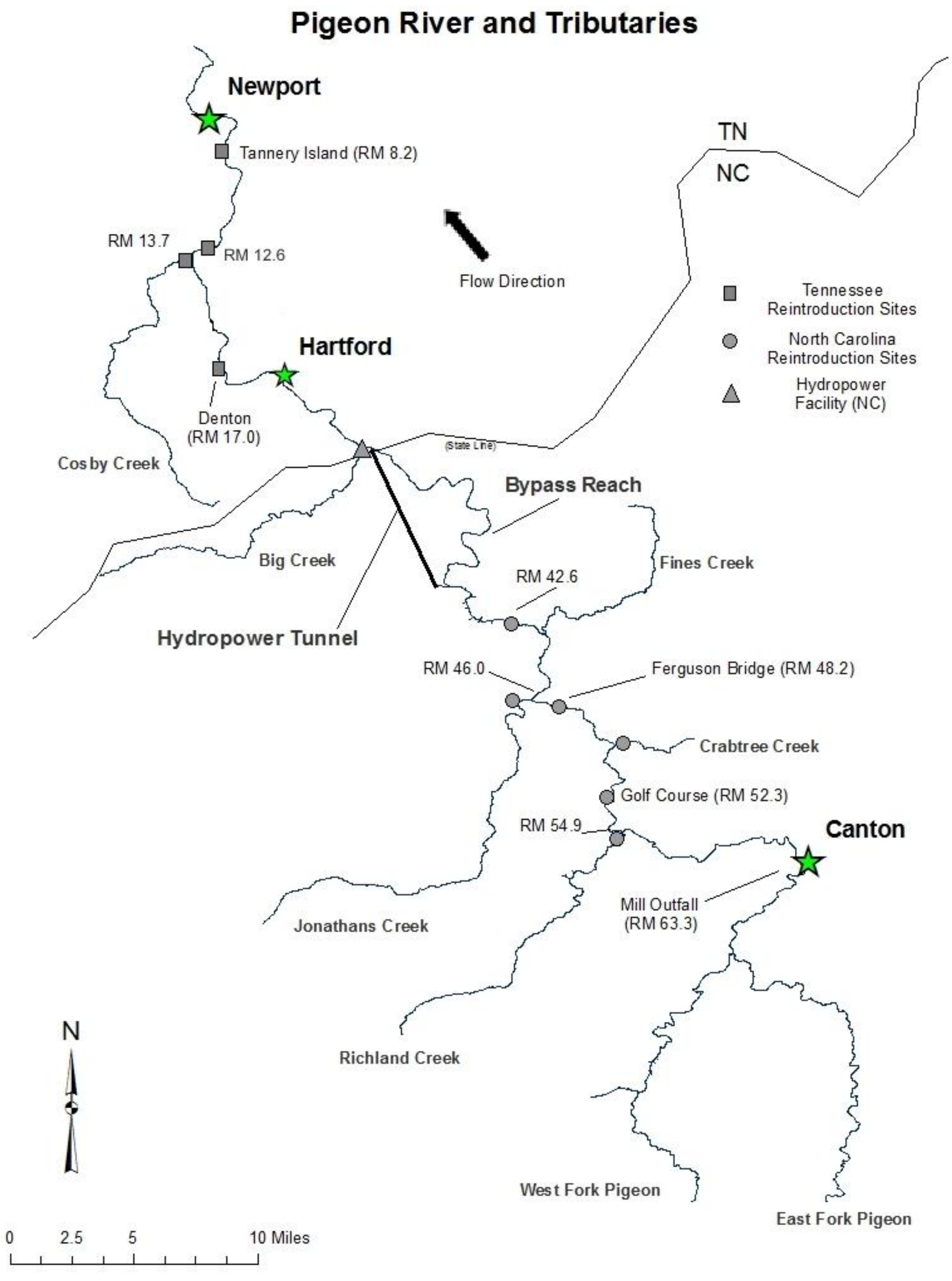


Figure 1. Map of the Pigeon River and its tributaries (Coombs, 2003).

Climate is varied based upon terrain and elevation within the Pigeon River Watershed including temperature and precipitation (WAP, 2002). Annual averages for temperature range in January at 4^{o}C to June at 22^{o}C with an annual rainfall of 114 cm and 33 cm of snowfall, respectively (WAP, 2002).

According to the National Resources Inventory (NRI) of 1982 and 1992 through the Natural Resources Conservation Service (USDA, 2009), land cover within the basin was dominated by "forestland" that covers approximately 50% of the land area followed by "other" at approximately 23%, and "agriculture" (cultivated and uncultivated cropland and pastureland) at approximately 17%. Two trends noted between an earlier inventory in 1982 showed a 72% decrease in agricultural activities and a 42% increase in the urban classification.

The NRI (1982, 1992) described "forestland" as land cover that is at least 10% stocked by single-stemmed trees of any size that will be at least 4.0 meters at maturity, and land bearing evidence of natural regeneration of tree cover. The minimum area for this type is 0.4 hectares (hec) and it must be a minimum of 304.8 m wide. For "agriculture", cultivated cropland is harvestable crops including row crop, small grain, and hay crops, nursery and orchard crops, and other specialty crops, while uncultivated crops are summer fallow or other cropland not planted. "Urban and built-up land" includes airports, playgrounds with permanent structures, cemeteries, public administration sites, commercial sites, railroad yards, construction sites, residences, golf courses, sanitary landfills, industrial sites, sewage treatment plants, institutional sites, water control structure spillways, and parking lots. This type also includes highways, railroads, and other transportation facilities surrounded by other urban and built-up areas as well as tracts of less than 4.1 hec that are completely surrounded by urban and built-up lands. Finally, the "other" land cover type includes rural transportation such as all highways, roads, railroads and associated rights-of-way and built-up areas, private roads to farmsteads, logging roads, and other private roads not including field lanes. "Small water areas" are those waterbodies less than 16.2 hec in size and streams less than 0.8 km wide. "Census water cover" is the area of large waterbodies consisting of lakes and estuaries greater than 16.2 hec, and rivers greater than 0.8 km wide. "Minor land" is land that has not been classified in the other five land cover types.

Within the Pigeon River Subbasin, human population numbers grew from 1970 to 1990 from 38,670 persons to 43,746 persons (11.6% increase). During that time period, not all areas had population growth; the town of Canton decreased 18.2% from 1980 to 1990, and an additional 1.9% decrease in population since 1990 to present. While the Canton population decreased, Haywood County experienced a population growth trend and was the fourth fastest growing county in North Carolina with a 7.5% population increase growth from 1990–1996. The North Carolina Office of State Planning has predicted an increase in Haywood County population of 6.6% by 2016, to approximately 54,000 county residents but Haywood County's population was 59,036 residents in 2010 according to the U.S. Census Bureau (2010).

In contrast to these human population changes, agricultural operations have decreased in the Pigeon River Subbasin. The area has shown a decrease in total swine capacity and total dairy capacity from 1994 to 1998 according to the North Carolina Department of Agriculture (WAP, 2002). Swine capacity has decreased 87% and dairy capacity has decreased 21% during this time period. However, in order for a feedlot with animal waste management system to be registered, it must have a minimum of 100 head of cattle, 75 horses, 250 swine, 1,000 sheep or

30,000 birds (chickens and turkeys) with a liquid waste system. Those feed lots that do not have the minimum number of animals may register voluntarily.

Because of land use activities, water quality in the Pigeon River quality has deteriorated since the early 20th century with the great impact of the paper mill in Canton becoming operational beginning in 1908 [Watershed Action Plan] (WAP, 2002). According to the 1999 Integrated Pollutant Source Identification (IPSI) survey presented in the WAP (2002), eroding stream banks (Figure 2), unpaved roads, unauthorized dumpsites (Figures 2-4), pastures in poor conditions, and animal access to the streams have influenced the river (Figure 5). The removal of river rock by private landowners (Figure 6) can also has dramatic impacts on macroinvertebrate communities and sediment loads in the river. The survey also noted that sediment is the primary impact to the system.

The regional economy has been primarily agriculture-based and forest-based. Europeans settled the area in the 1800s and minimal impacts began to occur to the watershed (WAP, 2002). The natural erosion levels in the region have been estimated to be 0.1 metric ton/hec/year. Various products were grown and open range livestock were raised. During the 1900s, farmers fenced the land and improved pasture land. In 1999 agricultural income accounted for an estimated $24 million to the community, and one-third of this amount was livestock production (WAP, 2002). With an increase in productivity, the human population increased over time. However, in recent years, the anthropogenic activities have shifted from agriculture to development with a 3% decrease in agricultural revenues to the area during the latter part of the 20th century.

Figure 2. Eroding stream banks and an unauthorized dumpsite on the Pigeon River in Haywood County, North Carolina (September 19, 2007).

Figure 3. Abandoned dump site visible only from the Pigeon River (September 19, 2007).

Figure 4. Dump site of metal drums; number, and contents of the drums are unknown (September 19, 2007).

Figure 5. Example of direct livestock access to the Pigeon River (September 19, 2007).

Figure 6. Collection and removal of river rock; rocks were transported out of the Pigeon River along a dirt road in the riparian zone (September 27, 2007).

Human impacts to the watershed were accelerated and land features were altered with the completion of the railroad system in 1882 to Haywood County (WAP, 2002). Large tracts of lumber were harvested and entire subwatersheds were altered by the removal of all usable timber products. With the vegetation removal and natural steep mountain terrain, the landscape was exposed to rainfall and allowed large quantities of silt and sediment to enter the waterways, thus causing severe damage to the river habitat. The historical deposition is still present within the system (WAP, 2002).

The geology of the region influences the Pigeon River system as well. Within the watershed, at the East and West Forks as well as Richland Creek, the underlying rocks form the Ashe metamorphic suite (WAP, 2002). These sediment layers of gravel, sand, and silt are over 700 million years old and have metamorphosed to form the present day mica, gneisses, and schists as well as zones of quartz and feldspar. Because of these layers, there are two main concerns. During weathering of the layers, zones of pyretic and sulfitic rocks are exposed and produce a weak acid. When the runoff enters the streams, there is an increase in acidity that can affect the aquatic life. Secondly, there is severe jointing in the rock that when exposed can lead to rock and mudslides that may deposit additional sediment into the waterways.

Paper Mill

Another human activity impacted the river system when a paper mill was built by Champion Fiber Company (Champion International) in 1908 on the river in Canton, North Carolina, at PRM 63.8 (WAP, 2002). The mill provided economic opportunities and growth in the area, but the development also came with a huge environmental price. Due to the paper making process, large amounts of chemical waste products were discharged into the river (sulfur, chlorine, sodium hydroxide, sodium carbonate, sodium sulfate, sodium chlorate, titanium dioxide, aluminum sulfate, and lime (Bartlett, 1995). Other pollutants included tannin, lignin, dioxins, furans, and chloroform (Bartlett, 1995). The biological community was immediately impacted and numerous fish and other aquatic species were killed and/or extirpated. It has been noted that continued exposure to these contaminants from pulp mill effluent can lead to genotoxic effects, endocrine disruption, and immune dysfunction as well as lowered growth, survival, and reproductive rates of fish (Adams et al., 1989, 1992, 1996). The pulp-to-paper process used the cooler water of the Pigeon River and discharged it back into the river at higher temperatures.

During the remainder of the 20th century, environmental conditions in the river continued to degrade due to the mill's discharge site in Canton, North Carolina, and eventually the discharge impacted the water quality in Tennessee. Though the United States Environmental Protection Agency (US-EPA) was responsible for regulations on the mill, little enforcement occurred and changes were slow (Saylor et al., 1993). Beginning in 1982, local environmental groups and Tennessee state officials asked for improvements to occur, but it was not until 1997 that the US-EPA used the Clean Water Act (US-EPA, 1977) to assess the situation due to mill discharge (Bartlett, 1995). Pollution levels continued to rise and the impacts remained unchecked for decades. Finally, by 1997 Champion was required to reduce discharge pollutants by 50% (Bartlett, 1995).

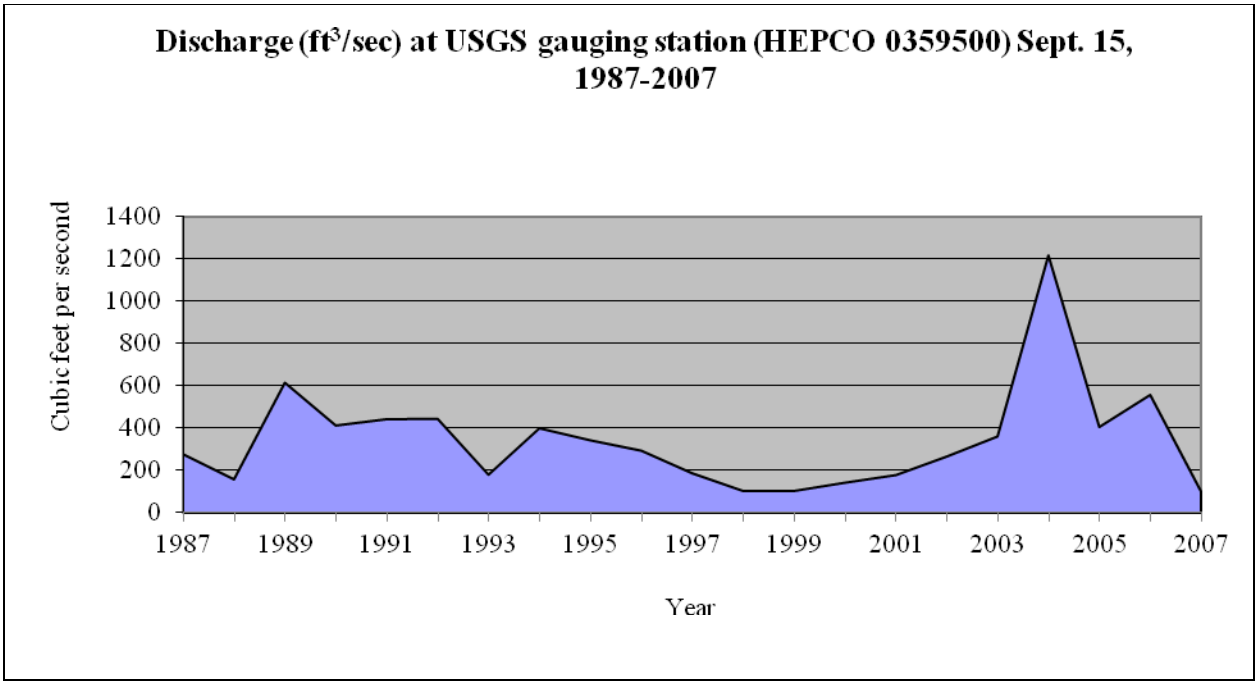
Riverine hydrology was also affected when an impoundment for hydroelectric power at Walters Dam (PRM 38.0) was completed in 1930 by Phoenix Electric Company (Bishar et al., 1999). The concrete dam is 180 feet high and 863 feet long with the spillway at the center of the arch (Bishar et al., 1999). A 4.3 m diameter, 10 km-long tunnel through the mountain transports water down the slope into three penstocks upstream of the powerhouse. Walters Dam impounds the Pigeon River 20.7 river miles below the mill. Table 4 shows discharge at the HEPCO USGS station on the Pigeon River, September 15, 1987-2007 (USGS, 2012).

Improvements in Water Quality

Water quality improvements began in 1992. Paper mill employees purchased the mill from Champion and formed Blue Ridge Paper Products Inc. The new ownership changed the paper bleaching process. The chlorine bleaching process was replaced by a chlorine dioxide and oxygen delignification system that basically eliminated the toxic byproducts dioxins, furans, and chloroform in the waste water, and the amount of water usage was reduced by 35 % (Bartlett, 1995). As a result of the decrease in pollutants there was a change in water color. In 1988 -89, the annual average effluent of color of 158,757 kg/day had decreased to less than 22,680 kg/day in 2000-2001. Improvements continued and the last discharge permit stated that the annual average was to be less than 16,783 kg/day (TDEC, 2010). Furthermore it has been proposed by Tennessee Department of Environment and Conservation (TDEC) (2010) that, due to the effluent color increases by as much as 25% over a two-day period, best management practices would allow effluent loading to be reduced to 14,515 kg/day as an annual average.

Biological surveys have confirmed that these and the previous improvements have allowed the aquatic community to recover. Improvements include the fish advisories from the 1980s being lifted, all designated uses of the river supported, and there have been walleye migrating from Douglas Lake being collected in the Tennessee section of the Pigeon River.

Table 4. Discharge (ft^3/sec) at USGS gauging station, HEPCO (#0359500), September 15, 1987-2007.



Also, rainbow trout have been collected at the Thickety sampling location, which is approximately two miles downstream of the mill (WAP, 2002).

Pigeon River Watershed in Tennessee and North Carolina

This portion of the watershed has been designated 0600106 by the USGS and covers approximately 1,725 km^2 with 396 km^2 within the state of Tennessee (TDEC, 2008). There are 311 tributary stream miles. As the Pigeon River crosses the North Carolina state line and enters Tennessee, it flows through Cocke, Sevier, and Jefferson Counties before it enters the French Broad River (Figure 7).

This area of the state has relatively low population levels with Newport the largest municipality with 7,242 individuals according to the 2000 census. In 2001, land use and land cover descriptive were designated using Multi-Resolution Land Cover (MRLC) satellite imagery (TDEC, 2008). The dominant land uses of the area were "deciduous forest" (64%) and "pasture" (12%). The other notable land uses included "evergreen forest" (7%), "low intensity residential" (6%), and "mixed forest" at 5%. Each of the 10 remaining land uses was 2% or less.

Pigeon River Recovery Project

Beginning in 2001, state and federal agencies assessed the possibility of reintroducing native fish species back into the Pigeon River based upon improvements of the physical habitat and water quality. Agencies included Tennessee Department of Environment and Conservation (TDEC), Tennessee Valley Authority (TVA), University of Tennessee, Knoxville (UTK), U. S. Geological Survey (USGS), U. S. Fish and Wildlife Service (USFWS), Conservation Fisheries, Inc. (CFI), and Blue Ridge Paper Products Inc. in Canton, North Carolina. The collective

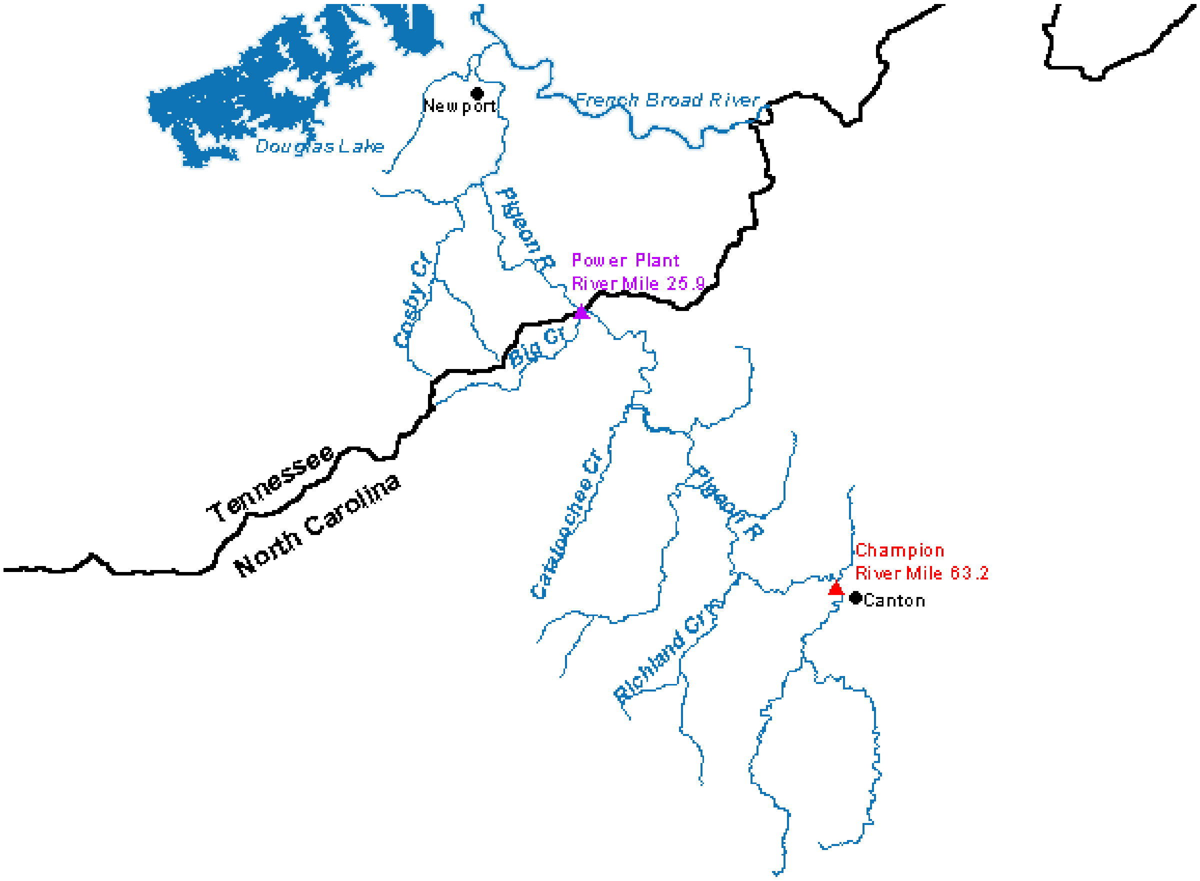


Figure 7. Location of the Pigeon River Watershed (Clouse and Tucker, 2012).

agencies formed the Pigeon River Recovery Project (PRRP) to address the reintroduction efforts. Since its inception, the PRRP has reintroduced, through capture and relocation efforts, 20 fish species, three snail genera, and nine mussel species.

Re-introduction Efforts in Tennessee

In March 2001, fish reintroduction efforts began in the Pigeon River, Tennessee, based upon water quality improvements (Table 5). Eight fish sources have been used that included propagation efforts at Conservation Fisheries Inc. (CFI) in Knoxville, Tennessee, and there were several sample areas where target species were collected for relocation to the Pigeon River: French Broad River, Little Chucky Creek, Little River at Coulters Bridge, Little River at Townsend, Middle Prong of the Little Pigeon River, Nolichucky River, and White Creek. Tennessee release sites have included Tannery Island, McSween Memorial Bridge, the lower area at Denton (PRM 16.5), the upper area at Denton (PRM 17.0), and at the mouth of Cosby Creek.

Re-introduced fish species include five darters: gilt, *Percina evides* (Jordan and Copeland 1877), 1821 specimens; bluebreast, *Etheostoma camurum* (Cope, 1870), 933 specimens; blueside, *E. jessiae* (Jordan and Brayton, 1878), 1010; stripetail, *E. kennicotti* (Putnam, 1863), 1460 specimens; and tangerine, *P. aurantiaca* (Cope 1868), 69 specimens. There were also: one minnow, stargazing, *Phenacobius uranops* Cope 1867, 877 specimens; two chubs: river, *Nocomis micropogon* (Cope 1865), 226 specimens; and blotched, *Erimystax insignis* (Hubbs and Crowe 1956), 197 specimens; one madtom: mountain, *Noturus eleutherus* Jordan 1877, 2409 specimens; two lampreys; American brook, *Lethenteron appendix* (DeKay 1842), 919 specimens; and mountain brook, *Ichthyomyzon greeleyi* Hubbs and Trautman 1937,

Table 5. Fish re-introductions in Pigeon River in Tennessee (Coombs, pers commun, 2012).

collection	**Darter**					**Minnow**	**Chub**		**Madtom**	**Lamprey**		**Topminnow**		Collect	release
dates	Gilt	Bluebreast	Blueside	Stripetail	Tangerine	Stargazing	River	Blotched	Mt	Am Brook	Mt Brook	N. Studfish	Blackstripe	site	site
3/14/01			128											MPLP	TI
5/23/01	120		1											MPLP	TI
10/2/01	132		4											MPLP	TI
10/9/01	41	121												N	TI
11/6/01	52	122	6											N	TI
2/8/02	51		113			4								MPLP	TI*
2/15/02	43		107			18								MPLP	TI*
3/15/02			145			31								MPLP	TI *
4/26/02									116					FB	TI
5/21/02	157					56								MPLP	TI
5/28/02	136					116								MPLP	TI
6/25/02									68					FB	TI
8/28/02	28	86							9					N	TI
10/23/02	126					6								MPLP	TI
3/13/03	61		115	5		2								MPLP	TI *
4/3/03	42		84	29										MPLP	TI *
5/30/03									163					FB	TI
6/3/03			20	64										MPLP	TI *
7/21/03	14	5				5			2					LRCB	TI
7/28/03										48	10			LRT	TI
8/15/03			5	66										WC	TI *
8/21/03										237	108			LRT	TI
8/26/03									23					FB	TI
9/26/03										192	121			LRT	TI
10/14/03			27	141		4								MPLP	TI *
10/28/03	12		11	188		28								MPLP	TI *
2/20/04			211											LC	MMB
4/16/04			19	54		42								MPLP	TI*
4/30/04						174								MPLP	TI
5/12/04									194					FB	TI
8/13/04										72	97			LRT	TI
8/20/04									102					FB	TI
9/22/04			14	70		5								MPLP	TI
9/24/04										115	198			LRT	TI
10/22/04				112										MPLP	TI
3/22/05	111					8								MPLP	UPD/TI
4/26/05	114			2		52	6							MPLP	UPD/TI

Table 5. (Continued)

collection	**Darter**					**Minnow**	**Chub**		**Madtom**	**Lamprey**		**Topminnow**		Collect	release
dates	Gilt	Bluebreast	Blueside	Stripetail	Tangerine	Stargazing	River	Blotched	Mt	Am Brook	Mt Brook	N. Studfish	Blackstripe	site	site
5/18/05		23					16		200					FB	TI
5/26/05	47					120	15							MPLP	UPD/TI
6/29/05										73	90			LRT	TI
10/5/05	22			197		19	2							MPLP	UPD/TI
10/24/05	31	28				7	26		9					N	UPD
11/7/05										118	102			LRT	UPD
3/27/06	259					76	1							MPLP	UPD/TI
5/16/06	171			1		76								MPLP	UPD/TI
5/23/06		3							222					FB	TI
9/27/06										64	52			LRT	UPD
10/24/06				54										MPLP	LD
4/5/07					46									CFI	LD
4/19/07		7							139					FB	UPD/TI
5/23/07		23							149					FB	UPD/TI
6/8/07	17	122				8	4							N	UPD
8/28/07							4	96	21					FB	TI
9/18/07	34	47				20	10		12					N	UPD/TI
9/21/07							15	68	117					FB	TI
6/9/08					23									CFI	LD
9/26/08							22	33	237					FB	TI
10/2/08				68			1							MPLP	UPD
10/7/08		121					21		34					N	UPD/TI
5/27/09		45							159					FB	TI
9/11/09				28			1						12	MPLP	CCM
10/30/09				131								34		WC	CCM
5/19/10									259					FB	TI
5/19/10		17												FB	CCM
6/14/10				14										MPLP	CCM
10/8/10		103					19							N	CCM
10/8/10									37					N	TI
5/19/11									137					FB	TI
5/19/11		21												FB	CCM
8/5/11				8								14		WAC	CCM
8/18/11		39					63							N	CCM
11/2/11				157								43		WC	CCM
11/7/11				71								12		WAC	CCM

Table 5. (Continued)

collection	**Darter**					**Minnow**	**Chub**		**Madtom**	**Lamprey**		**Topminnow**		Collect	release
dates	Gilt	Bluebreast	Blueside	Stripetail	Tangerine	Stargazing	River	Blotched	Mt	Am Brook	Mt Brook	N. Studfish	Blackstripe	site	site
Totals	1821	933	1010	1460	69	877	226	197	2409	919	778	103	12		

Note for collection sites: CFI (Propagated @ CFI), FB (French Broad), LC (Little Chucky Creek), LRCB (Little R., Coulters Br), LRT (Little R., Townsend), MPLP (Mid Prong, L Pigeon), N (Nolichucky), WC (White Creek), WAC (Waldens Creek)
Release sites: TI* (Tannery Island including blueside darters), LD (Low Denton RM16.5) UPD (Up Denton, RM 17.0) CCM (Cosby Cr., mouth)

778 specimens; and two topminnows: northern studfish, *Fundulus catenatus* (Storer 1846), 103 specimens, and blackstripe, *F. notatus* (Rafinesque 1820), 12 specimens.

Other aquatic species have been, and continue to be, reintroduced to the Pigeon River. In 1996, native freshwater snails were collected and relocated. Snails from the genera *Io, Pleurocera*, and *Leptoxis* were reintroduced into the Pigeon River near Newport, Tennessee, including an estimated 20,000 specimens between 2000 and 2004. *Pleurocera* and *Leptoxis* have been reported to be actively reproducing in that section of the river.

Another riverine group of interest has been the freshwater mussels. Nine mussel species have been reintroduced: elktoe, *Alasmidonta raveneliana* (Lea 1834), three ridge, *Amblema plicata* (Say 1817), purple pimpleback, *Quadrula refulgens* (Lea 1868), spike, *Elliptio dialatuatus* (Rafinesque 1820), wavyrayed lampmussel, *Lampsilis fasciola* Rafinesque 1820, plain pocketbook, *L. cardium* Rafinesque, 1820, kidneyshell, *Ptychobranchus greenii* Conrad 1834, orange-footed pimpleback, *Plethobasus cooperianus* (Lea 1834), and creeper, *Strophitus undulatus (*Say 1817).

Re-introduction Efforts in North Carolina

In March 2004, fish reintroduction efforts began in the Pigeon River, North Carolina, due to improvements in water quality (Table 6). Ten collection sites were chosen and included Boylston Creek; French Broad River at Rosman (FBRM 217.5); Mills River, Upper Pigeon River (PRM 64.5); Prices Creek, Swannanoa River (SRM 1.5), French Broad River at Paint Rock Creek, Spring Creek; French Broad River at Hot Springs; and French Broad River at Hannah Road (FBRM 212.8). North Carolina release sites included Ferguson Bridge at Riverside; Golf Course (PRM 52.5); Crabtree Creek; mouth of Crabtree Creek; mouth of

Table 6. Fish re-introductions in the Pigeon River in North Carolina (Coombs, pers commun, 2012).

Collection	Darters		Chub	Shiner							Collect	Release
Dates	Gilt	Banded	Bigeye	Highland	Mirror	Saffron	Silver	Telescope	TN	Striped	Sites	Sites
3/11/04					171	78					UPR	FBR
3/30/04							167	275			CC	FBR
8/25/04							318	666			CC	FBR
8/26/04					973	155					UPR	FBR
3/30/05							312	505			CC	FBR
3/31/05	39										BC	GC
4/11/05	20										MR	GC
8/23/05					713	85					UPR	FBR
8/24/05							262	460			CC	FBR
8/25/05	25										MR	GC
4/4/06							306	238			CC	FBR
4/6/07					583						UPR	FBR
4/7/06	60										BC/MR	FBR
10/3/06							149	214			CC	CTM
10/4/06					1608						UPR	CTM
10/5/06	92										FBNC	GC
4/3/07							160	175	670		CC	GC
4/4/07					1269						UPR	GC
4/5/07	87										FBNC	GC
5/30/07										27	PC	CTM
10/16/07										63	PC	CTC
4/2/08							434	250			CC	CTC
4/3/08	93								338		CC	HB
4/4/08					325						FBNC	CTM
3/30/09							474	428	518		CC	GC
3/31/09											UPR	JC
4/1/09	121				276						FBNC	RC
10/6/09		57							441		SW	GC
10/6/09	117										SW	RC
10/6/09									442		SW	CTM
10/7/09	27										SW	RC
10/7/09		15									FBPR	GC
10/7/09			12	42				20	20		FBPR	CTM
10/7/09		40							55		SC	GC
4/6/10	136										SW	RC
4/6/10		52	4						277		SW	GC
4/7/10	2										SC	RC
4/7/10		19									SC	GC
4/7/10				272					311		FBHS	CTM
4/8/10					194						UPR	JC
4/13/10					198						UPR	JC
9/28/10					480						UPR	JC
10/5/10	82	6									SW	RC
10/5/10			22						903		SW	GC
10/6/10		14									FBHS	RC
10/6/10			130	325					159		FBHS	CTM
10/6/10	1	51									SC	RC
10/7/10	82	21									FBHR	RC
4/5/11	64										FBNC	RC
4/5/11	44								11		BC	RC
4/7/11					349						UPR	JC
5/12/11			10	469					36		FBHS	CTM
10/4/11			67				12		720		SW	PR47
10/4/11	199	14	72								SW	RCW
10/5/11				229					14		FBHS	GC
10/5/11		74									FBHS	RCW
10/6/11					901						UPR	JC
Totals	1291	363	317	1337	8040	318	2594	3231	4915	90		

Note for collection sites: CC (Cosby Creek, TN), BC (Boylston Creek, NC), FBNC (French Broad, Rosman, RM 217.5), MR (Mills River, NC), UPR (Upper Pigeon, RM 64.5), PC (Prices Creek), SW (Swannanoa River, RM 1.5), FBPR (French Broad, Paint Rock Creek), SC (Spring Creek, NC), FBHS (French Broad, Hot Springs), FBHR (French Broad, Hannah Rd, RM 212.8)

Release sites: FBR (Ferguson Bridge, Riverside), GC (Golf Course, RM 52.5), CTC (Crabtree Creek, mouth), JC (Jonathan Creek, mouth), HB (HEPCO Bridge, RM 42.6), RC (Richland Creek Road Bridge), RCW (Richland Creek, Walnut Tr.), PR47 (Pigeon River, PRM47.0).

Jonathan Creek; HEPCO Bridge (PRM 42.6); the bridge at Richland Creek Road; Richland Creek at the Walnut Tributary; and the Pigeon River (PRM 47.0). Fifty-eight fish relocation efforts have been conducted since March 2004 in North Carolina.

Re-introduced fish species into the North Carolina portion of the Pigeon River included two darters: gilt, *Percina evides* (Jordan and Copeland 1877), 1291 specimens; and banded, *Etheostoma zonale* (Cope 1868), 363 specimens; one chub: bigeye, *Hybopsis amblops* (Rafinesque 1820), 317 specimens; and seven shiners: highland, *Notropis micropteryx* (Cope 1868), 1337 specimens; mirror, *N. spectrunculus* (Cope 1868), 8040 specimens; saffron, *N. rubricroceus* (Cope, 1868), 318 specimens; silver, *N. photogenis* (Cope 1865), 2582 specimens; telescope, *N. telescopus* (Cope, 1868), 3231 specimens; Tennessee, *N. leuciodus* (Cope 1868), 4195 specimens; and striped, *Luxilus chrysocephalus* Rafinesque 1820, 90 specimens.

Water Quality Monitoring in the Pigeon River

In recent years the state of North Carolina has been classifying water quality conditions in selected streams throughout the state. The classification system was designed by the Environmental Management Commission, which is a unit within the North Carolina Department of Environment and Natural Resources (NCDENR). Eleven water quality parameters were measured at 27 sites throughout the Pigeon River Watershed (Table 7). The parameter values were compared to naturally occurring concentration ranges or state water quality standards. The stream segments surrounding the sample sites were assigned a quality letter of "A", "B", "C", or "D". "A" scores represent values in the "Very Good" category, “B” represents “Good”, “C” represents “Fair”, and "D" represents values in the "Poor" category.

Table 7. Classification grades (A-D) based upon parameters and ranges from water quality trends of Haywood County, North Carolina (WAP, 2002).

Site	pH	Alk	Turb	TSS	Cond	Cu	Pb	Zn	Ortho P	NH_3-N	NO_3-N
1-West Fork Bethel	A	D	A	A	A	B	A	A	A	A	A
2- East Fork Bethel	A	D	C	A	A	A	A	A	A	A	A
3-East Fork Cruso	D	D	A	A	A	B	A	A	A	A	A
4-Pigeon River, DS Canton	A	A	C	B	D	B	A	B	D	C	B
5-Pigeon River Hepco Bridge	A	A	D	D	D	D	B	D	D	B	C
6-Rush Fork at Crabtree	A	A	C	B	D	B	A	B	D	D	C
7-Fines Creek, DS	A	B	C	C	C	B	B	B	C	B	C
8-Eaglenest Creek	A	B	B	B	C	B	B	B	B	C	C
9-Plott Creek	B	C	C	B	B	B	A	A	B	A	B
10-Richland Creek, West Waynesville	A	D	B	B	B	A	A	A	A	A	B
11-Richland Creek, Lake Junaluska	A	C	C	B	C	B	B	B	B	B	B
12-Jonathan Creek, DS	A	C	C	B	B	C	B	B	B	B	B
13-Allens Creek	A	D	C	B	B	B	A	B	A	A	A
14-Rush Fork, US	A	B	C	D	D	A	A	A	D	A	B
15-Fines Creek, MS	A	B	C	C	C	B	A	A	C	A	A
19-Fines Creek, US	A	C	D	D	B	A	A	A	C	A	B
20-Cove Creek	A	C	C	D	D	A	A	B	D	A	C
21-Hyatt Creek, US	A	B	D	D	C	B	A	D	D	A	C
22-Hyatt Creek, DS	A	B	D	D	C	A	A	B	D	A	C
23-Ratcliff Cove Branch	A	A	B	A	C	A	A	A	D	A	C
24-Raccoon Creek, US	A	A	B	B	C	A	A	A	D	A	C
25-Raccoon Creek, DS	A	A	B	A	C	A	A	A	C	A	C
26-Crabtree Creek	A	B	B	A	C	A	A	A	C	A	B
27-Jonathan Creek, Maggie Valley	A	D	A	A	A	A	A	A	C	A	A

Note for sites: DS = downstream; MS = midstream; US = upstream; Classification grades: A = Very Good, B = Good, C = Fair, D = Poor; Water parameters: pH = acidity, Alk = alkalinity, Turb = turbidity, TSS= total suspended solids, Cond = conductivity, Cu = copper, Pb = lead, Zn = zinc, Ortho P = orthophosphate, NH_3-N = ammonia nitrogen, NO_3-N = nitrate

The Environmental Management Commission, which was established by the Watershed Action Plan (WAP) (2002), revised the water supply watershed classification system through the Water Supply Watershed Protection Act (WSWPA) of 1989 (Howells, 1989). One of the goals of the WSWPA was for the state to provide and increase protection of those surface waters that are used as public drinking water supplies (WAP, 2002). The water supply watershed classifications were updated and minimal protection rules implemented. These changes have forced the municipalities to enforce these regulations. Each water supply watershed has been designated as one of five classifications, WS-I through WS-V, with designations based on watershed characteristics. The WS-I class is still natural and undeveloped and is usually publicly owned. The WS-II through WS-IV classes have increasing levels of development. The Waynesville water supply on Allens Creek is a WS-I watershed, and the water supplies at Canton and Maggie Valley are classified as WS-III.

The Index of Biotic Integrity (IBI) was conducted at each of the locations on each stream during the 1990s to determine their ecological health. Collections focused on fish species and their numbers. TVA and NCDENR use the physical habitat assessments and the biological surveys and have determined there are variations between sampling sites. The physical habitat scores were higher than the Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies) or EPT data. Reasons for these differences include an artifact of sampling efforts, specific and localized conditions, and watershed history. The agricultural and railroad timber harvest practice created a large sediment load throughout numerous reaches (WAP, 2002). The flowing waters appear to be clean; however, the sediment deposits have caused damage to the habitats and have affected the biological community. It is recommended that, if for example, the environmental pressures were decreased throughout the watershed, it would allow the system to continue to recover and further system improvements would be identified by physical assessments and biological surveys. However, current human activities and future impacts may not allow these improvements to occur.

The North Carolina Department of Environment, Health, and Natural Resources, NCDEHNR (1997) classified stream health based upon the following EPT index ranges which correspond to water quality ratings: excellent, >27 genera; good, 21 – 27 genera; good to fair, 7 – 13 genera; and poor, 0 – 6 genera. The EPT Index is useful in determining cumulative effects of all watershed activities. Over time, the index is useful in creating a baseline for overall water conditions, identifying point and non-point pollutants and their sources within the watershed, and determining if water quality has improved due to BMPs.

The situation of anthropogenic activities impacting the physical environment and the biological communities within the Pigeon River Watershed is common throughout the country. The effects of nonpoint source pollution throughout the watershed are evident. Stormwater runoff further compounds the issues because of the level of human activities in the area. Pollutants such as sediment, nutrients, petroleum products, heavy metals, toxins, and bacteria are common in the runoff that enters the waterways. Not only is the amount of runoff important, but also the rate of runoff. The runoff rate has increased because of decreased riparian zones and increased levels of impervious surfaces such as roads, parking lots, roofs and other development. Sediment enters the system during precipitation events when stormwater runoff levels are high. The steep mountainous slopes adjacent to the streams compound this situation. The riparian zones have been reduced or eliminated due to past timber harvest. Another example of these activities is the point source of the paper mill effluent discharge into the Pigeon River in Canton, North Carolina that has increased water temperature.

The Integrated Pollutant Sources Identification (IPSI) (WAP, 2002) study quantified nonpoint pollution sources throughout the Pigeon River Watershed. The research was able to estimate the amount of sediment deposition occurring in the streams and showed that land use contributed to this type of pollution. Of the identified sources, five of the land use designations accounted for 95% of sediment deposition. Stream bank erosion and roads accounted for 73% of the deposition. The other sources of deposition were low residue cropland, pastures in poor condition and forest. The "road source" includes newly constructed roads, eroding road banks and unpaved roads and ditches. Within the Pigeon River Watershed there are approximately 5,150 km of private and state roads. The current condition of road density is 1.6 km per 43 hec of land. However, the density is increasing and most of the new roads are on steep slopes with erodible soils. Because there are no regulations describing where or how these roads are being constructed, there is an increasing percentage of impervious areas throughout the watershed especially in areas of new housing development. One example of these changes is observed in the Plott Creek Watershed located near Richland Creek. Much of the land is forested (76%); however, there are development plans for the area. Once development is completed, the impervious surface will probably increase from 0 to 10%. As a result, there will be increased runoff rates and a continued increase in environmental pressures on the watershed and its resources. Other points of interest from the IPSI 1999 study included high numbers of unauthorized dump sites (231) and the number of farm animal access points (222) (Figures 8-9).

Figure 8. Example of direct cattle access to the Pigeon River (September 27, 2007). Note water color at the animal access point.

Figure 9. Example of direct cattle access to the Pigeon River (September 27, 2007).

Water Quality Monitoring on Pigeon River Watershed

The Pigeon River Watershed is divided into four subwatersheds: Upper Pigeon, Lower Pigeon, Richland Creek, and Jonathan Creek. The Upper Pigeon Subwatershed includes the East and West Forks of the Pigeon River and the area between the Forks down to Richland Creek. Within this area are the towns of Canton and Clyde. The Lower Pigeon River Watershed begins at the confluence of Richland Creek and the Pigeon River and continues to the Tennessee state line. The Richland Creek Subwatershed begins on the southwestern boundary of the Pigeon River Watershed and flows to the northeast through the most developed portion of Haywood County including the municipal water supply for the Town of Waynesville which is one of the highest quality municipal water supplies in the state. The Jonathan Creek Subwatershed begins on the western boundary of the Pigeon River Watershed and flows to the northeast until it joins the Pigeon River.

Upper Pigeon Subwatershed

Because these headwaters are part of the Pisgah National Forest, they are designated "trout streams" and a large area is classified as 'High Quality Waters'. Moving downstream, the land use increases and road densities increase (WAP, 2002). One example of the designated trout streams is near the town of Canton, North Carolina, in the Rough Creek Watershed. Even though the Subwatershed is very small, being less than 405 hec, it has been designated as WS-I, or 'Outstanding Resource'.

The paper mill and the town of Canton both obtain their water from the Upper Pigeon River Subwatershed. Canton owns much of the watershed and it is used as a municipal reservoir. Land use is divided among forest (73%), pasture (11%) and residential (8%), the latter concentrated in the towns of Canton and Clyde. Most of the residential use is classified as low density. Finally, an estimated 2.3% of the watershed is considered impervious surfaces, which includes 1621 km of roads.

Within this subwatershed, eroding stream banks are the number one contributor to sediment at 45%, followed by roads with 30%, and pastures at 12% (WAP, 2002). The eroding banks are highly concentrated in the northern half of the Upper Pigeon, and 7% of all banks are classified as eroding.

Eleven biological surveys were conducted by NCDENR in the watershed since 1997 (WAP, 2002). Ten sites were above the mill, and all were classified as 'Good to Excellent'. IBI scores were based upon 40 EPT samples. Another survey was conducted below the mill in the town of Clyde. Previously, this area was classified as 'Poor to Fair' but the 2001 sample was classified as 'Fair to Good'. It is believed that the new regulations reducing color and enforcing maximum discharge levels from the mill were partially responsible for these improvements (WAP, 2002).

Tennessee Valley Authority collected fish and macroinvertebrate data at five sites beginning in 1997 (WAP, 2002). Of the five sites, two were rated to be the best within the county. These were Pigeon River at Pisgah Memorial Stadium and West Fork of the Pigeon River at Riverside Baptist Church. One site, the Hyder Mountain Bridge, rated only 'Poor to Fair' for fish and 'Fair to Good' for aquatic insects; however, these scores reflect improvements in conditions since the early 1990s. Another site on Bird Creek tested 'Poor' for both fish and macroinvertebrates in April 1999. It is believed that this is a localized habitat and nutrient pollution issue. The site on the East Fork of the Pigeon River above Lenoir Creek scored 'Poor' for fish and 'Good' for macroinvertebrates. It is believed that historical degradation of habitat, unresolved metric issues, and localized environmental problems have influenced these ratings. Overall, the physical habitat impacts the biological community with numerous sources of sediment input; however, the area has better water quality than many of the other watersheds of the Pigeon River.

Lower Pigeon Subwatershed

The Lower Pigeon Subwatershed is located immediately below the paper mill in Canton. All land downstream of the mill in Canton, North Carolina, to the state line, 60,333 hec, is included within this subwatershed except for the Richland and Jonathan Creek Subwatersheds. Within this subwatershed is a section of the Great Smoky Mountains National Park that includes most of the Big Creek and Cataloochee Creek Watersheds. Both of these have been designated by the state as the highest quality watersheds. There are also trout waters located at the north end of the watershed.

This area has low-density residential use with only a few small communities. There are some agricultural operations including vegetable crop production and areas designated for forest practices. However, there is the 138 hec Carolina Power and Light (CP&L) Walters Reservoir that is used to generate hydroelectric power that began operation in 1930. This is one of the largest hydroelectric facilities in the South, with the three generators producing 108,000 kilowatts of electricity (WAP, 2002).

Land use classification shows this subwatershed to be 84% forested, the highest of all Pigeon River subwatersheds. Other land uses include 11% pasture and 3% divided equally between cropland, commercial, and residential. The remaining 2% of the land use was classified as 'Other'.

Even though this is the most rural subwatershed of the Pigeon River Watershed, the area is being impacted by anthropogenic factors. There are 1662 km of road providing a road density of 1.6 km per 58.3 hec. Because of this road density, the contribution of sediment to the system is 35%. Other factors impacting the system include eroding stream banks (32%) and pastures (20%). Of the four subwatersheds with sediment loads from pastures, the Lower Pigeon has the highest percentage (WAP, 2002). Farm animal access points, cropland, construction sites, and other activities represent the remaining 13% of the sediment input sources.

Sampling efforts were conducted at seven Volunteer Water Information Network (VWIN) sites in this subwatershed and results were presented in the annual report from the Environmental Quality Institute (2000). There were four sites on Fines Creek, two sites located on Rush Fork Creek, and the remaining one on the Pigeon River at the Hepco Bridge near Fines Creek.

Of the 24 VWIN monitoring sites in Haywood County, Fines Creek and Rush Fork Creek sites exhibited some of the greatest sedimentation and nutrient loading levels recorded. The downstream sites had median levels for all parameters that exceeded the levels for the entire region. Also, at these two sites, the maximum levels for the nutrient parameters were higher than the average maximum levels of the region. All downstream sites on these creeks were in the 'Poor' range. On Rush Fork Creek at the downstream site, nitrate/nitrite concentrations were 4.5 mg/L and ammonia-nitrogen concentrations were 1.55 mg/L in July 1999; both levels exceeded the water quality standard of 1.0 mg/L in the summer. These two areas have some of the poorest rated streams in Haywood County.

According to WAP (2002) it is believed that these low scores reflect the effects of past and present human activities. These streams flow from the western slopes of the Newfound Mountains and the sediment and nutrient loads in Rush Fork Creek and Fines Creek reflect levels similar to streams on the eastern slopes of the mountain range in Buncombe County. Both areas have been deforested and cleared for agriculture up to headwater elevations. Other human alterations to the streams include channel straightening and the removal of riparian zones. Land uses have changed in some areas from agriculture to rural development (WAP, 2002). These changes, coupled with eroding stream banks and steep slopes, have led to higher maximum turbidity levels at the upstream sites. In turn, downstream sites have higher maximum turbidity levels than other county sites as well as regional maximum levels.

The IBI sampling has not occurred in either Rush Fork Creek or Fines Creek, though both NCDENR and TVA have sampled the Pigeon River. The chemical and physical sample results ranged from 'Fair to Good' in this segment. NCDENR collected EPT samples in the Pigeon River that were rated 'Good to Fair'. TVA sampled at Hepco Bridge and the EPT rating was 'Fair' but the IBI rating was 'Poor'. Finally, VWIN ratings at Hepco Bridge were the poorest of any stream segment sampled in the entire study.

Richland Creek Subwatershed

One of the smaller subwatersheds, the Richland Creek Watershed has an area of 17,663 hec. One water resource located in the subwatershed is Lake Junaluska. This resource contributes approximately $30 million to the local economy through tourism and property taxes from the residents on the lake (WAP, 2002). Lake Junaluska is being impacted by the activities in Haywood County. The lake is an area for deposition and the sediment inputs are high. The sediment removal project began in 1964 with a removal of 305,822 to 382,277 m^3. Nine years later an additional 298,940 m^3 were removed. Sediment removal continues today with a budget of approximately $25,000 per year; however, the sediment deposition rate is greater than the project can maintain. It is estimated that an addition $3 million will be needed to remove the sediment (WAP, 2002). Even if all of the sediment is removed from Lake Junaluska, there is still the issue of the natural process and the amount and rate of incoming sediment to the system. The obvious solution is to reduce the rate of sedimentation by identifying the sources and introducing practices that will aid in these changes.

With the amount of development in this area, the percentage of forest has been reduced to 63% which is the smallest amount within the entire Pigeon River Watershed. This percentage will continue to decrease as development (16%) continues in the area thus is a sediment source. Other uses include pasture (10%), various other uses (8%), commercial uses (2%), and cropland (1%) (WAP, 2002).

The Richland Creek Subwatershed had similar sources of sediment as the other subwatersheds. Eroding stream banks are responsible for 47% of the inputs followed by roads with 32% (WAP, 2002). Pastures (9%), other sources (6%), farm animal access (5%), and cropland (1%) also contributed sediment to the streams (WAP, 2002). Because the eroding banks are located on hundreds of private properties ranging in size from less than 0.4 - 40.7 hec, this raises the issue with landowner participation when efforts are implemented to reduce sediment input to the system. State mandates may require owner action before any changes will be determined. Though the short term interest of establishing Best Management Practices (BMPs) is to improve conditions, these practices must be maintained long term and interest can decrease over time (WAP, 2002). It is estimated that almost 13,411 m of these eroding banks exist throughout Richland Creek Subwatershed. One cause of the eroding stream banks is the percentage of the riparian zone that has been reduced and has been classified as marginal to inadequate. Approximately 24 km of riparian zone on both banks are in the current condition (WAP, 2002).

In this subwatershed there are 1,006 km of roads that provides a density of 1.6 km per 27.9 hec. This is the highest road density throughout the entire Pigeon River Watershed. Of the road miles, 496 km are unpaved and approximately 26% of those have eroding road banks compared to only 8% of the paved roads having eroding road banks. One issue to address is there are no state approved BMPs for stabilizing road networks in the mountains. However, plans have been proposed to reduce the level of eroding road banks and other erosion problems by 25% during the next five years. The stabilization of eroding road banks would reduce sediment loading in Richland Creek by approximately 8%.

The third major sediment contributor in Richland Creek is pasture condition and farm animal access points and is seen in 14% of these streams. There are 1,243 hec of 'Fair' condition pastureland with 35 identified farm animal access points. Many of these identified areas coincide with eroding stream banks.

The VWIN sampling sites on Richland Creek are located at seven locations. They are: one on Richland Creek above Waynesville, two on Hyatt Creek, one on Plott Creek, one in the Allen Creek Watershed, one on Eaglenest Creek, and one on Richland Creek at Lake Junaluska.

VWIN sampling scores ranged from 'Poor' at the two Hyatt Creek sites to 'Good' above Waynesville and at Allen Creek. Four of the sites (above Waynesville, Plott Creek, Eaglenest Creek, and above Lake Junaluska) all showed lower scores compared to previous sampling efforts. Parameters for turbidity, total suspended solids, orthophosphate, and nitrate/nitrite-nitrogen at the Hyatt Creek sites were higher than the average for all sites in western North Carolina. According to the VWIN (2001) score card, each of these water parameters could have been assigned a quality letter grade of 'A' (very good), 'B' (good), 'C' (fair), or 'D' (poor). Each of the parameters scored a 'D'. Turbidity values were greater than 10 NTU or exceeded 50 NTU in more than 10% of the samples. Total suspended solids (TSS) values were greater than 10 mg/L or the maximum values exceeded 100 mg/L in more than 10% of the samples and there was a high level of land disturbance. Orthophosphate (Ortho P) values exceeded a value greater than 0.20 mg/L. Nitrate nitrogen (NO3 - N) values exceeded at least one sample at 5 mg/L that was above the normal range of 0.3 mg/L to 1.0 mg/L.

Monitoring was conducted by TVA at two Richland Creek sites: Vance Street Park, and Raccoon Creek at Junaluska Elementary School. The fish IBI assessment at both sites scored in the 'Poor' range. At the park, scores from fish sampling were lower than expected and it is believed to be the result of poor water quality. Of all fish sampling sites, this was the worst site because of the percentage of omnivorous fish and diseased fish present. Another site at Lake Junaluska School was also classified as 'Poor'. It was reported by TVA that the physical habitat parameters, including reduced instream cover, sedimentation, low habitat diversity, bank instability, and reduced riparian vegetation, led to these issues. EPT scores were 'Poor to Fair' at Vance Street Park and 'Fair' at Raccoon Creek.

There were six EPT sites in the subwatershed surveyed by NCDENR. Shiny Creek above the Allen Creek reservoir was scored as 'Excellent'. The two sites in the Hyatt Creek Watershed tested in the 'Poor to Fair' range and the two sites on Richland Creek at SR 1519 and the Dayco site scored in the 'Fair' to 'Fair to Good' range. The site at SR 1184 in Waynesville has improved from 'Poor' scores in 1983 to the 'Fair to Good' range in 1997.

Jonathan Creek Subwatershed

The smallest subwatershed is the Jonathan Creek Watershed with 17,311 hec. The Town of Maggie Valley is located here and collects its municipal water from Campbell Creek and Jonathan Creek. Unlike other municipalities, the water supply quality is based upon water filtration technology rather than the water's source.

Data indicated that "forest" covers 74% of the watershed. This percentage will probably decrease, however, due to continued residential development (currently at 10%) which is second behind Richland Creek. Other uses include pasture (9% with 7.5% in fair condition), commercial practices (2%), and other practices (4%).

Another similarity to Richland Creek is road density. There are 912 km with a density of 1.6 km per 30.5 hec. This road density is responsible for 46% of the sedimentation occurring in the watershed. Other sources include eroding stream banks (29%), pastures (9%), farm animal access (7%), and cropland (5%).

There were two VWIN sampling sites in Jonathan Creek. The upstream site was at Moody Farm Road and was scored as 'Excellent'. The lower site, located at the confluence of the Pigeon River scored below average and has continued to score lower on consecutive efforts. TVA's sampling effort was at White Oak Road. The EPT data were in the 'Good' range;

however, the fish IBI was in the 'Poor to Fair' range with numerous omnivorous and diseased fish. NCDENR sampled at three locations in Jonathan Creek, where the creek was crossed by SR 1306, 1322, and 1349. The sites were scored as 'Excellent' in 1997.

Of the four subwatersheds, Jonathan Creek and Upper Pigeon Subwatersheds are in better shape than Richland or Lower Pigeon Subwatersheds. The VWIN research indicated that many of these issues are centralized and not identified throughout the watersheds. Lake Junaluska continues to deal with severe sedimentation problems not only in the amount of pressures, but with the cost to try and offset these issues. When one compounds the issue with the socio-economic benefits of the lake, it is easy to see just how important this struggle is between human activities and the importance of the region. Hyatt Creek, a tributary of Richland Creek, has numerous issues and has been placed on the 303(d) list by the state (NCDENR, 2010). Other areas of concern are the Fines Creek-Rush Fork Creek Watersheds because of the potential for water quality improvements. Richland Creek and Hurricane Creek in the Lower Pigeon River Watershed are 303(d) listed (NCDENR, 2010).

Current Activities in the Watershed

Efforts have been conducted to protect the riparian zone and to decrease the effects of development throughout the Pigeon River Watershed. However, the research has shown that some areas are being more positively affected than other areas and the impacts continue to impact the aquatic system. The WAP study (2002) divided human activities into 24 land use and land cover classes. The most common classes included forest, active pasture, cropland including row crops, residential, commercial, and other.

Human attitudes towards environmental impacts on river systems have changed during the last 30 years. Legislation has also been passed to help with enforcing these changes such as with the Clean Water Act (US-EPA, 1977). Before clean up and water improvements can be implemented, assessment of the river's health must be completed. In 1988, several agencies began biological monitoring of the Tennessee portion of the Pigeon River that included Tennessee Department of Environmental Control (TDEC), Tennessee Valley Authority (TVA), and Tennessee Wildlife Resources Agency (TWRA). The goal of this monitoring was to determine river condition and recovery time once improvements were begun. Assessment was based upon fish samples to determine the Index of Biotic Integrity (IBI). The river scored a 38 out of a possible 60 indicating a 'Poor' condition. Above the mill, the IBI scores were in the 'Good' to 'Excellent' range (Saylor et al., 1993). Because of the mill's outdated methods color levels exceeded those levels mandated by the Clean Water Act (US EPA, 1977), and as a result, the State of Tennessee sought legal action. The outcome was a different permit that significantly reduced mill discharge, and the river began to recover (TDEC, 2008). During this century, IBI scores and fish species richness have increased (EA Engineering, 2001).

CHAPTER IV

METHODS

The Pigeon River has undergone many changes over the past 100 years in regards to stream health in North Carolina, and in Tennessee (Bartlett, 1995). Once a pristine river, the impacts to the system have included changes in land use practices, the use of the river by the paper mill in Canton, North Carolina for the paper making process and to discharge impurities from the process away from the town, and changes in the flow regimes due to the impoundments such as Lake Junaliska and Walters Dam. Over time, the physical environment was so severely degraded that the biological community was impacted with many fish species being extirpated. Through legal actions and public pressure, government agencies intervened and mandated improvements be made to improve water quality issues. With these improvements, collection and re-introduction efforts began for fish species. Water quality has continued to improve and these efforts to return the community expanded. Natural occurrences including flooding from hurricanes in 2004 and exceptional drought conditions in 2007 have further altered the system.

Because of these changes over time, there is a need to describe the substrate conditions of the Pigeon River in Haywood County, North Carolina, and Cocke County, Tennessee. Research has focused on physical habitat descriptions in conjunction with the collection efforts and the water quality monitoring sites sampled by WVIN volunteers, state agencies, and TVA. Many of these sites are chosen based upon easy access for workers. After the hurricanes and drought conditions those sites have either physically changed such as dominant vegetation or substrate composition and/or the fish community has migrated to suitable habitat (Wilson, pers commun, 2011). Not all of these locations have been relocated nor the number and lengths of suitable habitat is unknown for those fish species. By mapping continuous stretches above and below the mill in both states and generating a georeferenced database this will allow future efforts a greater chance of success because those suitable habitats will be better defined than by previous efforts from those monitoring agencies.

The purpose of this project was to assess Pigeon River streambed habitat by video recording the current conditions in Haywood County, North Carolina, and Cocke County, Tennessee. Video was analyzed to classify habitat quality based upon substrate conditions and the quality assessment utilized a QHEI.

Field Work Survey Schedule

The field work for the study was conducted from August 1, 2007, through October 1, 2007. There was a total of eight field work days with four days spent in Tennessee, and four days spent in North Carolina. Video was recorded onto a total of 26 full length, 120-minute, Sony DVD disks. Survey dates, Pigeon River locations, float entry sites, number of disks used, put in and take out elevations and river gradients of each float were documented (Table 8). Due to technical issues, such as camera batteries dying or the DVDs not being able to finalize the formatting process to ensure the DVD could be viewed at a later time, some areas were assessed a second time, such as the September 27, 2007, effort.

The Pigeon River was divided into survey sections based upon several factors. These included weather conditions of the day, best location for put-in and take-out, accessibility to those locations such as private property or distance from public roads, and most efficient use of human resources. The float could last as long as 10 hours; therefore safety was a concern.

Table 8. Field work schedule of the study in Tennessee and North Carolina.

State	Survey Date	Location on the Pigeon River (PRM)	Disks	Put-in elevation (ft)	Take out elevation (ft)	Gradient (change elevation(ft)/float distance (ft)
Tennessee	July 26, 2007	Pool above Tannery Island (8.2-5.1)	2	1047	1038	0.0005
	August 1, 2007	I - 40 bridge to Newport (12.8-8.2)	4	1110	1047	0.0026
	August 3, 2007	Denton to I - 40 bridge, Cosby Creek (16.4-12.8)	4	1164	1110	0.0028
	October 1, 2007	Denton to I - 40 bridge (16.4-12.8)	4	1164	1110	0.0028
North Carolina	August 22, 2007	PRM 59 – 54.9, Richland Creek	3	2523	2492	0.0014
	September 13, 2007	Richland Creek to Panther Creek (54.9-47.0)	3	2492	2406	0.0021
	September 19, 2007	West and East Fork Pigeon River to Canton above mill (69.2-64.4)	4	2642	2577	0.0026
	September 27, 2007	Canton below mill to Richland Creek (63.3-54.9)	5	2566	2492	0.0017

The primary purpose of the current project was to observe the current substrate conditions of the Pigeon River by video recording the river bottom and to combine the video with differentially-corrected geographic positioning system (DGPS) information. From the video, the habitat would be classified based upon a modified Qualitative Habitat Evaluation Index (QHEI). The Pigeon River's substrate conditions were recorded in one continuous longitudinal effort from the headwaters of Pigeon River at the confluence of the East Fork and West Fork Pigeon Rivers at PRM 69.2 to the take-out point near Panther Creek at PRM 47.0 in Haywood County, North Carolina. A second continuous longitudinal effort occurred on the Pigeon River in Cocke County, Tennessee. The substrate conditions were recorded from the I-40 bridge between Brown Island and the town of Denton at PRM 16.0 to the take-out point near the Memorial Bridge in Newport at PRM 5. Along with the video, locations along the study site were geo- referenced to provide researchers the ability to visit any location for collection and reintroduction efforts.

Video Mapping System

The mapping process is divided into two parts: field collection of data, and processing the data in the laboratory. The mapping system utilized a Delta Vision Industrial grade color underwater video camera, two underwater lasers, a Sony Handycam, a Sony DVD recorder, a Trimble AgGPS 332 unit (Trimble, 2007), a Garmin 160C depth sensor (Garmin Products, 2007), and an Acumen data logger (Acumen, 2007) to create the geo-referenced video footage (Figure 10). The same method was utilized for gathering geo-referenced video mapping

Figure 10. Underwater video equipment including Trimble 332, Garmin 160C depth finder, Noland mutliplexer, Sony Handycam, Sony DVR, and underwater video camera system (beginning upper left to bottom right).

data of the Pigeon River. Video images of the river's substrate and composition, and fish community were recorded using the Ocean System Inc. Delta Vision Deep Blue camera (OSI, 2006) (Figure 10-11). On each side of the camera, a fixed laser was mounted that was used to measure substrate size.

The video was recorded onto two separate DVD recorders. The Sony Handycam utilized mini-DVDs, and the Sony DVD recorder used full-sized DVDs. Sseparate recorders were used to ensure image collection.

Data processing was the second part of the video process. Images on the mini- DVDs were transferred to regular size for easier use. After this process, all DVDs were reviewed to classify streambed substrate conditions. All DVDs were analyzed and important habitats such as those for future re-introductions and sources of sediment inputs and were identified.

The Delta Vision Deep Blue camera was manufactured by Ocean Systems Inc. (OSI, 2006). The stainless steel housing protects the 3.6-mm wide-angle lens from impacts from rocks and woody debris. The military grade umbilical cable had a nominal working load of 250 lbs (113.4 kg) and supported 4.5 kg of ballast weight. The image was NTSC composite video with a resolution of 500 TV lines. Auxiliary light was ultra-sensitive white LEDs with a light sensitivity of 0.5 lux. The camera had a fixed 2.54 cm to focal infinity focus.

The underwater video camera was deployed on its umbilical cable with a stabilizer fin and 1.0-kg ballast weight. The camera was tethered behind the canoe or hand-held while

Figure 11. Use of handheld camera for fish community observations on the Pigeon River (September 19, 2007).

transporting the canoe over shallow riffle areas of the Pigeon River. Camera depth was adjusted by the person sitting in the rear of the canoe by feeding or removing cable by hand to allow for sudden changes in water depth or objects in the water such as submerged trees or rock overhangs. Depending on water depth, ambient light conditions, and the level of suspended solids in the water column, the video camera would be suspended above the substrate to allow the lasers to strike the substrate. Distances from the substrate ranged from 2.54 cm to 1.0 m.

The two underwater lasers were used to measure the substrate particles. Each laser was fixed on an aluminum plate using O-rings. Because they were fixed on the plate, the distance between the two beams remained constant regardless of the camera's distance to the substrate. The lasers were powered by two 1.5-volt AA batteries and were waterproof to 50 m with a range of 500 – 800 m. The lasers operated at a wavelength between 600 – 650 nm with an output of 5 mW. The model used was the ACCDL70 underwater laser pointer by Marine Sports (123Scuba, 2007).

The AgGPS 332 was a differentially-corrected global positioning system (DGPS) receiver with sub-meter accuracy using a subscription from OmniSTAR. The receiver output was 0183 NEMA sentences at a rate of 4800 bps. The GPS/DGPS antenna was attached to the AgGPS 332 by a coaxial cable and which allowed for separate placement on the canoe.

Two recording devices were used to record the video footage from the Delta Vision underwater camera. They were the Sony DCR-DVD203 Handycam and the Sony VRD-VC30 recorder (Sony, 2007). Neither camera was placed in the water; instead both were housed in Pelican® waterproof cases in the canoe. For the Handycam, the video auxiliary input jack was used to record images from the underwater camera. Sony DVD-R 30-minute, 1.4-GB, mini-disks were used in the Handycam. Sony DVD-R 60-minute DVDs were used in the recorder.

A Garmin Fishfinder 160C sonar unit was used to record river depth, and depths were recorded in 0.1-foot increments in the thalweg of the mainstem. These measurements were transmitted as NMEA 0183 version 3.01 outputs to the data logger. The Garmin used a dual frequency transducer at 200 kHz and 80 kHz. In shallow areas such as riffles where there was not enough water flowing to record depth (areas that the boat was hitting the substrate), the depth sensor was lifted out of the water to protect it from damage. The sensor was attached to an aluminum swing arm that was attached to the canoe’s hull. If the canoe became stuck, the two researchers exited the canoe and walked it to deeper water and the sensor would be returned to the water for depth readings.

The outputs from the Trimble AgGPS 332 and from the Garmin were in different NMEA formats. These outputs were transmitted to a NoLand NMEA NM42 0183 Serial Multiplexer, which joined the input sentences into one output of combined 0183 NMEA strings (Noland Engineering, 2007). The output was transmitted to an Acumen Instruments Corporation DataBridge SDR-CF and stored as one file (Acumen Instruments Corporation, 2007).

The canoe used to conduct research on the Pigeon River, a Mad River Explorer 14TT, was chosen for its price, high maneuverability in riffle-run sequences, lightweight design, and ruggedness (Figure 12). It was 4.42 m (14’6”) in length, 38.1 cm wide, weighed 32.5 kg, and had two seats with a capacity of 386 kg. The Explorer had a shallow V-hull design and care-free TripleTough construction for good maneuverability in the river (Mad River Canoe Company, 2007).

Figure 12. Mad River canoe with GPS and video equipment (September 19, 2007).

Tributary Sediment Delta Mapping

As the canoe floated downstream recording video, any tributary emptying into the Pigeon River was observed to assess water conditions and sediment deposition (Figures 13 - 14). The areas adjacent to the tributary were video recorded both above and below the water's surface. The area of the sediment delta was determined by walking the GPS unit around the perimeter of the delta (Figure 14), which included one walk downstream and one walk upstream into the tributary. Depth measurements were taken using a 1.0-meter stick. The stick was pushed into the sediment as far as possible and the depth measurement was recorded. Each recorded measurement was taken approximately one meter from the previous one around the delta's perimeter as well as the center of the delta. Sediment depth measurements were taken several meters in the tributary.

Turbidity Readings at Each Tributary

Three water samples were taken to determine turbidity readings with values recorded in Nephelometric Turbidity Units (NTUs) (Figure 15 - 17). Samples were taken approximately 5 m upstream of the tributary to avoid any mixing between the mainstem and the tributary flows, and approximately 5 m below the tributary where the waters from the tributary and the river were well-mixed. The order for collecting samples was: (1) upstream of the tributary while floating in the canoe, (2) below the tributary in the mixing area, and (3) upstream in the tributary. This order was performed in order to minimize disturbing the substrate causing the sediment to

Figure 13. Tributary conditions near Clyde, North Carolina (September 27, 2007).

Figure 14. Example of low flow conditions at a tributary (September 27, 2007).

Figure 15. Measuring the area of a tributary sediment delta (September 13, 2007).

Figure 16. Collecting a water sample in the main stem of the Pigeon River (September 19, 2007).

Figure 17. Water sample collected within a tributary (September 19, 2007).

resuspend and providing an artifact. For each sample, approximately 200 ml of water was collected and stored in a Ziploc sealed container. After the water temperature equaled air temperature, the turbidity reading was taken using a LaMotte portable turbidity meter Model 2020-E (LaMotte, 2011). This model had a range of 0-1100 NTU with an accuracy rate +/- 2% for readings less than 100 NTU. The water was mixed to re-suspend the sediment and 50 ml of water was decanted into a 50-ml beaker three times. The first 100 ml was discarded and the third 50-ml was analyzed. From this water, two readings were taken and averaged. If one of the readings was greater than 50% of the other reading, the process was repeated with the remaining water.

Qualitative Habitat Evaluation Index (QHEI)

The underwater video was reviewed to assign a modified Qualitative Habitat Evaluation Index (QHEI) values in order to develop a habitat suitability index to identify microhabitat preferences. The current study used a modified QHEI that focused on the substrate parameters visible on the video when the camera was in the water above the Pigeon River's substrate. The parameters were the two dominant substrate (best type and/or other type), origin of the substrate, silt quality, level of embeddedness, maximum water depth, riffle or run depth, level of riffle or run embeddedness, and riffle or run substrate in relation to stability for a total of nine parameters used per observation. Values were assigned approximately every five seconds of the video. The nine parameters are listed in Table 9 with their assigned values; all values were combined to provide a cumulative value for each observation based on the QHEI formula. Values ranged

Table 9. Modified Qualitative Habitat Evaluation Index (QHEI) parameters and their associated values.

SUBSTRATE	POOL/RIFFLE/RUN QUALITY
BEST TYPES (VALUE)	**POOL MAXIMUM DEPTH (VALUE)**
BOULDER/SLABS (10)	> 1 M (6)
BOULDER (9)	0.7 - <1 M (4)
COBBLE (8)	0.4 - <0.7 M (2)
GRAVEL (7)	0.2 - <0.4 M (1)
SAND (5)	<0.2 M (0)
ORIGINS (VALUE)	**RIFFLE/RUN EMBEDDEDNESS (VALUE)**
LIMESTONE (1)	NONE (2)
TILLS (1)	LOW (1)
WETLANDS (0)	MODERATE (0)
HARDPAN (0)	EXTENSIVE (-1)
SANDSTONE (0)	**RIFFLE DEPTH (VALUE)**
RIP RAP (0)	BEST AREAS > 10 CM (2)
LACUSTRINE (0)	BEST AREAS 5 - 10 CM (1)
SHALE (-1)	BEST AREAS < 5 CM (0)
COAL FINES (-2)	RUN DEPTH (VALUE)
OTHER TYPES (VALUE)	MAXIMUM >50 CM (2)
HARDPAN (4)	MAXIMUM < 50 CM (1)
DETRITUS (3)	**RIFFLE/RUN SUBSTRATE (VALUE)**
MUCK (2)	STABLE I.E. COBBLE (2)
SILT (2)	MOD. STABLE I.E. GRAVEL (1)
ARTIFICAL (0)	UNSTABLE I.E. SAND (0)
SILT QUALITY (VALUE)	
HEAVY (-3)	
MODERATE (-1)	
NORMAL (0)	
FREE (1)	
EMBEDDEDNESS (VALUE)	
EXTENSIVE (-2)	
MODERATE (-1)	
NORMAL (0)	
NONE (1)	

The formula for the modified QHEI was:
Q = Σ Substrate (Best type substrate + Other type of substrate + Substrate origins + Silt Quality + Embeddedness) + Pool/Riffle/Run Quality (Maximum Depth + Riffle/Run Embeddedness + Riffle Depth + Run Depth + Riffle/Run Substrate).
(Note: Only riffle depth or run depth would be used, therefore only 9 values were recorded per observation).

from 34 (best habitat) to -6 (lowest quality habitat). Habitat quality was based upon the cumulative score from the nine parameters. Habitats scores greater than 26 were classed as 'Excellent', scores 19 to 25 were 'Good', scores 14 to 18 were 'Fair', and 13 or less were 'Poor'.

Each parameter was scored based upon Ohio EPA's (2006) definition of each classification. Substrate types were defined as bedrock, solid rock forming a continuous surface; boulder, rounded stones greater than 256 mm in diameter; cobble, stones 64-256 mm in diameter; gravel, rounded material 2.0-64 mm in diameter; sand, gritty material 0.06-2.0 mm in diameter; silt, 0.004-0.06 mm in diameter; hardpan, particles less than 0.004 mm in diameter and clay in nature; detritus, dead and unconsolidated organic material that covers the bottom; muck, black, fine, flocculent, and completely decomposed organic matter; and artificial, substrate such as rock baskets, gabions, bricks, trash, and concrete placed in the stream for reasons other than habitat mitigation. Substrate origin classes were defined as limestone, can contain fossils and is usually bedrock, flat boulders and cobble; tills, sediment deposited by glaciers; wetlands, organic muck and detritus; hardpan, clay that is smooth and can be slippery; sandstone, rounded fragments of sand cemented together; rip/rap, artificial boulders; lacusturine, old lake bed sediments, shale, sedimentary rock made of silt/clay and is soft and cleaves easily; and coal fines, black fragments of coal. Silt quality, also known as silt cover, is the extent that a silt layer covered the stream bed. Silt composition is based upon fine silt size particles. Silt heavy means that nearly the entire stream bottom is layered with silt. Silt moderate means extensive cover of silt but there are areas of cleaner substrate such as riffle areas. Silt normal is areas with small amounts of silt that has minimal functional significance. Embeddedness is the degree that cobble, gravel, and boulder is surrounded and covered by fine materials such as sand and silt. Those substrates that are greater than 50% covered in fine material are classified as embedded.

Ohio EPA (2006) definitions of the pool, riffle, and run characters were utilized for classification purposes in the modified QHEI in the study. Pool maximum depth was recorded and those pools with a depth of less than 20 cm were considered to have lost their function, and thus scored a 0. Riffle and run embeddedness was the degree that the cobble, gravel, and boulder substrates were surrounded by fine material, sand and silt, in riffle and run habitat only. Those areas that the fine material cannot be easily dislodged are classified as greater than 50%. The area was classified based upon the pervasiveness of the embedded substrate: extensive, greater than 75% of the stream area; moderate, 50-75%; sparse, 25-50%; and low, less than 25%. Riffle depth was based upon the depth characteristics of the best riffle area observed. If the riffle depth was less than 5 cm, the riffle was considered to have lost function and the value was 0. Run depth was based upon the depth characteristic of the area that was clearly a run and not a transitional zone between a pool and run or a riffle and a run. Riffle and run substrate was based upon the dominant substrates present in each of the habitats.

After the video was reviewed to classify river bed substrate conditions based upon the modified QHEI, float maps were generated using ArcMap 10 software (ESRI, 2012). The maps were generated based upon river segments of continuous habitats and from the parameters listed in Table 10. Float distance traveled (RM) and float time (min) were used to determine the float rate (m/min) of the canoe. Put-in and take-out GPS coordinates were also recorded. At each five-minute interval of the video, GPS coordinates were determined and recorded based upon the video segments and points of interest along the Pigeon River, such as landmarks or roads.

Table 10. GPS coordinates for map generation in Haywood County, North Carolina, and Cocke County, Tennessee (August-October, 2007).

State	Date	Location (PRM)	Float time (min)	Float Distance (RM)	Float Rate (m/min)	Put-in Latitude	Put-in Longitude	Take-out Latitude	Take-out Longitude
North Carolina									
	Sep 13	54.9-47.0	167	7.9	76.1	35 32 38.42	-82 55 50.11	35 37 19.39	-82 58 36.47
	Sep 19	69.2-64.4	329	4.8	23.5	35 28 46.65	-82 52 55.20	35 31 42.50	-82 50 26.86
	Sep 27	63.3-54.9	241	8.4	56.1	35 32 26.83	-82 50 45.11	35 32 38.42	-82 55 50.11
Tennessee									
	Jul 26	8.2-5.1	102	3.1	48.9	35 57 07.89	-83 10 43.20	35 58 03.64	-83 10 47.88
	Aug 1	12.8-8.2	210	4.6	33.6	35 53 29.64	-83 11 23.37	35 57 07.89	-83 10 43.20
	Oct 1	16.4-12.8	222	3.6	26.1	35 50 29.18	-83 10 50.90	35 53 29.64	-83 11 23.37

Each of the GPS coordinates were plotted and applied to the center of the stream line to generate the float maps.

CHAPTER V

RESULTS AND DISCUSSION

Underwater Video Mapping of Riverbed Substrate

Current substrate conditions were video recorded in August-October 2007 and geo-referenced in sections of the Pigeon River in Haywood County, North Carolina, and Cocke County, Tennessee. A total of 22 river miles was videoed in North Carolina and a total of 11 river miles were videoed in Tennessee. In Haywood County, a total of 17 flowing tributaries were located and sediment delta areas and depths were recorded at each. Turbidity readings were recorded at these and six locations in the mainstem of the Pigeon River. Fish collection sites were identified in Haywood County based upon the fish community being observed as well as other important factors necessary in collection efforts. The substrate was qualified based upon a QHEI. A supplemental file to this dissertation (File 1, QHEINCTN.xls) displays the scores.

The first objective was to record current streambed conditions of the Pigeon River using underwater video and to determine habitat quality present in Haywood County, North Carolina, and in Cocke County, Tennessee. The put-in location of the first North Carolina float was at the confluence of the East Fork and West Fork rivers (PRM 69.2) that merge to form the Pigeon River. The float continued into Canton, North Carolina, and the take-out location (PRM 64.4) was downstream of the armory. The float continued downstream of the mill and the next put-in was immediately below the mill in Canton and continued to Richland Creek (PRM 54.0). The last float began at PRM 54.0 and continued to the final take-out location downstream at Panther Creek (PRM 47.0). This end point was chosen for safety concerns and accessibility in and out of the Pigeon River. The length of the float was approximately 22 river miles in Haywood County, North Carolina, and took four days to complete. In Tennessee the float began at the put-in location (PRM 16.4) near Brown Island at the I-40 bridge and the take-out location was at the I-40 bridge near Vinson Island at PRM 12.8. The float continued from Vinson Island to the pool above Tannery Island at PRM 8.2. The final float section was from the pool above Tannery Island to upstream of the Memorial Bridge in Newport at PRM 5.1. The float was approximately 11 river miles in Cocke County, Tennessee.

The elevation changed from the first put-in location to the last takeout location in both states (Table 9, p. 75). In North Carolina, at the confluence of the East Fork and West Fork rivers, the elevation was 2642 feet and decreased to the take-out location in Canton above the mill at 2577 feet (Table 9). This was a change of 75 feet with a gradient of 0.0026 feet/river feet. The elevation continued to decrease from below the mill to Richland Creek. The elevation changed from 2566 feet to 2492 feet with a gradient of 0.0017 feet/river feet. The third sampling reach in North Carolina changed from 2492 feet at Richland Creek to 2406 feet at Panther Creek at PRM 47.0 with a gradient of 0.0021 feet/river feet. In Tennessee, the first float's put in location was at Brown Island near the I-40 bridge in Denton (elevation 1164 feet) to Vinson Island near Newport (elevation 1110 feet) with a gradient of 0.0028 feet/river feet. The second float, Vinson Island (elevation 1110 feet) to Tannery Island (elevation 1047 feet) had a gradient of 0.0026 feet /river feet. The third float, Tannery Island (elevation 1047 feet) to the Memorial Bridge (1038 feet) had a gradient 0.0005 feet/river feet.

The three float distances of the Pigeon River in Haywood County, North Carolina, (Table 8) were based upon elevations which corresponded with float efforts. The substrate conditions of the river in the first section were characterized by a mix of substrate with some levels of embeddedness. Overall, much of the area showed clean substrate and, on numerous occasions the fish community was observed. The second section was different than the first with high levels of embeddedness with a homogenous substrate composition. Many areas were covered in moderate to extensive levels of embeddedness. Fines covered the bedrock in the deeper pools. Runs were also characterized as being heavily embedded with fines and the cobble and gravel mix in these areas were covered with fines as well. The riffle areas exhibited moderate levels of embeddedness, and the attached macrophytes were often dusted in fines. The last section in Haywood County, North Carolina, also had sections of severe embeddedness; however, the dominant substrate changed to larger substrate such as small to large boulders and vertically exposed bedrock. The faces of the bedrock were clean but most of the fines were deposited between sections of bedrock. These conditions persisted until the end of the float.

The three float distances in Cocke County, Tennessee, were based upon accessibility, distances of the floats and elevations (Table 8). Substrate conditions in Cocke County did not change from the first put-in location near Brown Island to the final take-out location in Newport. In slow flowing and deeper pool habitat the stream bed was embedded with fines in each of the sections. Shallow and faster flowing areas were cleaner than the pools but still had high areas of embeddedness. Of the dominant river habitats, riffles had the least amount of embeddedness observed.

Sediment Loading and Turbidity

The second objective was to identify the tributaries that were impacting the Pigeon River by transporting sediment loads. Because the flows in the area were at record lows, these conditions provided the opportunity to record the sediment deltas both underwater as well as above the water. A total of 17 tributary junctions were located and current conditions were video recorded (Table 11). Of these, 11 of them were named tributaries and six were un-named ones. At each tributary the turbidity levels (NTUs) were recorded upstream in the mainstem of the Pigeon River, upstream in the tributary to determine the levels from the entering stream, and finally downstream from each tributary below the mixing area of the tributary and the Pigeon River (Table 11). Of the first five locations where turbidity readings were recorded in the Pigeon River; four of these values ranged 0.2 to 1.1 NTUs (Figure 18). The first flowing tributary, Garden Creek (location #4), was above the mill and had a NTU reading of 9.4. Garden Creek flowed through Canton, North Carolina before entering the mainstem of the Pigeon River. At location #6, NTUs were also measured in the Pigeon River, and the first one taken below the mill had a reading of 9.6 NTU. As the distance from the mill increased the NTU readings decreased from 9.5 to 5.0 NTUs at the take-out location near Panther Creek (Figures 18). Figure 19 compared the mainstem NTU readings above each flowing tributary to the readings below each flowing tributary. The data indicated relatively little impact on turbidity levels from the flowing tributaries (Figure 20). This maybe attributed to the extreme drought conditions prior to and during the study. Correlation analysis of the NTU readings in the flowing tributaries and the NTU readings below the flowing tributaries showed no significant impacts attributed to the flowing tributaries. Again, due to the flow conditions of the these tributaries, the amount of water flowing into the mainstem of the Pigeon River contained lower amounts of sediment and did not affect turbidity levels. below the flowing tributaries.

The readings in the tributaries changed regardless of location on the Pigeon River and readings ranged from 0.1-3.0 NTUs. Five of the smaller un-named tributaries had NTU values

Table 11. Sample sites located on mainstem and flowing tributaries on the Pigeon River including turbidity levels (NTUs), sediment depths, sediment delta areas, and sediment delta volumes (August 22-September 27, 2007).

Location #	Tributary	Latitude	Longitude	Mean Reading Upstream Tributary (NTU)	Mean Reading in Tributary (NTU)	Mean Reading Downstream Tributary (NTU)	Mean Sediment Depth Readings	Estimated Delta Area (m^2)	Estimated Delta Volume (m^3)
1	West Fk	35 28.806	-82 52.946			0.2			
2	East Fk	35 28.710	-82 52.875			0.2			
3	Mainstem	35 28.712	-82 52.934			0.3			
4	Garden Cr*	35 31.056	-82 50.748	9.5	1.3	9.4	8.54	39.02	3.3
5	Mainstem (Above mill)	35 31.672	-82 50.416			1.1			
6	Mainstem (Below mill)	35 32.466	-82 50.763			9.6			
7	Unnamed*	35 32.736	-82 50.702	9.5	1.6	9.5	5.61	13.00	0.7
8	Thickety Cr*	35 32.780	-82 52.043	9.5	2.1	9.4	9.49	47.66	4.5
9	Bowen Br*	35 32.759	-82 52.213	9.1	0.7	9.1	16.67	49.05	8.2
10	Patton Br*	35 32.554	-82 52.707	9.0	1.3	9.0	15.49	68.56	10.6
11	Hayes Br*	35 32.535	-82 52.890	8.6	2.1	8.7	14.45	52.02	7.5
12	Unnamed*	35 32.332	-82 53.619	8.6	0.2	8.6	10.84	5.57	0.6
13	Conner Mill Br*	35 32.107	-82 54.463	8.6	0.8	8.6	11.60	8.36	1.0
14	Unnamed*	35 32.952	-82 56.387	8.4	1.0	8.4	32.21	43.48	14.0
15	Unnamed*	35 32.952	-82 56.387	8.4	1.1	8.4	13.68	7.43	1.0
16	Richland Cr*	35 32.996	-82 56.801	8.1	1.4	7.9	14.68	20.44	3.0
17	Unnamed*	35 37.060	-82 58.153	7.7	3.0	7.8	20.32	14.96	3.0
18	Crabtree Cr*	35 36.031	-82 57.069	5.7	2.3	5.8	46.84	62.43	29.2
19	Unnamed*	35 36.035	-82 57.062	5.5	0.1	5.4	42.94	61.87	26.6
20	Mainstem	35 37.335	-82 58.941			5.0			
21	Jonathan Cr*	35 37.619	-82 59.984	7.3	2.6	7.1	45.43	187.20	85.0

Note: * = flowing tributary of the Pigeon River

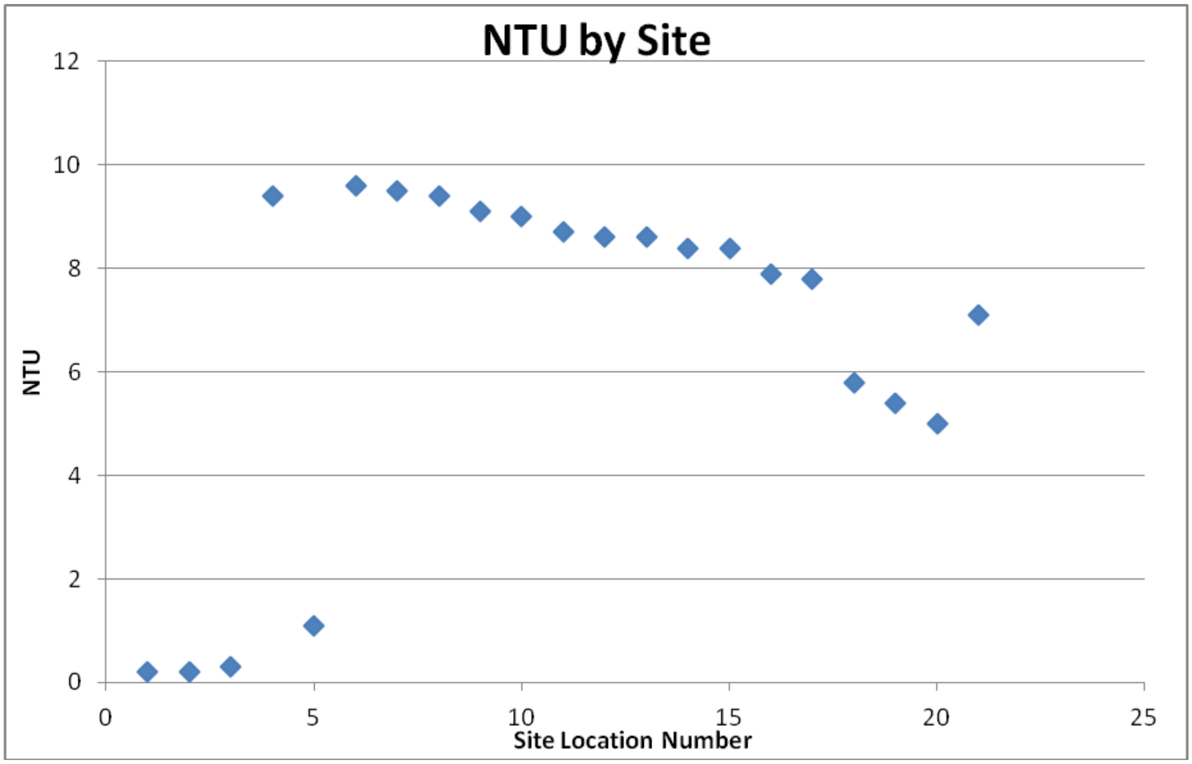


Figure 18. Turbidity readings (NTU) at each flowing tributary.

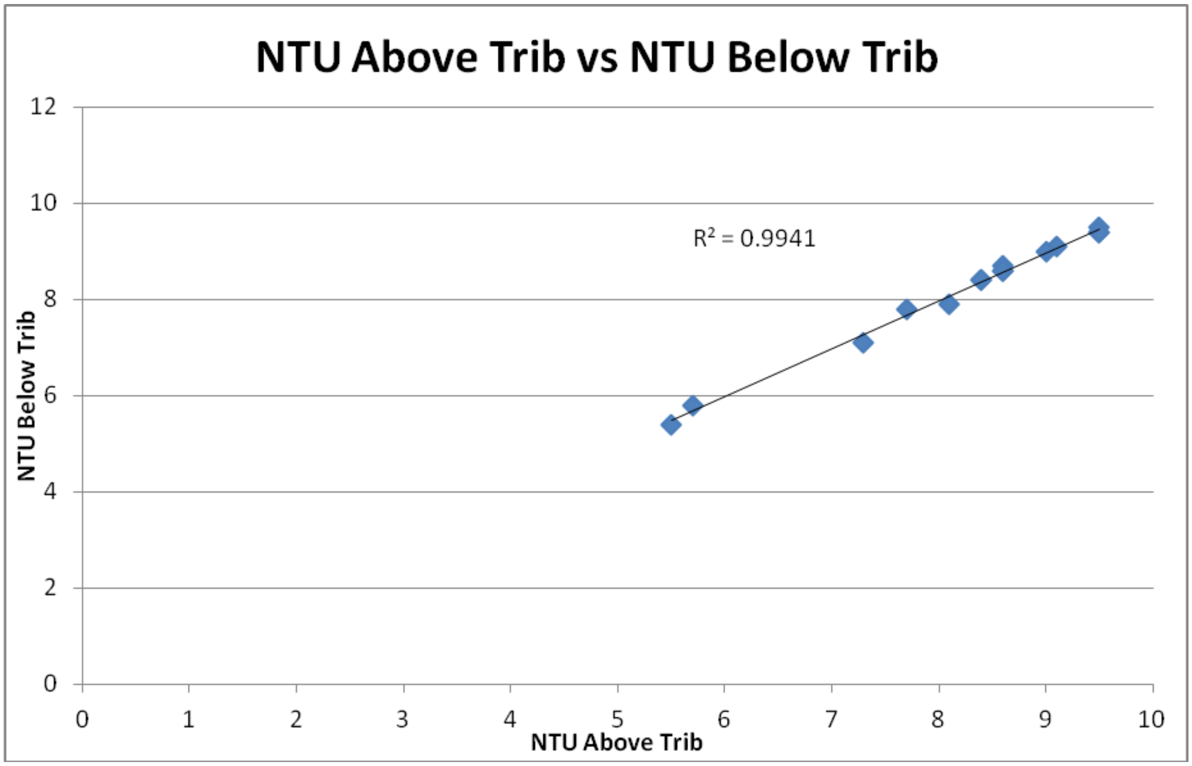


Figure 19. NTU readings above the flowing tributaries compared to NTU readings below the flowing tributaries.

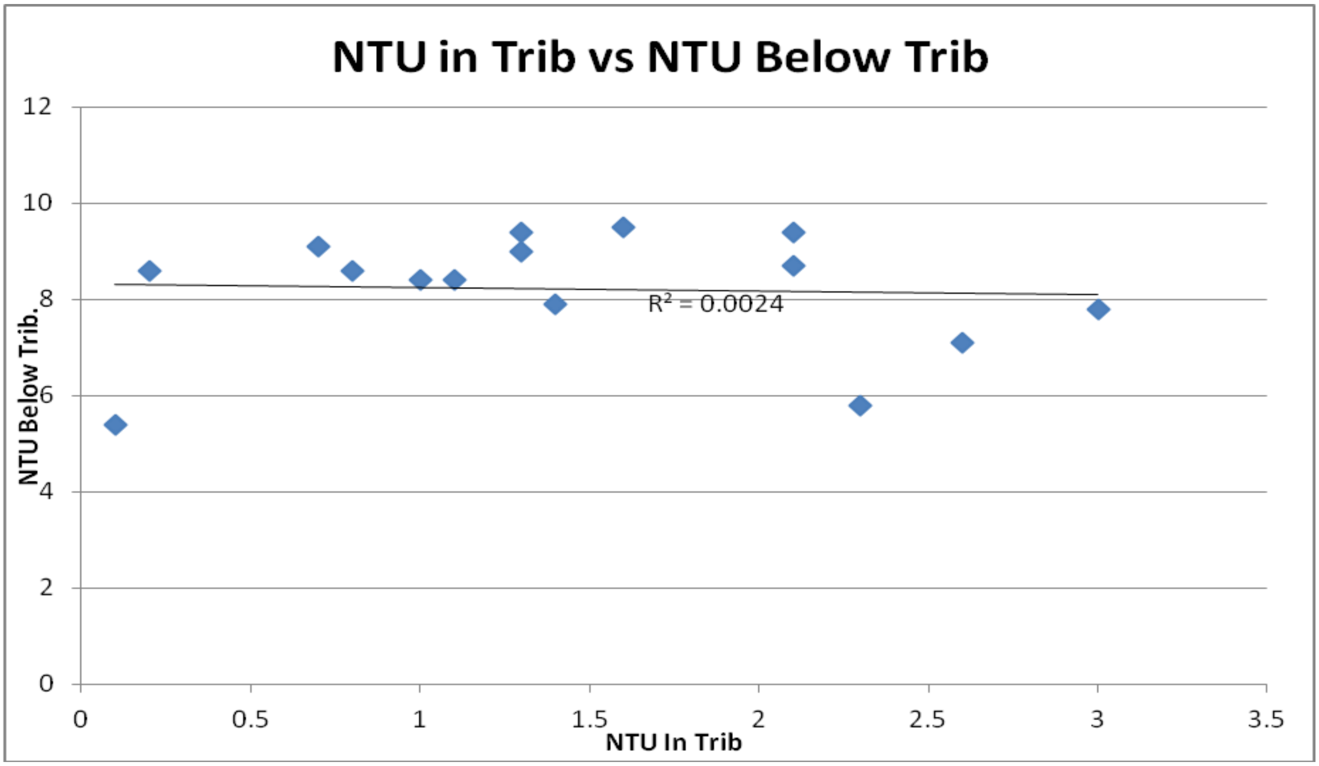


Figure 20. In-tributary NTU readings compared to NTU readings below the flowing tributaries.

less than or equal to 1.0. Two named tributaries, Bowen Branch and Conner Mill Branch, had similar readings. Of the major tributaries flowing into the Pigeon River (Richland Creek, Jonathan Creek, and Crabtree Creek), Jonathan Creek had the highest in tributary reading of 2.6 NTUs. However, this section of the Pigeon River had a lower turbidity reading than Richland Creek (7.3 compared to 8.1 NTUs). Though the low-flow conditions were beneficial to observation of these deltas, there were several occasions that the research team was unable to locate both named and un-named tributaries, even after an extensive visual search of their known locations on the maps. Data from these tributaries were not collected and their impacts to the system remain undocumented. NTU readings in each of the tributaries changed regardless of location along the Pigeon River or size of the tributary.

It is believed that these differences in NTUs were caused by several factors. First, any flowing tributary would have the ability to transport sediment to the Pigeon River, therefore the elevation gradients would have an impact to the Pigeon River. Second, in relation to these gradient differences, current land use practices would have an impact to the level of input to the system. In those areas with higher levels of residential land use much of that development is adjacent to these tributaries such as the areas in Clyde. The land has been altered, the riparian zones have been reduced or eliminated, and impervious surfaces such as paved and unpaved roads have increased. Agriculture is still an important land use practice though in recent years that amount has been decreased. However, during the study there were new active fields being used adjacent to the Pigeon River and to these tributaries; they were observed during driving from input to take-out locations for the day's float. In other areas, fields had been abandoned therefore they were not being maintained to prevent additional sediment from entering the system.   Third, conditions prior to the study would impact sediment impacts. For example, according to WAP (2002) one of the major sources of sediment was eroding stream banks. Prior to and during the study, Haywood County was under exceptional drought conditions (NCDMAC, 2007). According to NCDMAC (2007), the possible impacts to the county included exceptional and widespread crop and pasture loses and water shortages in reservoirs streams and wells. During an exceptional drought condition, USGS weekly stream flows are reduced to 0-2% of normal flow conditions. Because of these conditions, those wetted areas had become dry and the stream banks became weakened. Over time, these banks could become further weakened, and the bank faces could shear and sediment enter the system. This would lead to additional issues, such as widening of the streams, or banks that could become undercut. Once drought conditions were reduced or eliminated such as during an episoditic rain event, these newly exposed stream banks could weaken further, erode into the tributary, and eventually sediment from the tributary be transported to the Pigeon River. Another example caused by weakened and eroding stream banks was the number of cattle access points observed on the Pigeon River and the number of points recorded during the WAP (2002) study. Fourth, because there have been historic sediment impacts to the system as long as the area has been settled (e.g., silverculture practices on steep mountain slopes). Some of the sediment impacts could be attributed to these past conditions, and they will remain until the current levels of sedimentation decrease below the threshold to allow the Pigeon River to begin to scour these areas.

According to the water quality trends data (WAP, 2002), the sites that were sampled in that study and those sampled in the current study followed similar trends in turbidity values. Turbidity values at both the West Fork and the East Fork sites were rated as ‘A’, which was the highest visibility category for the IPSI (2002) report, and NTU values were 0.2 for each branch. The site (location #6) below the mill in Canton was rated as ‘C’ and was 9.6 NTU for this study. Turbidity values were recorded throughout the Pigeon River down to Maggie Valley and values near Fines Creek, Jonathan Creek, and Cove Creek were rated at ‘C’. However, turbidity values increased downstream at Ratcliff Cove Branch ('B'), Crabtree Creek ('B'), and Jonathan Creek with values of ‘A’ in Maggie Valley and 'C' at the Jonathan Creek downstream site. The NTU mean values for the current study followed similar trends. Below the mill at Garden Creek and Thickety Creek, the NTU mean value was 9.5. Once the study team reached Richland Creek and Jonathan Creek, the mean NTU values decreased to 8.1 and 7.3, respectively. Finally, one of the last tributary surveyed, an unnamed one above Panther Creek, had the lowest mean NTU value at 5.5.

Sediment Delta Area

Sediment depth readings were recorded in cm at the delta area deposited at each of the tributary mouths (Table 11). The number of readings at each tributary corresponded to the size of the sediment delta, as well as accessibility to the delta such as water depth less than chest deep due to safety concerns. As the survey team traveled downstream, the mean sediment depth of the delta areas increased and continued to increase until the last sampling effort at the unnamed tributary below Crabtree Creek, but above the final take-out location near Panther Creek (Table 11).

Recorded depth values at the unnamed tributaries followed similar trends compared to the named ones. Mean sediment depth readings ranged from a low value of 5.61 cm at location #7 at the beginning of the survey to a high value at Crabtree Creek with a value of 46.84 cm. Again, these values were recorded during the lowest known flows of the area; it is believed that the deposition would be scoured after flows returned to normal levels.

Two creeks with large sediment deltas were Jonathan Creek and Crabtree Creek. Observations of the current land use practices within the subwatersheds indicated the dominant use was 'forest' at 74 and 84%, respectively. Based upon this value, it would seem that the amount of sediment deposition from these creeks should be lower. However, the other land use practices, such as 'residential' at 10% at Jonathan Creek and 'pasture' at 11%, with 9% in only 'fair' condition at Crabtree Creek, raise concerns over land use changes over time. It is believed that the land use activities will continue to change over time and the level of 'forest' will decrease while 'residential' will increase. One personal observation from the current study was the additional removal of the riparian zones along many of these areas would impact the system in the future. Often roadways adjacent to the river could be viewed for long distances from the canoe. Also, agricultural practices, such as tomato farms, as well as new development, impacted these zones.

Suitable Sites

The third objective was to observe and identify locations on the Pigeon River thatwere suitable for additional sites for the Pigeon River Recovery Project that may otherwise be missed. Sites that were selected were based upon presence of existing fish species, suitable habitat, and ease of relocation efforts. Examples of such sites were at the confluence of the East Fork and West Fork Pigeon Rivers at PRM 69.2. The second site was at PRM 68.8. The third location was at PRM 66.7 adjacent to the Haywood Memorial Church at the confluence of Stamey Cove. Each of these locations was chosen because the fish community was observed during the float and the QHEI values were recorded. The substrate had a mixture of boulders, cobble, and gravel with a low to normal level of embeddedness. Though the float occurred during extreme drought conditions, there were sufficient flows to provide continuous habitat to those targeted fish species. In normal flow conditions, it is believed that the substrate would be scoured and the habitat area would increase. IBI scores (WAP, 2002) further support the presence of the fish community at each of these sites. The value of knowing the locations of the targeted fish species and their associated QHEI composite values is two-fold. First, a QHEI study can be conducted at the targeted fish species home location to determine the values here. This would allow the researchers to document the current conditions at this location and determine where similar conditions were present at the Pigeon River. By determining the QHEIs, there is a greater success rate of future re-location efforts by the Pigeon River Recovery Project and other interested parties. The second value to knowing the current QHEI values is to determine how the Pigeon River has changed over time due to an increase in flow conditions from the time of this study and any future one. One observation that could be made would be to see if the targeted fish species still preferred those habitats of the current study or if the fish were simply using the habitats that were available at that time.

Float Maps

Float maps were generated based upon the modified QHEI composite scores. In Haywood County, North Carolina, there were 115 habitat segments and there were 86 habitat segments in Cocke County, Tennessee. Within each habitat segment, the GPS coordinates, individual QHEI scores and the composite QHEI were available. Figure 21 represents the QHEI composite ratings of the Pigeon River in Haywood County, North Carolina. The composite

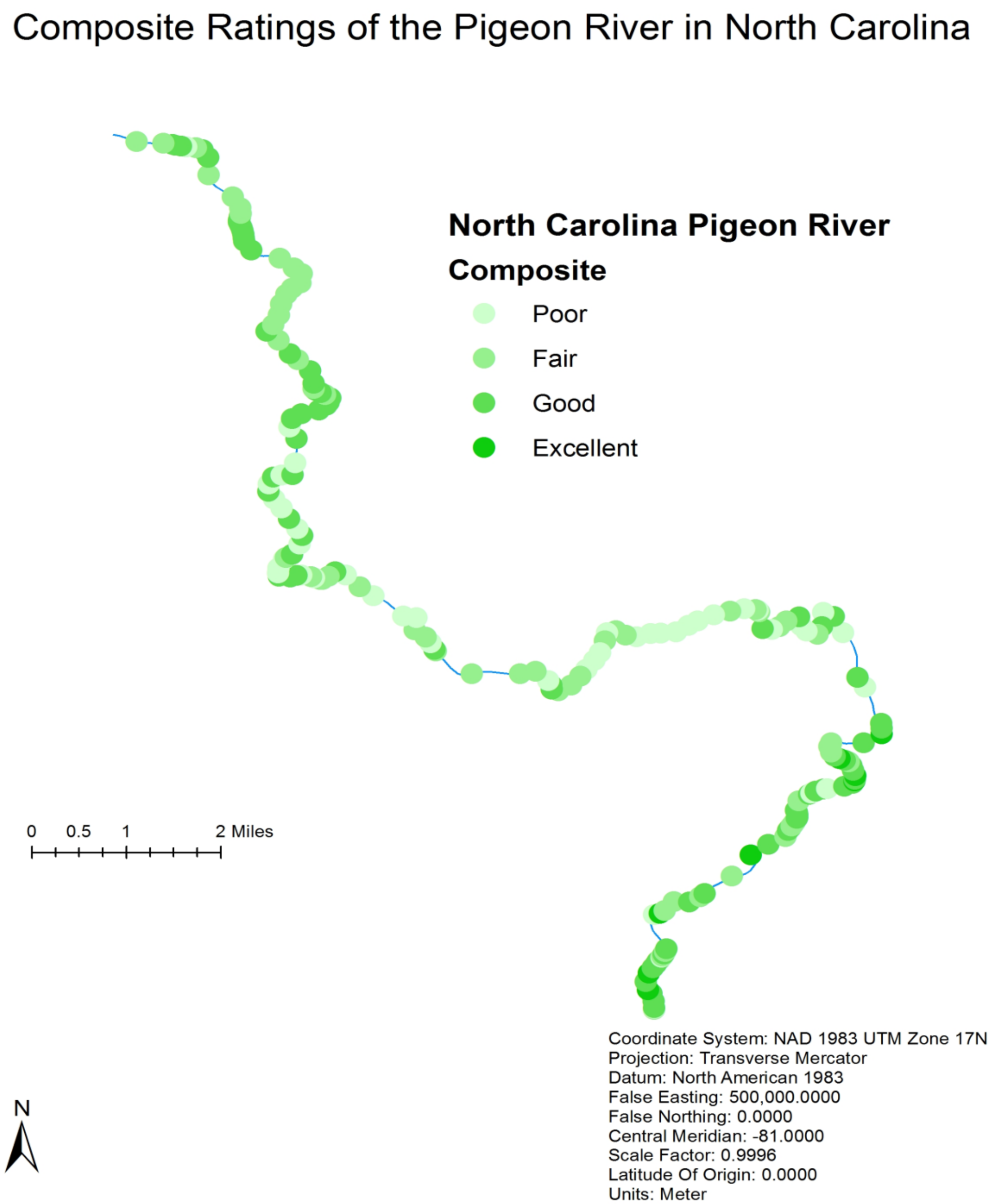


Figure 21. Composite ratings of the Pigeon River in North Carolina.

score was separated into four classifications ranging from ‘excellent’ to ‘poor’. There were 87 habitat segments that were classified as ‘excellent’ to ‘good’. These habitats had a composite score greater than 19 and were represented by the darker segments. Some of these segments are being utilized (Table 6, p. 54). Of these habitat segments, there were eight reaches of the Pigeon River that should be further investigated for recovery efforts based upon QHEI composite scores and review of the video. Many of the 87 segments were accessible by canoe only, but these can be used for future re-introduction efforts. From the confluence of the East Fork and West Fork Pigeon Rivers to PRM 65.5 was a continuous segment that the fish community was observed. One area of interest was adjacent to the Haywood Memorial Church. Another segment above the mill was in Canton, North Carolina, at PRM 65.0 near the football stadium. This segment would allow for easy access. Below the mill, the reach at Thickety Creek, PRM 61.0, and within the town of Clyde, North Carolina, contained segments of good habitat and fish were observed at each of these locations. Further downstream at Richland Creek, PRM 54.9, ratings returned to the ‘good’ classification. The next segment was at PRM 50.0 that had ‘excellent’ habitat scores. At the final take out point at Panther Creek, PRM 47.0, there were sections in the ‘good’ category.

Figure 22 illustrates the depth of the Pigeon River in Haywood County, North Carolina. There were four depth categories ranging from 8" to greater than 39". The lighter bands represent shallow areas such as riffles and the darker bands represent pools. The pool segments indicated lower gradients with slower flowing water such as the section near Clyde, North Carolina, and the segments that were riffles and runs had higher gradients with faster flowing

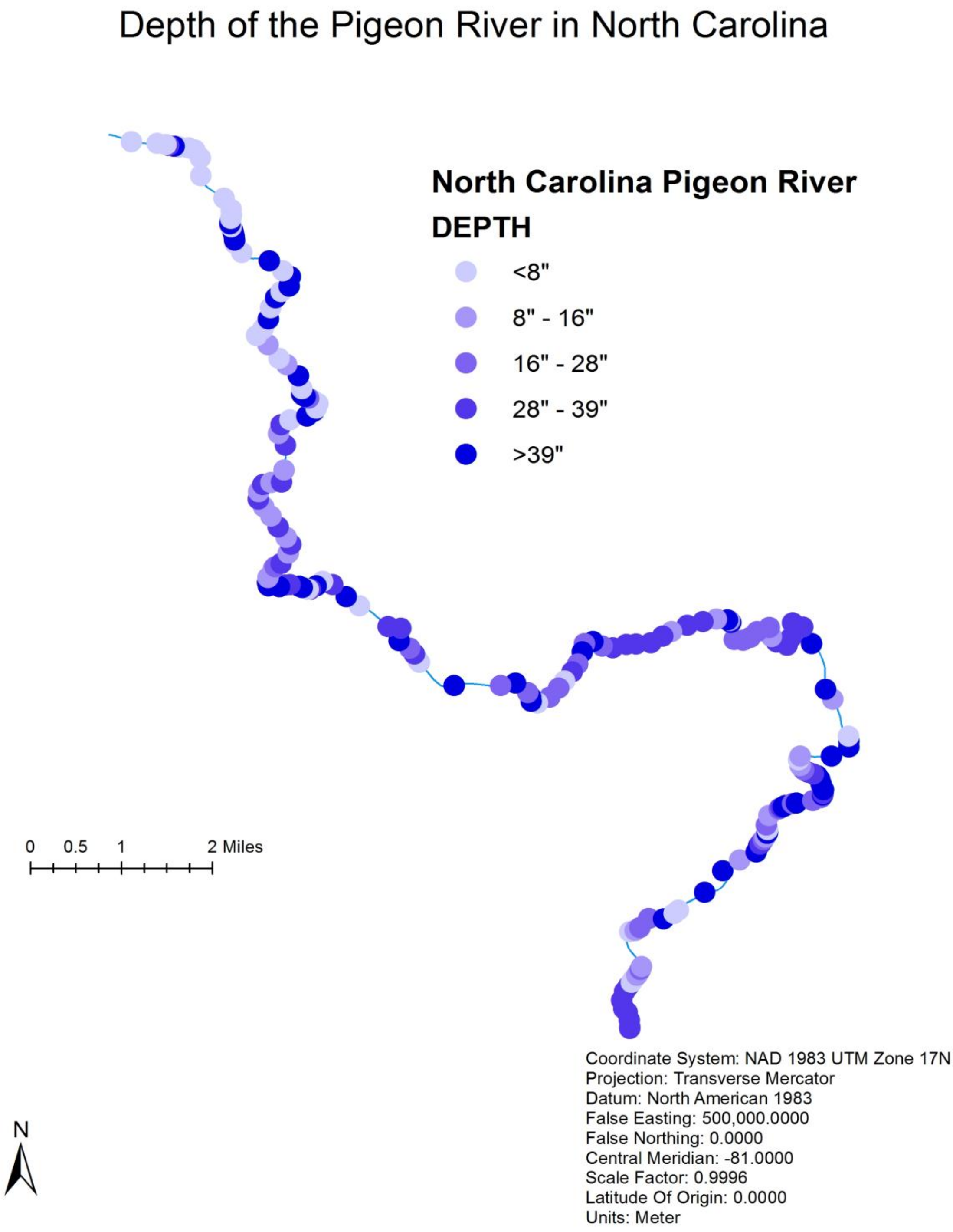


Figure 22. Depth of the Pigeon River in North Carolina.

water such as the section above the take-out location above Canton, North Carolina. The section from the confluence of the East Fork and West Fork Pigeon Rivers to above the mill was primarily run sequences and some pool habitats. As the float continued downstream to Canton, North Carolina, several deep pools were observed that were greater than 1 m deep. Immediately below the mill and through Clyde, North Carolina, the segments were primarily slow moving pools with that were difficult to video record due to water color and water depth. The section of the Pigeon River below Richland Creek, PRM 54.9, continued to have pool sequences but there were riffle and run habitats observed in a repeated sequence. From Richland Creek to the final take out point at Panther Creek, PRM 47.0, there were 19 habitat segments that had little to no flow. In many of these segments, the field team had to exit the canoe and drag it across the river bed until suitable water was found. This section of the Pigeon River was characterized by vertical bedrock faces with pockets of deeper water between the shallow areas.

The embeddedness level of the Pigeon River in Haywood County, North Carolina, was determined (Figure 23). The embeddedness levels ranged from 'extensive' to 'none'. The lighter bands resent higher embeddedness levels and the darker bands represent cleaner substrate conditions. From the confluence of the East Fork Pigeon and West Fork Pigeon Rivers to PRM 67.0, the river had little to no embeddedness observed. In the section and below land use activities included a gravel quarry and agriculture that could be depositing sediment into the Pigeon River. Downstream of this section but above the mill in Canton the embeddedness level decreased on the mainstem of the Pigeon River. The segment from the mill to the final take out at Panther Creek, PRM 47.0, had higher levels of embeddedness than above the mill and, with

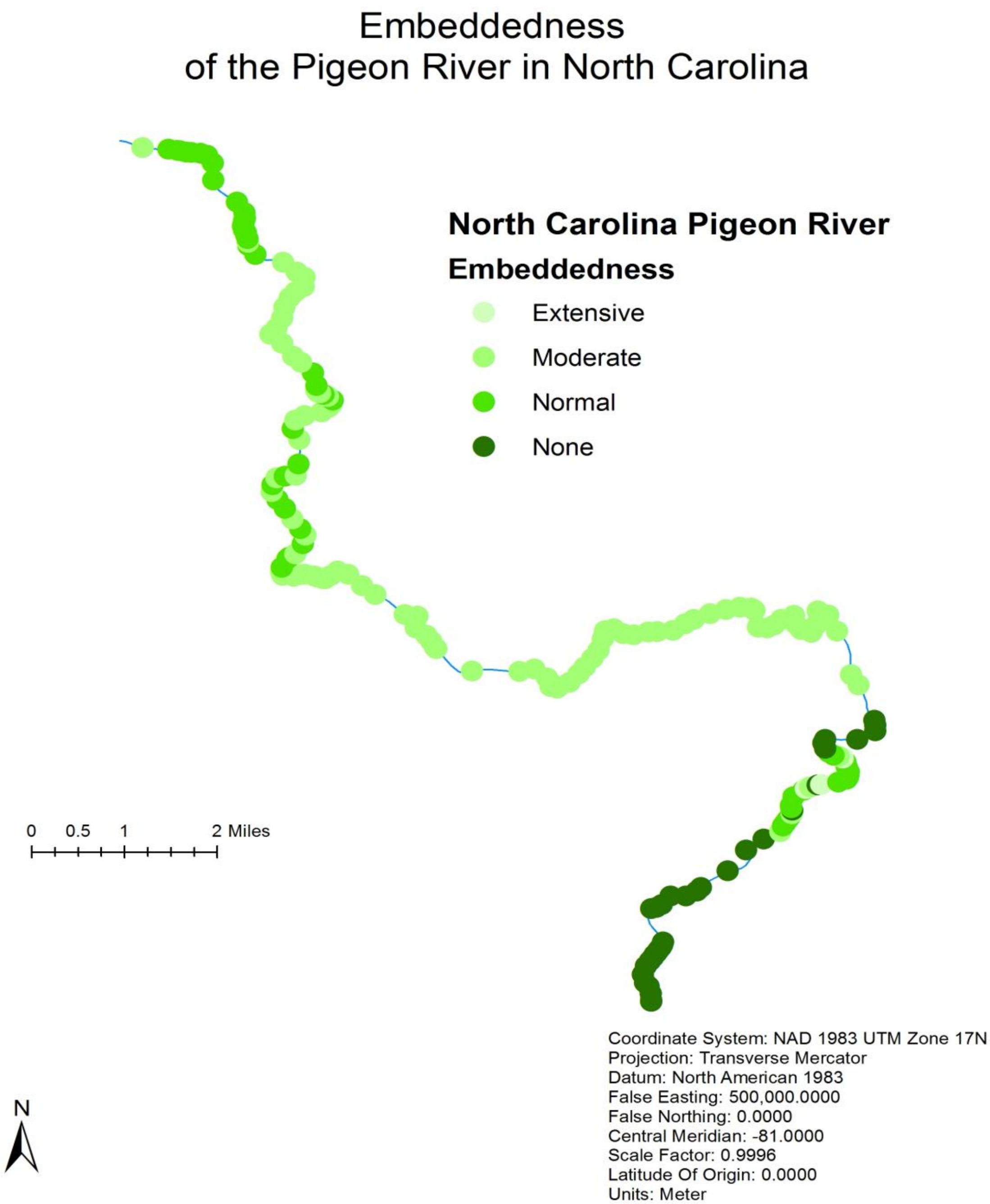


Figure 23. Embeddedness of the Pigeon River in North Carolina.

With this lower visibility there were lengths of the Pigeon River that were difficult to video conditions and classify the habitat segments. This segment was characterized by slow, deep pools where deposition was observed in the video analysis, such both above and below Clyde, North Carolina. This section was characterized by a low gradient. Traveling downstream, embeddedness levels were rated as 'moderate' to 'extensive' but habitat segments were classified as 'normal' upstream of the final North Carolina take-out location at Panther Creek (PRM 47.0)

. The QHEI composite score of the Pigeon River in Cocke County, Tennessee were calculated (Figure 24). There were three ratings in Cocke County, Tennessee: ‘good’, ‘fair’,habitat and the darker bands were classified as 'good' habitat. The section from Brown Island (PRM 16.4) to Vinson Island (PRM 12.8) was rated overall as ‘fair’ to ‘poor’. Downstream of Vinson Island to the pool above Tannery Island (PRM 8.2) the riffle/run sequences increased and the QHEI composite scores increased. Fish were observed in the riffle/run sequences in this section and substrate was cobble and gravel mix in these areas. The section from above Tannery Island to the final take out at PRM 5.1 had ‘good’ composite scores as the float floated into Newport. Fish were observed in this section of the river. The section above Tannery Island was pool sequences with larger substrate such as boulders and bedrock.

The depth measurements of the Pigeon River in Cocke County, Tennessee are presented in Figure 25. The light bands represent shallow depths such as in riffle and run sequences and the darker bands represent deeper runs and pool habitats. Much of the habitat was shallow run habitats throughout this reach of the river. Pools were observed above the islands along the river including Vinson and Tannery Islands. Unlike the North Carolina section, flowing water was

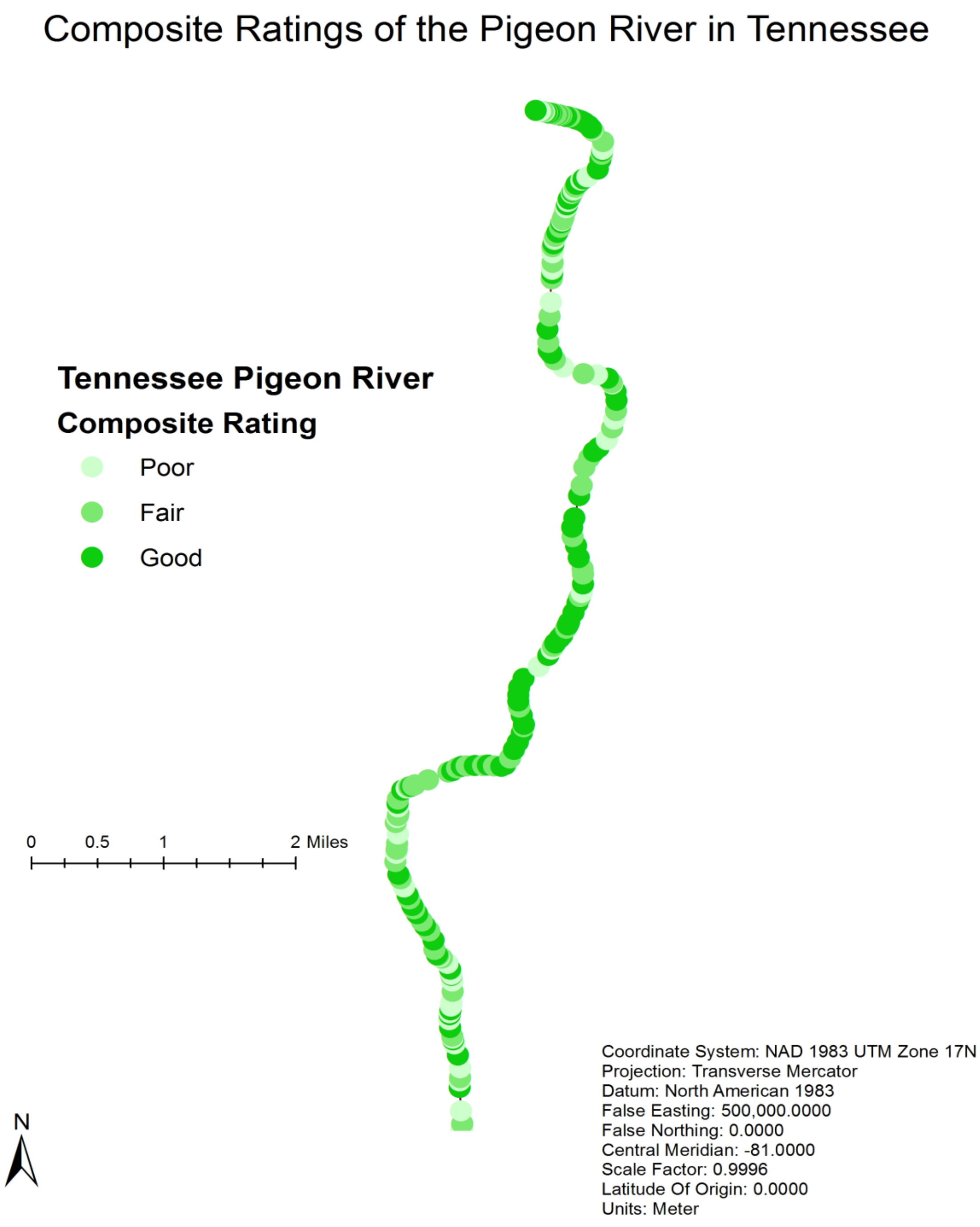


Figure 24. Composite ratings of the Pigeon River in Tennessee.

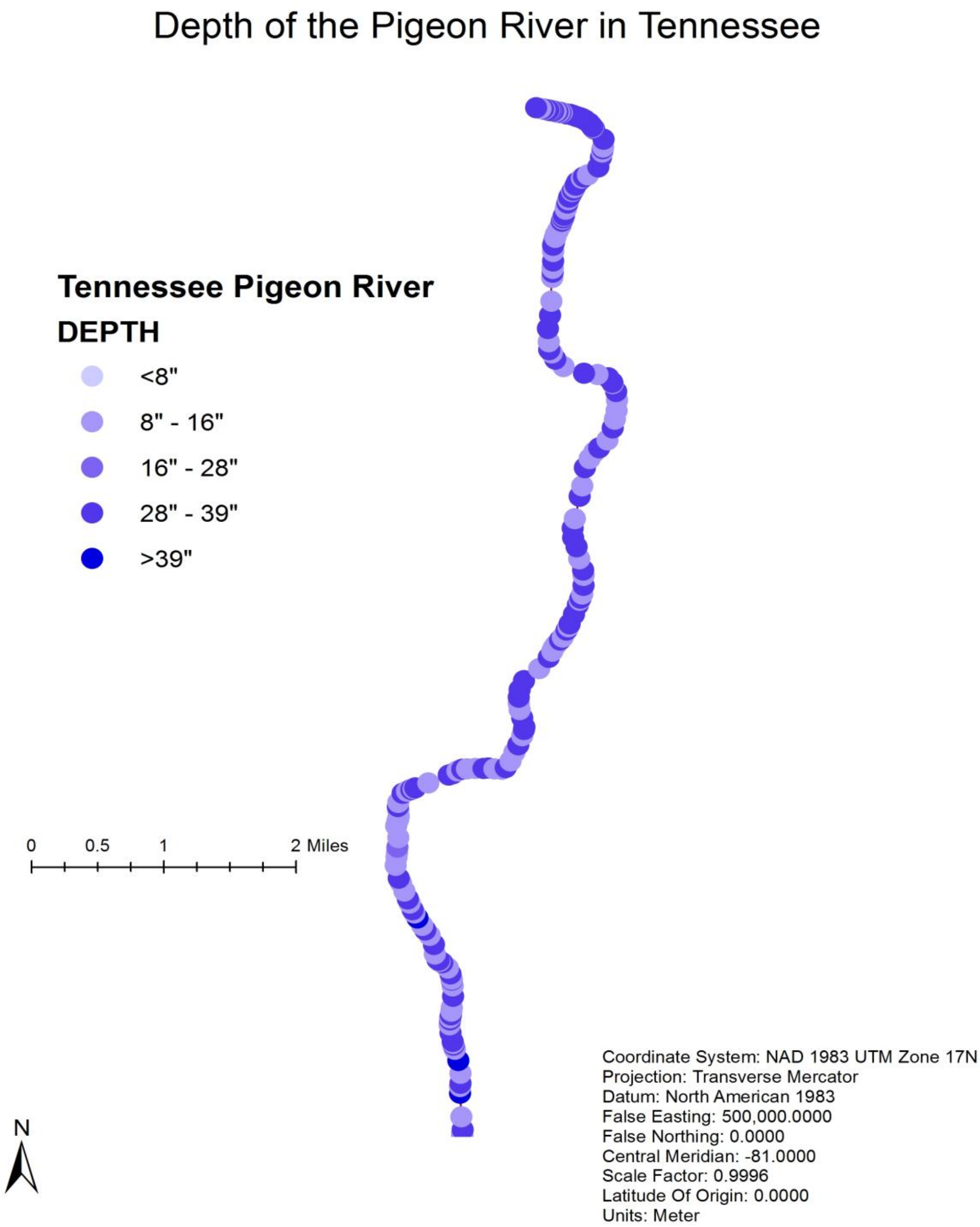


Figure 25. Depth of the Pigeon River in Tennessee.

present throughout the floats and the survey crew did not have to leave the canoe to carry it to deeper water.

Figure 26 represents the level of embeddedness of the Pigeon River in Cocke County, Tennessee. The darker bands were 'normal' embeddedness levels and the lighter bands were 'moderate' levels of embeddedness. The level was homogenous throughout the entire Tennessee section of the Pigeon River and all habitat segments were rated as ‘normal’ except segment #85. This habitat was rated as ‘moderate’ and was adjacent to Cosby Creek. Agriculture practices were observed upstream of this habitat segment and it is believed that the land use practices were impacting sediment levels of the system.

Land Use Practices

The Pigeon River Watershed has been going through a process of change in regards to land use practices. As these practices change,such as forest to developed areas, there have been impacts to the system. As a result, the level of sedimentation has continued, or increased, in the subwatersheds. The two major sources for sedimentation for the entire Pigeon River Watershed in Haywood County are eroding stream banks and roads (both private and state) at 73%. According to IPSI (2002) data, the majority of input is the result of high stormwater runoff during episodic rain events due to the alteration of the land through the subwatersheds. Other notable sources are pastureland at 11%, and eroding stream banks that constitute 6% of the sediment sources, especially in the larger perennial streams. Currently, there are an estimated 1,932 road km within Haywood County and that number will probably increase in the future.

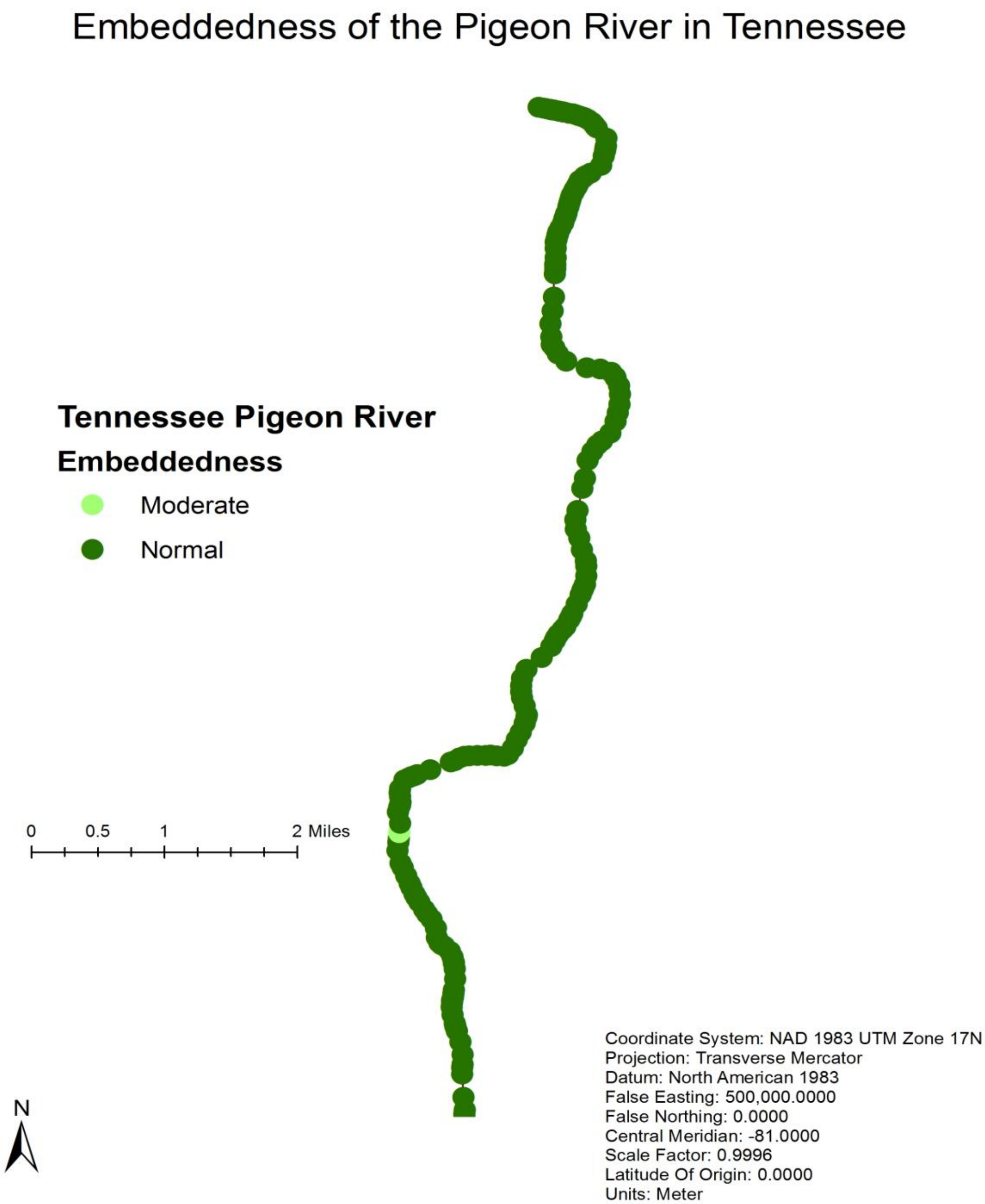


Figure 26. Embeddedness of the Pigeon River in Tennessee.

The video footage revealed several important and useful pieces of information. First, it provided the current substrate conditions both above and below the mill in a continuous longitudinal dimension. Areas of sediment input, including eroding stream banks, and the tributaries were identified. Because of the severe drought conditions during the survey, low flow conditions were observed along the entire survey. Areas of sediment deposition were located, and the severity of the deposition were observed that otherwise would have been missed. Once deposition occurred at the tributary mouths, the sediment deltas were stationary but could be altered when flow conditions increased such as from the next storm event. Visual observations at some of the tributaries showed that little to no flows over these deltas were occurring therefore no water was scouring the area. The kinetic energy of the flowing water was too low to disturb the delta sediment and re-suspend it. It is believed that once flows returned to normal or flood conditions, enough energy would be available to transport the sediment downstream once again. Scores ranged from a maximum of 36 points which would describe a well-mixed river bed with little to no embeddedness, to a minimum of -4 which would describe a river bed with muck and silt substrate and a severe level of embeddedness.

The Upper Pigeon River Subwatershed follows these trends. Sources include eroding stream banks (45%), eroding roads at 30%, pastureland at 12%, new construction (12%), and farm animal access at 13%. Many of the eroding stream banks are located in the northern section of the subwatershed. Though these trends are of concern, three of the four WVIN sites rated in the “Excellent” range and are considered to have higher water quality than the other subwatersheds.

The Lower Pigeon Subwatershed, which is located below the mill in Canton, North Carolina, to the North Carolina-Tennessee state line, follows these trends as well. Sediment loads resulted from eroding roads at 35%, eroding stream banks at 32%, pastureland at 20%, and farm animal access points, cropland, and construction at 13%. The increase in pastureland is the result in the increase in the land use of that category specific to the areas. Each of the six WVIN sites at Fines Creek and Rush Fork Creek demonstrated significant sediment and nutrient problems. These elevated levels are the result of the creeks' origins from the western slopes of the Newfound Mountains which were deforested and used for agricultural practices.

The greatest source of sedimentation to Richland Creek Subwatershed was eroding stream banks at 47%. Roads, ditches and eroding road banks accounted for 32% while pasture was at 9%, other at 6%, farm animal access at 5%, and cropland was at 1% (WAP, 2002).

Within each of the Pigeon River's subwatersheds, land use practices follow similar trends. The percentage of forest land use has decreased and the percentage of development has increased over time. The sediment sources are the direct result of these changes such as eroding roads. Development and agricultural practices within the riparian zones along the Pigeon River and its tributaries have impacted the eroding stream banks because of the exposed soils as well as an increased rate of stormwater run off into the system. Because of this shift, it is important to note the level of sediment deposition within the Pigeon River could remain constant but more likely it will continue to increase and have a negative impact to the physical environment that will in turn affect the biological communities. If the predicted population and development increases are observed over the next 15 years without an implemented plan by local government agencies conditions will degrade.

CHAPTER VI

SUMMARY AND RECOMENDATIONS

The current study yielded the following results:

1. A continuous geo-referenced video of the substrate conditions in Haywood County, North Carolina, and Cocke County, Tennessee, in August-October, 2007.
2. Identification of 17 flowing tributaries along the mainstem of the Pigeon River in Haywood County, North Carolina.
3. NTU readings from 21 locations in Haywood County, North Carolina.
4. Sediment readings from 15 flowing tributaries in Haywood County, North Carolina.
5. Identification of possible fish reintroduction sites for targeted species in Haywood County, North Carolina.
6. Creation of QHEI of substrate conditions for the geo-referenced video in Haywood County, North Carolina, and Cocke County, Tennessee, and the potential to utilize QHEIs to select 'Excellent' to 'Poor' habitat sites for future re-introduction efforts.

There are several recommendations for future efforts in Haywood County, North Carolina, in regards to additional underwater video recording. Reasons include that the Pigeon River has undergone episodic events including the hurricanes in 2004 and the severe drought conditions in 2007, and it would be important to determine how the river has recovered from these events during the past several years. Another reason would be that the Pigeon River should be experiencing normal flow conditions, and it would be important to determine if the same conditions are present in the future as they were present in 2007. Finally, an additional effort would be able to better describe the effects of land use change in the area. If the predicted trends became a reality, then the conditions of the Pigeon River Watershed , in regards to sedimentation, could be worse than previously suggested.

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APPENDICES

APPENDIX A: SEDIMENT DEPTH READINGS AT TRIBUTARY CONFLUENCES

Mainstem locations of the Pigeon River were not measured for sediment depths therefore they were omitted from Appendix A. The first column corresponds with the location number from Table 11. The second column corresponds to the name of the tributary or if the tributary was unnamed. The depth readings were recorded in cm and were taken at the mouth of each flowing tributary to determine sediment depths and mean depth. Each measurement was taken approximately 1 m from the previous one.

Depth readings (cm)

Location #	Name	Depth (cm)	Location #	Name	Depth (cm)	Location #	Name	Depth (cm)
4	Garden	0			12.7			7.62
	Creek	2.54			19.05			2.54
		2.54			17.78	10	Patton	0
		7.62			20.32		Branch	3.81
		13.97			15.24			2.54
		11.43			8.89			7.62
		8.89			15.24			16.51
		8.89			5.08			12.7
		8.89			6.35			10.16
		6.35			2.54			20.32
		12.7			13.97			15.24
		11.43			12.7			11.43
		19.05			11.43			26.67
		15.24			6.35			21.59
		7.62			5.08			19.05
		6.35	9	Bowen	5.08			15.24
		6.35		Branch	3.81			13.97
		5.08			2.54			12.7
		24.13			2.54			10.16
		5.08			2.54			12.7
		3.81			7.62			16.51
		0			8.89			29.21
7	Unnamed	2.54			8.89			26.67
		6.35			19.05			24.13
		6.35			38.1			38.1
		8.89			34.29			41.91
		12.7			38.1			34.29
		8.89			31.75			21.59
		6.35			27.94			17.78
		2.54			27.94			12.7
		5.08			25.4			10.16
		2.54			27.94			7.62
		2.54			22.86			7.62
		2.54			17.78			6.35
8	Thickety	3.81			13.97			11.43
	Creek	5.08			8.89			3.81
		10.16			11.43			0
		7.62			6.35			
		11.43			5.08			

Location #	Name	Depth (cm)	Location #	Name	Depth (cm)	Location #	Name	Depth (cm)
11	Hayes	2.54		Mill	7.62			29.21
	Branch	2.54		Branch	5.08			21.59
		2.54			11.43			12.7
		7.62			19.05			3.81
		15.24			24.13	15	Unnamed	5.08
		11.43			25.4			7.62
		8.89			20.32			27.94
		11.43			16.51			30.48
		16.51			11.43			20.32
		19.05			8.89			12.7
		20.32			6.35			11.43
		21.59			3.81			5.05
		22.86			3.81			2.54
		25.4			3.81	16	Richland	6.35
		25.4	14	Unnamed	0		Creek	11.43
		20.32			8.89			15.24
		22.86			10.16			17.78
		33.02			13.97			16.51
		20.32			10.16			11.43
		13.97			17.78			7.62
		12.7			21.59			22.86
		6.35			20.32			33.02
		3.81			22.86			25.4
		0			25.4			22.86
12	Unnamed	5.08			26.67			15.24
		7.62			27.94			10.16
		8.89			24.13			6.35
		7.62			35.56			6.35
		11.43			39.37			6.35
		16.51			44.18	17	Unnamed	6.35
		13.97			64.77			11.43
		16.51			55.88			25.4
		11.43			59.69			38.1
		20.32			53.34			29.21
		17.78			49.53			41.91
		10.16			86.36			49.53
		7.62			63.5			24.13
		5.08			52.07			22.86
		2.54			35.56			16.51
13	Conner	6.35			29.21			11.43

Location #	Name	Depth (cm)	Location #	Name	Depth (cm)	Location #	Name	Depth (cm)
		8.89			13.97			31.75
		10.16			29.21			55.88
		5.08			41.91			63.5
		3.81			49.53			78.74
18	Crabtree	5.08			27.94			91.44
	Creek	10.16			66.96			87.63
		12.7			62.23			96.52
		19.05			38.1			99.06
		11.43			12.7			99.06
		10.16			13.97			97.79
		17.78			41.91			88.9
		27.94			57.15			85.09
		33.02			66.04			91.44
		40.64			80.01			74.93
		41.91			87.63			83.82
		43.18			96.52			85.09
		58.42			97.79			68.58
		73.66			86.36			63.5
		83.82			71.12			54.61
		88.9			63.5			63.5
		76.2			55.88			39.37
		99.06			52.07			62.23
		96.52			50.8			34.29
		99.06			41.91			20.32
		86.36			20.32			12.7
		80.01			16.51			3.81
		72.39			24.13			15.24
		69.85			11.43			12.7
		85.09			11.43			12.7
		55.88			7.62			8.89
		50.8			2.54			3.81
		38.1	21	Jonathan	10.16			3.81
		19.05		Creek	12.7			3.81
		12.7			13.97			2.54
		12.7			19.05			0
		8.89			22.86			
		5.08			25.4			
19	Unnamed	5.08			24.13			
		12.7			27.94			

VITA

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He is married to his wife, Misty, and has three children, Madison, Grayson, and Brayden.