To the Graduate Council:

I am submitting herewith a thesis written by Joseph Michael Parker entitled "The Influence of Hydrological Patterns on Brook Trout (*Salvelinus fontinalis*) and Rainbow Trout (*Oncorhynchus mykiss*) Population Dynamics in the Great Smoky Mountains National Park." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Civil Engineering.

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The Influence of Hydrological Patterns on Brook Trout (*Salvelinus fontinalis*) and Rainbow Trout (*Oncorhynchus mykiss*) Population Dynamics in the Great Smoky Mountains National Park

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

Joseph Michael Parker
December 2008

Acknowledgments

Foremost I would like to thank Dr. John Schwartz for serving as my major professor. He has helped me since I first arrived at the University of Tennessee and has made this study possible. I would also like to express my gratitude to Dr. Glen Tootle and Dr. Ray Albright for sitting on my committee and their encouragement and professional guidance throughout this study and my graduate career.

Steve Moore and Matt Kulp are duly owed a great amount of appreciation for providing the large amount of trout survey data used in this study. Their hard work and attention to detail made this study possible. I would also like to thank Matt Kulp for giving me insight into the life histories of brook and rainbow trout.

This study would not have been possible without the help of many others. I would like to thank Keil Neff and Mei Cai in helping me solve some of the many obstacles faced in this study. I would also like to thank Patrick and Samantha Massey, my two West Tennessee buddies, for their friendship, support, and advice. I would also like to thank Daniel Johnson, Lee Mauney, and Tom Zimmerman for helping me to stay positive and have fun during this long journey. Finally, I would like to thank my family for their love and support.

This study would not have been possible without the data collected by: the U.S. Geological Survey (USGS), the National Park Service (NPS), National Oceanic and Atmospheric Administration (NOAA), and Tennessee Valley Authority (TVA).

Research for this project was funded by U.S. Department of Interior, National Park Service Cooperative Agreement Grant No. 1443-CA-5460-98-006 (Amendment

10); in addition the U.S. Environmental Protection Agency through the Tennessee Natural Resource Policy Center, USEPA Grant No. EM-83298901-1.

Abstract

Hydrologic processes impact the functioning of aquatic ecosystems and influence fish population dynamics. The flow regime of a stream affects the structure, composition, and productivity of fish communities by regulating abiotic habitat conditions and biotic community processes. In the Great Smoky Mountains National Park (GRSM), native brook trout (*Salvelinus fontinalis*) populations have declined in some watersheds over the past decade, believed to be primarily due to episodic acidification. The potential affects long-term hydrologic patterns, temporal hydrologic trends, and hydrologic extremes have on brook and rainbow trout (*Oncorhynchus mykiss*) populations were explored in this study. The current GRSM fish sampling program began nearly two decades ago; a total of 69 streams, including 369 sites, are routinely sampled by GRSM fisheries biologists with standard methods. Detailed data is collected on the trout populations. The Nature Conservancy's Indicators of Hydrologic Alteration (IHA) was used to quantify the flow regime of each stream into 67 ecological relevant parameters. Because the trout sites were located in remote ungaged streams, the Hydrologic Simulation Program FORTRAN (HSPF) was used to simulate flows at each trout site for a study period lasting 18 years (1990-2007). Using local climate data the model was calibrated by adjusting parameters including storage, infiltration, runoff, and ground water for three elevation classes (low $<$ 800 m $\leq$ middle $\leq$ 1,200 m $<$ high) to observed stream flows from two USGS gaging stations and one NPS gaging station. The parameters defined by IHA included the a) magnitude, b) frequency, c) duration, d) time, and e) rate of change of hydrological events. IHAs were statistically compared to the surveyed trout populations. Results

indicated the abundance of young-of-the-year (YOY) brook and rainbow trout significantly declined after extreme floods and droughts. In particular, low-flows during droughts significantly reduced recruitment for both brook and rainbow trout, which is likely due to decreased spawning habitat. Brook trout populations in larger low-elevation streams showed more stability compared to smaller headwater streams. The study provided GRSM resource managers a calibrated hydrology model with unique flow parameters characterizing GRSM watersheds, and possible influences hydrologic conditions may have on trout populations.

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Chapter 1: Introduction

Biota in riverine ecosystems are strongly dependent on the river's natural flow regime (Poff et al., 1997). The hydrologic characteristics of streamflow play a central role in determining the structure and integrity of the aquatic community (Richter et al., 1996). Floods and droughts are the major forms of natural hydrologic extremes that impact riverine biological communities. Pickett and White (1985) define a disturbance as: a distinct event in time that disrupts an ecosystem, community, or population structure and that changes resources, availability of substratum, or the physical environment. Resh et al. (1988) modified this definition of disturbance by adding that the event must fall outside a predictable range because organisms are adapted to predictable seasonal fluctuations in their habitat.

A natural disturbance's predictability, timing, frequency, duration, and magnitude may decide whether the habitat conditions favor the success or failure of certain species populations in the stream's ecosystem (Poff et al., 1997; Lake, 2000). Dolloff (1994) for instance, found that Hurricane Hugo, although a large disturbance, did not have a significant effect on the biota inhabiting an Appalachian stream because the hurricane occurred in early fall, a time when most fish assemblages were able to find refugia. Moderate disturbances, such as increases in discharge frequencies and magnitudes, may actually be important in supplying gravel, bedload which is of considerable benefit to salmonid spawning and egg incubation (Reice et al., 1990). When the disturbances are severe and unpredictable, however, there may be a negative feedback in the ecosystem. In the Cascade Mountains of Oregon, the population of cutthroat trout (*Oncorhychus clarki*), for example, was locally decimated by a severe debris flow associated with heavy rainfall and flooding in the headwaters of the McKenzie River (Lamberti et al., 1991). The impact of a disturbance may also be dependent on the region in which it occurred; for instance, a large flood in a mountain stream may be devastating, causing extensive loss of habitat, but flooding in lowland rivers that have extensive floodplains may be beneficial to the ecosystem allowing the aquatic organisms access to more food and habitat (Resh et al., 1998).

A river's hydrologic regime may be assessed using a method proposed by Richter et al. (1996) referred to as Indicators of Hydrologic Alteration (IHA). The IHA method uses 32 parameters organized into five hydrological groups to statistically characterize hydrologic variation in the flow regime. The 32 parameters provide information on ecologically-significant features such as the magnitude, timing, frequency, duration, and rate of change of the hydrologic variation. In 2005, 34 new parameters called environmental flow components (EFCs) were added to complement the original parameters. The EFCs draw on five components important to river ecosystem health; they include extreme low flows, low flows, high-flow pulses, small floods, and large floods. The IHA proves useful in helping water resource mangers and fisheries biologists characterize unaltered flow regimes and human-induced changes to river flows thus enabling them to make sound environmental flow recommendations and lead monitoring and research programs, flow restoration, and protection activities (Mathews & Richter, 2007).

The Hydrologic Simulation Program FORTRAN (HSPF) model, a U.S. Environmental Protection Agency, (USEPA) sponsored hydrologic and water quality model, is an invaluable tool for water resource mangers in modeling watershed hydrology (Skahill, 2004). Numerous scholarly studies have been successful in using HSPF to predict and simulate watershed runoff, water quality, and sediment transport over a wide range of watersheds around the globe (Jacomino & Fields, 1997; Al-Abed & Whiteley, 2002; Bergman et al., 2002; Albek et al., 2004; Ackerman et al., 2005; Singh et al., 2005; Lian et al., 2007; Mohamoud, 2007; Said et al., 2007). Although there have been many studies using HSPF as a tool involving the development of best management practices, such as total maximum daily loads (TMDLs), for watershed management, few studies have used the model as basis for understanding how aquatic ecosystems are connected to stream hydrology.

The aim of the current study was to evaluate how watershed hydrology simulated by HSPF and characterized by IHA flow metrics, relate to trout populations in the Great Smoky Mountain National Park (GRSM). The first step of the study included calibrating the hydrology model HSPF using U.S. Geological Survey (USGS) gaging stations in two watersheds in GRSM. Once calibrated the model was used to simulate the hydrology in selected ungaged watersheds with years of surveyed trout population data, collected by the GRSM fisheries biologists. The simulated hydrology of the watersheds with trout sites was then characterized using IHA software quantifying 67 unique hydrologic parameters. These parameters were then statistically correlated with trout population data to evaluate which parameters influence trout populations in GRSM.

Overall the study assists watershed managers and fishery biologists of mountainous watersheds containing trout fisheries, giving them insight on how particular hydrologic trends or disturbances affect the trout community. The current study, will also contribute a working and useful calibrated hydrology model with local, unique parameters that characterize the park's watersheds, which then could be used for further water resource research in the park.

Chapter 2: Literature Review

2.1 Flow Regime and Aquatic Ecology

2.1.1 Importance of a River's Flow Regime

A river's flow regime significantly influences the daily lives of organisms in a lotic community. The natural flow regime of a river plays a critical role in determining the distribution, diversity, and abundance of riverine species. The river's flow regime over time provides the unique habitat for many riverine organisms to complete their life cycles. For many riverine species the stream flow's quantity and timing are critical components of the ecological integrity of the community (Poff & Ward, 1997). Natural intra-annual and inter-annual variations in a river's flow regime are necessary in order to sustain the native riverine community's biodiversity and its ability to adapt and flourish in its surroundings (Richter et al., 1996). Hydrologic processes such as the timing, frequency, or duration of a flood can provide natural biological cues to fish for spawning and migrations. Native riverine species have evolved over time to possess historical life traits that give them the ability to survive and reproduce within their constantly varying surroundings.

Many natural processes within the riparian community are dependent on the hydrology of the watershed. For instance a river's flow regime can affect abiotic characteristics such as flow depth and velocity, temperature, oxygen content, turbidity, streambed substrate, and morphology among other physical and chemical conditions in the aquatic community (Richter et al., 1997). The biotic processes in the riverine community may also be influenced by the flow regime (Poff & Ward, 1997). For instance scarcity of food and degree of competition in a riverine community may be affected by the abundance of water flowing through the community. Chapman (1966) observed that stream fish particularly salmonids would reduce their aggression and their population would increase in number along with their biomass if the food supply was relatively abundant. The amount of drifting invertebrates, a large food source for many riverine species, was found to typically increase with a corresponding increase in the river's flow (Sweka & Harman, 2001). Although larger floods may reduce food abundance as observed by Elwood and Waters (1969) and Angradi (1997), during two large floods in an Appalachian headwater stream, and four large floods in east-central Minnesota, mean macroinvertebrate density decreased significantly shortly after each flood.

The biotic organization of a riverine community, to an extent may be controlled by the combination of a river's range and dependability of normal flows, floods, and low flows (Poff & Ward, 1989). In the study by Poff and Allan (1995), stream fish assemblages in 34 Midwestern stream sites were not only observed to be constrained by the local biotic interactions, but also by larger-scale environmental factors such as the watershed's hydrologic processes. The authors were able to classify the sites as either hydrological stable or variable. A stable hydrologic regime would have a high predictability of daily flows and a stable baseflow, and a variable site would have higher variation in daily flows and an increase in floods. Poff and Ward found the functional organization of stream fish assemblages in terms of the presence and absence of certain species was explained by hydrological variation. For instance they found fish assemblages with generalized feeding strategies were associated with hydrological variable streams and more specialists feeding strategies were associated with hydrological stable streams.

Extreme hydrologic events such as floods and droughts are often considered to be major regulators of aquatic communities (Cattaneo, 2002). Floods may cause rapid noticeable effects on the community mostly from their high water velocities and debris movement downstream, which may cause death or displacement of riverine species. Floods may also cause long-term effects on the community by moving, creating, or destroying the habitat used by the riverine species. Droughts may reduce abundance in the community by reducing the amount of water, lowering water velocity and amount of oxygen, and increasing the water temperature (Jowett, 2005). The severity of the hydrologic event is not always dependent on the magnitude but also on the timing of the event relative to the fish developmental stage. For instance, young-of-the-year (YOY) fish may be particularly sensitive to droughts or floods mainly because they cannot deal with a large range of variability in their surroundings.

2.1.2 Floods

Water discharge in a river varies widely from season to season and day to day. A flood occurs when the flow reaches channel capacity and flows over the river's banks, becoming overbank flow. The bankfull stage of a river may be expected to happen, on the average, once a year to once every two years (Leopold, 1962). Due to the frequency and intensity of floods, the communities of aquatic organisms are most affected by floods (Swanson et al., 1998). In a study by Harvey (1987) the drift of larval and juvenile fish in

Brier Creek, Oklahoma was observed during two floods in June and July 1985. During the June storm the author observed a complete loss of fish larvae 5-10 mm in total length after the first few hours of the flood, yet fish 10-25 mm were able survive. Harvey (1987) concluded the ability of fish to maintain their position in stream under high flow increased rapidly with size, with larger fish being stronger and having better swimming ability to deal with swift currents. After studying the effects of high spring floods on the survival and growth of both the Atlantic salmon (*Salmo salar*) and brown trout (*Salmo Trutta*) in Norway, Jensen and Johnsen (1999) were able to conclude that high flows may affect fish populations in several ways: 1) sediment transport increases leading to sedimentation of fine material on spawning gravel causing decreased oxygen availability to developing embryos and physically trapping emerging alevins; 2) fish eggs and larvae may also be damaged by substrate put into motion during strong flows; 3) and both fish and invertebrates populations may be harmed from displacement caused by swift flow and also by damage to their habitat. Ortlepp and Murle (2003) observed that in experimental floods caused by dam release in the River Spol, Swiss National Park, the main threat to fish was being stranded in isolated pools from the main channel once the flood wave had receded. Elwood and Waters (1969) observed two year classes of brook trout nearly eliminated by strong floods along with adult trout being reduced in east-central Minnesota due to the transport of sand and sediment into pools and riffles, causing a loss in their habitat.

High elevation stream communities and habitat are especially prone to large disturbances caused by floods (Elwood & Waters, 1969; Dolloff et al., 1994; Angradi, 1997; Swanson et al., 1998; Roghair et al., 2002; Carline & McCullough, 2003; Sato, 2006). Mountain headwater streams are usually small morphologically therefore aquatic communities are susceptible to availability of habitat to grow, forage, and reproduce and also are more sensitive to variations in streamflow (Elwood & Waters, 1969). In high gradient streams, fish populations and the stream morphology are largely influenced by extreme flow events (Roghair et al., 2002). Floods in mountainous watersheds are noticeably different than floods occurring in lowlands. In high elevation streams, the time of concentration is small due to steep slopes and channels causing the peak flow to come rapidly and last only hours to a day. Mountainous watershed's steep topography usually is associated with hillslope land slides and debris flows triggered by heavy rains. Debris flow may contain large logs, boulders, and sediment, causing substantial physical damage to the riparian ecosystem by tearing down trees, scouring stream channels, depositing new materials, and eliminating entire instream faunas (Swanson et al., 1998; Roghair et al., 2002).

Carline and McCullough (2003) found floods during January and May, 1996, in Monongahela National Forest, West Virginia, severely reduced brook trout populations. The authors noted the floods were strong enough to move substantial amount of stream substrates, resulting in an increase of pools and riffles. All redds after the January flood were destroyed causing a 98% loss in YOY brook trout, the adult brook trout population also had significant losses near 84%. The authors concluded that severe flooding in salmonid streams commonly destroys the year class of fish that are still incubating or have recently emerged and can take two to three years to recolonize. Carline and

McCullough (2003) also concluded the timing was important with winter flooding destroying redds of fall spawning brook trout and spring floods destroying redds of spring spawning rainbow trout.

In a catastrophic flood and debris flow in Shenandoah National Park, Roghair et al. (2002) observed a significant impact on the riparian community directly in the path of the debris flow. The debris flow effects included: 1) the scouring of the stream channel and deposition of new substrates, 2) the tearing down of trees in a 30-m band in the riparian zone, the piling of large woody debris into large stacks on the stream banks, and 3) the complete loss of fish from the effected areas. Brook trout populations took two to three years to recover along with some of the instream habitat variables.

A dramatic decline in population of the Kirikuchi charr (*Salvelinus leucomaenis*), in headwaters of the Kii peninsula, Japan was observed by Sato (2006) during debris flow caused by a severe flood. Over a two-day period, a typhoon dropped 395 mm of rain causing torrential flooding, landslides and debris flows. The debris flow scoured the channel, deposited new substrate and woody debris was piled onto the banks. The char population was dramatically reduced with fish over 100 mm falling by 98% and only one 0+ year fish remaining after the flood. The author concluded the debris flow was so detrimental on the habitat no spawning redds were observed after the flood, and it was questionable whether the fish population would be able to recover.

2.1.3 Droughts

Drought is a water shortage over a significant period of time and can be associated with lack of rainfall, high temperatures, and low humidity (Chang, 2006). The riverine community can be affected by drought from dwindling water levels. Drought is a natural disturbance of aquatic ecosystems, and unlike most floods, the duration can last from months to years. During a drought, the hydrology of the watershed goes through a sequential decline in precipitation, runoff, infiltration, interflow, groundwater levels, and stream flow. Depending on the length and intensity of the drought, the aquatic community may face a great deal of stress. The lack of precipitation during a drought can also be exacerbated due to higher temperatures, lower humidity, and higher winds all of which cause more evaporation thereby worsening the effects on the aquatic community. Droughts have noticeable effects on population densities, the size and age structure of the population, community composition and diversity, and on the ecosystem processes. A drought can affect the aquatic community into two main ways; by physically decreasing the surface area and volume of the water body and by altering the water quality, e.g., water temperature and available oxygen; (Canton et al., 1984; Cowx, 1984; Mundahl, 1990; Closs & Lake, 1996; Lake, 2003; Magoulick & Kobza, 2003; Matthews & Marsh-Matthews, 2003; Hakala & Hartman, 2004; Jowett, 2005). Tramer (1997) concluded that a drought is likely the primary factor affecting first-order stream communities, and repeated events may cause populations to be restricted.

The loss of water to the stream means a loss of fish habitat leading to increased fish abundance. As the fish population increases, their habitat becomes densely populated, causing biotic interactions to increase among individuals. The increased interaction may have a harmful effect on the community including increased predation, pressures, and competition for diminishing food supplies. The dangers from terrestrial predators, such as birds and mammals, may also become more prevalent as lower water levels make prey easier to find and catch. Tramer (1977) and Mundahl (1990) observed high mortality in stream fish trapped in shrinking pools, resulting from high temperatures and low oxygen content. Any migration to less crowded habitat may not be possible if water levels drop enough to expose shallow areas of the bed thereby breaching the connectivity of the stream and essentially trapping the aquatic species. Although, in high-elevation mountain streams this effect on fish is highly unlikely. Low water levels may also prevent aquatic species access to spawning grounds leading to possible loss of a year class (Richter, 1996; Lake, 2003; Magoulick & Kobza, 2003).

In regions with a more stable perennial flow regime, the aquatic community may be more susceptible to drought than regions characterized by harsh physical conditions. The local aquatic community might experience catastrophic losses due to them having little tolerance to heat or drought compared to regions that experience frequent dry seasons, such as tropical dry seasons where the fish living in those areas have already been naturally selected for drought resistance (Matthews, 1998; Matthews & Marsh-Matthews, 2003). Severe drought may reduce deep groundwater flow (e.g. springs) into streams, negatively affecting spawning grounds for many fish species that utilize discharging groundwater to regulate temperature, chemistry, and hydrology within redds (Curry et al., 1994; Curry et al., 1995).

Droughts in freshwater systems generally can be seen in two different ways seasonal or aseasonal. Seasonal droughts disturbances commonly can be described as a pulse or press, meaning the dry period happens close to the same time of year and is usually associated with a certain period of time in the year. Aseasonal droughts are not predictable, usually occurring on the scale of decades, and are marked by a decrease in usual precipitation and water availability. They usually act like ramps, meaning they grow intensity and disturbance during a longer period in time (Detenbeck et al., 1992; Humphries & Baldwin, 2003; Lake, 2003). Because seasonal droughts are predictable, the biota living in the surroundings has adapted throughout many generations to possess survival advantages such as life cycle timing, adaptive use of refugia, and high resilience physiology, in order to survive under extreme conditions. Because aseasonal droughts are unpredictable in timing and duration, aquatic organisms are not able to evolve specific adaptations and are, therefore, more harmful to the aquatic community accustomed to perennial streamflow or seasonal dry spells (Lake, 2003). For instance, MacAvoy and Bulger (1995) concluded low flow in three streams in Shenandoah National Park (SNP) during the Fall of 1993 allowed for brook trout eggs to become infected with the fungus *Saprolegnia*, thereby reducing the next year's recruitment.

The authors Hakala and Harman (2004) found brook trout habitat, in a forested headwater stream in eastern West Virginia, was harmed in quality and quantity due to low flows. Discharge in the study streams was 96% lower than an non-drought year, causing the average stream width to decrease by 32%, an increase in fine sediment in spawning substrate, and riffle habitat to be 60% shallower. The authors observed a 60% drop in population of adult trout and 67% drop in YOY trout from the beginning of the drought. The body weight and Fulton's Condition of adult trout was also significantly lower indicating the adults were in poorer condition with little or no net growth. The

YOY trout were harmed the most with their average body weight dropping by 31% compared to non-drought conditions. The authors suggested the diminishing abundance in trout was due to declining food availability, and the poor numbers of YOY trout were due to high mortality of adults, poorer condition of adults, low water levels leading to desiccation of eggs and aided the growth of *Saprolegnia*, and loss of spawning habitat. They also suggested the lack in food abundance was due to a loss in the benthic macroinvertebrate population, reduction in surface area available to catch falling terrestrial insects, and diminished invertebrate drift, the principal food source for salmonids.

Closs & Lake (1996) found brown trout mortality was observed to be consistently higher in the most upstream reaches of a stream in southeast Australia. A drought lasting from 1989 to 1991, associated with high temperatures and low or no flows, occurred during the study period. The mortality of the brown trout was close to a 100% at the uppermost reach in two of the three years. They concluded that the higher rate of mortality observed progressively upstream was caused by streamflow cessation beginning earlier and lasting longer; reaches downstream with more watershed area contributing to their flow showed persistent pools and less trout mortality.

Cowx et al. (1984) found a drought during the summer of 1976 eliminated a year class of salmon in an upland stream in Wales. The loss of livable habitat decreased during the drought due to the reduction of depth and width of the river. They concluded loss of habitat was the main factor in the 60% loss of total number of invertebrates. The most significant effect of the 1976 summer drought was the failure of the 1976 year class of salmon. The authors also concluded the salmon alevins were less tolerant than the older fish and the prolonged exposure to temperatures around their upper thermal limit led to increasing mortality throughout June and July.

Canton et al. (1984) found a severe drought in a Colorado third-order mountain stream caused a temporary cessation of surface flow. They observed the total macroinvertebrate density decreased by 50% and fish populations were severely reduced with no fish collected in most of the study area during the low-flow year compared with a normal non-drought year. The authors noted the brook trout collected were moribund and thin when handled during the drought and had regenerated scales, an indicator of environmental stress, after the drought demonstrated the harsh effects of the drought on the aquatic community. They concluded the loss in invertebrates was primarily due to loss of habitat and fish loss due to populations being restricted to shallow pools, which often become warm, stagnant, and overcrowded.

2.1.4 Refugia

During periods of extreme hydrological disturbance, aquatic communities generally have increased chances of survival if there is available shelter (Pearsons et al., 1992). During droughts deep pools and downstream reaches may act as refugia for biota by providing habitat when water in their surroundings is disappearing. Beaver ponds and natural springs may also provide protection to riverine organisms from dry spells and low flows (Lake, 2003; Magoulick & Kobza, 2003). During floods habitat features such as deep pools with permanent structures, floodplains, and broad reaches, provide protection against swift currents and moving debris. Generally, more complex stream reaches are able to provide better shelter than simple reaches due to the diversity of features able to be utilized by aquatic species under extreme hydrological events.

2.2 Hydrologic Processes

A watershed is a contiguous area that drains to a single outlet and is divided from neighboring watersheds by a ridge line (Bedient & Huber, 2002; Chang, 2006). The basic components of the hydrological cycle include precipitation, evapotranspiration, infiltration, overland flow, interflow, streamflow, and groundwater flow. Because this cycle varies greatly in time and space, extreme events such as floods or droughts may arise. Precipitation is the major source of water to a watershed and is delivered to earth in solid or liquid states from water vapor in the atmosphere. Precipitation can vary over time, during seasons or a single storm, and spatially over the watershed. Evapotranspiration is the combined loss of water vapor to the atmosphere through the transpiration of plants, from the stomata in leaves, and the evaporation of moisture from the soil, water bodies, streams, snowpack, and vegetation. Infiltration is the movement of water into the soil under gravity and capillary forces, the rate of infiltration depends on rainfall intensity, soil type, surface condition, and vegetation cover. When the precipitation intensity is greater than the storage capacity or infiltration rate of the soil, the excess water will run over the surface, overland flow, to the nearest stream channel. Water flowing underneath the soil can either be interflow or groundwater flow; interflow is water running laterally in the soil profile, and groundwater flow is associated with deep percolation of water. Streamflow is a body of moving water often associated with brooks, creeks, or rivers. Water in streams can come for precipitation directly intercepted, overland flow, interflow, or groundwater flow.

Forested watersheds have key differences in their hydrological process than non-forested watersheds (Chang, 2006). The amount of precipitation reaching the forest floor is reduced by interception from the canopy. Canopy interception also provides water storage and protection to the forest floor from rainfall impact. Transpiration through the root, stem, and leaf system of a tree moves a great amount of water from the forest floor into the atmosphere. A forest's root system, organic matter, and litter floor increase the infiltration rate and storage capacity of the soil. The combination of these three processes makes forested watersheds have little overland runoff, long times of concentration, and a lower water yield compared to non-forested watersheds. Peak flows, from storms of short duration and low intensity, in forested watersheds are generally lower in a given region.

2.3 Indicators of Hydrologic Alteration

The Indicators of Hydrologic Alteration (IHA) software program was originally developed in the early 1990s by the Nature Conservancy to quickly process daily hydrologic records to enable characterization of the flow regime in natural and altered watersheds. The IHA is generally used to evaluate on how humans have changed the natural flow regime from civilization (e.g. dams, channelization, and urbanization). The IHA parameters were specifically designed for setting ecological river management targets for river systems, in which the hydrological regime has been substantially altered by humans. The power of the IHA method is that it can be used to summarize long periods of daily hydrologic data into manageable ecological flow parameters (Richter et al., 1996; Richter et al., 1997; Mathews & Richter, 2007; Nature Conservancy, 2007).

The 32 ecological parameters are based upon five fundamental characteristics of hydrologic regimes including: magnitude, timing, frequency, duration, and rate of change (Table 1). The magnitude is the availability of water and defines such habitat attributes as wetted area, habitat volume, and current velocity (Richter et al., 1996). The seasonality or timing of the regime can determine whether aquatic organisms' life cycles are met and influence the degree of stress hydrologic events may have on the community. The frequency of occurrence of certain hydrological events may affect the river biota. The duration of a hydrological event may determine whether certain life cycles can be completed and the extent of environmental stress the biological community may experience. The rate of change in the hydrologic regime may be tied to stranding aquatic species on the river's edge or isolated pools and also may affect the ability of plant roots to maintain contact with water supplies (Nature Conservancy, 2007). Sixteen of the hydrologic characteristics focus on the magnitude, duration, timing, and frequency of extreme events because of the significant influence these events have on ecosystems and geomorphology. The other sixteen parameters measure the central tendency (e.g. mean and median) of either the magnitude or rate of change of the flow. Richter (1997) recommends at least 20 year flow record should be used in computing IHA parameter values for characterizing the natural range of variation to dampen any daily discharge outliers. There are a limited amount of published studies on the use of IHA parameters (Mathews & Richter, 2007; Richter et al., 2003).

Table 1: IHA Statistics Group (Richter et al. 1997)

IHA statistics group	Regime Characteristics	Hydrologic parameters
Group 1: Magnitude of monthly water conditions (subtotal 12 parameters)	Magnitude Timing	Mean or Median for each calendar month
Group 2: Magnitude and duration of annual extreme water conditions (subtotal 10 parameters)	Magnitude Duration	Annual minima 1-day means Annual maxima 1-day means Annual minima 3-day means Annual maxima 3-day means Annual minima 7-day means Annual maxima 7-day means Annual minima 30-day means Annual maxima 30-day means Annual minima 90-day means Annual maxima 90-day means
Group 3: Timing of annual extreme water conditions (subtotal 2 parameters)	Timing	Julian date of each annual 1 day maximum Julian date of each annual 1 day minimum
Group 4: Frequency and duration of high low pulses (subtotal 4 parameters)	Magnitude Frequency Duration	No. of high pulses each year No. of low pulses each year Mean or median duration of high pulses within each year Mean or median of low pulses within each year
Group 5: Rate and frequency of water condition changes (subtotal 4 parameters)	Frequency Rate of change	Mean or median of all positive differences between consecutive daily means Mean or median of all negative differences between consecutive daily means No. of rises No. of falls

The Range of Variability Approach (RVA) was introduced by Richter et al. (1997) and draws on the IHA parameters to set streamflow-based river ecosystem management targets. The RVA has six basic steps for setting, implementing, and refining the management target for the specific river reach. Step one includes an IHA analysis of natural flows to characterize the flow conditions and habitats to which the aquatic species have adapted, enabling hypotheses of flow and ecology relationships. Step two draws a comparison of human hydrologic alteration to the natural flow regime to classify the types and degrees of alterations. Step three constructs an ecological model that links life history traits and habitat needs to the species in the community. Step four and five include monitoring and research on the riverine community based on the ecological model. Step six calls for revision of any management targets based on the monitoring and research (Mathews & Richter, 2007).

In 2005, 34 new parameters called environmental flow components (EFCs) were added to the IHA software to complement the original parameters and characterize the hydrograph in a manner that is representative of key ecology and flow relationships (Table 2). The EFCs include five major components of flow: extreme low flows, low flows, high flow pulses, small floods, and large floods. The five flow components are considered ecologically important and provide a heuristic framework for describing the ways organisms live with river flow variability (Mathews & Richter, 2007).

2.4 Hydrologic Simulation Program FORTRAN

The application of hydrologic models that simulate processes occurring in the hydrological cycle are increasingly significant in watershed management and are possible

Table 2: EFC Statistics Group (Mathews & Richter, 2007)

Environmental Flow Component	Definition	IHA Statistics
Group 1:Extreme low flows (subtotal 4 parameters)	10th percentile of all low flows	Mean or median value for: Magnitude Frequency Duration Timing
Group 2: Low flows (subtotal 12 parameters)	Low flow (base flow) in each month	Mean or median value for: Monthly low flows
Group 3: High flow pulses (subtotal 6 parameters)	Flows greater than low flows but less than bankfull	Mean or median value for: Magnitude Frequency Duration Timing Rate of rise and fall
Group 4: Small floods (subtotal 6 parameters)	Flow equal to or greater than bankfull flows but less than the 10 year flood	Mean or median value for: Magnitude Frequency Duration Timing Rate of rise and fall
Group 5: Large floods (subtotal 6 parameters)	Flows equal to or greater than the 10 year flood	Mean or median value for: Magnitude Frequency Duration Timing Rate of rise and fall

with technological advances. The Hydrological Simulation Program FORTRAN (HSPF) is a robust hydrological model with the ability to simulate a variety of hydrological processes in natural or developed watersheds. The original development of HSPF was sponsored by the Environmental Research Laboratory, U.S. Environmental Protection Agency (USEPA), Athens, Georgia, with more recent development being sponsored by the U.S. Geological Survey Water Resources Division in Reston, Virginia (Bicknell et al., 2001; Skahill, 2004). During the initial development, the functions and processes included in HSPF came from four predecessor models: Hydrocomp Simulation Programming (HSP), NonPoint Source (NPS) Model, Agricultural Runoff Management (ARM) Model, and Sediment and Radionuclides Transport (SERATRA). WinHSPF was built as an interactive Windows interface to HSPF as a response to the need to make HSPF input sequences easier to build and modify. WinHSPF was created for the USEPA's Better Assessment Science Integrating Point and Nonpoint Sources (BASINS) system (Duda et al., 2001). BASINS is a multipurpose environmental analysis system developed by the USEPA for the use by regional, state, and local agencies in performing watershed-based studies (USEPA, 2001).

HSPF can simulate at temporal scales ranging, from minutes to days, and spatial scales ranging from a three acre farm to the 7,515,600-hectare Illinois River Basin (Skahill, 2004; Lian et al., 2007). HSPF uses meteorological data and parameters related to watershed geometry, land use patterns, soil characteristics, and land use activities. The algorithms used to simulate the hydrologic processes are a combination of physically based and empirical approaches. Although the model is generally classified as a lumped parameter model, a watershed can be subdivided into similar land segment (Skahill, 2004). Many scholarly studies have been successful in using HSPF to predict and simulate watershed runoff, water quality, and sediment transport over a wide range of watersheds throughout the world (Jacomino & Fields, 1997; Al-Abed & Whiteley, 2002; Bergman et al., 2002; Albek et al. 2004; Ackerman, 2005; Singh et al., 2005; Lian et al., 2007; Mohamoud, 2007; Said et al., 2007).

In the HSPF model, a watershed is usually subdivided into individual land segments considered to generate the same hydrologic response (AQUA TERRA, 2008). Land segments generally have similar meteorology, topography, geology, soils, land use, channel properties and other relevant watershed characteristics. HSPF consists of a set of modules that carry out a specific function alone and with other modules, enabling the simulation of the hydrologic processes. There are two general types of operating modules utility modules and application modules. Utility modules are used to manage model input and model generated time series data generally from a Watershed Data Management (WDM) file. Application modules are used to represent processes, or groups of processes, which occur in the real world. The HSPF model consists of three application modules: PERLND (pervious land), IMPLND (impervious land), and RCHRES (reach). The PERLND and IMPLND application modules simulate runoff and water quality constituents from pervious and impervious land areas, respectively. The RCHRES application module is used to route runoff and water quality elements simulated by PERLND and IMPLND modules through a single reach of open or closed channel or a completely mixed lake. The HSPF model consists of five utility modules COPY, PLTGEN, DISPLY, DURANL, GENER, and MUSTIN (Bicknell et al., 2001; Skahill, 2004).

The HSPF application modules contain compartments that completely account for the land components of the hydrologic cycle (Bicknell et al., 2001; Skahill, 2004). The PRLND module has fifteen compartments (Figure 1): the primary compartments simulate snow accumulation and melt SNOW; the water budget PWATER; sediment produced by land surface erosion SEDMNT; and water quality elements by various methods PQUAL and the agri-chemical sections MSTLAY, PEST, NITR, PHOS, and TRACER. Supplementary compartments include ATEMP for use in correcting air temperature for elevation differences to predict snowmelt, PSTEMP for estimating soil temperature, and PWTGAS for estimating water temperature and dissolved gas concentrations, and PDTOT, PBAROT, and PPRINT all three are used to manipulate the data produced. The IMPLND module has nine compartments which are principally urban land categories. The RCHRES has ten compartments that simulate hydraulic behavior, water temperature, cohesive and noncohesive sediment, nutrients, dissolved oxygen, and pH, among others. The RCHRES module uses a basic continuity equation for the volume of flow and the routing in the channel falls in the class known as “storage routing” or “kinematic wave” methods. Generally the time series data needed to model streamflow include hourly precipitation, potential evapotranspiration, air temperature, dew point temperature, wind speed, and solar radiation. The PWATER compartment of PRLND is the key compartment because it is the basis for all subsequent major compartments of PRLND (Bicknell et al., 2001; Skahill, 2004). The number of time series required by PWATER

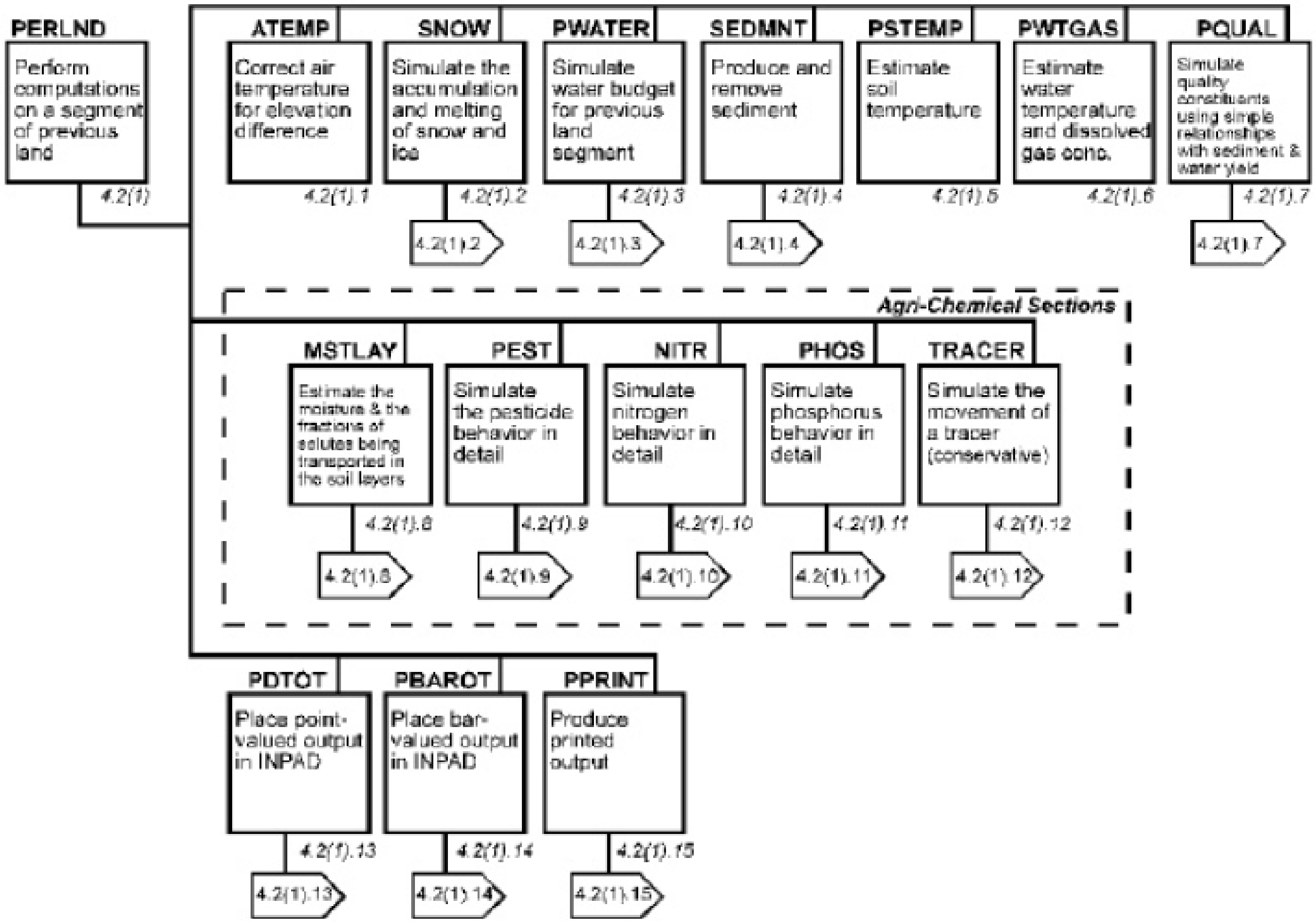

Figure 1: Structure chart for PERLND Module (Bicknell et al., 2001)

depends on if snowfall accumulation will be included in the model. When snow is not considered, only potential evapotranspiration and precipitation are required and when snow is considered air temperature, rainfall, snow cover, water yield, and ice content of the snowpack are also required.

The hydrological cycle, shown in Figure 2, begins as precipitation falling on the land surface and becomes stored as vegetation interception, which is modeled as a reservoir that must be filled before precipitation reaches the ground. Precipitation reaching the ground becomes surface detention storage and either enters the upper zone as potential direct runoff, or it will infiltrate into the ground, depending on the soil moisture and infiltration rate. Water not infiltrating into the ground may be routed as runoff from surface detention, interflow storage, or may stay on the overland flow plane, from which it runs off or infiltrates at a later time. The amount of direct surface runoff depends on slope, roughness, and distance from a first order stream, interflow storage is stored in a reservoir and empties based on a decay rate, and water staying on the overland flow plane represents ditches, swales, or depressions on the watershed surface. Water in the upper zone storage can evaporate, percolate, or become direct runoff or interflow during the next time step. Water infiltrating through the surface and percolating from the upper zone storage may become stored within the lower zone storage, active ground water storage, or deep inactive groundwater. Active groundwater is stored in a reservoir and eventually reappears as base flow. The water-holding capacity of the upper and lower zone of soil storages is defined in terms of nominal capacity to keep a smooth transition in hydrologic performance as the water content fluctuates. Evapotranspiration is modeled

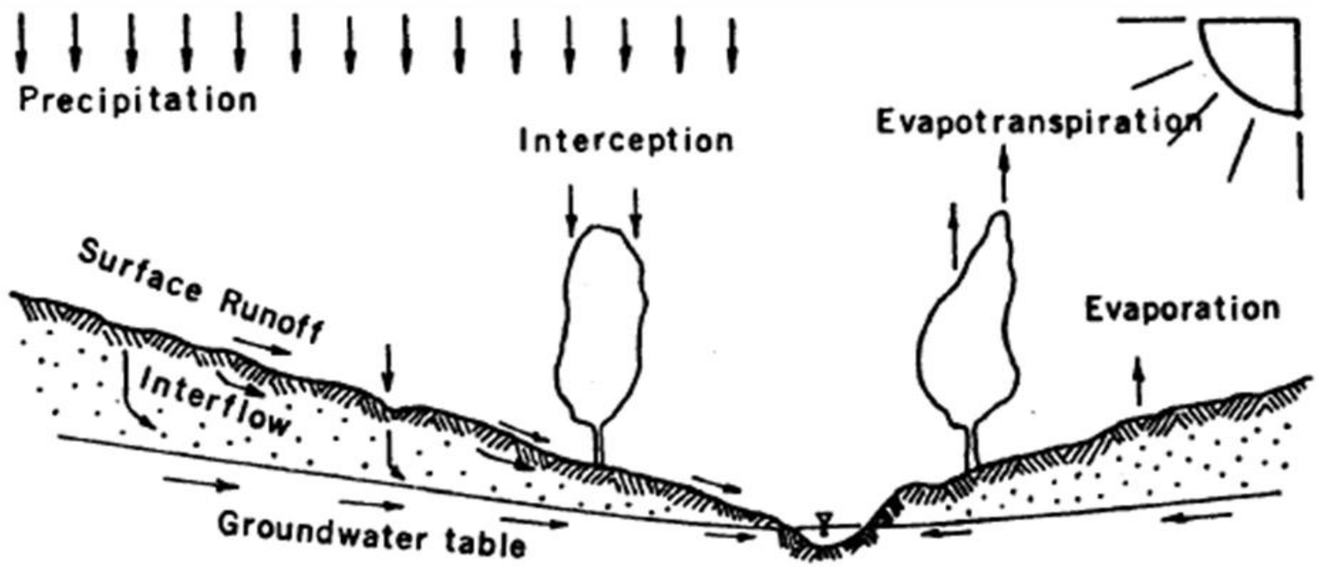

Figure 2: Hydrologic Cycle (Bicknell et al., 2001)

by evaporating water from five possible storages: baseflow, interception storage, upper zone storage, active groundwater, and lower zone storage. The hydrology PWATER is run by many algorithms contained in specific subroutines, similar to other compartments in all three application modules (Bicknell et al., 2001).

The USEPA, U.S. Geological Survey (USGS), and others have developed numerous software programs to support HSPF model development and application (Skahill, 2004; USEPA, 2001). Among others, these programs include WDMUtil (Hummel et al. 2001; USEPA, 1999), WinHSPF, GenScn (Kittle et al., 1998), HSPEXP (Lumb et al., 1994), HSPFParm (Donigian et al., 1999) and PEST (Doherty & Johnston, 2003). In addition HSPF is the nonpoint source interfaced within BASINS to support Total Maximum Daily Load (TMDL) analysis nationwide. The WDMUtil program is used to manage the large volumes of WDM files, which are used by HSPF for input and output time series data. The HSPFParm software package is used to help identify reasonable initial values and possible ranges based on previous HSPF application across North America. The HSPEXP software package provides advice on parameter adjustments during the calibration process. GenScn is a postprocessor software package allowing comparisons and analysis of output data and create simulation scenarios of best management practices. PEST is a robust model-independent parameter estimator.

Geographic Information Systems (GIS) can also aid the HSPF modeling process by quantifying and locating physical watershed data including elevation, channel geometry, soils, vegetation, and land use and land cover (LULC), among others. GIS also aids in generation and delineation of the watershed boundaries, stream reaches, and outlets. ArcGIS is compatible with recently released BASINS 4.0 MapWindow GIS software (Skahill, 2004; USEPA, 2001). Figure 3 shows a schematic of the steps and applications involved in a typical HSPF project.

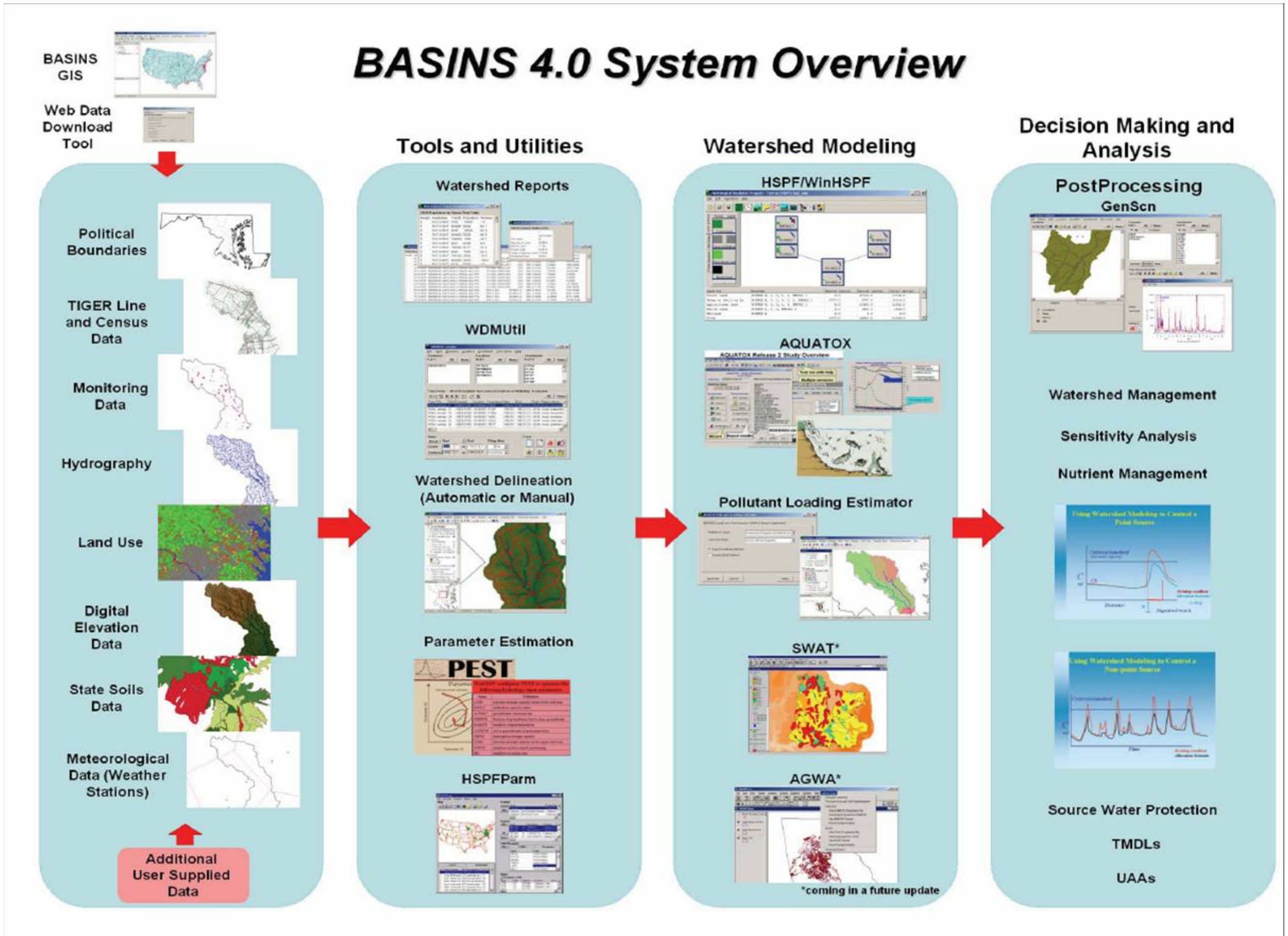

Figure 3: BASINS System Overview (AQUA TERRA, 2008)

Chapter 3: Methods

3.1 Study Area Background

3.1.1 Location

The study area, located in the Blue Ridge Mountains of Eastern Tennessee and Western North Carolina is within the GRSM (Figure 4). The GRSM was established in 1936 and is the second largest national park in the eastern United States, encompassing nearly 220,000 hectares (850 square miles). The GRSM is the most visited national park, receiving close to 10 million visitors per year. The GRSM is located in Blount, Cocke, and Sevier counties of Tennessee and Swain and Haywood counties of North Carolina. The towns of Gatlinburg, Tennessee and Cherokee, North Carolina are near the Park's main entrances.

3.1.2 Fisheries

The state of Tennessee has the richest freshwater fauna of any in the United States with approximately 300 species of native fish recorded in the state's waters (Etnier & Starnes, 1993). In the southern Appalachian Mountains, salmonids are at the southern margin of their range in eastern North America. The Great Smoky Mountains National Park's 2,115 miles of streams are home to three species of trout: the brook (*Salvelinus fontinalis*), rainbow (*Oncorhynchus mykiss*), and brown (*Salmo trutta*). Brook trout is the only salmonid species indigenous to the southern Appalachian Mountains. The historic range of the brook trout extended down the spine of the Appalachian Mountains through western Virginia and North Carolina and eastern Tennessee to northeastern Georgia

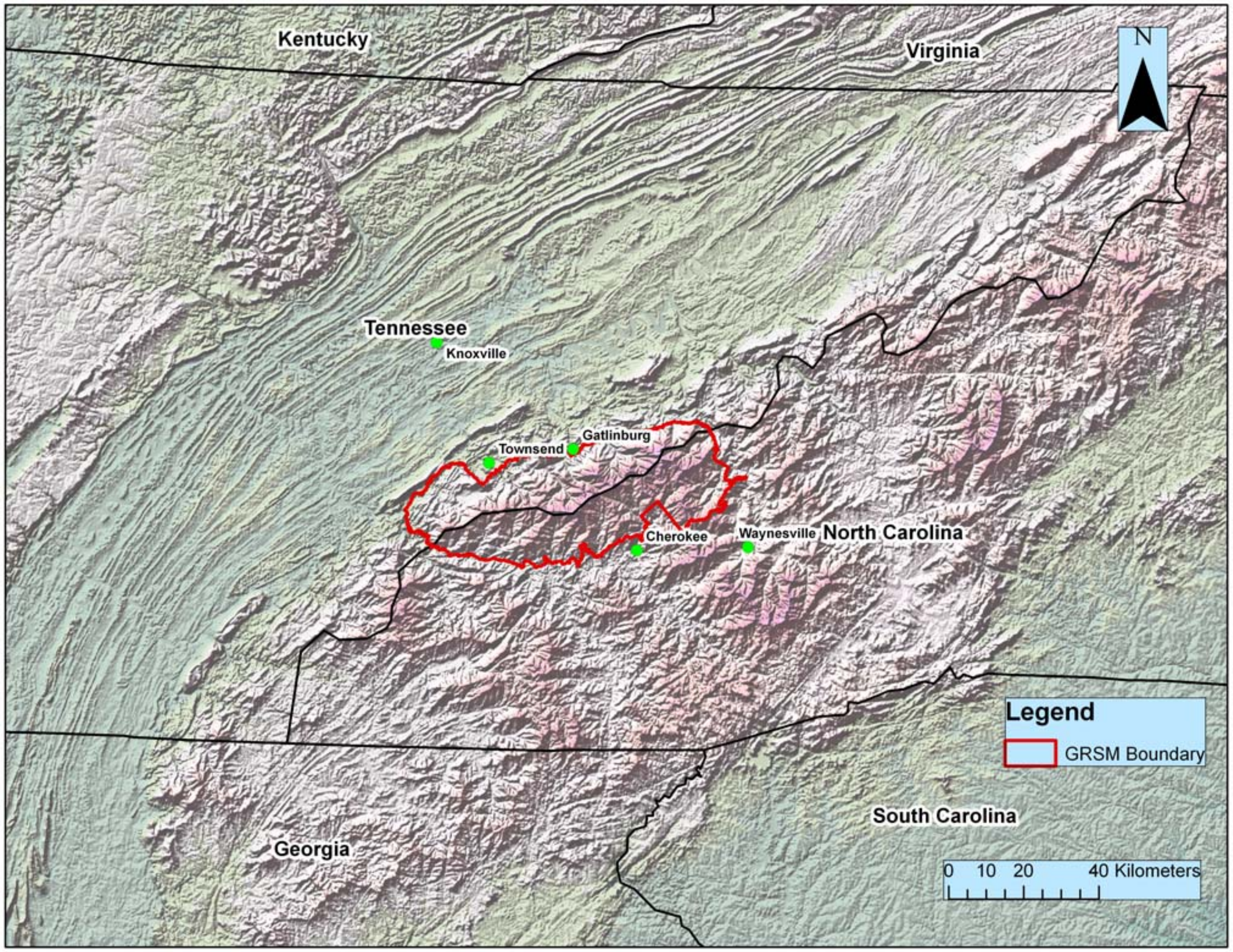

Figure 4: Great Smoky Mountain National Park

(Flebbe, 1994). Around 1910, rainbow trout were introduced into what is now the Great Smoky Mountain National Park. Because of this introduction, the native brook trout populations throughout the Southern Appalachians often exist sympatrically with the introduced rainbow trout (Larson & Moore, 1985). Rainbow trout usually dominate lower elevation streams, whereas brook trout are predominantly found in headwaters. The distribution of the native brook trout populations has seen a general decline since 1900 (Moore & Kulp, 2008). The population decline was at first attributed to extensive logging in the early 1900s and heavy fishing pressure, but the advancement and the success of the rainbow trout is generally accepted as the major cause of the decline in the brook trout in later years (Whitworth & Strange, 1983; Larson & Moore, 1985; Lohr &West, 1992). Brown trout native to Europe and western Asia were introduced into North America in 1883 with stocking in the Blue Ridge in larger creeks and tailwaters. Among the three trout in the park, the brown trout is the most tolerant of higher temperatures and grows largest in streams. Brown trout are generally found in larger lower elevation streams where they exist sympatrically with rainbow trout and in a few cases with brook trout (Bivens et al., 1985; Etnier & Starnes, 1993).

3.1.3 Climate

The GRSM's climate can be described as humid subtropical with hot, humid summers and mild winters (NCDC, 2008; NPS, 2008). Most summer rainfall occurs during thunderstorms and an occasional tropical storm. Winter precipitation is usually in the form of rain, occasionally as snowfall, especially in higher elevations, and is associated with large-scale frontal systems lasting for longer periods of time. Summer and early spring generally have the most abundant precipitation; rainfall averages near 12.7 and 20.32 cm a month in lower and upper elevations respectively. The fall is the driest season due to slow-moving high pressure systems, with rainfall totals around 7.62 and 12.7 cm a month in lower and upper elevations, respectively. The average annual rainfall varies significantly throughout the park with lower elevations generally receiving near 127 cm and some higher elevation sites near 215.9 cm. Snowfall at lower elevations is scarce with totals accumulating around 25.4 cm; higher elevations receive significantly more snowfall. Snow cover rarely lasts more than a few days.

Temperatures are significantly warmer at lower elevations; Gatlinburg, a low elevation town, has an average annual temperature near 14 °C; and Clingmans Dome the highest point in GRSM and has an average annual temperature of 6°C (NOAA 2002; NPS, 2008). January is the coldest month of the year, averaging near 4°C at lower elevations and near -7°C at higher elevations. July is the warmest month of the year with average temperatures near 24°C at lower elevations and near 16°C at higher elevations.

Generally, most of Tennessee receives abundant precipitation throughout the year. Dry spells usually occur at least once a year during the summer and fall and may last for weeks at a time. Heavy and prolonged precipitation during the winter and early spring can cause periods of widespread flooding and local flash floods. Heavy downpours from summer thunderstorms frequently cause local flash flooding (NCDC, 2008).

3.1.4 Physiographic Characteristics

The GRSM lies in the Blue Ridge physiographic region, seen in Figure 5, located in the Southern Appalachians (Clark, 2007). The physiographic region is characterized by

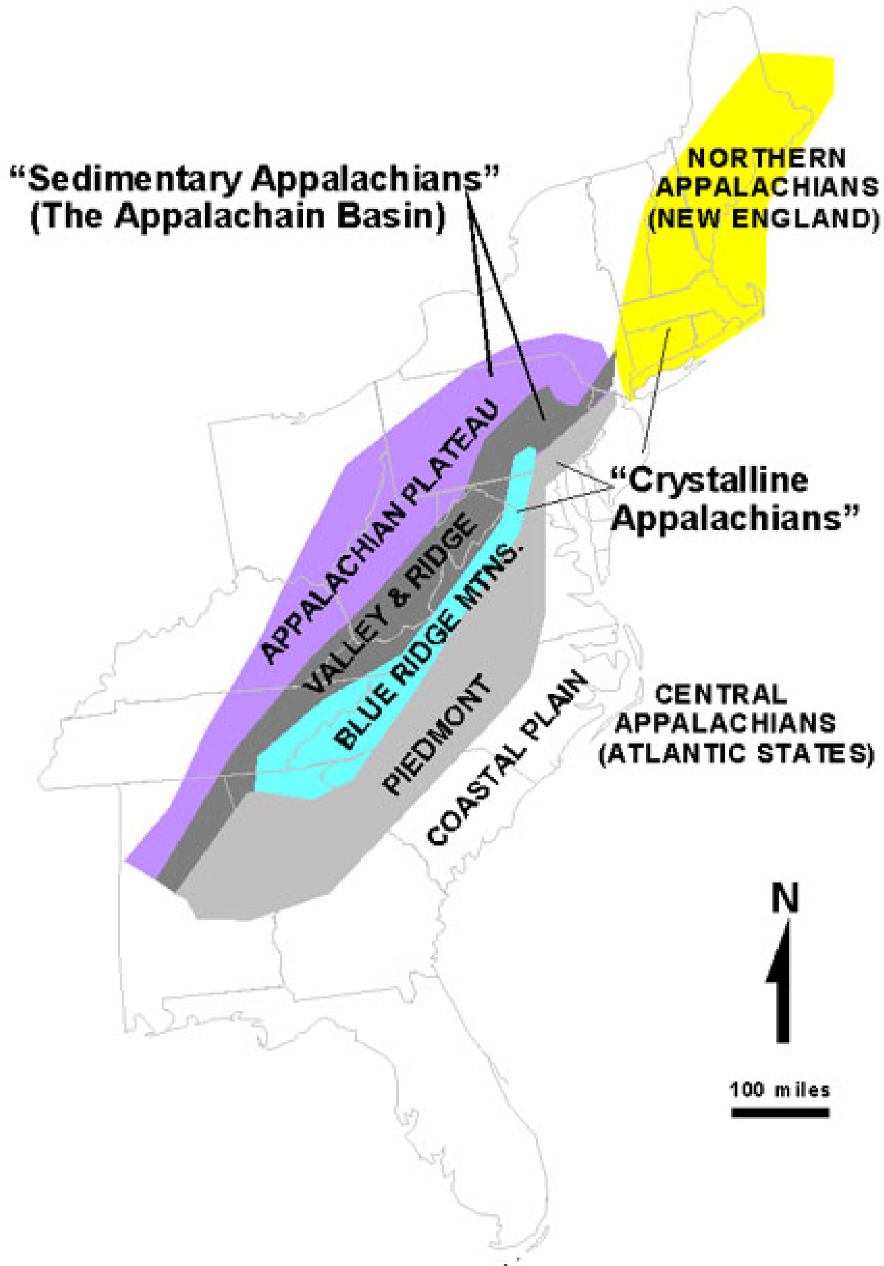

Figure 5: Blue Ridge Mountains (Clark, 2007)

rugged topography, heavily forested slopes, and steep mountain streams which flow westward to the Tennessee River system. The steep mountain streams are generally associated with numerous riffles and falls over bedrock and boulders with sand and gravel bottom pool areas. Altitudes range from about 300 m along the Little Tennessee River, to a little over 1,900 m on Clingmans Dome. The crest, also called the Unaka Mountains, forms the border between Tennessee and North Carolina.

The present day geology of the Blue Ridge Mountains was formed during the late Pennsylvanian and Mississippian periods nearly 300 million years ago (Southworth et al., 2003; Southworth et al., 2005). The western highlands and foothills region are predominantly underlain by fine and coarse metasedimentary bedrock. The eastern Blue Ridge is predominantly underlain by metamorphic rocks such as gneiss and schist. Slopes are mostly covered with soil and residuum 1.8 to 9.75 m deep. One of the most distinguishing features of the mountains is the creeks containing very coarse boulders of metasandstone. Boulders can range from 1.52 to 9.15 m across with smaller ones able to be actively transported during high flows.

The GRSM's soils can be described as being extremely bouldery, stony, and rocky with steep slopes varying from 30 to 95% (Haan et al., 1994; NRCS, 2008). The soils generally fall into the hydrologic soil groups B and C. According to Soil Conservation Service (1986) soils group B and C have low to moderate infiltration (0.13-0.76 cm/hr) rates when thoroughly wetted. The soils generally have a taxonomic classification as being fine to coarse loamy.

The GRSM is part of the Tennessee River drainage basin. Watersheds in GRSM are located in six hydrologic unit codes (HUC) including: 06010201 North Fork Holston; 06010202 South Fork Holston; 06010203 Watauga; 06010204 Holston; 06010106 Pigeon; and 06010107 Lower French Broad. Major rivers in GRSM include the Littler River, Cataloochee Creek, Abrams Creek, Forney Creek, Hazel Creek, and Middle Prong of the Little Pigeon River.

3.1.5 Vegetation and Land Cover

Because of the old age, diversity, and protection of habitats in the park, the flora is rich, containing approximately 1,300 species of flowering plants, including 130 native trees (NPS, 2008; Whittaker, 1956). Approximately 80% of the park is comprised of deciduous forests. There are five major forest types found in the park. The Cove Hardwood Forest is dominant in lower elevations and is the most botanically diverse due to deep rich soils in sheltered valleys; dogwoods are common species found in this type of forest. The Spruce-fir Forest is found at elevations of 1,300 m with Fraser fir and red spruce being the dominant species able to survive in the harsh climate. The Northern Hardwood Forests dominate the middle to upper elevations from 1,000 to 1,500 m. Common species include maples, yellow birch, and American Beech. The Hemlock Forests dominate stream sides and moist, shady slopes up to 1,200 m and are currently threatened by the hemlock woolly adlegid (Ford & Vose, 2007). The Pine and Oak Forest dominate the exposed slopes and ridges common trees include oaks, hickories, and pines. Grassy and heath balds also occur at mid to high elevation in the park. Cataloochee Creek watershed and Cades Cove, Abrams Creek watershed, are the only two areas in the park with tracts of extensive non-forested land; both have historic farmland that is kept cleared by the national park service (Figure 6).

3.2 Description of GRSM Trout Monitoring

The GRSM fishery biologists have surveyed brook and rainbow trout populations at 369 sites located on 69 different streams since 1990 (Moore & Kulp, 2007). Trout survey sites range in elevation from 231 to 1,367 m and can be found on 1^{st} to 5^{th} order streams. Trout samples were collected in the summer and early fall (May to October) annually using backpack electro fishing units. Most of the trout sites were surveyed every three to five years although around 25 were surveyed annually. Trout were removed from a 100 m representative section of stream by a standard three-pass removal technique (Reynolds, 1996). The sampling areas were calculated by multiplying the stream width by the length of representative section (100 m). After removal, trout were separated into two age groups, young-of-the year (YOY) and adults and were measured for total length (mm) and weight (g). Trout less than 100 mm in length were classified as YOY trout. A software program, using a maximum likelihood estimator, was used to generate population estimates based on the number of trout removed from a section of stream. Trout densities were then calculated as the population per unit area of stream (number of trout/100 m^2). Trout biomass is reported as the kilograms of trout per hectare (kg/ha). The trout dataset can be considered complete; when trout were found at a site all trout metrics were calculated. The ratio of adult brook density and rainbow adult density was also computed for each trout survey site containing both brook and rainbow trout (Moore & Kulp, 2008).

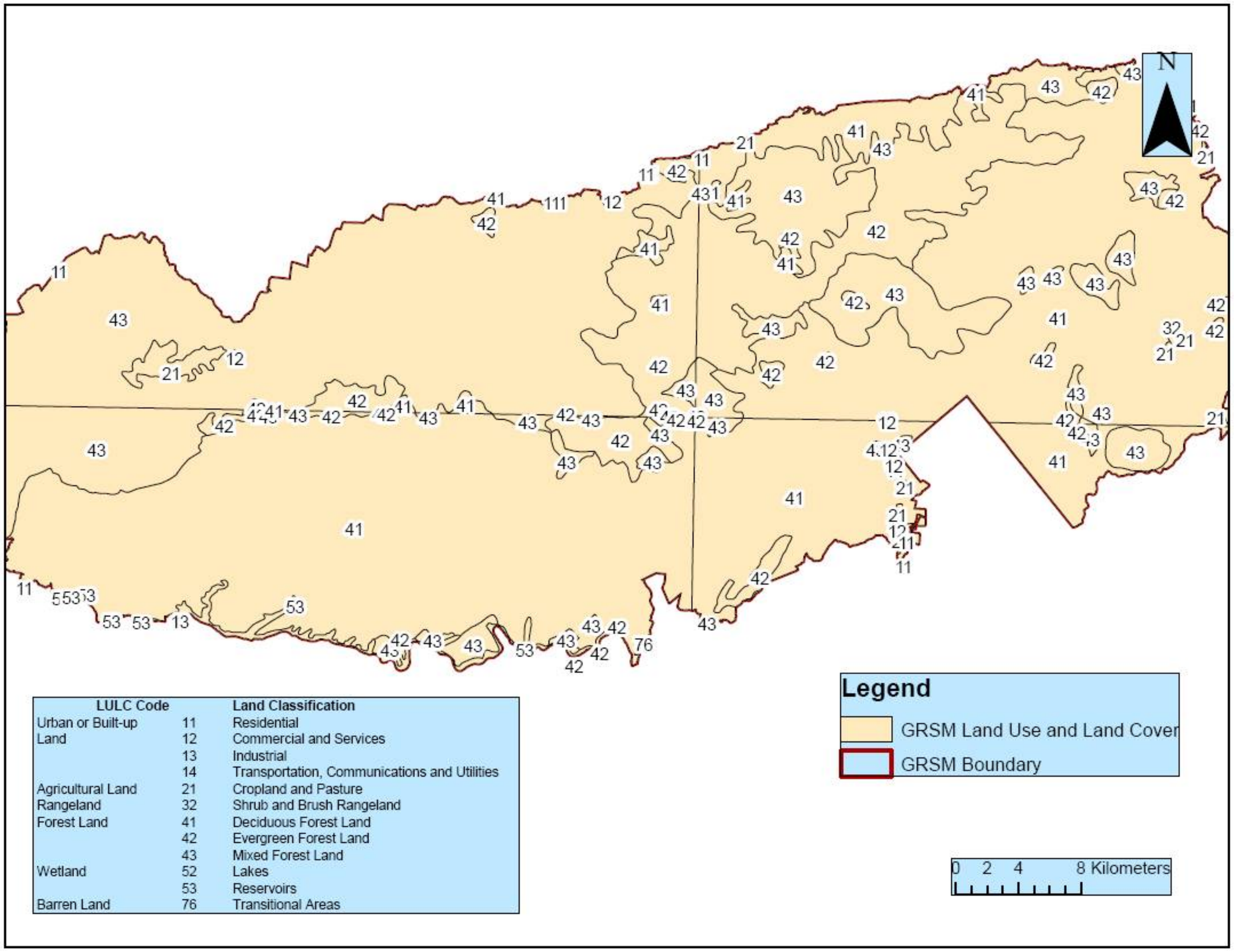

Figure 6: Land Use and Land Cover (USGS, 2008)

3.3 Study Design

The intention of this study was to evaluate how hydrology patterns influence the brook and rainbow trout populations inhabiting the waters of GRSM. The study period was between January 1, 1990 and December 31, 2007 corresponding to the collection of the trout survey data. Because each trout site was located on an ungaged stream the hydrology was simulated using the HSPF hydrology model.

The model was calibrated by adjusting hydrologic parameters including storage, infiltration, runoff, and groundwater for three elevation classes (low<800 m ≤ middle ≤ 1,200 m < high) to observed flows from two USGS gaging station and one NPS gaging station. The high elevation hydrologic parameters were calibrated to the flows of NPS gaging station Noland Divide in a previous study (Cai & Schwartz, 2008). The middle elevation parameters were calibrated to the observed flow of Cataloochee Creek (USGS Station 03460000) and the low elevation parameters were calibrated to the observed flow of Little River (USGS Station 03497300).

Once the model was calibrated trout survey data collected by GRSM fishery biologists was compiled into a manageable data set. Trout sties falling within 700 m of one another were combined only if a confluence or physical barrier did not separate them. The distance of 700 m was chosen because it gave a manageable amount of sites and did not combine sites that had significant differences in hydrology. The combination reduced the number of trout sites to a more manageable 138; a description of each site can be found in Appendix A. The trout data for a combined site was the average of all the sites combined to form that particular site. Once the trout sites were compiled, their hydrology was simulated for the entire study period using local metrological data.

The simulated hydrology for each trout site was then characterized by the Indicators of Hydrologic Alteration Software. From the daily flows of each trout site the IHA software computed 67 ecologically relevant hydrologic parameters. The 67 IHA hydrology parameters were then statistically compared to brook and rainbow trout metrics including: density (YOY and adult), total biomass, and ratio of brook adult density to rainbow adult density for each site.

3.4 HSPF Requirements

3.4.1 Climate Data

To simulate hydrology in HSPF two sets of time series data are needed: hourly potential evapotranspiration and hourly precipitation (Bicknell et al., 2001). More data is required if snow accumulation and snow melt are considered. Based on the limited amount of recorded snowfall throughout the park, snow accumulation and melt was not considered. The watershed data management utility (WDMUtil), HSPF’s primary storage and management of all time series data, was used to calculate evapotranspiration based on the daily high and low values and latitude. Due to the park’s vast size, many weather stations were needed to accurately simulate each watershed’s hydrology. Hourly rainfall and daily temperature data were gathered from many sources including Tennessee Valley Authority (TVA), National Oceanic and Atmospheric Administration (NOAA) through the National Climatic Data Center (NCDC), and the National Park Service (NPS). Missing rainfall and temperature data was estimated by correlating with a nearby station using simple linear regression. Because the timing of rain events was different for nearby stations, the daily totals of each station were used in comparison between sites. Rainfall data from TVA was recorded in 6 hour increments; the 6 hour total was evenly distributed into hourly rainfall. A total of sixteen weather stations throughout the park were used in the study (seen in Figure 7 and Table 3).

3.4.2 Watersheds and Segmentation

A delineated watershed layer is needed by the HSPF model to create a boundary representing the area contributing to a particular outlet. Delineation is also needed to segment the watershed into manageable and particular sub-areas and define the boundaries of the study. Preliminary delineation of watershed boundaries was done in GIS ArcMap 9.2 through the use of ArcMap's powerful Spatial Analyst Hydrology toolset. The first step in the delineation process was to locate the trout sites throughout the GRSM and create a watershed outlet for each of the 138 trout survey sites.

Because most watersheds in the park have large changes in elevation between the headwaters and the outlet, segmentation of the hydrologic parameters and input climate data was needed. Based on the elevations of the calibration outlets three "bands" of hydrologic parameters were used during modeling. Subwatersheds with outlets over 1,200 m in elevation were associated with the Noland Divide high elevation parameters. Subwatersheds with outlets between 800 m and 1,200 m in elevation were associated with the Cataloochee Creek middle elevation parameters. Subwatersheds with outlets below 800 m in elevation were associated with the Little River low elevation parameters

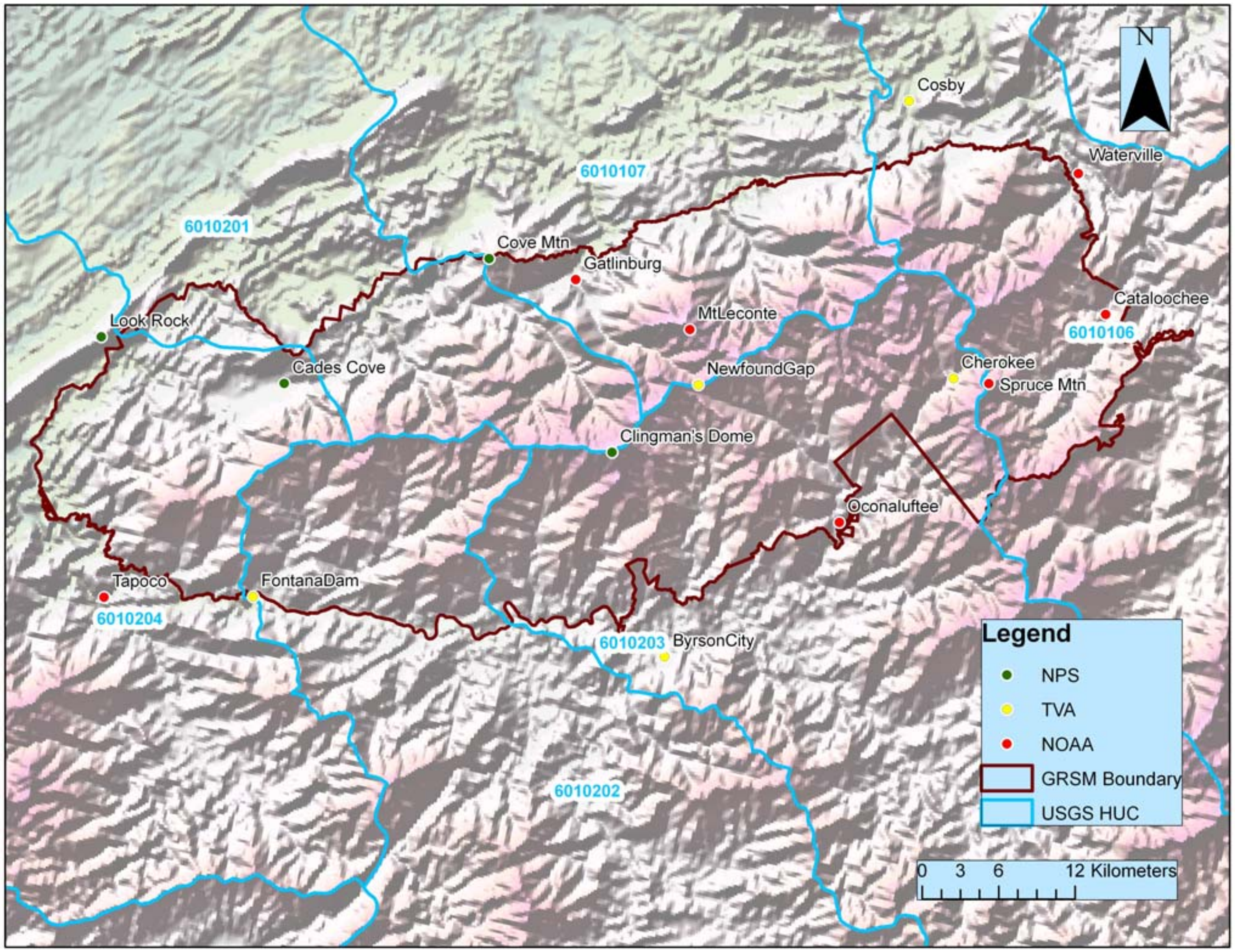

Figure 7: Climate Stations used in the Study

Table 3: Climate Stations used in the Study

Station Name[2]	Elevation (meters)	State	UTM NAD83 17N Northing (meters)	UTM NAD83 17N Easting (meters)	HUC[1]	Agency
Bryson City	591	NC	277,706	3,922,220	06010203	TVA
Cades Cove	561	TN	247,889	3,943,612	06010204	NPS,TVA
Cataloochee	754	NC	312,315	3,949,051	06010106	NOAA
Cherokee	977	NC	300,375	3,944,005	06010203	TVA
Clingmans Dome	2,009	NC	273,590	3,938,230	06010203	NPS
Cosby	410	TN	296,900	3,965,792	06010106	TVA
Cove Mtn.	1,216	TN	263,969	3,953,445	06010201	NPS
Fontana Dam	520	NC	245,450	3,926,933	06010202	TVA
Gatlinburg	444	TN	270,743	3,951,783	06010107	NOAA,TVA
Look Rock	806	TN	233,565	3,947,242	06010204	NPS
Mt. Leconte	1,786	TN	279,736	3,947,950	06010107	NOAA
Newfound Gap	1,531	TN	280,376	3,943,523	06010107	TVA
Oconaluftee	659	NC	291,430	3,932,774	06010203	NOAA
Spruce Mtn.	1,587	NC	300,748	3,943,661	06010106	NOAA
Tapoco	389	NC	233,763	3,926,903	06010204	NOAA
Waterville	524	NC	310,162	3,960,102	06010106	NOAA

[1]Hydrologic Unit Code
[2]All but Cataloochee and Spruce Mtn. are currently operational

Weather data was segmented into high-and low-elevation classes with subwatersheds outlets lower than 1,000 m in elevation associated with a low-elevation station and outlets above 1,000 m in elevation associated with a high-elevation station. The separation elevation of 1,000 m was chosen based on trail runs of the HSPF model. A combination of a high-elevation station and a low-elevation station was labeled a climate "layer".

Because BASINS segments a watershed by creating sub-watersheds the general process for segmenting a watershed was to locate when a stream reached a certain elevation based on segmentation criteria and then create an outlet. Subwatersheds would then be created for each of these outlets and all area contributing to that outlet would be associated with the respective hydrologic parameters and climate data (Figure 8). The three tier hydrologic parameter "band" was used throughout the park under the assumption the major change in the hydrologic parameters was due mainly to elevation changes. Seven different climate "layers" containing a unique combination of the sixteen weather stations were used to simulate the study watersheds throughout the park (Table 4). Generally each of the six HUCs in GRSM had it own climate "layer" used to simulate the watersheds within its boundaries.

The second and final step in the delineation process was to bring the previously delineated subbasins layer into BASINS. The manual delineation tool in BASINS was used for watershed characterization. The manual delineation tool requires underlying data characterizing the land features of the watershed. The three data layers needed represent the topography, streams, and subbasins boundaries. A digital elevation model (DEM) was

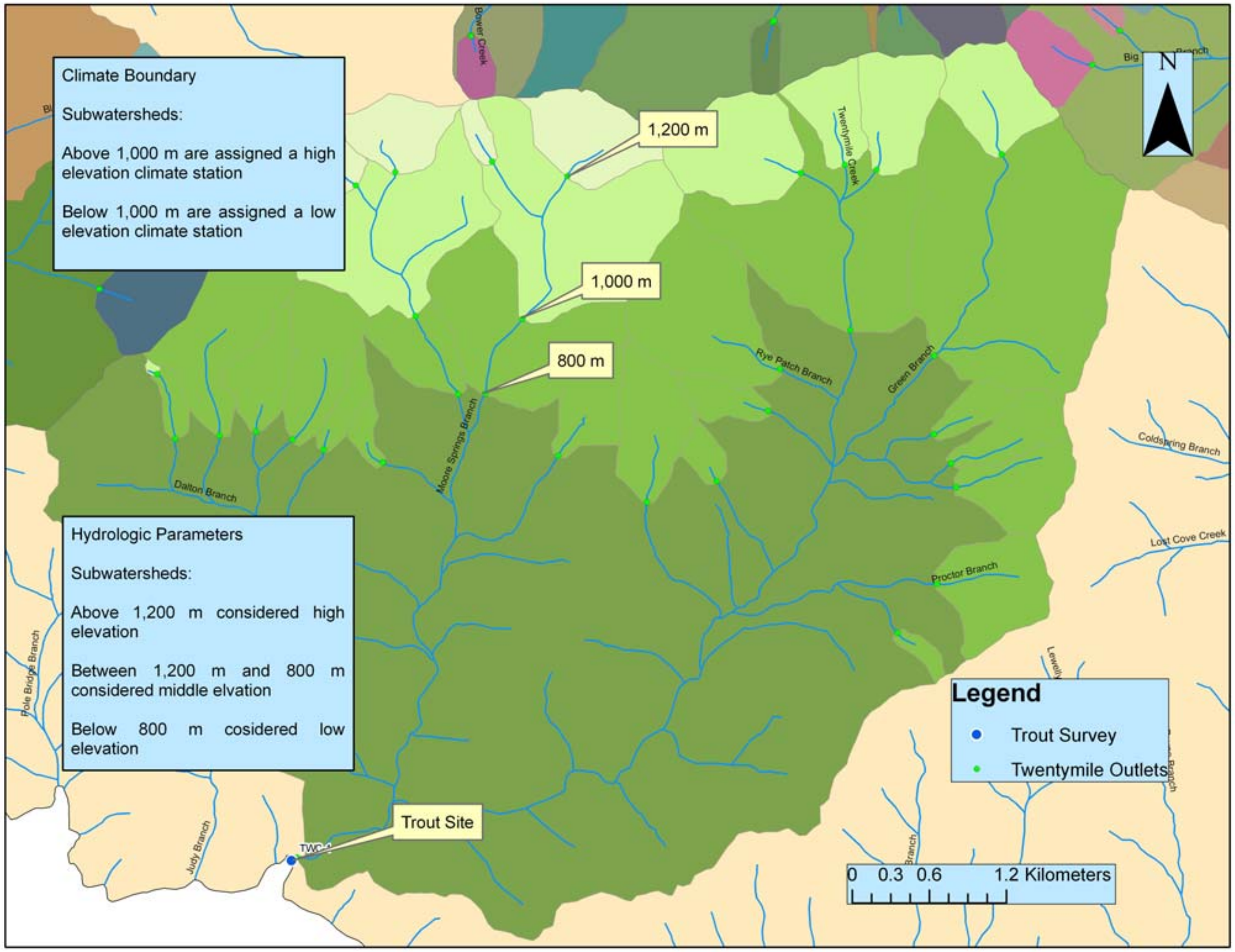

Figure 8: Twentymile Creek: Example of Subwatershed Elevation Bands

Table 4: Climate Layers used in Simulation

Climate "Layer"	Associated HUC	Climate Stations: High Elevation	Low Elevation	Additional
Little River	06010101	Clingmans Dome	Cades Cove	Cove Mtn.
Abrams Creek	06010204	Clingmans Dome	Look Rock	
Hazel Creek	06010202	Clingmans Dome	Fontana Dam	Tapoco
Forney Creek	06010203	Clingmans Dome	Cherokee	Oconaluftee and Bryson City
Cataloochee Creek	06010106	Newfound Gap	Cherokee	Oconaluftee, Cosby, Waterville
Cataloochee Creek[1]	06010106	Spruce Mtn.	Cataloochee	Waterville
Middle Prong Little Pigeon	06010107	Newfound Gap	Gatlinburg	Mt. Leconte

[1]Cataloochee Calibration

used to characterize the topography of the park. The DEM, given by NPS, had a resolution of 9 meters meaning the cells on the raster images were 9 meters square. This high resolution ensured suitable representation of the park topography. The streams layer was downloaded, using BASINS, from the National Hydrologic Dataset (NHD). The subbasin boundary layers created in ArcMap were used to define watershed boundaries. The manual delineator tool in BASINS used these three layers to create the map layers required for setting up an HSPF model, including defining and physically characterizing the stream network, calculating subbasin slopes and areas, and defining the outlets among others. The final data layer needed for the model represented the landuse of the watershed. This layer was obtained from USGS Land Use and Land Cover digital data archive. The data provided information on nine major classes of land use such as urban, agricultural, or forested land (USGS, 2008).

3.4.3 Calibration and Simulation

Three gaged watersheds were used to characterize and calibrate HSPF's hydrologic parameters in the park (Table 5). The Little River and Cataloochee Creek watersheds were chosen based on their location, elevation, and outlets having long term

Table 5: HSPF Calibration Watershed Outlets

				UTM NAD83 17N		
Calibration Watershed	**Elevation (meters)**	**Stream Order**	**Watershed (hectares)**	**Northing (meters)**	**Easting (meters)**	**Flow[1] (cms)**
Cataloochee Creek	754	4	12,745	312,567	3,948,945	2.715
Little River	231	5	27,475	254,597	3,950,151	6.288
Noland Divide	1,712	1	18	275,275	3,938,542	0.006

[1]Mean of Monthly Medians

recorded streamflow. A third high-elevation watershed, Noland Divide calibrated in a previous study was also used in this study to characterize high-elevation hydrologic parameters (Cai & Schwartz, 2008). The USGS gages, Little River above Townsend, Tennessee (Station 03497300), and Cataloochee Creek near Cataloochee, North Carolina (Station 03460000) were used as locations for the outlets of both calibration watersheds (Figures 9 and 10). The Noland Divide watershed hydrology was measured by means of an H-flume monitored by stage recorders by the University of Tennessee (Figure 11 and 12). The calibration period for both the Little River and Cataloochee Creek watersheds was approximately 10 years. The long period of calibration was desirable to ensure the calibration period did not fall exclusively within an extreme wet or dry period. The Cataloochee Creek watershed had a calibration period beginning on September 1, 1965 and ending on September 1, 1975. The Little River watershed had a calibration period beginning on January 1, 1993 and ending on January 1, 2003. The reason behind making the calibration period of Cataloochee Creek more than 30 years ago was due to the availability of hourly precipitation data. The climate data seemed to influence the model the most so it was important to have hourly weather data during calibration.

The HSPF model contains over 20 hydrologic parameters used to characterize the watershed; six of those hydrologic parameters may vary monthly. The hydrologic parameters characterize processes such as evapotranspiration, infiltration, groundwater discharge, and storage among others. Calibration was completed manually with support from previous studies (Donigian, 1978; Fontaine & Jacomino, 1997; USEPA, 2000; Doherty & Johnston, 2003; Albek et al., 2004; El-Kaddah & Carey, 2004; Singh et al.,

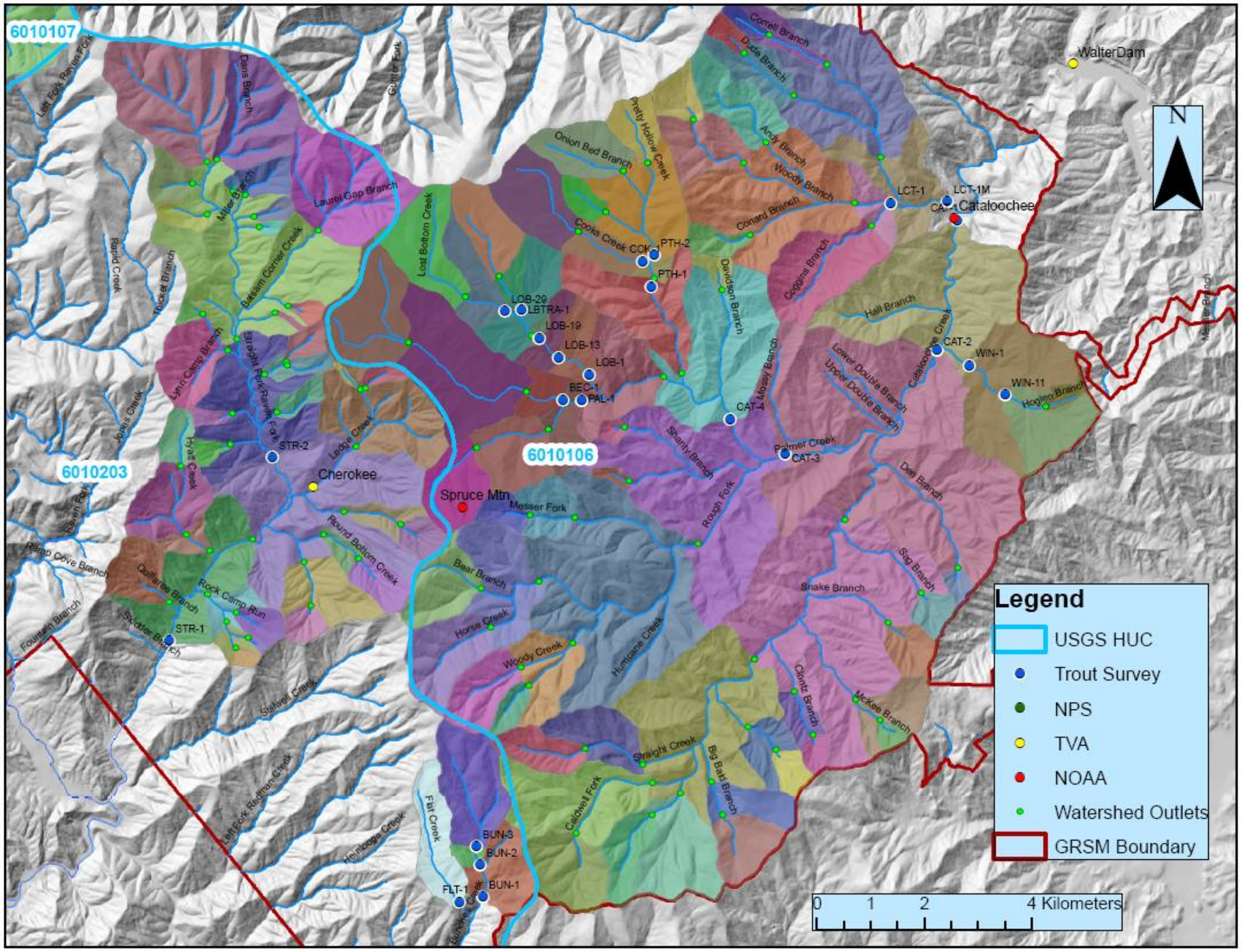

Figure 9: Cataloochee Creek Watershed 06010106

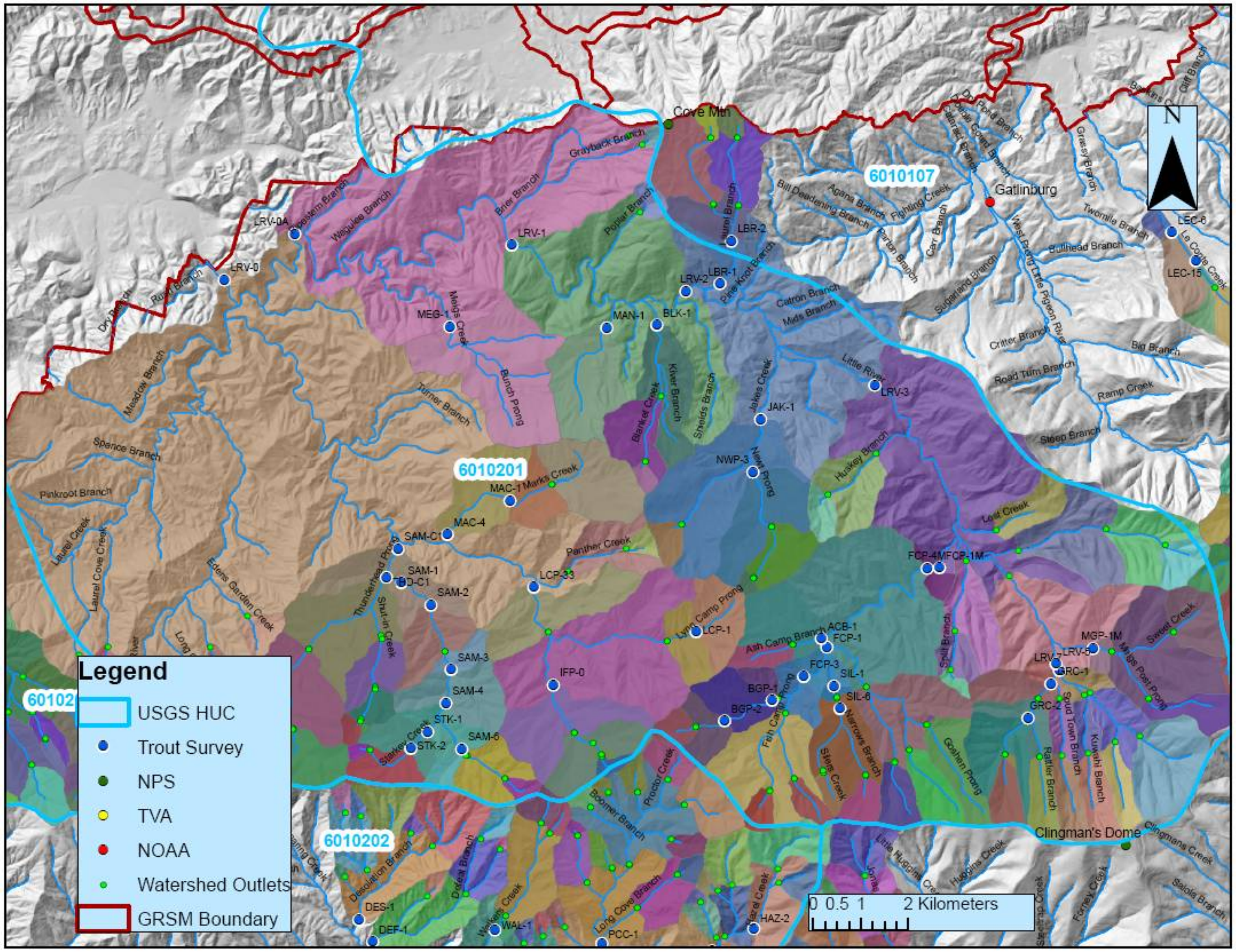

Figure 10: Little River Watershed 06010201

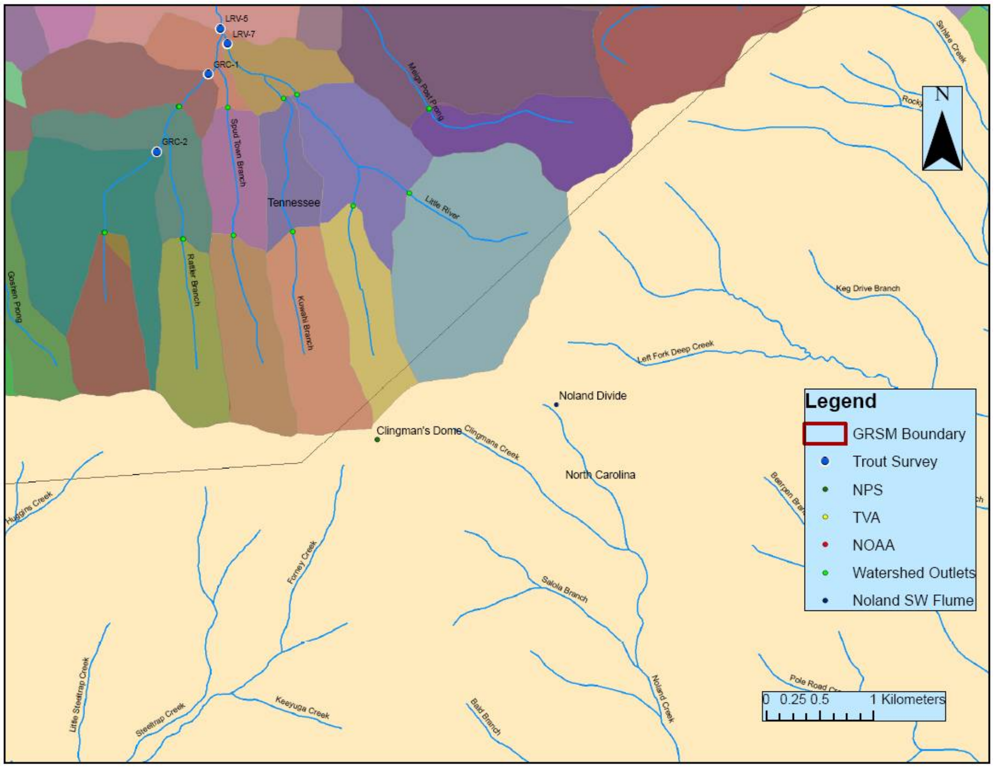

Figure 11: Noland Divide

Figure 12: Noland Divide Flume

2005; Lian et al., 2007; Mohamoud, 2007; Cai & Schwartz, 2008; Diaz-Ramirez et al., 2008). The resulting parameters can be seen in Appendix D. Table 6 shows the key parameters adjusted during calibration of the model.

A one-year “warm-up” period was used during calibration and simulation; a “warm-up” period was needed for the HSPF model because it takes a few months of preliminary simulation for the hydrologic cycle to get recharged. The first step of the HSPF calibration process was to meet the annual water volume balance, parameters dealing with deep groundwater and evapotranspiration losses were adjusted to calibrate the model. Once the annual water balance was adequate, monthly volumes and base flows were examined, adjusting parameters such as infiltration and monthly evapotranspiration rates and storage capacities, was needed. The final adjustment of parameters dealt with the hydrograph shape, parameters dealing with interflow and upper zone storage were adjusted to finely tune the peak of the hydrograph and the recession rate. During the entire calibration process the adjustment of parameters values was done keeping in mind the goal of getting a unique and realistic set of parameters characterizing GRSM. The adjustment of the parameters therefore had to make logical sense and be comparable to other study parameters within a similar setting. Calibration was considered complete once certain visual and technical criteria were met.

The post processing software Generation Scenarios (GenScn) was used to manage the high volumes of output data from the HSPF model. GenScn allows for a quick visual analysis of how well the model is simulating the stream hydrology, three comparison plots generated by GenScn were used in calibration. The scatter plot creates an x-y plot of

Table 6: Key HSPF Hydrologic Parameters used in Calibration

Key Parameters	Description	Unit
LZSN	Lower zone nominal storage	mm
LZETP	Lower zone evapotranspiration parameter	coefficient
INFILT	Index to the infiltration capacity of the soil	mm/hr
DEEPFR	Fraction of groundwater inflow which will enter deep (inactive) groundwater and be lost	fraction
AGWRC	Basic groundwater recession rate constant	day^{-1}
KVARY	Parameter affecting the behavior of groundwater recession flow, enabling it to be nonexponential in its decay with time	mm^{-1}
BASETP	Faction of remaining potential ET which can be satisfied from base flow (groundwater flow)	fraction
UZSN	Upper zone nominal storage	mm
INTFW	Interflow inflow parameter	coefficient
IRC	Interflow recession parameter	day^{-1}
CEPSC	Interception storage capacity	mm

the observed and simulated flows and gives a linear correlation coefficient. Correlation coefficients closer to one indicate better model performance. The intensity duration curve plot creates a statistical plot of the percentage of time a flow value is exceeded. The closer the observed and simulated curves match the better the model is performing. The hydrograph time series plot gives a visual of how well the observed and simulated hydrographs compare over time. The better the simulated and observed hydrographs match the better the model is performing.

After the model was adjusted based on the visual plots, goodness-of-fit measures were used to finely adjust the model parameters. Goodness-of-fit measures give a more technical visualization of how well the model is simulating hydrology. The preliminarily statistics done to get a general idea of how the model was performing was to calculate the volume difference/deviation (%) between the observed and simulated flows (Equation 1). Yearly and monthly volumes were examined during calibration. Approximate guidelines from Donigian et al. (1983) were generally used, these included when simulated and observed stream flow percent deviation was 10% or less the fit was considered very good, between 10% and 15% good, and 15 and 25% fair. During model calibration the annual volume difference was considered good once they fell under 10% and monthly volumes were generally considered sufficient if they were below 15%.

Equation 1: Volume Difference

$$Difference(\%) = \frac{TotalSimulatedVolume}{TotalObservedVolume}$$

The coefficient of determination (R^2) is the square of the Pearson's product-moment correlation coefficient and describes the proportion of the total variance in the observed data that can be explained by the model (Equation 2). The coefficient ranges from 0.0 to l.0, with higher values indicating better model performance (Kim et al., 2007). A coefficient of determination of 0.70 for daily flows and 0.75 for monthly flow is considered good model performance with values lower than 0.6 considered poor (BASINS, 2007).

Equation 2: Coefficient of Determination (Kim et al., 2007)

$$R^2 = \left\{ \frac{\sum_{n=1}^{N} (Q_{obs,n} - \overline{Q}_{obs})(Q_{sim,n} - \overline{Q}_{sim})}{[\sum_{n=1}^{N} (Q_{obs,n} - \overline{Q}_{obs})^2]^{1/2} [\sum_{n=1}^{N} (Q_{sim,n} - \overline{Q}_{sim})^2)]^{1/2}} \right\}^2$$

The Nash and Sutcliffe (1970) coefficient of efficiency (NSE) was also used to evaluate the predictive power of the model (Equation 3). The coefficient ranges from minus infinity to 1.0, with higher values indicating better agreement. If coefficient is greater than zero, the model is considered to be a better predictor of system behavior than the mean of the observed. According to common practice simulation results are considered to be good for values of E >= 0.75, while for values between 0.75 and 0.36 the simulation are considered satisfactory (Kim et al. 2007; Motovilov et al., 1999).

Equation 3: Nash and Sutcliffe (Kim et al., 2007)

$$NSE = 1.0 - \frac{\sum_{n=1}^{N} (Q_{obs,n} - Q_{sim,n})^2}{\sum_{n=1}^{n} (Q_{obs,n} - Q_{obs})^2}$$

After the model was calibrated and met the visual and goodness-of-fit criteria. A five year validation period was conducted in Cataloochee Creek, before trout watershed simulation to ensure the model ran well without the aid of calibration.

After the HSPF model was calibrated and validated, the hydrology of each trout site was simulated for the period between January 1, 1990 and December 31, 2007 corresponding to the years the parks has been surveying trout populations. A description of each of the 138 trout site can be found in Appendix A. The long term trout survey sites by the NPS fisheries can be seen in (Figure 13 and 14).

3.5 Indicators of Hydrologic Alteration

Once simulation of the trout watersheds was completed, the daily flows for each trout site were characterized into ecologically relevant parameters using IHA software, Version 7 developed by the Nature Conservancy. The IHA software was used in the study because it can be used to summarize long periods of daily hydrologic data into manageable ecologically relevant hydrologic parameters. Most studies agree a good baseline requirement for the number of years necessary to obtain reasonably results in characterizing the stream's flow regime is 20 years (Richter, 1997; Nature Conservancy, 2007). The IHA calculates a total of 67 statistical parameters subdivided into two groups, the IHA parameters and the Environmental Flow Component (EFC) parameters. The IHA parameters were calculated using non-parametric (median and percentile) statistics because of the non-normal nature of the daily hydrology data, recommended by the Nature Conservancy. All standard classifications for events such as large floods, high flows, and low flows were kept according to the IHA manual.

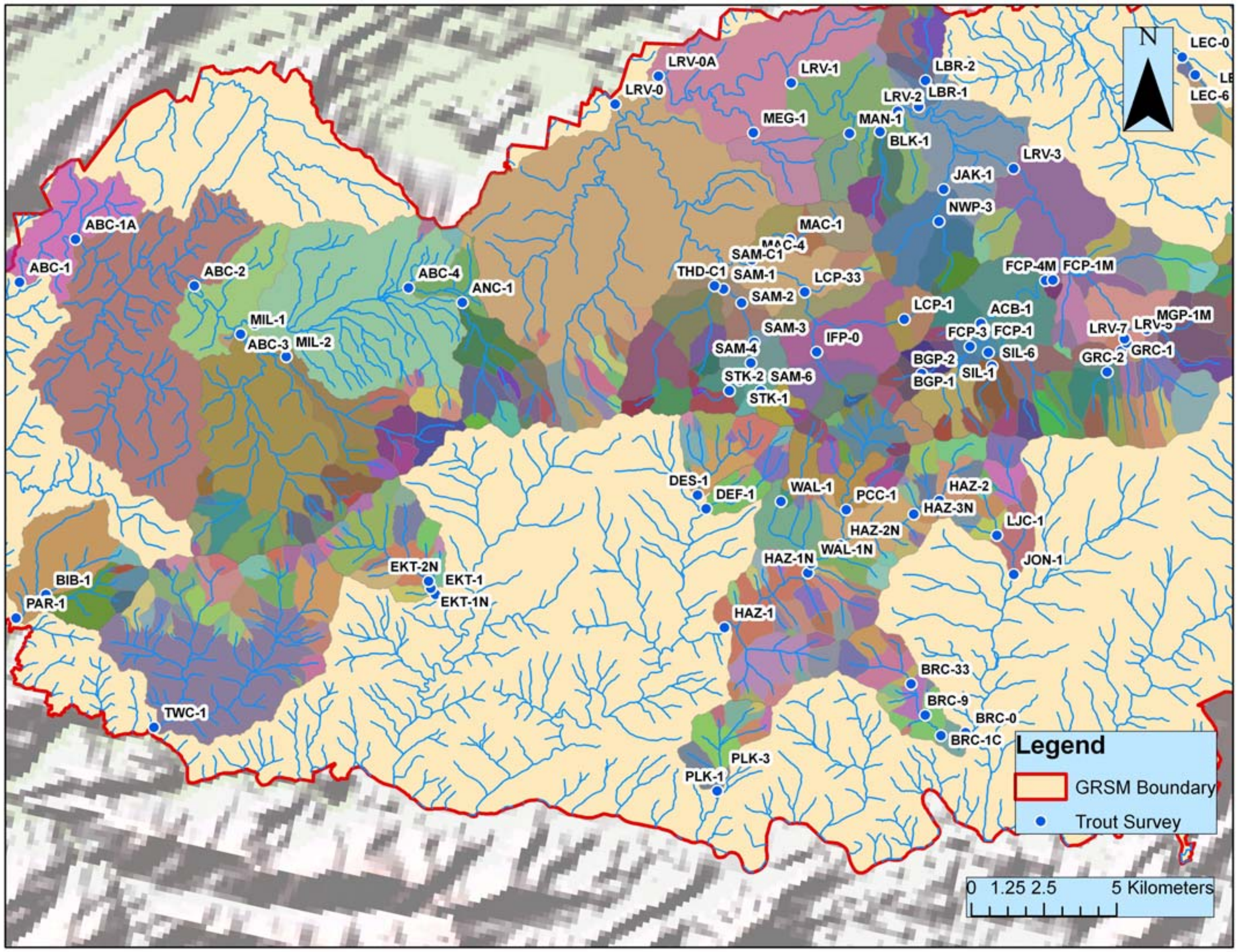

Figure 13: NPS Western Trout Survey Sites (1990-2007)

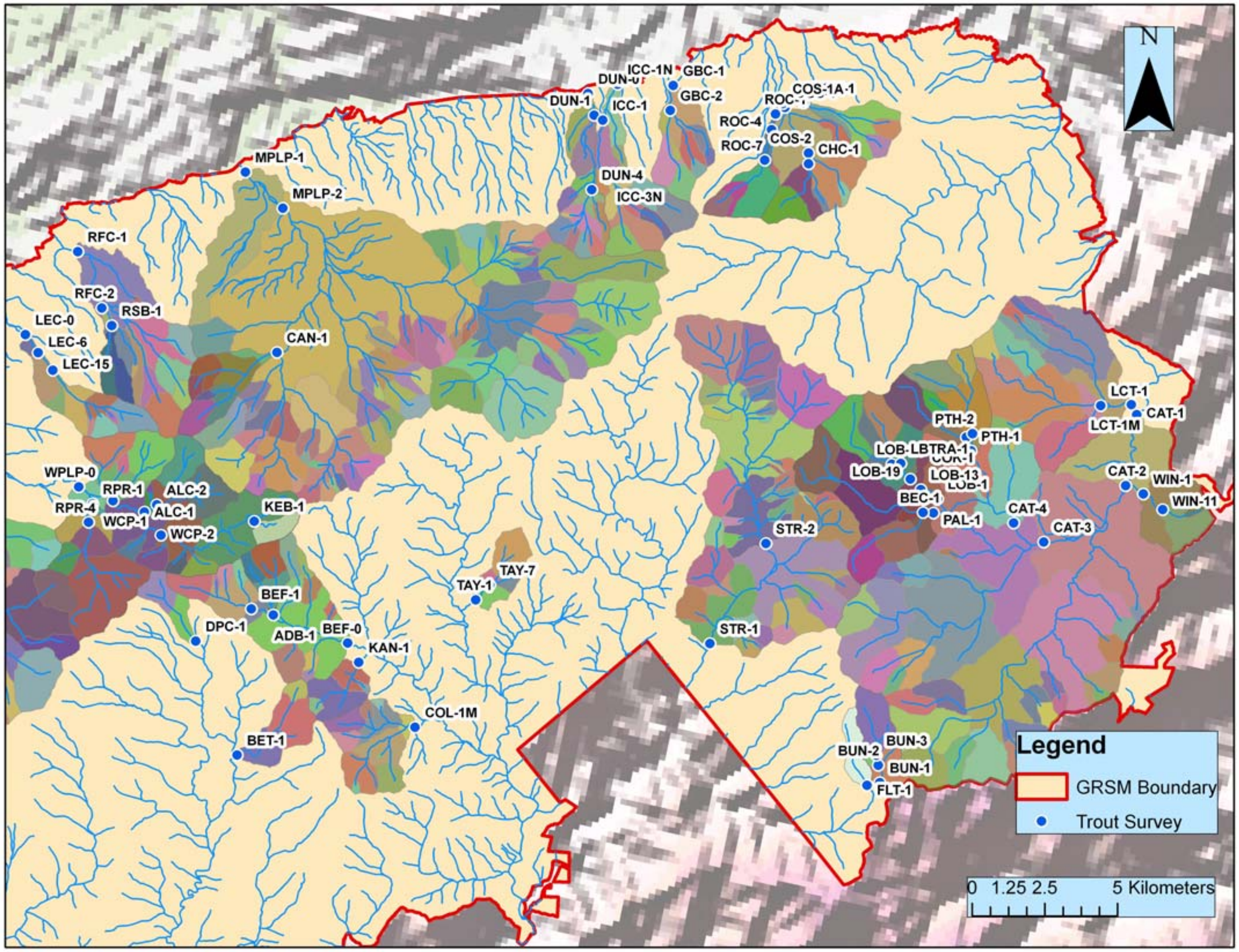

Figure 14: NPS Eastern Trout Survey Sites (1990-2007)

3.6 Statistical Analysis

The trout metrics and IHA hydrology variables were statistical analyzed in three distinct steps. The first step examined the relationship between trout populations and hydrology patterns over the entire study period. The preliminary step in the analysis was to find the mean of each trout metric and IHA variable for all survey sites over the whole study period. The means of IHA variables were normalized due to the large variation in magnitude of streamflow among sites. Normalization was done by taking IHA variable with units of flow and dividing them by the mean flow (average of the monthly medians) for the trout site. After normalization the mean trout and IHA variables were placed in a nonparametric multivariate analysis (using JMP 7.0 platform) to be used for the distinction of significant correlation between the trout metrics and IHA variables.

The second step examined the relationship between noticeable trends in trout populations and hydrology. A trend is defined as a noticeable decline or increase in a trout metric for at least four consecutive years. Trends had to have a linear regression correlation coefficient value above 0.70. The preliminary step was to find at least 15 positive and negative trends for each brook and rainbow trout metric. Young-of-the-year trout were not included in this analysis because of the small amount of observable four-year trends. The ratio of adult brook density and adult rainbow density trends were limited to at least three years in order to get enough data. After a trend was found a linear regression line was fitted to the trend. The slope of the fitted line was used to characterize the trend. The IHA hydrology variables during the trout trend were characterized in the same fashion. The characterized trout metrics and IHA trends were placed in a nonparametric multivariate analysis (using JMP 7.0 platform) to be used for the distinction of significant correlation between 4 to 5 year trends in trout population and hydrology. An additional variable, trout watershed area, was added to the analysis. The watershed area was taken in thousands of hectares in order to keep all variable within the same order of magnitude.

The third step in the analysis examined the relationship between hydrological extremes and trout abundance. Three IHA variables were chosen to represent hydrological extremes these included: the 90-day minimum, 10-year flood, and 2-year flood. The 90-day minimum was used because it characterized an extended dry period which has been shown to significantly affect aquatic communities (Richter, 1996; Lake, 2003; Magoulick & Kobza, 2003). Trout populations were examined for a four-year period during the two smallest 90-day minimums occurring during the study period. Adult brook and rainbow densities along with total biomass were examined before, during, after, and two years following the drought. The affects of the drought on the YOY brook and rainbow trout population densities were evaluated by comparing the mean YOY population and the post-drought population.

Similar to the 90-day minimum analysis, trout populations were examined before and after a large flood. A large flood consisted of the 10-year flood and the top two 2-year floods. Adult densities of both rainbow and brook trout were examined two years before and after the large flood event. YOY brook and rainbow trout were also included in the analysis with average YOY population density being compared to the post flood population. The reasoning behind using the average YOY population density was because the YOY trout before the hydrologic extreme could possibly be the adults by the time of the next year's sampling. The only criterion used in finding trout sites included whether the trout site had been surveyed within the time period of the event. Over 50 data points were used for each year in both the flood and drought analysis. A means comparison using the each pair Student's t pairwise comparison was performed in the JMP 7.0 platform. Outliers were dealt with by determining standardized residuals (Equation 4) by finding the residual and sample standard deviation (Equation 5). According to Tamhane and Dunlop (2000) a standardized residual exceeding two standard deviations was regarded as an outlier.

Equation 4: Standardized Residuals (Tamhane & Dunlop, 2000)

$$e_i \approx \frac{e_i}{s}$$

Equation 5: Sample Standard Deviation (Tamhane & Dunlop, 2000)

$$s = \sqrt{\frac{1}{1-n}\sum_{n=1}^{n}(x_i - \bar{x})^2}$$

Chapter 4: Results

4.1 HSPF Modeling

4.1.1 Model Calibration

The visualization plots of both Cataloochee Creek and Little River calibration periods and the validation period can be found in Appendix C. The goodness of fit measures for calibration and validation indicated the HSPF hydrology model was able to adequately represent the hydrological processes in GRSM. Tables 7 to 9 show the results of the goodness-of-fit measures by year for both calibration periods and the validation period. Tables 10 to 12 show the calibration results by month. Results of the Noland Divide calibration can be found in Cai & Schwartz, (2008). The results from the Cataloochee Creek calibration period indicated good model performance: all but one year met the annual 10% volume difference; eight out of ten years had daily R^2 values above 0.7; and the Nash and Sutcliffe coefficient for all years was above 0.36. The results from the Little River calibration also indicated good model performance: ten of the eleven years met the 10% annual volume difference; nine out of eleven years had R^2 values above 0.7; and the Nash and Sutcliffe coefficient for all years was above 0.36. The results from the Cataloochee Creek validation period further indicated good model performance without the aid of calibration: three of the five years met the 10% annual volume difference; all R^2 values were above 0.6; and the Nash and Sutcliffe coefficient for all years was above 0.36. Calibration and validation results by month showed the model generally met the 15% volume difference, but consistently overestimated fall flow rates; the majority of R^2 values and Nash

Table 7: Cataloochee Creek Calibration Results by Year

Year	Volume Simulated/Observed[2]	Coefficient of Determination[3] (R^2)		Nash and Sutcliffe Efficiency[4] (NSE)	
		Daily Flows	Monthly Flows	Daily Flows	Monthly Flows
1965[1]	1.146	0.72	0.96	0.39	
1966	0.965	0.46	0.55	0.45	0.54
1967	0.954	0.82	0.85	0.81	0.83
1968	0.928	0.72	0.90	0.71	0.86
1969	1.033	0.74	0.88	0.73	0.87
1970	1.068	0.84	0.93	0.74	0.91
1971	0.911	0.65	0.80	0.61	0.75
1972	0.966	0.74	0.78	0.72	0.76
1973	1.044	0.89	0.91	0.89	0.91
1974	1.063	0.84	0.94	0.79	0.93
1975[1]	1.014	0.84	0.97	0.84	0.95
Total (65-75)	0.995	0.78	0.90	0.78	0.90

[1]Shortened Years, Calibration began on 9/1/65 and ended on 9/1/75
[2]Considered good when between 1.10 and 0.90
[3]Considered good when daily above 0.70 and monthly above 0.75
[4]Consideered satisfactory above 0.36 and good above 0.75

Table 8: Little River Calibration Results by Year

Year[1]	Volume Simulated/Observed[2]	Coefficient of Determination[3] (R^2)		Nash and Sutcliffe Efficiency[4] (NSE)	
		Daily Flows	Monthly Flows	Daily Flows	Monthly Flows
1993	0.751	0.51	0.59	0.45	0.48
1994	0.949	0.71	0.81	0.62	0.76
1995	1.141	0.68	0.60	0.66	0.60
1996	0.903	0.64	0.87	0.61	0.83
1997	1.017	0.80	0.91	0.80	0.89
1998	0.985	0.78	0.91	0.76	0.89
1999	1.044	0.78	0.84	0.78	0.84
2000	0.989	0.80	0.81	0.79	0.76
2001	1.055	0.65	0.58	0.64	0.52
2002	0.989	0.80	0.87	0.77	0.85
Total (93-02)	0.978	0.70	0.80	0.67	0.79

[1]Calibration began on 1/1/93 and ended on 1/1/03
[2]Considered good when between 1.10 and 0.90
[3]Cosidered good when daily above 0.70 and monthly above 0.75
[4]Considered satisfactory above 0.36 and good above 0.75

Table 9: Cataloochee Creek Validation Results by Year

Year[1]	Volume Simulated/Observed[2]	Coefficient of Determination[3] (R^2)		Nash and Sutcliffe Efficiency[4] (NSE)	
		Daily Flows	Monthly Flows	Daily Flows	Monthly Flows
1993	0.695	0.63	0.67	0.50	0.40
1994	1.050	0.85	0.94	0.83	0.91
1995	1.004	0.61	0.63	0.60	0.61
1996	0.815	0.60	0.77	0.52	0.57
1997	1.030	0.72	0.94	0.72	0.86
Total (93-97)	0.929	0.70	0.78	0.69	0.76

[1]Validation began on 1/1/93 and ended on 1/1/97

[2]Considered good when between 1.10 and 0.90

[3]Considered good when daily above 0.70 and monthly above 0.75

[4]Considered satisfactory above 0.36 and good above 0.75

Table 10: Cataloochee Creek Calibration Results by Month

Month	Volume Simulated/Observed[1]	Coefficient of Determination[2] (R^2)	Nash and Sutcliffe Efficiency[3] (NSE)
January	0.964	0.92	0.92
February	0.903	0.70	0.60
March	0.936	0.97	0.94
April	0.916	0.93	0.86
May	0.988	0.94	0.88
June	0.928	0.93	0.87
July	1.016	0.82	0.72
August	1.127	0.64	0.56
September	1.131	0.88	0.52
October	1.242	0.95	0.49
November	1.247	0.75	0.32
December	0.998	0.84	0.84

[1]Considered good when between 1.15 and 0.85
[2]Considered good when above 0.70
[3]Considered satisfactory above 0.36 and good above 0.75

Table 11: Little River Calibration Result by Month

Month	Volume Simulated/Observed	Coefficient of Determination (R^2)	Nash and Sutcliffe Efficiency (NSE)
January	1.007	0.93	0.92
February	0.825	0.88	0.61
March	0.716	0.78	0.32
April	0.824	0.88	0.76
May	0.948	0.36	0.03
June	1.062	0.92	0.90
July	1.098	0.63	0.54
August	1.075	0.60	0.59
September[1]	1.340	0.91	0.06
October	1.366	0.78	0.15
November	1.183	0.91	0.83
December	1.308	0.60	0.13

[1]September had two years taken out of the analysis 95 and 97 because if rainfall data
[2]Considered good when between 1.15 and 0.85
[3]Considered good when above 0.70
[4]Considered satisfactory above 0.36 and good above 0.75

Table 12: Cataloochee Creek Validation Results by Month

Month	Volume Simulated/Observed (%)	Coefficient of Determination (R^2)	Nash and Sutcliffe Efficiency (NSE)
January	0.808	0.99	0.34
February	0.796	0.70	0.25
March	0.799	0.83	0.22
April	0.843	0.88	0.69
May	0.929	0.28	-0.15
June	1.175	0.76	-0.05
July	1.206	0.64	-0.52
August	0.983	0.73	0.72
September[1]	1.222	0.84	0.14
October	1.132	0.79	0.69
November[1]	1.341	0.91	0.19
December	0.943	0.19	0.15

[1]The year 1996 was taken out of the analysis due to un-observed Fall storms
[2]Considered good when between 1.15 and 0.85
[3]Considered good when above 0.70
[4]Considered satisfactory above 0.36 and good above 0.75

and Sutcliffe values were within the acceptable range. Overall the calibration and validation results are comparable to results from other scholarly studies (Bergman et al., 2002; Kim et al. 2007; Diaz-Ramirez et al., 2008).

4.1.3 Hydrological Parameters

The values of the calibrated hydrological parameters did show a generally trend with change in elevation. A noticeable decrease in amount of water lost to deep groundwater was seen with a decrease in elevation. A noticeable increase in storage, evapotranspiration, and seasonal changes was observed with a decrease in elevation. Overall the parameter used to model the trout watersheds generally made physically sense and where not out of normal bounds with USEPA recommendations (USEPA, 2000). The calibrated values of each PWATER parameter can be seen in Appendix D.

4.2 Indicators of Hydrologic Alteration

The 67 ecological-relevant hydrologic parameters were computed for each of the 138 trout survey sites using the IHA software. A description of each of the hydrologic parameters computed by IHA can be seen in Appendix B. Figure 13 below is example of a hydrograph for the trout site FCP-1 with EFC classifications.

4.3 Statistical Analysis

4.3.1 Correlation of Hydrological Patterns with Trout Abundance

The objective of this statistical analysis was to examine whether long-term hydrology patterns related to brook and rainbow trout abundance. Relationships between each IHA hydrology variable and trout metric were examined using correlation and

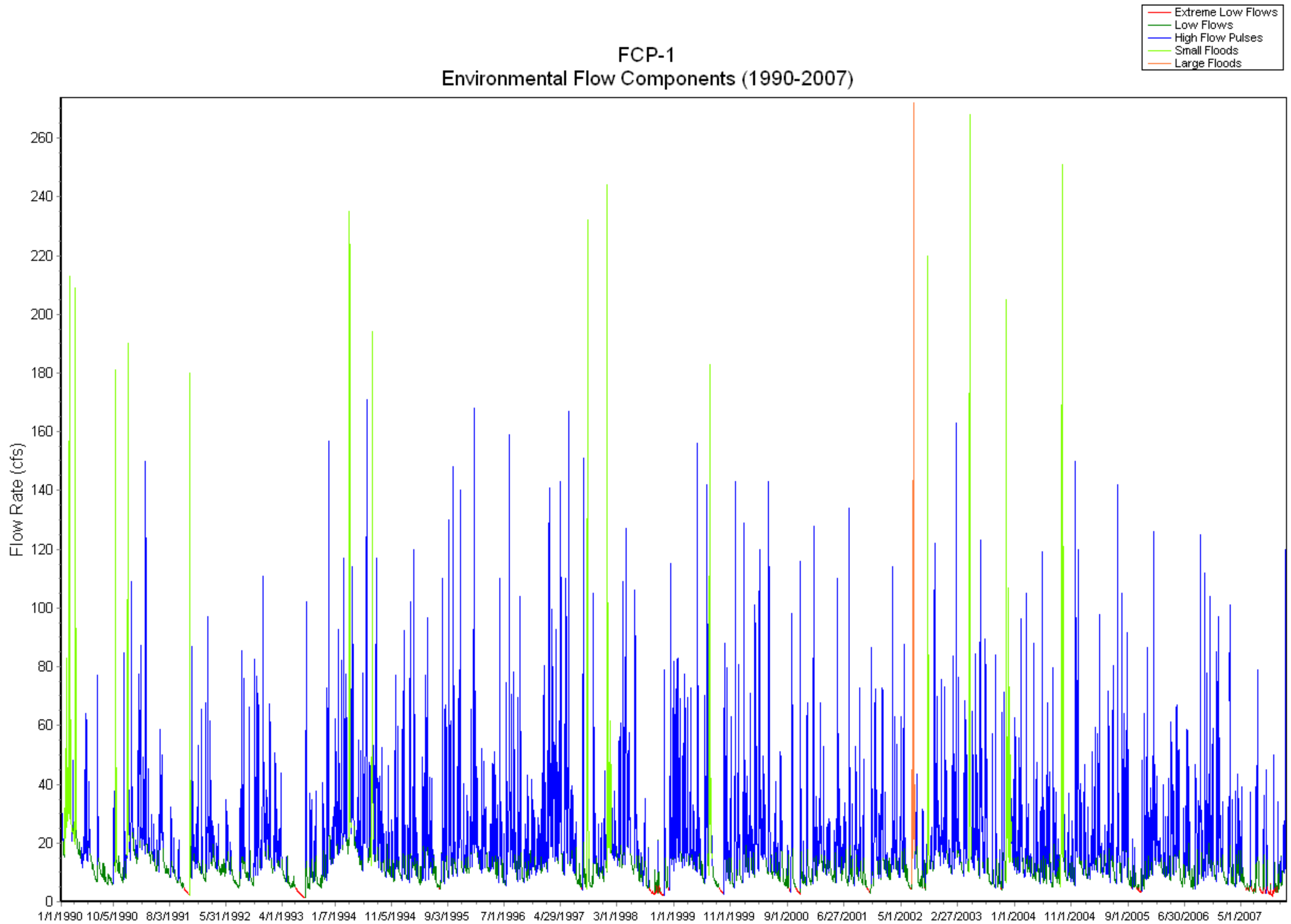

Figure 15: FCP-1: EFC Hydrograph

significance metrics (Spearman's Rho and a p-values). The criteria set for examining the results was a p-value less than 0.01 for the brook relationship was considered significant and 0.05 for rainbow. A level of significance of 0.01 was used for brooks because many IHA variables were significantly correlated with brook metrics.

Tables 13 to 18 showed results that were significant from the analysis; complete results can be seen in Appendix E. Tables 13 and 14 indicated brook trout were more abundant in streams with larger fall flows seen by a positive correlation they had with mean stream flows in September, October, and November. Brook trout were also positively correlated with high and low pulse lengths. Brook trout were found less abundant in streams with larger spring flows indicated by the negative relationship they had with mean stream flows in February, March, April, and May. Brook trout were negatively correlated with the fall rate and reversals. Tables 15 and 16 indicated rainbow trout were more abundant in streams with larger mean spring flows seen by a positive correlation they had with stream flows in March, April, and May. Rainbow trout were also positively correlated with reversals. Rainbow trout were found less abundant in streams with longer high and low pulse lengths. Tables 17 and 18 indicated similar results to Table 13 and 14, with higher ratio of brook trout adult densities found in streams with higher mean monthly flows in the fall and lower ratio corresponding to higher mean monthly flows in the spring.

4.3.2 Correlation of Hydrological Temporal Trends with Trout Abundance

The objective of this statistical analysis was to examine whether short term hydrology temporal trends were related to temporal trends in brook and rainbow trout

Table 13: Positive Correlation: Brook Abundance and Hydrology Patterns

Parameter Group	Hydrologic Parameter	Trout Metric	Spearman ρ	Prob.>│ρ│
1. Magnitude of monthly water conditions (IHA)	October	Adult Brook Density	0.40918	0.00003
	November	TOT Biomass Brook	0.37133	0.00017
	November	Adult Brook Density	0.36105	0.00028
	October	TOT Biomass Brook	0.35899	0.00028
	September	Adult Brook Density	0.32873	0.00101
	November	YOY Brook Density	0.28821	0.00560
	September	TOT Biomass Brook	0.27363	0.00640
	September	TOT Biomass Brook	0.27363	0.00640
4. Frequency and duration of high and low pulses (IHA)	Hi pulse L	TOT Biomass Brook	0.50	0.00
	Hi pulse L	Adult Brook Density	0.47925	0.00000
	Hi pulse L	YOY Brook Density	0.48419	0.00000
	Lo pulse L	TOT Biomass Brook	0.44105	0.00001
	Lo pulse L	YOY Brook Density	0.43709	0.00001
	Lo pulse L	Adult Brook Density	0.42258	0.00002
1. Monthly low flows (EFC)	Oct lowf	Adult Brook Density	0.31420	0.00172
	Sept lowf	Adult Brook Density	0.28140	0.00523
	Oct lowf	TOT Biomass Brook	0.27047	0.00707
	Nov lowf	TOT Biomass Brook	0.26265	0.00898

Table 14: Negative Correlation: Brook Abundance and Hydrology Patterns

Parameter Group	Hydrologic Parameter	Trout Metric	Spearman ρ	Prob.>│ρ│
1. Magnitude of monthly water conditions (IHA)	April	Adult Brook Density	-0.39620	0.00006
	April	TOT Biomass Brook	-0.36752	0.00020
	March	Adult Brook Density	-0.32552	0.00114
	February	Adult Brook Density	-0.29802	0.00303
	March	TOT Biomass Brook	-0.29012	0.00376
	April	YOY Brook Density	-0.28737	0.00575
	May	TOT Biomass Brook	-0.26976	0.00723
	May	YOY Brook Density	-0.27842	0.00753
5. Rate and frequency of water condition change (IHA)	Fall rate	Adult Brook Density	-0.41857	0.00002
	Fall rate	TOT Biomass Brook	-0.40782	0.00003
	Reversals	YOY Brook Density	-0.34794	0.00073
	Fall rate	YOY Brook Density	-0.32365	0.00175
	Reversals	TOT Biomass Brook	-0.30997	0.00190
	Reversals	Adult Brook Density	-0.29050	0.00390
1. Monthly low flows (EFC)	Jan lowf	Adult Brook Density	-0.41186	0.00003
	Mar lowf	Adult Brook Density	-0.37336	0.00017
	Jan lowf	TOT Biomass Brook	-0.36070	0.00026
	Apr lowf	TOT Biomass Brook	-0.35254	0.00037
	Apr lowf	Adult Brook Density	-0.35059	0.00043
	Mar lowf	TOT Biomass Brook	-0.34262	0.00055
	May lowf	TOT Biomass Brook	-0.28938	0.00385
	Feb lowf	Adult Brook Density	-0.28823	0.00420
	May lowf	Adult Brook Density	-0.27011	0.00746
	Feb lowf	TOT Biomass Brook	-0.26248	0.00903

Table 15: Positive Correlation: Rainbow Abundance and Hydrology Patterns

Parameter Group	Hydrologic Parameter	Trout Metric	Spearman ρ	Prob.>│ρ│
1. Magnitude of monthly water conditions (IHA)	May	TOT Biomass Rainbow	0.29449	0.00377
	May	Adult Rainbow Density	0.24225	0.01802
5. Rate and frequency of water condition change (IHA)	Reversals	TOT Biomass Rainbow	0.42586	0.00002
	Reversals	Adult Rainbow Density	0.23957	0.01937
	Reversals	YOY Rainbow Density	0.23154	0.03635
1. Monthly low flows (EFC)	Apr lowf	TOT Biomass Rainbow	0.26636	0.00908
	Apr lowf	Adult Rainbow Density	0.25366	0.01312
	Jan lowf	TOT Biomass Rainbow	0.24627	0.01614
	May lowf	TOT Biomass Rainbow	0.24108	0.01860
	Jan lowf	YOY Rainbow Density	0.24498	0.02654
	Jan lowf	Adult Rainbow Density	0.22183	0.03073
	May lowf	Adult Rainbow Density	0.22159	0.03092
	Mar lowf	TOT Biomass Rainbow	0.21981	0.03232
	Mar lowf	Adult Rainbow Density	0.21513	0.03630

Table 16: Negative Correlation: Rainbow Abundance and Hydrology Patterns

Parameter Group	Hydrologic Parameter	Trout Metric	Spearman ρ	Prob.>│ρ│
4. Frequency and duration of high and low pulses (IHA)	Hi pulse L	TOT Biomass Rainbow	-0.50217	0.00000
	Lo pulse L	TOT Biomass Rainbow	-0.46740	0.00000
	Hi pulse L	YOY Rainbow Density	-0.42304	0.00008
	Lo pulse L	YOY Rainbow Density	-0.38251	0.00039
	Hi pulse L	Adult Rainbow Density	-0.30281	0.00286
	Lo pulse L	Adult Rainbow Density	-0.25451	0.01281

Table 17: Positive Correlation: Ratio and Hydrology Patterns

Parameter Group	Hydrologic Parameter	Trout Metric	Spearman ρ	Prob.>│ρ│
1. Magnitude of monthly water conditions (IHA)	October	BKTDen/RBTDen	0.25722	0.02489
	November	BKTDen/RBTDen	0.23634	0.03984
4. Frequency and duration of high and low pulses (IHA)	Hi pulse L	BKTDen/RBTDen	0.52208	0.00000
	Lo pulse L	BKTDen/RBTDen	0.47579	0.00001

Table 18: Negative Correlation: Ratio and Hydrology Patterns

Parameter Group	Hydrologic Parameter	Trout Metric	Spearman ρ	Prob.>│ρ│
1. Magnitude of monthly water conditions (IHA)	April	BKTDen/RBTDen	-0.26794	0.01928
	February	BKTDen/RBTDen	-0.25165	0.02832
	March	BKTDen/RBTDen	-0.24082	0.03612
	May	BKTDen/RBTDen	-0.22707	0.04854
1. Monthly low flows (EFC)	Apr lowf	BKTDen/RBTDen	-0.31639	0.00536
	Jan lowf	BKTDen/RBTDen	-0.30275	0.00785
	Mar lowf	BKTDen/RBTDen	-0.27899	0.01467
	May lowf	BKTDen/RBTDen	-0.24681	0.03161
	Feb lowf	BKTDen/RBTDen	-0.24137	0.03569

abundance. Relationships between each IHA hydrology variable and trout metric were examined using the Spearman's Rho and a p-value similar to the previous analysis. A relationship among trout and predictor variables was considered significant if the p-value was less than 0.05. Only the selected IHA hydrology parameters shown to be significant in previous analysis were examined in this analysis. The hydrological and trout temporal trends used in the analysis along with complete results can be found in Appendix F.

Results indicated smaller watersheds have steeper declines and inclines in brook trout populations meaning larger streams have less steep trends in brook trout populations (Table 19 and 20). Table 19 showed brook trout inclines in abundance positively correlated with inclines in high and low pulse lengths. Table 20 showed the decline in the ratio of brook adult density to rainbow adult density was correlated with declines in February and March mean flows.

4.3.3 Correlation of Hydrological Extremes with Trout Abundance

The objective of this statistical analysis was to examine whether trout populations were impacted by hydrological extremes (i.e., floods and droughts). A means comparison using Student's t pairwise comparison was performed in (JMP 7.0 statistical platform). The paired data consisted of the trout metric values before and after a hydrological extreme event. A connecting letters report, least squares difference matrix, and ordered difference report were used to examine the results of the means comparison. Figures comparing mean YOY trout densities during a drought or before the flood were labeled 1yr and following the drought or flood were labeled 2yr. Figures comparing mean adult densities and total biomass during a drought showed means for four years; the mean

Table 19: Results of Correlation with Positive Trout Trends

Trout Metric	IHA Variable	Spearman p	Prob.>│ρ│
BKT Den Slope	Area (1,000 Hectares)	-0.72288	0.00047
BKT Den Slope	September	-0.68978	0.00108
BKT Den Slope	Rise rate	0.64737	0.00273
BKT Den Slope	October	-0.61053	0.00550
BKT Biomass Slope	Area (1,000 Hectares)	-0.63100	0.00660
BKT Den Slope	November	-0.56491	0.01173
BKT Den Slope	Lo pulse L	0.55312	0.01403
BKT/RBT Slope	Area (1,000 Hectares)	-0.51968	0.01576
BKT/RBT Slope	October	-0.50878	0.01850
RBT Den Slope	1-day min	-0.60440	0.02206
BKT Den Slope	Sept lowf	-0.50461	0.02757
BKT Den Slope	Hi pulse L	0.46904	0.04278
RBT Den Slope	May	-0.54725	0.04282
BKT/RBT Slope	Lo pulse L	0.44293	0.04434

Table 20: Results of Correlation with Negative Trout Trends

Trout Metric	IHA Variable	Spearman ρ	Prob.>│ρ│
BKT Biomass Slope	Area (1,000 Hectares)	0.68772	0.00114
BKT Density Slope	Area (1,000 Hectares)	0.56876	0.00373
BKT/RBT Slope	Reversals	-0.58910	0.01634
BKT/RBT Slope	February	-0.58824	0.01654
BKT/RBT Slope	March	-0.51988	0.03900

before the drought was labeled 1yr; the mean during the drought was labeled 2yr; the mean following the drought is labeled 3yr; and mean the second year following the drought is labeled 4yr. Figures comparing mean adult densities during a flood show means for four years; the mean two years before the flood is label 1yr; the mean a year before the flood is labeled 2yr; the mean a year following the flood is labeled 3yr; and the mean two years following is labeled 4yr. Trout data used in this analysis can be found in Appendix G.

Figures 16 and 17 showed YOY brook and rainbow trout declined in density following a drought. Figure 18 showed adult brook densities significantly increased two years following a drought. Figure 19 showed adult rainbow densities significantly declined after a drought and then recovered a year later. Figure 20 showed total brook biomass significantly increased two years following a drought. Figure 21 showed total rainbow biomass significantly declined a year after the drought and then recovered a year later. Figure 22 and 23 showed YOY brook and rainbow trout significantly declined following a flood. Figure 24 showed adult brook densities were not significantly affected by a larger flood. Figure 25 showed adult rainbow densities did not significantly decline a year following a flood, but do see a significantly declined two years following. The means comparison reports for Figures 16 to 25 are in Appendix G.

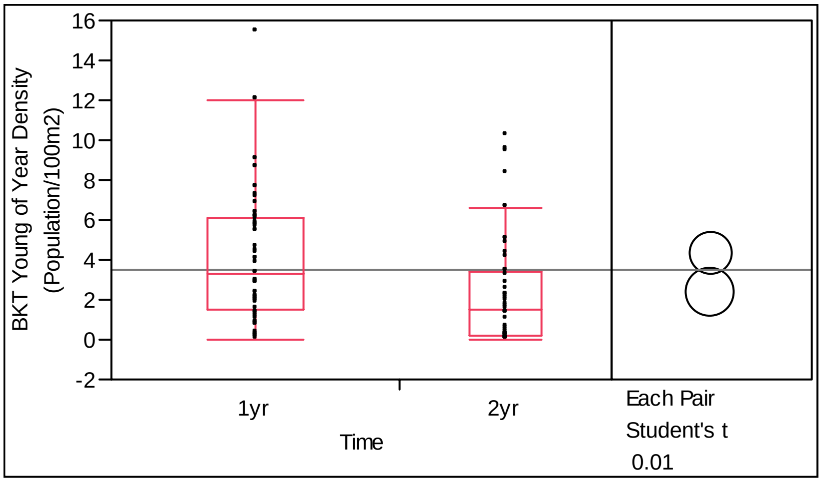

Figure 16: YOY Brook Density following a Drought

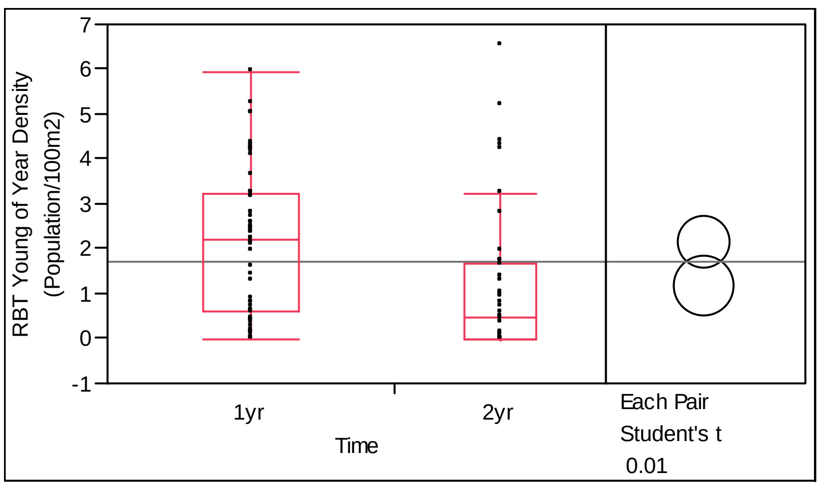

Figure 17: YOY Rainbow Density following a Drought

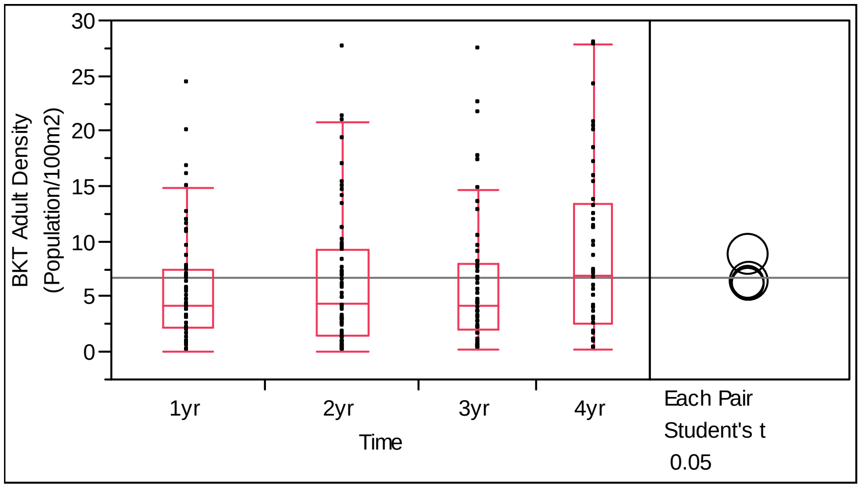

Figure 18: Adult Brook Density following a Drought

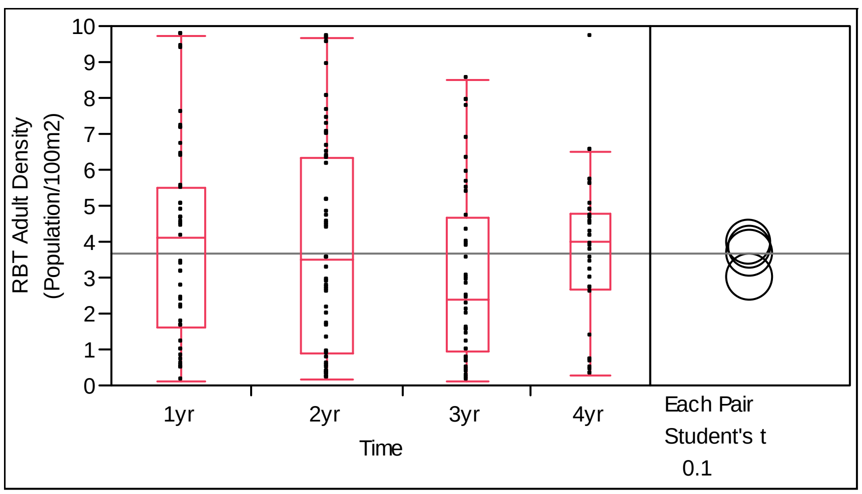

Figure 19: Adult Rainbow Density following a Drought

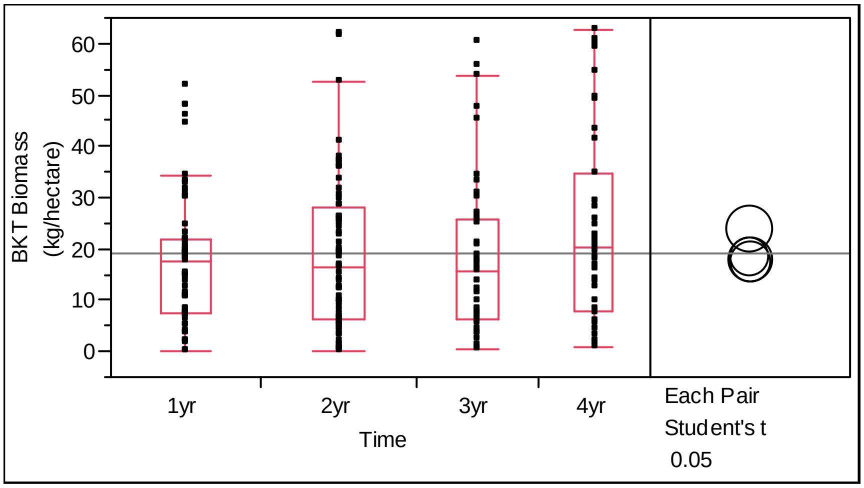

Figure 20: Total Brook Biomass following a Drought

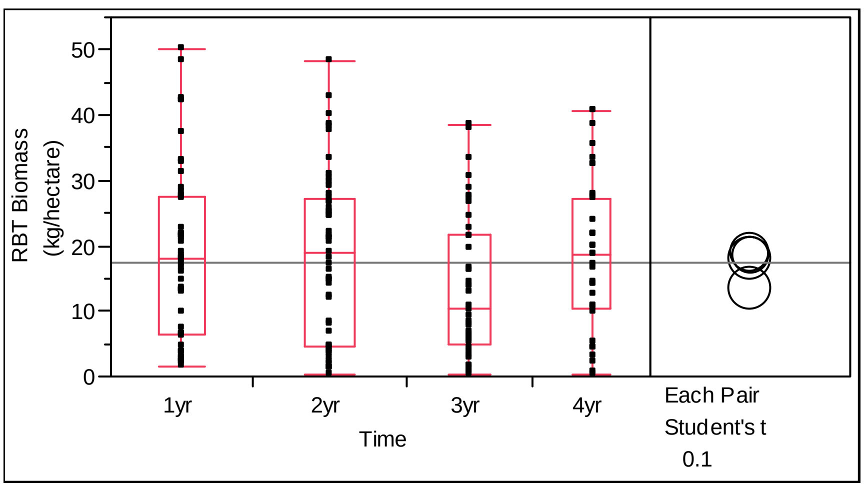

Figure 21: Total Rainbow Biomass following a Drought

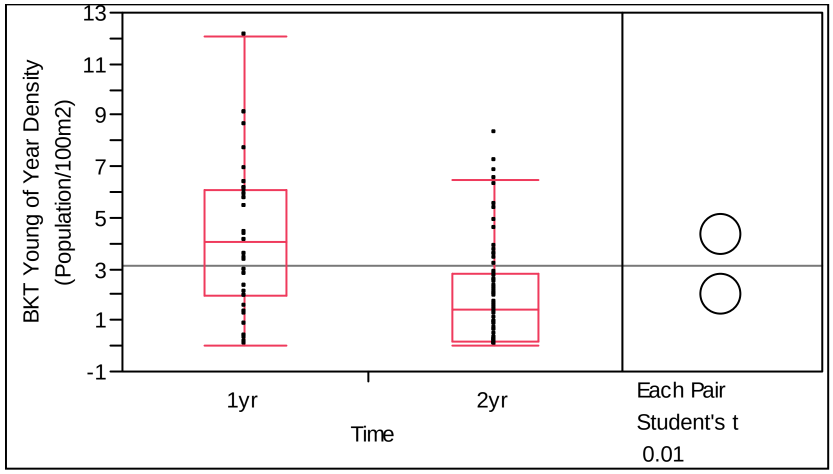

Figure 22: YOY Brook Density following a Large Flood

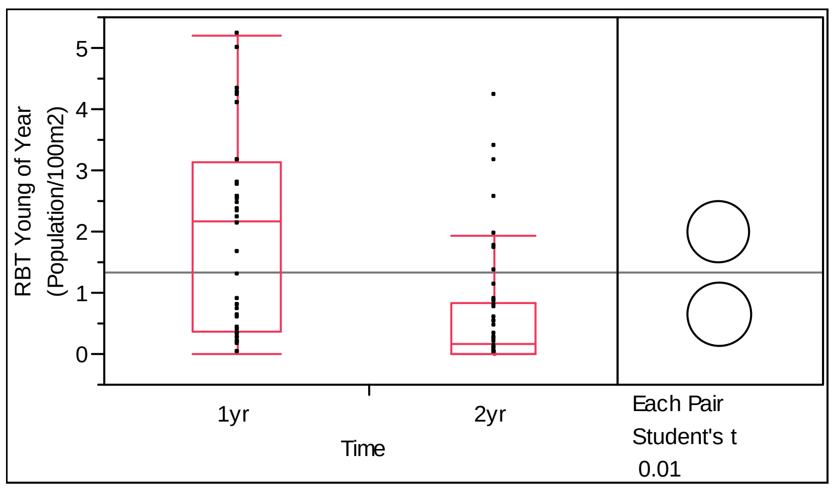

Figure 23: YOY Rainbow Density following a Large Flood

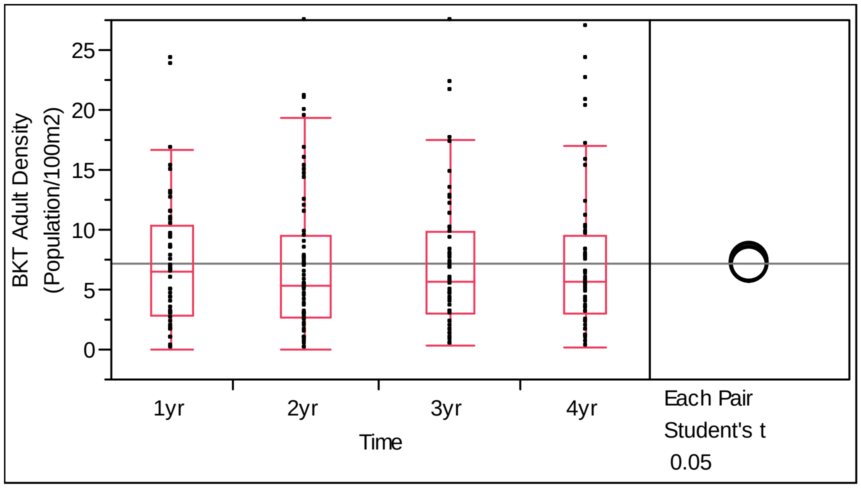

Figure 24: Adult Brook Density following a Large Flood

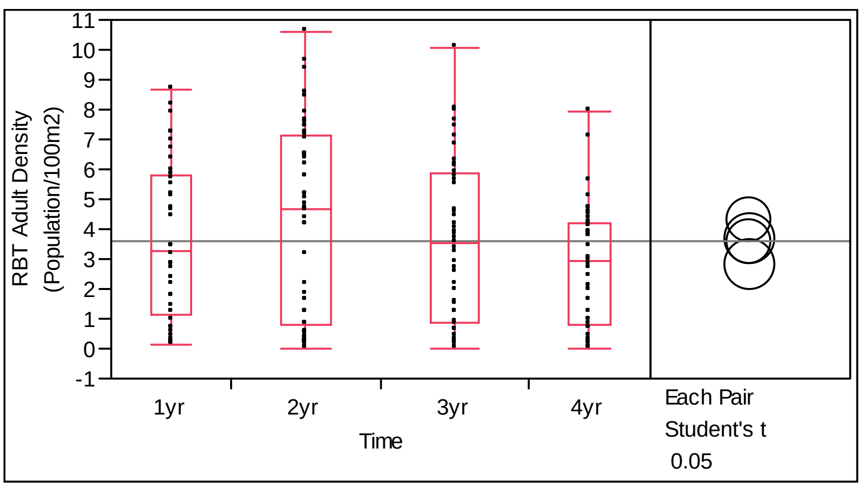

Figure 25: Adult Rainbow Density following a Large Flood

Chapter 5: Discussion

Brook trout were found more abundant in streams with larger mean flows in September, October, and November which corresponds to spawning (Etnier & Starnes, 1993; Hakala & Harman, 2004; Moore & Kulp, 2008). Brook trout spawn from late September to early November. Spawning substrate usually consists of gravel. Lower mean flows during these critical months, were found to harm recruitment especially after severe droughts occurring in late summer and early fall. Low flows associated with a severe drought may have influenced brook recruitment in several ways: 1) adult brook trout surviving the drought months likely had diminished body fat reserves leading to reduced egg deposition (Canton et al., 1984); 2) low water levels during the falls months would also have exposed more stream bed and decreased the spawning habitat available (Hakala & Harman, 2004); and 3) lower flows may also have allowed for sediment to deposit on the redds which can possibly keep oxygen from getting to the embryos (Reice et al., 1990). Hydrograph fall rates were also seen to be negatively correlated with brook trout abundance and may have impacted recruitment by exposing eggs and thereby causing desiccation of redds. Adult brook trout were found to be more resistant to severe drought than YOY trout. Young-of-the-year trout may be less tolerant than older trout due to higher temperatures and decreased oxygen content associated with lower flows (Closs & Lake, 1996). Decreased riffle habitat may have also led to the increased mortality of YOY trout (Cowx, 1984). Similar to brooks, rainbow trout were found more abundant in streams with a larger mean flows when spawning occurs. Rainbow trout spawn from late winter to early summer, and would similarly have better recruitment with better habitat conditions influenced by hydrology.

The strong influence severe droughts have on rainbow trout abundance was apparent from the results. Similar to brook trout YOY, rainbow YOY densities declined significantly after major droughts. Unlike adult brook trout, adult rainbow densities and total rainbow biomass significantly declined after severe droughts. These declines could possibly be attributed to: 1) adult rainbow trout being significantly larger than brook trout and having a harder time finding refugia (Moore & Kulp, 2008); 2) diminishing habitat and food both of which would cause increased competition during drought conditions (Chapman, 1966; Canton et al., 1984); and 3) rainbow trout are also not native to Eastern Tennessee and would not have evolved survival traits specific to the Southern Appalachians (Moore & Kulp, 2008). Adult rainbow abundance did show a strong recovery the second year after the drought to near pre-drought levels, which indicated the resilience of the species.

Brook trout were found less abundant in streams with larger mean spring flows and this may be due to smaller yearly recruitments associated with loss of redds, or displacement of recently hatched YOY by stronger currents (Harvey, 1987). Large flood events also usually occurred in late winter or early spring, corresponding to incubation and emergence of the brook trout year class. There were significantly fewer YOY brook trout after large flood events. This may be attributed to incubating eggs and YOY trout not being able to maintain their position under strong currents and being swept downstream against debris and substrate. Seegrist and Gard (1972) and Carline (2003) both found similar results and concluded winter floods destroyed incubating or recently emerged year classes. Adult brook densities, however, did not change significantly after large flood events. This is likely due to their strong swimming ability and ability to find refugia in complex habitat morphology (Dolloff, 1994). Similar to brook trout, rainbow YOY densities sharply declined after larger floods, where as adult densities did not.

The reason smaller streams have steeper shifts in brook trout populations may be attributed to increased frequency of extreme hydrological events and less habitat and refugia to take shelter in during large disturbances (Elwood & Waters, 1969). Larger streams may be more diverse and would be able to provide more refugia such as deep pools which would be utilized under extreme hydrological events (Pearsons et al., 1992). Smaller streams would also have smaller numbers of trout and more limited in their total production and would thereby be more vulnerable to larger shifts in abundance caused by extreme hydrological events.

Characterizing stream ecosystems and evaluating the ecohydrology relationships was better utilized when the species traits were examined in contrast to ecological communities. Mathews and Richter (2007) suggested looking at ecohydrology relationships utilizing IHA metrics in stages corresponding to important life cycles of the aquatic species of interest. Their proposed IHA methodology was successfully done in this study. By identifying the important life cycles of both brook and rainbow trout, such as spawning and emergence, and splitting the trout populations into two separate age-groups, the ecohydrology relationships were identified and useful conclusions were made on how hydrological patterns influence the population dynamics of brook and rainbow trout in GRSM.

5.1 Conclusions

Stream hydrological patterns do play an important role in determining the abundance of brook and rainbow trout in GRSM. The magnitude and timing of extreme hydrological events, such as droughts and floods, was seen to be a major regulator of trout assemblages. The mean magnitude of monthly water conditions was shown to be a dominant control in the distribution and abundance of rainbow and brook trout. Trout spawning success was also strongly dependent on hydrology with the strength of yearly recruitments shown to correspond to certain hydrological patterns. The IHA software was also shown to adequately characterize the flow regime into manageable ecohydrology parameters that could be statistically compared to brook and rainbow trout abundance. The conclusions of this study helps GRSM fisheries biologist understand how certain hydrology patterns and extremes influence the brook and rainbow trout populations, allowing them to manage GRSM's valuable resources appropriately.

5.2 Suggestions for Future Research

Further research into this topic of study may include: examining how the 2007 drought (Figure 26), one of the worst droughts in recent decades, effected brook trout recruitment; and examining how climate change caused by global warming could effect trout populations, would also be interesting to examine and possibly lead to future management practices. The analysis could also be tailored to examine how the ecohydrology relationship differs in brook only streams and sympatric brook-rainbow streams; brook trout abundance for instance may benefit from certain hydrological events that harm rainbows in brook-rainbow streams. Further analysis should also include the relationship baseflow water chemistry has with brook and rainbow trout abundance, because it has been shown brook trout are negatively affected by episodic acidification corresponding to acid deposition and storm events (Neff, 2007).

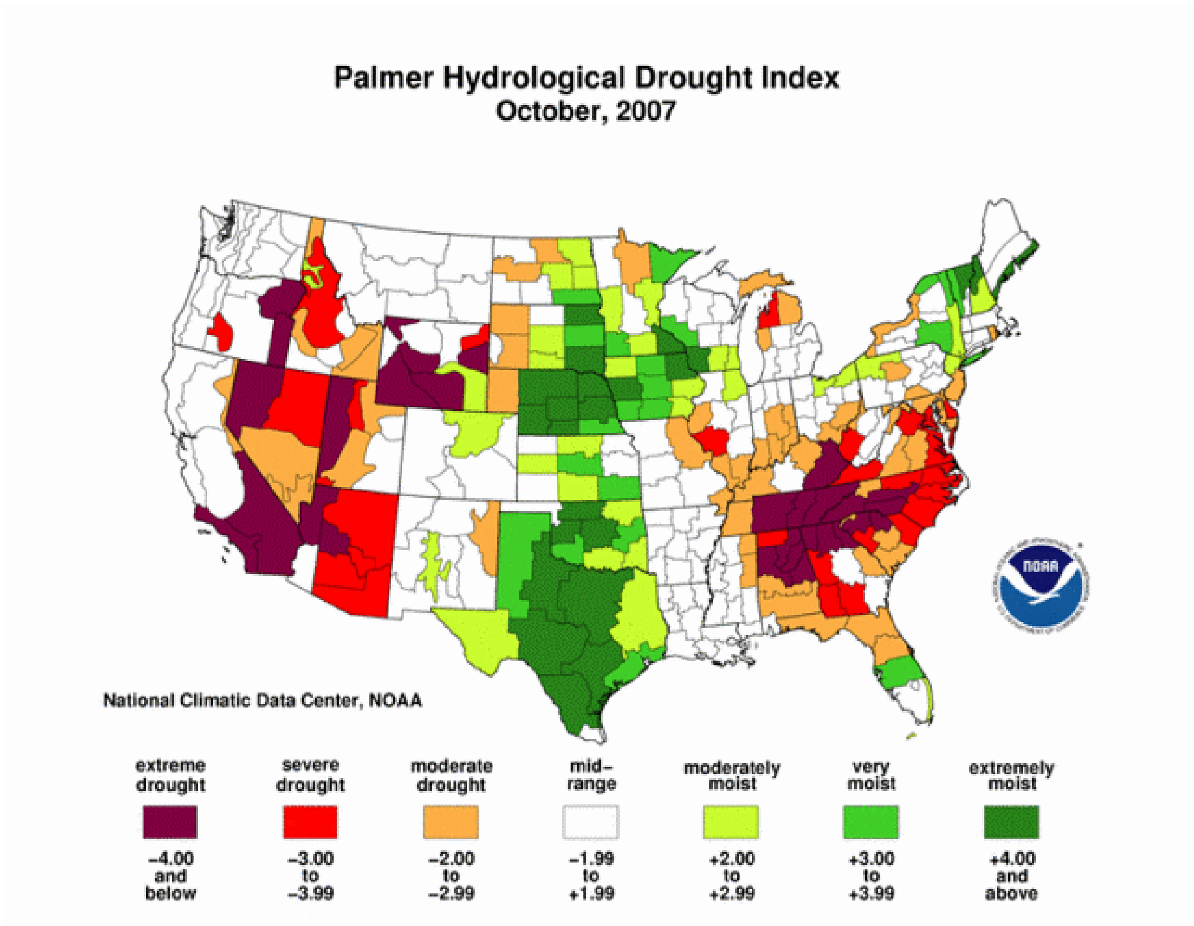

Figure 26: October 2007 East Tennessee Drought

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List of References

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Appendices

Appendix A: Description of Trout Survey Sites

A total of 138 trout survey sites were simulated throughout the park. The maps below are generally divided by HUC; trout watersheds were located in a total of 6 different HUCs throughout the park. The tables give a description of each site.

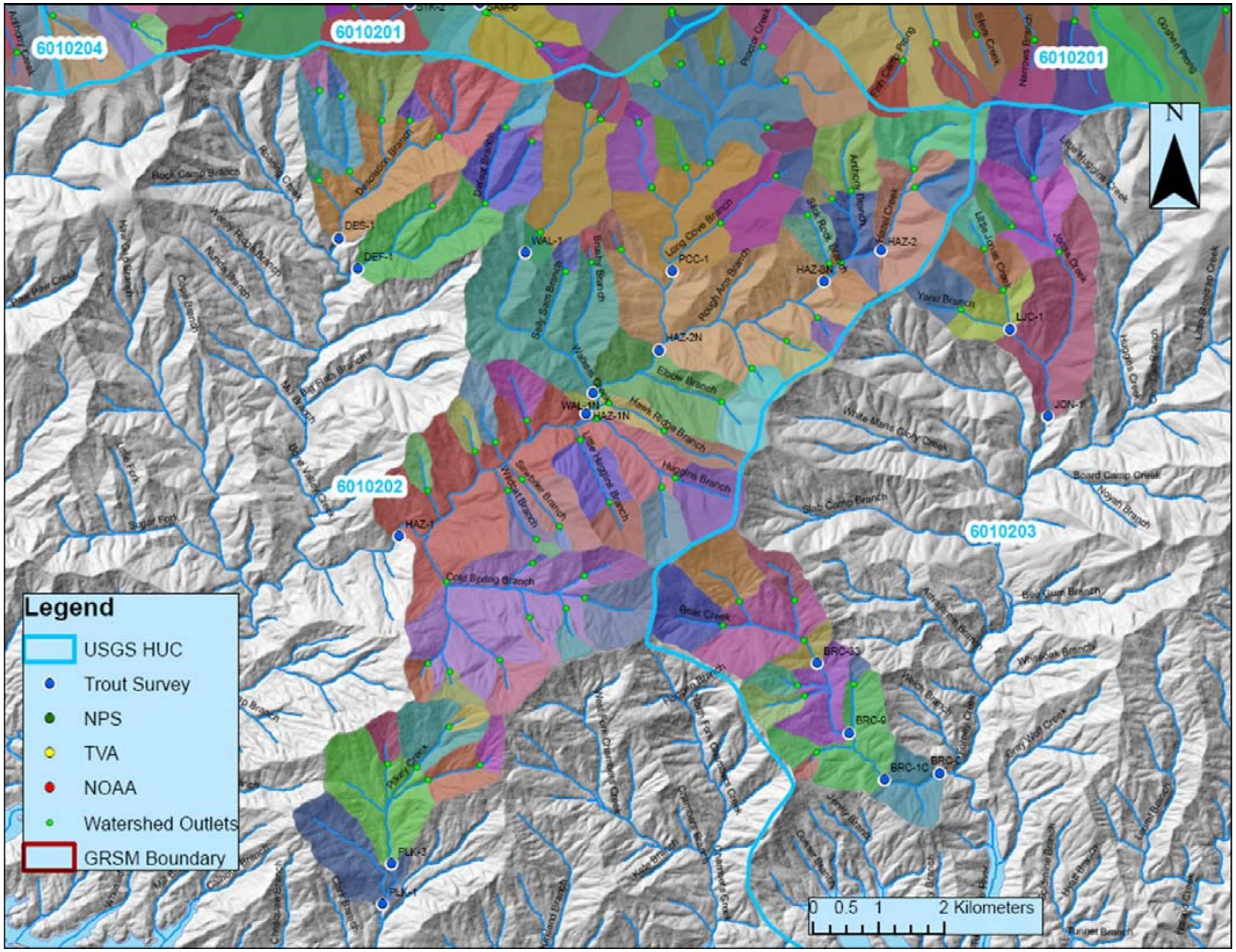

Figure A.27: Hazel Creek 06010202 and 06010203

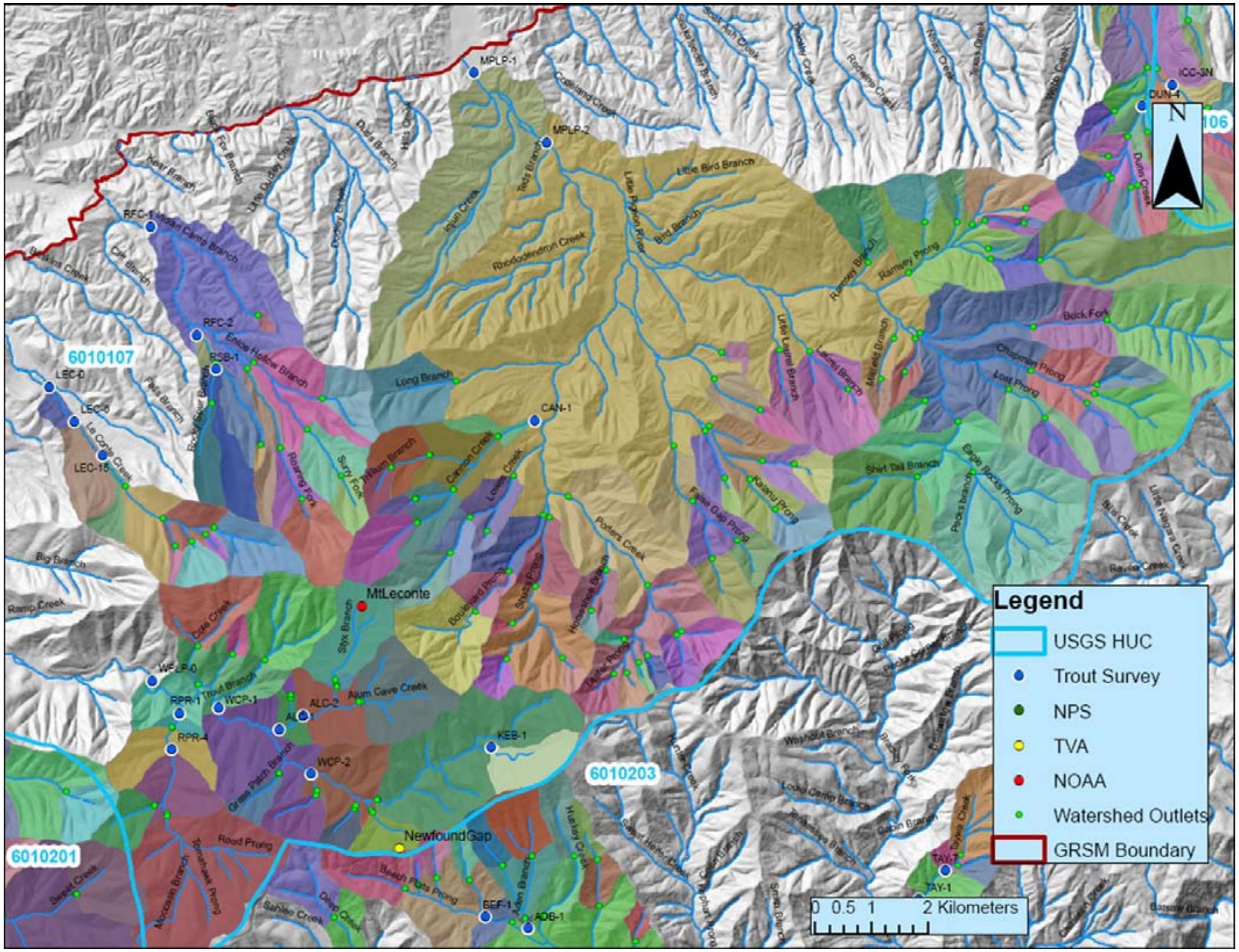

Figure A.28: Middle Prong of the Little Pigeon 06010107

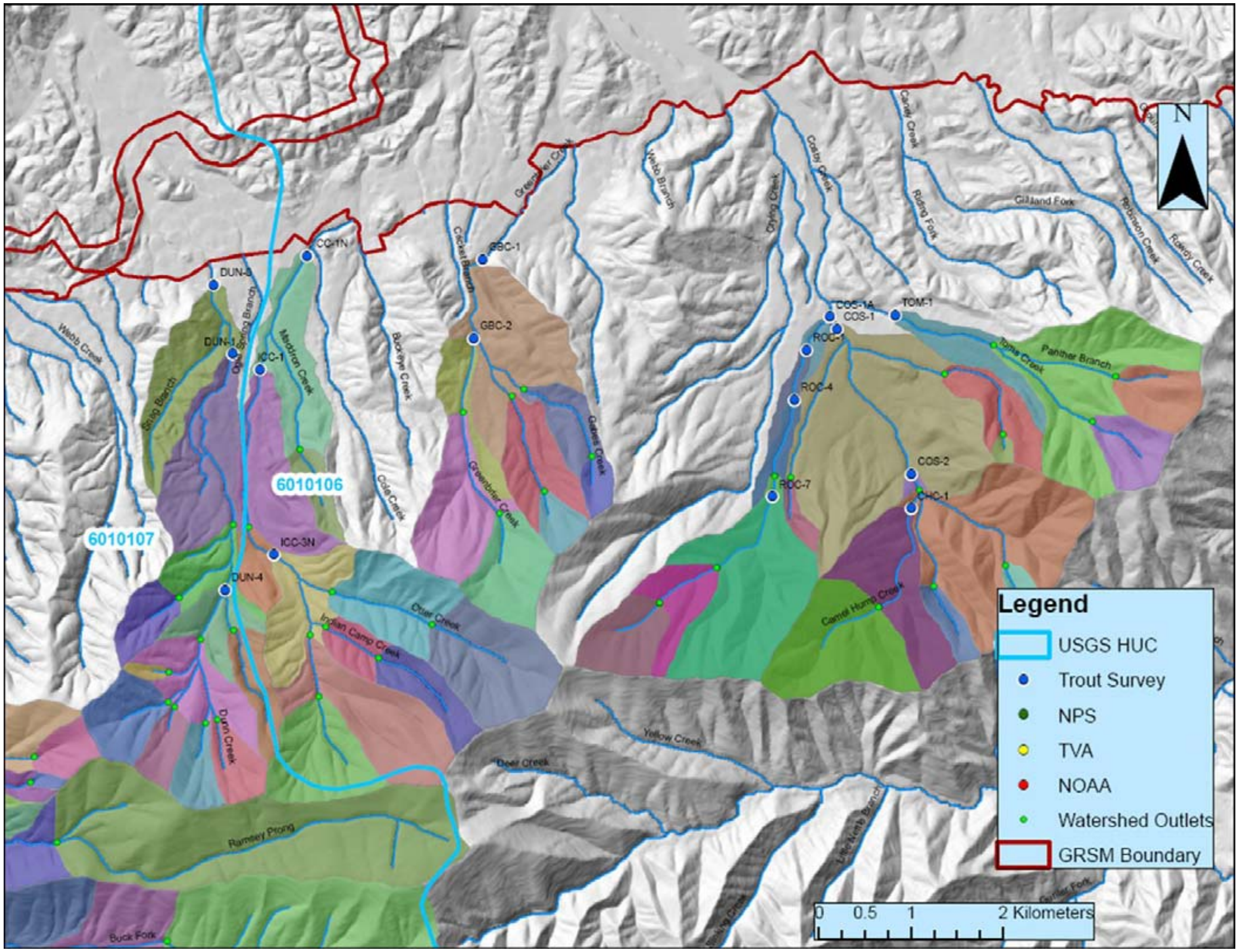

Figure A.29: Cosby Creek 06010106

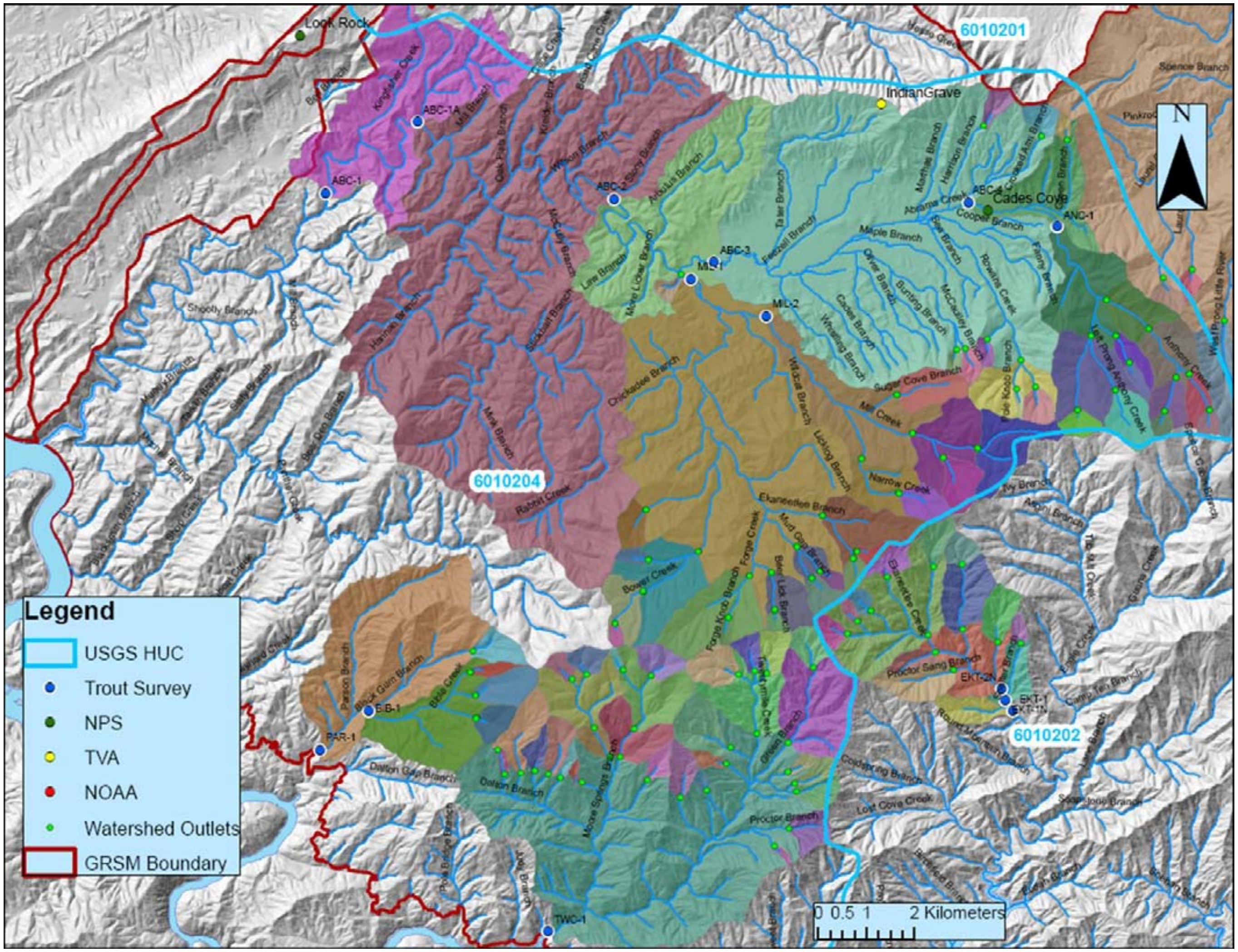

Figure A.30: Abrams Creek 06010204

Table A.21: Trout Sites within HUC 06010203 (Tuckasegee)

No.	Trout Site	Elevation (meters)	Stream Name	Stream Order	Mean[2] (cms)	Watershed (acres)	NAD83 17N Northing (meters)	NAD83 17N Easting (meters)
1	ADB-1	1,092	Aden Branch	2	0.074	605	282,690	3,942,097
2	BRC-0[1]	461	Bear Branch	2	0.212	2,211	266,706	3,928,454
3	BRC-1C	596	Bear Branch	2	0.196	1,995	265,836	3,928,344
4	BRC-9	651	Bear Branch	2	0.160	1,521	264,310	3,929,058
5	BRC-33	755	Bear Branch	2	0.126	1,093	264,804	3,930,090
6	BEF-0	777	Beech Flats Prong	3	0.396	3,980	285,265	3,941,152
7	BEF-1[1]	1,034	Beech Flats Prong	3	0.117	951	281,908	3,942,311
8	BET-1[1]	750	Beetree Creek	2	0.118	962	281,417	3,937,257
9	BUN-1	1,301	Bunches Creek	2	0.119	978	303,538	3,936,307
10	BUN-2	1,354	Bunches Creek	2	0.076	622	303,492	3,936,905
11	BUN-3	1,367	Bunches Creek	2	0.069	571	303,423	3,937,253
12	COL-1M[1]	678	Collins Creek	3	0.157	1,684	287,557	3,938,214
13	DPC-1[1]	1,055	Deep Creek	2	0.068	491	280,013	3,941,198
14	FLT-1	1,360	Flat Creek	1	0.048	392	302,972	3,936,190
15	JON-1[1]	691	Jonas Creek	3	0.235	2,063	268,324	3,933,896
16	LJC-1	851	Little Jonas Creek	1	0.077	626	267,745	3,935,245
17	KAN-1	802	Kanati Fork	2	0.079	773	285,606	3,940,466
18	STR-1	824	Straight Fork	4	1.188	12,126	297,695	3,941,113
19	STR-2	942	Straight Fork	4	0.739	6,552	299,615	3,944,561
20	TAY-1[1]	885	Tayway Creek	2	0.075	751	289,632	3,942,617
21	TAY-7[1]	962	Tayway Creek	2	0.064	548	290,111	3,943,136

[1]Combined Site
[2]Mean of Monthly Medians

Table A.22: Trout Sites within HUC 06010202 (Upper Little Tennessee)

No.	Trout Site	Elevation (meters)	Stream Name	Stream Order	Mean[2] (cms)	Watershed (acres)	NAD83 17N Northing (meters)	NAD83 17N Easting (meters)
1	DEF-1	841	Defeat Creek	2	0.101	984	257,724	3,936,177
2	DES-1[1]	771	Desolation Creek	3	0.189	1,625	257,439	3,936,633
3	EKT-1[1]	556	Ekaneetlee Creek	2	0.240	3,018	248,420	3,933,210
4	EKT-1N	575	Ekaneetlee Creek	2	0.230	2,841	248,251	3,933,413
5	EKT-2N[1]	602	Ekaneetlee Creek	2	0.216	2,631	248,180	3,933,669
6	HAZ-1	721	Hazel Creek	4	1.374	13,223	258,378	3,932,075
7	HAZ-1N	746	Hazel Creek	3	0.957	8,611	261,239	3,933,953
8	HAZ-2[1]	1,068	Hazel Creek	2	0.122	881	265,755	3,936,461
9	HAZ-2N	811	Hazel Creek	3	0.691	5,905	262,362	3,934,931
10	HAZ-3N	987	Hazel Creek	3	0.217	1,606	264,883	3,935,985
11	PLK-1[1]	460	Pilkey Creek	2	0.101	1,447	258,113	3,926,426
12	PLK-3[1]	519	Pilkey Creek	2	0.079	1,068	258,255	3,927,039
13	PCC-1	887	Proctor Creek	3	0.340	2,722	262,413	3,936,129
14	WAL-1[1]	971	Walker Creek	2	0.101	742	260,302	3,936,412
15	WAL-1N	866	Walker Creek	2	0.187	1,856	261,356	3,934,260

[1]Combined Site
[2]Mean of Monthly Medians

Table A.23: Trout Sites within HUC 06010201 (Watts Bar Lake)

No.	Trout Site	Elevation (meters)	Stream Name	Stream Order	Mean[2] (cms)	Watershed (acres)	NAD83 17N Northing (meters)	NAD83 17N Easting (meters)
1	ACB-1[1]	916	Ash Camp Branch	2	0.056	610	267,214	3,942,573
2	BLK-1[1]	635	Blanket Creek	3	0.075	987	263,723	3,949,208
3	BGP-1	994	Buckeye Gap	2	0.095	681	266,300	3,941,332
4	BGP-2	1,124	Buckeye Gap	2	0.049	350	265,166	3,940,855
5	FCP-1[1]	909	Fish Camp Prong	4	0.398	3,020	267,313	3,942,410
6	FCP-3[1]	945	Fish Camp Prong	3	0.274	2,043	266,825	3,941,783
7	FCP-1M[1]	748	Fish Camp Prong	4	0.830	7,207	269,692	3,944,078
8	FCP-4M[1]	770	Fish Camp Prong	4	0.823	7,106	269,435	3,944,068
9	GRC-1	953	Grouse Creek	2	0.173	1,345	272,042	3,941,629
10	GRC-2	1,041	Grouse Creek	2	0.091	654	271,576	3,940,918
11	IFP-0	853	Indian Flats Prong	3	0.121	1,165	261,530	3,941,597
12	JAK-1[1]	655	Jakes Creek	3	0.206	2,338	265,916	3,947,212
13	LBR-1	520	Laurel Branch	3	0.116	1,448	265,049	3,950,065
14	LBR-2	648	Laurel Branch	3	0.103	1,269	265,300	3,950,953
15	LRV-0[2]	231	Little River	5	6.288	67,894	254,597	3,950,151
16	LRV-0A	261	Little River	4	3.515	37,693	256,074	3,951,108
17	LRV-1	406	Little River	4	3.040	31,115	260,659	3,950,885
18	LRV-2	496	Little River	4	2.693	26,521	264,325	3,949,904
19	LRV-3[1]	607	Little River	4	2.142	19,657	268,318	3,947,927
20	LRV-5[1]	912	Little River	3	0.467	3,579	272,132	3,942,050

[1]Combined Site

[2]Mean of Monthly Medians

Table A.23 Continued: Trout Sites within HUC 06010201 (Watts Bar Lake)

No.	Trout Site	Elevation (meters)	Stream Name	Stream Order	Mean[3] (cms)	Watershed (acres)	NAD83 17N Northing (meters)	NAD83 17N Easting (meters)
21	LRV-7[1]	921	Little River	2	0.231	1,734	272,204	3,941,909
22	LCP-1[1]	1,051	Lynn Camp Prong	2	0.057	406	264,540	3,942,725
23	LCP-33[1]	679	Lynn Camp Prong	4	0.401	4,301	261,143	3,943,667
24	MAN-1[1]	527	Mannis Branch	2	0.050	724	262,680	3,949,143
25	MAC-1	826	Marks Creek	3	0.071	981	260,611	3,945,488
26	MAC-4	563	Marks Creek	3	0.111	1,569	259,302	3,944,751
27	MEG-1[1]	483	Meigs Creek	3	0.098	1,424	259,361	3,949,173
28	MGP-1M[1]	954	Meigs Post	2	0.221	1,618	272,895	3,942,368
29	NWP-3	791	Newt Prong	2	0.096	962	265,755	3,946,098
30	SAM-1[1]	553	Sams Creek	3	0.248	2,649	258,329	3,943,761
31	SAM-2[1]	641	Sams Creek	3	0.230	2,408	258,951	3,943,308
32	SAM-3[1]	788	Sams Creek	3	0.192	2,014	259,379	3,941,945
33	SAM-4[1]	854	Sams Creek	3	0.153	1,366	259,284	3,941,230
34	SAM-6[1]	974	Sams Creek	2	0.071	557	259,607	3,940,270
35	SAM-C1[1]	484	Sams Creek	4	0.527	5,812	258,258	3,944,477
36	SIL-1[1]	968	Silers Creek	2	0.110	803	267,455	3,941,596
37	SIL-6[1]	1,018	Silers Creek	2	0.100	716	267,581	3,941,116
38	STK-1	903	Starkey Creek	3	0.061	542	258,900	3,940,621
39	STK-2[1]	984	Starkey Creek	3	0.041	294	258,534	3,940,256
40	THD-C1	525	Thunderhead Prong	3	0.254	2,815	258,051	3,943,875

[1]Combined Site

[2] USGS Gaging Station (Littler River Calibration Outlet)

[3]Mean of Monthly Medians

Table A.24: Trout Sites within HUC 06010107 (Lower French Broad)

No.	Trout Site	Elevation (meters)	Stream Name	Stream Order	Mean[2] (cms)	Watershed (acres)	NAD83 17N Northing (meters)	NAD83 17N Easting (meters)
1	ALC-2[1]	1,094	Alum Cave Creek	3	0.172	1,411	278,659	3,945,896
2	ALC-1	1,165	Alum Cave Creek	3	0.159	1,300	278,005	3,945,451
3	CAN-1[1]	635	Cannon Creek	2	0.129	1,238	282,806	3,951,160
4	DUN-0	508	Dunn Creek	3	0.158	1,631	293,509	3,960,103
5	DUN-1[1]	570	Dunn Creek	3	0.140	1,364	293,714	3,959,357
6	DUN-4	900	Dunn Creek	3	0.096	829	293,630	3,956,791
7	KEB-1	1,354	Kephart Branch	2	0.034	276	281,999	3,945,339
8	LEC-0[1]	516	Leconte Creek	2	0.130	1,404	274,130	3,951,784
9	LEC-6[1]	595	Leconte Creek	2	0.126	1,332	274,564	3,951,170
10	LEC-15[1]	708	Leconte Creek	2	0.108	1,055	275,079	3,950,560
11	MPLP-1	306	MPL Pigeon	5	2.629	28,973	281,725	3,957,357
12	MPLP-2	334	MPL Pigeon	5	2.518	27,261	282,988	3,956,145
13	RPR-1[1]	957	Road Prong	3	0.265	2,172	276,458	3,945,952
14	RPR-4[1]	1,039	Road Prong	2	0.223	2,124	276,309	3,945,298
15	RFC-1[1]	450	Roaring Fork	3	0.303	3,627	275,932	3,954,634
16	RFC-2	634	Roaring Fork	2	0.048	695	276,753	3,952,707
17	RSB-1	735	Rocky Spur Branch	1	0.040	424	277,109	3,952,102
18	WCP-1	1,008	Walker Camp Prong	3	0.554	4,450	277,129	3,946,047
19	WCP-2	1,113	Walker Camp Prong	3	0.186	1,493	278,795	3,944,852
20	WPLP-0	879	WPL Pigeon	4	0.988	8,202	275,923	3,946,506

[1]Combined Site

[2]Mean of Monthly Medians

Table A.25: Trout Sites within HUC 06010106 (Pigeon)

No.	Trout Site	Elevation (meters)	Stream Name	Stream Order	Mean[2] (cms)	Watershed (acres)	NAD83 17N Northing (meters)	NAD83 17N Easting (meters)
1	BEC-1[1]	958	Beech Creek	3	0.216	1,759	305,038	3,945,631
2	CHC-1	759	Camel Hump Creek	1	0.063	618	301,087	3,957,676
3	CAT-1[2]	754	Cataloochee Creek	4	2.715	31,496	312,567	3,948,945
4	CAT-2	775	Cataloochee Creek	4	2.461	28,671	312,079	3,946,500
5	CAT-3	819	Cataloochee Creek	4	1.488	16,337	309,185	3,944,401
6	CAT-4	884	Cataloochee Creek	4	0.925	9,308	308,073	3,945,282
7	COK-1	1,016	Cooks Creek	2	0.083	679	306,542	3,948,227
8	COS-1	514	Cosby Creek	4	0.194	2,390	300,201	3,959,758
9	COS-1A[1]	525	Cosby Creek	4	0.275	3,298	300,271	3,959,628
10	COS-2[1]	693	Cosby Creek	3	0.122	1,327	301,081	3,958,048
11	GBC-1	540	Greenbrier Creek	3	0.112	1,342	296,437	3,960,369
12	GBC-2	683	Greenbrier Creek	3	0.052	572	296,331	3,959,541
13	ICC-1[1]	576	Indian Camp Creek	3	0.207	1,919	294,005	3,959,192
14	ICC-1N	483	Indian Camp Creek	3	0.230	2,249	294,514	3,960,422
15	ICC-3N	838	Indian Camp Creek	3	0.181	1,561	294,155	3,957,170

[1]Combined Site
[2]Mean of Monthly Medians

Table A.25 Continued: Trout Sites within HUC 06010106 (Pigeon)

No.	Trout Site	Elevation (meters)	Stream Name	Stream Order	Mean[3] (cms)	Watershed (acres)	NAD83 17N Northing (meters)	NAD83 17N Easting (meters)
16	LCT-1[1]	714	Little Cataloochee	3	0.215	3,139	311,162	3,949,323
17	LCT-1M[1]	651	Little Cataloochee	4	0.373	5,340	312,208	3,949,350
18	LOB-1[1]	932	Lost Bottoms	3	0.223	2,045	305,522	3,946,103
19	LOB-13[1]	971	Lost Bottoms	3	0.211	1,820	304,958	3,946,430
20	LOB-19[1]	1,016	Lost Bottoms	3	0.198	1,615	304,460	3,946,838
21	LOB-29[1]	1,083	Lost Bottoms	2	0.097	794	303,964	3,947,297
22	LBTRA-1[1]	1,069	Lost Bottoms Trib. A	1	0.054	441	304,256	3,947,324
23	PAL-1	958	Palmer Creek	4	0.314	2,762	305,034	3,945,630
24	PTH-1	957	Pretty Hollow	2	0.257	2,096	306,710	3,947,767
25	PTH-2	1,112	Pretty Hollow	2	0.254	2,075	306,712	3,948,353
26	ROC-1[1]	553	Rock Creek	3	0.078	877	299,955	3,959,403
27	ROC-4[1]	620	Rock Creek	3	0.076	842	299,812	3,958,868
28	ROC-7	768	Rock Creek	2	0.072	777	299,576	3,957,818
29	TOM-1[1]	580	Toms Creek	1	0.077	873	300,896	3,959,774
30	WIN-1[1]	729	Winding Stair Branch	3	0.071	1,272	312,588	3,946,287
31	WIN-11[1]	826	Winding Stair Branch	3	0.030	494	313,266	3,945,744

[1]Combined Site

[2]USGS Gaging Station (Cataloochee Creek Calibration Outlet)

[3]Mean of Monthly Medians

Table A.26: Trout Sites within HUC 06010204 (Lower Little Tennessee)

No.	Trout Site	Elevation (meters)	Stream Name	Stream Order	Watershed (acres)	UTM NAD83 17N Northing (meters)	UTM NAD83 17N Easting (meters)
1	ABC-1	329	Abrams Creek	5	39,094	234,078	3,944,019
2	ABC-1A	354	Abrams Creek	5	36,617	236,023	3,945,476
3	ABC-2[1]	402	Abrams Creek	5	24,993	241,408	3,942,175
4	ABC-3	410	Abrams Creek	4	12,188	242,146	3,942,362
5	ABC-4	437	Abrams Creek	3	2,615	247,470	3,943,576
6	ANC-1	503	Antony Creek	3	2,543	249,245	3,943,288
7	BIB-1	409	Bible Creek	3	1,172	234,982	3,933,208
8	MIL-1	412	Mill Creek	4	10,468	241,700	3,942,211
9	MIL-2	436	Mill Creek	3	2,676	243,267	3,941,437
10	PAR-1	321	Parson Branch	3	3,633	233,979	3,932,396
11	TWC-1	281	Twentymile Creek	3	9,681	238,764	3,928,652

[1]Combined Site

Appendix B: Description of IHA Parameters

IHA Parameter Group	**Hydrologic Parameters**	**Ecosystem Influences**
1. Magnitude of monthly water conditions	Mean or median value for each calendar month *Subtotal 12 parameters*	• Habitat availability for aquatic organisms • Soil moisture availability for plants • Availability of water for terrestrial animals • Availability of food/cover for fur-bearing mammals • Reliability of water supplies for terrestrial animals • Access by predators to nesting sites • Influences water temperature, oxygen levels, photosynthesis in water column
2. Magnitude and duration of annual extreme water conditions	Annual minima, 1-day mean Annual minima, 3-day means Annual minima, 7-day means Annual minima, 30-day means Annual minima, 90-day means Annual maxima, 1-day mean Annual maxima, 3-day means Annual maxima, 7-day means Annual maxima, 30-day means Annual maxima, 90-day means Number of zero-flow days Base flow index: 7-day minimum flow/mean flow for year *Subtotal 12 parameters*	• Balance of competitive, ruderal, and stress- tolerant organisms • Creation of sites for plant colonization • Structuring of aquatic ecosystems by abiotic vs. biotic factors • Structuring of river channel morphology and physical habitat conditions • Soil moisture stress in plants • Dehydration in animals • Anaerobic stress in plants • Volume of nutrient exchanges between rivers and floodplains • Duration of stressful conditions such as low oxygen and concentrated chemicals in aquatic environments • Distribution of plant communities in lakes, ponds, floodplains • Duration of high flows for waste disposal, aeration of spawning beds in channel sediments

Figure B.31: IHA Groups 1 and 2 (Nature Conservancy, 2007)

3. Timing of annual extreme water conditions	Julian date of each annual 1-day maximum Julian date of each annual 1-day minimum ——————— *Subtotal 2 parameters*	• Compatibility with life cycles of organisms • Predictability/avoidability of stress for organisms • Access to special habitats during reproduction or to avoid predation • Spawning cues for migratory fish • Evolution of life history strategies, behavioral mechanisms
4. Frequency and duration of high and low pulses	Number of low pulses within each water year Mean or median duration of low pulses (days) Number of high pulses within each water year Mean or median duration of high pulses (days) ——————— *Subtotal 4 parameters*	• Frequency and magnitude of soil moisture stress for plants • Frequency and duration of anaerobic stress for plants • Availability of floodplain habitats for aquatic organisms • Nutrient and organic matter exchanges between river and floodplain • Soil mineral availability • Access for waterbirds to feeding, resting, reproduction sites • Influences bedload transport, channel sediment textures, and duration of substrate disturbance (high pulses)
5. Rate and frequency of water condition changes	Rise rates: Mean or median of all positive differences between consecutive daily values Fall rates: Mean or median of all negative differences between consecutive daily values Number of hydrologic reversals ——————— *Subtotal 3 parameters* ——————— **Grand total 33 parameters** ———————	• Drought stress on plants (falling levels) • Entrapment of organisms on islands, floodplains (rising levels) • Desiccation stress on low-mobility streamedge (varial zone) organisms

Figure B.32: IHA Groups 2, 3, and 5 (Nature Conservancy, 2007)

EFC Type	Hydrologic Parameters	Ecosystem Influences
1. Monthly low flows	Mean or median values of low flows during each calendar month *Subtotal 12 parameters*	• Provide adequate habitat for aquatic organisms • Maintain suitable water temperatures, dissolved oxygen, and water chemistry • Maintain water table levels in floodplain, soil moisture for plants • Provide drinking water for terrestrial animals • Keep fish and amphibian eggs suspended • Enable fish to move to feeding and spawning areas • Support hyporheic organisms (living in saturated sediments)
2. Extreme low flows	Frequency of extreme low flows during each water year or season Mean or median values of extreme low flow event: • Duration (days) • Peak flow (minimum flow during event) • Timing (Julian date of peak flow) *Subtotal 4 parameters*	• Enable recruitment of certain floodplain plant species • Purge invasive, introduced species from aquatic and riparian communities • Concentrate prey into limited areas to benefit predators

Figure B.33: EFC Groups 1 and 2 (Nature Conservancy, 2007)

3. High flow pulses	Frequency of high flow pulses during each water year or season Mean or median values of high flow pulse event: • Duration (days) • Peak flow (maximum flow during event) • Timing (Julian date of peak flow) • Rise and fall rates *Subtotal 6 parameters*	• Shape physical character of river channel, including pools, riffles • Determine size of streambed substrates (sand, gravel, cobble) • Prevent riparian vegetation from encroaching into channel • Restore normal water quality conditions after prolonged low flows, flushing away waste products and pollutants • Aerate eggs in spawning gravels, prevent siltation • Maintain suitable salinity conditions in estuaries
4. Small floods	Frequency of small floods during each water year or season Mean or median values of small flood event: • Duration (days) • Peak flow (maximum flow during event) • Timing (Julian date of peak flow) • Rise and fall rates *Subtotal 6 parameters*	Applies to small and large floods: • Provide migration and spawning cues for fish • Trigger new phase in life cycle (i.e insects) • Enable fish to spawn in floodplain, provide nursery area for juvenile fish • Provide new feeding opportunities for fish, waterfowl • Recharge floodplain water table • Maintain diversity in floodplain forest types through prolonged inundation (i.e. different plant species have different tolerances) • Control distribution and abundance of plants on floodplain • Deposit nutrients on floodplain

Figure B.34: EFC Groups 3 and 4 (Nature Conservancy, 2007)

5. Large floods	Frequency of large floods during each water year or season Mean or median values of large flood event: • Duration (days) • Peak flow (maximum flow during event) • Timing (Julian date of peak flow) • Rise and fall rates *Subtotal 6 parameters* **Grand total 34 parameters**	Applies to small and large floods: • Maintain balance of species in aquatic and riparian communities • Create sites for recruitment of colonizing plants • Shape physical habitats of floodplain • Deposit gravel and cobbles in spawning areas • Flush organis materials (food) and woody debris (habitat structures) into channel • Purge invasive, introduced species from aquatic and riparian communities • Disburse seeds and fruits of riparian plants • Drive lateral movement of river channel, forming new habitats (secondary channels, oxbow lakes) • Provide plant seedlings with prolonged access to soil moisture

Figure B.35: EFC Group 5 (Nature Conservancy, 2007)

Appendix C: HSPF Calibration and Validation Results

Appendix C includes the visualization plots from GenScn. RCH 17 is the Cataloochee Creek simulated watershed outlet and RCH 43 is the Little River's.

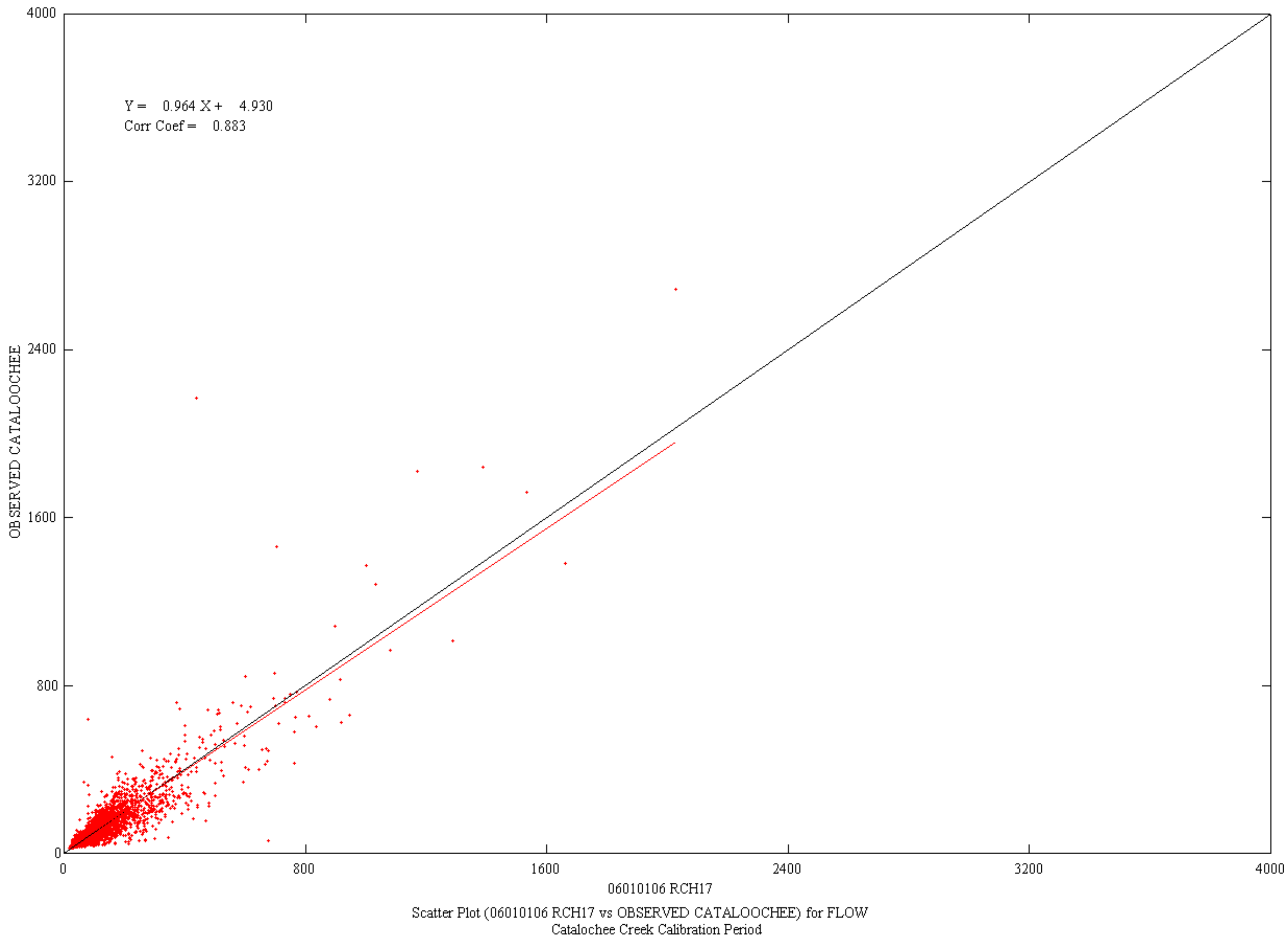

Figure C.36: Scatter Plot: Cataloochee Creek Calibration

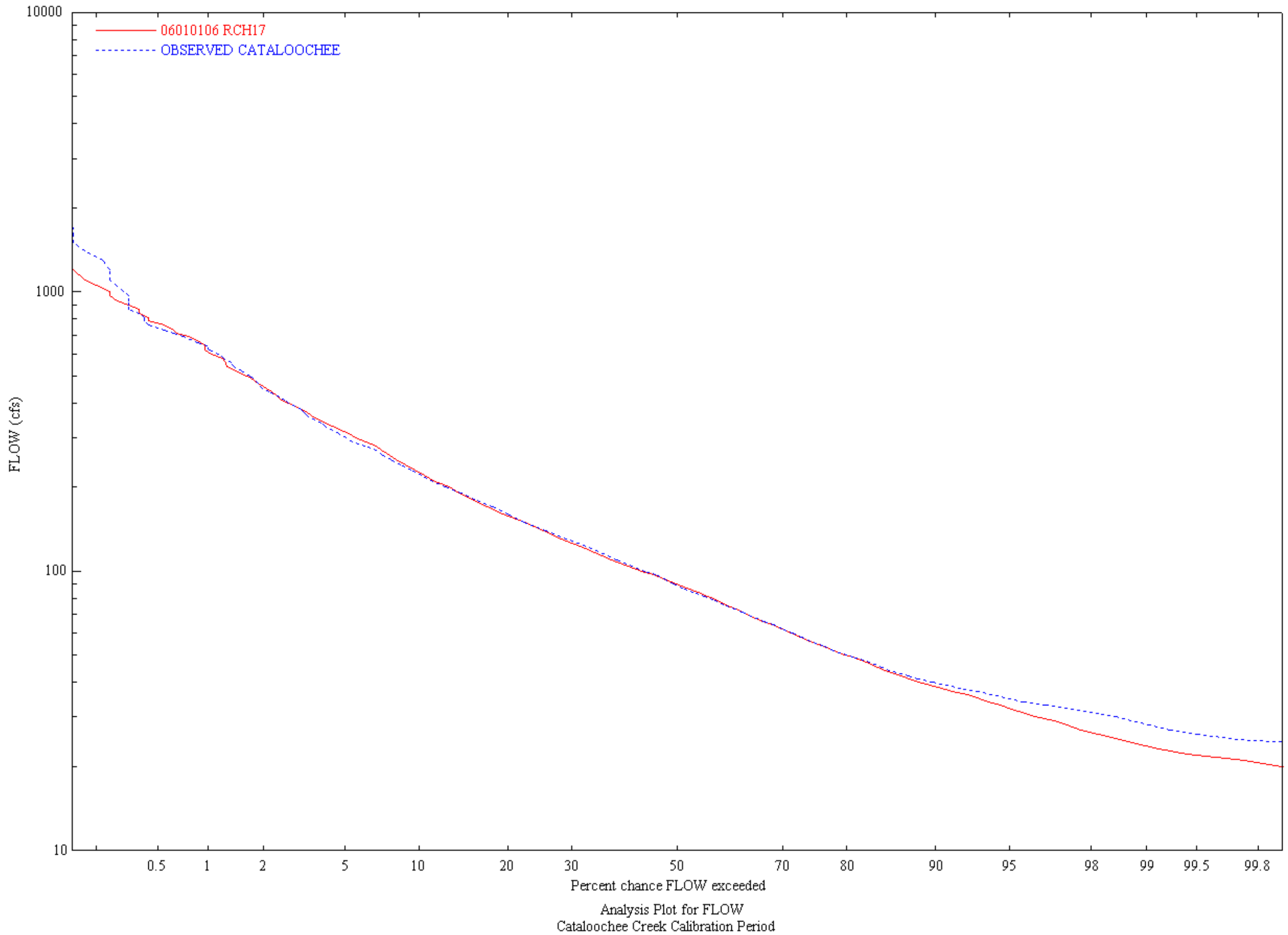

Figure C.37: Duration Curves: Cataloochee Creek Calibration

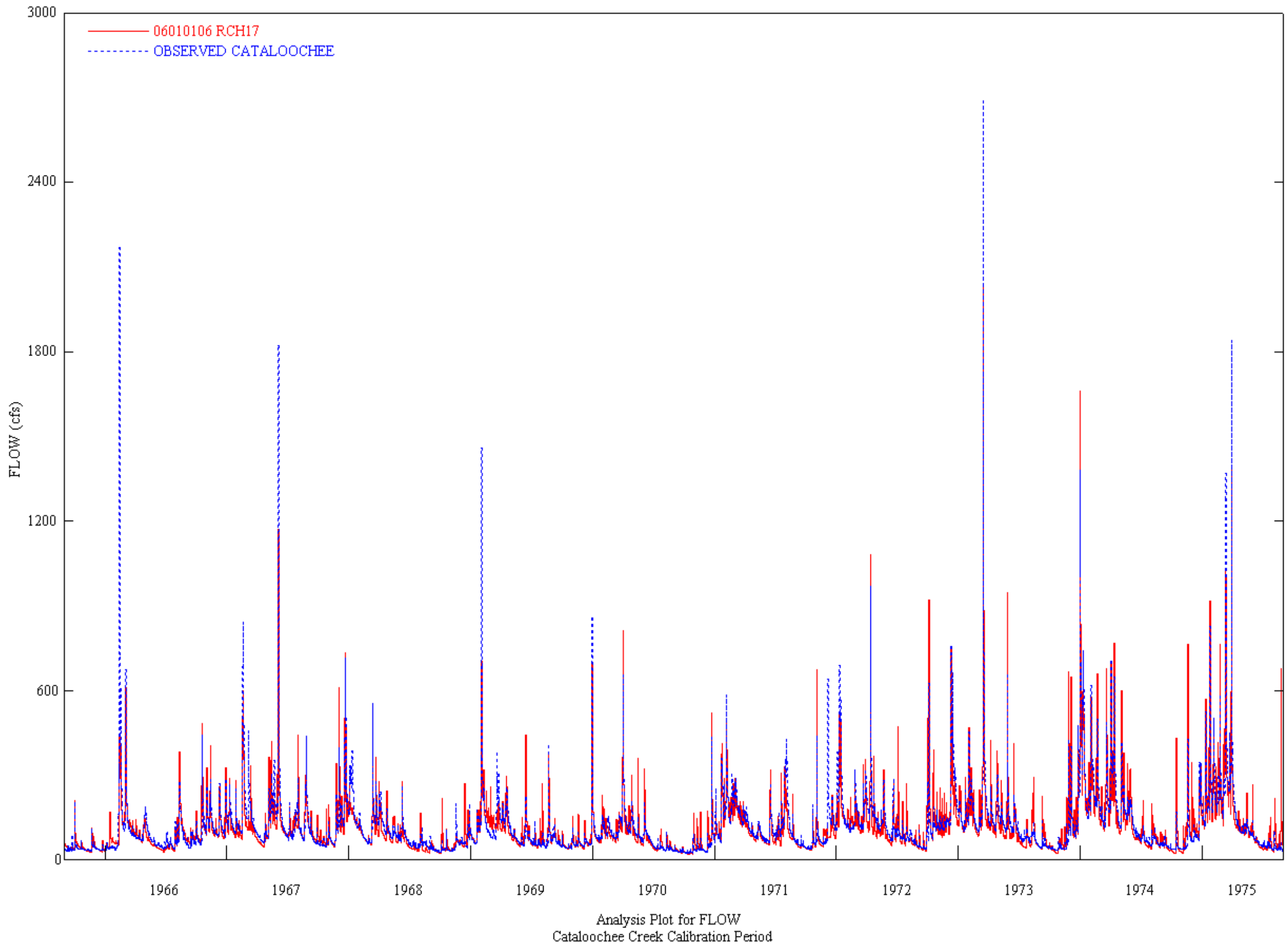

Figure C.38: Comparison Hydrographs: Cataloochee Creek Calibration

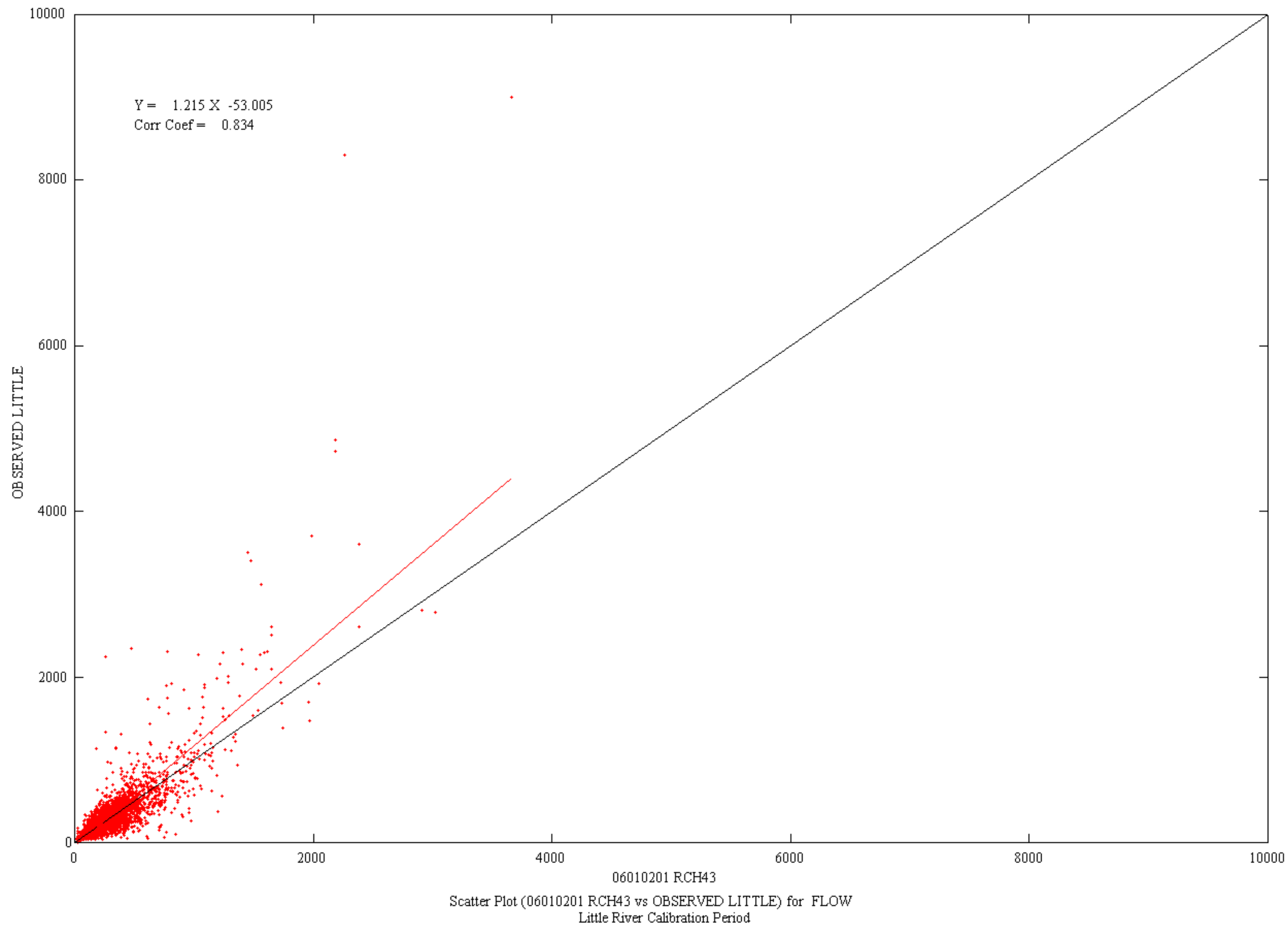

Figure C.39: Scatter Plot: Littler River Calibration

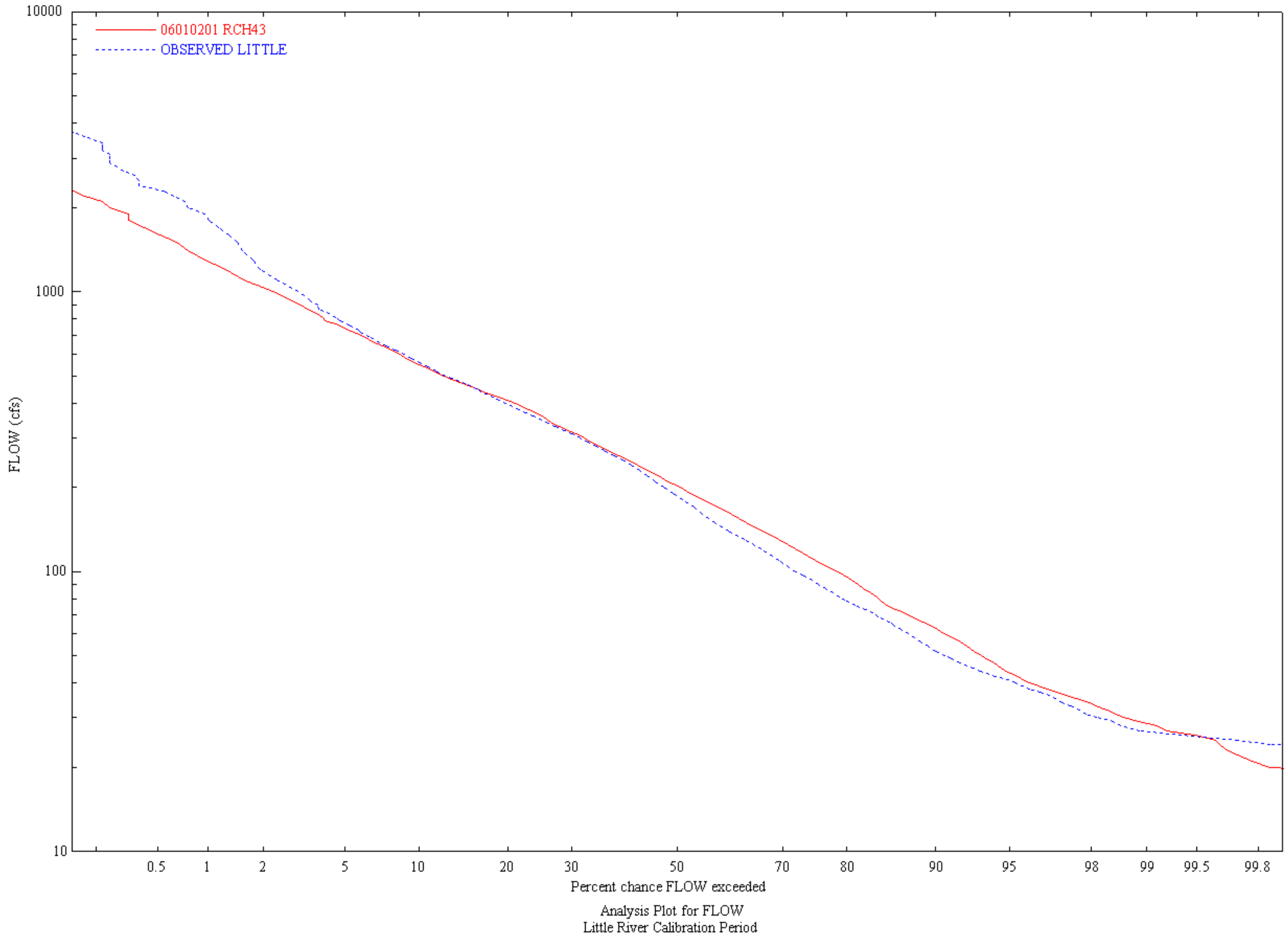

Figure C.40: Duration Curves: Little River Calibration

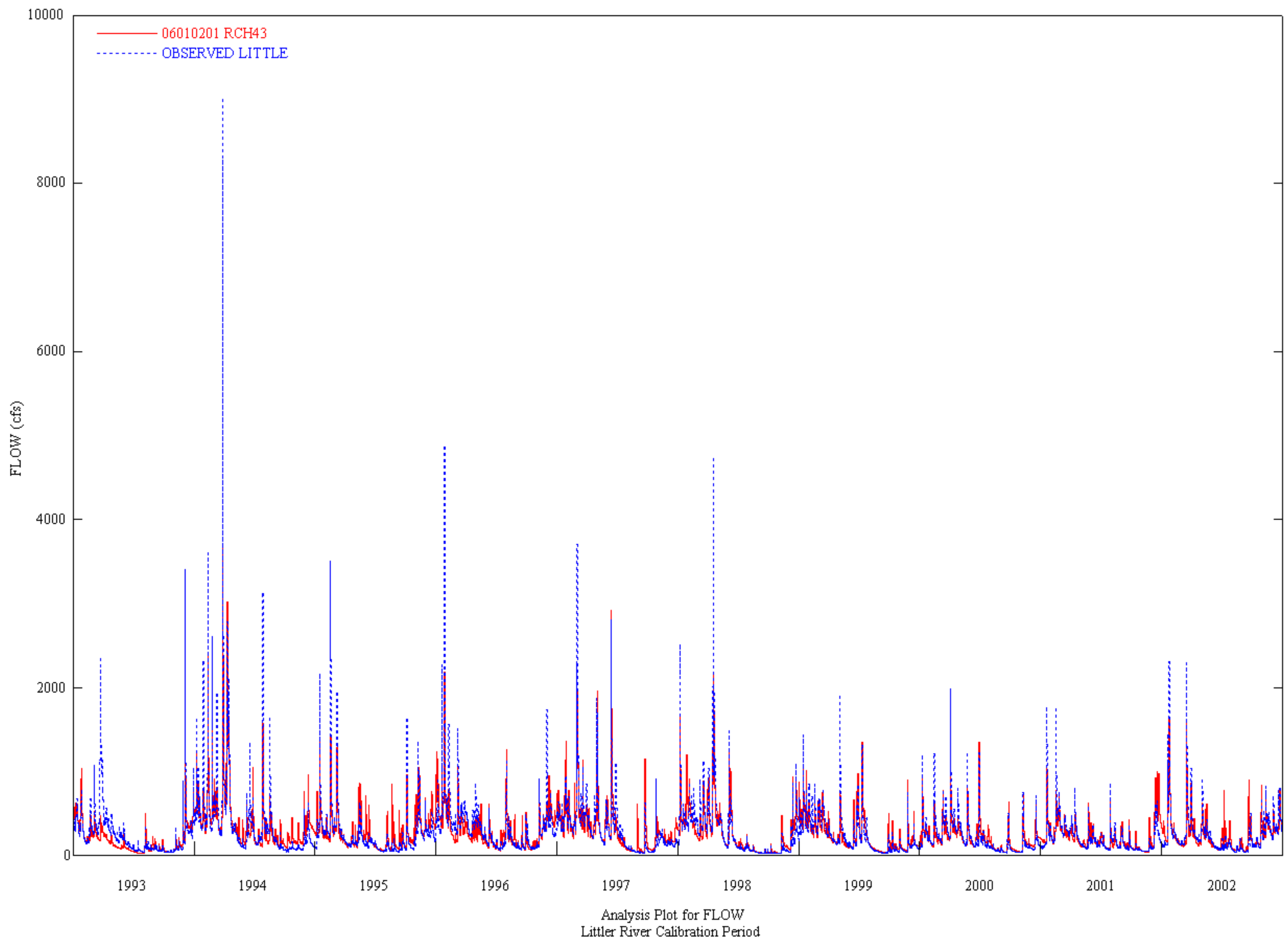

Figure C.41: Comparison Hydrographs: Little River Calibration

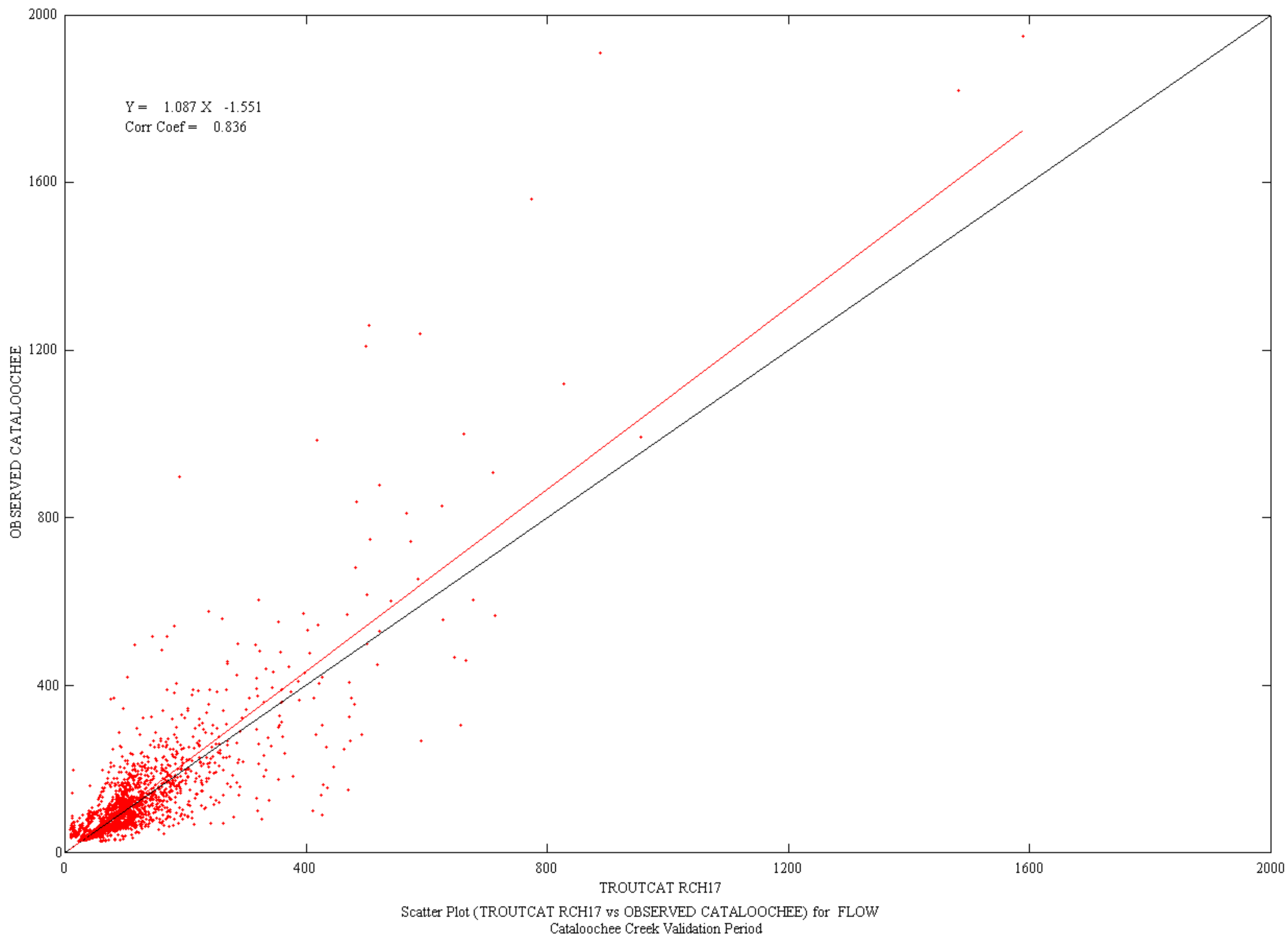

Figure C.42: Scatter Plot: Cataloochee Creek Validation

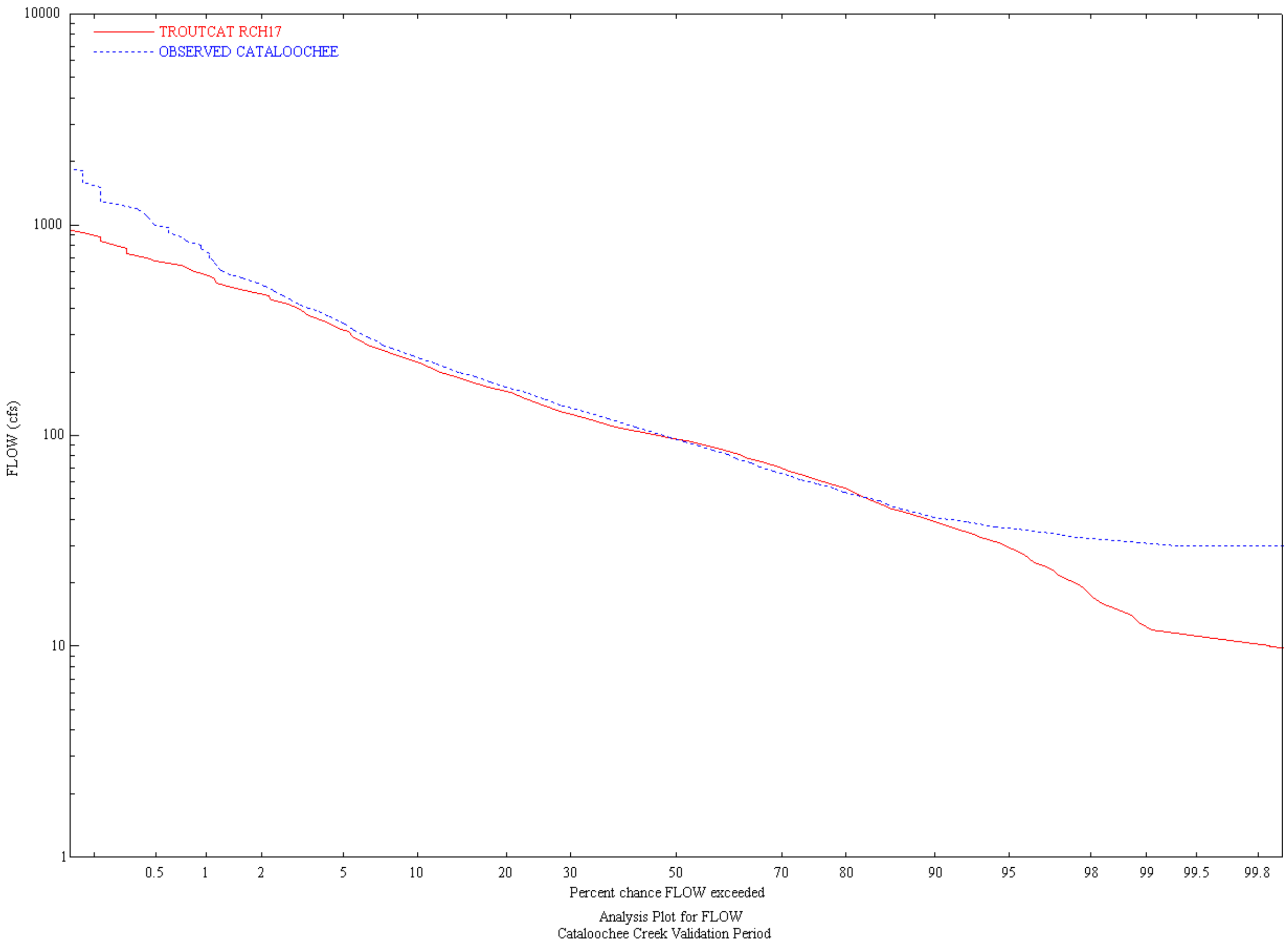

Figure C.43: Duration Curves: Cataloochee Creek Validation

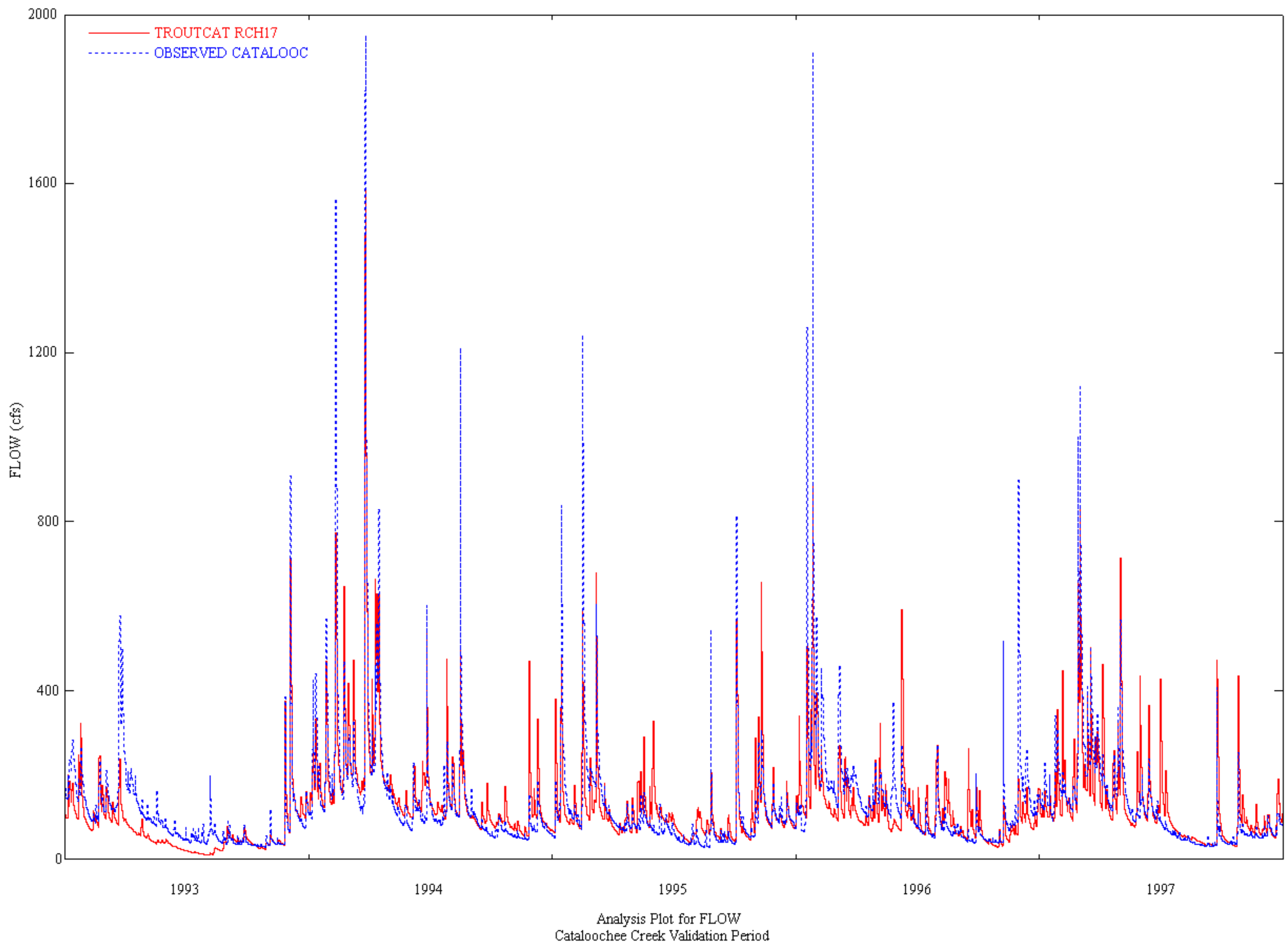

Figure C.44: Comparison Hydrographs: Cataloochee Creek Validation

Appendix D: HSPF Calibrated Hydrological Parameters

Table D.27: PARM 1

Parameter	Description	Elevation Band		
		High	Middle	Low
CSNOFG	Flag snow simulation	0	0	0
RTOPFG	Flag overland flow method	1	1	1
UZFG	Flag upper zone method	1	1	1
VCSFG	Flag monthly, CEPSC	1	1	1
VUZFG	Flat monthly, UZSN	1	0	0
VMNFG	Flag monthly, NSUR	0	0	0
VIFWFG	Flag monthly, INTFW	0	0	0
VIRCFG	Flag monthly, IRC	0	0	0
VLEFG	Flag monthly, LZETP	1	1	1

Table D.28: PARM 2

Parameter	Description	Unit	Elevation Band		
			High	Middle	Low
FOREST	Fraction of forested land	none	1	1	1
LZSN	Lower zone nominal soil moisture storage	in	5	8	11
INFILT	Index to mean soil infiltration rate	in/hr	0.2	0.23	0.23
LSUR	Length of overland flow plane	ft	150	400	400
SLSUR	Average slope of overland flow plane	none	0.21	0.18	0.17
KVARY	Groundwater recession flow parameter	1/in	0	0.02	1.8
AGWRC	Groundwater recession rate	1/day	0.95	0.98	0.99

Table D.29: PARM 3

Parameter	Description	Unit	Elevation Band		
			High	Middle	Low
PETMAX	Temp ET will be reduced by 50%	deg. F	40	40	40
PETMIN	Temp ET will be zero	deg. F	35	35	35
INFEXP	Exponent affecting infiltration rate	none	2	2	2
INFILD	Max to mean soil infiltration capacity	none	2	2	2
DEEPFR	Fraction water lost to deep aquifers	none	0.1	0.08	0.075
BASETP	ET by riparian vegetation	none	0.02	0.02	0.03
AGWETP	Fraction of land subject to direct evaporation, e.g. wetlands	none	0	0	0

Table D.30: PARM 4

Parameter	Description	Unit	Elevation Band		
			High	Middle	Low
CEPSC	Interception storage capacity of vegetation	in	0.1	0.2	0.2
UZSN	Nominal upper zone soil moisture storage	in	0.58	0.7	1.2
NSUR	Manning's n for overland flow plane	none	0.25	0.4	0.4
INTFW	Interflow inflow parameter	none	2	5	5
IRC	Interflow recession coefficient	none	0.5	0.5	0.5
LZETP	Index to lower zone evapotranspiration	none	0.2	0.4	0.7

Table D.31: MON-INTERCEP

Month	Elevation Band[1]	
	Middle (in)	Low (in)
January	0.01	0.01
February	0.01	0.01
March	0.1	0.01
April	0.1	0.01
May	0.1	0.3
June	0.1	0.3
July	0.3	0.4
August	0.3	2
September	0.3	2
October	0.3	2
November	0.3	0.7
December	0.1	0.5

[1]High Elevation Parameters were set as HSPF default values

Table D.32: MON-LZET

Month	Elevation Band[1]	
	Middle	Low
January	0.2	0.2
February	0.2	0.2
March	0.3	0.3
April	0.3	0.3
May	0.4	0.5
June	0.4	0.6
July	0.5	0.7
August	0.5	0.7
September	0.5	1.3
October	0.45	1.2
November	0.4	0.5
December	0.2	0.3

[1]High Elevation Parameters were set as HSPF default values

Appendix E: Hydrological Patterns and Trout Abundance: Full Results

This section contains the complete results of the relationships brook and rainbow trout abundances have with hydrological patterns over the entire study period.

Table E.33: Hydrology Patterns: Positive Brook Trout with IHAs

IHA Parameter Group	IHA Variable	Trout Metric	Spearman ρ	Prob.>p
1. Magnitude of monthly water conditions	October	Adult Brook Density	0.40918	0.00003
	November	TOT Biomass Brook	0.37133	0.00017
	November	Adult Brook Density	0.36105	0.00028
	October	TOT Biomass Brook	0.35899	0.00028
	September	Adult Brook Density	0.32873	0.00101
	November	YOY Brook Density	0.28821	0.00560
	September	TOT Biomass Brook	0.27363	0.00640
	September	TOT Biomass Brook	0.27363	0.00640
2. Magnitude and duration of annual extreme water conditions	1-day max	Adult Brook Density	0.38847	0.00008
	7-day max	Adult Brook Density	0.38835	0.00008
	3-day max	Adult Brook Density	0.38092	0.00012
	7-day max	TOT Biomass Brook	0.37222	0.00016
	1-day max	TOT Biomass Brook	0.34834	0.00044
	Zero days	TOT Biomass Brook	0.34644	0.00047
	3-day max	TOT Biomass Brook	0.33980	0.00062
	Zero days	Adult Brook Density	0.33363	0.00084
	30-day max	TOT Biomass Brook	0.32981	0.00091
	Zero days	YOY Brook Density	0.33800	0.00105
	30-day max	Adult Brook Density	0.32549	0.00114
	7-day max	YOY Brook Density	0.32774	0.00152
	30-day max	YOY Brook Density	0.30268	0.00354
	90-day max	Adult Brook Density	0.29266	0.00363
	90-day max	TOT Biomass Brook	0.28898	0.00390
	3-day max	YOY Brook Density	0.28927	0.00542
	1-day max	YOY Brook Density	0.28344	0.00648
	90-day min	Adult Brook Density	0.26585	0.00849
3. Timing of annual extreme water conditions	Date max	Adult Brook Density	0.31954	0.00142
	Date max	TOT Biomass Brook	0.26725	0.00781
4. Frequency and duration of high and low pulses	Hi pulse L	TOT Biomass Brook	0.49703	0.00000
	Hi pulse L	Adult Brook Density	0.47925	0.00000
	Hi pulse L	YOY Brook Density	0.48419	0.00000
	Lo pulse L	TOT Biomass Brook	0.44105	0.00001
	Lo pulse L	YOY Brook Density	0.43709	0.00001
	Lo pulse L	Adult Brook Density	0.42258	0.00002
5. Rate and frequency of water condition change	Rise rate	YOY Brook Density	0.32040	0.00196
	Rise rate	Adult Brook Density	0.45999	0.00000
	Rise rate	TOT Biomass Brook	0.41528	0.00002

Table E.34: Hydrology Patterns: Positive Brook Trout with EFCs

EFC Parameter Group	EFC Variable	Trout Metric	Spearman ρ	Prob.>p
1. Monthly low flows	Oct lowf	Adult Brook Density	0.31420	0.00172
	Sept lowf	Adult Brook Density	0.28140	0.00523
	Oct lowf	TOT Biomass Brook	0.27047	0.00707
	Nov lowf	TOT Biomass Brook	0.26265	0.00898
2. Extreme low flows				
3. High flow pulses	High1 rise	Adult Brook Density	0.31960	0.00142
	High1 rise	TOT Biomass Brook	0.27932	0.00535
4. Small floods	Sfld1 rise	Adult Brook Density	0.34673	0.00050
	Sfld1 peak	Adult Brook Density	0.31158	0.00189
	Sfld1 freq	Adult Brook Density	0.31041	0.00197
	Sfld1 rise	TOT Biomass Brook	0.30591	0.00219
	Sfld1 peak	TOT Biomass Brook	0.27500	0.00614
	Sfld1 freq	TOT Biomass Brook	0.27431	0.00627
5. Large floods				

Table E.35: Hydrology Patterns: Negative Brook Trout with IHAs

IHA Parameter Group	IHA Variable	Trout Metric	Spearman p	Prob.>p
1. Magnitude of monthly water conditions	April	Adult Brook Density	-0.39620	0.00006
	April	TOT Biomass Brook	-0.36752	0.00020
	March	Adult Brook Density	-0.32552	0.00114
	February	Adult Brook Density	-0.29802	0.00303
	March	TOT Biomass Brook	-0.29012	0.00376
	April	YOY Brook Density	-0.28737	0.00575
	May	TOT Biomass Brook	-0.26976	0.00723
	May	YOY Brook Density	-0.27842	0.00753
2. Magnitude and duration of annual extreme water conditions				
3. Timing of annual extreme water conditions	Date min	TOT Biomass Brook	-0.30617	0.00217
	Date min	Adult Brook Density	-0.27730	0.00596
4. Frequency and duration of high and low pulses				
5. Rate and frequency of water condition change	Fall rate	Adult Brook Density	-0.41857	0.00002
	Fall rate	TOT Biomass Brook	-0.40782	0.00003
	Reversals	YOY Brook Density	-0.34794	0.00073
	Fall rate	YOY Brook Density	-0.32365	0.00175
	Reversals	TOT Biomass Brook	-0.30997	0.00190
	Reversals	Adult Brook Density	-0.29050	0.00390

Table E.36: Hydrology Patterns: Negative Brook Trout with EFCs

EFC Parameter Group	EFC Variable	Trout Metric	Spearman p	Prob.>p
1. Monthly low flows	Jan lowf	Adult Brook Density	-0.41186	0.00003
	Mar lowf	Adult Brook Density	-0.37336	0.00017
	Jan lowf	TOT Biomass Brook	-0.36070	0.00026
	Apr lowf	TOT Biomass Brook	-0.35254	0.00037
	Apr lowf	Adult Brook Density	-0.35059	0.00043
	Mar lowf	TOT Biomass Brook	-0.34262	0.00055
	May lowf	TOT Biomass Brook	-0.28938	0.00385
	Feb lowf	Adult Brook Density	-0.28823	0.00420
	May lowf	Adult Brook Density	-0.27011	0.00746
	Feb lowf	TOT Biomass Brook	-0.26248	0.00903
2. Extreme low flows	Xlow1 time	TOT Biomass Brook	-0.35314	0.00036
	Xlow1 time	Adult Brook Density	-0.32080	0.00136
	Xlow1 time	YOY Brook Density	-0.30367	0.00343
3. High flow pulses	High1 fall	Adult Brook Density	-0.34435	0.00055
	High1 fall	TOT Biomass Brook	-0.29481	0.00321
4. Small floods	Sfld1 dur	Adult Brook Density	-0.39096	0.00008
	Sfld1 fall	Adult Brook Density	-0.37666	0.00014
	Sfld1 dur	TOT Biomass Brook	-0.36844	0.00019
	Sfld1 fall	TOT Biomass Brook	-0.33553	0.00073
5. Large floods				

Table E.37: Hydrology Patterns: Positive Rainbow Trout with IHAs

IHA Parameter Group	IHA Variable	Trout Metric	Spearman p	Prob.>p
1. Magnitude of monthly water conditions	May	TOT Biomass Rainbow	0.29449	0.00377
	May	Adult Rainbow Density	0.24225	0.01802
2. Magnitude and duration of annual extreme water conditions	3-day min	TOT Biomass Rainbow	0.21352	0.03774
	1-day min	TOT Biomass Rainbow	0.21340	0.03785
	1-day min	Adult Rainbow Density	0.21118	0.03995
	3-day min	Adult Rainbow Density	0.21054	0.04056
	7-day min	TOT Biomass Rainbow	0.20566	0.04556
3. Timing of annual extreme water conditions				
4. Frequency and duration of high and low pulses				
5. Rate and frequency of water condition change	Reversals	TOT Biomass Rainbow	0.42586	0.00002
	Reversals	Adult Rainbow Density	0.23957	0.01937
	Reversals	YOY Rainbow Density	0.23154	0.03635

Table E.38: Hydrology Patterns: Positive Rainbow Trout with EFCs

EFC Parameter Group	EFC Variable	Trout Metric	Spearman p	Prob.>p
1. Monthly low flows	Apr lowf	TOT Biomass Rainbow	0.26636	0.00908
	Apr lowf	Adult Rainbow Density	0.25366	0.01312
	Jan lowf	TOT Biomass Rainbow	0.24627	0.01614
	May lowf	TOT Biomass Rainbow	0.24108	0.01860
	Jan lowf	YOY Rainbow Density	0.24498	0.02654
	Jan lowf	Adult Rainbow Density	0.22183	0.03073
	May lowf	Adult Rainbow Density	0.22159	0.03092
	Mar lowf	TOT Biomass Rainbow	0.21981	0.03232
	Mar lowf	Adult Rainbow Density	0.21513	0.03630
2. Extreme low flows	Xlow1 time	Adult Rainbow Density	0.29706	0.00346
	Xlow1 time	YOY Rainbow Density	0.29087	0.00802
	Xlow1 time	TOT Biomass Rainbow	0.34395	0.00064
3. High flow pulses				
4. Small floods	Sfld1 fall	YOY Rainbow Density	0.23754	0.03165
5. Large floods				

Table E.39: Hydrology Patterns: Negative Rainbow Trout with IHAs

IHA Parameter Group	IHA Variable	Trout Metric	Spearman p	Prob.>p
1. Magnitude of monthly water conditions				
2. Magnitude and duration of annual extreme water conditions	7-day max	TOT Biomass Rainbow	-0.32901	0.00113
	30-day max	TOT Biomass Rainbow	-0.32655	0.00124
	7-day max	Adult Rainbow Density	-0.29549	0.00365
	3-day max	TOT Biomass Rainbow	-0.28966	0.00441
	3-day max	Adult Rainbow Density	-0.27735	0.00651
	30-day max	Adult Rainbow Density	-0.27327	0.00738
	7-day max	YOY Rainbow Density	-0.28712	0.00891
	1-day max	Adult Rainbow Density	-0.25842	0.01145
	1-day max	TOT Biomass Rainbow	-0.25838	0.01147
	3-day max	YOY Rainbow Density	-0.27704	0.01174
	1-day max	YOY Rainbow Density	-0.27554	0.01223
	90-day max	TOT Biomass Rainbow	-0.24453	0.01693
	30-day max	YOY Rainbow Density	-0.23471	0.03380
	90-day max	Adult Rainbow Density	-0.20950	0.04159
3. Timing of annual extreme water conditions				
4. Frequency and duration of high and low pulses	Hi pulse L	TOT Biomass Rainbow	-0.50217	0.00000
	Lo pulse L	TOT Biomass Rainbow	-0.46740	0.00000
	Hi pulse L	YOY Rainbow Density	-0.42304	0.00008
	Lo pulse L	YOY Rainbow Density	-0.38251	0.00039
	Hi pulse L	Adult Rainbow Density	-0.30281	0.00286
	Lo pulse L	Adult Rainbow Density	-0.25451	0.01281
5. Rate and frequency of water condition change				

Table E.40: Hydrology Patterns: Negative Rainbow Trout with EFCs

EFC Parameter Group	EFC Variable	Trout Metric	Spearman p	Prob.>p
1. Monthly low flows				
2. Extreme low flows	Xlow1 freq	TOT Biomass Rainbow	-0.20784	0.04327
3. High flow pulses				
4. Small floods	Sfld1 peak	YOY Rainbow Density	-0.24759	0.02492
	Sfld1 rise	Adult Rainbow Density	-0.20523	0.04603
5. Large floods	Lfld1 peak	TOT Biomass Rainbow	-0.32271	0.00142
	Lfld1 peak	Adult Rainbow Density	-0.30964	0.00226
	Lfld1 peak	YOY Rainbow Density	-0.31692	0.00372

Table E.41: Hydrology Patterns: Positive Ratio with IHAs

IHA Parameter Group	IHA Variable	Trout Metric	Spearman p	Prob.>p
1. Magnitude of monthly water conditions	October	BKTDen/RBTDen	0.25722	0.02489
	November	BKTDen/RBTDen	0.23634	0.03984
2. Magnitude and duration of annual extreme water conditions	7-day max	BKTDen/RBTDen	0.28859	0.01147
	3-day max	BKTDen/RBTDen	0.27125	0.01778
	30-day max	BKTDen/RBTDen	0.26152	0.02249
	1-day max	BKTDen/RBTDen	0.24653	0.03180
3. Timing of annual extreme water conditions				
4. Frequency and duration of high and low pulses	Hi pulse L	BKTDen/RBTDen	0.52208	0.00000
	Lo pulse L	BKTDen/RBTDen	0.47579	0.00001
5. Rate and frequency of water condition change	Rise rate	BKTDen/RBTDen	0.31057	0.00632

Table E.42: Hydrology Patterns: Positive Ratio with EFCs

EFC Parameter Group	EFC Variable	Trout Metric	Spearman p	Prob.>p
1. Monthly low flows				
2. Extreme low flows				
3. High flow pulses				
4. Small floods	Sfld1 freq	BKTDen/RBTDen	0.23809	0.03835
	Sfld1 rise	BKTDen/RBTDen	0.23573	0.04036
5. Large floods				

Table E.43: Hydrology Patterns: Negative Ratio with IHAs

IHA Parameter Group	IHA Variable	Trout Metric	Spearman p	Prob.>p
1. Magnitude of monthly water conditions	April	BKTDen/RBTDen	-0.26794	0.01928
	February	BKTDen/RBTDen	-0.25165	0.02832
	March	BKTDen/RBTDen	-0.24082	0.03612
	May	BKTDen/RBTDen	-0.22707	0.04854
2. Magnitude and duration of annual extreme water conditions				
3. Timing of annual extreme water conditions	Date min	BKTDen/RBTDen	-0.24003	0.03676
4. Frequency and duration of high and low pulses				
5. Rate and frequency of water condition change	Reversals	BKTDen/RBTDen	-0.31651	0.00534
	Fall rate	BKTDen/RBTDen	-0.27683	0.01548

Table E.44: Hydrology Patterns: Negative Ratio with EFCs

EFC Parameter Group	EFC Variable	Trout Metric	Spearman p	Prob.>p
1. Monthly low flows	Apr lowf	BKTDen/RBTDen	-0.31639	0.00536
	Jan lowf	BKTDen/RBTDen	-0.30275	0.00785
	Mar lowf	BKTDen/RBTDen	-0.27899	0.01467
	May lowf	BKTDen/RBTDen	-0.24681	0.03161
	Feb lowf	BKTDen/RBTDen	-0.24137	0.03569
2. Extreme low flows	Xlow1 time	BKTDen/RBTDen	-0.36640	0.00113
3. High flow pulses				
4. Small floods	Sfld1 dur	BKTDen/RBTDen	-0.35499	0.00165
	Sfld1 fall	BKTDen/RBTDen	-0.26983	0.01841
5. Large floods				

Appendix F: Hydrological Trends and Trout Abundance: Full Results

This section contains the complete results of the relationships brook and rainbow trout abundances have with 4 to 5 year hydrologic trends that occurred during the study period.

Table F.45: Trends: Positive Brook Adult Density

#	Trout Site	Density/year	R^2	Begin	End
1	ACB-1	3.1099	0.852	2001	2004
2	BUN-1	5.1348	0.997	2003	2007
3	BUN-1	4.3025	0.910	1992	1998
4	BUN-2	5.2305	0.892	1995	1998
5	FLT-1	7.4002	0.925	2002	2005
6	HAZ-1N	0.8634	0.905	1998	2001
7	ICC-1	1.6225	0.888	1992	1995
8	ICC-1	1.4448	0.964	1999	2002
9	ICC-1N	0.6642	0.931	1998	2002
10	LEC-15	3.7511	0.914	2000	2003
11	LEC-6	2.4141	0.922	2000	2003
12	LOB-1	1.5875	0.734	1997	2000
13	ROC-1	1.3247	0.936	1992	1996
14	ROC-4	1.4225	0.956	1992	1996
15	RPR-1	0.9196	0.790	1993	1996
16	SAM-4	3.4802	0.954	2004	2007
17	SAM-6	3.8741	0.736	1994	1997
18	SAM-6	2.6797	0.911	2003	2007
19	WCP-1	0.3816	0.853	1998	2002

Table F.46: Trends: Results in Positive Brook Adult Density

Hydrology Variable	Spearman ρ	Prob.>p
Area (1,000 Hectares)	-0.72288	0.00047
Sept	-0.68978	0.00108
Rise Rate	0.64737	0.00273
Oct	-0.61053	0.00550
Nov	-0.56491	0.01173
Low Pulse Length	0.55312	0.01403
Septlowf	-0.50461	0.02757
High Pulse Length	0.46904	0.04278
3day max	0.43684	0.06147
90day max	0.42807	0.06749
Octlowf	-0.38718	0.10148
Date max	0.26778	0.26770
Small Flood freq	-0.11796	0.63055

Table F.47: Trends: Negative Brook Adult Density

#	Trout Site	Density/year	R^2	Begin	End
1	BUN-1	-7.3343	0.970	1998	2001
2	BUN-2	-7.9473	0.860	1998	2001
3	BUN-3	-5.9879	0.848	1997	2001
4	COS-1	-0.4527	0.844	1996	2000
5	COS-2	-0.9266	0.912	2004	2007
6	DUN-1	-3.0004	0.978	2002	2005
7	FLT-1	-5.9234	0.893	1997	2000
8	ICC-1	-1.7581	0.985	2002	2005
9	ICC-1N	-0.9426	0.920	2002	2005
10	ICC-3N	-1.7022	0.917	1995	1999
11	ICC-3N	-2.0863	0.963	2002	2005
12	KAN-1	-1.7972	0.961	2000	2003
13	LOB-1	-1.6067	0.698	1993	1997
14	ROC-1	-1.405	0.955	1996	2000
15	ROC-1	-0.5478	0.700	2002	2005
16	ROC-4	-1.7103	0.813	1996	1999
17	ROC-4	-0.5193	0.979	2002	2006
18	RPR-1	-1.1074	0.919	2002	2005
19	RPR-4	-1.0934	0.814	2002	2007
20	RPR-4	-1.1403	0.882	1998	2001
21	SAM-3	-0.3121	0.874	2000	2006
22	SAM-6	-1.7609	0.907	1990	1994
23	TAY-7	-1.2944	0.850	2000	2004
24	WCP-1	-0.475	0.872	2002	2005

Table F.48: Trends: Results in Negative Brook Adult Density

Hydrology Variable	Spearman ρ	Prob.>p
Area (1,000 Hectares)	**0.56876**	**0.00373**
Feb	-0.31007	0.14033
Date min	-0.30876	0.14210
High1 fall	-0.27652	0.19086
Rev	0.26875	0.20414
Nov	-0.12000	0.57649
April	0.09478	0.65954
Oct	-0.07913	0.71322
Mar	0.06697	0.75586
Sept	-0.01652	0.93892
Fall rate	-0.00131	0.99516

Table F.49: Trends: Positive Brook Total Biomass

#	Trout Site	Biomass/year	R^2	Begin	End
1	ACB-1	5.7887	0.792	2001	2004
2	BUN-1	16.836	0.900	1992	1997
3	BUN-2	9.7708	0.944	1995	1998
4	BUN-3	10.025	0.974	2003	2006
5	BUN-3	10.97	0.856	1994	1997
6	BUN-3	10.117	0.929	1990	1993
7	FLT-1	10.811	0.711	1992	1996
8	FLT-1	13.551	0.928	2002	2005
9	HAZ-1N	2.0524	0.952	1997	2001
10	ICC-1N	3.4952	0.752	1997	2000
11	LBTR-A	4.028	0.993	1991	1995
12	LEC-15	9.1606	0.996	2000	2003
13	ROC-1	3.2667	0.933	1992	1995
14	ROC-1	1.7177	0.913	2003	2007
15	RPR-1	1.6155	0.977	1994	1997
16	SAM-4	9.46	0.907	2004	2007
17	WCP-1	2.0601	0.839	1998	2002

Table F.50: Trends: Results in Positive Brook Total Biomass

Hydrology Variable	Spearman p	Prob.>p
Area (1,000 Hectares)	-0.631	0.0066
90day max	0.39706	0.11454
3day max	0.33088	0.19454
High Pulse Length	-0.24045	0.35257
Oct lowf	-0.21078	0.41675
Oct	-0.16422	0.52882
Low Pulse Length	0.14951	0.56683
Sept	-0.13366	0.60905
Rise Rate	-0.08088	0.75763
Nov	-0.07598	0.77194
Date max	-0.07112	0.7862
Small Fld freq	-0.03087	0.90639
Nov lowf	0.01104	0.96647

Table F.51: Trends: Negative Brook Total Biomass

#	Trout Site	(Biomass/year)	R^2	Begin	End
1	BUN-1	-22.318	0.957	1997	2001
2	BUN-2	-17.489	0.968	1998	2001
3	BUN-3	-12.555	0.983	1997	2001
4	COS-1	-1.403	0.742	1997	2000
5	COS-2	-2.02	0.863	1998	2001
6	DUN-1	-4.0058	0.942	2002	2005
7	FLT-1	-12.073	0.921	1996	2002
8	HAZ-2	-6.6012	0.965	1999	2002
9	ICC-1	-2.333	0.836	2002	2006
10	ICC-3N	-5.1315	0.897	1995	1999
11	ROC-1	-2.3785	0.956	1995	1999
12	ROC-4	-2.7474	0.923	1995	1999
13	RPR-1	-2.2052	0.794	2002	2005
14	RPR-4	-2.6421	0.957	1998	2001
15	SAM-3	-0.7198	0.986	2000	2006
16	SAM-6	-5.294	0.953	1990	1994
17	TAY-7	-2.9256	0.993	2000	2004
18	WCP-1	-1.5918	0.765	2002	2006
19	WCP-2	-3.66	0.984	1996	1999

Table F.52: Trends: Results in Negative Brook Total Biomass

Hydrology Variable	Spearman ρ	Prob.>p
Area (1,000 Hectares)	0.68772	0.00114
Date min	-0.31930	0.18270
Nov	-0.26491	0.27305
Sept	0.25789	0.28643
High1 fall	-0.23684	0.32893
Oct	-0.23219	0.33880
April	-0.19825	0.41588
Rev	0.19403	0.42606
Fall Rate	-0.18822	0.44032
May	-0.17903	0.46335
March	0.02456	0.92050

Table F.53: Trends: Positive Rainbow Adult Density

#	Trout Site	Density/year	R^2	Begin	End
1	BEC-1	1.2562	0.721	1990	1993
2	CAT-1	1.1335	0.901	1995	1998
3	CAT-4	2.2973	0.819	1995	1998
4	COS-1	0.8884	0.772	1994	1997
5	COS-1	1.2033	0.848	2004	2007
6	ICC-1N	0.1214	0.789	1999	2003
7	LBR-1	1.1774	0.860	1994	1998
8	LRV-1	0.2468	0.831	1999	2003
9	LRV-2	0.6418	0.702	1991	1994
10	ROC-1	0.4071	0.780	2003	2006
11	RPR-1	2.0725	0.912	1994	1997
12	SAM-3	2.4106	0.818	1994	1997
13	SAM-4	2.7962	0.809	1994	1997
14	STK-1	0.7836	0.919	1994	1997

Table F.54: Trends: Results in Positive Rainbow Adult Density

Hydrology Variable	Spearman ρ	Prob.>p
1day min	-0.60440	0.02206
May	-0.54725	0.04282
Rev	-0.36084	0.20498
Area (1,000 Hectares)	-0.18922	0.51706

Table F.55: Trends: Positive Rainbow Total Biomass

#	Trout Site	(Biomass/year)	R^2	Begin	End
1	CAT-1	6.3613	0.955	1994	1997
2	CAT-3	8.3223	0.927	1994	1997
3	CAT-4	9.6867	0.945	1995	1998
4	COS-1	3.1861	0.954	2003	2007
5	JAK-1	5.1997	0.873	2002	2005
6	LRV-1	5.8815	0.902	1994	1998
7	LRV-2	16.568	0.941	1995	1998
8	RFC-1	17.599	0.887	1999	2002
9	RFC-2	10.009	0.807	1999	2004
10	ROC-1	2.0232	0.914	2003	2006
11	RPR-1	9.1698	0.959	1994	1997
12	RPR-1	7.2609	0.946	2001	2004
13	SAM-4	11.634	0.960	1994	1997
14	STK-1	3.6329	0.832	1994	1997
15	WCP-1	3.4664	0.731	2001	2005
16	WCP-2	1.6905	0.863	2000	2005

Table F.56: Trends: Results in Positive Rainbow Total Biomass

Hydrology Variable	Spearman ρ	Prob.>p
Rev	0.28698	0.28118
Area (1,000 hectares)	0.20015	0.45735
1daymin	-0.16176	0.54948
May	0.13824	0.60967

Table F.57: Trends: Negative Rainbow Adult Density

#	Trout Site	Density/year	R^2	Begin	End
1	BEC-1	-1.5453	0.944	1996	2002
2	CAN-1	-1.9955	0.859	1997	2000
3	CAT-1	-1.4234	0.959	1998	2001
4	CAT-2	-0.6567	0.894	1998	2003
5	CAT-3	-1.5927	0.911	1997	2001
6	COS-1	-1.4176	0.999	2001	2004
7	HAZ-2	-1.401	0.882	2000	2004
8	HAZ-3N	-0.5646	0.974	2000	2005
9	JAK-1	-1.9789	0.908	2001	2004
10	LBR-1	-0.8484	0.763	2002	2006
11	LEC-0	-1.0949	0.968	2002	2005
12	LOB-1	-2.2433	0.812	1996	2002
13	LOB-29	-1.4464	0.898	1990	1993
14	NWP-3	-3.0425	0.860	1992	1995
15	RFC-1	-4.283	0.775	1998	2001
16	ROC-1	-0.396	0.756	2000	2003
17	RPR-1	-1.7905	0.909	2003	2007
18	WCP-1	-1.38	0.814	1996	2001

Table F.58: Trends: Results in Negative Rainbow Adult Density

Hydrology Variable	Spearman ρ	Prob.>ρ
3day max	0.23220	0.35384
90day max	0.10423	0.68064
Area (1,000 Hectares)	-0.09598	0.70481
Low Pulse Length	-0.07950	0.75383
High Pulse Length	0.00000	1.00000

Table F.59: Trends: Negative Rainbow Total Biomass

#	Trout Site	(Biomass/year)	R^2	Begin	End
1	BEC-1	-5.5833	0.960	1996	2002
2	CAN-1	-8.4597	0.895	1997	2000
3	CAT-1	-5.8256	0.984	1997	2002
4	CAT-2	-3.1082	0.810	1998	2003
5	CAT-4	-8.5018	0.868	1998	2002
6	COS-1	-3.3451	0.869	2000	2003
7	HAZ-1N	-4.5985	0.924	1998	2002
8	HAZ-2	-3.0582	0.942	2000	2004
9	LBR-1	-3.3396	0.826	2001	2006
10	LOB-1	-12.698	0.973	1996	2000
11	LOB-29	-4.281	0.845	1990	1994
12	LRV-1	-4.7536	0.834	1998	2002
13	LRV-3	-6.6469	0.972	1997	2003
14	ROC-1	-1.0672	0.772	1993	1996
15	RPR-1	-9.2346	0.811	2004	2007
16	WCP-1	-4.4955	0.928	1997	2001

Table F.60: Trends: Result in Negative Rainbow Total Biomass

Hydrology Variable	Spearman ρ	Prob.>p
90day max	0.49412	0.05172
3day max	0.42647	0.09950
Area (1,000 hectares)	-0.30000	0.25894
Extreme Low Frequency	-0.28529	0.28414
Low Pulse Length	-0.22075	0.41131
High Pulse Length	-0.03693	0.89200

Table F.61: Trends: Positive Ratio

#	Trout Site	Ratio/year	R^2	Begin	End
1	BEC-1	3.0968	0.736	1999	2002
2	BEC-1	3.8191	0.903	2003	2005
3	COS-1	0.1131	0.989	2000	2002
4	FCP-3	0.9948	0.893	2002	2004
5	HAZ-1N	0.4212	0.943	1999	2002
6	HAZ-2	13.734	0.942	2001	2004
7	HAZ-3N	0.3521	0.997	2000	2002
8	LOB-1	38.916	0.794	1991	1993
9	LOB-1	1.2017	0.865	1997	2000
10	LOB-13	31.551	0.889	1991	1993
11	LOB-19	11.664	0.934	1990	1993
12	LOB-29	22.915	0.963	1991	1994
13	ROC-1	1.4981	0.949	1992	1996
14	ROC-1	5.4167	0.978	2000	2002
15	ROC-4	8.0234	1.000	1992	1994
16	RPR-1	0.1183	0.862	1993	1996
17	RPR-1	1.002	0.897	2004	2007
18	SAM-1	0.0892	1.000	2004	2006
19	SAM-4	0.6173	0.998	1998	2000
20	WCP-2	28.944	0.980	1999	2001
21	WCP-2	14.872	0.881	1996	1998

Table F.62: Trends: Results in Positive Ratio

Hydrology Variable	Spearman ρ	Prob.>p
Area (1,000 Hectares)	-0.51968	0.01576
Oct	-0.50878	0.01850
Low pulse Length	0.44293	0.04434
Small Fld freq	-0.42232	0.05651
Nov	-0.41169	0.06370
High pulse Length	-0.29660	0.19169
Rise rate	-0.23254	0.31040
1day max	-0.07922	0.73285
30day max	0.05714	0.80566

Table F.63: Trend: Negative Ratio

#	Trout Site	Ratio/year	R^2	Begin	End
1	BEC-1	-0.1406	0.986	1990	1993
2	COS-1	-0.2155	0.859	2004	2006
3	COS-1	-0.131	0.999	1996	1998
4	HAZ-2	-18.833	0.979	2004	2006
5	ICC-1	-17.5	0.927	2002	2004
6	ICC-1N	-1.4	0.871	1999	2001
7	LOB-1	-20.732	0.751	1995	1997
8	PTH-1	-0.0984	0.907	1991	1993
9	ROC-1	-2.667	0.923	1998	2000
10	RPR-1	-0.3647	0.847	2001	2004
11	SAM-4	-0.0714	0.984	1996	1998
12	SAM-4	-0.0419	0.881	1990	1995
13	STK-1	-12.75	0.915	1993	1995
14	WCP-1	-1.8404	0.953	2001	2003
15	WCP-2	-32.387	0.937	2001	2003
16	WCP-2	-4.373	0.930	2004	2006

Table F.64: Trends Results in Negative Ratio

Hydrology Variable	Spearman ρ	Prob.>p
Rev	-0.58910	0.01634
Feb	-0.58824	0.01654
March	-0.51988	0.03900
Fall rate	0.49446	0.05154
May	-0.40000	0.12475
Area (1,000 Hectares)	0.22402	0.40423
April	-0.13529	0.61737
Date min	-0.01176	0.96551

Appendix G: Hydrological Extremes and Trout Abundance: Data

This section contains the trout survey data used in the statistical analysis comparing trout abundance and hydrologic extreme events. This section also contains the mean comparison reports from the analysis.

Table G.65: Brook Trout Population during 90 day min

		Disturbance		YOY Brook Density		Adult Brook Density				Total Brook Biomass			
#	Trout Site	Year	90 day min (cfs)	YOY Avg.	Following	Before	During	Follow yr	2nd After	Before	During	Follow yr	2nd After
1	ALC-1	1993	0.89	0.11	0.00		0.68	0.76	0.97		3.87	3.72	5.54
2	ALC-2	1993	0.79	0.00	0.00		0.29	0.36	0.17		4.22	4.40	0.68
3	BEC-1	1993	1.36	4.03	0.12	2.89	2.83	3.02	2.36	3.79	6.11	5.88	7.32
4	BEC-1	1998	2.75	4.03	5.03	2.02	2.13	3.40	11.11	7.25	7.00	8.06	21.71
5	BRC-0	2007	2.22	5.56		1.82	6.63			7.55	15.38		
6	BRC-33	2007	1.89	7.12		4.54	13.96			19.62	25.69		
7	BUN-1	1993	0.48	12.03	0.16	6.87	15.19	17.19	15.17	29.94	37.17	45.11	62.51
8	BUN-1	1998	1.45	12.03	10.17	32.29	33.61	22.45	18.23	119.50	109.25	68.83	49.63
9	BUN-2	1993	0.3	15.42	0.27	16.65	31.19	27.33	20.21	45.82	73.49	60.46	59.65
10	BUN-2	1998	0.92	15.42	16.47	34.72	35.93	29.41	27.62	84.55	87.22	68.83	59.01
11	BUN-3	1993	0.28	19.75	1.33	14.85	32.19	27.89	24.10	44.23	61.48	55.64	60.52
12	BUN-3	1998	0.84	19.75	18.60	38.12	35.47	31.64	27.87	90.19	79.81	71.54	54.68
13	CHC-1	1993	0.78	1.46	1.26	3.80	3.62	4.19		12.59	10.37	9.91	
14	COK-1	1993	0.43	7.19		9.48	9.65			29.89	25.10	33.28	
15	COS-1	1998	2.05	0.22	0.00	1.45	0.32	0.32	0.18	21.73	28.64	25.86	22.63
16	COS-1	2007	1.36	0.22		0.31	1.04			18.03	36.02		
17	COS-2	1998	1.76	8.57	2.77	5.52	9.13	7.88	6.57	21.73	28.64	25.86	22.63
18	COS-2	2007	1.18	8.57		6.54	8.11			18.03	36.02		
19	DUN-1	1993	1.2	6.10	0.55		5.05	6.59			18.34	17.06	
20	FCP-1	1998	4.47	0.14	0.00		0.30	0.18			1.10	0.48	
21	FLT-1	1993	0.19	22.13	8.27	24.15	27.39	35.95	30.66	47.88	52.37	53.85	60.54
22	FLT-1	1998	0.58	22.13	17.88	38.50	35.01	31.67	19.88	90.39	61.94	47.56	41.29
23	HAZ-1N	1998	11.05	1.78	3.35	1.17	1.48	1.54	2.76	3.53	4.72	7.08	8.16
24	HAZ-2	1998	1.32	9.03	18.87	15.85	9.92	9.42	13.07	34.09	30.25	34.43	24.49
25	HAZ-2N	1998	7.87	1.25			2.73	2.11		7.44	6.66		

Table G.65: Continued: Brook Trout Population during 90 day min

		Disturbance		YOY Brook Density		Adult Brook Density				Total Brook Biomass			
#	Trout Site	Year	90 day min (cfs)	YOY Avg.	Following	Before	During	Follow yr	2nd After	Before	During	Follow yr	2nd After
26	ICC-1	1993	1.56	5.70	2.18	4.24	7.12	7.01	9.69	18.37	24.29	15.64	25.81
27	ICC-1	1998	2.35	5.70	5.01	4.57	5.74	3.82	3.82	15.14	18.92	13.72	13.82
28	ICC-1N	1998	2.45	2.03	1.72	0.54	0.60	0.86	1.70	1.62	1.95	3.74	12.67
29	ICC-3N	1998	2.33	4.40	4.34	11.80	11.12	7.35	7.33	32.55	22.47	16.18	15.93
30	KAN-1	2007	1.08	4.30		10.68	7.00			20.72	16.38		
31	LBTRA-1	1993	0.26	6.30	2.50	8.57	16.75	21.56	16.96	21.26	26.07	29.89	34.49
32	LOB-1	1993	1.42	7.63	2.25	6.65	14.91	12.62	11.04	24.39	31.45	26.58	29.26
33	LOB-1	1998	3.21	7.63	9.39	6.78	6.88	7.63	11.82	21.27	21.18	20.83	19.55
34	LOB-13	1993	1.28	6.84	1.58	6.56	20.83	13.32	12.24	19.00	37.16	25.29	29.22
35	LOB-19	1993	1.14	9.02	1.50	10.89	21.07	14.68	15.73	30.87	40.79	24.77	34.86
36	LOB-29	1993	0.52	5.98	1.98	12.43	19.26	17.51	20.59	31.74	37.75	30.78	43.27
37	PTH-1	1993	1.44	3.84		4.94	4.75			11.49	12.16		
38	PTH-2	1993	1.42	4.59		2.06	3.99			5.20	7.91		
39	ROC-1	1998	1.04	1.85	0.17	3.58	2.34	0.50	0.22	6.94	5.58	1.36	1.47
40	ROC-1	2007	0.74	1.85		3.08	2.52			6.10	9.72		
41	ROC-4	1998	1.04	2.91	0.37	4.07	2.81	2.60	4.07	14.60	8.54	7.46	13.90
42	ROC-4	2007	0.74	2.91		2.44	2.91			8.16	19.81		
43	ROC-7	1998	1.02	2.76	0.00	6.18	3.08	2.02	2.97	18.78	9.91	6.24	5.83
44	ROC-7	2007	0.73	2.76		3.58	4.06			6.96	12.46		
45	RPR-1	1993	1.37	0.80	0.00		0.07	0.26	0.75		0.33	0.32	2.15
46	RPR-1	1998	3.3	0.80	1.33	1.83	1.20	1.45	1.49	5.04	3.10	5.63	3.17
47	RPR-4	1993	1.04	2.30	0.11	4.24	4.77	3.46	4.89	10.58	13.66	7.67	19.84
48	RPR-4	1998	2.74	2.30	3.23	5.60	6.70	6.27	5.42	20.43	22.94	21.18	16.87
49	SAM-1	2007	2.59	1.01		3.04	2.72			19.03	16.64		
50	SAM-3	1998	2.22	1.26		0.00	0.13			0.05	0.21		

Table G.65: Continued: Brook Trout Population during 90 day min

		Disturbance		YOY Brook Density		Adult Brook Density				Total Brook Biomass			
#	**Trout Site**	**Year**	**90 day min (cfs)**	**YOY Avg.**	**Following**	**Before**	**During**	**Follow yr**	**2nd After**	**Before**	**During**	**Follow yr**	**2nd After**
51	SAM-3	2007	2.48	1.26		0.00	1.15			0.04	9.20		
52	SAM-4	1998	1.75	2.76	1.86	2.90	0.67	2.03	3.84	7.30	3.22	6.70	9.72
53	SAM-6	1993	0.77	3.29	0.12	11.32	9.44	5.91	13.61	33.08	25.17	18.20	48.92
54	SAM-6	1998	0.81	3.29	4.14	19.83	9.20	10.23		51.75	25.96	26.84	
55	SIL-1	1993	1.01	6.10	0.17	7.40	7.46	7.90	6.84	17.67	14.22	13.51	20.54
56	SIL-1	1998	1.23	6.10	4.76	4.01	5.60	3.51	8.50	10.39	19.28	16.23	17.81
57	SIL-6	1993	0.89	5.37	0.52	7.23	5.95	8.82	9.41	22.83	12.07	18.91	28.10
58	SIL-6	1998	1.11	5.37	6.57	7.57	11.09	5.11	11.22	19.97	29.51	17.38	28.05
59	STK-1	1993	0.8	2.06	0.00	6.46	14.54	2.93	1.00	13.72	36.35	7.32	4.37
60	STK-1	1998	0.7	2.06	9.50	0.82	0.74	2.52	3.39	11.10	5.00	3.70	5.36
61	STK-2	1993	0.4	1.99	0.16		13.26	4.39			33.37	11.81	
62	STR-1	1993	7.95	0.33		0.08	0.00			8.33	0.61		
63	STR-2	1993	4.37	0.69		0.83	1.67			2.11	6.44		
64	STR-2	1998	10.17	0.69	0.18		0.09	0.13	0.20		0.54	0.77	0.71
65	TAY-1	1993	0.61	5.82	2.06	2.88	6.30	4.52	4.96	18.96	19.56	17.52	21.52
66	TAY-7	1993	0.49	6.30	3.36	3.08	2.44	5.44	5.78	14.96	5.54	12.08	13.85
67	WCP-1	1998	2.92	1.15	0.97	0.80	0.32	0.43	0.89	3.40	1.19	2.36	2.18
68	WCP-2	1998	2.32	3.34	6.61	5.20	3.86	4.22	7.09	19.69	16.40	11.50	18.52

Table G.66: Rainbow Trout Population during 90 day min

		Disturbance		YOY Rainbow Density		Adult Rainbow Density				Total Rainbow Biomass			
#	Trout Site	Year	90 day min (cfs)	YOY Avg.	Following	Before	During	Follow yr	2nd After	Before	During	Follow yr	2nd After
1	ALC-1	1993	0.89	0.00	0.00		0.17	0.13			0.41	0.39	
2	BEC-1	1993	1.36	3.14	1.93	6.68	9.62	7.91	9.65	22.63	27.79	24.52	33.28
3	BEC-1	1998	2.75	3.14	0.99	7.15	7.37	4.67	3.50	28.73	25.68	16.62	12.47
4	BLK-1	1998	0.5	5.94	15.02	6.36	4.52	2.96	5.01	27.09	16.10	14.32	14.37
5	CAN-1	1998	1.56	1.27	0.00	6.41	2.55	0.64	0.39	28.17	12.11	5.54	2.16
6	CAT-1	1998	22.92	5.21	4.29	5.00	6.28	4.26	3.71	42.10	38.54	38.54	27.42
7	CAT-2	1993	19.41	4.30	1.35	2.13	6.47	6.81	3.82	18.20	29.75	30.71	35.42
8	CAT-3	1993	10.99	4.23	1.71	3.39	7.00	5.45	3.38	21.13	30.23	21.33	27.80
9	CAT-4	1993	6.37	4.05	4.21	3.11	7.22	6.30	2.97	13.13	28.92	26.51	19.88
10	COK-1	1993	0.43	1.56	0.00		9.48	9.65			25.10	33.28	
11	COS-1	1998	2.05	2.55	0.32	7.10	4.43	2.99	4.83	21.54	16.98	10.62	10.62
12	COS-1	2007	1.36	2.55		4.51	4.35			17.76	21.07		
13	DUN-1	1993	1.2	1.42	0.00		1.69	0.72			8.38	5.66	
14	EKT-2N	1998	2.43	0.42	0.48		1.62	0.94			11.98	7.68	
15	FCP-1	1998	4.47	0.86	0.90		9.67	3.97			38.20	19.70	
16	HAZ-1	1998	15.26	2.40	3.23	4.63	2.83	2.45		27.59	21.52	22.61	
17	HAZ-1N	1998	11.05	1.91	2.79	3.09	2.62	3.49	4.65	16.01	33.16	27.47	21.80
18	HAZ-2	1998	1.32	0.24	1.27	2.16	1.94	0.95	5.64	9.85	14.84	5.27	14.15
19	HAZ-2N	1998	7.87	2.69		2.73	2.11			7.44	6.66		
20	ICC-1N	1998	2.45	2.33	0.00	0.14	0.90	0.14	0.46	1.64	3.23	1.39	5.22
21	JAK-1	2007	2.11	2.49		5.45	6.61			17.12	26.63		
22	LBR-1	1998	1.04	0.12	0.00	5.02	8.01	2.79	4.51	14.82	27.06	13.88	18.58
23	LBR-1	2007	0.8	0.12		0.93	1.25			4.56	4.68		
24	LOB-1	1993	1.42	0.38	0.77	0.68	0.18	1.48	0.26	2.75	1.98	6.00	0.51
25	LOB-1	1998	3.21	0.38	0.43	9.31	6.13	3.84	2.66	42.30	30.92	16.21	10.52

Table G.66: Continued: Rainbow Trout Population during 90 day min

		Disturbance		YOY Rainbow Density		Adult Rainbow Density				Total Rainbow Biomass			
#	Trout Site	Year	90 day min (cfs)	YOY Avg.	Following	Before	During	Follow yr	2nd After	Before	During	Follow yr	2nd After
26	LOB-13	1993	1.28	0.56	0.00	0.43	0.32	0.60		2.11	2.76	1.56	
27	LOB-29	1993	0.52	0.31	0.00	0.56	0.33	0.25		3.15	2.24	0.51	
28	LRV-0	1998	35.93	0.05		0.45	0.26			6.12	4.48		
29	LRV-1	1998	26.85	2.43	8.87	4.44	3.52	1.54		32.79	42.75	28.80	
30	LRV-1	2007	33.81	2.43		2.36	0.83			20.41	7.92		
31	LRV-2	1998	19.2	4.20	5.16	4.82	7.63	5.60	3.18	31.29	48.28	73.81	32.25
32	LRV-2	1993	32.21	4.20	0.08	5.48	5.11	5.88	4.45	42.40	26.58	27.13	23.90
33	LRV-3	1998	23.68	4.98	11.97	13.06	6.94	5.31		66.40	63.15	53.40	
34	LRV-3	1993	26.85	4.98	0.54	9.36	8.90	7.74	5.58	56.28	40.02	37.80	53.08
35	PTH-1	1993	1.44	3.62		9.73	13.00			33.09	37.52		
36	PTH-2	1993	1.42	2.34		4.09	6.32			12.83	20.45		
37	RFC-1	1998	2.99	2.21	0.09		19.17	8.49	6.49		66.37	4.33	40.64
38	RFC-1	1998	0.56	2.21	4.38		15.04	7.91	11.95		59.72	2.69	38.55
39	ROC-1	1998	1.04	0.16	0.00	1.59	0.43	0.33	1.32	6.29	1.13	0.78	3.16

Table G.66 Continued: Rainbow Trout Population during 90 day min

		Disturbance		YOY Rainbow Density		Adult Rainbow Density				Total Rainbow Biomass			
#	Trout Site	Year	90 day min (cfs)	YOY Avg.	Following	Before	During	Follow yr	2nd After	Before	During	Follow yr	2nd After
40	RPR-1	1993	1.37	0.76	0.12	2.34	5.11	1.52	4.64	13.31	24.50	7.93	21.83
41	RPR-1	1998	3.3	0.76	0.00	7.57	4.41	1.93	4.24	37.26	18.96	9.03	14.15
42	RPR-4	1993	1.04	0.00		1.19	0.49			3.66	3.74		
43	SAM-3	1998	2.22	2.78	1.73	9.71	3.48	2.23	2.55	48.16	21.87	13.62	17.07
44	SAM-4	1998	1.75	2.11	0.68	11.78	3.51	2.37	2.69	50.03	18.09	16.28	16.57
45	SAM-4	1993	2	2.11	0.00	4.41	4.78	2.88	3.87	18.13	24.39	12.90	27.09
46	SAM-6	1993	0.77	0.00		0.52	0.24			2.52	1.13		
47	STK-1	1993	0.8	0.60	0.00	0.92	0.54	0.39	0.67	3.73	4.20	1.17	4.22
48	STK-1	1998	0.7	0.60	0.00	2.75	0.74	0.46	0.62	13.15	3.87	3.07	4.26
49	STR-1	1993	7.95	4.35	6.52	1.73	2.67	1.18		18.96	14.60	8.32	
50	STR-2	1993	4.37	3.23	8.88	3.35	4.69	3.89		16.46	25.06	21.44	
51	STR-2	1998	10.17	3.23	1.60		2.72	1.38	4.10		21.03	6.81	19.82
52	WAL-1N	1998	2.24	4.15	0.94		2.87	1.51			14.81	6.39	
53	WCP-1	1998	2.92	2.08	0.00	4.61	3.22	2.04	2.93	21.51	13.99	9.99	9.65
54	WCP-2	1998	2.32	0.70	0.00	0.78	0.26	0.70	0.27	2.18	1.22	3.53	0.37

t	Alpha
2.62169	0.01

Abs(Dif)-LSD

	1yr	2yr
1yr	-1.5099	0.2850
2yr	0.2850	-1.7619

Positive values show pairs of means that are significantly different.

Level			Mean
1yr	A		4.3066015
2yr		B	2.3809183

Levels not connected by same letter are significantly different.

Figure G.45: Mean Comparison of YOY Brook Density: 90 day min

t	Alpha
1.97127	0.05

Abs(Dif)-LSD

	4yr	3yr	2yr	1yr
4yr	-2.6582	-0.1270	0.1185	0.2827
3yr	-0.1270	-2.6010	-2.3535	-2.1894
2yr	0.1185	-2.3535	-2.2646	-2.1011
1yr	0.2827	-2.1894	-2.1011	-2.2831

Positive values show pairs of means that are significantly different.

Level			Mean
4yr	A		8.8377337
3yr	A	B	6.3350515
2yr		B	6.2500064
1yr		B	6.0772826

Levels not connected by same letter are significantly different.

Level	- Level	Difference	Lower CL	Upper CL	p-Value
4yr	1yr	2.760451	0.28273	5.238174	0.0292*
4yr	2yr	2.587727	0.11850	5.056953	0.0401*
4yr	3yr	2.502682	-0.12704	5.132404	0.0620
3yr	1yr	0.257769	-2.18943	2.704967	0.8357
2yr	1yr	0.172724	-2.10113	2.446579	0.8811
3yr	2yr	0.085045	-2.35355	2.523639	0.9453

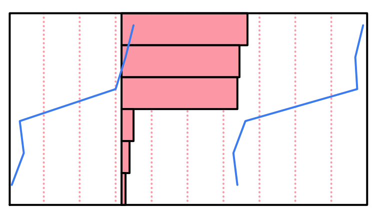

Figure G.46: Means Comparison of Adult Brook Density: 90 day min

t	Alpha
1.97101	0.05

Abs(Dif)-LSD

	4yr	2yr	3yr	1yr
4yr	-6.2386	-0.3420	-0.1432	0.5202
2yr	-0.3420	-5.2890	-5.1215	-4.4323
3yr	-0.1432	-5.1215	-6.0446	-5.3761
1yr	0.5202	-4.4323	-5.3761	-5.4175

Positive values show pairs of means that are significantly different.

Level			Mean
4yr	A		23.973055
2yr	A	B	18.531727
3yr	A	B	17.973859
1yr		B	17.610343

Levels not connected by same letter are significantly different.

Level	- Level	Difference	Lower CL	Upper CL	p-Value
4yr	1yr	6.362713	0.52022	12.20521	0.0329*
4yr	3yr	5.999196	-0.14316	12.14155	0.0555
4yr	2yr	5.441328	-0.34200	11.22465	0.0650
2yr	1yr	0.921384	-4.43227	6.27504	0.7348
2yr	3yr	0.557868	-5.12152	6.23725	0.8467
3yr	1yr	0.363516	-5.37611	6.10314	0.9008

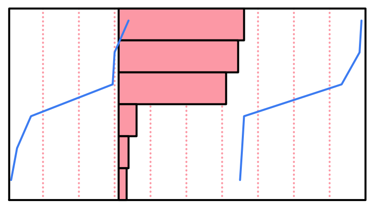

Figure G.47: Means Comparison of Brook Total Biomass: 90 day min

t	Alpha
2.63033	0.01

Abs(Dif)-LSD

	1yr	2yr
1yr	-0.83422	0.07739
2yr	0.07739	-0.96928

Positive values show pairs of means that are significantly different.

Level			Mean
1yr	A		2.1445863
2yr		B	1.1629235

Levels not connected by same letter are significantly different.

Figure G.48: Means Comparison of YOY Rainbow Density: 90 day min

t	Alpha
1.65351	0.1

Abs(Dif)-LSD

	1yr	2yr	4yr	3yr
1yr	-0.8777	-0.7097	-0.6180	0.0819
2yr	-0.7097	-0.8426	-0.7519	-0.0518
4yr	-0.6180	-0.7519	-0.9514	-0.2523
3yr	0.0819	-0.0518	-0.2523	-0.9176

Positive values show pairs of means that are significantly different.

Level			Mean
1yr	A		3.9798706
2yr	A	B	3.8292755
4yr	A	B	3.6825345
3yr		B	3.0001353

Levels not connected by same letter are significantly different.

Level	- Level	Difference	Lower CL	Upper CL	p-Value
1yr	3yr	0.9797353	0.081856	1.877614	0.0729
2yr	3yr	0.8291402	-0.051755	1.710035	0.1214
4yr	3yr	0.6823992	-0.252263	1.617061	0.2290
1yr	4yr	0.2973361	-0.617957	1.212630	0.5918
1yr	2yr	0.1505951	-0.709722	1.010912	0.7726
2yr	4yr	0.1467410	-0.751898	1.045380	0.7875

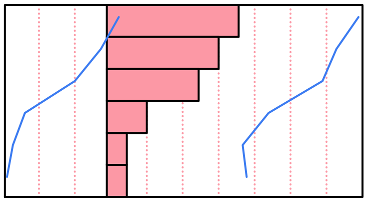

Figure G.49: Means Comparison of Adult Rainbow Density: 90 day min

t	Alpha
1.65361	0.1

Abs(Dif)-LSD

	1yr	2yr	4yr	3yr
1yr	-4.1520	-3.4775	-3.4352	1.2714
2yr	-3.4775	-3.9858	-3.9493	0.7590
4yr	-3.4352	-3.9493	-4.5580	0.1449
3yr	1.2714	0.7590	0.1449	-4.3922

Positive values show pairs of means that are significantly different.

Level			Mean
1yr	A		19.170837
2yr	A		18.578562
4yr	A		18.246351
3yr		B	13.625617

Levels not connected by same letter are significantly different.

Level	- Level	Difference	Lower CL	Upper CL	p-Value
1yr	3yr	5.545220	1.27144	9.819000	0.0333*
2yr	3yr	4.952946	0.75900	9.146889	0.0524
4yr	3yr	4.620734	0.14488	9.096592	0.0896
1yr	4yr	0.924486	-3.43524	5.284208	0.7263
1yr	2yr	0.592274	-3.47749	4.662043	0.8101
2yr	4yr	0.332212	-3.94928	4.613699	0.8981

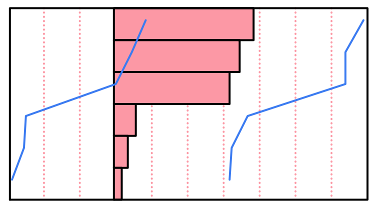

Figure G.50: Means Comparison of Rainbow Total Biomass: 90 day min

Table G.67: Brook Trout Populations during a “10 year” Flood Event

		Date Flood		YOY Brook Density		Adult Brook Density			
#	Trout Site	Begin	End	Avg. YOY	After	2nd Before	Before	After	2nd After
1	BEC-1	5/5/2003	5/14/2003	4.026	1.875	7.286	9.327	8.119	6.371
2	BUN-1	1/7/1998	1/31/1998	12.029	7.158	23.741	32.289	33.605	22.450
3	BUN-2	1/7/1998	2/1/1998	15.416	20.339	29.576	34.722	35.932	29.413
4	BUN-3	1/7/1998	1/31/1998	19.746	16.352	30.260	38.121	35.472	31.639
5	CHC-1	1/3/1994	5/19/1994	1.457	1.257	3.798	3.619	4.189	
6	COS-1	12/4/1993	5/17/1994	0.343	0.000		0.000	22.200	26.900
7	DUN-1	3/22/1994	4/24/1994	6.102	0.550		5.050	6.590	
8	FCP-3	6/30/2002	7/16/2002	3.500	2.680		6.040	4.510	5.300
9	FLT-1	1/7/1998	2/1/1998	22.128	18.487	38.160	38.504	35.014	31.669
10	HAZ-2	6/30/2002	7/16/2002	9.026	5.278	13.065	8.842	7.136	
11	ICC-1	3/22/1994	4/24/1994	5.697	2.181	4.240	7.116	7.013	9.693
12	MEG-1	3/21/1994	4/26/1994	1.250	0.080	3.313	1.336	1.228	
13	ROC-1	12/4/1993	5/18/1994	1.851	0.095	0.161	0.875	2.766	3.031
14	ROC-4	12/20/1993	5/19/1994	2.906	0.863	1.666	3.463	4.843	5.256
15	ROC-7	12/28/1993	5/20/1994	2.756	0.152	2.542	2.317	5.779	7.446
16	RPR-1	1/7/1998	1/31/1998	0.798	0.134	2.969	1.834	1.203	1.447
17	RPR-4	1/7/1998	1/31/1998	2.295	0.609	10.355	5.595	6.698	6.271
18	SIL-1	6/30/2002	7/16/2002	6.095	3.483	4.780	4.939	7.416	6.313
19	SIL-6	6/30/2002	7/16/2002	5.372	2.751	7.656	7.377	9.674	7.678
20	TAY-7	5/5/2003	2/13/2003	6.296	6.220	11.322	12.376	9.959	8.255
21	WCP-1	1/7/1998	2/1/1998	1.147	0.429	1.576	0.801	0.322	0.429
22	WCP-2	1/7/1998	2/1/1998	3.344	3.089	9.382	5.201	3.862	4.222

Table G.68: Brook Trout Population during the 2 Largest "2 year" Floods

		Date Flood		YOY Brook Density		Adult Brook Density			
#	Trout Site	Begin	End	Avg. YOY	After	2nd Before	Before	After	2nd After
1	ALC-1	3/22/1994	4/22/1994	0.113	0.000		0.680	0.760	0.972
2	ALC-2	3/22/1994	4/21/1994	0.000	0.000		0.288	0.360	0.172
3	BEC-1	3/22/1994	4/23/1994	4.026	0.123	2.886	2.829	3.018	2.356
4	BEC-1	1/7/1998	1/31/1998	4.026	3.704	2.202	2.017	2.127	3.395
5	BUN-1	3/25/1994	4/21/1994	12.029	0.158	6.867	15.185	17.191	15.169
6	BUN-2	3/25/1994	4/21/1994	15.416	0.273	16.654	31.193	27.334	20.213
7	BUN-3	3/25/1994	4/21/1994	19.746	1.328	14.851	32.190	27.890	24.095
8	CAT-4	1/7/1998	1/31/1998	0.224	0.000		0.000	0.270	
9	COS-1	3/8/1995	3/16/1995	0.343	0.766	0.000	1.543	0.766	1.874
10	COS-1	1/18/1996	2/21/1996	0.343	0.000	1.543	0.766	1.874	1.452
11	COS-2	1/18/1996	2/22/1996	8.570	0.000		6.906	12.571	5.519
12	COS-2	5/5/2003	5/18/2003	8.570	4.831	6.479	11.317	12.077	8.117
13	DUN-1	11/18/2003	12/15/2003	6.102	0.827	11.273	7.064	4.426	2.151
14	FCP-3	9/7/2004	9/23/2004	3.500	5.459	4.507	5.297	4.715	
15	FLT-1	3/25/1994	4/22/1994	22.128	8.274	24.148	27.385	35.949	30.664
16	HAZ-2	1/7/1998	2/1/1998	9.026	3.853	15.238	15.851	9.924	9.418
17	HAZ-2N	1/7/1998	2/1/1998	1.249	1.136		2.725	2.110	
18	ICC-1	1/7/1998	2/9/1998	5.697	1.956		4.567	5.737	3.824
19	ICC-1	11/18/2003	12/15/2003	5.697	1.643	8.351	7.006	5.340	3.046
20	ICC-1N	1/7/1998	2/13/1998	2.028	0.150		0.541	0.602	0.862
21	ICC-3N	1/7/1998	2/1/1998	4.397	1.024		11.795	11.122	7.349
22	KAN-1	5/5/2003	5/13/2003	4.303	2.451	9.462	8.269	6.740	10.052

Table G.68 Continued: Brook Trout Population during the 2 Largest “2 year” Floods

		Date Flood		YOY Brook Density		Adult Brook Density			
#	Trout Site	Begin	End	Avg. YOY	After	2nd Before	Before	After	2nd After
23	LBTRA-1	3/22/1994	4/22/1994	6.295	2.499	8.569	16.748	21.556	16.955
24	LOB-1	3/22/1994	4/25/1994	7.631	2.249	6.653	14.909	12.616	11.041
25	LOB-1	1/7/1998	1/31/1998	7.631	15.243	12.812	6.778	6.883	7.630
26	LOB-13	3/22/1994	4/23/1994	6.836	1.582	6.559	20.825	13.324	12.240
27	LOB-19	3/22/1994	4/22/1994	9.021	1.501	10.894	21.073	14.679	15.726
28	LOB-29	3/22/1994	4/22/1994	5.976	1.975	12.433	19.255	17.511	20.591
29	ROC-1	3/6/1995	3/15/1995	1.851	6.470	0.875	2.766	3.031	5.707
30	ROC-1	5/5/2003	5/15/2003	1.851	0.220	1.778	2.845	1.537	0.929
31	ROC-4	1/18/1996	2/21/1996	2.906	0.769	4.843	5.256	7.882	4.069
32	ROC-4	5/6/2003	5/16/2003	2.906	1.407	2.778	4.371	3.988	3.338
33	ROC-7	1/18/1996	2/22/1996	2.756	0.155	5.779	7.446	7.608	6.175
34	ROC-7	5/5/2003	5/15/2003	2.756	2.793	0.762	2.993	4.422	2.229
35	RPR-1	3/22/1994	4/22/1994	0.798	0.563		5.107	1.523	4.636
36	RPR-4	3/22/1994	4/21/1994	2.295	0.105	4.238	4.770	3.462	4.891
37	SAM-6	1/7/1998	2/1/1998	3.292	2.530	10.590	19.829	9.202	10.234
38	SIL-1	1/7/1998	2/1/1998	6.095	2.133	6.854	4.014	5.599	3.509
39	SIL-1	9/7/2004	9/23/2004	6.095	6.794	6.313	9.706		
40	SIL-6	1/7/1998	2/1/1998	5.372	0.902	9.204	7.568	11.089	5.111
41	SIL-6	9/7/2004	9/23/2004	5.372	4.494		7.678	7.852	
42	STK-1	3/22/1994	4/24/1994	2.055	0.000	6.460	14.535	2.926	1.000
43	TAY-1	2/9/1994	5/10/1994	5.815	2.058	2.880	6.296	4.517	4.960
44	TAY-1	2/14/2003	3/3/2003	5.815	3.476	8.340	14.128	10.053	7.819
45	TAY-7	3/21/1994	4/27/1994	6.296	3.355	3.075	2.437	5.437	5.781

Table G.69: Rainbow Trout Populations during "10 year" Flood

		Date Flood		YOY Rainbow Density		ADT Rainbow Density			
#	Trout Site	Begin	End	Avg. YOY	After	2nd Before	Before	After	2nd After
1	BEC-1	5/5/2003	5/14/2003	3.140	0.00	2.821	0.829	2.160	1.178
2	COS-1	12/4/1993	5/17/1994	2.549	0.86		7.846	4.630	4.137
3	FCP-3	6/30/2002	7/16/2002	0.856	0.00		4.660	2.660	1.610
4	HAZ-2	6/30/2002	7/16/2002	0.242	0.00	5.641	4.358	1.211	
5	JAK-1	2/5/1994	5/19/1994	2.488	0.43	6.924	8.507	6.105	4.531
6	LRV-1	3/22/1994	4/24/1994	2.434	0.51	1.727	3.160	4.020	2.656
7	LRV-2	3/22/1994	4/24/1994	4.203	0.08	5.484	5.114	5.878	4.452
8	LRV-3	5/5/2003	5/14/2003	4.978	0.30	5.155	6.443	3.696	
9	NWP-3	3/21/1994	5/11/1994	2.289	0.74	12.566	7.414	3.533	3.718
10	RPR-1	1/7/1998	1/31/1998	0.757	0.00	7.229	7.567	4.409	1.929
11	RFC-1	3/22/1994	4/28/1994	2.205	0.00		11.623	18.942	
12	ROC-1	12/4/1993	5/18/1994	0.158	0.07	0.646	1.198	1.204	0.817
13	ROC-4	12/20/1993	5/19/1994	0.285	0.00	0.151	0.183	0.179	0.000
14	SAM-3	3/21/1994	5/10/1994	2.776	0.15	4.685	6.126	3.348	2.380
15	WCP-1	1/7/1998	2/1/1998	2.084	0.00	8.668	4.606	3.215	2.038
16	WCP-2	1/7/1998	2/1/1998	0.703	0.00	1.400	0.775	0.257	0.704

Table G.70: Rainbow Trout Populations after 2 Largest “2 year” Floods

#	Trout Site	Date Flood Begin	Date Flood End	YOY Rainbow Density Avg. YOY	YOY Rainbow Density After	Adult Rainbow Density 2nd Before	Adult Rainbow Density Before	Adult Rainbow Density After	Adult Rainbow Density 2nd After
1	ALC-1	3/22/1994	4/22/1994	0.000	0.000		0.170	0.127	
2	BEC-1	3/22/1994	4/23/1994	3.140	1.933	6.675	9.623	7.911	9.648
3	BEC-1	1/7/1998	1/31/1998	3.140	3.118	11.076	7.148	7.372	4.674
4	BLK-1	4/14/1998	5/14/1998	5.944	2.516	6.344	6.358	4.524	2.963
5	CAN-1	1/7/1998	2/1/1998	1.273	0.109	5.913	6.407	2.545	0.643
6	CAT-1	5/5/2003	5/18/2003	5.206	0.068	1.721	1.796	3.823	
7	CAT-2	2/9/1994	5/10/1994	4.304	1.349	2.131	6.472	6.807	3.816
8	CAT-2	1/7/1998	1/31/1998	4.304	6.515	5.043	4.122	5.751	4.175
9	CAT-3	2/9/1994	5/9/1994	4.227	1.712	3.390	6.996	5.446	3.381
10	CAT-3	1/7/1998	1/31/1998	4.227	5.495	5.781	8.411	7.040	4.065
11	CAT-4	3/21/1998	4/21/1998	4.054	4.214	3.107	7.222	6.295	2.966
12	CAT-4	1/7/1998	1/31/1998	4.054	5.660	8.131	7.388	10.872	4.329
13	COS-1	3/8/1995	3/16/1995	2.549	3.371	7.846	4.630	4.137	5.622
14	COS-1	1/18/1996	2/21/1996	2.549	9.541	4.630	4.137	5.622	7.097
15	FCP-3	9/7/2004	9/23/2004	1.635	1.751	2.659	1.611	3.850	
16	HAZ-2	1/7/1998	2/1/1998	0.242	0.242	2.811	2.160	1.937	0.950

Table G.70 Continued: Rainbow Trout Populations after two Largest 2 year Floods

		Date Flood		YOY Rainbow Density		ADT RBT Density			
#	Trout Site	Begin	End	Avg. YOY	After	2nd Before	Before	After	2nd After
17	ICC-1	11/18/2003	12/15/2003	0.016	0.000	0.113	0.146	0.137	0.000
18	ICC-1N	1/7/1998	2/13/1998	2.326	0.000		0.135	0.903	0.144
19	JAK-1	5/5/2003	5/14/2003	2.488	0.816	11.408	7.544	6.777	5.068
20	LBR-1	4/16/1998	5/13/1998	0.118	0.000		5.023	8.006	2.787
21	LOB-1	3/22/1994	4/25/1994	0.377	0.773	0.676	0.180	1.482	0.262
22	LOB-1	1/7/1998	1/31/1998	0.377	0.851	16.616	9.307	6.130	3.838
23	LOB-13	3/22/1994	4/23/1994	0.559	0.000	0.430	0.315	0.601	
24	LOB-19	3/22/1994	4/22/1994	0.384	0.000		0.442	0.585	
25	LOB-29	3/22/1994	4/22/1994	0.311	0.000	0.557	0.330	0.248	0.418
26	LRV-3	3/22/1994	4/24/1994	4.978	0.034	7.230	10.566	7.577	7.900
27	ROC-1	3/6/1995	3/15/1995	0.158	0.494	1.198	1.204	0.817	0.913
28	ROC-1	5/5/2003	5/15/2003	0.158	0.220	0.254	0.259	0.000	0.232
29	ROC-4	1/18/1996	2/21/1996	0.285	0.192	0.179	0.000	0.577	
30	RPR-1	3/22/1994	4/22/1994	0.757	0.563	2.338	5.107	1.523	4.636
31	SAM-1	1/18/1996	2/13/1996	2.743	1.085	3.431	5.760	10.040	3.729
32	SAM-4	3/22/1994	4/25/1994	2.109	0.000	4.408	4.783	2.879	3.871
33	STK-1	3/22/1994	4/24/1994	0.598	0.000	0.923	0.538	0.390	0.667

t	Alpha
2.61673	0.01

Abs(Dif)-LSD

	1yr	2yr
1yr	-1.1937	1.1658
2yr	1.1658	-1.1746

Positive values show pairs of means that are significantly different.

Level			Mean
1yr	A		4.3318856
2yr		B	1.9819048

Levels not connected by same letter are significantly different.

Figure G.51: Means Comparison of YOY Brook Density: Flood

t	Alpha
1.97071	0.05

Abs(Dif)-LSD

	4yr	2yr	1yr	3yr
4yr	-2.2484	-2.0613	-2.1105	-1.8523
2yr	-2.0613	-2.1155	-2.1676	-1.9067
1yr	-2.1105	-2.1676	-2.3136	-2.0567
3yr	-1.8523	-1.9067	-2.0567	-2.1330

Positive values show pairs of means that are significantly different.

Level		Mean
4yr	A	7.3272222
2yr	A	7.2055738
1yr	A	7.1564706
3yr	A	6.9880000

Levels not connected by same letter are significantly different.

Level	- Level	Difference	Lower CL	Upper CL	p-Value
4yr	3yr	0.3392222	-1.85225	2.530696	0.7606
2yr	3yr	0.2175738	-1.90669	2.341837	0.8402
4yr	1yr	0.1707516	-2.11048	2.451981	0.8829
1yr	3yr	0.1684706	-2.05667	2.393609	0.8815
4yr	2yr	0.1216485	-2.06130	2.304596	0.9127
2yr	1yr	0.0491032	-2.16764	2.265846	0.9652

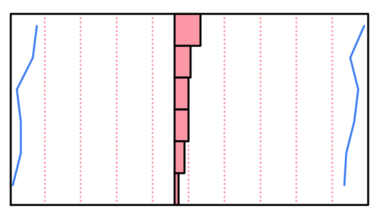

Figure G.52: Means Comparison of Brook Adult Density: Flood

t	Alpha
2.63094	0.01

Abs(Dif)-LSD

	1yr	2yr
1yr	-0.73034	0.61901
2yr	0.61901	-0.75429

Positive values show pairs of means that are significantly different.

Level		Mean
1yr	A	1.9956498
2yr	B	0.6342222

Levels not connected by same letter are significantly different.

Figure G.53: Means Comparison of YOY Rainbow: Flood

t	Alpha
1.97419	0.05

Abs(Dif)-LSD

	2yr	1yr	3yr	4yr
2yr	-1.0864	-0.5261	-0.4022	0.3226
1yr	-0.5261	-1.2210	-1.1006	-0.3728
3yr	-0.4022	-1.1006	-1.0978	-0.3728
4yr	0.3226	-0.3728	-0.3728	-1.2052

Positive values show pairs of means that are significantly different.

Level		Mean
2yr	A	4.2727083
1yr	A B	3.6431579
3yr	A B	3.5827660
4yr	B	2.8028205

Levels not connected by same letter are significantly different.

Level	- Level	Difference	Lower CL	Upper CL	p-Value
2yr	4yr	1.469888	0.32257	2.617201	0.0124*
1yr	4yr	0.840337	-0.37276	2.053438	0.1733
3yr	4yr	0.779945	-0.37283	1.932717	0.1835
2yr	3yr	0.689942	-0.40217	1.782056	0.2141
2yr	1yr	0.629550	-0.52606	1.785163	0.2837
1yr	3yr	0.060392	-1.10064	1.221424	0.9183

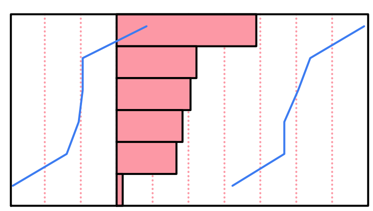

Figure G.54: Means Comparison of Adult Rainbow Density: Flood

Vita

Joseph Michael Parker was raised in the Germantown, Tennessee. He attended Houston High School and graduated in 2003. After graduating from high school, Joe went to Christian Brother University and graduated with a Bachelor's Degree in Civil Engineering in 2007. After graduation Joe wanted to be closer to Tennessee Football, and accepted a graduate assistantship at The University of Tennessee, Knoxville with the Environmental Engineering Department. After many hours of performing research, taking courses, and being a teaching assistant, Joe earned a Master's of Science in Environmental Engineering with a concentration in Water Resources in December 2008.