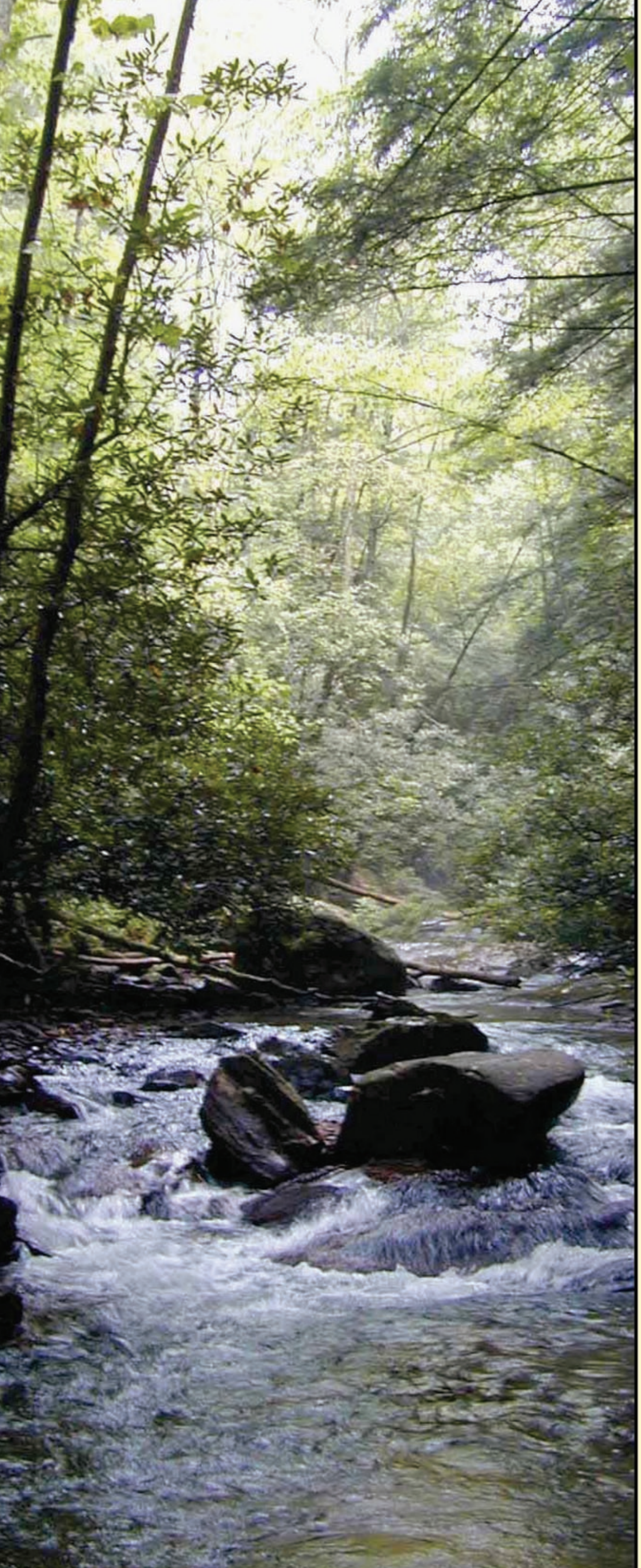

Implications of Changes in Riparian Buffer Protection for Georgia's Trout Streams

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The full report can be downloaded from the following University of Georgia website: www.rivercenter.uga.edu/publications.htm

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Cover photograph: Boggs Creek, North Georgia. Photograph by Krista Jones.

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IMPLICATIONS OF CHANGES IN RIPARIAN BUFFER PROTECTION FOR GEORGIA'S TROUT STREAMS

JUNE 2005

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The full report can be downloaded from the following University of Georgia website: www.rivercenter.uga.edu/publications.htm

EXECUTIVE SUMMARY

This report summarizes the findings of a three-year research project by University of Georgia scientists that evaluates the potential effects of House Bill 1426 on Georgia's trout streams. The goal of this research is to provide the State with scientific information on:

1. The effectiveness of 100- vs. 50-ft riparian buffer widths in protecting trout habitat in North Georgia's streams; and
2. The geomorphic and biological characteristics of headwater trout streams that are exempt from 50-ft riparian buffer requirements.

This study examined existing forest cover conditions for trout streams and their watersheds in North Georgia. Relationships were observed between:

- Trout populations and stream habitat (stream temperature and sediment conditions)
- Stream habitat and riparian forest cover
- Riparian forest cover and average forested riparian buffer widths for a 100-ft zone on both sides of the stream along the entire stream network above a sampling site

Relationships between trout populations, stream habitat, and average forested riparian buffer widths were used to evaluate the potential for North Georgia's streams to maintain high quality trout habitat given different riparian buffer widths. Trout are sensitive to alterations in stream habitat conditions because trout require stream habitats with cool temperatures and coarse substrates for spawning. Thus, trout can also be used as indicators of good water quality and stream habitat conditions that benefit many other aquatic species in North Georgia.

This study also investigated the characteristics and distribution of headwater streams with average annual flows less than 25 gallons per minute (gpm). These streams are currently exempt from 50-ft buffer requirements and can be buried within underground pipes ("piped") up to 200 ft by individual landowners. Since these headwater streams flow into larger trout streams, alterations to these headwater streams may impact the larger trout streams.

Summaries for each section of this report are given below. Figures and tables are located within the text of each section. Color plates are located at the end of subsections.

1. TROUT STREAMS AND FOREST CONDITIONS IN NORTH GEORGIA

- Private lands contain the majority of Georgia's trout stream miles, including most of the "primary" and large trout streams (Figures 1-3 and 1-4, Plate 2). Currently, most private-land trout streams have forested riparian buffers less than 100 ft wide, and 1/4 of these private-land streams have riparian buffers less than 50 ft wide (Figure 1-5). In the northern half of the study area, riparian zones are more heavily disturbed than their surrounding drainage basins. In the southern half, many riparian zones have higher forest cover than their drainage basins. Riparian forest cover is substantially lower on private lands than on public lands across the study region (Figures 1-6 and 1-7).
- Most public-land trout streams have riparian buffers of 100 ft or more in width and nearly complete forest cover in their watersheds. Where forest cover has been disturbed on public lands, the riparian zone is generally more disturbed than the surrounding watershed (Figure 1-5).
- As a group, trout streams on private lands in the northern half of the study region (where the highest concentration of primary trout streams exists) have riparian zones that are in the poorest condition of all trout streams in the state. (Figures 1-6 and 1-7). Thus, the best potential core habitat for trout has been most heavily disturbed.
- None of the trout streams in the State of Georgia have uniform, consistent, conterminous riparian buffers. Instead, riparian buffers are patchy, broken, and vary in width along the stream course. At any given location, riparian buffer widths are often dissimilar on either side of the same stream. Nonetheless, *average* forested riparian buffers widths can be estimated from satellite imagery by determining the percent forest cover within a 100-ft riparian zone on both sides of the stream along the entire stream network above a sampling site (Figure 1-11, Table 1-2).

2. PREDICTING YOUNG TROUT POPULATIONS FROM STREAM TEMPERATURE AND SEDIMENT CONDITIONS

- The presence or absence of stocked (hatchery raised) trout in a stream is not a reliable indicator of stream habitat quality. However, "young trout" (naturalized brown and rainbow trout less than 5.9 inches (150 mm) in length) are less influenced by stocking and angling and are indicators of reproducing trout populations. Since young trout are more reliable indicators of stream habitat quality, this research focuses on the presence and biomass of young trout populations.
- Trout require cool stream temperatures. The biomass of young trout and likelihood of young trout presence can be predicted by maximum seven-day average maximum (M7DAM) temperatures (Figures 2-1 and 2-2). M7DAM temperature is the average of daily maximum stream temperatures during the warmest 7-day period of the summer. This measure captures the magnitude of thermal stress experienced by trout within a given stream.
- Three temperature categories describe the relationships between M7DAM stream temperature and the likelihood of young trout presence and their biomass (Figures 2-1 and 2-2): 1) Below 67°F (19.5°C), young trout populations have high biomass and greater than

90% chance of occurrence; 2) From 67 – 71°F (19.5 – 21.5°C), young trout biomass declines and likelihood of occurrence drops from 90% to 50%; and 3) Above 71°F (21.5°C), young trout are rarely observed. Thus, streams with M7DAM temperatures less than 67°F (19.5°C) are most likely to support self-sustaining trout populations.

- Trout require coarse substrates for spawning. Fine sediments can fill in (embed) coarse substrates and "smother" trout eggs. Young trout are found in North Georgia streams where riffle habitats lack fine sediments (Figure 2-3). Streams with low amounts of fine sediment are better able to support self-sustaining trout populations.
- In combination, M7DAM stream temperature, maximum stream depth, and fine sediment in riffle habitats can predict the biomass of young trout within a stream (Figure 2-4). Young trout biomass increases significantly in cooler streams with fewer fine sediments, indicating that cool M7DAM stream temperatures and low levels of fine sediment are important habitat requirements for young trout populations in North Georgia's trout streams.

3. PREDICTING STREAM TEMPERATURE AND SEDIMENT CONDITIONS FROM RIPARIAN FOREST COVER

- M7DAM stream temperatures are influenced by riparian forest cover and elevation (Figure 3-4). While low elevation streams are naturally warmer than high elevation streams, loss of riparian cover results in increased stream temperature (and corresponding reduction in trout habitat quality) at any elevation.
- Riparian forest cover along the entire stream network is the best scale of forest cover for predicting M7DAM temperatures (Figure 3-7 A) whereas basin forest cover is a less reliable predictor of M7DAM temperatures (Figure 3-7 B).
- Riffle embeddedness, a measure of fine sediments within riffle habitats, can be predicted by riparian forest cover and maximum stream velocity (Figure 3-10). While slow-moving streams naturally have more fine sediments than streams with faster flow, loss of riparian cover yields an increase in fine sediments (and corresponding reduction in trout habitat quality) for streams that flow at any velocity (Figure 3-12).
- The M7DAM stream temperature and sediment conditions necessary for high quality trout habitat are associated with a high percentage of forest cover in a 100-foot riparian zone along the entire stream network.

4. IMPLICATIONS OF REDUCTIONS IN RIPARIAN BUFFER WIDTHS FOR YOUNG TROUT

- Equations developed in the previous sections were used to explore the consequences of reducing forested riparian buffer widths from 100 ft to 50 ft.
- When widths of forested riparian buffers are reduced from 100 to 50 ft, M7DAM stream temperatures warm by 2.9°F in a cool, wet summer and by 4.2°F in a warm, dry summer (Table 4-1) and fine sediment in riffle habitats increases by 11% (Table 4-2).
- Although these changes may appear small numerically, the biological consequences are large. In any North Georgia trout stream where riparian buffer width is reduced from 100 ft to 50 ft, associated changes in stream temperature and sediment are expected to reduce the young trout populations by 81 – 88% (Tables 4-3 and 4-4).

- Given 100-ft riparian buffers, 63% of trout stream miles would support temperatures indicative of high or marginal quality trout habitat (less than 71°F) whereas 37% would have temperatures associated with poor quality trout habitat (greater than 71°F). Given 50-ft riparian buffers, approximately 9% of Georgia's trout stream miles would support temperatures indicative of high or marginal quality trout habitat whereas over 91% would have temperatures associated with poor quality trout habitat (Plate 3).
- Riparian buffers on most private lands and some public lands are currently less than 100 ft (Plate 5). 33% of Georgia's trout stream miles (most on private lands) have M7DAM temperatures ranging from 2 – 5°F warmer than would be expected with a 100-ft forested riparian buffer. This pattern of stream warming is already occurring (especially on private lands) and is of concern because the M7DAM temperature difference between high quality trout habitat and poor quality trout habitat is only 4°F. In the transition zone between high and poor quality habitat, there a ~15% decrease in the likelihood of trout occurrence for each degree (°F) of warming (Figure 2-2). Thus, existing reductions in riparian cover and associated increases in M7DAM stream temperature of 2 to 5 °F may have already yielded as much as a 30% to 75% reduction in the likelihood of finding trout in streams where riparian cover has been reduced.

5. ATTRIBUTES OF HEADWATER STREAMS EXEMPT FROM RIPARIAN BUFFER REQUIREMENTS

- In the Blue Ridge physiographic province of North Georgia, a watershed with a drainage area of 16 acres yields a mean annual discharge of 25 gpm. Drainage area is an accurate predictor of average discharge even for very small Blue Ridge streams (Figure 5-2). This relationship is only applicable to the Blue Ridge province.
- A definable channel is formed in a basin ranging from 7 – 20 acres whereas perennial flow is yielded in a basin ranging from 11 – 32 acres (Figure 5-1). A stream with a mean annual discharge of 25 gpm has an active channel 4 – 5 ft wide, though flowing water only occupies a small portion of the channel during much of the year and the channel may dry completely.
- 41% of private lands in North Georgia drain into headwater trout streams that are in the size range exempt from 50-ft riparian buffer regulations and could be piped up to 200 ft by individual landowners (Plate 6).
- Three small headwater streams that could potentially be piped were sampled for aquatic organisms. These streams had 29 – 35 aquatic taxa (Table 5-3). 10 – 14 taxa at each site were indicators of high water quality (EPT taxa: Ephemeroptera, Plecoptera, Trichoptera). These small headwater streams provide habitat for an abundance of aquatic life. Piping would eliminate the habitat supporting this aquatic life.
- Insects drifting downstream from these three headwater streams were also diverse. In each stream, 9 – 22 taxa were in the drift. 5 – 6 of these taxa were indicators of high water quality (EPT taxa). In contrast, only one EPT organism was captured in the drift net below a piped stream. 89% of the organisms collected from this piped stream were aquatic worms indicating poor water quality.

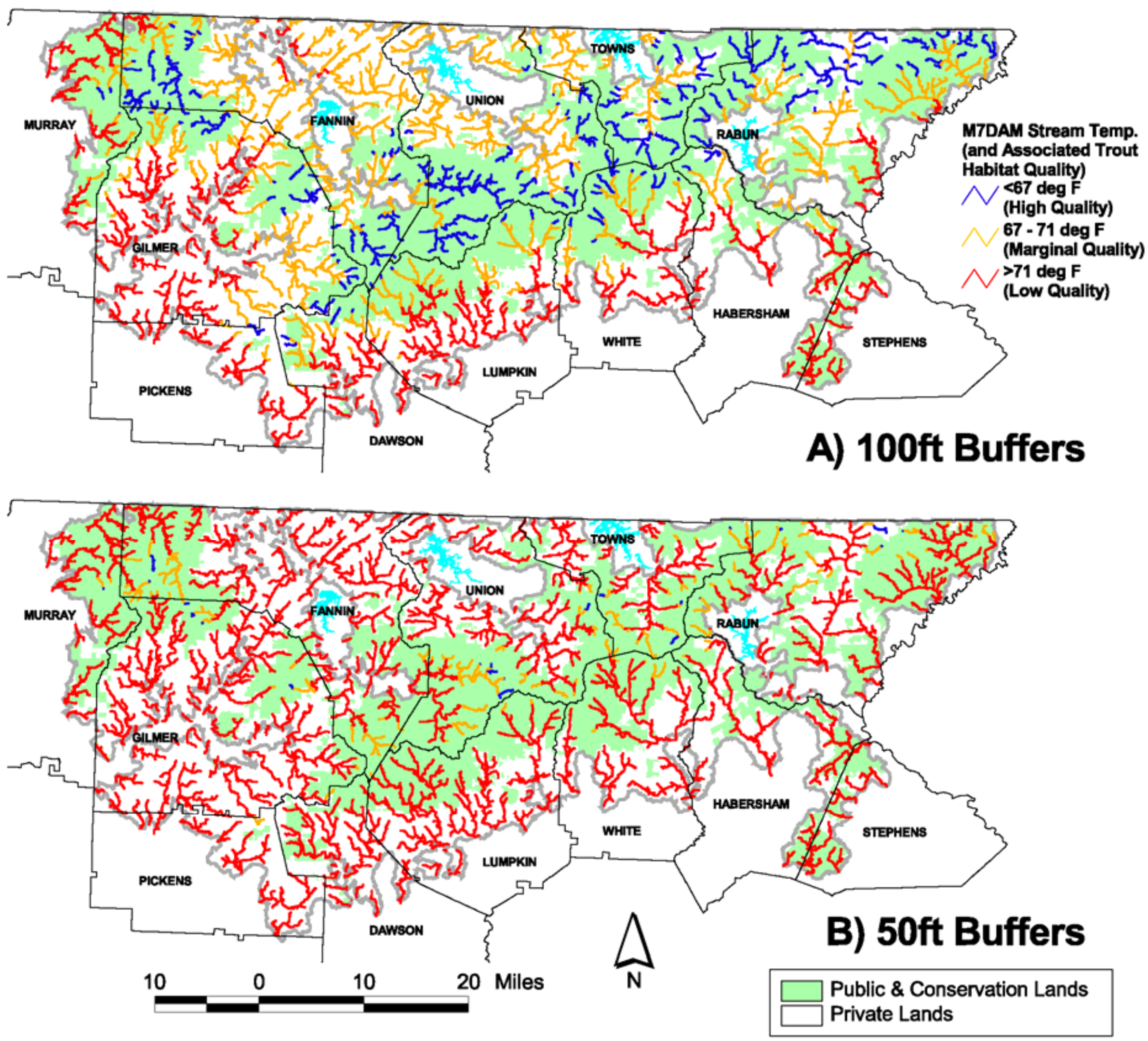
CONCLUSIONS

- Changes in riparian buffer regulations could greatly impact Georgia's trout populations because a significant fraction of Georgia's trout stream miles are on private lands.
- We developed models based on the relationships observed between: 1) young trout populations and stream habitat (stream temperature and sediment conditions); and 2) stream habitat and riparian buffer widths. Calculations using these models suggest that if riparian buffer widths are reduced from 100 to 50 ft on all trout streams, then significant thermal alteration of Georgia's trout streams could occur. The geographic distribution of these changes in trout habitat quality is indicated in the color plate on page 6.

Percent of Georgia's trout stream miles that would support stream temperatures indicative of high, marginal, and poor trout habitat with either 100 ft or 50 ft buffers.

Trout Habitat Quality	**100-ft Riparian Buffer**	**50-ft Riparian Buffer**
High (Below 67°F)	18.8%	0.7%
Marginal (67 – 71°F)	44.4%	8.1%
Poor (Above 71°F)	36.8%	91.2%

- On average, in a stream where the forested riparian buffers were reduced from 100 ft to 50 ft along the length of the stream, the biomass of young trout would be reduced by over 80% due to associated stream warming and increased amounts of fine sediments.
- Headwater trout streams with drainage areas of 16 acres or less are exempt from current 50-ft riparian buffer regulations and can be piped 200 ft by individual landowners. 41% of private lands in North Georgia drain into such streams. Piping these streams will reduce habitat for aquatic organisms and drifting organisms supplied to downstream trout populations. The impact of this piping on downstream trout populations will be a function of its extent.



Distribution of Maximum Seven-Day Average Maximum Stream Temperatures and Associated Trout Habitat Quality Expected with 100ft and 50ft Riparian Buffers on North GA Trout Streams

Temperature data are estimated from a multiple regression equation using parameters derived from 2001 (a year with intermediate air temperature and rain fall) to predict summertime maximum seven-day average maximum water temperature from stream elevation and upstream riparian cover.

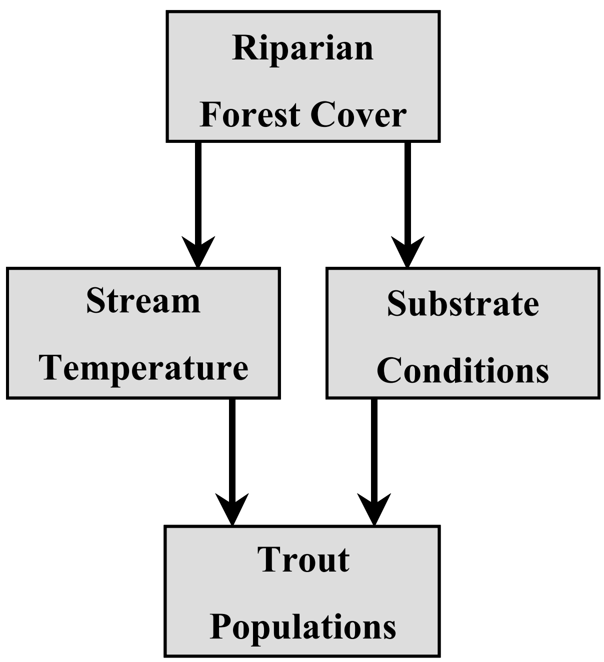
INTRODUCTION

The Georgia General Assembly passed House Bill 1426 during the 2000 session. The following provisions were included in this legislation:

1. The mandatory forested riparian buffer width on trout streams was reduced from 100 feet to 50 feet.
2. An exemption from riparian buffer requirements was granted allowing small headwater tributaries of trout streams (with a mean annual flow less than 25 gpm) to be piped.
3. A three-year study was to be conducted by University of Georgia scientists to evaluate the implications of these regulatory changes.

This report summarizes the results of the three-year study. The goal of this research is to provide the State with rigorous scientific information for use in policy decisions and management relating to the State's trout streams.

Trout need clean, cool water and coarse substrate for spawning. Trout are sensitive to changes in stream habitat (stream temperature and sediment conditions) because of their strict habitat requirements. Thus, we used the following conceptual model to investigate whether trout populations in North Georgia are apt to be impacted by reductions in riparian buffer widths, the first provision of House Bill 1426.



This conceptual model reflects the current understanding of how trout populations are linked to riparian forest conditions. Trout are adversely affected by these changes in stream temperature (Theurer 1985; Beschta 1987; Beschta 1988; Li 1994; Beschta 1997; Poole 2001) and sediment conditions (Megahan 1992; Eaglin and Hurbert 1993; Espinosa 1997; Huntington 1998). Riparian forest cover provides shade maintaining cooler stream temperatures. Also, riparian forest cover reduces inputs of fine sediments, thereby protecting the coarse substrate habitats needed by trout for spawning. Warmer stream temperatures, increased sedimentation, and reduced trout populations are likely outcomes of reductions in riparian forests. This report quantifies the expected changes in stream temperature, sediment conditions, and trout populations associated with reducing riparian buffer widths from 100ft to 50ft.

A quantitative relationship between riparian forest cover extent and trout stream conditions in North Georgia had not been determined prior to this study. We recognize that forested riparian zones impact stream ecosystems in many ways such as by removing excess nutrients (Correll 1997) and providing food resources for aquatic organisms (Wallace et. al 1997). This study, however, focuses on the effects of riparian forests on stream temperature and sediment conditions because these two environmental variables are most directly related to trout habitat in North Georgia, the southernmost extent of the distribution of trout in the eastern United States (Behnke 2002).

To provide scientific information on how reducing riparian buffer widths from 100 ft to 50 ft is likely to impact Georgia's trout populations, we conducted an assessment of riparian and basin forest cover conditions along the trout stream network of North Georgia (**Section 1**) and then related:

1) Trout presence and biomass to stream temperature and sediment conditions (**Section 2**);
2) Stream temperature and sediment conditions to the extent of forest cover in a 100-foot riparian zone along the entire stream network and also in the entire basin (**Section 3**)

Based on these relationships, we predicted trout biomass for 100-ft and 50-ft riparian buffer widths (**Section 4**).

To address the second provision of House Bill 1426, which exempts small headwater trout streams from riparian buffer regulations, we first determined what size watershed generates a mean annual discharge of 25 gallons per minute (**Section 5**). Based on this information, we calculated the area of private lands in North Georgia that drain into these small streams that are exempt from buffer regulations and can be piped. Also, we investigated the geomorphic characteristics of these small streams to determine if channel metrics and baseflow information are useful predictors of average stream discharge. We sampled the aquatic organisms supported by small headwater streams because these streams flow into larger trout streams and supplement the diets of downstream trout populations with drifting insects.

Analysis of changes relating to the implementation of trout stream buffer requirements was conducted by the Carl Vinson Institute of Government. Findings from this analysis will be available in a separate forthcoming report.

1. TROUT STREAMS AND FOREST CONDITIONS IN NORTH GEORGIA

- Summary: We assessed the riparian zones and drainage basins (watersheds) of roughly 8,000 stream segments that comprise Georgia's network of trout streams using a Geographic Information System. This assessment was used to: 1) Describe the existing landscape conditions (e.g., forest cover in riparian zones and whole basins); 2) Identify the distribution of trout streams on public versus private lands; and 3) Design a sampling strategy for the fieldwork necessary to conduct this study. This landscape assessment demonstrated that:

1. On public lands, forest cover in the riparian zones and basins of trout streams is only lightly disturbed. Most public-land trout streams have riparian buffers of 100 ft or more and nearly complete forest cover in their basins. Where forest cover has been disturbed on public lands, the riparian zone is generally more disturbed than the surrounding basin (Plate 1, Figure 1-5).

2. On private lands, forest cover in the riparian zones and basins of trout streams is highly disturbed. Most private-land trout streams have riparian buffers less than 100 ft wide, and 1/4 of these streams have riparian buffers less than 50 ft wide (Figure 1-5). In the northern half of the study area, riparian zones are more heavily disturbed than their surrounding basins. In the southern half, many riparian zones have higher cover than their basins. Riparian cover is substantially lower on private lands than on public lands across the entire study region (Plate 1, Figures 1-6 and 1-7).

3. Private lands contain the majority of the State's trout streams, including most "primary" and large trout streams (Figures 1-3 and 1-4).

4. Riparian zones in areas with the highest concentrations of primary trout streams (private lands in the northern half of the study region) are in poorer condition than elsewhere in the study region (Figures 1-6 and 1-7).

5. The landscape assessment allowed us to choose two groups of sampling sites in the study region (Plate 1). The initial group of study sites is representative of the diversity of trout streams, basin forest conditions, and riparian forest conditions within the study area, and allows us to relate trout populations to stream temperature and sediment conditions. The second group of study sites allows us to determine whether differences in stream habitat conditions are more closely related to forest cover conditions in the riparian zone or in the surrounding basin (Figure 1-8).

6. Average forested riparian buffers widths can be approximated using the percent forest cover within a 100-ft zone along both sides of the stream for the entire stream network above a sampling site (Figure 1-11). A 100-ft riparian buffer width is indicated by 96% riparian forest cover and a 50-ft buffer is associated with 50.2% riparian forest cover (Table 1-2).

1.1 Introduction

The northeastern corner of Georgia contains the southern terminus of the Appalachian Mountains, which span the eastern coast of the United States. Northeast Georgia is also the southernmost extent of the distribution of trout on the east coast (Behnke 2002). Mountain streams in Northeast Georgia potentially support stream habitats with cool temperatures and coarse substrate, two important habitat requirements for trout. A dense, closed canopy of trees shading the streams maintain cool stream temperatures in these high-elevation streams despite the potential for substantial solar heating of stream water during summer months. Coarse substrate habitats are also maintained by riparian (streamside) vegetation which reduces inputs of fine sediments into streams.

Historically, the streams of this region contained native brook trout (*Salvelinus fontinalis*). Today, the Wildlife Resource Division (WRD) of the Georgia Department of Natural Resources operates a fish hatchery program to maintain trout in North Georgia's streams. The WRD stocks two game species, rainbow trout (*Oncorhynchus mykiss*) and brown trout (*Salmo trutta*). Trout streams are classified as either "primary" streams where self-sustaining populations of trout may exist, or "secondary" streams where stocked trout are available to anglers but are not expected to reproduce or maintain viable trout populations.

1.2 Landscape Assessment

We assessed the landscape characteristics of the primary and secondary trout streams of North Georgia using a Geographic Information System (GIS) and then used these data to support the study. The GIS data layers used in this analysis are listed in Table 1-1.

Table 1-1. GIS data sources used in the Trout Stream Buffer Study.

Data Type	Source	Purpose
30-m Digital Elevation Model, Georgia	US Geological Survey	Used to determine the elevation and drainage area of potential study sites
1:24,000 Hydrography (stream network), Georgia	US Geological Survey	Provided stream locations on the landscape. Stream order[1] was determined using this layer.
1998 Landcover of Georgia (30-m resolution)	Natural Resources Spatial Analysis Laboratory (NARSAL), Institute of Ecology, University of Georgia	Landcover analyses. Data set derived from satellite data (1998 Landsat Thematic Mapper imagery)
Georgia Conservation Lands, and Georgia Department of Natural Resources.	Natural Resources Spatial Analysis Laboratory (NARSAL), Institute of Ecology, University of Georgia	Conservation lands are generally public lands managed by government agencies. Used to identify trout streams on private vs. public lands.
Rules and Regulations for Water Quality Control Chapter 391-3-6, Revised August 2000	Georgia Department of Natural Resources	Used with hydrography data to identify primary and secondary trout streams

[1] "Stream order" is an indicator of stream size. First order streams have no tributaries. A second order stream is formed by two or more first order streams. A third order stream is created by the joining of two or more second order streams, etc. (Figure 1-1)

Methods
The GIS data layers were analyzed as follows. First, the hydrography layer was organized as a "pure" dichotomous network. Streams were divided into lineal segments – lengths of stream flowing between channel junctions (Figure 1-1). More than 8,000 individual stream segments were required to represent all of the trout streams in North Georgia (Plate 1—located at the end of this subsection). Then, the flow direction of each segment was determined in order to allow automatic identification of all segments upstream of a given segment and to allow stream order to be calculated for each segment.

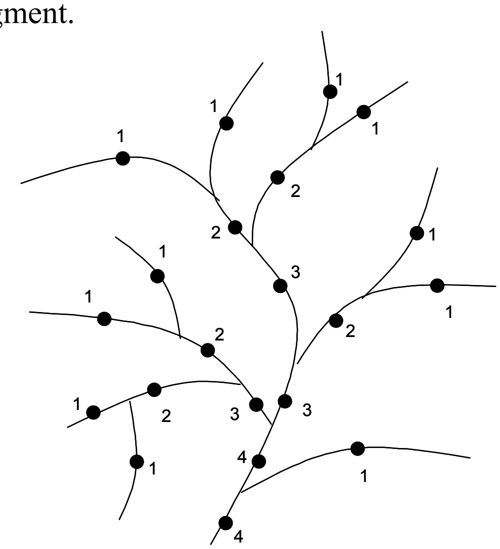


Figure 1-1. A hypothetical stream network where each dot identifies a "segment" – the linear stretch of river between tributary junctions. Numbers indicate the stream order of each segment.

The riparian zone for each segment was represented by a 100-ft (30-m) buffer on both sides of the stream along the entire stream network upstream from and including the stream segment. The 30-m digital elevation model was used to delineate the drainage basin and the direct contributing area ("adjacent area") (Figure 1-2) for the center point of each segment in streams 2nd order or greater. Inaccuracies in the digital elevation model resulted in incorrect drainage delineation for approximately 10% of the stream segments. Filtering algorithms were developed to locate these errors and each error was corrected by hand.

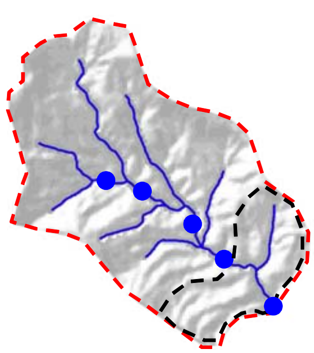


Figure 1-2. Segment center points (blue dots) were determined for each 2nd order or larger stream. Drainage basins (red line) and "adjacent areas" (black line) were delineated for every segment center (though only illustrated here for the downstream-most segment).

The percent forest cover within each stream buffer, adjacent area, and drainage basin was determined from the GIS landcover data layer. These forest cover statistics were broken down by land ownership to assess forest cover conditions in the riparian zones and basins of trout streams on public versus private lands in North Georgia. Forest cover for the adjacent area was used in the landscape assessment while forest cover for the drainage basin was used in all other analyses.

Results

Results from the landscape assessment are summarized in Plate 2A&B, which show the spatial relationships between land ownership, riparian buffer width, and basin forest cover.

Approximately 60% of Georgia's trout stream miles are found on private land. Primary trout streams are about evenly divided between public and private lands while secondary trout streams are relatively uncommon on public lands (Figure 1-3).

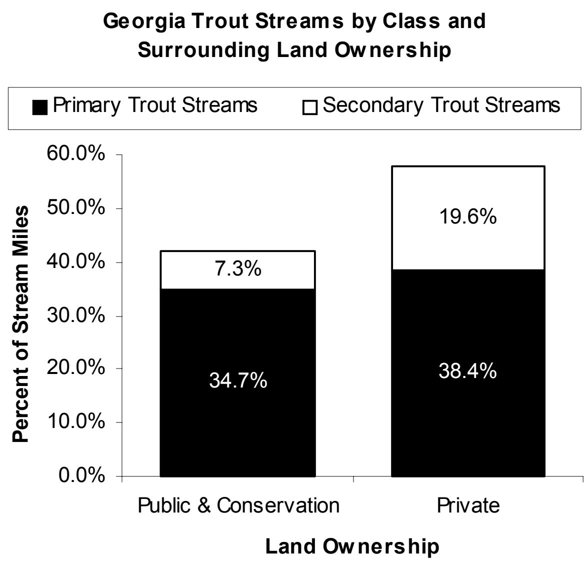


Figure 1-3. Distribution of primary and secondary trout streams among public and private land ownership.

As with almost any stream network, first order streams are by far the most common type of trout stream in Georgia. First order streams, however, are small and typically provide habitat for only juvenile trout. Larger streams (3rd through 5th order streams) provide habitat for larger fish and the best fishing opportunities, but make up successively smaller proportions of the stream network (Figure 1-4 A). These important larger streams also provide habitat linkages between subpopulations of trout, which are critical for maintaining self-sustaining trout populations. Thus, even though they are rare on the landscape, larger trout streams play important roles ecologically (for contributing habitat) and economically (for the fishing opportunities they provide). While 1st order streams are equally distributed among private and public lands, 3rd to 5th order trout streams are found primarily on private lands in Georgia (Figure 1-4 B).

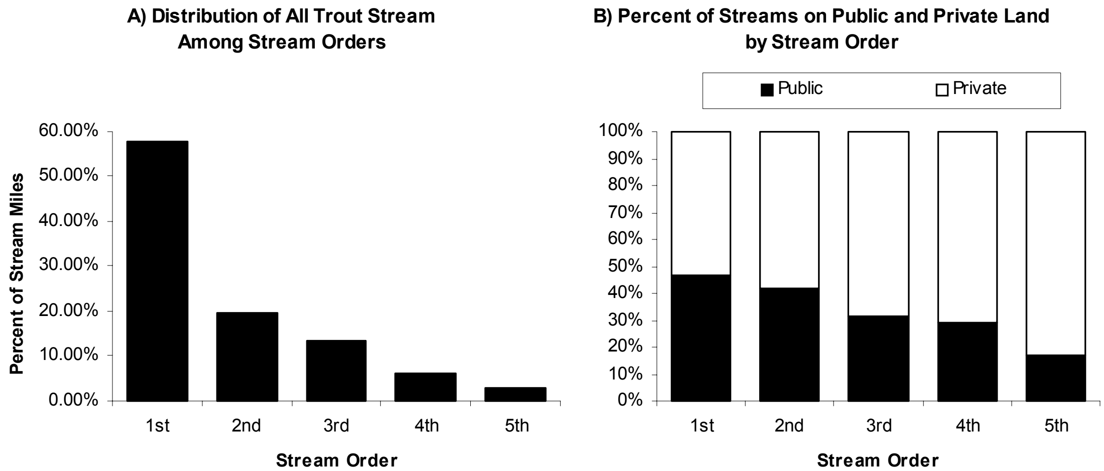


Figure 1-4. Distribution of primary and secondary trout streams by stream order among public and private land ownership.

Landcover data from 1998 (the most recent year for which these data were available) reveal that forest cover and riparian buffer widths are markedly higher on public lands than on private lands. Trout streams on public lands were approximately 4 times more likely than those on private lands to have riparian buffers of 100 ft or more, or to have adjacent drainage areas with forest cover of 90% or greater. Conversely, streams on private lands were 9 times more likely to have an average riparian buffer of less than 50 ft. Most private-land trout streams have riparian buffers less than 100 ft wide, and 1/4 of these streams have riparian buffers less than 50 ft wide (Figure 1-5). Nearly half of the trout streams on private lands had adjacent drainage areas with less than 75% forest cover, and 9% had adjacent areas with less than 50% cover. Only 3% of trout stream on public lands had adjacent drainage areas with less than 75% cover (Figure 1-5).

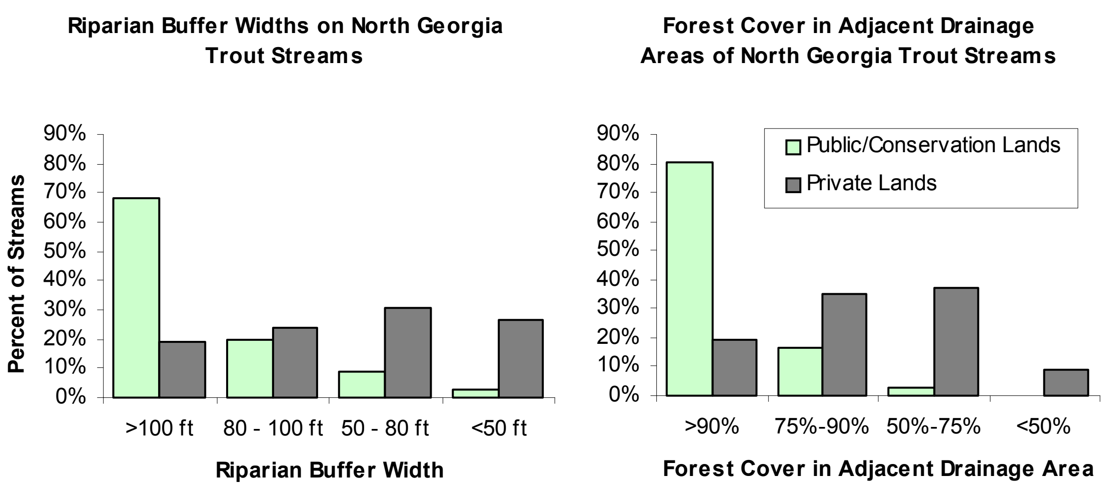


Figure 1-5. Riparian buffer widths and forest cover in the drainage basin adjacent to riparian buffers for public and private lands in North Georgia.

Riparian buffer conditions on private lands are generally poor. In some places, however, private-land riparian buffers are more forested than the adjacent basin areas that drain to the stream. Private-land riparian buffers located in the southern half of our study area (i.e., Dawson, Habersham, Lumpkin, Stephens, and White counties) tend to be wider than those in the northern half (i.e., Fannin, Gilmer, Rabun, Towns, and Union counties) even though the private-land forest cover in the associated drainage basins is approximately equal between northern and southern halves (Figure 1-6). This uneven spatial distribution of riparian buffer widths results in a band of private-land trout streams across the southern half where the riparian conditions are poor, but still more forested than the associated drainage basin areas adjacent to the riparian zone (Plate 2 C).

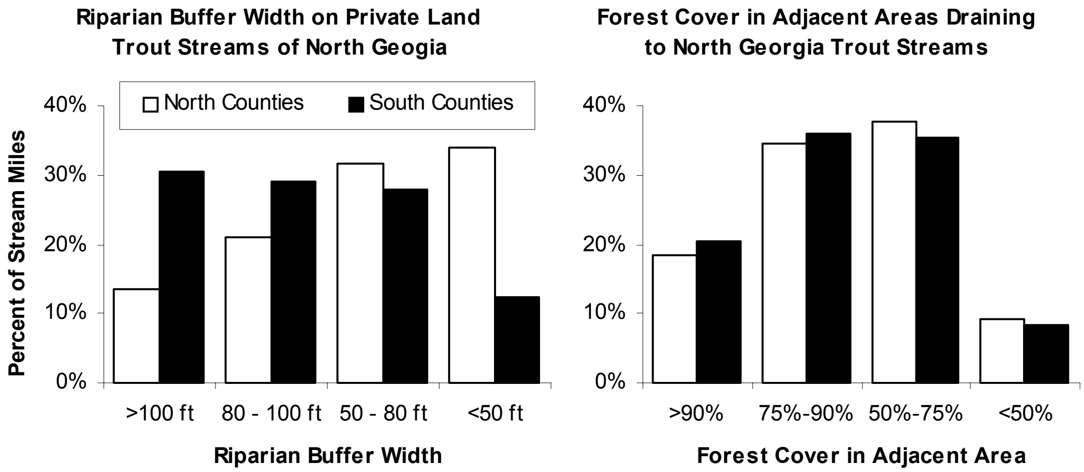


Figure 1-6. Riparian buffer widths and basin forest cover on private lands in the northern and southern halves of the study area.

The distribution of private-land trout streams, however, is not equal between northern and southern halves of the study area. Two thirds of the private-land trout stream miles are concentrated in the northern half where riparian conditions are the poorest. Secondary trout streams are evenly split between the north and south while there are three times as many primary trout streams on private land in northern half as in southern half (Figure 1-7).

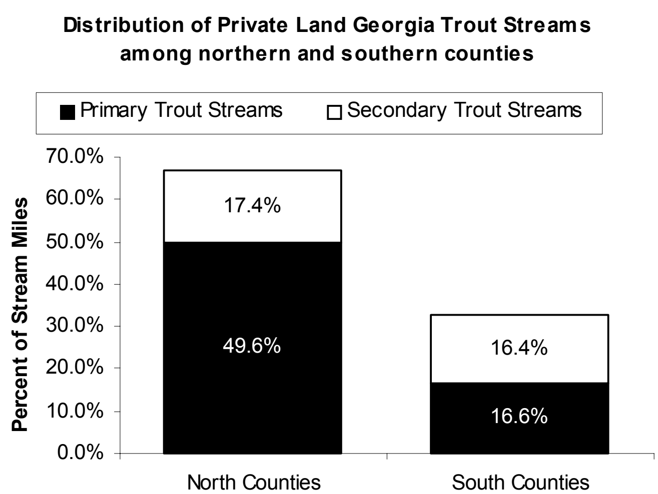


Figure 1-7. Distribution of trout streams on private lands among the northern and southern halves of the study area.

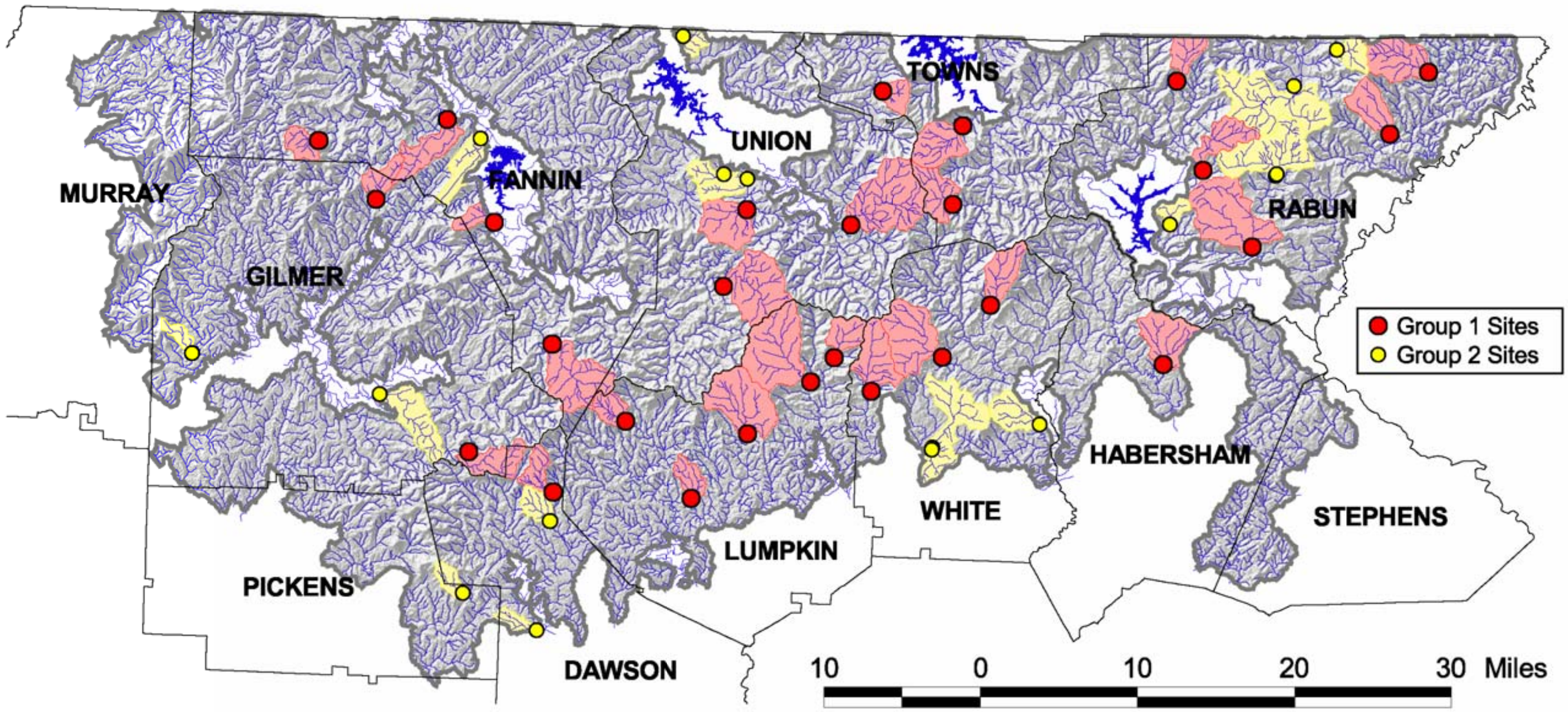
Discussion

In general, riparian zones and drainage basins have high forest cover on public lands. Plate 2 C reveals that many streams (those without red, gray, or blue dots) have greater than 90% cover in both their riparian zones and drainage basins. Where colored dots are present on public lands in Plate 2C, they are typically red or gray, meaning that either riparian cover is more than 25% less than basin cover or that riparian and basin cover are relatively similar. This finding indicates that the riparian zones of streams on public lands, while generally lightly disturbed (Figure 1-5), have been deforested preferentially relative to their basins. This preferential development is potentially a result of roads often being built along stream corridors.

Trout streams on private lands, however, have been subjected to substantial deforestation in both their riparian zones and in their basins. Furthermore, levels of riparian disturbance are the most extreme in the northern half of the study area where there is the highest density of private-land primary trout streams. One third of private-land trout stream miles in the northern half of the study area have riparian buffers with average widths of less than 50 ft. Another one third have average buffer widths between 50 and 80 ft. Only 13% of those streams have riparian buffers 100 ft or greater in width.

Riparian zones on private lands have already been highly disturbed in the study region (Figure 1-5, Figure 1-6, Plate 2). Since private lands contain the majority of trout streams in the State (including the majority of primary trout streams and large 3rd to 5th order trout streams), our study results (presented in **Sections 2** through **4** of this report) suggest that the loss of forested riparian buffers on private lands has likely had a substantial effect on the quality of trout habitat and thereby on trout populations in North Georgia.

Given that private lands contain so many of the State's primary trout waters, management actions on private lands are apt to substantially influence the viability of the North Georgia trout fishery. Therefore, the character and quality of trout habitat on private lands in North Georgia must be considered in order to understand the influence of land-use activities on trout populations and develop appropriate management strategies.



Trout Streams of Northeastern GA

Trout streams of Northern Georgia are displayed in blue overtop of a shaded relief map. The grey boundary of the shaded relief map circumscribes that portion of the study area containing streams with drainage areas less than 20 sq. miles. Streams with drainage areas larger than 20 sq. miles were not considered as potential sampling sites for this study. Sampling sites and their associated basins are shown on the map. County boundaries and names are shown in black. Major reservoirs are shown for reference.

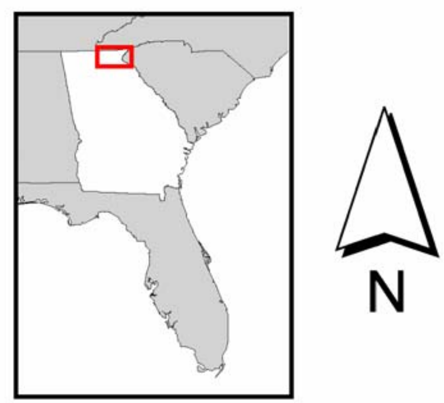
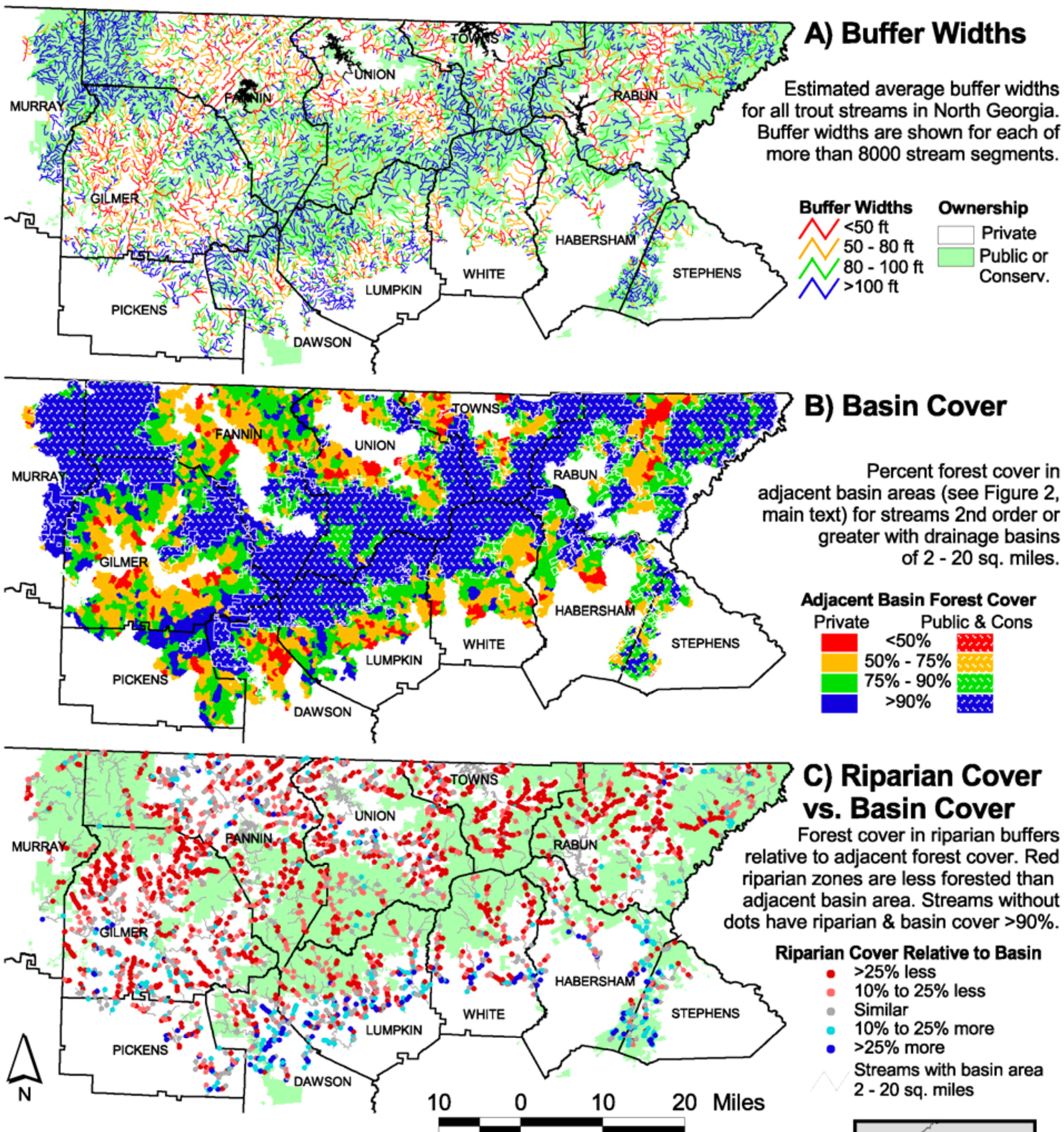


Plate 1



Riparian Buffer Conditions on Trout Streams of North Georgia

Riparian buffer widths and forest cover in the adjacent basin for North GA trout streams, by county and land ownership.
Forest cover data are derived from satellite imagery (Landsat) collected in 1998.

Plate 2

1.3 Site Selection

We used a multi-metric coarse filter approach to select a suite of specific sampling sites that would yield a statistically robust sample set and maximize the statistical power of the final data analyses. Study site selection occurred in two stages. First, in 2001, 28 sites were identified for sampling using the GIS database and landscape assessment described in **Section 1.2**. Data from these sites was used to relate trout populations to stream habitat (stream temperature and sediment conditions) in North Georgia's trout streams. We refer to this dataset as the "Group 1" sampling sites, which are further described in the **Section 1.3.1**.

Our preliminary data analysis revealed a strong correlation between percent forest cover in the basin and in the riparian zone for the Group 1 sampling sites after two years of data collection (Figure 1-8, red dots). Because of this correlation, it was impossible to determine whether forest cover conditions in the basin or in the riparian zone were driving the variation observed in stream habitat and trout populations. Therefore, in 2003, we returned to the GIS database and specifically chose 17 additional sampling sites that would allow us to determine if basin or riparian forest cover conditions were responsible for the observed variation in trout habitat and populations. This group of 17 sites is referred to as the "Group 2" sampling sites (yellow dots in Figure 1-8) and is discussed in **Section 1.3.2**.

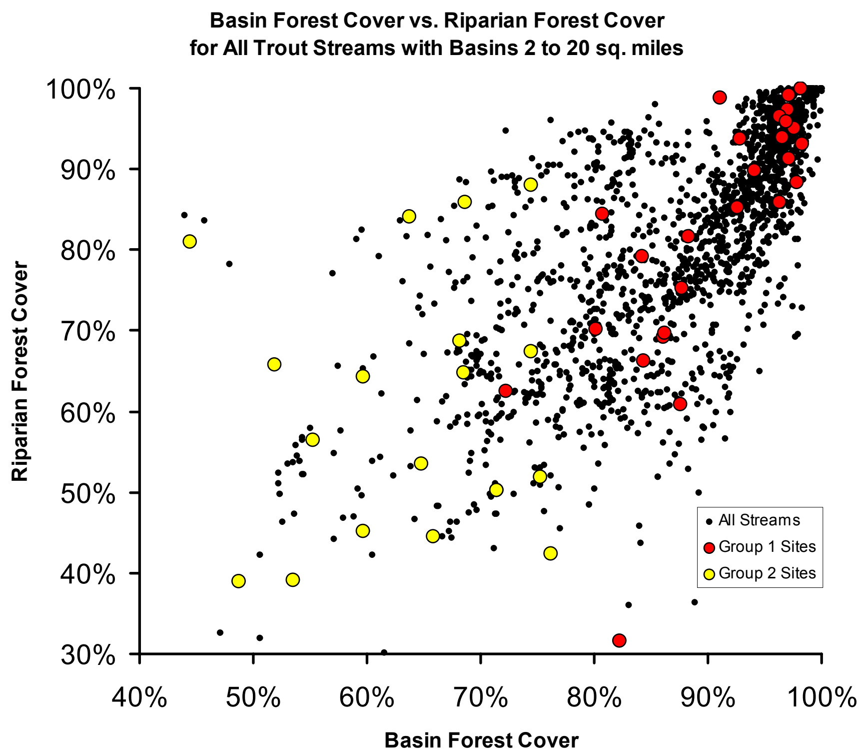


Figure 1-8. Basin forest cover versus riparian forest cover for all trout streams with basins 2 to 20 sq. miles.

1.3.1 Group 1 Sampling Sites

After consultation with fish biologists at the Georgia Department of Natural Resources, 3rd and 4th order primary trout streams with basin areas less than 50 km^2 (19.3 $miles^2$) were targeted for sampling. All stream segments meeting these criteria were extracted from the GIS database yielding 413 segments for consideration as potential sampling sites.

Previous studies have documented that stream elevation, basin area, and percent riparian cover are useful predictors of maximum stream temperature when combined (Scott et al. 2002). Thus, we used GIS analysis to classify stream order, elevation, basin area, and percent of forest cover in upstream riparian zones for all potential sampling sites. Elevation and basin area associated with each sampling site were determined from a 30-m digital elevation model while upstream riparian cover was calculated from the Landcover of Georgia dataset (Landsat 1998) as the percent forest cover within a 30-m (100 ft) zone along both sides of the streams and the entire stream network above the potential sampling site.

We had three specific objectives in selecting the final sampling sites from the pool of 413 potential sites: 1) To cover the range of variation for each independent variable (basin area, elevation, and percent riparian cover) existing in North Georgia; 2) To choose a sample set that was representative of trout streams across North Georgia; and 3) To minimize autocorrelation between independent variables. To optimize each of these objectives simultaneously, we performed a cluster analysis and classified the potential sampling sites into 15 groups based on basin area, elevation, and percent riparian cover (Figure 1-9). Sites within each group are more similar to one another than sites in other groups with respect to the independent variables. We then selected final study sites from each of the 15 groups in proportion to the size of each group, but with a minimum of one site per group.

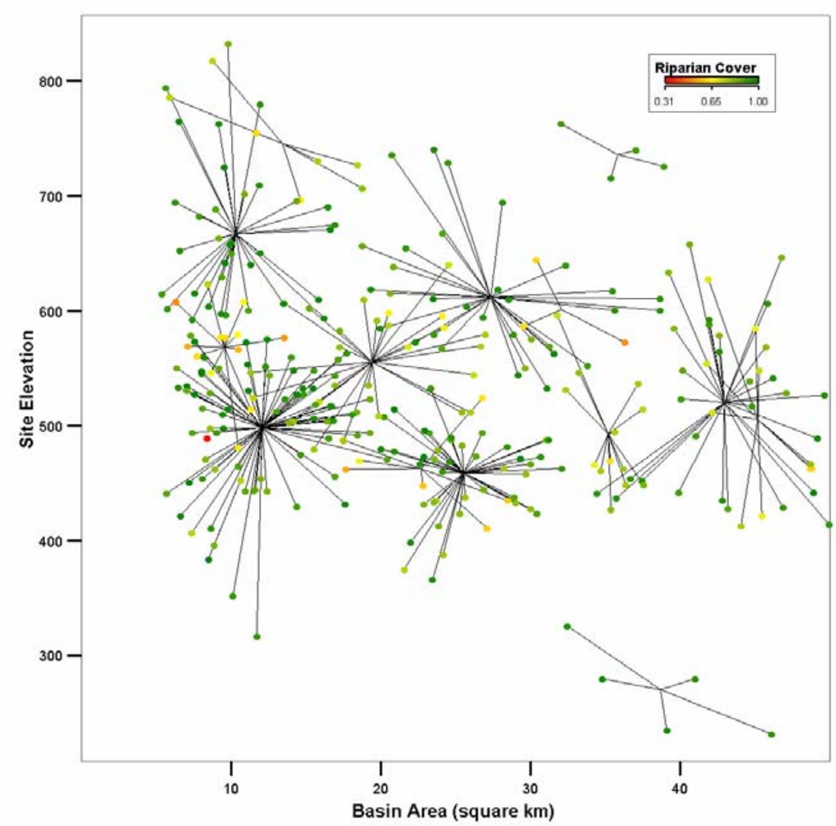


Figure 1-9. Results from a cluster analysis of potential sampling sites using elevation, basin area, and riparian forest cover. Dots represent characteristics of individual potential sampling sites. Lines group potential sampling sites into groups (clusters) where sites within each group are more similar to one another than to sites in other groups.

The final suite of 28 sites is representative of the North Georgia landscape as a whole because sites were selected proportionally from each group. Our sample sites cover the range of variation on the landscape because at least one site was chosen from each group. Also, autocorrelation between independent variables (elevation, basin area, and riparian cover) is avoided (Figure 1-10).

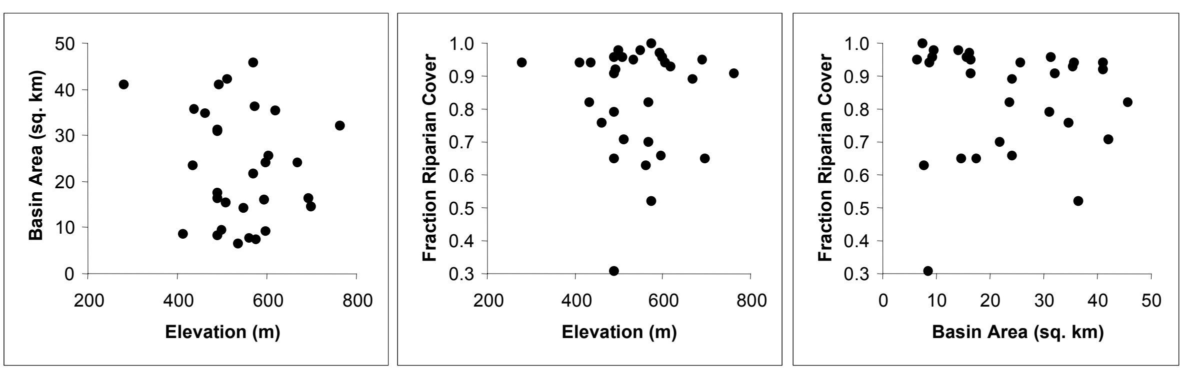


Figure 1-10. Plots of basin area, elevation, and riparian cover against one another illustrate the range of site characteristics sampled, the distribution across that range, the representative nature of the sample, and the lack of autocorrelation of independent variables within the data set.

The cluster analysis addressed our primary considerations in sample site selection (a representative sample that covered the range of variation but lacked autocorrelation between independent variables). Therefore, we were free to address other considerations when selecting sampling sites from within each sampling group. In making our final selections, we ensured: 1) the sites were well-distributed spatially across North Georgia; 2) no site was downstream from any other site (to ensure sampling independence); 3) at least two sites were located in each county within our sampling area; and 4) each site had adequate access. Sites chosen are in the Chattahoochee, Coosa, Savannah, and Tennessee River basins (Plate 1). **Appendix A** contains the information for the final 28 sampling sites in Group 1 that met our sampling design criteria.

1.3.2 Group 2 Sampling Sites

The purpose of collecting data from sampling sites in Group 2 was to examine whether basin or riparian forest cover conditions were driving variation in stream habitat conditions (stream temperature and sediment conditions) related to trout populations. Therefore, it was critical that we select a set of sampling sites where basin forest cover and riparian forest cover are not related. To accomplish this task, we plotted basin forest cover vs. riparian forest cover for all stream segments with basin areas of 2 to 20 sq. miles (Figure 1-8, black dots). This plot reveals a high correlation between basin forest cover and riparian forest cover within the population of trout streams in North Georgia. The correlation, however, is much less prominent in basins with less than 80 percent forest cover. Therefore, we developed a stratified sampling design for basins with less than 80 percent cover by placing a grid over the plot (Figure 1-8). One site was selected from each grid cell that contained at least one point. Because one grid cell (on the left in the second row) contained only one site, which could not be sampled, we selected a second site from one cell in that row. As evident in the distribution of Group 2 sites (yellow dots) in Figure 1-8, this site selection technique yielded a sample set with no autocorrelation between basin forest cover and riparian forest cover. Information for the final sampling sites in Group 2 is listed in **Appendix A**.

1.4 The Relationship Between Landcover Data Derived From Satellite Imagery and Aerial Photography

We used the 1998 Landcover of Georgia dataset derived from 1998 Landsat Thematic Mapper (TM) satellite imagery to assess forest cover conditions in North Georgia (**Section 1.2**) and select sampling sites (**Section 1.3**) because of Landsat's broad data coverage of the North Georgia landscape. Landcover data from this satellite imagery is expressed as percentages, such as percent riparian forest cover. The satellite data used to derive the landcover data are limited by their lack of resolution below 100 ft (30 m), meaning that ground features 100 ft by 100 ft in size are the finest level of detail detectable with satellite data. Color infrared aerial photography is another landcover data source with much greater resolution (3.3 ft or 1 m). We can make more precise measurements of landcover features, such as average forested riparian buffer widths, with this fine-scale resolution data. Like satellite imagery, however, aerial photography has its limitations. Since individual aerial photographs capture smaller pieces of the landscape than satellite imagery, we would have to purchase multiple photographs, many in non-digital form, and then manually process and analyze these photographs to generate landcover data for the entire study region. Purchasing and analyzing these photographs would increase both the cost and time required to complete this project by 10-fold or more. The benefits of using satellite-derived landcover versus aerial photography are broad data coverage, low cost, and time efficiency versus greater spatial resolution. To take advantage of these benefits and to stay within the operating budget of this project, we needed to determine what percentages of riparian forest cover (from satellite data) approximate average 100- and 50-ft forested riparian buffer widths (from aerial photographs).

For this analysis, we calculated and compared percent riparian forest cover as determined from the Landcover of Georgia dataset and average forested riparian buffer width as determined from aerial photographs for 18 sites; 7 sites in the Chattahoochee basin of White County and 11 in the Stekoa basin of Rabun County (See Appendix B for methods and site information). Percent riparian forest cover and average forested riparian buffer width for each site were determined within a zone 100 ft from the stream and along the entire network upstream of a sampling site.

This analysis yielded a tight and statistically significant relationship between percent forest cover within the 100-ft riparian zone and average forested riparian width (Figure 1-11).

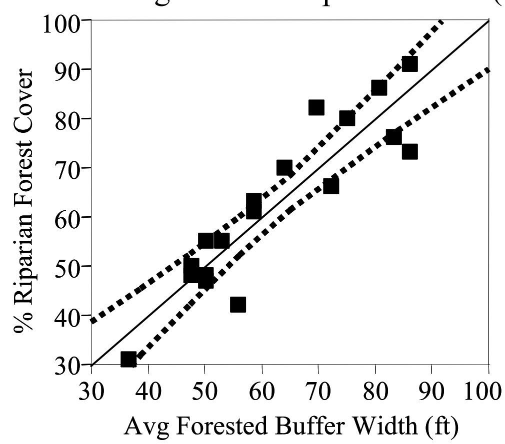


Figure 1-11. Percent riparian forest cover derived from satellite data related to average forested riparian buffer width (ft) derived from aerial photos for 18 sites in Rabun and White counties. Dotted black lines represent 95% confidence intervals. Solid line is the regression line. $n = 18$; $r^2 = 0.83$; p value <.0001. % Riparian Forest Cover = 8.813 + 2.758 (Average Forested Riparian Buffer Width in meters)

Based on this relationship and its equation, we can approximate average 100- and 50-ft forested riparian buffer widths using percent riparian forest cover values. The values for percent riparian forest cover reported in Table 1-2 were calculated for 100- and 50-ft riparian buffer widths.

Table 1-2. Percent forest cover within the 100-ft riparian zone corresponding with 100- and 50-ft forested riparian buffer widths.

Average Forested Riparian Buffer Width (ft)	Average Forested Riparian Buffer Width (m)	Percent Riparian Cover
100	30	91.6
50	15	50.2

Thus, we can relate average forested riparian buffer widths to percent riparian forest cover. We used these observed relationships to develop equations for predicting stream temperature (**Section 3.2**) and sediment conditions (**Section 3.3)** with percent riparian forest cover. An additional equation was developed for predicting trout biomass with stream temperature, sediment conditions, and maximum stream depth (**Section 2.5**). In **Section 4**, we then used these equations to forecast stream temperature, sediment conditions, and young trout biomass for 100- versus 50-ft forested riparian buffer widths using their corresponding percent riparian forest cover values.

This project was asked to investigate the effectiveness of 100- vs. 50-ft forested riparian buffer widths in protecting Georgia's trout populations. Thus, for the analyses reported throughout this report, we only consider riparian forest cover within 100 ft of the stream. Additional research would be required to investigate the relationships between stream temperature, sediment conditions, and young trout populations for riparian buffer widths greater than 100 ft.

2. PREDICTING YOUNG TROUT POPULATIONS FROM STREAM TEMPERATURE AND SEDIMENT CONDITIONS

- Summary: "Young trout," naturalized brown and rainbow trout less than 5.9 inches (150 mm) in length, are indicators of reproducing trout populations. Since their populations are minimally influenced by stocking and angling, young trout populations are indicative of habitat quality and therefore are the focus of this study. The biomass of young trout and likelihood of young trout presence are higher in streams with cool temperatures, low fine sediment, and low maximum stream depths. Specifically, our research demonstrates that:

1. Young trout require stream habitats with cool temperatures. Young trout biomass can be predicted by maximum seven-day average maximum (M7DAM) stream temperature, which is the average of daily maximum stream temperatures during the warmest 7-day period of the summer (Figure 2-1).

   $$\text{Log Young Trout Biomass (grams / 100 m}^2\text{)} = 6.178 + (-0.265)(\text{M7DAM Temperature °C})$$

2. The likelihood of young trout presence can be calculated as a function of M7DAM stream temperature (Figure 2-2).

   $$\text{Likelihood of Young Trout Presence (at M7DAM Temperature of } \mathbf{X}\text{°C)} = e^{(7.094 - 1.027*\mathbf{X})} / [1 + e^{(7.094 - 1.027*\mathbf{X})}]$$

3. We identified three temperature ranges to describe relationships between M7DAM stream temperature and the likelihood of young trout presence as well as their biomass (Figures 2-1 and 2-2):
   - Below 67°F (19.5°C), young trout populations have high biomass and greater than 90% chance of occurrence. Thus, streams with temperatures below 67°F are most likely to support self-sustaining populations of trout.
   - From 67 – 71°F (19.5 – 21.5°C), young trout populations decline in biomass and likelihood of occurrence drops from 90% to 50%.
   - Above 71°F (21.5°C), young trout are rarely observed. These results suggest that warmer streams are unlikely support self-sustaining young trout populations.

4. Young trout are found in streams where riffle habitats lack fine sediments (Figure 2-3). Streams with low amounts of fine sediment are better able to support self-sustaining trout populations.

5. The biomass of young trout can be predicted using M7DAM stream temperature, fine sediment conditions in riffle habitats, and maximum stream depth (Figure 2-4).

   $$\begin{aligned}\text{Log Young Trout Biomass (grams / 100 m}^2\text{)} = {} & (-0.284)(\text{M7DAM Temperature °C}) + \\ & (-0.064)(\text{Riffle Embeddedness Index}) + \\ & (-0.014)(\text{Maximum Stream Depth cm}) + 10.044\end{aligned}$$

We conclude that self-sustaining populations of young trout require habitats with cooler M7DAM stream temperatures and low fine sediment conditions within North Georgia's trout streams.

2.1 Introduction

Cool stream temperatures and clean, coarse substrate characterize high quality trout habitat in North Georgia's mountain streams. Stream temperature is one critical component of high quality trout habitat because: 1) Trout are coldwater fish species; and 2) North Georgia is on the edge of landscape conditions that can naturally support trout (e.g., the southern edge of the range of brook trout, Behnke 2002). Georgia's Department of Natural Resources designates trout streams in part based on stream temperature criteria; streams with maximum weekly average temperatures below 72°F (22.2°C) are listed as primary trout streams, which have the potential to support self-sustaining populations of trout, while streams with temperatures above 72°F (22.2°C) are secondary trout streams, which lack evidence of reproducing trout populations.

A second critical component of high quality trout habitat is the availability of clean, coarse substrate. Coarse substrate functions not only as spawning habitat (Jenkins and Burkhead 1994) but also as refuge and foraging habitat (Waters 1995). Sedimentation reduces the amount of coarse substrate habitat because fine sediments fill in the interstitial spaces between coarse substrates. When the interstitial spaces between particles are filled in by fine sediment, the larger particles are then embedded by the fine sediment. Embeddedness of coarse substrate adversely affects the incubation and emergence of trout fry (Kondolf 2000) because trout bury their eggs in "redds" (spawning nests) in coarse gravels. Measures of riffle embeddedness characterize not only substrate conditions in riffle habitats, which are usually dominated by coarse substrate particles, but also sedimentation. We first develop specific relationships between young trout populations and M7DAM stream temperature and sediment conditions to examine trout responses to these habitat requirements in North Georgia.

In **Section 2.2**, we first briefly outline our sampling methods. The results of this sampling are reported in **Sections 2.3**, **2.4**, and **2.5**.

2.2 Sampling Methods

Trout populations were sampled at 28 sites in 2001 and resampled at 10 sites in 2002 (**Appendix C**). Trout were collected within a designated 50-m (164-ft) reach using an electroshocker, dip nets, and seine net. We caught ~500 trout over the two years. Each trout was:

1) Identified by species (rainbow, *Oncorhyncus mykiss*, or brown trout, *Salmo trutta*);
2) Placed into 1 of 4 classes ("naturalized," "naturalized—uncertain," "stocked," and "stocked—uncertain");[2] and
3) Measured for total length[3]
4) Returned to the stream

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[2] Naturalized trout were differentiated from stocked trout by the presence of strong coloring and fully formed pectoral and pelvic fins (vs. the light coloring and eroded fins of stocked trout). If uncertainty existed concerning the appropriate trout class, trout were listed as either "naturalized—uncertain" or "stocked—uncertain." Over 2001 and 2002, we caught ~500 trout; only 19 trout were classified in one of the "uncertain" categories.

[3] These total length data (recorded in mm) were used to calculate the biomass of rainbow and brown trout with the equation: log wet weight in grams = a + b*log total length. For rainbow trout, a = -5.14777 and b = 3.05253; for brown trout, a = -5.03265 and b = 3.01000 (Schneider *et al*. 2000).

Rainbow trout made up 85% of the total catch of trout while brown trout made up 15%. Both rainbow and brown trout are introduced game species in North Georgia. This research focuses on "young trout," naturalized rainbow and brown trout less than 5.9 inches (150 mm) in length, because: 1) Young trout are indicators of reproducing trout populations; and 2) Young trout are below harvestable size and smaller than individuals used for stocking. Overall, focusing this research on young trout minimizes difficulties in data interpretation resulting from differential stocking intensities and fishing pressure (J. Durniak, Fisheries Biologist, GDNR). 68% of the 500 trout collected in 2001 and 2002 were young trout; only 2 stocked trout less than 150 mm in length were caught in 2001 and 6 in 2002.

Stream temperatures were continuously monitored at all sites during the summers of 2001, 2002, and 2003 using Onset Corp.® HOBO temperature data loggers. We calculated the average of daily maximum stream temperatures during the warmest 7-day period of the summer for each year (see **Appendix C** for all habitat sampling data). This measure of stream temperature is referred to as the "maximum 7-day average maximum temperature," or M7DAM temperature. This stream temperature value captures the peak temperature conditions when young trout likely experiencing thermal stress.

Riffle embeddedness, a measure of fine sediment conditions, was visually assessed at all sites with riffle habitats. To minimize observer bias, one person estimated the percent substrate embeddedness at all sites. Observations are based on four classes of increasing embeddedness (1 = 0 – 25%, 2 = 25 – 50%, 3 = 50 – 75%, and 4 = 75 – 100%). At each site, 10 observations were made in three riffles yielding a total of 30 riffle embeddedness observations. These observation classes were summed, by site, for a riffle embeddedness index value. The range of possible riffle embeddedness index values is 30 (0 – 25% riffle embeddedness for all observations) to 120 (75 – 100% riffle embeddedness for all observations). High riffle embeddedness indicates poor quality trout habitat because fine sediments affect the incubation and emergence of trout fry (Kondolf 2000). Sediment conditions were also evaluated following the Wolman method (Wolman 1954); we walked in a zigzag pattern throughout the study reach and measured the intermediate axis of 100 randomly chosen particles. The proportion of coarse substrate (particles greater than 64 mm in diameter) was calculated from these Wolman pebble counts.

Instream habitat conditions were measured with 3 additional variables. First, local stream slope was measured over 100 m, which included the 50-m sampling reach and 25 m above and below the reach. These values are reported as percent slope over 100 m. Second, 50 depth and velocity measurements were taken across each study reach (following the Wolman pebble count method) to capture the range of depth and velocity conditions. Velocity was measured using a Marsh-McBirney Flo-Mate 2000.™

2.3 Relationships Between Young Trout and Stream Temperature

Since stream temperature is such a strong influence on trout, we first used a simple regression model to relate the biomass[4] of young trout to M7DAM stream temperature (Figure 2-1). Young trout biomass declines predictably as stream temperatures warm. 2001 and 2002 M7DAM stream temperatures alone explain 53% of the variation observed in young trout biomass.

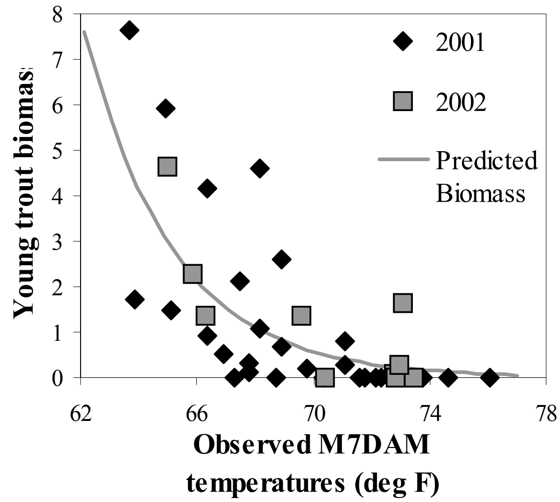

Figure 2-1. Young trout biomass (kg per hectare of streambed) versus observed M7DAM stream temperatures (°F) for sites sampled in 2001 and resampled in 2002. n = 38; $r^2 = 0.53$; p value <.0001 Log Young Trout Biomass (grams / 100 m^2) = 6.178 + (-0.265)(M7DAM Temperatures °C)

Furthermore, sites supporting young trout had significantly cooler stream temperatures than sites without young trout (p<.0001).[5] The mean M7DAM stream temperature for sites with young trout was 68°F (20.0°C) while the mean for sites without young trout was 72°F (22.2°C).

We then used a logistic regression model to determine the likelihood of young trout presence based on M7DAM stream temperatures (Figure 2-2). This logistic regression model first relates presence/absence data for young trout to M7DAM stream temperature values, and then uses this relationship to calculate the probability of young trout presence for specific M7DAM temperature values. This model shows that the likelihood that young trout are present in a stream declines with warmer M7DAM stream temperatures.

[4] In all data analyses reported in this document, the biomass of young trout was log transformed to increase statistical normality.

[5] A t-test was used to compare 2001 and 2002 M7DAM stream temperature values for sites with and sites without young trout.

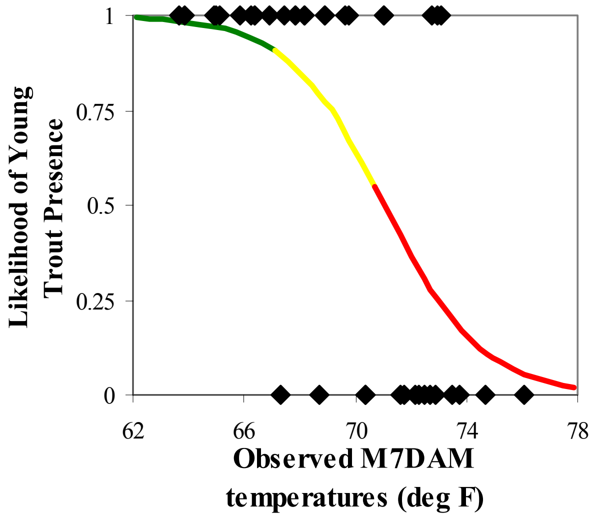

Figure 2-2. Likelihood of young trout presence versus observed M7DAM stream temperatures (°F) for sites sampled in 2001 and resampled in 2002. n = 38; p value <.0001

*Likelihood of Young Trout Presence (at M7DAM Temperature **X**°C) =*

$e^{(7.094 - 1.027*\mathbf{X})} / [1 + e^{(7.0944 - 1.027*\mathbf{X})}]$

Three temperature ranges describe the relationships observed between the biomass of young trout and likelihood of young trout presence and M7DAM stream temperature (Figures 2-1 and 2-2):

1) Below 67°F (19.5°C) M7DAM temperature, young trout populations have high biomass and greater than 90% chance of occurrence;
2) From 67 – 71°F (19.5 – 21.5°C) M7DAM temperatures, young trout populations enter a transition phase as the populations decline in biomass and likelihood of presence drops to from 90% to 50%; and
3) Above 71°F (21.5°C) M7DAM temperature, young trout are rarely observed; these warmer streams appear unlikely to support self-sustaining young trout populations.

Between 68 and 72°F, each temperature increase of 1°F yields a ~15% reduction in the likelihood that young trout will exist at a site. Overall, small changes in M7DAM temperature can have substantial effects on the likelihood that young trout populations will be present.

Clearly, M7DAM stream temperatures vary among summers as weather conditions differ. If trout remain in the same sections of stream despite these temperature fluctuations, they may grow more slowly because of elevated metabolic costs at higher temperatures (Behnke 2002). We sampled the same 10 sites in 2001 (summer with intermediate temperatures) and 2002 (a warm summer). In both years, the same 7 of the sites contained trout and the remaining 3 sites did not. This trend suggests that young trout populations persist in stream locations among years. As was expected, trout tended to be smaller in 2002. Young trout at five of the seven sites with young trout had lower mean lengths in 2002 than in 2001 (Appendix C). These shorter mean lengths suggest that the warmer 2002 M7DAM temperatures increased the metabolic costs for young trout and thus reduced growth rates. Cool stream temperatures over the long-term may be an important stream habitat component for ensuring not only the persistence of young trout populations, but also potentially higher survival and lower stress rates for individual young trout in North Georgia's trout streams.

2.4 Relationships between Young Trout and Sediment Conditions

We used t-tests[6] to compare fine sediment conditions as measured by riffle embeddedness values for sites with and without young trout. In 2001 and 2002, young trout were found at sites with significantly lower riffle embeddedness ($p = 0.018$, Figure 2-3). The mean riffle embeddedness value for sites with young trout was 37.7 while the mean for sites without young trout was 41.2. Riffle embeddedness for sites with young trout were primarily in class 1 (0 – 25% riffle embeddedness) with a few class 2 (25 – 50% riffle embeddedness) observations. In contrast, riffle embeddedness for sites without young trout were mostly class 2 (25 – 50% riffle embeddedness) and class 3 (50 – 75% riffle embeddedness) observations.

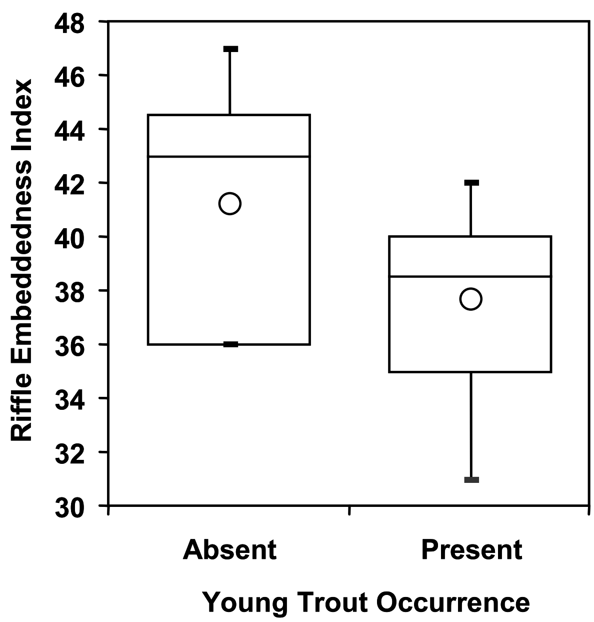

Figure 2-3. Box and whiskers plot showing the median, quartiles, and range of riffle embeddedness index values for the occurrence of young trout. Circles denote mean.

Thus, young trout are more likely to be found in streams with low amounts of fine sediments in riffle habitats.

2.5 Model for Predicting Young Trout Biomass Among Years

A multiple linear regression model was developed to predict young trout biomass among years for the sites with young trout in 2001 and 2002. This model included M7DAM stream temperatures and riffle embeddedness because these two variables are important predictors of young trout (**Sections 2.3 and 2.4**). Maximum reach depth was also found to be a significant predictor of young trout biomass and was included in the model. Thus, the following model

[6] Riffle embeddedness data were collected in 2001 and 2003. Riffle embeddedness values for these two years are not significantly different (t-test; $p = 0.1$). Therefore, 2001 riffle embeddedness values were used for both 2001 and 2002 values for t-tests reported in **Section 2.4** and when developing the regression model reported in **Section 2.5**.

combining stream temperature, riffle embeddedness, and maximum reach depth can be used to predict the biomass of young trout among years (Figure 2-4).

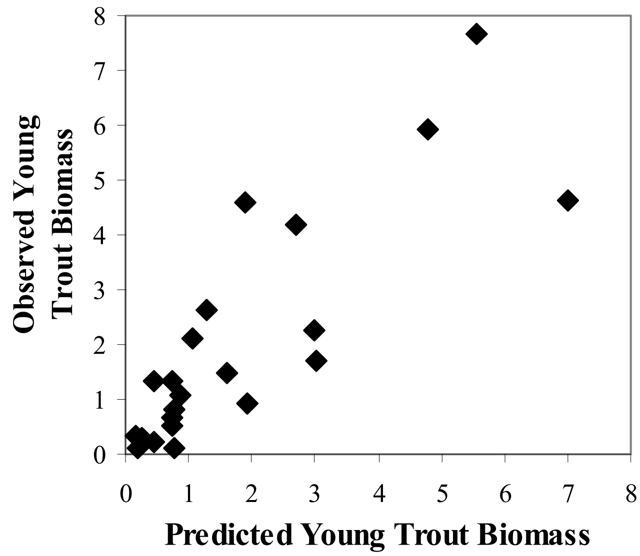

Figure 2-4. Observed versus predicted young trout biomass (expressed here as kg / hectare of streambed). Young trout biomass was predicted using M7DAM stream temperatures, riffle embeddedness index values, and maximum reach depth. n = 23; $r^2 = 0.72$; $p_{model} < .0001$; $p_{M7DAMT} < .0001$; $p_{MaxDepth} = 0.001$; $p_{riffle\ embeddedness} = 0.009$; *RMSE = 0.21 kg / hectare*

Log Young Trout Biomass (grams / 100 m²) = (-0.284)(M7DAM Temperatures °C) + (-0.064)(Riffle Embeddedness Index Value) + (-0.014)(Maximum Stream Depth cm) + 10.044

This model explains 72% of the differences observed in young trout biomass at the 23 sites supporting young trout in 2001 and 2002. Overall, young trout biomass is higher in streams with cooler stream temperatures, lower fine sediments in riffle habitats, and lower maximum stream depths. The equation derived from this model can be used to forecast the biomass of young trout for 100- vs. 50-ft forested riparian buffer widths (see **Section 4.4**).

Since deep pools are often considered good habitat for trout, the inverse correlation between stream depth and trout biomass may seem surprising. We do not interpret this result to suggest that shallower streams always provide the best trout habitat. Instead, the inverse relationship between biomass and stream depth may be a consequence of this study's focus on young trout. Deep habitats are apt to be most important for larger fish. Young trout may avoid deep habitats in order to avoid predation by larger fish. Similarly, habitat complexity can be reduced in the deepest parts of a stream. The best cover for small fish may exist in somewhat shallower water.

In conclusion, healthy self-reproducing trout populations in North Georgia require the availability of habitats with cool stream temperatures and low levels of fine sediments based on these observed relationships between young trout and stream temperature and sediment conditions.

3. PREDICTING STREAM TEMPERATURE AND SEDIMENT CONDITIONS FROM RIPARIAN FOREST COVER

- Summary: Having demonstrated that the biomass and presence of young trout in North Georgia's streams are strongly linked to M7DAM stream temperature and sediment conditions (**Section 2**), here we investigate whether riparian forest cover or whole basin forest cover is most important in determining stream temperature and sediment conditions. We express riparian forest cover as the percent of a 100-foot riparian zone along the entire stream network that is covered by trees. Our findings demonstrate that:

1. M7DAM stream temperatures are best predicted by riparian forest cover and elevation (Figure 3-4). Stream temperatures increase as riparian forest cover and elevation decrease.

   M7DAM temperatures (°C) = ***a*** [*arcsine* (% *Riparian Cover*$^{0.5}$)] + ***b*** (*Elevation m*) + ***c***
   Coefficients are reported in Table 3-4.

2. Riparian forest cover for the entire stream network is the best scale of forest cover for predicting M7DAM temperatures (Figure 3-7 A) whereas basin forest cover is a less reliable predictor of M7DAM temperatures (Figure 3-7 B). M7DAM temperatures increase as riparian forest cover decreases.

3. Fine sediment conditions (as measured by riffle embeddedness) can be predicted as a function of riparian forest cover and maximum stream velocity (Figure 3-9).

   Riffle Embeddedness Index Value = (-8.465)[arcsine (% Riparian Cover$^{0.5}$*)]*
   + (-5.328)(Maximum Velocity m/sec) + 54.374

   While slow-moving streams naturally have the highest levels of fine sediment in riffle habitats, reduction in forest cover will increase the amount of fine sediment in a given stream regardless of the stream's velocity (Figure 3-9). High quality trout habitat has adequate coarse substrate, which decreases as riffle embeddedness increases.

   Arcsine (% Coarse Substrate$^{0.5}$*) = (-0.028)(Riffle Embeddedness Index Value) + 1.796*

   The M7DAM stream temperature and sediment conditions necessary for high quality trout habitat are associated with a high percentage of forest cover within the 100-foot riparian zone.

3.1 Introduction

As shown in **Section 2**, stream temperatures and sediment conditions are critical habitat components related to the presence and biomass of young trout in North Georgia's streams. Because of these critical habitat requirements, trout populations are reduced or eliminated by a variety of land use practices such as urbanization, agriculture, and forestry practices (for a review, see Marcus 1990). These land use activities can adversely affect trout by increasing the temperature of streams (Theurer 1985; Beschta 1987; Beschta 1988; Li 1994; Beschta 1997; Poole 2001) or by increasing the rate of sediment delivery to streams (Megahan 1992; Eaglin and Hurbert 1993; Espinosa 1997; Huntington 1998). Healthy riparian buffers (mature forest vegetation left along stream banks) can mitigate the effects of land use activities on streams (Wenger 1999). Narrow riparian buffers, however, are less effective at protecting aquatic habitats because they reduce impacts only on selected habitat features (Davies 1994). Recommendations for minimum riparian buffer widths that protect a wide variety of aquatic habitat features vary from at least 100 ft (e.g., Davies 1994) to more than 300 ft (e.g., FEMAT 1993). Thus, we investigated the relationships between forest cover and stream temperature and sediment conditions to understand how reductions in riparian buffer widths from 100 ft to 50 ft may affect trout habitat in streams.

3.2 Relationships Between Stream Temperature and Riparian Forest Cover

Riparian forest cover influences stream temperature by shading streams from solar radiation and by minimizing temperature fluctuations. Riparian forests can maintain cooler and less extreme summer stream temperatures.

In addition to riparian forest cover, elevation also influences stream temperature. Just as air temperatures are cooler at higher elevations, so too are stream temperatures. Elevation can be included in this analysis of the relationships between stream temperature and riparian buffer widths because our sampling sites are located across an elevation gradient.

Interannual climate variation is a third factor influencing stream temperature. In different years, stream temperatures can be warmer or cooler depending on cloud cover, rainfall, and the patterns of warm and cold fronts that occur. For instance, 2002 and 2003 represent two extremes of climate conditions (Figure 3-1). 2002 (a warm, dry year) had warmer than average July and August maximum air temperatures and below average rainfall. In contrast, 2003 (a cool, wet year) had cooler than average July and August maximum air temperatures and above average rainfall. 2001 had intermediate July and August maximum air temperatures but low rainfall. Since we monitored stream temperature in 2001, 2002, and 2003, we can include different weather conditions in this investigation of the relationships between stream temperature and riparian buffer widths.

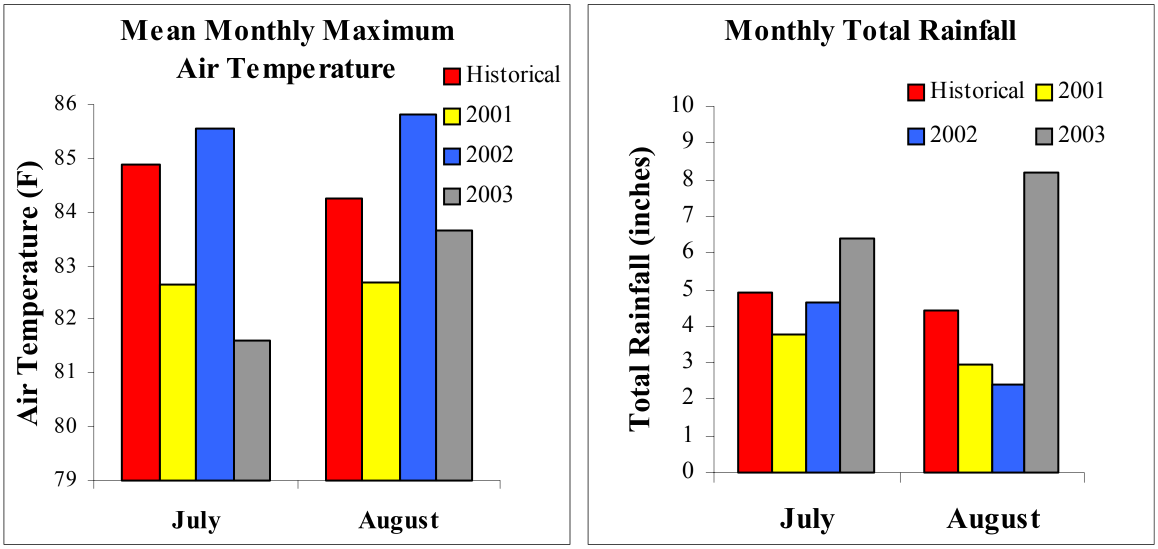

Figure 3-1. A) Mean July and August maximum air temperatures (°F) for Blairsville, Georgia which is centrally located within the study region of this project. B) July and August total rainfall (inches). Historical data covers the period from 1931 – 2003. Weather data were obtained from the Southeast Regional Climate Center.

For these analyses, stream temperatures for each site are described by the "maximum 7-day average maximum temperature," or M7DAM temperature (see **Section 2** for methods and **Appendix C** for values). This temperature metric captures the extreme summer stream temperature conditions. The biomass and presence of young trout in North Georgia are strongly related to this temperature metric. Cooler M7DAM stream temperatures indicate high quality trout habitat.

3.2.1 Drivers of Stream Temperature Among Years

We considered what factors consistently drive stream temperature because climate conditions vary from year to year. Multiple linear regression models combining elevation and forest cover were used to predict Group 1's M7DAM stream temperatures for 2001, 2002, and 2003. Riparian cover and basin forest cover are not correlated with elevation or basin area (Figures 1-11 and 3-2). Because of this lack of autocorrelation, we can use these data to distinguish the influence of forest cover on stream temperature from the influence of either elevation or basin area on stream temperature.

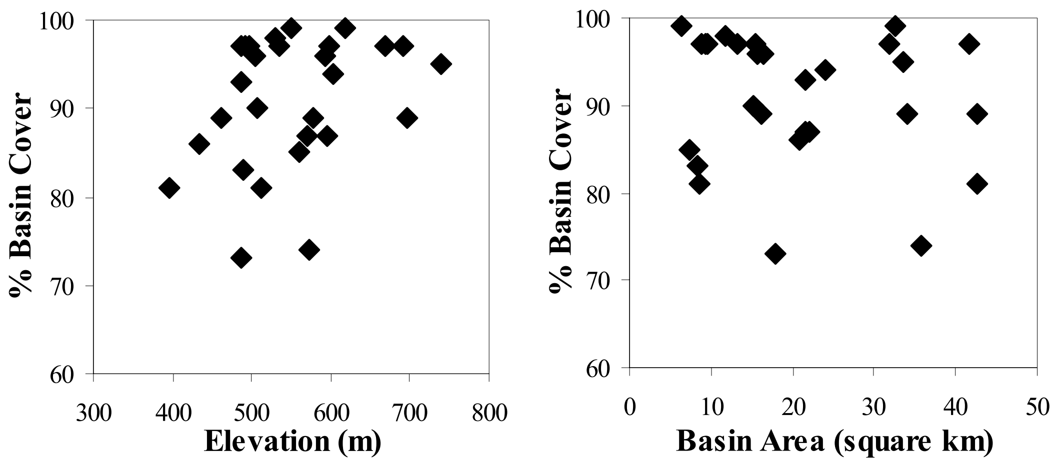

Figure 3-2. % Basin forest cover related to elevation and basin area for Group 1. No significant relationships (all p values > 0.1) were detected between these variables.

Riparian forest cover and basin forest cover values, however, are autocorrelated, meaning that for these Group 1 data, streams with high riparian forest cover also tend to have high basin forest cover (Figure 3-3).

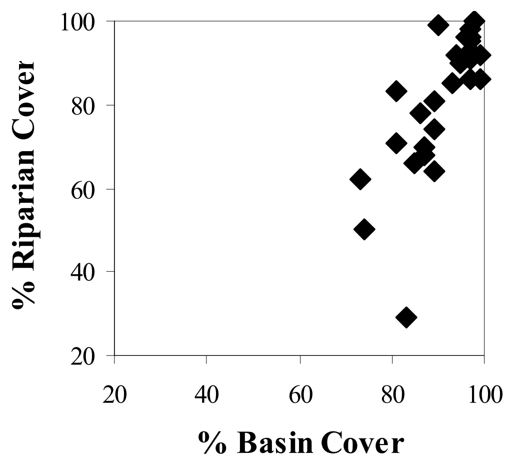

Figure 3-3. % Riparian forest cover related to % basin forest cover for Group 1. $n = 28$; $r^2 = 0.59$; $p < .0001$. Arcsine (% Riparian Cover$^{0.5}$) = 1.3495568 [arcsine (% Basin cover$^{0.5}$)] – 0.567627

We cannot tease apart the relative influences of riparian versus basin forest cover on stream temperature with this data group because of the strong relationship between riparian forest cover and basin forest cover. Instead, this question is addressed in **Section 3.2.2** using a different data set. Here, we investigate what spatial scale of forest cover, when combined with elevation, is the best predictor of stream temperature among years. Since forest cover could influence stream temperature at multiple spatial scales (e.g., locally or at the basin level), five scales of forest cover were included in separate multiple linear regression models with elevation to determine which spatial scale of forest cover was the best predictor of M7DAM stream temperatures. The five forest cover variables included are: 1) the fraction of forest cover within the 100-ft riparian buffer zone stretching 0.5 km upstream from the study site; 2) that zone extending 1 km upstream from the study site; 3) that zone extending 2 km upstream from the study site; 4) that zone extending along the entire stream network upstream of the study site (referred to as "riparian cover"); and 5) the fraction of forest cover within the entire basin upstream of the study site and outside the 100-ft riparian zones (referred to as "basin cover").

The following tables report the results of multiple linear regression models using elevation and one of the 5 forest cover variables[7] to predict Group 1's 2001, 2002, and 2003 M7DAM stream temperatures. For each regression model, we report:

1. *The r^2 Value*. This value tells how much of the variation observed within the M7DAM temperature data was explained by the individual regression model. For instance, an $r^2 = 0.58$ means that a model explained 58% of the variation observed in M7DAM temperature values.
2. *p Values For The Model, Elevation, and Forest Cover*. If the model's p value is less than 0.05, then the model can be used to predict M7DAM temperatures. If the p values for elevation and forest cover are less than 0.05, then these variables are significant predictors of stream temperatures. The (+) or (-) sign in front of the p values signify the direction of the influence of elevation and forest cover on M7DAM temperatures.
3. *Root Mean Square Error (RMSE)*. This value tells us how well the regression model is able to predict M7DAM temperatures. For instance, a RMSE value = 1.19 means that on average, a model predicted M7DAM temperature values that deviated 1.19°C from the observed M7DAM temperature values.

Table 3-1. Results from multiple linear regression models using elevation and one of five scales of forest cover to predict 2001 M7DAM temperatures (°C). The highlighted model using riparian cover is the best model for predicting 2001 M7DAM temperatures.

2001	r^2	p_{Model}	$p_{elevation}$	$p_{ForestCover}$	RMSE (+/- °C)
0.5 km riparian cover	0.58	<.0001	- 0.0018	- 0.0031	1.19
1 km riparian cover	0.64	<.0001	- 0.0019	- 0.0004	1.10
2 km riparian cover	0.67	<.0001	- 0.0021	- 0.0002	1.06
Riparian cover	0.73	<.0001	- <.0001	- <.0001	0.96
Basin cover	0.71	<.0001	- 0.0007	- <.0001	0.99

Table 3-2. Results from multiple linear regression models using elevation and one of five scales of forest cover to predict 2002 M7DAM temperatures (°C). The highlighted model using riparian cover is the best model for predicting 2002 M7DAM temperatures.

2002	r^2	p_{Model}	$p_{elevation}$	$p_{ForestCover}$	RMSE (+/- °C)
0.5 km riparian cover	0.51	0.0001	- 0.0053	- 0.0059	1.27
1 km riparian cover	0.57	<.0001	- 0.0068	- 0.0012	1.20
2 km riparian cover	0.61	<.0001	- 0.0077	- 0.0003	1.14
Riparian cover	0.70	<.0001	- <.0001	- <.0001	1.00
Basin cover	0.64	<.0001	- 0.0034	- 0.0001	1.09

[7] In all analyses, forest cover variables are arcsine squareroot transformed to increase statistical normality.

Table 3-3. Results from multiple linear regression models using elevation and one of five scales of forest cover to predict 2003 M7DAM temperatures (°C). The highlighted model using riparian cover is the best model for predicting 2003 M7DAM temperatures.

2003	r^2	p_{Model}	$p_{elevation}$	$p_{ForestCover}$	RMSE (+/- °C)
0.5 km riparian cover	0.44	0.0015	- 0.0094	- 0.0822	1.27
1 km riparian cover	0.48	0.0007	- 0.0098	- 0.0319	1.22
2 km riparian cover	0.53	0.0002	- 0.0121	- 0.0092	1.16
Riparian cover	0.57	<.0001	- 0.0054	- 0.0031	1.12
Basin cover	0.56	0.0001	- 0.0034	- 0.0042	1.13

Riparian cover, which was measured along the entire stream network, is the best scale of forest cover for predicting M7DAM temperatures for each year. Overall, the model using riparian forest cover and elevation had the lowest RMSE values for each year, i.e., it was the best at predicting M7DAM stream temperatures among sampling sites and over the three-year study period. These models demonstrate that among years with different weather conditions, stream temperatures are cooler for high elevation streams and streams with high riparian forest cover. Thus, streams at higher elevations and with higher riparian forest cover are most likely to have stream temperatures cool enough to maintain high quality trout habitat among years.
We can predict stream temperature using riparian forest cover and elevation with the following equation and coefficients derived from each year's regression model (Figures 3-4):

M7DAM stream temperatures (°C) = $\boldsymbol{a}$ [arcsine (% Riparian Cover$^{0.5}$)] + $\boldsymbol{b}$ (Elevation m) + $\boldsymbol{c}$

Table 3-4. Values for the riparian cover and elevation coefficients and the intercept used to calculate 2001, 2002, and 2003 M7DAM temperatures (°C).

	2001	**2002**	**2003**
***a* =**	- 4.482	- 4.716	- 3.278
***b* =**	- 0.012	- 0.011	- 0.011
***c* =**	32.967	33.712	29.904

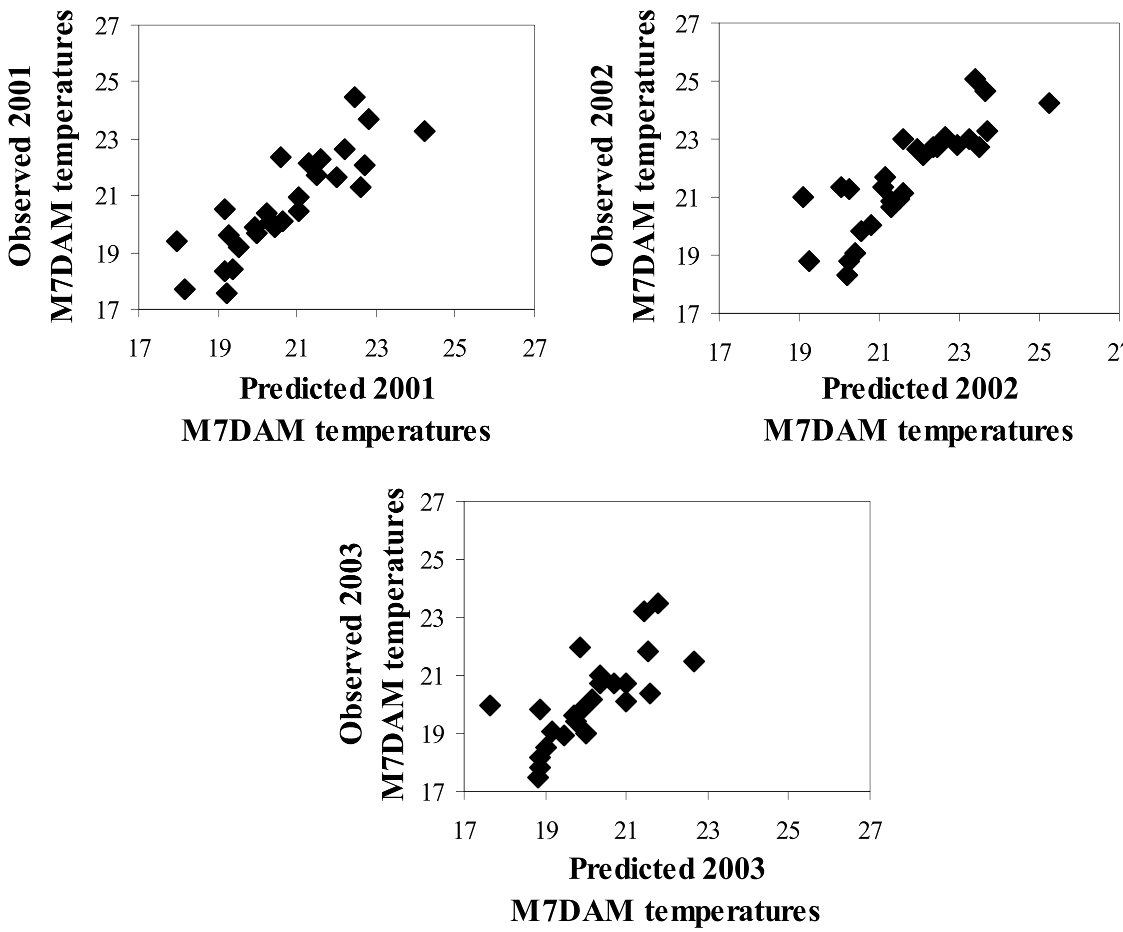

Figure 3-4. Observed M7DAM versus predicted M7DAM temperatures(°C) for: A) 2001; B) 2002; and C) 2003. M7DAM stream temperatures were predicted using % riparian forest cover and elevation and equation values reported in Table 12. The statistics for these models are reported in Table 3-4.

M7DAM stream temperatures among years are best predicted using elevation and riparian forest cover along the entire stream network. This suggests that maintaining riparian forest cover throughout the stream network is important for keeping stream temperatures in a range desirable for trout over a range of summer weather conditions.

3.2.2 Relative Influences of Riparian vs. Basin Forest Cover on Stream Temperature

Data from Group 2 were used to determine the relative influences of riparian versus basin forest cover on stream temperature because there is no relationship between riparian cover and basin forest cover for this group (Figure 3-5). In other words, among streams within this data group, high levels of riparian are not associated with high levels of basin cover.

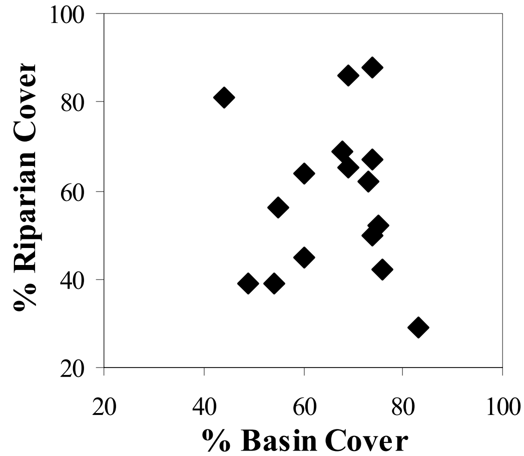

Figure 3-5. % Riparian forest cover versus % basin forest cover for Group 2. n = 16; $r^2 = 0$; p = 0.8

Unlike Group 1, however, riparian forest cover and elevation are related in this Group 2 dataset (Figure 3-6 A).[8] For Group 2 sites, riparian forest cover tends to be lower at higher elevations. Conversely, basin cover is not related to elevation (Figure 3-6 B). This relationship between riparian forest cover and elevation may be a consequence of the fact that valley-side slopes tend to be steeper at higher elevations. Thus, at higher elevations, arable or developable land on the valley slope is limited, constraining development to areas along stream courses.

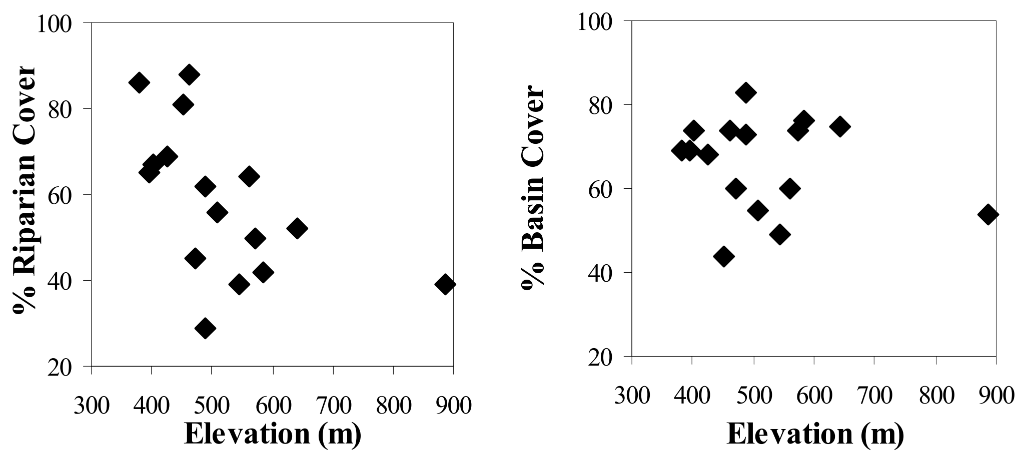

Figure 3-6. For Group 2: A) % Riparian forest cover versus elevation. n = 16; $r^2 = 0.38$; p = 0.0105. B) % Basin cover versus elevation. n =16; $r^2 = 0$; p = 0. 5.

Since riparian forest cover and elevation are related, these two variables cannot be combined in the same multiple linear regression model for predicting stream temperatures (like those used in **Section 3.2.1**). We have already quantified the effect of elevation on stream temperature using Group 1 data (**Section 3.1.1**). Thus, we adjusted Group 2's 2003 M7DAM temperatures by the 1/elevation coefficient (3571.755) derived from a model predicting the 2003 M7DAM

[8] This group's riparian cover and catchment cover were arcsine squareroot transformed and elevation was 1/x transformed to increase statistical normality.

temperatures for Group 1 sites not included in Group 2. The following equation was then used to finish calculating Group 2's elevation adjusted 2003 M7DAM stream temperatures.

Elevation adjusted 2003 M7DAM temperature (°C) = (-4.671)[arcsine (% Riparian Cover$^{0.5}$)] + + 18.979

$r^2 = 0.64$; $p_{model} < .0001$; $p_{riparian\ cover} = 0.0021$

These final elevation adjusted temperature values were related to riparian forest cover and basin forest cover (Figure 3-7). These analyses reveal that stream temperatures are warmer as riparian forest cover declines (Figure 3-7 A). In contrast, stream temperatures are not related to basin forest cover (Figure 3-7 B). Riparian forest cover—not basin cover—is the best predictor of M7DAM stream temperature.

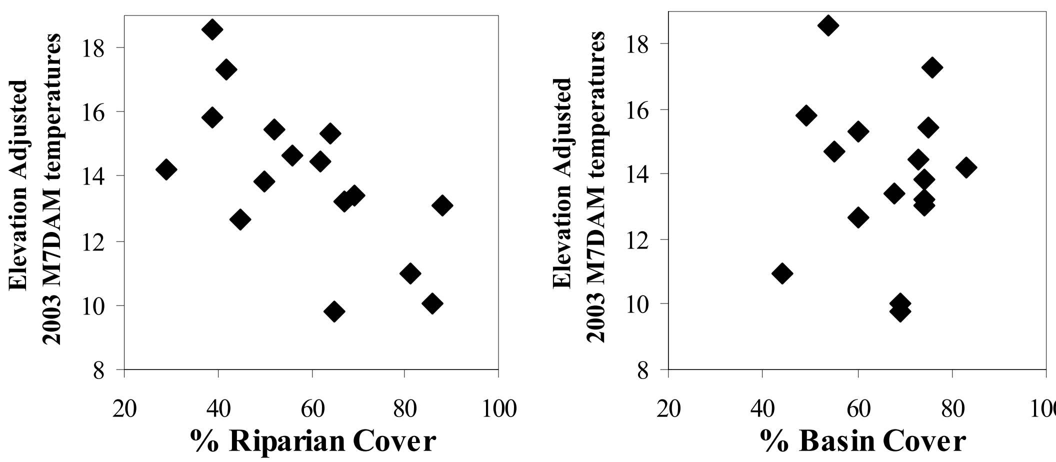

Figure 3-7. Elevation adjusted 2003 M7DAM stream temperatures related to A) % Riparian forest cover. n = 16; $r^2 = 0.43$; p = 0.006. B) % Basin forest cover. p = 0.9.

It is worth noting that this trend of low riparian forest cover at higher elevations is not unique to the Group 2 dataset. The pattern is widespread across the North Georgia landscape; this relationship was observed for 393 North Georgia stream segments with basin forest cover less than 80% (Figure 3-8).

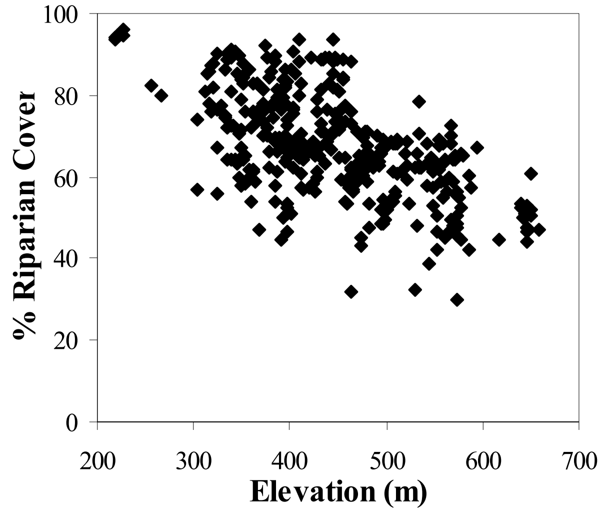

Figure 3-8. % Riparian forest cover and elevation for 393 stream segments with less than 80% basin cover in North Georgia.

Overall, these analyses of the relationships between stream temperature, forest cover, and elevation demonstrate that elevation and riparian forest cover both influence M7DAM stream temperature conditions in North Georgia, though regardless of elevation, M7DAM stream temperatures are warmer with decreasing riparian forest cover along the entire stream network. Thus, riparian forest cover throughout the stream network helps maintain stream temperatures cool enough to support self-sustaining populations of trout. Furthermore, our analyses of current conditions suggest that some potentially high quality trout habitat at high elevations appears to have been degraded due to large reductions in riparian forest cover.

3.3 Relationships Between Sediment Conditions and Riparian Forest Cover

Riparian forests influence instream sediment conditions by reducing stream bank erosion and acting as a zone of deposition for upland sediments that would otherwise be transported to the stream during rain events. Thus, forested riparian zones can reduce the rate at which fine sediments (silts and clays) enter a stream, resulting in a higher proportion of coarser and "cleaner" sand and gravel sediment particles in the streambed.

Other factors, however, also influence the distribution of sediment sizes within a stream. Where streams are steeper and swifter, fine sediments that enter the stream can be washed downstream and be deposited in areas where streams are flatter and water moves more slowly. Since natural variation in stream slope and water velocity influence the character of streambed substrate, data analyses must also account for potential effects of stream slope and/or velocity when investigating the influence of riparian buffer width on stream sediment size.

Riffle embeddedness, a measure of the extent to which fine sediments have filled in the spaces between coarser sediments, was collected from each study site (See methods in **Section 2.2**). The riffle embeddedness index is a visual estimate of the amount of fine sediment deposited within the pore spaces around gravels exposed in stream riffles. Higher embeddedness values indicate the presence of fine sediments and therefore reflect poorer trout habitat.

Instream sediment conditions were analyzed using reverse stepwise multiple linear regression. At the beginning of the analysis, the regression model included local sampling reach stream slope, maximum water velocity within the study reach, and a forest cover variable as independent variables. Non-significant independent variables ($\alpha = 0.95$) were removed from the model until only significant predictors of the sediment variable remained. Five different forest cover variables were each analyzed in a separate reverse stepwise multiple regression analysis. The five forest cover variables included: 1) the fraction of forest cover within the 100-ft riparian buffer zone stretching 0.5 km upstream from the study site; 2) that zone extending 1 km upstream from the study site; 3) that zone extending 2 km upstream from the study site; 4) that zone extending along the entire stream network upstream of the study site (referred to as "riparian cover"); and 5) the fraction of forest cover within the entire basin upstream of the study site (referred to as "basin cover").[9] The 0.5, 1, and 2 km riparian forest cover variables are measures of local riparian conditions whereas the riparian forest cover variable is a measure of forest cover conditions along the entire stream network.

Reverse stepwise regression analyses determined that models combining forest cover and maximum reach velocity explained the most variation in fine sediment conditions. The following table reports the results of individual multiple linear regression models using maximum velocity and one of the five scales of forest cover to explain variation observed in fine sediment conditions as measured by riffle embeddedness index values among sites.

Table 3-5. Results of regression models using maximum velocity and one of five scales of forest cover to predict riffle embeddedness. For descriptions of the statistics reported in this table, see ***Section 3.2.1***.

Cover Variable	r^2	p_{Model}	$p_{Forest\ Cover}$	$p_{Maximum\ Velocity}$	RMSE (+/- Riffle Embeddedness)
0.5 km	0.41	0.002	- 0.01	- 0.014	3.30
1 km	0.39	0.003	- 0.014	- 0.011	3.34
2 km	0.34	0.01	- 0.043	- 0.012	3.50
Riparian	0.40	0.003	- 0.013	- 0.025	3.34
Basin	0.26	0.035	- 0.206	- 0.061	3.71

When used in a multiple linear regression model with any riparian forest cover variable, the effect of water velocity on riffle embeddedness is apparent: as expected, the amount of fine sediments is lower in swiftly flowing streams. Additionally, streams with lower local and network riparian forest cover have higher levels of fine sediments in riffle habitats. Thus, losses of riparian forest cover result in poorer habitat for trout. In contrast, basin-scale forest cover was not a significant predictor of fine sediment conditions, suggesting that the character of the riparian zone is the dominant forest cover influencing the instream processes that determine fine sediments in riffle habitats. Regression models combining measures of riparian forest cover and maximum velocity can be used to predict fine sediment conditions within riffle habitats of North Georgia's trout streams (Figure 3-9).

[9] All scales of forest cover were arcsine squareroot transformed to increase statistical normality.

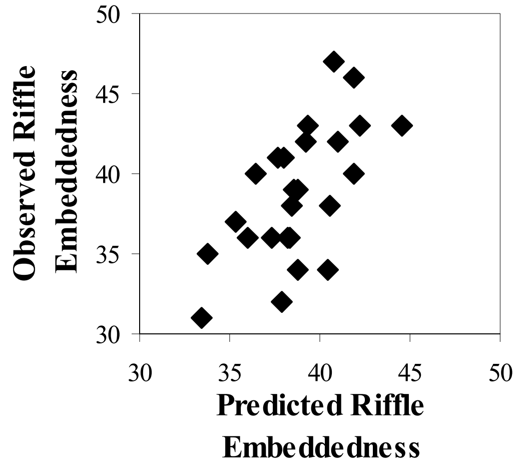

Figure 3-9. Observed versus predicted riffle embeddedness. Riffle embeddedness was predicted using % riparian cover and maximum velocity. n = 25; r^2 = 0.40; p model = 0.003; p riparian cover = 0.033; p maximum velocity = 0.025; RMSE = 3.33
Riffle Embeddedness = 54.374 – 8.465 [arcsine (%Riparian Cover $^{0.5}$)] – 5.328 (Maximum Velocity m/sec)

Overall, the watersheds of Group 1 are highly forested. Since this high forest cover limits the amount of sediment supplied to streams, instream sediment dynamics and conditions are likely limited by sediment supply. Riparian forest cover, however, tends to be less than watershed forest cover (Figure 3-3) because many land-disturbing activities (roads, agriculture, suburban development) occur within the riparian areas of these streams. These disturbed riparian areas increase the supply of fine sediment to streams. Thus, with higher local and network riparian forest cover, the supply of fine sediments is limited.

In addition, we found that the proportion of coarse substrates (sediment particles greater than 64 mm in diameter) declines as riffle embeddedness increases (Figure 3-10). Coarse substrate provides both spawning and foraging habitat for trout so reduced proportions of coarse substrate represent less desirable trout habitat.

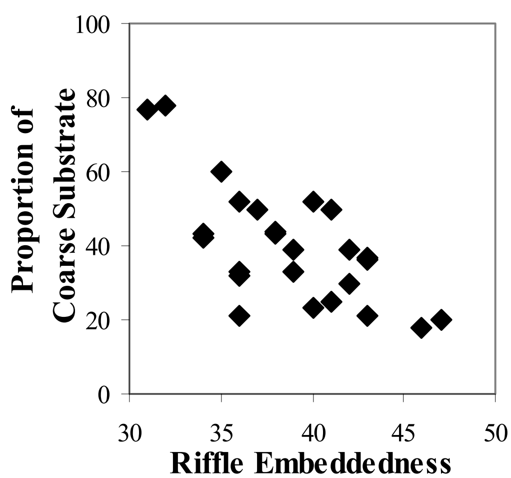

Figure 3-10. Proportion of coarse substrate related to riffle embeddedness. n = 25; r^2 = 0.49; p value = 0.0001. Arcsine (% Coarse Substrate$^{0.5}$) = (-0.028)(Riffle Embeddedness Index) + 1.796

Since the amount of fine sediments in riffle habitats is higher in streams with low local and network riparian forest cover, riparian forest cover is arguably the critical scale of forest cover driving the availability of coarse substrate habitats. Fine sediments supplied to streams fill in riffle habitats that are usually dominated by coarse particles. The transition from coarse substrate to embedded streambeds has been shown to adversely affect salmonid species (e.g., Eaglin and Hurbert 1993) because fine sediments "smother" eggs and prevent the flow of oxygenated water around eggs.

Thus, riparian forest cover throughout the stream network helps maintains clean sediment conditions for supporting self-sustaining populations of trout.

4. IMPLICATIONS OF REDUCTIONS IN RIPARIAN BUFFER WIDTHS FOR YOUNG TROUT

- Summary: M7DAM stream temperatures, fine sediment conditions, and biomass of young trout were calculated using equations developed in previous sections (**3.2.1, 3.3, and 2.5**) for the following conditions:
  - 100- vs. 50-ft riparian buffer widths
  - Three elevations
  - A cool, wet summer (2003) and a warm, dry summer (2002)

1. When the widths of forested riparian buffers are reduced from 100 to 50 ft, M7DAM stream temperatures increase by 2.9°F in a cool, wet summer and 4.2°F in a warm, dry summer (Table 4-1).

2. When the widths of forested riparian buffers are reduced from 100 to 50 ft, the amount of fine sediments in riffle habitats increases by 11% (Table 4-2).

3. While these increases in temperature and fine sediments appear small numerically, the biological impacts are substantial. In any North Georgia trout stream where riparian buffer width is reduced from 100 ft to 50 ft, associated changes in stream temperature and sediment are expected to reduce young trout populations by 81 – 88% (Tables 4-3 and 4-4).

4. With 100-ft riparian buffer widths, 63% of Georgia's trout stream miles would maintain cool temperatures associated with high or marginal quality trout habitat (defined as greater than 50% probability of occurrence for young trout). Temperatures for the remaining 37% would yield poor quality trout habitat (defined as less than 50% probability of occurrence for young trout). With 50-ft riparian buffer widths, less than 9% of Georgia's trout stream miles would maintain temperatures associated with high or marginal quality trout habitat; 91% would have temperatures associated with poor quality trout habitat.

5. Riparian buffers on most private lands and some public lands are currently less than 100 ft. 33% of trout stream miles (mostly on private lands) are classified as having M7DAM temperatures 2 – 5°F warmer than M7DAM temperatures expected with a 100-ft buffer. This pattern of stream warming is already occurring (especially on private lands) and is of concern because the M7DAM temperature difference between high quality trout habitat and poor quality trout habitat is only 4°F. In the transition zone between high and poor quality habitat, there a ~15% decrease in the likelihood of trout occurrence for each degree (°F) of warming (Figure 2-2). Thus, existing reductions in riparian cover and associated increases in M7DAM stream temperature of 2 to 5 °F may have already yielded as much as a 30% to 75% reduction in the likelihood of finding trout in streams where riparian cover has been reduced.

4.1 Introduction

In this section, we apply equations for predicting:

- M7DAM stream temperatures (reported in **Section 3.2.1**)
- Riffle embeddedness (reported in **Section 3.3**)
- Biomass of young trout (reported in **Section 2.5**)

to forecast expected young trout biomass for 100- versus 50-ft riparian buffer widths. Our goal is to determine the effectiveness of 100- versus 50-ft riparian buffer widths in protecting trout populations and critical components of trout habitat—stream temperature and sediment conditions. We recognize that current riparian buffers widths are not starting at 100 ft based on the findings of **Section 1**. However, we cannot calculate the change from current conditions to 50 ft with the available data.

4.2 Predicting Stream Temperatures for 100- versus 50-ft Riparian Buffer Widths

Values for M7DAM stream temperature, a critical component of high quality trout habitat, were predicted for 100- and 50-ft riparian buffer widths using the 2002 and 2003 multiple linear regression equations based on riparian forest cover and elevation (**Section 3.2.1** and Table 3-4). The 2002 equation captures the relative influences of riparian forest cover and elevation on stream temperatures during a warm, dry summer while the 2003 equation captures the influences of these variables during a cool, wet summer. We included three elevation values (488, 578, and 740 m) in addition to 100- versus 50-ft riparian buffer widths in this forecasting to represent the range of elevation where trout habitat occurs in North Georgia.[10]

Table 4-1. M7DAM stream temperatures expected for 100- versus 50-ft riparian buffer widths and 3 elevations. Lower values are expected stream temperatures during a cool, wet summer, and upper values are expected M7DAM stream temperatures during a warm, dry summer.

Elevation (m)	100-ft Buffer Width	50-ft Buffer Width	Temperature Increase From 100-ft to 50-ft Buffer Width
488	68.6 – 71.5°F 20.3 – 21.9°C	71.5 – 75.7°F 21.9 – 24.3°C	2.9 – 4.2°F 1.6 – 2.3°C
578	66.8 – 69.6°F 19.3 – 20.9°C	69.7 – 73.7°F 20.9 – 23.2°C	2.9 – 4.2°F 1.6 – 2.3°C
740	63.6 – 66.2°F 17.5 – 19.0°C	66.5 – 70.3°F 19.2 – 21.3°C	2.9 – 4.2°F 1.6 – 2.3°C

These equations predict that if riparian buffers widths are reduced from 100 ft to 50 ft, then M7DAM stream temperatures will warm by 2.9°F in cold, wet summers and 4.2°F in warm, dry summers. In **Section 2.3**, we reported that young trout were generally absent in streams with

[10] These elevation values represent the range of elevations where we collected young trout. Lowest elevation site with young trout = 488 m (SiteID 10); highest elevation site with young trout = 740 m (SiteID 7); 578 m is the average of the elevations values for sites where young trout were collected.

M7DAM temperatures greater than 71°F (21.5°C). Given 50-ft riparian buffer widths, trout habitat at many elevations is apt to be vulnerable to thermal alteration as stream temperatures warm above 71°F (21.5°C) during both types of summer weather conditions (Table 4-1).

4.3 Predicting Sediment Conditions for 100- versus 50-ft Riparian Buffer Widths

Fine sediment conditions, a second critical component of high quality trout habitat, were calculated for 100- versus 50-ft riparian buffer widths using the riparian cover and maximum velocity multiple linear regression equation[11] (**Section 3.3**).

Table 4-2. Riffle embeddedness index values expected for 100- versus 50-ft riparian buffer widths for a range of maximum velocities. This table includes the mean observed maximum velocity (1.0 m/sec) and range of observed values. The highlighted expected riffle embeddedness value for maximum velocity equal to 1.0 m/sec was used for predicting young trout biomass in Tables 4-3 and 4-4.

Maximum Velocity (m/s)	100-ft buffer width	50-ft buffer width	Percent Increase
0.4	41.4	45.6	10%
0.8	39.3	43.4	11%
1.0	38.2	42.4	11%
1.2	37.1	41.3	11%
1.6	35.0	39.2	12%

If riparian buffers widths are reduced from 100 ft to 50 ft, then the riffle embeddedness index (a measure of fine sediment conditions) for a given stream velocity increases by roughly 11%. In **Section 2.4**, we reported that the mean riffle embeddedness value for streams with young trout was 37.7 whereas the mean for streams without young trout was 42.2. Hence, the predicted fine sediment values for 50-foot buffers (Table 4-3) are exceeding or approaching levels that do not support young trout populations. Increased sedimentation is of particular concern in slow-moving streams, because they are most vulnerable to increasing riffle embeddedness resulting from sedimentation (i.e., values in first two rows in Table 4-2).

4.4 Predicting Young Trout Biomass for 100- versus 50-ft Riparian Buffer Widths

Using the stream temperature values in Table 4-1 and riffle embeddedness values predicted for maximum velocity equal to 1.0 m/sec in Table 4-2, we calculated the expected biomass of young trout for 100- versus 50-ft riparian buffer widths. Young trout biomass was predicted using the M7DAM temperature, riffle embeddedness, and maximum stream depth equation[12] (**Section 2.5**).

[11] 2001 Maximum velocity values for sites with young trout were averaged for a representative value (1.00 m/sec) used to predict riffle embeddedness.

[12] The 2001 maximum depth values for sites with young trout were averaged for a representative value (68 cm) used to predict young trout biomass.

Table 4-3. Expected young trout biomass (kilogram/hectare) during a cool, wet summer.[13]

Elevation (m)	100-ft Buffer Widths	50-ft Buffer Widths	Decrease in Trout Biomass
488	0.62	0.16	0.46
578	1.10	0.29	0.81
740	3.06	0.80	2.26

Table 4-4. Expected young trout biomass (kg/ha) during a warm, dry summer.[13]

Elevation (m)	100-ft Buffer Widths	50-ft Buffer Widths	Decrease in Trout Biomass
488	0.25	0.04	0.21
578	0.45	0.08	0.37
740	1.35	0.24	1.11

When riparian buffer widths are reduced from 100-ft to 50-ft, young trout biomass is expected to be reduced by 81 – 88 %, depending elevation and summer weather conditions.

4.5 Mapping Expected Stream Temperatures for 100- vs. 50-ft Riparian Buffer Widths Across the North Georgia Landscape

Using the equations for predicting M7DAM temperatures (**Section 3.2.1**) and the study's GIS data layers (**Section 1**), we predicted M7DAM temperatures for 8,000 stream segments in North Georgia under several different assumptions:

- 100-ft versus 50-ft forested riparian buffer widths under intermediate summer weather conditions;
- Current riparian forest cover conditions under cold/wet, intermediate, and warm/dry weather conditions; and
- Current M7DAM temperatures relative to expected M7DAM temperatures under 100-ft riparian buffer widths

The reader is cautioned that these plates do not represent "scenarios." It is unreasonable to assume that all trout streams in Georgia would have uniform riparian buffer widths of either 50 or 100 ft. Similarly, the model used to produce these maps is not sufficient, to provide accurate predictions for, say, a particular favorite fishing spot or neighborhood creek. Instead, the maps are intended to help the reader visualize the proportion and approximate the spatial distribution of stream segments in Georgia's trout stream network that would maintain stream temperatures adequate for supporting trout if 100- or 50-ft riparian buffers were applied throughout the stream network above that segment. Again, plates are located at the end of this section.

Plate 3 shows expected M7DAM temperatures for 100- versus 50-ft riparian buffer widths during a summer with intermediate weather conditions.[14] Tables 4-5 and 4-6 summarize these results.

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[13] 1 kg / hectare of streambed =10 grams / 100 m^2 of streambed = 0.89 lb / acre of streambed
[14] M7DAM temperatures were predicted with the 2001 equation (see Table 3-4).

Table 4-5. Cross tabulation of trout habitat quality vs. land ownership for streams with 100-ft riparian buffer widths. Trout habitat quality is defined based on estimated stream temperatures for 2001 (a year with intermediate temperature and rainfall): 1) high quality is less than 67º F; 2) marginal quality is 67º F to 71º F; and 3) low quality is above 71º F. Values are percentages of trout stream miles in each class.

100-ft Riparian Buffers

	Ownership		
Habitat Quality	Public	Private	Total
High	14.8%	4.0%	18.8%
Marginal	12.6%	31.8%	44.4%
Low	8.9%	27.9%	36.8%
Total	36.3%	63.7%	

Table 4-6. Cross tabulation of trout habitat quality vs. land ownership for streams with 50-ft riparian buffer widths. Trout habitat quality is defined based on estimated stream temperatures for 2001 (a year with intermediate temperature and rainfall): 1) high quality is less than 67º F; 2) marginal quality is 67º F to 71º F; and 3) low quality is above 71º F. Values are percentages of trout stream miles in each class.

50-ft Riparian Buffers

	Ownership		
Habitat Quality	Public	Private	Total
High	0.6%	0.1%	0.7%
Marginal	7.2%	0.8%	8.1%
Low	28.4%	62.8%	91.2%
Total	36.3%	63.7%	

Thus, with a 100-ft buffer, about 63% of trout stream miles in North Georgia could maintain temperatures associated with high or marginal quality trout habitat (greater than 50% occurrence of young trout) if 100 ft riparian buffers were applied to them. 37% of trout stream miles would have temperatures associated with poor quality trout habitat (less than 50% occurrence of young trout). With a 50-ft buffer, less than 9% of Georgia's trout stream miles would support temperatures associated with high or marginal quality trout habitat while 91% would have temperatures indicative of poor quality trout habitat.

Plate 4 illustrates how changes in summer weather conditions influence the potential distribution of trout habitat in North Georgia given current riparian buffer conditions. Riparian conditions on private lands are already degraded to the point that private lands can no longer maintain high or marginal quality trout habitat during warm, dry summers like 2002. Trout in Georgia's streams have a narrow temperature threshold where they can persist due to biological constraints and landscape conditions. Hence, relatively small changes in maximum stream temperatures can result in large changes in the extent of high and marginal quality habitat available for trout in North Georgia.

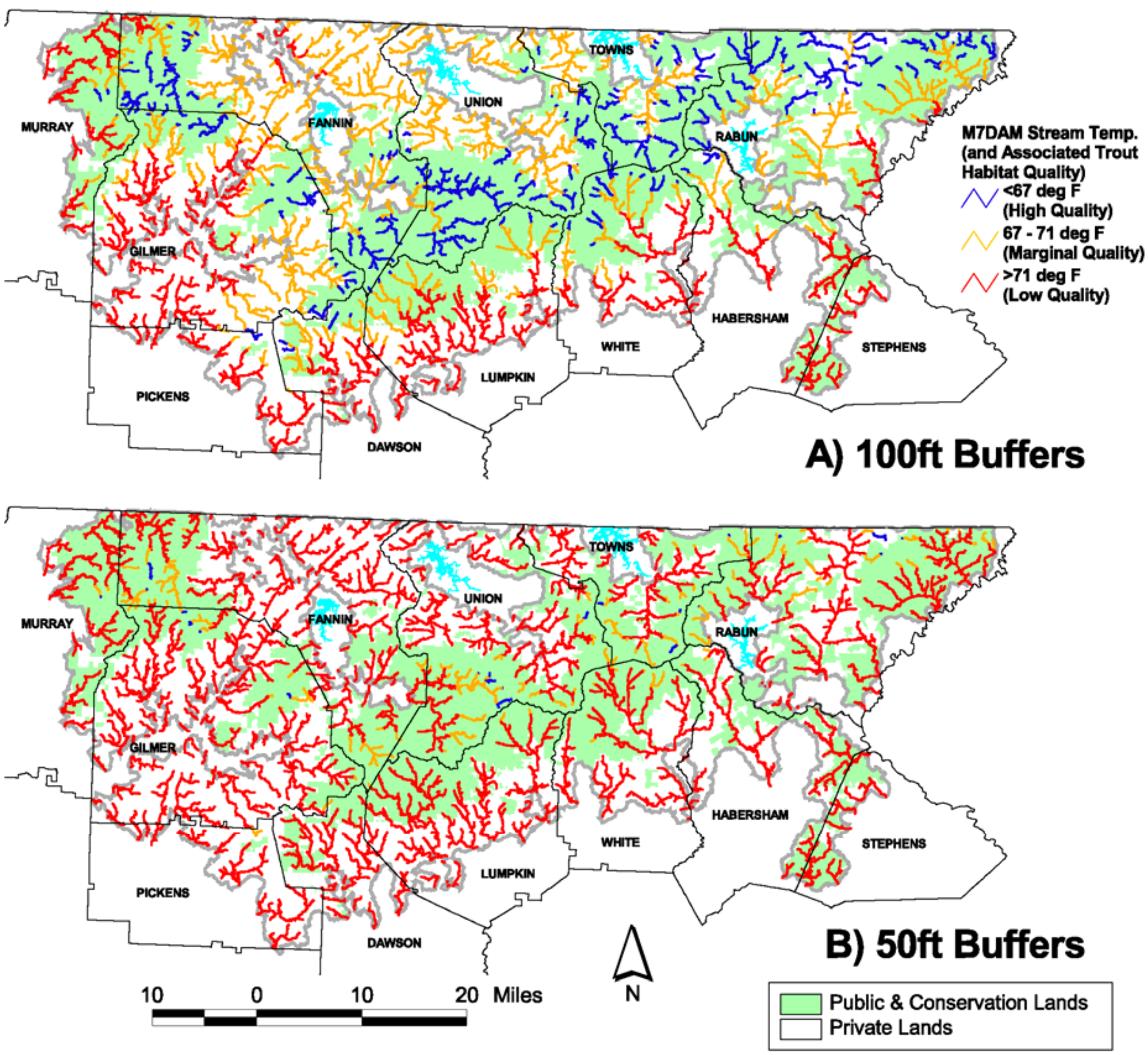
Plate 5 maps the current thermal alteration beyond conditions expected with 100 ft buffers along Georgia's trout streams. We expressed thermal alteration as the difference between M7DAM temperatures during a warm, dry summer[15] predicted for: 1) current forest cover conditions; vs. 2) 100-ft riparian buffer widths. Table 4-7 summarizes the results of Plate 5.

Table 4-7: Cross tabulation of thermal alteration vs. land ownership for trout streams with basin areas between 2 – 20 square miles. Alteration is measured by determining how much warmer streams are given their current riparian buffer than they would be with a 100-ft riparian buffer. Values are percentages of trout stream miles in each class.

	Ownership		
Alteration	Public	Private	Total
None	66.9 %	16.3 %	34.7 %
> 0 - 2°F	27.7 %	34.6 %	32.1 %
> 2 - 4°F	4.5 %	36.3 %	24.8 %
> 4°F	0.8 %	12.8 %	8.5 %
Total	36.3%	63.7%	

About 35% of Georgia's total trout stream miles (mostly on public lands) are classified as "none," meaning they have M7DAM temperatures equal to or cooler than temperatures expected with a 100-ft buffer. In contrast, 33% of total trout stream miles (mostly on private lands) are classified as "2-4°F" or ">4°F," meaning they have temperatures more than 2°F warmer than the temperatures expected with a 100-ft buffer. Whereas ~ 95% of stream miles on public lands have M7DAM temperatures <2°F warmer than expected with a 100-ft buffer, only 51% of stream miles on private lands fall in this thermal range. This pattern of existing stream warming on private lands is of concern because the difference between high quality trout habitat and poor quality trout habitat is only 4°F (Figure 2-2). Furthermore, in the transition zone between high and poor quality habitat, there is a ~ 15% decrease in the likelihood of trout occurrence for each degree (°F) of warming (Figure 2-2). Thus, existing reductions in riparian cover and associated increases in M7DAM stream temperature of 2 to 5°F may have already yielded as much as a 30% to 75% reduction in the likelihood of finding trout in streams where riparian cover has been reduced in the network.

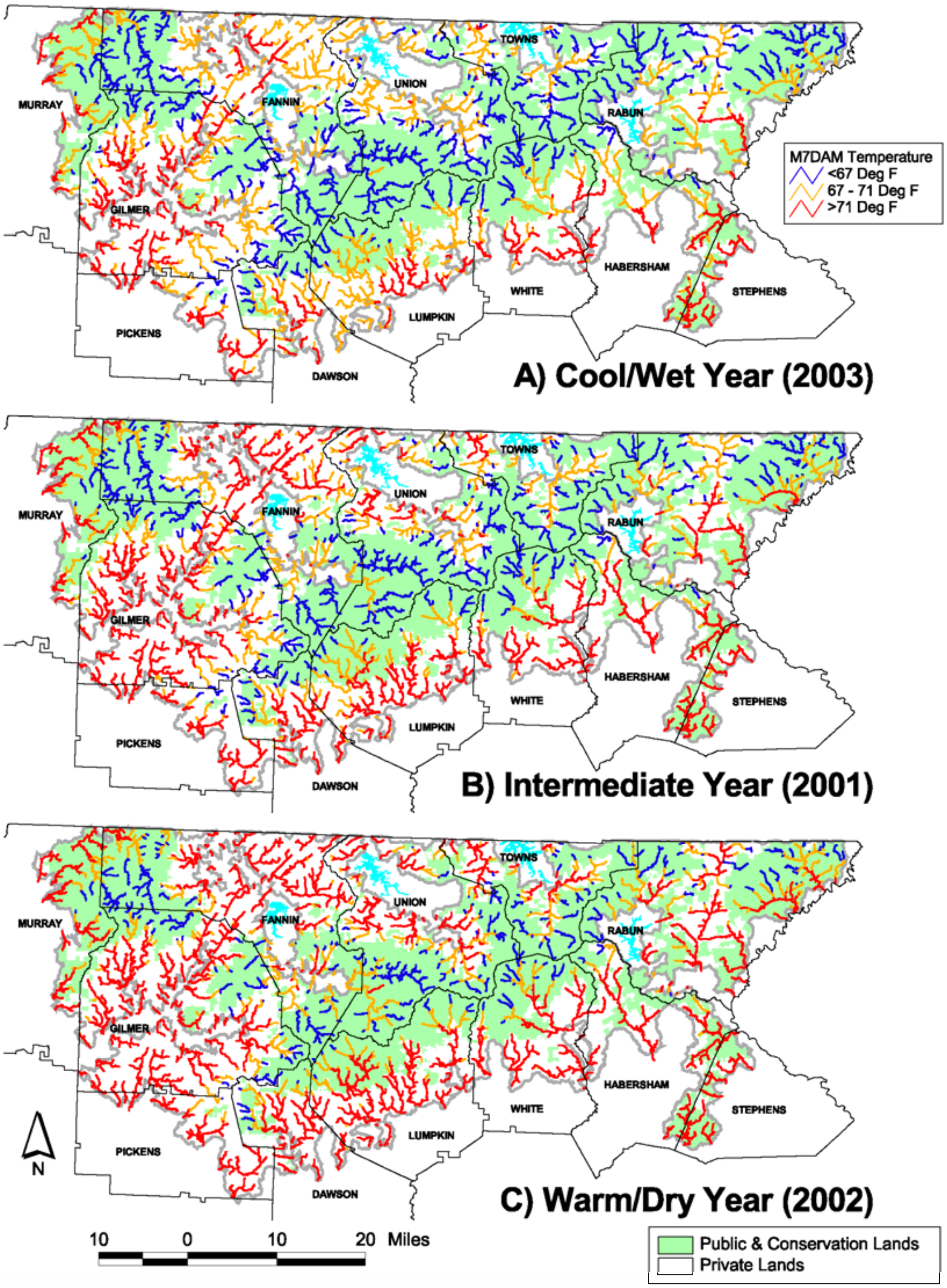
[15] M7DAM temperatures were predicted using the 2002 equation (Table 3.4).



Distribution of Maximum Seven-Day Average Maximum Stream Temperatures and Associated Trout Habitat Quality Expected with 100ft and 50ft Riparian Buffers on North GA Trout Streams

Temperature data are estimated from a multiple regression equation using parameters derived from 2001 (a year with intermediate air temperature and rain fall) to predict summertime maximum seven-day average maximum water temperature from stream elevation and upstream riparian cover.

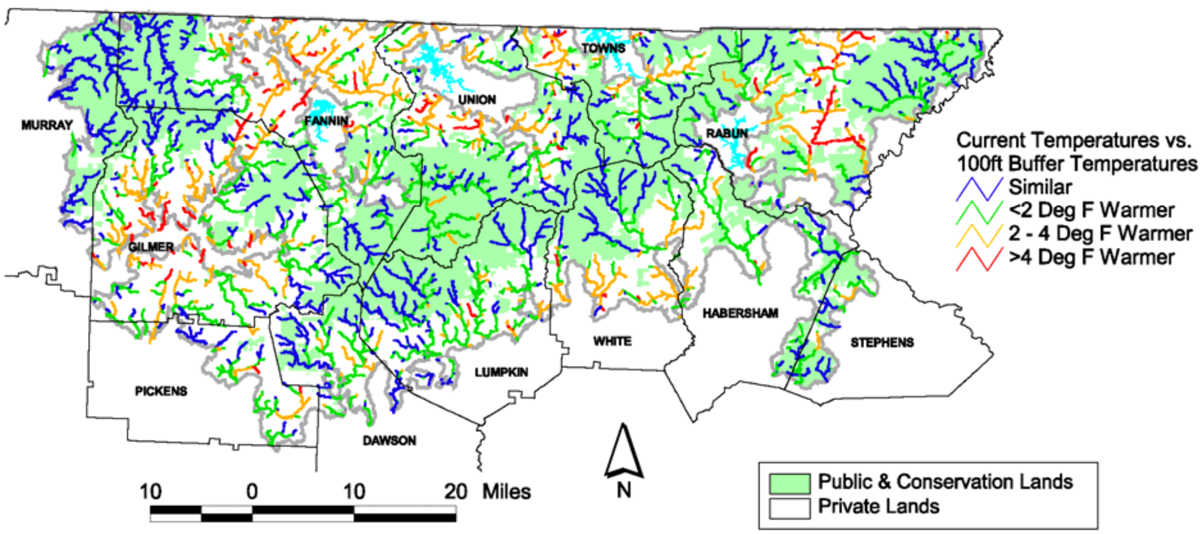
Plate 3



Interannual Variation in Maximum Seven-Day Average Maximum Temperatures in Trout Streams of North Georgia

M7DAM water temperature under current conditions for a cool, intermediate, and warm year. Data are estimated using year-specific multiple regression paramaters that predict M7DAM temperature from stream elevation and upstream riparian forest cover.

Plate 4



Thermal Degradation of Trout Streams in Georgia: Current Georgia Trout Stream Temperatures Relative to Temperatures Expected with 100ft Riparian Buffers

Summertime maximum seven-day average maximum stream temperatures estimated for current landscape conditions relative to temperatures expected with 100ft buffers. Estimates are derived for 2002 (a warmer and drier than average year) using a multiple regression model that predicts M7DAM temperature from stream elevation and upstream riparian cover.

Plate 5

5. ATTRIBUTES OF HEADWATER STREAMS EXEMPT FROM RIPARIAN BUFFER REQUIREMENTS

- Summary: Under current Georgia regulations, small trout streams with a mean annual discharge of 25 gallons per minute (gpm) are exempt from riparian buffer requirements. These streams have the following characteristics:

  1. In the Blue Ridge physiographic province of the Southern Appalachians, a watershed of 16 acres yields a mean annual discharge of 25 gpm. In this physiographic region, drainage area serves as an accurate predictor of average discharge even for these small streams (Figure 5-2). The relationships reported here apply only in this physiographic region.

  2. Basic channel metrics are not precise or accurate predictors of average discharge, but can be used to reaffirm estimates based on drainage area. Active channel width was the feature best correlated with discharge (Figure 5-4), and a stream with a mean annual discharge of 25-gpm has a channel 4-5 feet wide.

  3. Monthly baseflow values are highly variable (Figure 5-3) and cannot be used as accurate predictors of mean annual discharge.

  4. A definable channel is formed in a basin ranging from 7 to 20 acres, whereas a basin that yields perennial flow ranges from 11 to 32 acres (Figure 5-1).

  5. 41% of private lands in North Georgia drain into small headwater streams that are in the size range exempt from riparian buffer regulations and therefore could be piped (Plate 5).

  6. Three headwater streams gaged by UGA were sampled for aquatic organisms. These small streams that potentially could be piped had 29 to 35 different aquatic taxa (Table 5.3). Each site sampled had 10 – 14 taxa indicative of high water quality (EPT taxa: Ephemeroptera, Plecoptera, Trichoptera). These small streams support an abundance of aquatic life that is indicative of high water quality. Piping would eliminate the habitat supporting this aquatic life.

  7. The insects drifting downstream from these streams were also diverse. In each stream, 9 – 22 taxa were in the drift, 5 – 6 taxa were indicative of high water quality (EPT taxa). In contrast, only one EPT organism was captured in the drift net below a piped stream, and 89% of the organisms were aquatic worms indicating poor water quality.

5.1 Hydrologic and Geomorphic Characteristics of Small Streams Exempt from Riparian Buffer Requirements[16]

Small trout streams with average discharge of 25 gallons per minute (gpm) (0.057-cfs) or less are exempt from 50-ft riparian buffer requirements and can be piped up to 200 ft by individual landowners (GDNR 2000). This part of the study was designed to answer four questions for small Southern Appalachian streams:

1. What is the relationship between average discharge and drainage area?
2. What is the range of drainage areas necessary to produce a definable channel and to produce perennial flow?
3. What is the relationship between mean monthly baseflows and average discharge?
4. How do basic channel metrics relate to average discharge?

The overall goal of this research was to determine whether drainage area, average monthly baseflow, or channel metrics could be used as accurate surrogates for average discharge measurements in small ungaged basins. We targeted only streams in the Blue Ridge physiographic province to constrain variation in landscape characteristics such as soil types, climate, and topography that influence streamflow and channel morphology (e.g., Dunne and Leopold 1978). Therefore, the specific relationships reported here are applicable only to the Blue Ridge physiographic province of North Georgia.

An accurate measurement of average discharge in a stream requires several years of continuous stream gaging data. Even a crude measurement of average discharge requires at least a year of continuous flow data. Obviously, many regulatory determinations must be made quickly on the basis of map data or a single site visit. The contributing or drainage area of a particular stream can easily be measured or estimated using GPS technology and USGS topographical maps. This makes drainage area an ideal metric for estimating average discharge provided that the drainage area—average discharge relationship holds true for small streams.[17] Baseflows, while variable, can easily be measured at any time of the year. Therefore, seasonal or monthly averaged baseflows, as they relate to average discharge, are potentially useful metrics for estimating average discharge. Similarly, it is much easier to measure variables such as active channel width (ACW), channel cross-sectional area, channel slope, and functional large woody debris (FWD) than to measure average discharge. Relationships between physical characteristics and average discharge would greatly assist in rapid field determinations of average discharge.

We evaluated the average discharge versus drainage area relationship using continuous flow data from sixteen small streams in the Southern Appalachians, specifically northeast Georgia,

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[16] Rivenbark, B.L. and C.R. Jackson. 2004. Average discharge, perennial flow initiation, and channel initiation - small southern Appalachian streams. Journal American Water Resources Association 40(3): 639 – 649.

[17] A linear relationship between average discharge and drainage area is a basic tenet of hydrologic water budgets (Dunne and Leopold 1978). As long as the difference between precipitation and evapotranspiration is relatively constant, average discharge necessarily increases linearly with drainage area. Data from which this relationship has been repeatedly observed come mainly from USGS gages on streams draining 10's to 1000's of square miles. At the small scale (basins less than 200 acres), there is little observational data to test whether this relationship still holds, or whether groundwater underflow becomes a significant portion of a basin water budget.

southwest North Carolina, and southeast Tennessee. We defined average discharge as it is used by the USGS—the average of all discharges over the period of record. For sufficiently long records, average discharge is equivalent to mean annual flow.

Methods

A more detailed description of the methods used in this part of the study can be found in Rivenbark (2002). Previously monitored flow data were compiled from 13 small streams in the Southern Appalachian Mountains (Swank and Crossley 1988, Coweeta unpubl., and TVA unpubl.) located at the USFS Coweeta Hydrologic Laboratory, Otto, North Carolina and near Ducktown, Tennessee (Table 5-1). Wooden weirs for measuring discharge (referred to as UGA gages in this report) were constructed at three additional small streams in North Georgia that were selected for monitoring based on drainage area and accessibility. All 16 streams were either first- or second-order and drained a naturally forested watershed at the time of gaging. The Tennessee streams no longer exist due to strip mining. Drainage areas ranged from 6 to 140 acres (Table 5-1), and gradients ranged from 3.3 to 23 % (Table 5-2).

Additionally, 30 streams located throughout North Georgia were surveyed to find points of channel and perennial flow initiation. Channel initiation points were noted as places where a definable channel had formed that drain the landscape. Channel initiation points were identified using a Garmin global positioning system (GPS). Drainage areas were determined from USGS topographical maps. These streams were surveyed again to estimate points of perennial flow initiation between late June and early August, coinciding with the beginning and middle of the usual low-flow period.

The UGA gages were monitored for only one dry year (water year 2002). Hence, the measured average discharges underestimate the long-term average discharge. Therefore, we have reported the actual measured averages for these sites as well as an adjusted average calculated by using the local long-term USGS gages to determine a correction factor. Based on the three local USGS long-term gages (Table 5-1), the long-term average discharge was 55.7% higher than 2002 average discharge, so discharges from UGA gages were multiplied by 1.557 to estimate the long-term average for these stations. A 1% increase in daily discharge was used as the threshold to distinguish stormflow from baseflow for the baseflow analysis. Monthly baseflow averages were calculated and the distribution of baseflow values was determined for each month at fourteen of the sixteen streams.

Drainage area measurements were determined by walking the drainage area perimeter of each of the three UGA monitored streams with a GPS. Geomorphological characteristics were measured along the reach of eleven of the sixteen streams for a distance of twenty times the active flow width of the channel. The five TVA streams could not be surveyed because they no longer exist. Five active channel widths (ACWs) were taken at regular intervals (four times the ACW) along each reach. Five cross-sectional area measurements were made and the reach average slope was determined. The amount of functional large (diameter > 5 in) woody debris (FWD) was tallied for each reach.

Results
A definable channel is formed in a basin ranging from 7 to 20 acres (mean = 11 acres) whereas perennial flow is yielded by a basin ranging from 11 to 32 acres (mean = 19 acres) (Figure 5-1). Many of the gaged streams in this study would be considered intermittent. Based on actual flow data, streams I, J, K, L, M, O, and P were intermittent (Table 5-1).

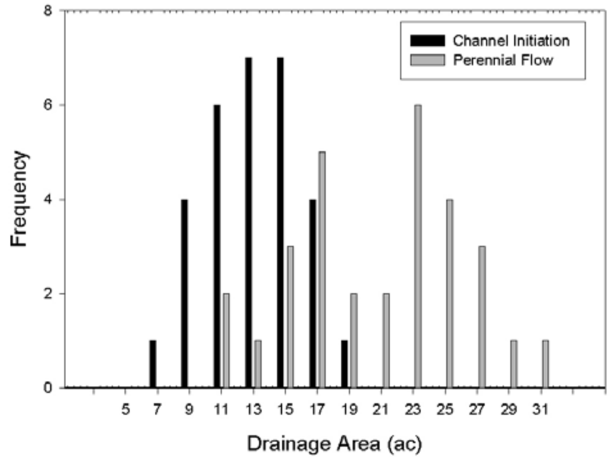

Figure 5-1. Channel and perennial flow initiation of small Southern Appalachian streams.

Table 5-1. Location, source, data period, mean discharge, and drainage area of small southern Appalachian streams.[18]

Watershed	Location County, State	Source**	Years of Data	Data Period	Average discharge (cfs)	Adjusted Average disch. cfs	DA++ acres
A	Macon, NC	CHL	65	1935-2000	0.1150	na	29.7
B	Macon, NC	CHL	50	1938-1988	0.6627	na	148.0
C	Macon, NC	CHL	62	1936-1998	0.1416	na	30.2
D	Macon, NC	CHL	50	1938-1988	0.4221	na	79.3
E	Macon, NC	CHL	52	1946-1998	0.7444	na	94.7
F	Macon, NC	CHL	57	1943-2000	0.8946	na	117.8
G	Macon, NC	CHL	15	1985-2000	0.0438	na	18.5
H	Macon, NC	CHL	15	1985-2000	0.0248	na	12.8
I+	Polk, TN	TVA	11	1940-1951	0.0236	na	15.6
J+	Polk, TN	TVA	5	1940-1945	0.0039	na	6.7
K+	Polk, TN	TVA	10	1942-1952	0.0049	na	6.5
L+	Polk, TN	TVA	11	1940-1951	0.0040	na	5.1
M+	Polk, TN	TVA	16	1935-1951	0.0106	na	6.0
N	Fannin, GA	UGA	1	2001-2002	0.1649	0.2567	30.2
O+	Stephens, GA	UGA	1	2001-2002	0.0176	0.0274	13.1
P+	Fannin, GA	UGA	1	2001-2002	0.0541	0.0843	20.8
2178400*	Rabun, GA	USGS	38	1964-2002	184	na	36160
2177000*	Oconee, SC	USGS	63	1939-2002	644	na	132480
3544947*	Towns, GA	USGS	17	1984-2001	5.35	na	1069
2330450*	White, GA	USGS	21	1981-2002	128	na	28608

*USGS gage numbers +Streams with intermittent flow in the gage record ++DA = drainage area **Source: Coweeta Hydrologic Laboratory (CHL), Tennessee Valley Authority (TVA), and The University of Georgia (UGA).

[18] The adjusted mean discharge reported for the UGA gages attempts to eliminate bias from the one-year record monitored during a drought period. Long-term USGS records were used to calculate an adjustment factor equal to the average ratio of measured average discharge for water year 2002 to the long-term average discharge determined from the whole record.

The relationship between average discharge and drainage area is shown in Figure 5-2. The drainage area that produces an average discharge of 25 gpm is about 16 acres in the Blue Ridge physiographic province. In the Ridge and Valley province, where limestone is common, variability in the relationship between basin area and mean annual flow is likely to be much greater. Mean annual flow in streams draining watersheds less than 16 acres is generally less than would be predicted for this relationship, suggesting that groundwater flow beneath stream gages becomes a significant portion of the water budget in these streams.

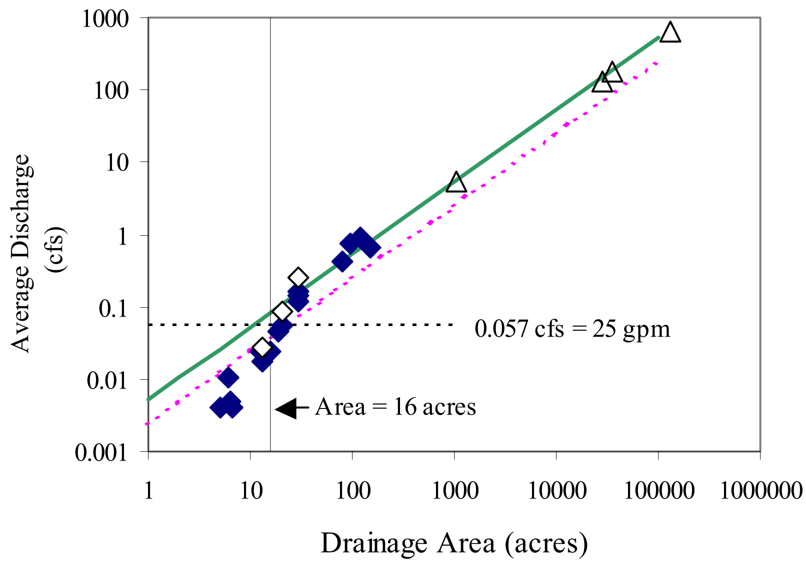

Figure 5-2. Average discharge-drainage area relationship in small Southern Appalachian streams. $r^2 = 0.90$, $p < 0.0001$. Small streams in this report are represented by solid diamonds, drought-adjusted `UGA gages by open diamonds, and nearby USGS gages by open triangles. Two trend lines are shown: 1) the upper trend line (solid green line) represents a water yield of 3.4 cfs/sq. mi.; and 2) the lower trend line (dotted pink line) represents a water yield of 1.6 cfs/sq. mi. Most of the gages fall between these two trend lines. The drainage area resulting in a 25 gpm average discharge is also included..

Figure 5-3 depicts Box-plots of monthly unit-area baseflow values. The high variability in monthly baseflows from year to year renders this statistic useless for average discharge estimation in a regulatory setting.

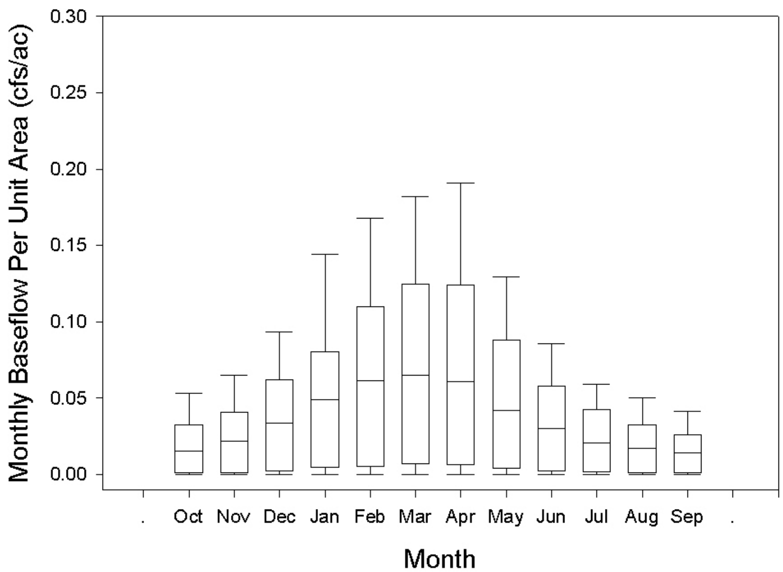

Figure 5-3. Mean monthly baseflow per unit area for sixteen small Southern Appalachian streams. Baseflow separated using a 1% threshold. Solid line indicates mean unit area discharge.

A summary of the channel metric values is presented in Table 5-2. Average discharge is positively correlated with ACW (Figure 5-4, $r^2 = 0.68$, $p = 0.0017$), but the relationship is not as strong as the average discharge—drainage area relationship. As expected, active channel width increases with increased drainage area (Figure 5-5, $r^2 = 0.53$, $p = 0.0104$). Cross-sectional area and bankfull width (based on Manning's equation) were all positively correlated with average discharge ($r^2 < 0.41$, $p > 0.030$) and drainage area ($r^2 < 0.31$, $p > 0.070$), but the relationships were weak.

Table 5-2. Channel Metrics of Small Southern Appalachian Streams including Active Channel Width (ACW), Slope, Cross-sectional Area (X-sec), and the Functional Large Woody Debris Frequency (FWD/ACW).

Watershed	Average discharge cfs	DA ac	ACW ft	Slope %	X-sec ft^2	FWD/ACW
A	0.1150	29.7	4.56	17	3.46	0.63
B	0.6627	148.0	8.27	13	6.73	1.89
C	0.1416	30.2	6.20	12	8.04	1.98
D	0.4221	79.3	6.40	16	6.99	2.34
E	0.7444	94.7	9.41	21	8.08	2.29
F	0.8946	117.8	11.15	18	10.63	3.57
G	0.0438	18.5	8.36	23	8.14	1.40
H	0.0248	12.8	5.58	19	5.30	0.94
N	0.1649	30.2	4.46	4.4	1.93	0.20
O	0.0176	13.1	3.74	3.3	1.71	0.11
P	0.0541	20.8	3.90	5.4	4.84	0.89

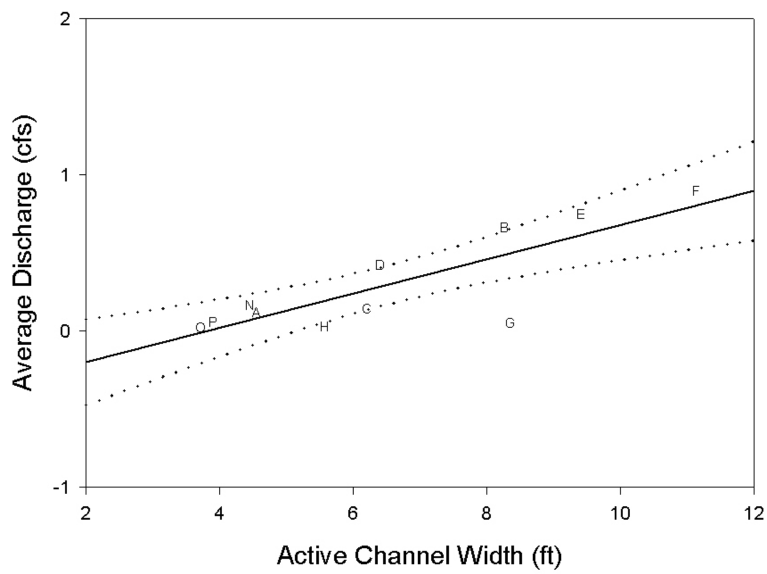

Figure 5-4. Average discharge with regard to active channel width in small Southern Appalachian streams. $r^2 = 0.68$, $y = 0.109X - 0.418$, $p = 0.0017$. Dotted lines represent 95 % confidence interval.

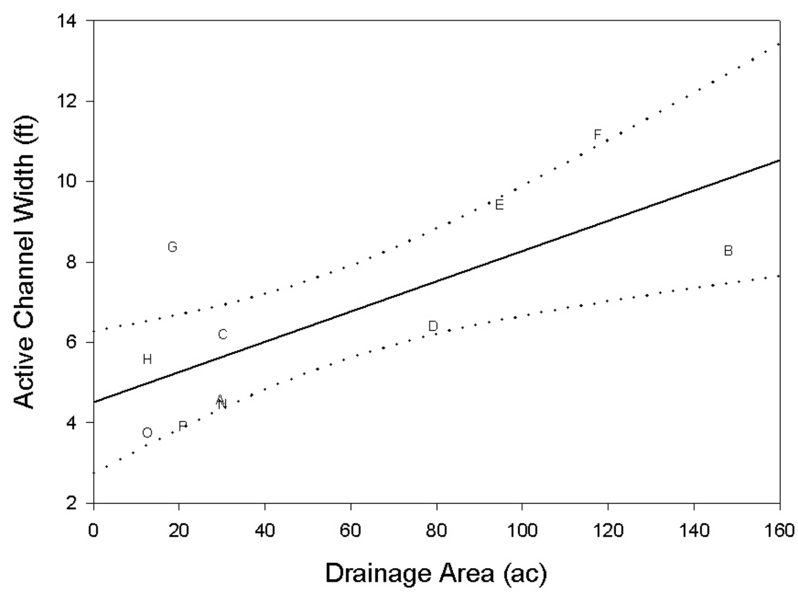

Figure 5-5. Active channel width versus drainage area in small Southern Appalachian streams. $r^2 = 0.53$, $y = 0.037X - 4.512$, $p = 0.0104$. Dotted lines represent 95 % confidence interval.

Active channel width tends to increase with average discharge. However, other investigators have found that a variety of factors including woody debris frequency, step frequency, and gradient affect ACW (Jackson and Sturm 2002). In small Southern Appalachian trout streams, ACW seems to be highly correlated with FWD frequency (Figure 5-6).

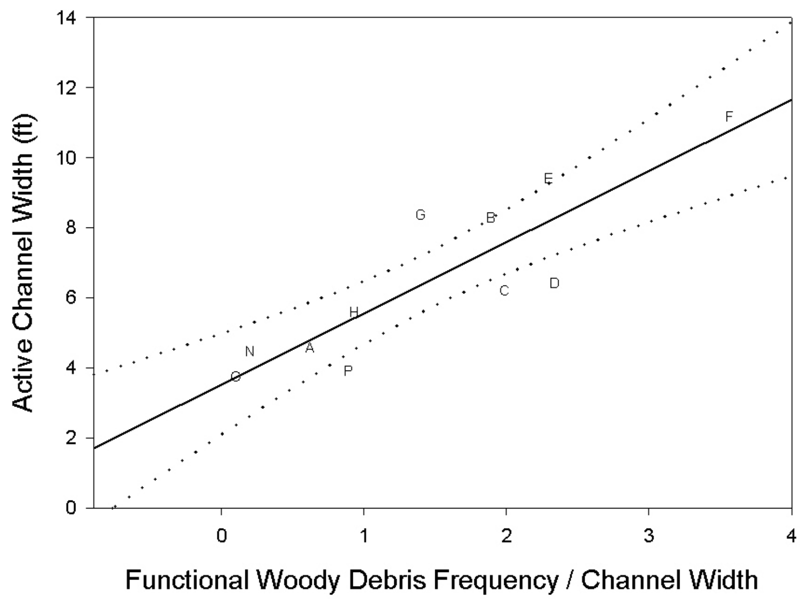

Figure 5-6. Active channel width with regard to functional large woody debris frequency in small Southern Appalachian streams. $r^2 = 0.76$, $y = 0.62 X - 1.08$, $p = 0.0004$. Dotted lines represent 95 % confidence interval.

Actually FWD frequency is a better predictor of channel width than average discharge. Therefore, a two-variable model of ACW versus average discharge and FWD was evaluated (Figure 5-7, $r^2 = 0.79$, $p = 0.001$). While active channel width is a crude predictor of average discharge, there is a lot of noise in the relationship, perhaps as a result of the frequency of woody debris.

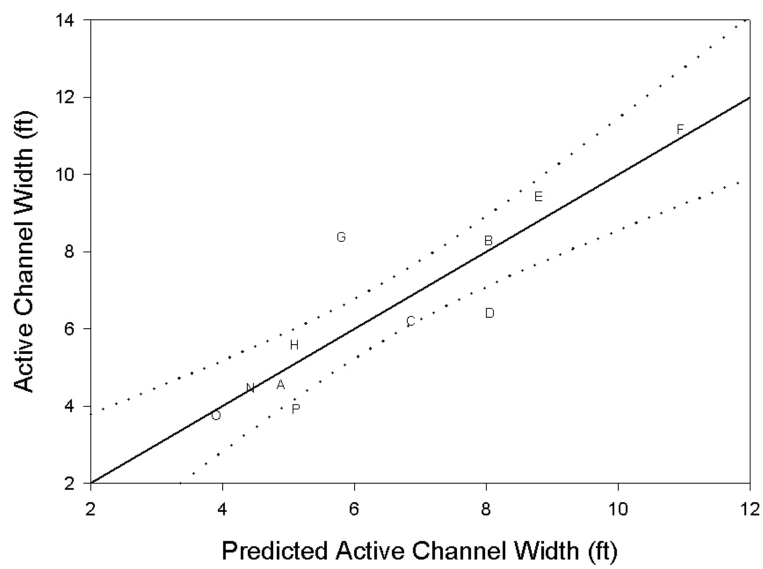

Figure 5-7. Active channel width and predicted active channel width determined by average discharge and functional large woody debris frequency model. $r^2 = 0.79$; $y = 0.99 X - 6.66$; $p = 0.0010$. Dotted lines represent 95 % confidence interval.

All the channel metrics were more closely related to average discharge than to drainage area. Predicting average discharge based solely on channel metrics is inaccurate, but channel metrics can be used as a check on predictions developed from discharge-drainage area relationships.

Drainage area can be easily measured using GPS technology and USGS topographic maps can serve as a predictor of mean annual flow for determining which streams may be exempt from riparian buffer requirements under current regulations.

5.2 Extent of Private Lands Drained by Streams Exempt from Riparian Buffer Requirements

In the Blue Ridge of North Georgia, streams with a mean annual flow of 25 gpm drain a watershed approximately 16 acres in size (**Section 5.1**). Georgia's current regulations permit the piping of streams of that size and smaller. Based on data presented in Figure 5-1, a defined stream channel can first be recognized in Southern Appalachian watersheds of about 7 acres in size. Hence, we have considered streams with watershed areas of 7 –16 acres as being eligible for piping. In this section, we used GIS to provide an estimate of the extent of the landscape drained by streams that could be piped under current riparian buffer regulations.

Using the USGS digital elevation model (DEM) representing the topography of the study area, a flow accumulation grid was generated to identify small drainages not delineated on other GIS coverages utilized in this project. The outlet of every drainage basin between 7 and 16 acres in size was identified and its drainage basin mapped. Any DEM grid cell contained within one of the identified 7 to 16 acre basins was shaded either red (for private lands) or green (for public lands) to generate Plate 6. The number of red grid cells was summed to determine the private land area potentially affected by the current piping legislation. Because the pressure to pipe small streams does not exist on public lands, we did not include these data in our calculations.

The study area has 1.29 million acres in private land. Of that area, 524,000 acres drain into streams that could be piped under the current regulations. Thus, 41% of private lands in North Georgia drain into headwater trout streams that could be piped up to 200 ft by individual landowners under current state regulations.

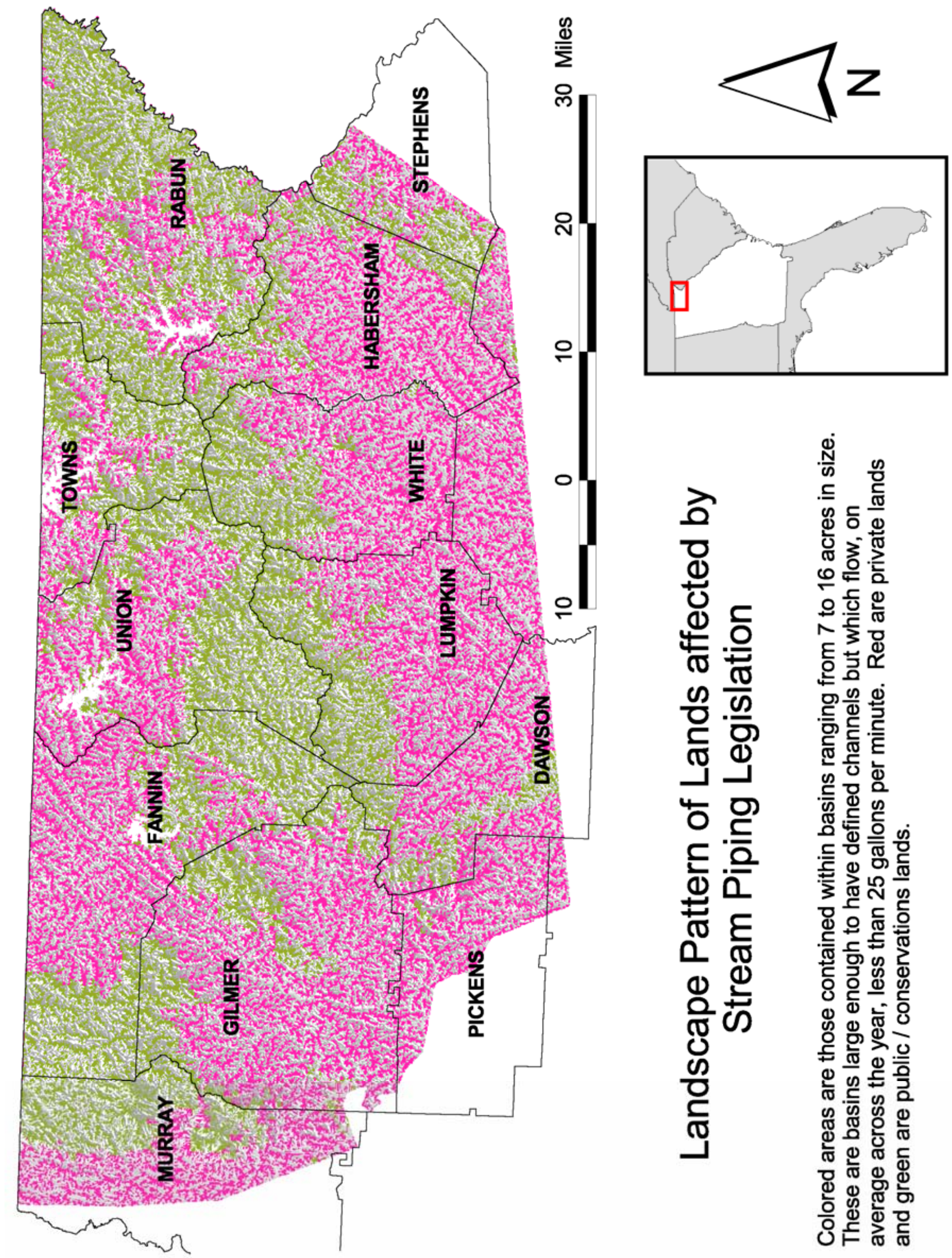
Landscape Pattern of Lands affected by Stream Piping Legislation
Colored areas are those contained within basins ranging from 7 to 16 acres in size. These are basins large enough to have defined channels but which flow, on average across the year, less than 25 gallons per minute. Red are private lands and green are public / conservations lands.
10 0 10 20 30 Miles
N
RABUN
STEPHENS
HABERSHAM
TOWNS
WHITE
UNION
LUMPKIN
DAWSON
FANNIN
GILMER
PICKENS
MURRAY

Plate 6

5.3 Impact of Piping on Ecological Services Provided by Small Streams

Piping small streams could impact trout streams in many ways since these small streams flow into large trout-bearing streams. Small streams maintain water quality, recharge the shallow groundwater, and reduce downstream flooding. In this section, we explore the potential impact of piping on aquatic life and on the drifting aquatic insects that provide food resources for downstream drift-feeding fishes such as trout.

Methods

To assess the impact of piping on aquatic life, we sampled benthic insects in the three small streams gaged by UGA and studied in **Section 5.1**. In March 2002, four replicate Surber samples were collected in riffle habitats of each stream by disturbing the substrate for three minutes. Samples were washed through sieves, and all invertebrates were picked from the > 1-mm fraction, stored in ethanol, identified to genus when possible, and measured for length. Biomass was estimated using standard length-mass equations (Benke et al. 1999, Sample et al. 1993).

Invertebrates that drift downstream can provide food for drift-feeding organisms, such as trout. To assess the impact of piping on the amount of drifting invertebrates, we placed drift nets in the three streams sampled for benthic insects and one piped stream (Figure 5-8). We were only able to locate one stream in the region that had been piped based on information from local issuing authorities and Georgia Environmental Protection Division. In the piped stream, a French drain collected water from a headwater seep, and a parking lot was built over the 190 ft long pipe. The piped section did not receive stormwater runoff from the parking lot. The drift net was placed about 8 inches from the pipe opening. The nets were in place at all sites for about two hours before and after sunset, the time period of maximum drift. All invertebrates were picked from the > 1-mm size fraction, stored in ethanol, and identified to genus when possible.

Figure 5-8. Picture of the piped stream sampled for drifting aquatic insects.

Results
The small headwater streams sampled had a diverse benthic fauna. A total of 54 taxa were collected at all sites, and the number of taxa per site ranged from 29 to 35 (Table 5-3). Aquatic insects that are EPT taxa (in the orders Ephemeroptera, Plecoptera, and Trichoptera, commonly known as mayflies, stoneflies and caddisflies) are used as indicators of high stream water quality. The three sites sampled each had 10 – 14 taxa in these three groups, indicating high water quality. Abundance of aquatic life in the small streams ranged from 465 to 2,249 individuals/ m^2 and biomass ranged from 724 to 1285 mg/m^2 (Table 5-3). Despite the fact that these streams do not flow throughout the year (**Section 5.1**), they support an abundance of aquatic life that is indicative of high water quality. The habitat supporting this aquatic life would be eliminated with piping.

Insects drifting downstream from the three headwater streams were also diverse and indicative of high water quality. 9 – 22 taxa were found in the drift samples from each stream, 5-6 of which were EPT taxa. In contrast, only one EPT organism was captured in the drift net below the piped stream. Also, 89% of the organisms collected from the piped stream were aquatic worms, which are indicative of poor water quality.

Table 5-3. Abundance and mass of aquatic organisms living on the bottom of small headwater streams (benthos) and drifting downstream. Stream designations are as in Tables 5.1 and 5.2. Values presented are means ± standard error.

Site	Benthos (Total # taxa)	Benthos (# EPT taxa)	Benthos (#/m^2)	Benthos (mg/m^2)	Drift (#/100 m^3)
O	35	14	465 ± 198	1285 ± 280	194
P	29	12	2249 ± 1117	724 ± 200	1984
N	32	10	506 ± 320	1206 ± 537	57
Piped	--	--	--	--	130

CONCLUSIONS

This study was designed to evaluate the implications of changes in riparian buffer regulations that went into effect with the passage of House Bill 1426. One provision of House Bill 1426 reduced the required width of vegetated riparian buffers for trout streams from 100 feet to 50 feet. We investigated the implications of this reduction in riparian forest for self-sustaining trout populations in North Georgia. We first quantified the relationship between the presence and biomass of young trout versus maximum summer stream water temperatures, the extent of fine sediments in riffles, and stream depth. Second, we demonstrated that percent forest cover measured using the Landcover of Georgia (a 100-ft resolution satellite derived dataset) can be used to determine the average width of a forested riparian buffer width within a 100-ft riparian zone. We then quantified the relationship between maximum summer stream water temperatures versus elevation and percent forest cover in the 100-ft riparian zone. We also quantified the relationship between the extent of fine sediment in riffles versus maximum stream velocity and percent forest cover in the 100-ft riparian zone.

To be able to explore the implications of regulatory changes, we first had to describe current landscape conditions. About 60% of trout stream miles are on private land. Although 100-ft riparian buffers on trout streams have been required since 1990, only 20% of streams on private land have forested buffers greater than 100 feet wide, and another 20% have buffers 80 – 100 feet wide (Figure 1-5). The remaining 60% of trout streams on private land currently have buffers less than 80 feet wide. Over 60% of trout stream miles in the northern half of the area have forested riparian buffers less than 80 feet wide, whereas about 40% of trout stream miles in the southern half of the area have forested riparian buffers less than 80 feet wide. These statistics demonstrate the extent to which the forested riparian zone has already been altered by human activities.

This landscape information can be used to predict maximum summer stream temperatures throughout North Georgia's trout streams based on the quantified relationships between riparian forest cover and stream temperature. Under current conditions, nearly 17% of trout streams (most on private lands) have maximum summer temperatures that are at least 2^{o}F higher than they would be if all streams had 100-ft forested riparian buffers. A temperature change of this magnitude can have negative consequences for trout populations. In fact, in the transition zone between high and poor quality habitat, there a ~15% decrease in the likelihood of trout occurrence for each degree ($^{\circ}$F) of warming (Figure 2-2). Thus, existing reductions in riparian cover and associated increases in stream temperature of 2 to 5 ^{o}F may have already yielded as much as a 30% to 75% reduction in the likelihood of finding trout in streams where riparian cover has been reduced.

Having quantified the relationships between trout and riparian buffer characteristics, we then combined this information with GIS maps of landscape conditions in North Georgia to explore changes likely to occur given 100- vs. 50-ft forested riparian buffers. If forested riparian buffer widths decline from 100 to 50 ft, maximum summer stream temperatures are predicted to increase by 2.9°F in a cool, wet summer and 4.2°F in a warm, dry summer. The extent of fine sediments in riffles is predicted to increase by 11%. The biomass of young trout will be reduced by over 80% because of warmer temperatures and increased fine sediments.

Using observed relationships between the occurrence of trout and maximum summer stream temperatures, we defined three classes of trout habitat: poor (less than 50% probability of the occurrence of young trout), marginal (50 – 90% probability of the occurrence of young trout), and high quality (greater than 90% probability of the occurrence of young trout). If all of Georgia's trout streams had 100-ft forested riparian buffer zones, 63% of the state's trout stream miles would have summer temperature regimes indicative of high or marginal quality trout habitat. If all trout streams have 50-ft forested riparian buffer zones, less than 9% of the state's trout stream miles would have summer temperature regimes indicative of high or even marginal quality trout habitat. These calculations suggest that reducing riparian buffer widths from 100 ft to 50 ft will result in thermal alteration of streams, a consequent reduction in good trout habitat, and a decline in trout populations. We developed equations to predict trout biomass from temperature and sediment conditions in North Georgia trout streams. Results from these equations reveal that changes in stream temperature and sediment conditions are expected to reduce young trout populations by 81 – 88% in North Georgia trout streams if the riparian buffer width is reduced from 100 ft to 50 ft.

A second provision of House Bill 1426 made very small streams exempt from 50-ft buffer requirements and permitted them to be piped up to 200 ft by individual landowners. This research has shown that, in the Blue Ridge province, these "exempt" streams with a mean annual discharge of 25 gallons per minute drain watersheds about 16 acres in size and have channels are 4-5 feet wide (although summer low flows may occupy only a small portion of this channel width). Neither channel metrics nor monthly baseflow values are reliable predictors of average stream discharge. Those measures are therefore are not likely to be useful in a regulatory context. Watershed area, however, does seem to be a useful criterion for determining mean annual discharge. Small streams with an intact riparian zone have diverse aquatic life that is indicative of high water quality, but the aquatic life inhabiting a piped stream is indicative of degraded water quality. We calculated the area of private lands in North Georgia that drain into small streams that are exempt from buffer regulations to evaluate the area potentially impacted by these regulatory changes. 41% of private lands in North Georgia drain into small trout stream tributaries that are now exempt from buffer regulations. Thus, development on a large fraction of the landscape is now exempt from riparian buffer regulations designed to protect water quality and trout populations in North Georgia.

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APPENDIX A—SAMPLING SITE INFORMATION FOR THE TROUT STREAM BUFFER PROJECT

GROUP 1 SAMPLING SITE INFORMATION.

Site ID	Site Name	County	Drainage	Basin Area (km^2)	Elevation (m)	% Riparian Cover	% Basin Cover
1	Anderson	Gilmer	Coosa	16.4	594	96	96
2	Boardtown	Gilmer	Coosa	8.2	489	29	83
3	Boggs	Lumpkin	Chattahoochee	11.8	531	100	98
4	Clay	Lumpkin	Chattahoochee	8.7	396	83	81
5	Cochrans	Dawson	Coosa	9.5	498	98	97
6	Coleman	Rabun	Savannah	13.2	691	95	97
7	Cooper	Union	Tennessee	33.5	740	90	95
8	Corn	Towns	Tennessee	7.4	561	66	85
9	Dick's	Lumpkin	Chattahoochee	41.6	491	91	97
10	Dukes	White	Chattahoochee	31.8	488	96	97
11	East Fork Smith	White	Chattahoochee	15.6	505	96	96
12	Flat	Fannin	Coosa	6.4	551	86	99
13	Fodder	Towns	Tennessee	22.0	596	68	87
14	Holcomb	Rabun	Savannah	24.0	604	92	94
16	Little Fightingtown	Fannin	Tennessee	9.3	598	96	97
17	Noontootla	Fannin	Tennessee	32.6	618	92	99
19	Shoal	Habersham	Chattahoochee	20.9	434	78	86
20	Soapstone	Towns	Tennessee	15.5	668	86	97
21	Stekoa	Rabun	Savannah	35.4	573	51	74
22	Sugar	Fannin	Tennessee	18.0	488	62	73
23	Tiger	Rabun	Savannah	42.6	512	71	81
24	Timpson	Rabun	Savannah	16.1	697	64	89
25	Town (Union County)	Union	Tennessee	42.6	579	81	89
26	Town (White County)	White	Chattahoochee	21.5	488	85	93
27	Walnut Fork	Rabun	Savannah	15.3	507	99	90
28	West Fork Coosa	Union	Tennessee	21.6	569	70	87
29	West Fork Montgomery	Lumpkin	Coosa	8.8	534	93	97
30	Yahoola	Lumpkin	Chattahoochee	34.1	461	74	89

GROUP 2 SAMPLING SITE INFORMATION.

SiteID	Site Name	County	Drainage	Basin Area (km^2)	Elevation (m)	% Riparian Cover	% Basin Cover
47	Amicalola	Dawson	Coosa	6.2	381	86	69
48	Brasstown	White	Chattahoochee	14.4	403	67	74
49	Bridge	Rabun	Savannah	6.5	585	42	76
50	Cochrans trib	Dawson	Coosa	8.4	451	81	44
51	East Fork Coosa	Union	Tennessee	8.8	544	39	49
52	Cox	White	Chattahoochee	9.0	425	66	52
53	Disharoon	Pickens	Coosa	6.5	463	88	74
54	Fir	Gilmer	Coosa	5.5	396	65	69
56	Kiutuestia	Union	Coosa	6.4	561	64	60
57	Licklog	Gilmer	Coosa	23.8	459	54	65
58	Little Tennessee	Rabun	Tennessee	45.6	643	52	75
59	Moccasin	Union	Tennessee	6.1	508	56	55
61	Mudd	Rabun	Tennessee	8.5	886	39	54
62	Tesnatee	White	Chattahoochee	25.4	425	69	68
63	Weaver	Fannin	Tennessee	14.6	473	45	60

APPENDIX B—METHODS FOR ANALYSIS OF RIPARAIN COVER INFORMATION DERIVED FROM SATELLITE IMAGERY AND AERIAL PHOTOGRAPHY

We obtained spatially explicit estimates of riparian buffer width by digitizing the riparian buffers from aerial photographs in two watersheds (one each in Rabun and White Counties) within the study area. To obtain estimates of riparian buffer widths for the remainder of the study area, we used the riparian buffer information obtained from these two watersheds to develop a relationship between measured buffer width and percent riparian forest cover obtained from satellite imagery (Landsat TM data).

Aerial Photography. The most suitable study watersheds to digitize were those deemed to contain a variety of land uses. Thus, Stekoa Creek Watershed in Rabun County was chosen on this basis as were several small creeks in White County. The percent of forested landcover in the riparian zone at these sites covers the range of conditions found across the study landscape.

The most recent digital orthographic quarter quadrangles (DOQQ) available for the study area were color infrared images from 1999 available through the United States Geological Society (USGS) National Aerial Photography Program (NAPP). Statewide production of DOQQs was incomplete at the time of our study. Raw color infrared positive transparencies from the 1999 USGS DOQQ project had been acquired and orthographically rectified as part of a previous project for the White County locations. Raw color positive transparencies from the same dataset were also acquired for the Rabun County study areas was acquired from the Unites States Geological Society (USGS) National Aerial Photography Program (NAPP). The color positive film. The film was scanned at a resolution of 600 dpi and imported into **ERDAS Imagine 8.5**. The aerial photos were orthographically rectified using the USGS supplied camera correction information, a 30 m resolution digital elevation model (DEM), and reference points located on the corresponding 1993 USGS digital orthographic quarter quadrangles (DOQQ). The final rectified images were then clipped to the extent of the corresponding 1993 DOQQ to remove overlapping edges.

Vector data inputs for the analysis consisted of the USGS 1:24,000 stream networks for the study area. We increased the accuracy of the analysis by editing the stream network to better fit the position of the stream channels as visible in the rectified aerial photography images. The revised stream network was then buffered at 100 ft using the *Buffer Selected Features* function in the **ArcView 3.2** extension *X Tools*. This 100 ft buffer polygon was overlaid on the rectified color infrared images, and polygons of forest and nonforest landcover within the buffer were digitized onscreen. Forested riparian buffer was defined as an area of contiguous forest cover from the banks of the stream channel upslope to the 100 ft buffer boundary. Riparian cover in a cell was classified as nonforest regardless of cover type when that cell was upslope of any disruptions in forest cover such as road, houses, or clearing. For example, if a house was 25 feet from the stream bank, extended 25 feet further into the buffer, and the remaining 50 feet of the buffer was forested, that buffer width was considered to be 25 feet.

Satellite Landcover Classification. We used the 1998 Georgia landcover classification as the source for satellite derived landcover data in this study. This *Landcover of Georgia* was derived from Landsat Thematic Mapper images at 30 m resolution at an overall statewide accuracy of 85%. The 30 m landcover raster was resampled using the nearest neighbor method to 1 m cells (i.e., 900 1-m pixels were created from one 30-m pixel) and clipped to the 100 ft. riparian buffer polygon . The forested area in this buffer was then determined using the forest polygon as described in the previous paragraph. Because we were calculating these values over fairly large areas, the % forest cover determined using the 1-m cells was essentially the same as that determined using 30-m cells ($Y = -3.7 + 1.08 X$, where Y = % forest determined with 30-m cells and X = % forest cover determined with 1-m cells, $r^2 = 0.99$).

Analyses of Aerial Photography versus Satellite Data. For the stream network as a whole, each study watershed, and each sub-basin in the study watersheds, we calculated: 1) the total 100 ft riparian buffer area; 2) the area of forested 100 ft riparian buffer; 3) the buffer network length; 4) the average width of the forested 100 ft riparian buffer; and 5) the percent forest cover within the 100 ft riparian buffer. The goal of these calculations was to establish the relationship between aerial-photography-based results and satellite-classification-based results at 30 m and 1 m cell sizes and determine if any statistical anomalies existed.

The total 100 ft riparian buffer area (1 above) was derived by calculating the area of the 100 ft riparian buffer polygon for the photographic analysis and calculating the area of all data-containing cells clipped from the landcover raster data in the satellite landcover analysis. The area of forested 100 ft riparian buffer (2) was derived by calculating the sum of the area of all polygons within the 100 ft riparian buffer classified as forest cover for the photographic analysis and calculating the area of all forest class cells clipped from the landcover raster in the satellite landcover analysis. The total length of the 100 ft riparian buffer polygon (3) was used as buffer network length for all calculations. The average width of the forested 100 ft riparian buffer (4) was calculated by dividing the area of forested 100 ft riparian buffer by the buffer network length and dividing by 2 to account for independent stream banks. The percent forest cover within the 100 ft riparian buffer (5) was calculated by dividing the area of forested 100 ft riparian buffer by the total 100 ft riparian buffer area and multiplying by 100.

Site Information and data for the 18 sites used in aerial photography versus satellite imagery analyses.

Site Name	County	Average Forested Riparian Buffer Width (m) from 1999 CIR Aerial Photo (1-m Pixel)	Percent Riparian Forest Cover From 1998 30-m Satellite Landcover (1-m pixel)
Stekoa Creek	Rabun	14	50
Upper Scott Creek	Rabun	20	70
Ashley Creek	Rabun	28	91
Unnamed trib to Scott Creek	Rabun	22	82
Lower Scott Creek	Rabun	16	55
Lower Middle Stekoa Creek	Rabun	15	48
Upper Middle Stekoa Creek	Rabun	15	47
Unnamed trib to Stekoa Crk	Rabun	17	42
Upper Stekoa Creek	Rabun	14	48
Saddle Gap Branch	Rabun	15	55
Norton Creek	Rabun	18	63
Cathey Creek	White	26	86
Hooch Creek	White	10	31
Mauldin Mill Creek	White	24	80
Tributary 1 to Town Creek	White	23	66
Tributary 2 to Town Creek	White	27	76
Tributary 3 to Town Creek	White	18	61
York Creek	White	28	73

APPENDIX C—TROUT AND HABITAT SAMPLING DATA COLLECTED FOR THE TROUT STREAM BUFFER STUDY.

Young trout sampling data.

SiteID	2001 Young Trout Biomass (grams per hectare)	2002 Young Trout Biomass (grams per hectare)	2001 Mean Length (mm)	2002 Mean Length (mm)
1	0			
2	0			
3	2.62		98.3	
4	0			
5	0	0		
6	1.70		90.7	
7	0.51		66.4	
8	0			
9	0.68	0.09	73.3	61.8
10	4.58		62.2	
11	0.32		51.2	
12	0.94		75.0	
13	0.21		77.0	
14	4.18		125.3	
16	7.66	4.62	76.9	78.1
17	1.48	1.35	68.9	66.1
19	0	0		
20	5.93	2.27	66.9	65.2
21	0	0		
22	0			
23	0.28	1.63	63.3	70.3
24	2.10		126.7	
25	0			
26	0.80	0.27	63.5	61.0
27	0.12		41.0	
28	0			
29	1.09	1.34	110.0	83.7
30	0			

Group 1’s M7DAM temperatures for 2001 – 2003.

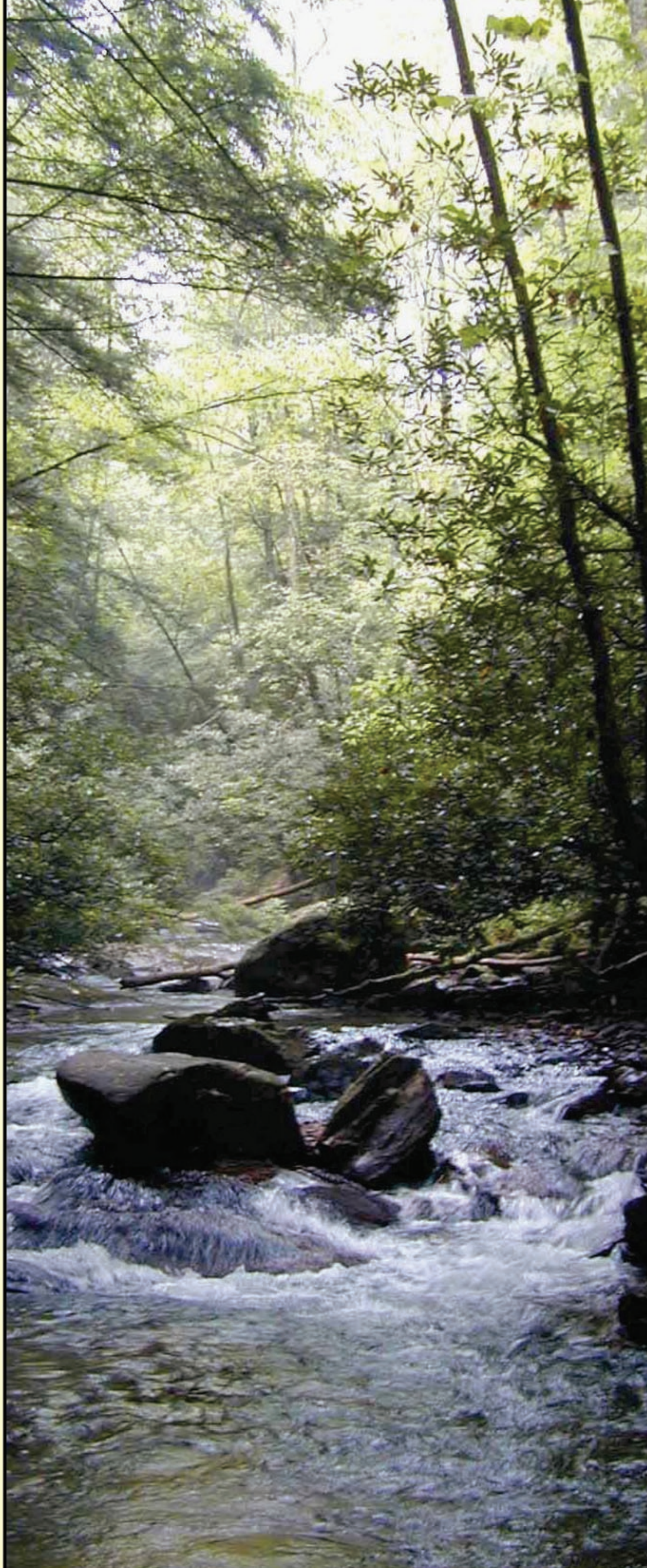
Site ID	M7DAM temperature (°F)			M7DAM temperature (°C)			Date of M7DAM temperature		
	2001	2002	2003	2001	2002	2003	2001	2002	2003
1	67.3	70.3	64.8	19.6	21.3	18.2	8/8	8/5	8/25
2	73.8	75.6	70.7	23.2	24.2	21.5	8/8	8/3	8/25
3	68.9	70.4	67.6	20.5	21.3	19.8	8/9	7/30	8/31
4	74.6	76.3	74.3	23.7	24.6	23.5	8/9	7/29	8/25
5	68.6	70.4	67.3	20.4	21.3	19.6	8/8	7/30	8/25
6	63.9	65.9	62.5	17.7	18.8	16.9	8/10	7/30	8/27
7	66.9	69.8	68.0	19.4	21.0	20.0	8/17	7/30	8/30
8	72.1	73.5		22.3	23.1		8/9	7/31	
9	68.8	72.8	69.3	20.5	22.6	20.7	7/11	7/31	8/25
10	68.1	69.7	66.2	20.1	20.9	19.0	8/9	7/31	8/28
11	67.7	69.2		19.9	20.7		8/9	8/19	
12		70.1	67.6		21.2	19.8		7/30	8/28
13	69.7	72.5	68.4	21.0	22.5	20.2	8/8	7/29	8/26
14	66.5	67.8	65.3	19.1	19.9	18.5	8/10	8/22	8/25
16	63.6	65.0	63.5	17.6	18.3	17.5	7/28	7/30	8/30
17	65.2	66.3	64.0	18.4	19.0	17.8	8/8	7/30	8/31
19	70.4	72.9	68.7	21.3	22.7	20.4	8/9	7/31	8/25
20	65.0	65.9		18.3	18.8		8/10	7/29	
21	72.8	73.4	68.1	22.6	23.0	20.1	8/10	7/7	8/27
22	71.7	73.8	71.2	22.0	23.2	21.8	8/8	8/1	8/28
23	71.0	73.1	69.2	21.7	22.8	20.7	8/10	7/30	8/25
24	67.5	68.5	66.5	19.7	20.3	19.1	8/10	7/30	8/25
25	72.3	73.3	71.7	22.4	23.0	22.0	8/9	8/22	8/26
26	71.1	73.0	69.2	21.7	22.8	20.7	8/9	7/30	8/25
27	67.9	68.0	66.1	19.9	20.0	18.9	8/10	7/31	8/26
28	71.9	73.0	69.8	22.1	22.8	21.0	8/8	7/31	8/31
29	68.2	69.6	66.9	20.1	20.9	19.4	8/10	8/22	8/25
30	76.0	77.1	73.7	24.5	25.1	23.2	7/11	8/1	8/27

Group 2's 2003 M7DAM temperatures.

Site ID	2003 M7DAM temperature (°F)	2003 M7DAM temperature (°C)	Date of M7DAM temperature
2	70.7	21.5	8/25
21	68.1	20.1	8/27
22	71.2	21.8	8/28
47	66.9	19.4	8/24
48	71.8	22.1	8/26
49	74.1	23.4	8/26
50	66.0	18.9	8/25
51	72.3	22.4	8/27
53	69.4	20.8	8/26
54	65.8	18.8	9/1
56	71.1	21.7	8/28
58	69.8	21	8/26
59	71.1	21.7	8/17
61	72.7	22.6	8/25
62	71.2	21.8	8/24
63	68.4	20.2	7/28

Habitat data collected from Group 1 sampling sites.

Site ID	Riffle Embeddedness	Proportion of Coarse Substrate	Local Stream Slope	Maximum Velocity (m/second)	Maximum Depth (cm)
1	41	25	0.59	0.96	89.5
2	43	36	1.30	0.93	65.5
3	31	77	3.33	1.43	77
4	46	18	0.35	0.52	49
5	36	33	1.80	0.73	31
6	38	43	1.04	0.85	75
7	39	33	0.55	0.94	79
8	43	21	1.01	0.78	49
9	39	39	0.81	0.96	58
10	34	43	0.46	0.75	60
11	37	50	2.05	1.4	123
12	41	50	2.33	1.19	48
13	34	42	0.56	1.07	84.5
14	36	52	1.07	1.4	60
16	35	60	2.48	1.69	72
17	40	52	1.25	1.33	71.5
19		66	1.39	1.61	64.5
20	42	39	1.59	0.95	32
21		25	0.31	1.56	66
22		78	2.01	2.2	64
23	40	23	0.36	0.76	61.5
24	38	44	1.21	1.13	67
25	36	21	0.29	1.41	42.5
26	32	78	0.86	1.24	64.5
27	36	32	0.57	0.7	82
28	47	20	0.31	0.97	35
29	42	30	0.45	0.44	47.5
30	43	37	0.45	1.17	67



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