ASSESSMENT OF THERMAL POLLUTION ASSOCIATED WITH RIPARIAN CANOPY CLEARING

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Abstract

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This report summarizes the results of monitoring water temperatures at 5 stream sites for 2+ years. The sites encompassed varying stream sizes and lengths, tree canopies, and road improvement activities. This study was designed to document water temperature in mountain streams that have had limited tree removal in the riparian corridor as a result of road improvement. Results showed that for a large stream (drainage area >10,000 ac) the temperature increase from upstream to downstream was <0.09 °F, even though the stream had a reach of 650ft without any tree canopy. Monitoring on 2 of the 4 smaller streams (drainage areas <1,000 ac) documented a decrease in temperature from upstream to downstream of a reach where road improvements had occurred. The reason for the decrease was not known, but clearly road improvements were not causing increases in stream temperatures. For the 2 small streams with increases in temperature, the greatest increase (0.61 °F) from upstream to downstream occurred for a stream reach of >3100ft with essentially no tree canopy. Altogether the data suggested that: 1) for larger streams (drainage area >10,000 ac), removing trees outside a 20ft stream buffer did not result in a measurable increase in temperature, 2) for larger streams (drainage area >10,000 ac), with all tree canopy up to a 650ft reach removed, the increase in temperature was <0.10 °F, 3) tree canopy is not the only factor influencing whether stream temperature increased in a monitored stream reach, 4) additional research is needed where stream temperature is monitored before during and after road improvement to more definitively document the effects of riparian canopy reductions on stream temperatures.

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DISCLAIMER

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INTRODUCTION

Removal of trees during road improvement projects is often necessary, especially in mountainous areas of North Carolina where forests dominate the land. In this area many roads are located along streams, so tree removal often occurs within the riparian corridor of a stream. Since many of the streams are trout supporting or are tributaries to designated trout waters, the question of whether the removal of trees from riparian corridors results in an increase in water temperature becomes important.

Water temperature is an important habitat variable for many aquatic organisms as it affects their metabolism, feeding and reproduction. Macroinvertebrates have been shown to be adversely affected by increases in water temperature (Sweeney, 1993). Trout, and other salmonids, are among the most sensitive to water temperature changes (Jones and Hunt, 2009). Previous studies have shown salmonids can become stressed at temperatures as low as 68 °F, avoid waters above 70 °F and cannot survive temperatures 77 °F (Coutant, 1977).

Although water temperature at a given location varies naturally due to diurnal and seasonal factors, anthropogenic changes can skew natural variability significantly. For example, several studies have shown that the removal of a large area of trees during logging resulted in increases in the temperature of streams located within the logged area (Beschta and Taylor, 1988; Holtby, 1988; Swift and Messer, 1971). However, few, if any, studies have documented the effects on stream temperature of removing selected trees or a small number of trees from within the riparian area such as would be done for road improvement projects.

Many factors affect the extent of thermal heating resulting from limited clearing of tree canopy, including stream flow rate, ambient air and water temperature, extent of clearing relative to total riparian corridor, width and depth of the water column, and possibly turbidity/solids concentration of the stream/waterbody. Studies of Pacifica and Alaskan streams have shown increases in stream temperature resulting from removing trees from riparian zones in some cases; however, they have also shown that, in small streams (<1 cfs), downstream water temperature returns to normal relatively quickly if the tree canopy is restored. Thus, there is a need to document under what conditions riparian canopy removal has a significant effect on stream temperature.

This study was designed to document water temperature during a three-year period in mountain streams that have had limited tree removal in the riparian corridor as a result of road improvement. Streams with different discharge rates, bed slopes, and tree canopy were monitored as well as streams with different extents of tree removal from road improvement. In addition, a single stream reach was monitored prior to road improvement to document changes in temperature following road improvement.

METHODOLOGY AND PROCEDURES

This study included continuous temperature monitoring of 5 streams reaches in Ashe and Mitchell Counties of North Carolina (Figure 1). One of these is a hatchery-supported trout stream and three others drain to hatchery-supported trout waters. Several of the reaches were on unnamed tributaries; hence, the names of sites used in this report may be the name of the road or another name assigned to the site. Location coordinates and watershed characteristics for the 5 stream sites/reaches are shown in Table 1. The drainage areas for the sites range from 371 to 16,064 acres. Because the sites were in the mountains elevations, average slope, and forested land use were high for North Carolina watersheds.

The North Carolina Department of Transportation provided a list of 12 road improvement projects where stream buffers had been impacted in the past 2 years or would be impacted in the near future. Stream reaches with minimal incoming waters were given preference. Other stream reaches were eliminated based on accessibility and uncommon features such as long culverts. Of the 5 stream reaches three were intensively monitored (Bear Wallow, Cranberry Creek, and Wallace Branch); two were less intensively monitored (Little Windfall and Raccoon Branch). All of the stream sites except Bear Wallow, were along roads that had been improved in the recent past, which required the removal of some trees within 50ft of the stream. The Bear Wallow site was monitored prior to an anticipated road improvement project, which is now in progress; however, data contained in this report include only the pre-improvement period. The three intensively monitored reaches included a variety of stream sizes and tree canopy removal extents. Intensive monitoring included continuous measurements, upstream and down, of water stage and temperature along with occasional measurements of water depth and width, solar radiation, and stream cross section. Air temperature was also monitored continuously 2-3 ft above the ground surface at several of these sites using the same types of sensors that were used to monitor water temperature.

A staff gage and an automated pressure transducer were installed at each discharge monitoring site to provide continuous water stage measurements and a reference for calibration. Because the pressure transducers were installed under water they measured the sum of the atmospheric and water pressure; thus, the atmospheric pressure had to be measured or otherwise determined and subtracted from the measurements to obtain water depth. Water depth measurements were then correlated to the staff gage to compute stage measurements. Stage measurements were converted to discharge using stage-discharge rating tables. Stage-discharge rating tables were developed from at least 5 manual measurements of discharge encompassing a range of stages. For most sites, the range of stages encompassed at least 70% of the range of stages actually measured. The manual measurements of discharge were conducted using standard stream gaging equipment and techniques.

At the two less intensively monitored sites, water temperature was also monitored continuously at upstream and downstream locations. However, only instantaneous discharge measurements were made occasionally to document current conditions and no solar radiation measurements were made.

All water and air temperature sensors had continuous measurement capability (15-30 minute interval). Sensors were installed at shaded locations, when possible, to prevent direct solar radiation on the sensor itself. For several sites shaded locations could not be found, so the sensor was placed inside a white PVC pipe to shade it from the sun and minimize solar heating. Although the water in most streams appeared to be well-mixed, temperature sensors were installed in areas of flow where the measured temperature was expected to be representative of the entire stream cross section. Atmospheric pressure was monitored at Bear Wallow and Wallace Branch during part of the project.

Because of the variable nature of climatic conditions, more than 2.5 years of data were collected to attempt to establish long-term relationships/trends as opposed to short-term trends caused by unusual climatic and/or other conditions. Temperature data from monitoring stations located upstream and downstream of stream reaches affected by highway improvements were collected. Paired t-tests were used to determine if differences between upstream and downstream temperatures were statistically significant. Unless otherwise stated all paired t-tests used 0.05 as the level of significance. The data were not tested for normalcy because the sample size was quite large (>500 data points).

To further characterize the stream reaches, analyses were performed to identify spatial influences, including topography and land cover, which limit exposure to solar radiation. A 50ft buffer was applied to the stream segment between the upstream and downstream monitoring stations at each site. This buffer was then used to clip subsequent data layers for analysis. Land cover classifications were divided into Pasture, Forested, and Developed (Open space). For this analysis, the Cultivated land cover classification is included in the Pasture classification based on ground truthing and aerial imagery disputing remote sensing data. The contributing area of each land cover class was then computed and a percentage of the total stream buffer calculated as shown in Table 2. A grid file representing hours of sun exposure during summer solstice (the longest day of the year) was utilized to quantify the maximum hours of sunlight the stream could receive in a day. Cell values ranging from 4 to 14 hours of sun exposure were extracted for analysis within 50ft stream buffer. Further processing allowed the amount of sun exposure to be summarized for the entire stream reach as shown in Table 3. This analysis represents an extreme scenario and disregards shading affects from surrounding vegetation.

RESULTS

Because of the amount of temperature and discharge data, only summaries will be presented in this report, except for graphical representations, which will often use all of the data. The statistical analysis depended on a comparison of upstream and downstream stations; therefore, when data were missing from one station, data from the other station were deleted to perform the statistical test.

Raccoon Branch Site

The Raccoon Branch site was located along SR1311 in Mitchell County (Figure 1). Road improvements involved widening and paving of the gravel road. All construction activities were completed prior to instrumentation. The monitored stream reach was about 3,000ft long and basically is within 50ft of the road for the whole reach (Figure 2). Within the 50ft stream buffer, 70% is classified as Developed/Open Space and the tree canopy over the stream is sparse until the last 100-200ft before the downstream station where there is a good tree riparian buffer with canopy (Table 2). The drainage area to the upstream station was 634 ac with 67.1% of the land classified as forested and 24.9% cultivated, although the vast majority of the land classified as cultivated appeared to be in pasture (Table 1). There were 70 acres draining to the creek between the stations. The width of the stream water was 3-5ft depending on discharge and location. The depth was 0.25-0.5ft during baseflow and baseflow discharge was 0.35 cfs measured on one occasion. Based on these metrics this section of Raccoon Branch was typical of many small mountain streams.

Mean monthly temperatures for Raccoon Branch are shown in Table 4. For the October through April period of each year the difference between upstream and downstream monthly mean temperature was negative indicating that the downstream temperature was less than upstream. The reverse was true for the May-September months where downstream temperatures were more than upstream temperatures. The increase during the May-September period was expected given that the tree canopy was sparse, but the reason for the decrease from upstream to downstream during the other months was unknown. Spatial analysis estimates 97% of the stream can receive between 11 and 12 hours of light during the longest summer days if no canopy is present. There was a greenhouse between the two stations, which releases water from its facility on occasion, but it is unknown how much and when the releases occur. For this 30-month period, the overall mean at the downstream station was 52.40 °F, which was 0.46 °F less than the upstream station over the same period (Table 5). The mean temperature at the downstream station was significantly less than the mean upstream temperature according to a paired t-test (Table 5). The difference was greater than the resolution (0.04 °F) and measurement accuracy of the temperature sensors (±0.36 °F) indicating that the overall decrease from upstream to downstream was real. For the growing season (May-September) data, there was a statistically significant increase in overall mean temperature of 0.57 °F according to a paired t-test. The growing season months are critical ones for temperature, and these data document a significant increase, but since there were no data collected prior to tree removal for road improvement, there is no way to determine how much or if road improvement contributed to the increase in temperature.

Little Windfall Branch Site

The Little Windfall (Branch) site was located along SR1358 in Ashe County (Figure 1). Road improvements which included widening and paving of the gravel road were completed prior to instrumentation. The monitored stream reach was about 3,500ft long and basically is within 50ft of the road for the whole reach. For the first several hundred feet of the reach, the stream was located between the road and a beef cow pasture (Figure 3). Tree canopy over the stream was mixed with some stretches of trees only on the banks, some stretches with woods (full canopy) on one-side, and some stretches with no tree canopy. Within the 50ft stream buffer 85.7% is classified as forested and 12.8% as pasture (Table 2). The stream primarily runs east-southeast providing good sun exposure all day. It is estimated that without canopy 97% of this site would receive between 12 and 14 hours of sunlight during long summer days (Table 3). The drainage area to the upstream station is 173 ac increasing to 371 ac at the downstream station. The upstream watershed has 56.9% of the land classified as forested and 37.4% cultivated although the vast majority of the land classified as cultivated appeared to be in pasture (Table 1). The width of the stream during visits varied from 1-3ft depending on discharge and location. Stream depth of 0.2-0.5ft during baseflow and a baseflow discharge of 0.06 cfs was measured on one occasion. Based on these metrics this section of Little Windfall Branch was typical of many small mountain streams.

Mean monthly temperatures for Little Windfall are shown in Table 4. For all months except May, 2011 downstream temperature was less than upstream temperature. This was unexpected as there was a considerable length of stream between the stations in which tree canopy was sparse. The reason for the decrease in temperature from upstream to downstream was unknown, but for the summer months at least, it may have been due to the influx of cooler groundwater. For the 3/24/11 to 3/7/12 period, the overall mean at the upstream station was 53.98 °F, which was the 2nd highest temperature from all sites (Table 5). The reason for this relatively high temperature was unknown, but could be due to the lack of canopy in pasture areas or the presence of a small pond in the upstream drainage area. In standing waters such as a pond the top of the water column absorbs solar radiation and increases water temperature; as the pond fills this warmer water is released into the stream potentially increasing the stream temperature. The mean temperature at the downstream station was significantly less than the upstream according to a paired t-test (Table 5). The difference (1.12 °F) was greater than the resolution (0.04 °F) and measurement accuracy of the temperature sensors (±0.36 °F) indicating that the overall decrease from upstream to downstream was real.

Wallace Branch Site

Wallace Branch was located along B.H. Duncan Road (SR1300) and NC Hwy 88 in western Ashe County (Figure 1). Roadway paving at this site was completed prior to monitoring. Just downstream from the upstream monitoring station, the stream flows along a wooded hill (Figure 6, left) where it has a tree canopy on one side, but for most of the length of the monitored reach the stream basically has no tree canopy, (Figure 6). The 50ft stream buffer consists of 52.2% Pasture and 45.4% Developed/Open Space between the upstream and mid stations (Table 2). Lack of riparian buffer and hill shading from the upstream station to the mid station causes nearly all of the 2000ft channel to be exposed to sunlight for 12-14 hours during the longest summer day. Just below the mid station the channel makes a hard turn and flows due north for 900ft. The 50ft buffer between the mid and downstream station is comprised of 48.7% Pasture and 51.3% Developed, most of which is roadway (Table 2). Due to the surrounding terrain this stream segment receives between 12 and 13 hours of sunlight during long summer days (Table 3). The width and depth of the stream varied considerably from the upstream to downstream station, but was generally from 3 to 5ft wide and 0.3 to 1.5ft deep during baseflow. The drainage area to the upstream monitoring station was 486 acres increasing to 608 acres at the downstream station. The watershed area contributing to the upstream station was 95.5% forested. This, along with aerial photographs indicated that there was excellent tree canopy coverage over the stream channel to the upstream station. Discharge measurements at the upstream station ranged from 0.45 to 2.28 cfs. Discharge, measured several times at the mid and downstream stations, was similar to the upstream measurement; this was expected since only 1 small tributary enters the stream between the stations.

Wallace Branch is not a designated trout water but drains to the North Fork of the New River which is a hatchery-supported trout water. From October 2010 through March 2013 the upstream monitoring station records never exceeded the critical 68 °F limit for salmonids. However, the downstream sensor logged 140 days when the temperature met or exceeded 68 °F for an hour or more. Instances of 68 °F readings were observed to begin in May-June and continued intermittently into August-September.

Mean monthly temperature data for the three stations are shown in Table 4 and Figure 7. The sensor at the mid station was vandalized twice; thus, the data for this station is missing for several months. During the growing season (May-September), mean monthly temperature increased consistently from upstream to mid to downstream with the greatest increase coming from the upstream to the mid station. The exact reason for the temperature increase from up to mid was unknown. In addition, the effect of removing trees for road improvement from the last ~50ft of the reach cannot be determined, because the water temperature prior to the tree removal was unknown. There was ~2020ft of stream channel from the upstream to the mid station with several small pools and basically no tree canopy over the stream channel. Also, a small intermittent tributary entered the stream between the stations. Both of these features could have contributed to the increase in stream temperature between the stations. The increase in temperature from the mid station to downstream station was much less than from upstream station to mid station during the growing season. This was expected, to some extent, as the lower reach was about half (~900ft) the length of the upper reach with no vegetative canopy. The stream channel slope in the lower reach was even less than the upper reach suggesting that the slower moving water should absorb more heat. There was slightly more water in the channel, which may have helped to temper the temperature change.

Cranberry Creek Site

The Cranberry Creek site was located along Upper Cranberry Creek Road (SR1609) in eastern Ashe County (Figure 1). Road improvements included widening of the gravel road but no paving. Trees were removed outside of the 20ft stream buffer and minimal grading was done to the adjacent hillside. Road construction was completed prior to instrumentation. The stream channel was within 50ft the road for the entire monitored reach. The 50ft stream buffer for this reach consists of 39.2% Pasture, 24.4% Forest and 36.4% Developed/Open Space, most of which is gravel road (Table 2). Spatial analysis estimated the majority of this stream reach would receive between 12-13 hours of direct sunlight if no riparian canopy were present (Table 3). The 875ft reach from the upstream to mid station had a moderately dense tree canopy over the stream with mature trees on both banks. There was a field on one side and the road on the other side about 20-50ft from the streambank. From the mid to downstream station (650ft) the stream basically had no tree canopy (Figure 8). The channel slope in this section was also relatively flat resulting in slow-moving, deeper water. The width and depth of the stream varied considerably from the upstream to downstream station, but was generally from 30 to 50ft wide and from 0.6 to 3ft deep during baseflow. The drainage area to the upstream monitoring station was 15,808 acres increasing to 16,064 acres at the downstream station. The watershed area to the upstream station was 60.1% forested and 29.3% pasture.

Nine discharge measurements at the downstream station ranged from 15 to 143 cfs. Discharge, measured several times at the mid and upstream stations, was similar to the downstream measurement, which was expected as only 1 small tributary enters the stream between the stations. The stream cross section at the downstream station remained stable but the cross sections at the other two stations did not, so only continuous discharge measured at the downstream station was considered accurate enough to be used in the data analyses.

The monitored stream reach of Cranberry Creek was a hatchery-supported trout water during this study. During the 27 months of continuous data collection, both the upstream and downstream stations logged events equal to or greater than 68 °F, the temperature when trout begin to show signs of stress. The upstream station logged 126 days when 68 °F was exceeded for over an hour. Similarly the downstream station logged 129 days at or above 68 °F. Temperature readings exceeding 68 °F began during late May; however, most instances occurred during July and August. An extreme example occurred 7-18-11 through 8-20-11, when the 68 °F threshold was exceeded almost continuously.

Mean monthly temperature data for the three stations are shown in Table 4. During the study sensors became inundated with sediment at various times. Sediment around the sensor tends to buffer temperature variations. Data during periods of observed sediment inundation were excluded for the purposes of reporting as shown in Table 4. This effect of sediment inundation on sensor readings is illustrated by Figure 9. It is likely the high discharge on 1/31/13 carried sediment that inundated the upstream sensor and caused temperature buffering indicated by the lack of diurnal variability at the upstream station (red line in Figure 9).

Mean monthly temperatures increased from upstream to downstream during all but 3 of the months in the monitoring period. Increases were greater during the growing season with the maximum (0.34 °F) occurring August 2012. This was expected since there was no tree canopy over the last 650ft of the stream reach between the stations. Comparison of temperature increases from upstream to mid and mid to downstream during the May-September period shows no consistent trend in either year; for some months there was a greater increase from upstream to mid and for other months the increase from mid to downstream was greater. This was unexpected as the greatest increase in temperature was expected to occur from mid to downstream where the stream had no canopy and was slow-moving. This indicates that the presence/absence of tree canopy may not be the most important factor in determining changes in stream temperature. The differences in temperature between these stations is relatively small (<0.21 °F) when compared to the accuracy of the sensors (±0.36 °F) and the effect of sediment deposition on temperature measurements, may be quite dynamic during the periods between observations.

Using all of the data from 10/15/10 to 1/31/13, the mean downstream temperature was significantly greater than the upstream according to a paired t-test (Table 5). However, the difference in overall means was only 0.09 °F. This difference was slightly greater than the resolution (0.04 °F), but was much less than the reported measurement accuracy of the temperature sensors (±0.36 °F) indicating that the decrease from upstream to downstream is within the range of measurement uncertainty. For the May-September data, the downstream mean was 0.18 °F greater than the upstream, which was also statistically significant according to a paired t-test, but was still half of the reported measurement accuracy of the sensor. Given the above information and data we cannot say with confidence that there was a real increase in temperature from upstream to downstream.

Stream discharge had an effect on water temperature during growing season in that higher stream discharge tended lower mean temperatures by reduce the diurnal peaks in temperatures as shown in Figure 10. Following the increased discharge on 6/14-15, daily peak temperature decreased. Whether this can be attributed more to higher discharge or perhaps lower solar radiation due to cloud cover during these days has yet to be determined.

Bear Wallow Site

The Bear Wallow site was located along SR1358 in northern Ashe County (Figure 1). This site was instrumented prior to road construction and no road improvement activities were conducted during the 30 month period reported. This unnamed tributary is not deemed a trout water but does flow to Big Horse Creek a hatchery-supported trout stream. The stream channel was within 50ft the road for the entire monitored reach (Figure 12). The reach had a moderately dense tree canopy over much of its 5,220ft of length. The elevation drops 460ft between the stations making the average channel slope equal to 8.8%. An analysis based on the spatial orientation of the stream and the surrounding terrain was performed to. Given a 20ft wide stream corridor, 67% of the stream receives 10-11 hours of sunlight during the summer solstice (Table 3). The estimated hours of sun exposure are much less than other sites because the stream flows through a narrow valley, approximately 200ft wide, and is bound by steep ridges on either side 400ft tall. This analysis represents a worst case scenario and disregards shading affects from surrounding vegetation. The preconstruction stream buffer consists of 43.4% Developed/Open Space, 45.6% Forest, and 10.9% Pasture (Table 2). The width and depth of the stream varied from the upstream to downstream station, but was generally from 2 to 4ft wide and 0.1 to 1.0ft deep during baseflow. The drainage area to the upstream monitoring station was 140 acres increasing to 365 acres at the downstream station. The percentage of the watershed area to the upstream station classified as forested was 46.5% and as cultivated was 47.6%. Observation from driving in the area and aerial photographs indicated that most, if not nearly all, of the cultivated land was in pasture. Eight discharge measurements were conducted at the downstream station with results ranging from 0.3 to 7.4 cfs. Discharge, measured several times at the upstream station, was similar to the downstream measurement. Because one of the original temperature and pressure sensors was lost and discharge was similar between upstream and downstream, continuously discharge measurement was only performed at the downstream station.

Mean monthly temperature data for the two stations are shown in Table 4. Temperature data for the downstream station was missing from March, 2011 through June, 2011 due to the loss of the sensor. Mean monthly temperatures showed no consistent seasonal trend, except that downstream temperatures were greater during January to March. During the growing season, the mean temperature at the downstream station was greater or less than the upstream an equal number of months. The reason for the lack of consistent results is unknown. A paired t-test using all of the paired data points showed that the overall mean at the upstream station (49.62 °F) was significantly less than the overall mean (49.71 °F) at the downstream station; however, the difference 0.09 °F was quite small compared to the reported measurement accuracy of the temperature sensors (±0.36 °F). Using data from the May-September months only, documented that the mean temperature at the upstream station (62.86 °F) was significantly greater than the mean (62.71 °F) at the downstream station. The decrease (0.15 °F) was unexpected, especially for the warmer months and the length of channel between stations. During the 30 months of this study the upstream sensor measured 191 days where the temperature exceeded the 68 °F trout stress threshold for more than one hour; while the downstream station logged only 82 days. These instances began to occur in late May and continued throughout the growing season. The decrease in temperature from upstream to downstream may be influenced by factors outside of the defined stream reach. The area above upstream station includes a cow pasture and farmstead with lots of stream channel exposed to solar radiation; it could be that the water temperature was elevated due to this open area. Then as the water flowed through more shaded sections between the stations where the channel was also narrower it cooled slightly before reaching the downstream station. In any case, the decrease in temperature from upstream to downstream was relatively little, but the more important test will be whether the relationship remains the same following road improvement, which is occurring now.

DISCUSSION AND SUMMARY

Comparing differences between upstream and downstream temperatures, the data show that Raccoon Branch and Little Windfall had decreases in mean temperature; all the other sites had increases (Table 5). Decreasing temperatures from upstream to downstream indicate road improvement between the stations was not resulting in significant thermal pollution during the monitoring period. However, the decrease in temperature at the Raccoon Branch, Little Windfall Branch and Bear Wallow (May-Sept only) suggests stream temperatures were even higher above the upstream stations. This seems likely since there is less discharge in the upper channel and all three were observed to have sparse canopy above the upstream sensors. To quantify the extent of the riparian canopy above the upstream station, a similar spatial analysis and temperature monitoring as done in the research reach should be performed to back this hypothesis. To verify increases in discharge between upstream and downstream stations additional flow measurements should be conducted.

Among the smaller streams with increases in temperature, the Bear Wallow site had the least increase (0.09 °F) and the Wallace Branch site had the greatest (0.61 °F). This was expected since Wallace Branch had more than 2900ft without tree canopy while Bear Wallow research reach had less than 2000ft without canopy and received 20% less sun exposure during summer months. It is anticipated the ongoing road construction, canopy removal and excavation of the adjacent hillside will further daylight the Bear Wallow stream corridor. Ongoing data collection at this site will document changes in the temperature regime during construction and post construction to verify impacts of daylighting the stream.

Of the 5 sites four are designated trout waters or drain to trout waters. All downstream stations observed periods where temperatures exceeded 68 °F, the point when trout become stressed, for ten consecutive hours or more. Although this temperature cannot be attributed solely to the effects of canopy removal due to road construction it is notable. High stream temperatures were observed as early as May and persisted intermittently until late September at all sites. However, the months of July and August consistently had more instances of prolonged high temperatures. Many factors come into play during this time period. July and August are known to be the drier months of the year. Long intervals without rain typically reduces base flow in streams. This was observed at all sites where discharge was calculated. Less water volume paired with higher air temperatures promote in stream temperature increases. Thus lack of precipitation and summer heat are suspected to be the driving factors behind higher temperatures during July and August.

Mean temperature differences were confirmed to be statistically significant for all sites. However, the error of a single sensor is ±0.36°F, thus the maximum expected error between any upstream and downstream instruments is ±0.72°F. Since the mean temperature difference at Raccoon Branch, Bear Wallow, Wallace Branch, and Cranberry Creek were so small the actual temperature differences remain uncertain. The mean temperature difference at Little Windfall Branch, -1.23°F, is greater than the possible instrument error. Thus, Little Windfall Branch is the only site within this study with a truly significant temperature change.

Further analysis of this data may provide more insight to stream thermodynamics. Moving forward, the overall difference of mean temperatures may not be the best indicator of road improvement impacts. All sites exhibition diurnal and seasonal trends to some extent. To determine if solar heating is causing stream temperature increases, it would be beneficial to examine the more extreme instances that occur throughout the year. Isolating daytime measurements within the months of June, July and August would yield a subset of data where light exposure is the longest, discharge is greatly reduced and air temperatures are highest. Repeating the same statistical analysis with these data points will likely show a greater mean temperature increase by eliminating the dampening effect of night time and winter temperatures on the average.

In summary, temperature upstream and downstream of a section of 5 streams of various sizes was monitored during a 2+ year period. On 3 of the 5 streams, discharge was also monitored continuously. For the large stream (drainage area >10,000 ac) the temperature increase from upstream to downstream was <0.09 °F, even though it contained a reach of 650ft without any tree canopy. Data suggest that relatively long sections of canopy removal is likely required to significantly raise water temperatures in larger streams. Monitoring on 2 of the 4 smaller streams (drainage area <1,000 ac) documented a decrease in temperature from upstream to downstream of a reach where road improvements had occurred. The reason for the decrease was not known, but clearly road improvements were not causing increases in stream temperatures. For the small streams with increases in temperature, Wallace Branch had the greatest increase (0.61 °F), which was expected given that the distance between the monitoring stations was >3100ft with essentially no tree canopy. While not definitive the data suggest the following:

- For larger streams (drainage area >10,000 ac), removing trees from outside of 20ft from the stream channel did not result in a measurable increase in temperature
- For larger streams (drainage area >10,000 ac), even if all of the tree canopy in up to a 650ft reach were removed the increase in temperature was <0.10 °F.
- For smaller streams (drainage area <1,000 ac), if the riparian canopy above the road improvement area is sparse, the effects of riparian canopy removal should be minimal.
- Reduced discharge is a key factor of stream heating during summer months.
- Great care must be taken to locate temperature sensors where they will not be inundated with sediment or exposed to the air and/or sun, especially for streams in which the channel is narrow and/or shallow.
- If stream temperature is degraded prior to entering the road improvement area it is unlikely to see a temperature increase and a temperature decrease is likely due to mixing with cooler ground water and increased discharge.
- Additional research is needed where stream temperature is monitored before, during, and after road improvement to more definitively document the effects of riparian canopy reductions on stream temperatures.

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Table 1. Location Coordinates and Watershed Characteristics for the 5 Sites.

Site	Lat Deg.	Long Deg.	Area[1] ac	Elev.[1] ft	Reach ft	Pasture[1] %	Developed[1] %	Forested[1] %
Raccoon Branch								
up	36.03	82.27	634	2580	-	24.9	6.0	67.1
down	36.03	82.27	704	2560	3000	23.1	6.0	68.5
Little Windfall								
up	36.56	81.56	173	3570	-	37.4	5.0	56.9
down	36.56	81.55	371	3420	3500	21.1	3.7	74.6
Wallace Branch								
up	36.38	81.71	486	3590	-	2.5	1.2	95.5
mid	36.38	81.71	595	3540	2200	6.9	1.9	88.5
down	36.39	81.71	608	3540	1100	7.4	2.5	87.5
Cranberry Creek								
up	36.42	81.29	15808	3110	-	29.3	6.3	60.1
mid	36.42	81.29	15872	3110	875	29.4	6.3	60.0
down	36.42	81.29	16064	3110	650	29.6	6.3	59.8
Bear Wallow								
up	36.58	81.54	141	3580	-	47.6	4.9	46.5
down	36.56	81.54	371	3400	5220	36.5	4.7	58.5

[1] Drainage area, mean elevation, and land use (based on 2006 data) from USGS StreamStats website.

Table 2. Land Cover inside the 50 Foot Stream Buffer

	Upper Wallace Br		**Lower Wallace Br**		**Raccoon Br**		**Little Windfall**		**Bear Wallow**		**Cranberry Cr**	
Land Cover Type	Acres	Percent	Acres	Percent	Acres	Percent	Acres	Percent	Acres	Percent	Acres	Percent
Developed/Open Space	2.1	45.4	1.1	51.3	5.1	73.1	0.1	1.5	5.0	43.4	1.4	36.4
Forested	0.1	2.4	0.0	0.0	1.7	23.8	7.6	85.7	5.3	45.6	0.9	24.4
Pasture	2.4	52.2	1.1	48.7	0.2	3.1	1.1	12.8	1.3	10.9	1.5	39.2
Total	4.68		2.16		6.95		8.86		11.55		3.74	

Table 3. Hours of Sunlight during the Summer Solstice inside the 50 Foot Stream Buffer

	Upper Wallace Br		**Lower Wallace Br**		**Raccoon Br**		**Little Windfall**		**Bear Wallow**		**Cranberry Cr**	
Hours of Sunlight	Acres	Percent	Acres	Percent	Acres	Percent	Acres	Percent	Acres	Percent	Acres	Percent
9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.4	12.1	0.0	0.0
10	0.0	0.0	0.1	7.0	0.1	0.7	0.0	0.0	6.8	58.3	0.0	0.0
11	0.1	2.3	0.6	29.3	1.8	26.0	0.2	2.6	2.7	23.0	0.3	8.5
12	1.2	26.7	1.3	63.7	5.0	71.1	3.5	39.4	0.7	6.1	2.1	56.9
13	2.5	53.6	0.0	0.0	0.2	2.2	3.3	36.4	0.0	0.4	1.3	34.7
14	0.8	17.5	0.0	0.0	0.0	0.0	1.9	21.5	0.0	0.0	0.0	0.0

Table 4. Monthly Mean Atmospheric and Water Temperature Data.

	Total Rain	Air Temp.	Solar Rad.	Mean Stream/Water Temperature Up	Mid	Down	Down-Up
	in	°F	W/m^2	°F	°F	°F	°F
Wallace Branch							
Nov-10	5.89[2]	43.1[2]	111.8[2]	44.81	na	45.28	0.47
Dec-10	0.79[2]	25.6[2]	131.2[2]	35.57	na	35.50	-0.07
Jan-11	1.11[2]	29.3[2]	157.6[2]	35.46	na	35.63	0.17
Feb-11	2.76[2]	38.6[2]	255.5[2]	39.77	na	40.39	0.62
Mar-11	8.31[2]	43.0[2]	245.5[2]	45.03	45.17	45.37	0.34
Apr-11	9.09[2]	55.27[5]	315.6[2]	51.39	51.83	52.27	0.88
May-11	5.93[2]	58.47[5]	326.7[2]	54.55	55.85	56.42	1.87
Jun-11	5.15[2]	64.57[5]	297.7[2]	59.43	61.64	62.38	2.95
Jul-11	3.04[2]	68.16[5]	256.8[2]	61.40	64.86	65.65	4.25
Aug-11	1.83[2]	66.34[5]	268.7[2]	61.73	65.20	65.77	4.04
Sep-11	6.99[2]	60.9[2]	160.9[2]	59.01	60.87	61.25	2.24
Oct-11	3.48[2]	50.5[2]	157.1[2]	53.20	51.90	52.13	-1.07
Nov-11	5.89[2]	45.4[2]	135.3[2]	47.78	46.00	46.19	-1.59
Dec-11	6.09[2]	39.9[2]	100.3[2]	43.35	42.81	43.21	-0.13
Jan-12	3.96[2]	36.9[2]	95.4[2]	41.62	40.86	41.49	-0.14
Feb-12	0.34[2]	39.3[2]	165.2[2]	43.00	41.85	42.57	-0.43
Mar-12	2.63[2]	51.5[2]	194.1[2]	49.46	49.82	49.76	0.30
Apr-12	5.69[2]	52.7[2]	221.6[2]	52.07	52.33	52.18	0.12
May-12	4.87[2]	61.7[2]	223.4[2]	56.14	57.72	57.63	1.49
Jun-12	0.00[2]	62.5[1]	226.2	57.90	60.61	60.14	2.24
Jul-12	2.38[2]	67.7[1]	196.3	61.66	64.35	64.84	3.18
Aug-12	3.95[2]	64.5[1]	185.8	60.85	62.86	63.27	2.42
Sep-12	4.31[2]	60.9	162.3	59.01	59.85	60.10	1.09
Oct-12	2.92[2]	50.5	117.8	52.90	na	52.90	0.00
Nov-12	0.74[2]	40.1	176.5	46.10	na	43.94	-2.16
Dec-12	5.43[2]	39.2	111.6	44.79	na	43.43	-1.36
Jan-13	0.12[2]	37.7	139.7	43.06	na	42.54	-0.52
Feb-13	3.07[2]	33.6	136.6	41.49	na	41.07	-0.42
Mar-13	4.21[2]	35.2	152.2	41.91	na	41.64	-0.27
Bear Wallow							
Nov-10	5.89[2]	43.1[2]	111.8[2]	44.66	na	44.15	-0.51
Dec-10	0.79[2]	25.6[2]	131.2[2]	35.57	na	34.79	-0.78
Jan-11	1.11[2]	29.3[2]	157.6[2]	35.51	na	35.71	0.20
Feb-11	2.76[2]	38.6[2]	255.5[2]	37.57[3]	na	37.81[3]	0.24
Mar-11	8.31[2]	43.0[2]	245.5[2]	44.66	na	na	na
Apr-11	9.09[2]	55.0[2]	315.6[2]	51.66	na	na	na
May-11	5.93[2]	59.1[2]	326.7[2]	56.88	na	na	na
Jun-11	5.15[2]	71.0[2]	297.7[2]	63.78	na	na	na

Jul-11	3.04[2]	73.9[2]	256.8[2]	68.88	na	68.22	-0.66
Aug-11	1.83[2]	71.9[2]	268.7[2]	66.18	na	65.67	-0.51
Sep-11	6.99[2]	60.9[2]	160.9[2]	60.80	na	60.96	0.16
Oct-11	3.48[2]	50.5[2]	157.1[2]	51.78	na	51.82	0.04
Nov-11	5.89[2]	45.4[2]	135.3[2]	46.55	na	46.21	-0.34
Dec-11	6.09[2]	39.9[2]	100.3[2]	43.58	na	43.97	0.39
Jan-12	3.96[2]	36.9[2]	95.4[2]	41.25	na	41.84	0.59
Feb-12	0.34[2]	39.3[2]	165.2[2]	41.94	na	42.29	0.35
Mar-12	2.63[2]	51.5[2]	194.1[2]	49.38	na	49.55	0.17
Apr-12	5.69[2]	52.7[2]	221.6[2]	51.93	na	51.87	-0.07
May-12	4.87[2]	61.7[2]	223.4[2]	58.27	na	58.32	0.04
Jun-12	0.00[2]	64.8[2]	226.2[2]	61.50	na	60.93	-0.57
Jul-12	2.38[2]	70.7[2]	196.3[2]	66.48	na	66.46	-0.02
Aug-12	3.95[2]	66.2[2]	185.8[2]	64.05	na	64.10	0.04
Sep-12	4.31[2]	60.9[2]	162.3[2]	60.12	na	60.24	0.11
Oct-12	2.92[2]	48.83[1]	117.8[2]	51.47	na	51.83	0.36
Nov-12	0.74[2]	38.18[1]	176.5[2]	42.43	na	42.64	0.20
Dec-12	5.43[2]	37.53[1]	111.6[2]	41.75	na	41.93	0.18
Jan-13	0.12[2]	36.52[1]	139.7[2]	41.13	na	41.76	0.63
Feb-13	3.07[2]	33.12[1]	136.6[2]	38.83	na	39.67	0.84
Mar-13	4.21[2]	34.38[1]	152.2[2]	39.82	na	40.76	0.95
<u>Cranberry Creek</u>							
Nov-10	5.89[2]	43.1[2]	111.8[2]	44.10	na[6]	44.10	0.00
Dec-10	0.79[2]	25.6[2]	131.2[2]	34.20	na[6]	34.10	-0.10
Jan-11	1.11[2]	29.3[2]	157.6[2]	34.50	na[6]	34.50	0.00
Feb-11	2.76[2]	38.6[2]	255.5[2]	39.74	na[6]	39.80	0.06
Mar-11	8.31[2]	43.0[2]	245.5[2]	45.45	na[6]	45.52	0.07
Apr-11	9.09[2]	55.0[2]	315.6[2]	52.92	52.76	53.00	0.08
May-11	5.93[2]	59.1[2]	326.7[2]	57.13	56.88	57.23	0.10
Jun-11	5.15[2]	71.0[2]	297.7[2]	62.50	62.48	62.64	0.14
Jul-11	3.04[2]	73.9[2]	256.8[2]	66.21	66.28	66.36	0.15
Aug-11	1.83[2]	71.9[2]	268.7[2]	66.28	66.39	66.48	0.20
Sep-11	6.99[2]	60.9[2]	160.9[2]	61.04	61.23	61.16	0.12
Oct-11	3.48[2]	50.5[2]	157.1[2]	52.15	52.27	52.28	0.13
Nov-11	5.89[2]	45.4[2]	135.3[2]	46.44	na[7]	46.50	0.06
Dec-11	6.09[2]	39.9[2]	100.3[2]	43.97	na[7]	43.96	-0.01
Jan-12	3.96[2]	36.9[2]	95.4[2]	40.74	na[7]	40.75	0.01
Feb-12	0.34[2]	39.3[2]	165.2[2]	42.18	na[7]	42.19	0.02
Mar-12	2.63[2]	51.5[2]	194.1[2]	50.64	na[7]	50.71	0.07
Apr-12	5.69[2]	52.7[2]	221.6[2]	53.26	53.46	53.48	0.22
May-12	4.87[2]	61.7[2]	223.4[2]	59.33	59.39	59.45	0.11
Jun-12	0.00[2]	64.8	226.2	62.09	62.16	62.23	0.14
Jul-12	2.38[2]	70.7	196.3	67.00	67.08	67.24	0.24

Aug-12	3.95[2]	66.2	185.8	65.18	65.39	65.52	0.34
Sep-12	4.31[2]	60.9	162.3	60.81	60.99	61.09	0.27
Oct-12	2.92[2]	50.5	117.8	52.33	52.44	52.45	0.12
Nov-12	0.74[2]	40.1	176.5	41.75	41.86	41.82	0.07
Dec-12	5.43[2]	39.2	111.6	41.12	41.18	41.12	0.00
Jan-13	0.12[2]	37.7	139.7	40.99	40.92	40.87	-0.12
Feb-13	3.07[2]	33.6	136.6	na[7]	39.85	39.84	na
Mar-13	4.21[2]	35.2	152.2	na[7]	41.10	41.10	na
Raccoon Branch							
Nov-10	5.60[1]	45.8[1]	104.0[1]	48.38	na	47.05	-1.33
Dec-10	1.52[1]	27.5[1]	72.8[1]	40.35	na	37.91	-2.44
Jan-11	1.47[1]	31.7[1]	79.6[1]	39.53	na	37.73	-1.80
Feb-11	3.65[1]	41.2[1]	119.2[1]	43.10	na	41.81	-1.29
Mar-11	7.51[1]	45.7[1]	128.2[1]	47.84	na	47.54	-0.30
Apr-11	8.22[1]	58.4[1]	215.6[1]	54.24	na	54.20	-0.04
May-11	5.33[1]	62.9[1]	218.2[1]	58.37	na	58.78	0.41
Jun-11	5.15[2]	71.0[2]	297.7[2]	63.41	na	64.13	0.72
Jul-11	3.04[2]	73.9[2]	256.8[2]	65.83	na	66.88	1.06
Aug-11	1.83[2]	71.9[2]	268.7[2]	65.83	na	66.74	0.91
Sep-11	6.99[2]	60.9[2]	160.9[2]	62.24	na	62.53	0.30
Oct-11	3.48[2]	50.5[2]	157.1[2]	54.06	na	53.17	-0.89
Nov-11	5.89[2]	45.4[2]	135.3[2]	48.74	na	47.23	-1.51
Dec-11	6.09[2]	39.9[2]	100.3[2]	45.94	na	44.63	-1.32
Jan-12	3.96[2]	36.9[2]	95.4[2]	43.55	na	42.41	-1.14
Feb-12	0.34[2]	39.3[2]	165.2[2]	43.23	na	41.97	-1.26
Mar-12	2.63[2]	51.5[2]	194.1[2]	51.62	na	51.34	-0.29
Apr-12	5.69[2]	52.7[2]	221.6[2]	55.07	na	54.98	-0.08
May-12	4.87[2]	61.7[2]	223.4[2]	60.75	na	60.81	0.06
Jun-12	0.00[2]	64.8	226.2	62.46	na	62.95	0.49
Jul-12	2.38[2]	70.7	196.3	67.45	na	67.93	0.48
Aug-12	3.95[2]	66.2	185.8	66.07	na	66.79	0.72
Sep-12	4.31[2]	60.9	162.3	63.06	na	63.57	0.51
Oct-12	2.92[2]	50.5	117.8	55.26	na	54.78	-0.48
Nov-12	0.74[2]	40.1	176.5	46.93	na	45.19	-1.74
Dec-12	5.43[2]	39.2	111.6	45.39	na	44.22	-1.17
Jan-13	0.12[2]	37.7	139.7	44.41	na	43.45	-0.96
Feb-13	3.07[2]	33.6	136.6	43.17	na	42.28	-0.90
Mar-13	4.21[2]	35.2	152.2	44.15	na	43.63	-0.52
Little Windfall Branch							
Feb-11	2.76[2]	38.6[2]	255.5[2]	43.89	na	na	na
Mar-11	8.31[2]	43.0[2]	245.5[2]	46.00	na	na	na
Apr-11	9.09[2]	55.0[2]	315.6[2]	51.44	na	51.43	-0.01
May-11	5.93[2]	59.1[2]	326.7[2]	55.51	na	55.56	0.05

Jun-11	5.15[2]	71.0[2]	297.7[2]	62.06	na	61.48	-0.58
Jul-11	3.04[2]	73.9[2]	256.8[2]	66.31	na	65.30	-1.01
Aug-11	1.83[2]	71.9[2]	268.7[2]	65.70	na	64.73	-0.98
Sep-11	6.99[2]	60.9[2]	160.9[2]	60.94	na	60.25	-0.69
Oct-11	3.48[2]	50.5[2]	157.1[2]	53.59	na	51.58	-2.02
Nov-11	5.89[2]	45.4[2]	135.3[2]	48.20	na	45.72	-2.48
Dec-11	6.09[2]	39.9[2]	100.3[2]	45.42	na	43.74	-1.67
Jan-12	3.96[2]	36.9[2]	95.4[2]	43.65	na	42.02	-1.64
Feb-12	0.34[2]	39.3[2]	165.2[2]	43.91	na	42.51	-1.40
Mar-12	2.63[2]	51.5[2]	194.1[2]	49.85	na	na	na
Apr-12	5.69[2]	52.7[2]	221.6[2]	51.85	na	na	na
May-12	4.87[2]	61.7[2]	223.4[2]	56.42	na	na	na
Jun-12	0.00[2]	64.8	226.2	59.77	na	na	na
Jul-12	2.38[2]	70.7	196.3	65.37	na	na	na
Aug-12	3.95[2]	66.2	185.8	64.38	na	na	na
Sep-12	4.31[2]	60.9	162.3	61.13	na	na	na
Oct-12	2.92[2]	50.5	117.8	53.56	na	na	na
Nov-12	0.74[2]	40.1	176.5	44.42	na	na	na
Dec-12	5.43[2]	39.2	111.6	43.95	na	na	na
Jan-13	0.12[2]	37.7	139.7	43.62	na	na	na
Feb-13	3.07[2]	33.6	136.6	41.99	na	na	na
Mar-13	4.21[2]	35.2	152.2	42.68	na	na	na

[1] Daily mean values measured on-site.
[2] From weather station at Laurel Springs, NC.
[3] From 2/1/11 to 2/17/11.
[4] From 2/18/11 to 2/28/11
[5] Measured on-site
[6] Sensor lost
[7] Sensor covered with sediment (buffered)

Table 5. Statistical Comparison between Stations for the 5 Sites.

Site	Date First Observation	Date Last Observation	Number of Observations	Mean Upstream °F	Mean Downstream °F	Road Improvement Status
Raccoon Branch						
up vs down	10/15/10	4/18/13	65,993	52.86	52.40	Completed
Little Windfall						
up vs down	3/24/11	3/7/12	25,108	53.98	52.86	Completed
Wallace Branch						
up vs down	10/15/10	4/15/13	62,920	49.45	50.06	Completed
Cranberry Creek						
up vs down	10/15/10	1/31/13	60,475[1]	51.33	51.42	Completed[2]
Bear Wallow						
up vs down	10/7/10	4/18/13	55,555	49.62	49.71	Unimproved

[1] Does not include data collected when sensor under sediment.
[2] Road way improvements did not include paving
*Note: Road improvement status did not change throughout this portion of the study.

Table 6. Comparison between Stations for the 5 Sites.

Site	Road Improvement Status	Trout Habitat	Extreme Sun Exposure 50ft buffer Hours	Upstream Exceeds 68°F for 1hour or more	Downstream Exceeds 68°F for 1hour or more
Raccoon Branch	Completed	No	11.7	0	0
Little Windfall Branch	Completed	Drains to	12.8	27	29
Wallace Branch	Completed	Drains to	12.5	0	140
Cranberry Creek	Completed	Yes	12.3	126	129
Bear Wallow	Unimproved	Drains to	10.2	191	82

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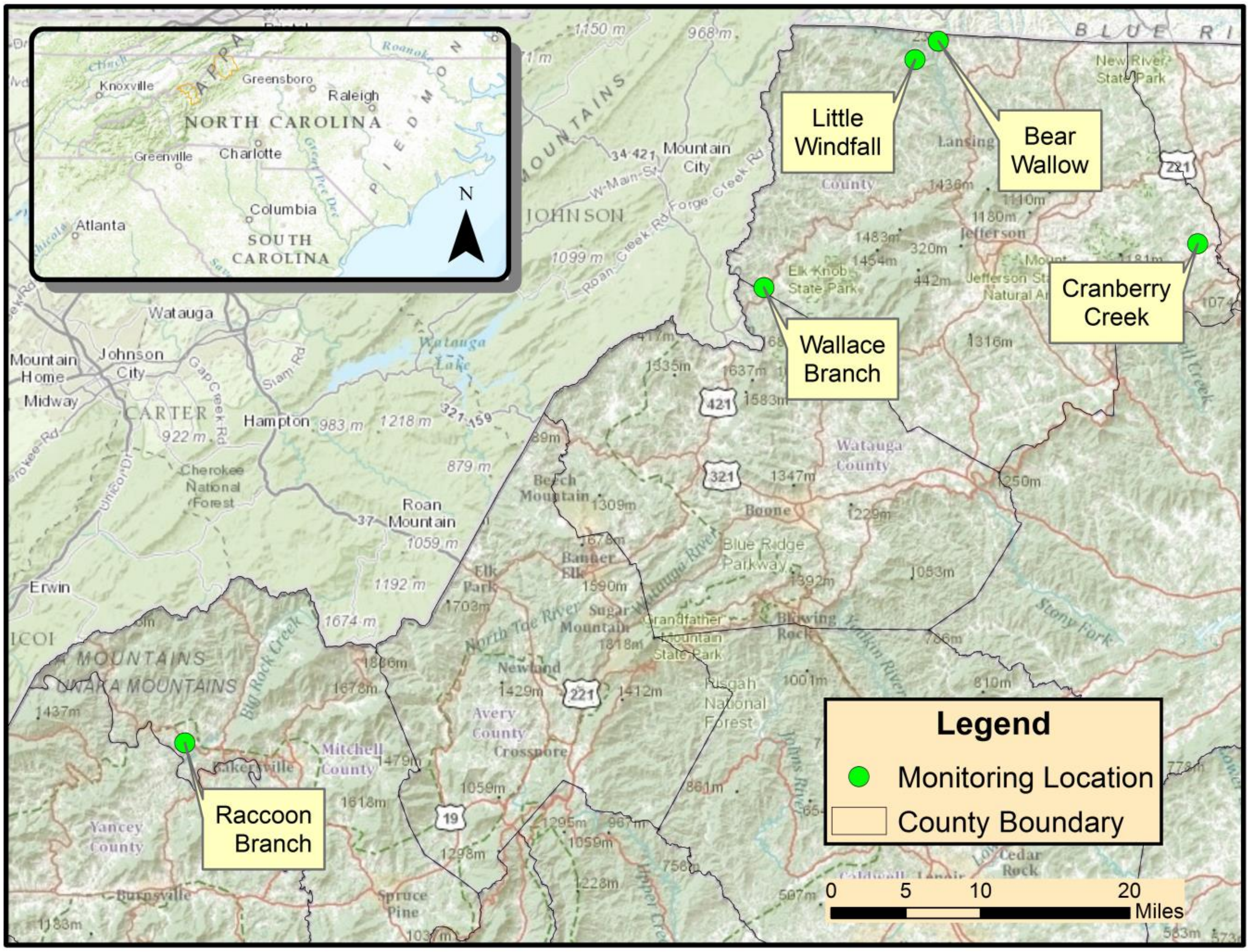

Figure 1. Locations of the stream sites.


Figure 2. Raccoon Branch downstream of upstream station.

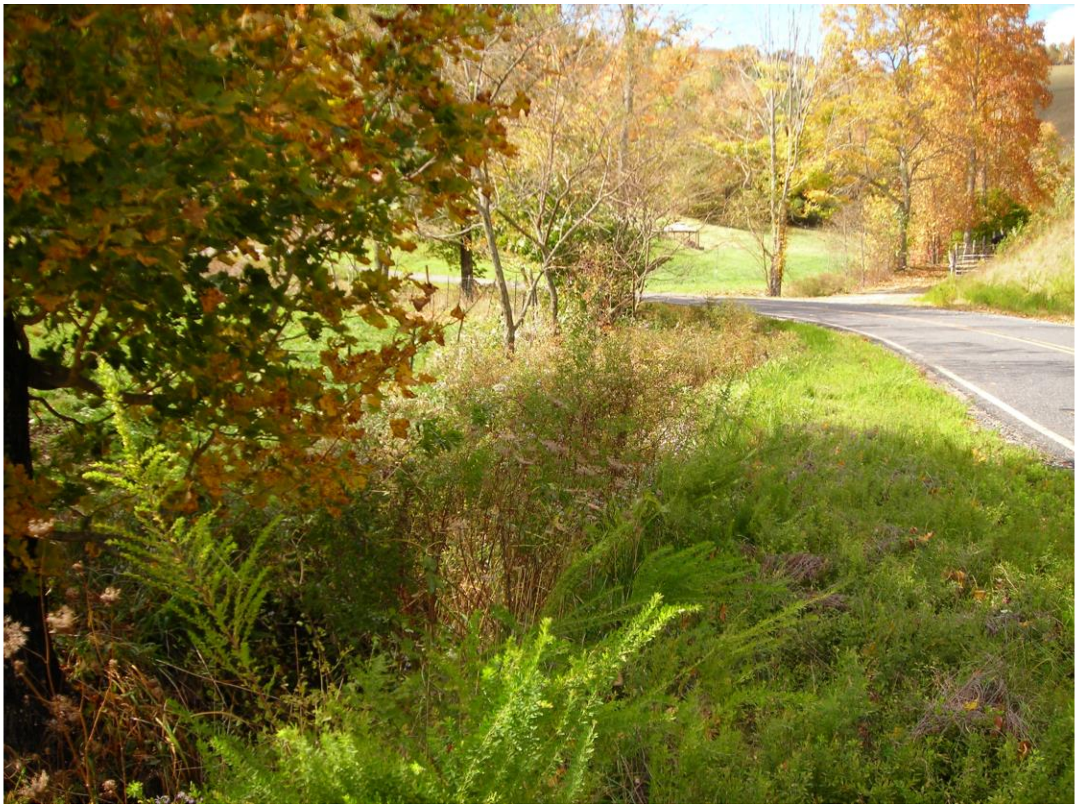
Figure 3. Little Windfall Branch near upstream station.


Figure 6. Wallace Branch near upstream station (left) and mid station (right).

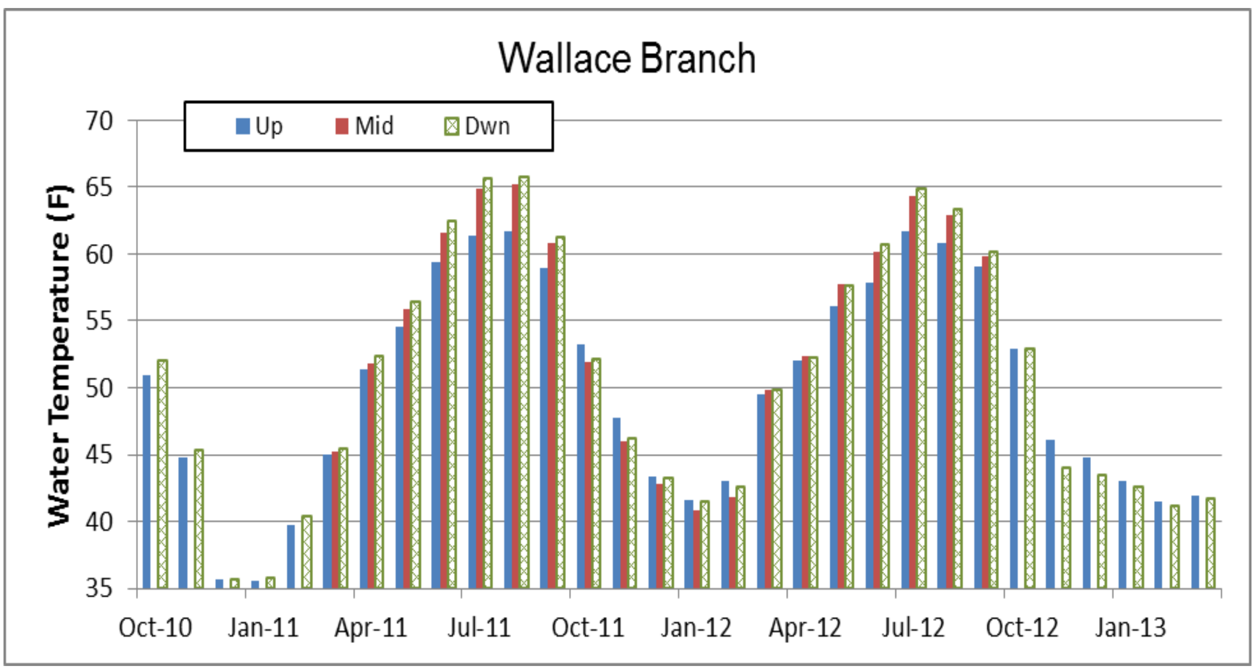

Figure 7. Monthly mean temperatures for the 3 stations on Wallace Branch.

Figure 8. Looking upstream from downstream monitoring station.

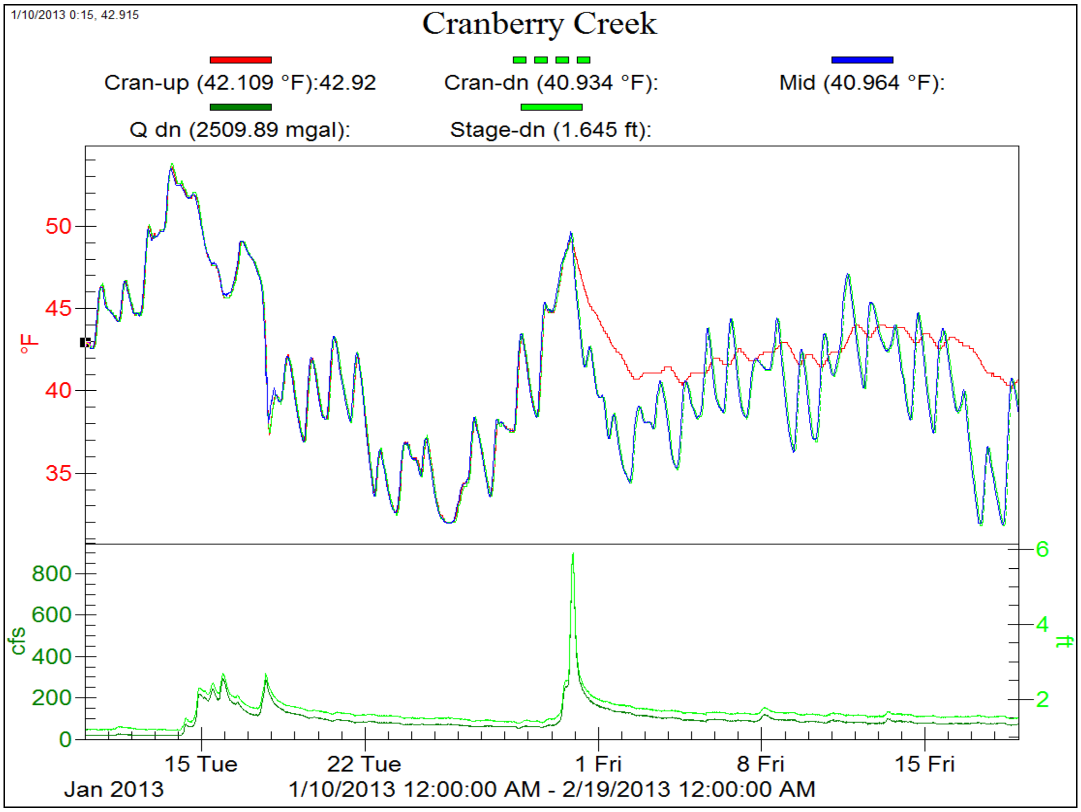

Figure 9. Cranberry Creek site temperature and flow data.

Figure 11. Tree canopy removal from utility crews.

Figure 12. Typical section of the stream at the Bear Wallow site.