AWRA 2009 SPRING SPECIALTY CONFERENCE
Anchorage, Alaska
May 4-6, 2009

TEMPORAL AND SPATIAL VARIABILITY IN NORTH CAROLINA PIEDMONT STREAM TEMPERATURE

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ABSTRACT

Understanding temporal and spatial patterns of in-stream temperature can provide useful information to managing future impacts of climate change on these systems. This study will compare temporal patterns and spatial variability of headwater in-stream temperature in six catchments in the piedmont of North Carolina in two different geological regions, Carolina slate belt and Triassic basin. The NC Neuse River Buffer Rules were established in the 1990s to protect nutrient sensitive waters through maintaining and protecting existing buffers. These buffers can also moderate diurnal fluctuations and stream temperature maximums. In October 2007 six catchments ranging from 12 to 46 hectares (i.e., four on Hill Demonstration Forest and two on Umstead Research Farm) with perennial stream channels were outfitted with stream discharge, meteorological and water temperature monitoring equipment. There were similarities in winter and summer daily maximum stream temperature and mean diurnal fluctuations within the paired and larger watersheds. However, the winter and summer water temperature patterns varied significantly between geological regions. There were smaller ranges in summer diurnal fluctuations (e.g., 0.4 ^{o}C to 2.0 ^{o}C) compared to winter fluctuations (e.g., 0.3 ^{o}C to 4.7 ^{o}C) in all watersheds, suggesting that the trees along the riparian buffers are moderating the affects of air temperature on water temperature by reducing wide fluctuations in temperature. A regression model predicted that a 2 ^{o}C increase in daily maximum air temperature would increase daily maximum water temperature 0.6 ^{o}C to 1.0 ^{o}C in the winter and 0.2 ^{o}C to 0.8 ^{o}C in the summer between watersheds.

Keywords: BMP, stream temperature, air temperature.

INTRODUCTION

In the future rapid increases in global climate shifts and variability is expected to increase surface water temperature in watercourses by 2 to 3 ^{o}C as air temperature increases 3 to 5^{o}C (Morrill et al., 2005; IPCC, 2007). Landcover changes such as alteration in tree species composition and shade around stream channels as well as differences in watershed geology and groundwater inflow can also change water quantity and quality (i.e., water temperature) (Swift and Messer, 1971; Amaranthus et al., 1989; Sun et al., 2001; Tague et al., 2007). The location and intensity of the change or influence will determine the overall magnitude and duration of water temperature responses and sensitivity levels (Stednick, 2000). Sharp peaks in water temperature as well as sustained increases may alter stream chemistry and its physical ability to sustain aquatic life and habitat for fisheries and aquatic insects including species of mayflies (Ephemeroptera) and stoneflies (Plecoptera) (Noel et al., 1986; Beschta et al., 1987; Richardson et al., 1994). For example, increases in daily temperature fluctuation by about 2^{o}C can influence aquatic species health (Corn and Bury, 1989).

NC Environmental Management Commission Rule 15A NCAC 02B .0211 mandates that water temperature in class C waters “should not exceed 2.8^{o}C above the natural water temperature and in no case exceed 29^{o}C for mountain and upper piedmont waters and 32^{o}C for lower piedmont and coastal plain waters.” Class C stream classification as defined by the Environmental Management Commission Rule 15A NCAC 02B .0301 will best support and can be used for aquatic life propagation and survival, fishing, wildlife, and secondary recreation. The NC Neuse River Buffer Rules were established in the 1990s in an effort to protect these nutrient sensitive streams and other surface waters through maintaining and protecting existing buffers.

Stream buffers across the US have been shown to protect streams by moderating diurnal fluctuations and in-stream daily temperature maximums and means (Kochenderfer and Edwards, 1990, Carroll et al., 2004; Pollock et al., 2009). However, little work has been done to describe water temperature within streamside buffer zones between different geological regions in the piedmont of NC. Therefore, the purpose of this study is to describe temporal patterns and spatial variability in North Carolina piedmont stream temperature in the Carolina slate belt and Triassic basin and to test how increases in daily maximum air temperature might increase daily maximum stream temperature.

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MATERIALS AND METHODS

In October 2007 six watersheds ranging from 12 to 46 hectares with perennial stream channels were outfitted with discharge monitoring equipment (Sigma 900 Max water depth sensor) and a water temperature probe (Onset Corporation, Bourne, MA, Hobo) at each flume or weir (Figure 1). Discharge and temperature measurement were recorded continuously at 10 minute intervals. Zero stream discharge data meant that there was not sufficient stream water to completely submerge the stream temperature sensor (i.e., dry periods during the summer). Those stream temperature data were discarded as the stream temperature sensor was in effect measuring air temperature. If possible those discarded stream temperature data points were modeled using a linear model that was generated from existing watershed stream temperature data. Temperature sensors were carefully placed as not to receive direct sunlight A meteorological station (Onset Corporation, Bourne, MA) is located on the Hill Forest site to monitor weather conditions every hour including precipitation, relative humidity, wind speed/direction/gust, air temperature, dew point, and solar radiation.

The first pair of watersheds, HF1 and HF2, is located at North Carolina State University's Hill Forest in northern Durham County, NC with Carolina slate belt as the underlying geology. The other pair, UF1 and UF2, is located in the North Carolina Department of Agriculture and Consumer Services Umstead Research Farm in Granville County, NC in Triassic basin geology. The linear distance between sites is about 8 kilometers. The two larger watersheds are labeled as HFW1 and HFW2 and are located in the Carolina slate belt. Table 1 highlights the watershed characteristics within the paired and larger watersheds. The major differences between Hill Forest and Umstead are the geological regions that have allowed for differences in stream channel formation. Streams found in Hill Forest (HF1, HF2, HFW1 and HFW2) are generally shallow, connected to their floodplain and have relatively steep upland slopes. Conversely, streams in Umstead (UF1 and UF2) have deeper stream channels that are detached from their floodplain with gentle upland slopes. One other physical characteristic to note is that HF2 has a consistent spring fed flow originating at the head of the channel which can affect surface water quantities and conditions.

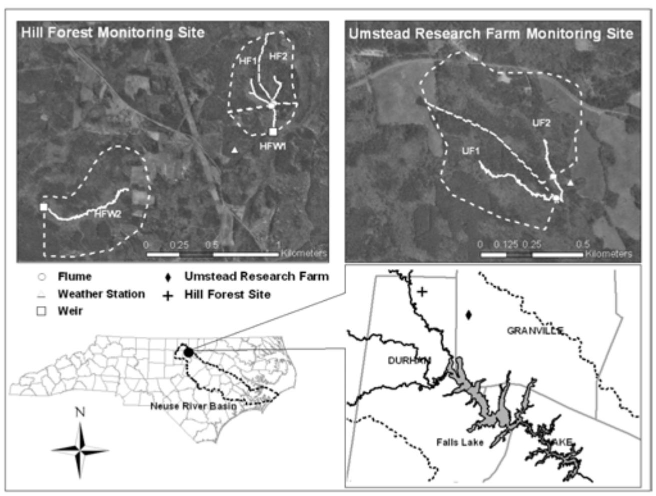

Figure 1. Watershed, weir, flume, meteorological station and stream temperature monitoring locations. Continuous stream temperature monitoring locations are at the flumes and weirs.

Table 1. Watershed characteristics

	HF1	HF2	UF1	UF2	HFW1	HFW2
Size (ha)	12	12	18	28	32	46
Aspect	South	South	Southeast	Southeast	South	South
Soil texture	Sandy Loam, Silty Loam	Sandy Loam, Silty Loam	Loam, Sandy Loam	Loam, Sandy Loam	Sandy Loam, Silty Loam	Sandy Loam, Silty Loam
Soil series	Tatum	Tatum	Tatum	Helena	Tatum	Tatum and Wedowee
Geologic regions	Carolina Slate Belt	Carolina Slate Belt	Triassic Basin	Triassic Basin	Carolina Slate Belt	Carolina Slate Belt

RESULTS

Water temperature and air temperature data from a water year, October 2007 to September 2008 are presented. The range in daily maximum air temperature during the winter was wider than range in daily maximum air temperature during the summer. The winter daily maximum stream temperature was similar within the paired and larger watersheds but varied slightly between geological regions, Carolina slate belt and Triassic basin (Table 2). The summer daily maximum stream temperature varied within the paired and larger watersheds and between geological regions with streams in the Carolina slate belt (HF1 and HF2) having the lowest summer daily maximum stream temperature (Table 2). For all watersheds the winter or summer daily maximum stream temperature did not exceed 29 ^{o}C, the stream temperature maximum mandated by the NC Environmental Management Commission.

The winter mean diurnal fluctuations were similar within the paired and larger watersheds and varied slightly between geological regions with HFW1 and HFW2 having the highest fluctuation values (Table 2). The summer mean diurnal fluctuations were also similar within the paired and larger watersheds but produced slightly more variability between geological regions than the winter fluctuations (Table 2). There were smaller ranges in summer mean diurnal fluctuations compared to winter fluctuations in paired watersheds, suggesting that the trees along the riparian buffers are moderating the affects of air temperature on water temperature by reducing wide fluctuations in summer temperature (Table 2). There were also smaller fluctuations in the summer seven day running average of daily maximum compared to winter (Figure 2).

Our regression model showed that the relationship between daily maximum air temperature and daily maximum water temperature are more coupled during the winter months with significantly higher r^2 values when compared to the summer within the paired watersheds. The r^2 values were similar during the winter and summer in the larger watersheds, suggesting that little air and water decoupling occurred during the summer (Table 3). The regression model also predicted that a 2 ^{o}C increase in daily maximum air temperature would increase daily maximum water temperature 0.6 ^{o}C to 1.0 ^{o}C in the winter and 0.2 ^{o}C to 0.8 ^{o}C in the summer between watersheds (Table 3).

Table 2. Winter and summer range in daily maximum air temperature, daily maximum stream temperature and mean diurnal fluctuation in paired and larger watersheds in Carolina slate belt and Triassic basin geological regions.

	Range in Daily Maximum Air Temperature		Daily Maximum Stream Temperature		Mean Diurnal Fluctuation	
	Winter (^{o}C)	**Summer (^{o}C)**	**Winter (^{o}C)**	**Summer (^{o}C)**	**Winter (^{o}C)**	**Summer (^{o}C)**
Carolina slate belt						
HF1	-0.15 – 30.0	21.3 – 37.0	18.1	22.0	2.1 (0.3 - 4.7)	1.3 (0.4 - 2.0)
HF2	-0.15 – 30.0	21.3 – 37.0	17.9	21.4	1.9 (0.3 - 4.3)	1.2 (0.4 - 1.8)
HFW1	-0.15 – 30.0	21.3 – 37.0	20.3	25.8	3.6 (1.1 - 8.9)	3.2 (0.8 - 4.9)
HFW2	-0.15 – 30.0	21.3 – 37.0	18.7	24.8	3.3 (0.8 - 8.4)	3.1 (0.7 - 4.7)
Triassic basin						
UF1	-0.15 – 30.0	21.3 – 37.0	17.2	25.7	2.0 (0.3 - 4.3)	1.8 (0.4 - 6.5)
UF2	-0.15 – 30.0	21.3 – 37.0	17.1	24.8	2.2 (0.3 - 4.8)	1.8 (0.4 - 4.4)

Values in parentheses represent the minimum and maximum diurnal fluctuation values. HF1, HF2, UF1, UF2 = paired watersheds; HFW1, HFW2 = larger watersheds.

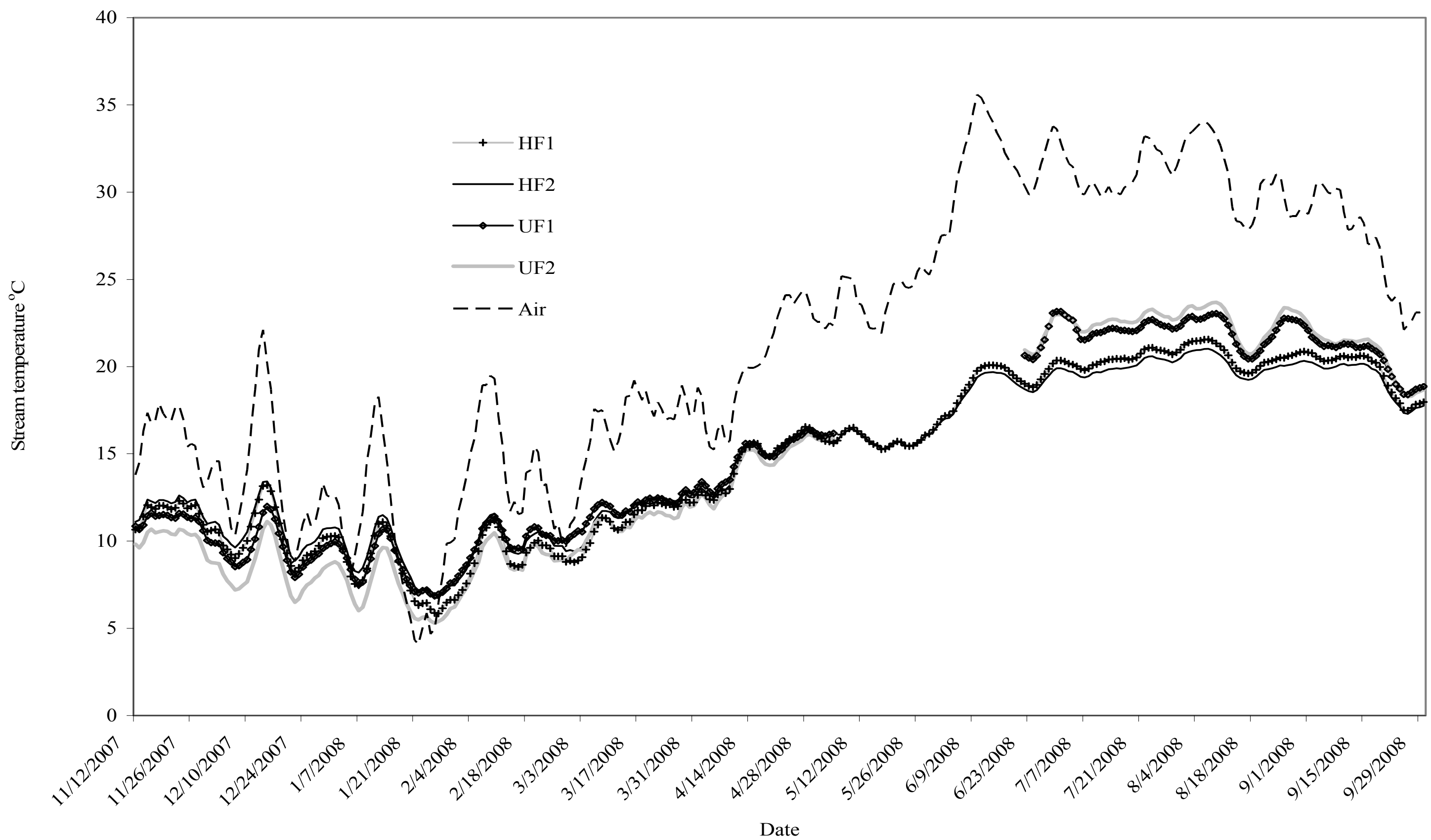

Figure 2. Paired watersheds seven day running average of daily maximum stream and air temperature in Carolina slate belt (HF1 and HF2) and Triassic basin (UF1 and UF2). There are missing stream temperature data points from April – June, 2008 due to lack of consistent flow to submerge the water sensor in both streams, UF1 and UF2.

Table 3. Linear regression model of winter and summer daily maximum air temperature vs daily maximum stream temperature. Also shown are the predicted increases in daily maximum stream temperature assuming a 2°C increase in daily maximum air temperature.

	Regression Model	r^2	Predicted Increase in Winter Daily Maximum Stream Temperature (°C)	Regression Model	r^2	Predicted Increase in Summer Daily Maximum Stream Temperature (°C)
	Winter			**Summer**		
Carolina slate belt						
HF1	y = 0.37x + 5.4	0.68	0.7	y = 0.13x + 16.2	0.15	0.3
HF2	y = 0.33x + 6.3	0.68	0.7	y = 0.12x + 16.0	0.17	0.2
HFW1	y = 0.51x + 3.7	0.75	1.0	y = 0.42x + 10.1	0.73	0.8
HFW2	y = 0.46x + 4.0	0.74	0.9	y = 0.38x + 10.6	0.68	0.8
Triassic basin						
UF1	y = 0.31x + 6.4	0.57	0.6	y = 0.24x + 14.6	0.32	0.5
UF2	y = 0.35x + 4.8	0.57	0.7	y = 0.24x + 15.1	0.30	0.5

y=mean maximum stream temperature, x=mean maximum air temperature (mm/day). Data used are from a water year, October 2007 to September 2008.

DISCUSSION

Daily maximum stream temperature, mean diurnal fluctuation and seven day running average of daily maximum analysis are a few of many stream temperature variables that can be used to assess and compare the effects of watershed physical conditions on stream temperature maximums, fluctuations and responses (Swift and Clinton, 1997; Black, 2005). Although there are limitations to using daily maximum stream temperature as it can represent an atypical maximum value for a given period, it has been shown to provide useful information about the physical characteristics of stream temperature and conditions (Sullivan et al., 1990). The running average in general tends to capture chronic temperature increases and remove the occasional spike in stream temperature that can be observed in daily maximums. In addition, running average stream temperature values above thresholds set by state and federal agencies to minimize chronic stream temperature impacts are more likely to have more ecological significance than daily maximums. Controls on stream temperature are wide ranging from latent heat fluxes and net radiation to water depth, stream bed conduction, streamside vegetation, topography, precipitation and groundwater inflow (Hansen, 1988; Swift and Clinton, 1997; Poole and Berman, 2001; Tague et al., 2007). This study found temporal and spatial variability in stream temperature sensitivity to energy inputs within watersheds and between geological regions that appear to be linked to differences in vegetation cover and geological regions.

Larger watersheds

Shade levels around the weirs at the larger watersheds were significantly less than the paired watersheds. This probably can account for the differences in summer and winter daily maximum stream temperature and mean diurnal fluctuation between the larger watersheds and the paired watersheds (Tables 2) (Swift and Messer, 1971). There are pools of water behind the weirs at the larger watersheds that exposes them to the consequences of extended periods of direct solar radiation inputs and air temperature. Therefore this water is less protected from fluctuations. Similar winter and summer r^2 values also suggest that there is little shade affect on daily maximum temperature in the large watersheds (Table 3). Reduced shade levels have been shown to increase surface water temperatures (Arthur et al., 1998; Rutherford et al., 2004; Polluck et al., 2009).

Paired watersheds

The streams in UF appear more sensitive to prolonged changes in water temperature in the summer as reflected by the higher summer daily maximum stream temperature, larger diurnal variation and higher seven day running average of daily maximum compared to the stream in HF1 and HF2 (Table 2, Figure 2). The summer seven day running average of daily maximum stream temperature at the UF streams is about 2.5 ^{o}C warmer than HF streams. Although the storm-based hydrology between the geological regions is different with UF streams generally having higher total discharge and peak runoff rate, the average seasonal in-stream flows are similar. This suggests that water depth or discharge is not the principle control on the higher summer daily maximums and diurnal fluctuations observed in UF streams.

We believe the differences in summer daily stream temperature maximum and mean diurnal fluctuation between HF and UF are due to patchy shade level, underlying geology and source water differences (Poole and Berman, 2001; Tague et al., 2007). The shade level is more patchy around UF streams when compared to HF. Patchy shade conditions around headwater streams have been shown to change water temperature 4 ^{o}C to 5 ^{o}C (Rutherford et al., 2004) with seasons being a principle control on the degree to which patchiness affects water temperature regimes and equilibriums. The source water at HF is primarily groundwater or spring water which in general has near constant temperature throughout the year before emerging as surface water to the channel. The difference in underlying geology may have contributed to decreased streambed conduction, thus indirectly creating in-stream conditions that contributed to more sustained stream temperature in UF than HF (Tague et al., 2007).

CONCLUSIONS

Generally state and federal regulatory agencies used daily maximum, diurnal fluctuation, seven day running averages of daily maximum, and/or seven day running averages of daily average to assess water quality in watercourses. Our results from daily maximum stream temperature, seven day running averages of daily maximum and predicted increases in daily maximum stream temperature did not exceed the 29 ^{o}C threshold to maintain healthy stream habitat for aquatic as set by NC regulatory limits during any portion of the water year in any stream.

There are differences in the temporal patterns and spatial variability of maximum stream temperature in the piedmont of NC with various types of controls on energy inputs and consequences. The ability of a watershed to increase or moderate maximum stream temperature appears to be linked to its physical conditions and characteristics including source water, geology, in-stream hydrology and shade level. As the climate continues to warm, careful consideration should be given to site condition or geology when planning strategies to maintain water quality standards, measures and regulatory limits. Certainly our study duration and spatial extent is limited, so additional research efforts in understanding stream temperature dynamics, functions, and controls in the piedmont of NC are warranted.

ACKNOWLEGEMENTS

This project is being funded by the North Carolina Division of Water Quality and EPA 319 Grant Program and the USDA Forest Service Southern Global Change Program. This study has been managed and designed by the USDA-Forest Service in cooperation with North Carolina Department of Environment and Natural Resources Division of Forest Resources, Nonpoint Source Program.

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