Grant Final Report

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Section 319h of the Clean Water Act
N.C. Department of Environment and Natural Resources
Division of Water Quality

"BMP Effectiveness Monitoring Study - Phase II"

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NONPOINT SOURCE MANAGEMENT PROGRAM
Section 319(h) of the Clean Water Act
319 GRANT

USDA-Forest Service,
Southern Research Station

Eastern Forest Environmental
Threat Assessment Center

North Carolina
Non-point Source
Program

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List of Abbreviations

BMP(s)	Best Management Practice(s)
DBH	Diameter at Breast Height
ET	Evapotranspiration
FPGs	North Carolina Forest Practices Guidelines Related to Water Quality
HF	Hill Demonstration Forest
NCDA&CS	N.C. Department of Agriculture & Consumer Services
NCDFR	N.C. Division of Forest Resources
NCDWQ	N.C. Division of Water Quality

NCSU	North Carolina State University
NPS	Nonpoint source
SMZ(s)	Streamside Management Zone(s)
UF	Umstead Research Farm
USDA-FS	U.S. Department of Agriculture - Forest Service

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Executive Summary

This final BMP grant report describes and documents (1) pre-harvest or baseline hydrology and water quality data in a set of paired watersheds, (2) implementation of treatment (harvest) at one of two study sites, (3) limited post-harvest hydrology data, (4) bridgemat and stream crossing effectiveness at one study site, and (5) scientific outreach activities.

Forestry best management practices (BMPs) are practices designed to protect water quality during forestry operations on a site-specific basis. In many circumstances, BMPs are recognized by federal and state regulatory agencies as the primary method to prevent nonpoint source pollution from forestry activities. In North Carolina, BMPs are defined for forestry in N.C. Administrative Code 15A NCAC 01I .0102 as:

> *"Best Management Practice (BMP) means a practice, or a combination of practices, that is determined to be an effective and practicable (including technological, economic, and institutional considerations) means of preventing or reducing the amount of pollution generated by nonpoint sources to a level compatible with water quality goals."*

Although BMPs are accepted as standard approaches to protect water quality during forestry operations, prior to this study there have been few attempts to quantity BMP effectiveness in small piedmont first order headwater watersheds.

This BMP effectiveness project was implemented in two phases. Phase I was intended to serve as the baseline pre-treatment (harvest) monitoring period and Phase II was intended to extend pre-harvest baseline monitoring and include post-harvest monitoring. Pre-harvest monitoring occurred in both Phases I and II, with thirty two months of data collected and processed. Only two months of post-harvest monitoring occurred in Phase II. The limited amount of post-harvest data is primarily due to unexpected project delays that occurred during the timber sale process. Each cooperating landowner (NCSU and NCDA&CS) experienced difficulty executing the timber sale, which was either due to state procedures for transactions involving "real property" or due to limited staff resources. In addition, following the harvest on NCDA&CS's Umstead Research Farm (UF), limited rainfall resulted in few stormflow sampling events. Therefore, the original objective, which was to monitor watershed response conditions one year post-harvest and include those data in this final grant report, was not fully realized. The USDA-FS, NCDFR, NCSU, and NCDA&CS plan to continue post-harvest monitoring through December 2013, and will provide an addendum to this final report for NCDWQ records.

Pre-harvest watershed hydrology data were successfully used to calibrate the paired watersheds (i.e., quantify through time the hydrological relationship between pairs). Annual and stormflow pre-harvest water yield varied slightly between pairs because of differences in soil physical properties, with more runoff generating from UF watersheds which have shrink/swell clay subsoil. Pre-harvest water quality data indicated that nutrient and sediment concentrations and exports were within background levels for the studied watersheds. Limited post-harvest streamflow data indicated timber harvest increased peakflow by 400% from 50 L/s to 250 L/s and total discharge by 300% from 70 L/s to 285 L/s. Visual observation of water samples suggests that TSS concentrations were slightly higher post-harvest. The increase in TSS was largely a result of legacy in-channel sediment movement with streambed soil particles being re-suspended. A qualitative buffer survey post-harvest did not reveal any sediment breakthroughs or transport of sediment overland. Post-harvest monitoring will continue through 2013 to quantify watershed hydrology, risks to water quality, and overall BMP effectiveness.

To avoid confounding water quality conditions in the paired watershed study, a different site was selected to evaluate the effectiveness of stream crossing BMPs. Preliminary data suggest that these management activities were successful in protecting water quality as sediment concentrations did not increase significantly downstream from the crossing during the one month monitoring period. This result is based on a limited amount of experimental data, thus additional stream crossing study sites and water sampling are needed to fully assess their effectiveness on water quality protection. Additional study sites will be identified and evaluated by December 2013. An additional stream crossing site has been setup with monitoring stations and water sampling equipment and is currently being monitored.

Training and site visits proved to be invaluable teaching, outreach, and collaboration tools for local universities. Fifteen seminars, field visits, or education tours were given during Phases I and II of this project. An estimate of 40 visitors participated in these outreach activities. Visitors ranged from college students, staff at Watershed Education for Communities and Officials, Raleigh, NC to international visiting scientists from Chile and China. Given the unique opportunity to understand details about linkages between streamflow, groundwater, and tree water use in the gauged paired watersheds, we are leveraging the opportunity presented by this 319-Grant by taking additional measurements and working with other scientists to:

- Monitor sapflow, soil respiration, and energy inputs to further assess streamside buffer effectiveness (e.g., How does buffer tree transpiration change following a clear cut and selective cutting of trees in an upland riparian area? How does forest management impact rates of carbon loss from upland forest soils?).
- Create a model using leaf area index, solar radiation, and vapor pressure deficit to estimate tree and stand transpiration in the piedmont.
- Continue project database development to contribute to validating regional scale hydrological models such as the Water Supply Stress Index (WaSSI) model.

Introduction & Background

Fifty eight percent of streams in the piedmont of NC are first order headwater streams (NCDWQ, 2005). Protecting these streams from degradation through proper management with BMPs will help protect quality stream channel networks and supply water for downstream tributaries and rivers. The piedmont is an area under rapid urbanization with the population in Wake County, NC projected to increase from 627,000 to 1,560,000 in the next 30 years (North Carolina Office of State Budget and Management, 2008). Thus, quantifying baseline and storm discharge volumes and water quality data from forested watersheds in this region can be valuable for future land-use and water supply planning. These data can also help to guide and inform strategies to moderate effects of droughts, population growth, and loss of open space.

The paired watershed approach has been used for years by researchers to quantify and document changes in watershed hydrology and risks to water quality post-harvest, with and without BMPs. The general experimental design consists of at least two watersheds (control and treatment), a calibration period, a treatment period, and a post-treatment monitoring period. Calibrating the paired watersheds is when a quantifiable hydrological and water quality relationship is developed through time between pairs. Pre-harvest calibration as noted by Swank et al. (2001) is a major factor to assessing and developing predictive models of treatment effects in a paired watershed design. The calibration period for determining these effects varies across watersheds due to different controlling factors such as watershed size, soil types, surface cover, and topography (Brooks et al. 2003). Based on Wilm (1944, 1948) equation, we found that our watersheds could potentially be calibrated in 10 months (Boggs et al. 2008).

In the United States, the best quality water comes from forested watersheds (Binkley and Brown, 1993), even when forests are managed primarily for timber production. However, forestry activities such as access and logging roads, skid trail construction, site preparation, and other disturbances to the forest floor have potential to cause soil erosion and contribute sediment and nutrients to streams. Sediment and nutrients are the major water quality parameters of concern when developing and implementing BMPs (Prud'homme and Greis, 2002). BMPs have emerged as the most effective tool for addressing non-point pollution problems in forest management activities since this concept was developed in the late 1970's to control non-point source water pollution (Prud'homme and Greis, 2002; Ice et al., 1997).

Forestry BMPs in North Carolina are defined as a practice or combination of practices that is determined to be an effective and practical means of preventing or reducing the amount of pollution generated by nonpoint sources to a level compatible with water quality goals (NCDFR, 2005). Evaluating the effectiveness of forestry BMPs in North Carolina through field study is necessary to determine if the BMPs are sufficient to protect water quality during forestry operations. While numerous forestry BMP effectiveness studies have been conducted in the southeastern U.S., this watershed monitoring study is the first to evaluate the effectiveness of forestry BMPs in North Carolina on a small headwater watershed scale.

Purpose & Goals

The overall purpose of this watershed monitoring study is to help fill a gap in knowledge regarding the effectiveness of forestry BMPs at preventing nonpoint source pollution during forestry operations in North Carolina. The primary goals for this study are to: 1) quantify the effectiveness of forestry BMPs on a small headwater watershed scale at preventing erosion and sedimentation, 2) evaluate the Neuse River Basin Riparian Buffer Rule as it relates to forestry operations, and 3) quantify the benefits of bridgemat stream crossings as compared to other crossing alternatives.

Given the opportunity provided by this 319-Grant, project resources have been leveraged to address additional research questions. Study data will be used to understand low flow characteristics, annual and seasonal discharge patterns, and nutrient concentrations and exports in small forested watershed streams associated with forest management activities. These data will ultimately add to model database development and lead to improved stream discharge and water quality estimates in larger watersheds following land management or natural disturbances.

Deliverables

Deliverables are from proposal specific to Phase II of this watershed monitoring study. Details of each deliverable are provided in the outputs and results section.

1. Monitor the study watersheds and collect calibration and baseline water quality data for one and a half years pre-harvest.
2. Implement study treatment harvest to two watersheds in accordance with the Neuse Buffer Rule and FPG's.

3. Monitor the treatment effects (i.e., harvesting) on water quality for one year post-harvest.
4. Establish and monitor sediment loading at five stream crossings established on active timber harvests located in central/piedmont North Carolina.
5. Evaluate data and develop a Final Grant Report of study findings and also include forest management recommendations.
6. Conduct BMP training seminars and education tours for internal and external customers to promote soil conservation and water quality protection, at least three events per annum.
7. Provide quarterly reports; publish research results in peer-review scientific journal(s) and/or professional conferences.

Methodology & Execution

Project Administration

The NCDFR serves as the primary project coordinator and administrator. Day-to-day project implementation, data collection and analysis are being performed by research staff of the Eastern Forest Environmental Threat Assessment Center, a unit of the USDA-FS Southern Research Station that is based on the campus of NCSU. This staff consists of a hydrologist, biological scientist, and research ecologist all of whom have several years of experience in implementing scientific methods to assess watersheds and forested ecosystems.

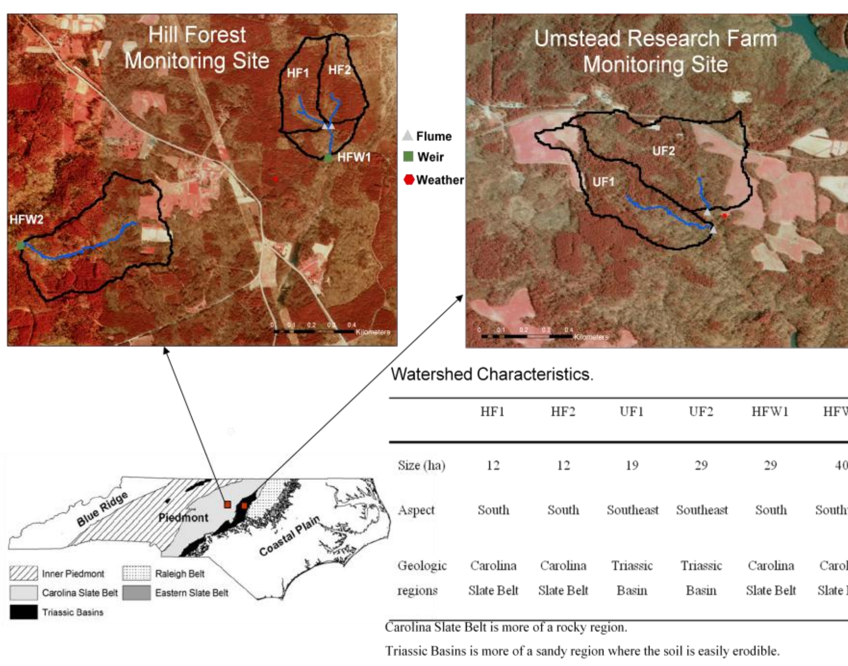
By partnering with the USDA-FS, we have a unique opportunity to tap into their expertise and undertake this project in a manner that is more likely to be received by the forestry community as viable, defensible and readily transferrable to other regions of the U.S.

Phases I and II

At the onset of funding for this study from the North Carolina 319-Grant Program, a decision was made to divide this multi-year project into two phases. The motivating factors for dividing the project centered on administering the contractual and funding processes needed to implement the study. As a result, Phase I was determined to include establishment of the study sites, installation of instrumentation and collection of baseline pre-harvest data, 2007-2008. The final report for Phase I on contract EW06020 was delivered in September of 2008. Phase II would continue baseline data collection and incorporate available post-harvest watershed hydrology and water quality data into the effectiveness analysis, 2008 to 2010.

Watershed Study Sites

The study watersheds are located in the Neuse River Basin. Four watersheds ranging from 12 to 28 hectares with perennial stream channels were gauged for flow monitoring and water quality sampling. The



Watershed Characteristics.

	HF1	HF2	UF1	UF2	HFW1	HFW2
Size (ha)	12	12	19	29	29	40
Aspect	South	South	Southeast	Southeast	South	Southwest
Geologic regions	Carolina Slate Belt	Carolina Slate Belt	Triassic Basin	Triassic Basin	Carolina Slate Belt	Carolina Slate Belt

Carolina Slate Belt is more of a rocky region.
Triassic Basins is more of a sandy region where the soil is easily erodible.

Figure A. Study sites and watershed characteristics first pair, HF1 and HF2, is located in the Lake Michie-Flat River subwatershed (030202010104) at NCSU's Hill Demonstration Forest in northern Durham County, NC (Figure A). The other pair, UF1 and UF2, is located in the Upper Knap of Reeds Creek subwatershed (030202010401) at the NCDA&CS Umstead Research Farm in Granville County, NC (Figure A). The distance between sites is approximately five miles. We are also monitoring hydrological processes including stage and discharge with a Sigma 900 Max (Hach Company, Loveland, CO) and water quality in two larger (i.e., 29 and 40 hectares) watersheds at Hill Demonstration Forest, HFW1 and HFW2.

One watershed from each pair serves as a control or reference watershed (no harvesting within the watershed). The first stream flow measurements were taken in October 2007, marking the beginning of the calibration period. The first thirty two months served as a calibration period for all watersheds, which is essential to capture the seasonal and annual climatic variability and collect sufficient data to establish relationships among water parameters prior to treatment. At the end of baseline monitoring and calibration, one watershed (UF1) was clear cut leaving a 50 foot SMZ around the perennial stream channel. The other treatment watershed (HF1) harvest was recently initiated late November 2010, which will provide replication and account for site variability. The SMZ around the stream in UF1 followed prescriptions outlined in N.C. Administrative Code 15A NCAC 2B .0233, commonly known as the Neuse River Basin Riparian Buffer Rule (Neuse Buffer Rule).

Photo 1. Two-foot H-flume outfitted with monitoring and sampling equipment.

Water quality parameters including, Total Suspended Sediment (TSS), Nitrate (NO_3), Ammonium (NH_4), Total Nitrogen (TN), Total Phosphorus (TP), and Total Organic Carbon (TOC) were sampled bi-weekly with grab samples and routinely following storm events that triggered sampling equipment based on in-stream flow rate of change. The storm-based samples were collected on a stratified sampling program, intensive sampling during the rising limb (six samples in one hour) and less intense during the recession limb (six samples over 6 to 10 hours) of the hydrograph. Therefore, to avoid the potential to overemphasize one limb of the hydrograph, time weighted mean concentration for each parameter was computed. Flow weighted mean concentrations were also calculated and can be found in Appendix. Stream temperature was also monitored. All measured parameters and other study support data are shown in Table 1.

The major difference between HF and UF is the ecoregion that has allowed for differences in stream channel formation, streambed substrates, and erodibility (Cleland et al. 2007). Streams found in HF (HF1, HF2, HFW1 and HFW2) are generally shallow, connected to their narrow floodplain, rocky substrate, and have relatively steep upland slopes with watersheds underlined by Carolina Slate Belt soils. Conversely, streams in UF (UF1 and UF2) have deeper stream channels that are detached from their wide floodplain, sandy substrate, and gentle upland slopes with watersheds underlined by Triassic Basin soils. Some reaches of the UF streams, particularly UF2, have what appear to be channelized or straightened segments likely due to homestead uses or agricultural practices.

Table 1. Type of data collection frequency and methods used in NC Piedmont paired watershed study.

Data Category	Parameters	Measurement Frequency	Methods
Meteorology	Rainfall, air temp, relative humidity, total solar radiation, wind speed	Sampled every 4 minutes, logged every hour	Onset micrometeorological station
Stream flow	Water depth, flow rate, flow volume	10 minute intervals 10 minute intervals	Weirs or flumes and associated water level recorders;
Water Table	Water below ground surface	Hourly	Global Water pressure transducer
Soil Respiration	Carbon loss	Twice a month	EGM
Transpiration	Tree water use	10 minute intervals	Sapflow (thermal dissipation technique)
Soil Moisture/Temperature	Moisture and Temperature	10 minute intervals	Onset thermocouples
Vegetation	SMZ overstory, midstory and groundcover survey	Pre- and post-harvest	Caroline Vegetation Survey
Land topography	Digital Elevation Model	Once	NC Floodmaps LiDAR
Water quality (NCSU)	TSS, NO_3, NH_4, TP, TKN, TOC at the watershed outlets	During stormflow and baseflow	Sigma sampler programmed for storm event sampling.
	Stream Temperature	10 minute intervals	Hobo Water Temp Pro V2 Logger
	Turbidity	10 minute intervals	Global Water Turbidity Sensor
Stream channels	Channel geomorphology: Cross sections, longitudinal profiles, and stream patterns	Pre-harvest and post-harvest	Total Station
Stream crossing	TSS and Nutrients	Three days with similar flow/rain conditions; from at least 5 harvest sites in piedmont of N.C.	Sigma sampler programmed for storm-based water sampling.

Data Category	Parameters	Measurement Frequency	Methods
Benthic Macroinvertebrate	Quantity	Sampling periods will be completed during low flow conditions in the winter, spring, and summer.	Protocols according to NCDWQ.

Benthic Macroinvertebrate Component

Pre-harvest sampling of benthic macroinvertebrates was conducted with the assistance of NCSU's Department of Biological & Agricultural Engineering, and from consultant Dr. Dave Penrose. Post-harvest sampling will be funded with the assistance of Weyerhaeuser Company's forest research unit. Weyerhaeuser Company has a long history of extensive forestry and hydrological research and is one of the last remaining integrated forest-products companies that continues to have a full-time staff of researchers dedicated solely to forestry and environmental studies.

Photo 2. Retired NCDWQ scientist Dave Penrose (left) and NCDFR Forestry NPS Senior Specialist David Jones (right) use kick net to sample benthic macroinvertebrates.

Photo 3. Stonefly (Plecoptera) nymph collected from stream. Stonefly presence is indicative of excellent water quality.

Outputs & Results

1. Monitor the study watersheds and collect calibration and baseline water quality data for at least 1½ years pre-harvest (**Accomplished**).

Watershed Calibration

Pre-harvest watershed calibration is a major factor to assessing and developing predictive models of treatment effects in a paired watershed design. Calibration period for determining these effects varies across watersheds due to different controlling factors such as watershed size, soil types, surface cover, and topography. Thirty two months of baseline data were use to calibrate these paired watersheds. This calibration period generated predictive models that indicate the paired watersheds are responding similarly to precipitation inputs and are sufficient to detect treatment effects once they occur (Figure B).

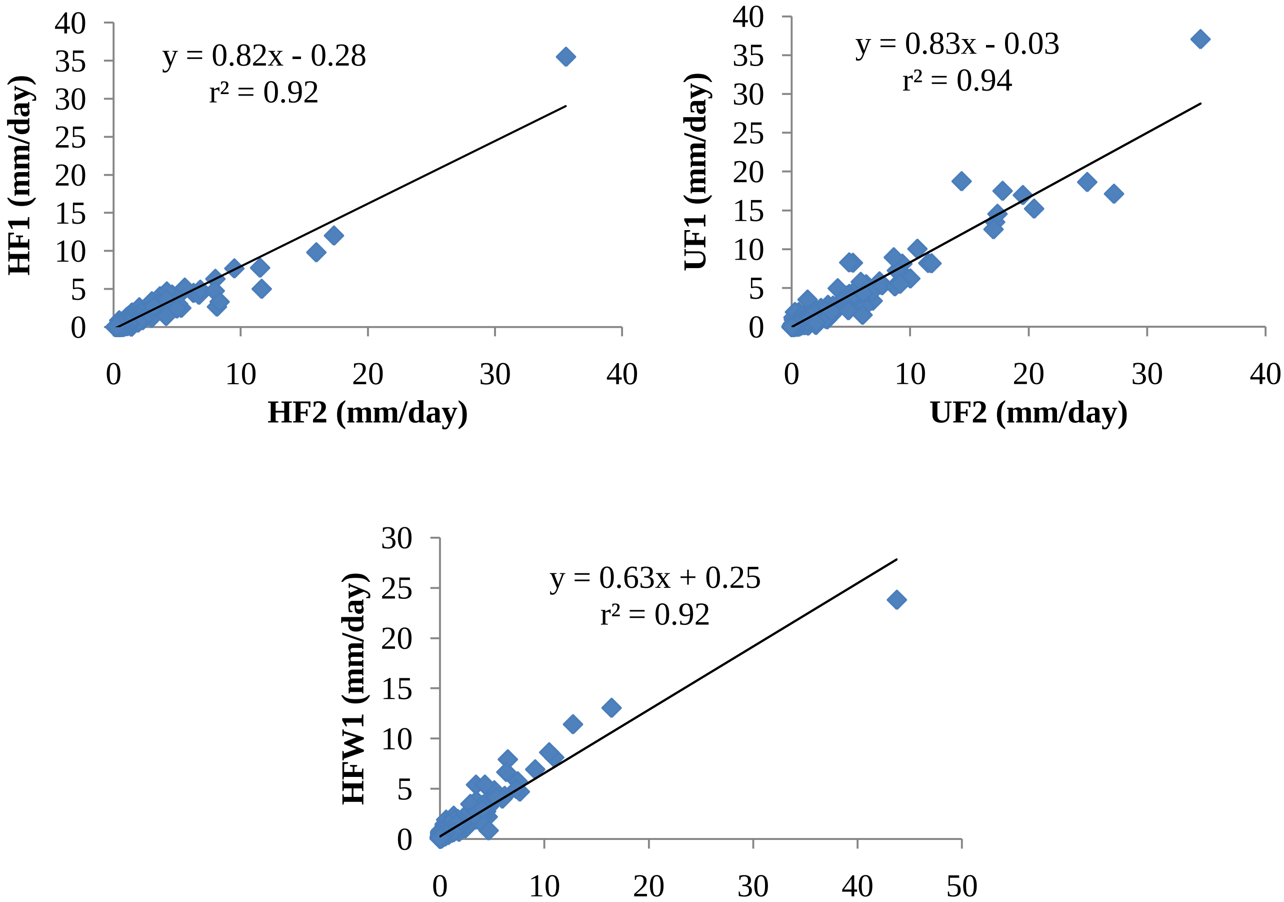


Figure B. Daily discharge relationship in watersheds during calibration period, November 2007 – June 2010.

Evaluating stream discharge and water quality data at different temporal scales (annual, storm-based, and seasonal) in the pre-harvest phase can provide useful information to understanding hydrological watershed processes and dynamics. Temporal scale data are described below.

Annual Discharge

Annual discharge analyses were conducted based on water years April 1, 2008 – March 31, 2009 and April 1, 2009 – March 31, 2010. This period coincides with what Weaver (1998) report as a climatic year for low-flow analyses in NC. These analyses provide valuable water resources and planning data for municipal, county, and state governments especially during dry periods. Data are presented in millimeters (mm) to make them comparable with other data sources such as precipitation.

HF2 watershed is spring fed contributing about 32% and 27% more annual discharge than HF1 (its paired watershed) in 2008 and 2009, respectively. A column in Tables 2 and 3 is added to adjust for annual spring flow contribution. HF annual discharge ranged from 162mm to 200mm in year one (April 2008 – March 2009) and 205mm to 293mm in year two (April 2009 – March 2010) (Table 1). HF percent evapotranspiration (ET) ranged from 83% to 87% in year one and 77% to 84% in year two. The runoff/rainfall ratio in HF ranged from 0.13 to 0.17 in year one and 0.16 to 0.23 in year two. UF annual discharge ranged from 235mm to 246mm in year one and 245mm to 333mm in year two (Table 1). UF percent ET ranged from 81% to 82% in year one and 73% to 80% in year two. The runoff/rainfall ratio in UF ranged from 0.18 to 0.19 in year one and 0.20 to 0.27 in year two. Variant in % ET between HF and UF is likely due to differences in how the watersheds stored and released water during and after the 2007 drought. Streams in UF are considered to have the lowest baseflows in NC and is likely due to low infiltration rates and low topographic relief.

Table 2. Discharge, rainfall, ET, and runoff/rainfall ratio for water year 2008-2009 in NC Piedmont paired watersheds.

	Discharge mm	Rainfall mm	ET mm	ET %	Runoff/Rainfall ratio
HF1	162	1207	1045	87	0.13
HF2	279	1207	928	77	0.23
HF2 Adjusted	189	1207	1018	84	0.16
HFW1	186	1207	1021	85	0.15
HFW2	200	1207	1007	83	0.17
UF1	235	1279	1044	82	0.18
UF2	246	1279	1033	81	0.19

Table 3. Discharge, rainfall, ET, and runoff/rainfall ratio for water year 2009-2010 in NC Piedmont paired watersheds.

	Discharge mm	Rainfall mm	ET mm	ET %	Runoff/Rainfall ratio
HF1	205	1268	1063	84	0.16
HF2	361	1268	907	72	0.28
HF2 Adjusted	263	1268	1005	79	0.21
HFW1	277	1268	991	78	0.22
HFW2	293	1268	975	77	0.23
UF1	245	1215	970	80	0.20
UF2	333	1215	882	73	0.27

Storm-Based and Seasonal Discharge

Stormflow and baseflow for the selected storm events were derived from a standard flow separation method using a constant slope (0.05 $ft^3/sec/mi^2/hr$) as described by Hewlett and Hibbert (1967). Storm-based discharge that include peak rate, time to peak, outflow, baseflow, stormflow, and runoff/rainfall ratio are indicative of how watersheds store, process, and release water after a storm event. Seasonal discharge can provide useful information to land managers to evaluate issues such as reservoir release requirements, land acquisition strategies, and project management options. In general, UF watersheds released more water compared to HF after a storm event with the largest difference occurring in dormant season (Table 4). For example, average UF peak rate was 300% higher than average HF peak rate during dormant season and only 72% higher during growing season.

Controls on watershed response variables varied between watershed areas (HF vs. UF) with begin flow being a significant control on outflow, baseflow, and runoff/rainfall ratio in UF watersheds (Table 5) while begin flow was not a significant control on response in HF (Table 6). Total rainfall was the only significant variable controlling stormflow in the HF with 60% of the variability being explained (Table 6). In contract, season and total rainfall indicated a significant control on stormflow in the UF with 80% of the variability being explained. Different control variables on event outflow parameters between watershed areas was likely a result of topography and soil physical properties related to soil texture, depth, and porosity. Dreps (2010) found that in the dormant season UF stormflow response is controlled by or “turned on” due to highly expansive clay subsoil. HF watersheds have non-expansive soils that allow for deeper infiltration and consequently less discharge and lower peak rates compared to UF. HF stormflow response is controlled primarily by topography.

Table 4. Stormflow characteristics of ten storms in NC Piedmont paired watersheds, dormant vs. growing season.

Watershed	Event Duration hours	Begin Flow mm/day	Peak Rate mm/day	Time Peak hours	Event Outflow mm	Baseflow mm	Stormflow mm	Precipitation mm	Runoff/Rainfall ratio
					Dormant Season				
HF1	19.3	0.4	4.3	8.9	2.1	0.8	1.3	25.6	0.07
HF2	20.3	0.7	8.1	8.3	3.8	1.2	2.5	26.0	0.12
HFW1	19.0	0.5	6.1	8.2	2.9	1.0	1.9	26.2	0.08
HFW2	23.8	0.4	8.6	10.0	4.8	1.3	3.4	24.7	0.14
UF1	30.1	0.4	25.0	11.7	10.8	1.8	9.0	27.3	0.33
UF2	31.2	0.4	29.1	13.3	13.2	1.8	11.4	31.7	0.34
					Growing Season				
HF1	7.7	0.1	12.1	3.4	2.0	0.1	1.9	25.9	0.03
HF2	8.3	0.6	15.1	2.5	2.4	0.3	2.1	28.5	0.04
HFW1	12.6	0.3	8.1	2.9	1.7	0.2	1.5	29.0	0.03
HFW2	7.8	0.4	8.4	2.6	2.0	0.3	1.7	22.3	0.03
UF1	11.2	0.1	18.9	2.7	4.3	0.2	4.1	26.1	0.09
UF2	9.8	0.1	18.9	3.0	3.9	0.2	3.7	31.7	0.06

Table 5. General linear regression model stepwise analysis comparing control of independent variables on several response variables in UF paired watershed.

	Independent Variables			
	Season	Begin Flow	Total Rainfall	r^2
Response Variables				
Peak Rate	ns	ns	0.00	0.4
Time to Peak	0.00	ns	0.00	0.6
Event Outflow	0.00	0.02	0.00	0.8
Baseflow	0.01	0.00	0.00	0.6
Stormflow	0.00	ns	0.00	0.8
Runoff/Rainfall ratio	0.00	0.00	0.00	0.6

p values are shown. ns, not significant at $p < 0.05$.

Table 6. General linear regression model stepwise analysis comparing control of independent variables on several response variables in HF paired watershed.

	Independent Variables			
	Season	Begin Flow	Total Rainfall	r^2
Response Variables				
Peak Rate	ns	ns	0.00	0.6
Time to Peak	0.00	ns	0.00	0.4
Event Outflow	0.00	ns	0.00	0.7
Baseflow	0.00	0.00	0.00	0.6
Stormflow	ns	ns	0.00	0.6
Runoff/Rainfall ratio	0.00	0.00	0.00	0.4

p values are shown. ns, not significant at $p < 0.05$.

Annual Water Quality

Annual water quality parameters were computed based on time and flow weighted mean concentrations to account for differences in sampling time and streamflow, respectively. Time weighted data are presented below because they typically represent common stream and aquatic exposure conditions. Flow weighted data are shown in the Appendix. Generally time and flow weighted mean concentrations were similar with differences controlled by large storm events.

In 2008, annual concentration of TSS and nutrients varied only slightly between HF and UF (Table 7). UF2 had the highest 2008 exports for all measured variables except NH_4 and TP (Table 8). In 2009, UF2 had the highest annual concentrations of all measured variables except TP (Table 9). UF2 had the highest 2009 exports for all measured variables (Table 10). Higher annual concentrations in UF2 compared to the other watersheds are likely due to presence of a fertilized agricultural field partially within the watershed and in close proximity.

Annual TSS, TP, and TKN concentrations were equal to or higher in 2009 compared to 2008 for all watersheds. Annual exports for all parameters were generally higher in 2009 compared to 2008 for all watersheds. These yearly differences are likely due to variability in weather conditions that include rainfall amount and intensity.

Overall, water quality parameters in all watersheds were within background levels for forested watersheds and represent baseline forest conditions.

Table 7. Nutrient and TSS concentrations in NC Piedmont paired watersheds in 2008.

Watersheds			TSS	TOC	NH_4 ----mg/l---	NO_3	TP	TKN
HF1								
	Mean		17.3 (22.6)	7.2 (4.4)	0.01 (0.02)	0.01 (0.04)	0.04 (0.04)	0.40 (0.36)
	Median		11.0	6.3	0.00	0.00	0.03	0.27
	n	41						
HF2								
	Mean		25 (41.1)	7.4 (5.7)	0.00 (0.01)	0.01 (0.03)	0.07 (0.09)	0.51 (0.55)
	Median		15.0	4.3	0.00	0.00	0.05	0.34
	n	49						
HFW1								
	Mean		15.1 (19.1)	6.2 (4.0)	0.01 (0.03)	0.02 (0.13)	0.05 (0.04)	0.42 (0.33)
	Median		5.8	4.4	0.00	0.00	0.04	0.30
	n	45						
HFW2								
	Mean		17.6 (26.8)	5.7 (3.9)	0.04 (0.20)	0.05 (0.11)	0.12 (0.32)	0.58 (0.78)
	Median		7.3	4.8	0.00	0.00	0.06	0.38
	n	44						
UF1								
	Mean		19 (27.7)	10.7 (6.9)	0.02 (0.08)	0.02 (0.07)	0.06 (0.06)	0.51 (0.56)
	Median		11.5	8.8	0.00	0.00	0.03	0.31
	n	28						
UF2								
	Mean		22.3 (28.0)	11.8 (7.4)	0.02 (0.08)	0.20 (0.25)	0.04 (0.04)	0.66 (0.47)
	Median		12.0	9.5	0.00	0.15	0.04	0.50
	n	46						

Standard deviations are in parentheses. Total Suspended Sediment (TSS), Total Organic Carbon (TOC), Ammonium (NH_4), Nitrate (NO_3), Total Phosphorus (TP), and Total Kjeldahl Nitrogen (TKN).

Table 8. Nutrient and TSS export in NC Piedmont paired watersheds in 2008.

Watersheds	TSS	TOC	NH_4	NO_3	TP	TKN	Discharge
			---kg/ha/yr---				l/s
HF1	21	8.7	0.01	0.01	0.05	0.48	0.46
HF2	60	17.8	0.01	0.01	0.17	1.23	0.91
HF2 (adjusted)	40	11.9	0.00	0.02	0.11	0.82	0.61
HFW1	22	9.2	0.01	0.03	0.08	0.62	1.37
HFW2	27	8.7	0.06	0.08	0.19	0.88	1.93
UF1	30	16.8	0.02	0.03	0.09	0.80	0.88
UF2	40	21.2	0.03	0.35	0.08	1.18	1.61

Standard deviations are in parentheses. Total Suspended Sediment (TSS), Total Organic Carbon (TOC), Ammonium (NH_4), Nitrate (NO_3), Total Phosphorus (TP), and Total Kjeldahl Nitrogen (TKN). HF2 adjusted = annual spring flow contribution removed.

Table 9. Nutrient and TSS concentrations in NC Piedmont paired watersheds in 2009.

Watersheds			TSS	TOC	NH_4	NO_3	TP	TKN
					---mg/l---			
HF1								
	Mean		38.8 (34.1)	5.6 (3.1)	0.01 (0.03)	0.00 (0.01)	0.09 (0.11)	0.79 (0.98)
	Median		25.0	4.7	0.00	0.00	0.04	0.36
	n	47						
HF2								
	Mean		30.1 (24.1)	6.8 (4.3)	0.01 (0.03)	0.00 (0.01)	0.07 (0.08)	0.64 (0.62)
	Median		26.0	6.5	0.00	0.00	0.05	0.43
	n	55						
HFW1								
	Mean		26.8 (18.6)	6.2 (3.6)	0.00 (0.00)	0.02 (0.10)	0.06 (0.05)	0.46 (0.28)
	Median		23.0	6.6	0.00	0.00	0.05	0.40
	n	46						
HFW2								
	Mean		32.4 (32.7)	5.5 (3.7)	0.02 (0.10)	0.04 (0.07)	0.12 (0.14)	0.63 (0.63)
	Median		21.0	4.4	0.00	0.00	0.07	0.38
	n	39						
UF1								
	Mean		34.7 (20.7)	10.1 (5.6)	0.01 (0.03)	0.00 (0.02)	0.09 (0.08)	0.70 (0.49)
	Median		29.0	9.5	0.00	0.00	0.07	0.59
	n	28						
UF2								
	Mean		41.9 (32.7)	12.3 (6.6)	0.07 (0.44)	0.23 (0.41)	0.11 (0.12)	0.97 (0.98)
	Median		32.0	12.2	0.00	0.09	0.05	0.66
	n	44						

Standard deviations are in parentheses. Total Suspended Sediment (TSS), Total Organic Carbon (TOC), Ammonium (NH_4), Nitrate (NO_3), Total Phosphorus (TP), and Total Kjeldahl Nitrogen (TKN).

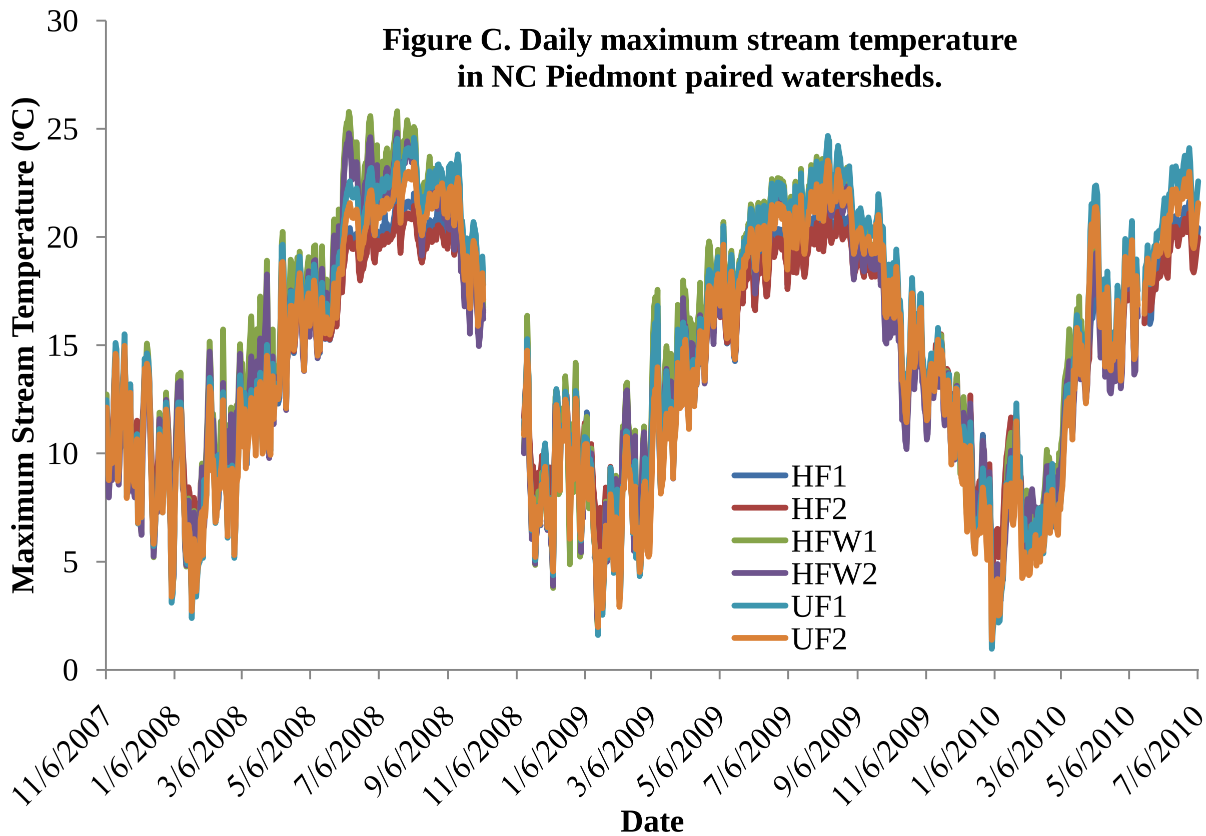
Table 10. Nutrient and TSS export in NC Piedmont paired watersheds in 2008.

Watersheds	TSS	TOC	NH_4	NO_3	TP	TKN	Discharge
			---kg/ha/yr---				l/s
HF1	84	12.0	0.02	0.01	0.20	1.71	0.82
HF2	102	22.9	0.03	0.01	0.25	2.16	1.29
HF2 (adjusted)	74	16.8	0.02	0.00	0.17	1.58	0.94
HFW1	72	16.5	0.00	0.04	0.16	1.24	2.46
HFW2	87	14.8	0.06	0.11	0.32	1.68	3.40
UF1	99	29.0	0.02	0.01	0.25	2.01	1.72
UF2	142	41.8	0.24	0.78	0.36	3.30	3.12

Standard deviations are in parentheses. Total Suspended Sediment (TSS), Total Organic Carbon (TOC), Ammonium (NH_4), Nitrate (NO_3), Total Phosphorus (TP), and Total Kjeldahl Nitrogen (TKN). HF2 adjusted = annual spring flow contribution removed.

Seasonal Water Quality

There was no clear seasonal pattern for NO_3 and NH_4 between paired watersheds. Many of the NO_3 and NH_4 values were zero or below detection limit even during high rainfall events and dormant seasons. TSS, TKN, and TP generally peaked during high stormflow with concentrations being within acceptable exposure limits that maintain aquatic species health. A clear seasonal pattern was observed in daily maximum stream temperature with values being slightly higher in UF compared to HF (Figure C). 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 pre-harvest water year in any stream.



Benthic Macroinvertebrate

Two sets of benthic macroinvertebrate surveys were completed to document pre-harvest composition and abundance. Data from the two collections are shown in Table 11. Total mayfly (Ephemeroptera), stonefly (Plecoptera), and caddisfly (Trichoptera) (EPT) taxa richness declined between surveys in all watersheds except HF1. Biotic index also declined or improved in all watersheds except UF1, where the index stayed the same. The variant between surveys is likely due to slight seasonal influences. Additional surveys will be collected for seasonal corrections. More details on taxa, NC biotic index, and trophic status in each stream from the January and April surveys can be found in the Appendix.

Table 11. Pre-harvest benthic metric results in NC Piedmont paired watersheds in 2010.

	Total Taxa Richness	Total EPT Taxa Richness	EPT abundance	Biotic Index
HF1	32/26	13/16	41/74	4.5/3.3
HF2	43/35	21/17	83/88	3.8/3.0
HFW1	50/43	24/22	110/106	4.0/3.3
HFW2	34/29	20/17	95/58	4.1/2.8
UF1	35/25	16/12	44/36	4.8/4.8
UF2	38/25	18/10	75/36	4.5/4.0

January survey/April survey. Criteria for NC Biotic Index: Excellent < 5.24, Good 5.25 - 5.95, Good-Fair 5.96 - 6.67, Fair 6.68 - 7.70, Poor > 7.71 (Source: Lenat 1993).

2. Implement study treatment harvest to 2 watersheds in accordance with the Neuse Buffer Rule and North Carolina FPG's (**Accomplished to the extent of project activities within our control. Treatment was implemented in one watershed at UF. The replicate treatment in HF will occur late 2010/early 2011**).

The harvest at UF started on July 7, 2010. The UF property owner, NCDA&CS, prepared the timber sale agreement and invitation to bid. Field staff from NCDFR and the USDA-FS provided assistance with GIS and field survey work. This included performing a timber examination or cruise, defining the sale area and property lines, marking boundaries and buffer zones, and generating a series of land descriptive maps for pre-harvest planning. The pre-harvest plan is designed to protect soil and water quality and to ensure that proper and most effective BMPs are implemented. Based on a final site inspection on September 8, 2010 by David Jones (NCDFR) and others, the timber removal operation was completed in accordance with the Neuse River Buffer Rules and FPGs. The harvest at HF was initiated November 29, 2010. Similar activities were undertaken at NCSU's HF to plan for the harvest and develop the timber sale agreement and bid. Harvest activities will be conducted in accordance with the study objectives and a final inspection will be performed to ensure these objectives were achieved.

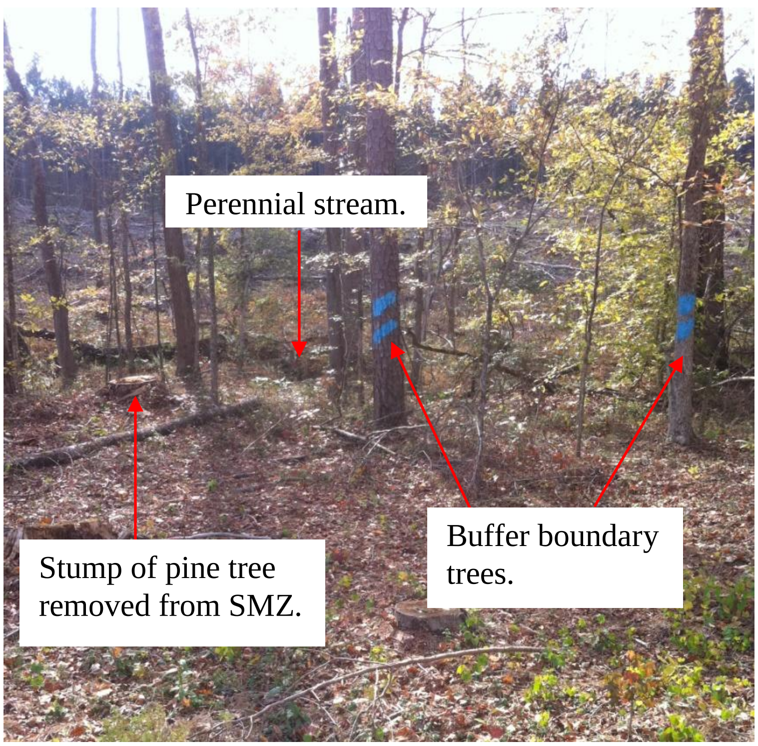


Photo 4. Example of tree removed from SMZ in UF1, outer zone 1 (10 to 30 feet of stream) as outlined in NC Administrative Code 15A NCAC 2B .0233.

3. Monitor the treatment effects (i.e., harvesting) on water quality for 1 year post-harvest. (**Accomplished to the extent of project activities within our control. Timber sale process, timber product supply and demand markets, weather, and other factors limited post-harvest data collection period to two months**).

Storm-Based Discharge

The first storm event after the harvest in UF was September 27th – September 30th, 2010, only two weeks after harvesting was completed. The treatment watershed received 6.5 inches of rainfall from this event. Effect of treatment on a storm-based hydrograph is shown in Figure D. Peakflow increased by 400% from 50 L/s to 250 L/s.

Treatment decreased baseflow during the storm by 7%, while total discharge and stormflow increased (Table 12). Although baseflow decreased slightly in this storm-based analysis, total baseflow increased 130% over the two month monitoring period (data not shown). Post-harvest monitoring of watershed hydrology characteristics and water quality conditions will continue through 2013 to capture seasonal and annual variability and document watershed hydrology dynamics.

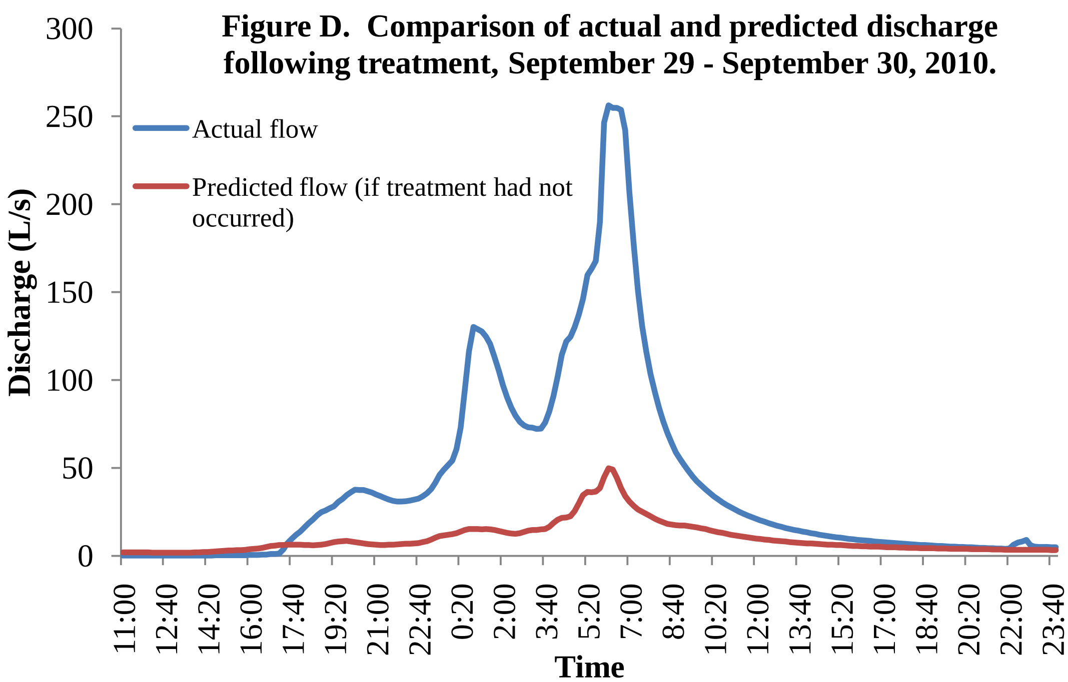


Table 12. Streamflow characteristics post-harvest in NC Piedmont watershed.

	Total Discharge	Stormflow	Baseflow
		---L/s---	
Actual flow	285.4	284	1.4
Predicted flow	70.0	68.5	1.5
% change	+300	+314	-7

+ increase; - decrease.
Slope separation method (Hewett and Hibbert 1967).

4. Establish and monitor sediment loading at 5 bridgemat stream crossings established on active timber harvests located in central/piedmont North Carolina (**Accomplished to the extent of project activities within our control. Only one bridgemat stream crossing was evaluated due to a lack of available logging sites. An additional site was established November 2010)**.

Evaluating the effectiveness of proper bridgemat use and stream crossing rehabilitation and stabilization is important to water quality protection during forestry operations. The stream crossing study was located in Duke Forest, Durham, NC. Figure E depicts the stream crossing study location and watershed forest management practices. For this study we used the upstream-downstream approach where one water quality sampler was placed approximately 10 meters above and below the stream crossing, Photo 5. TSS was monitored at the crossing for four weeks. A total of six baseflow samples and forty eight storm event samples were collected during two storms. TSS concentrations were similar in the upstream and downstream water following Storm 1, with the downstream TSS concentrations being only slightly higher. Differences in baseflow, average, and peak TSS concentrations were, however, not significantly different between locations (Table 13).

TSS export could not be determined at this study site due to limited field resources to estimate flow rates. As of November 9, 2010, a portable H flume has been fabricated and can be easily installed at future stream crossing study sites across the state. This flow control structure will allow for quick and reasonable estimates of streamflow rates without developing a channel rating curve (stage-discharge relationship). Concentration and export will be estimated at future crossing sites.

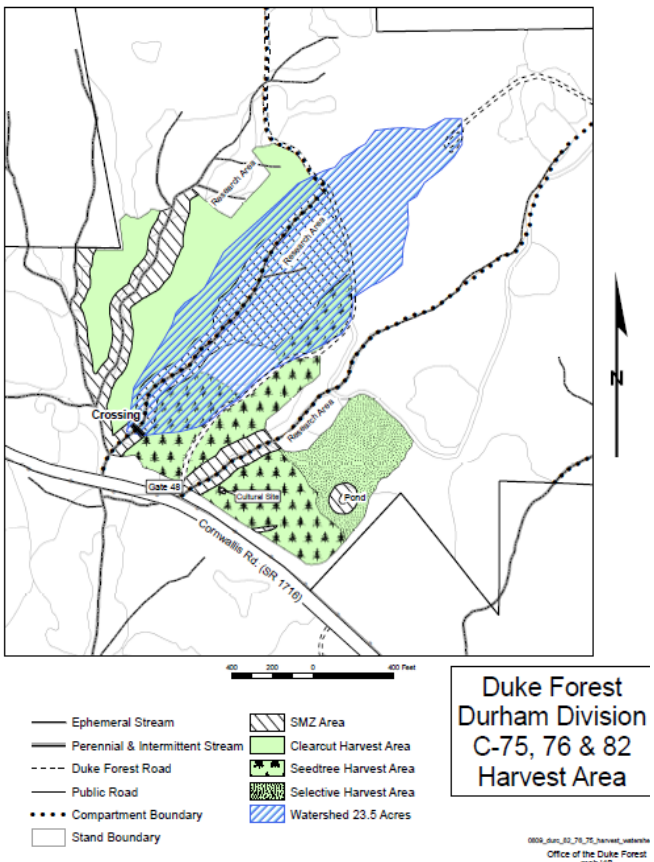


Figure E. Stream crossing study location and watershed forest management practices (Source: Office of Duke Forest).

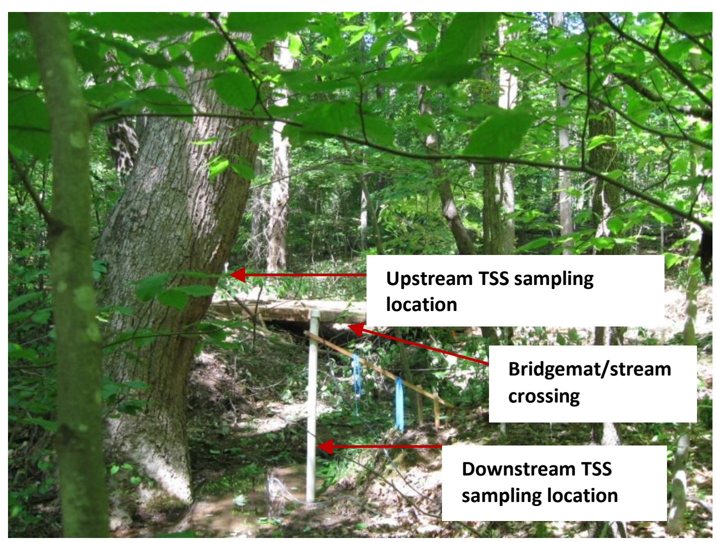


Photo5. Upstream and downstream sampling locations.

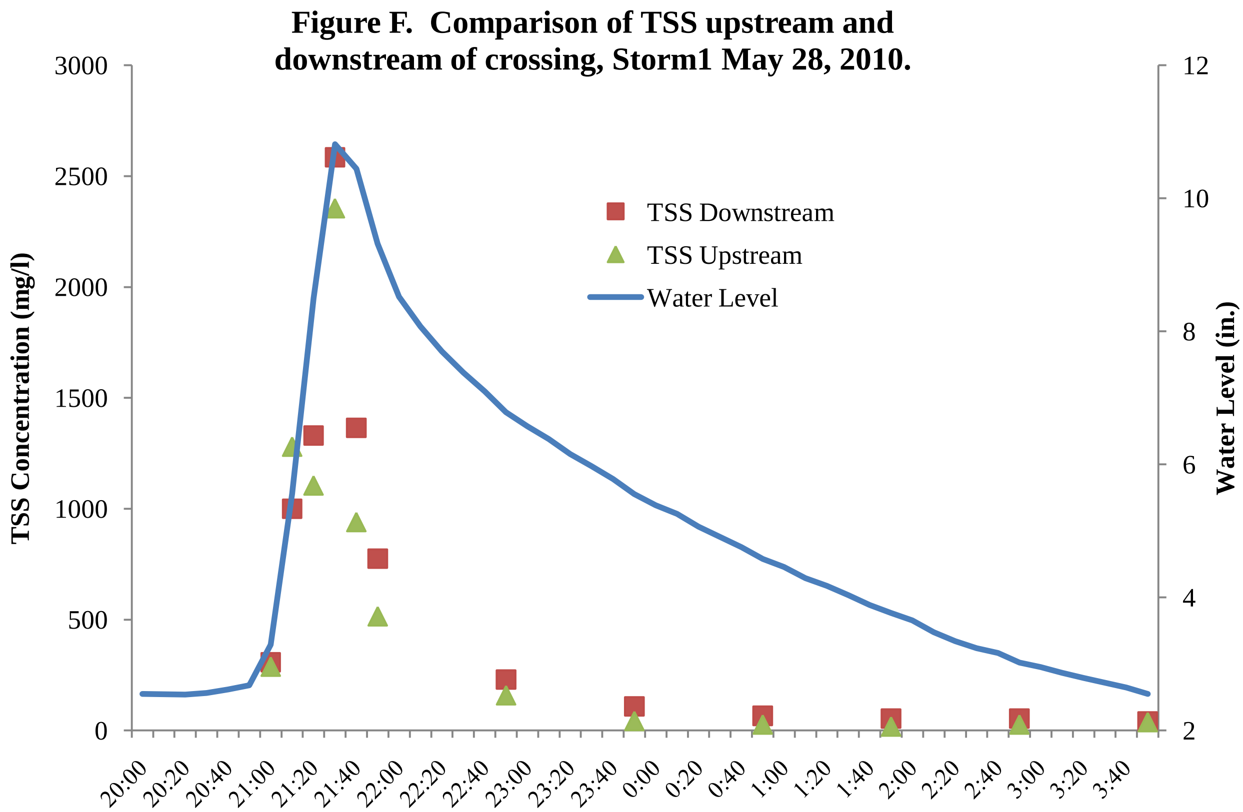


Table 13. Baseflow, average, and peak TSS concentrations in NC Piedmont watershed in 2010, Duke Forest.

		Average Stormflow TSS		Peak Stormflow TSS	
	Baseflow	Storm1	Storm2	Storm1	Storm2
		----mg/l---			
Upstream	1.8 (7.2)a	566.3 (219.2)a	95.3 (38.4)a	2355	415
Downstream	10 (7.2)a	659.7 (219.2)a	69.3 (36.8)a	2585	390

Mean values are shown with standard errors in parenthesis. Means with the same letters are not significantly different at $p < 0.05$.

5. Evaluate data and develop a Final Grant Report of study findings and also include forest management recommendations **(Accomplished).**

Calibration and baseline hydrology, and water quality data were presented and published in proceeding papers, abstracts, and posters at a range of scientific meetings and conferences. This report serves as the final grant report. An addendum to this report will be provided to NCDWQ at the completion of the post-harvest monitoring period (expected December 2013).

6. Conduct BMP training seminars and education tours for internal and external customers to promote soil conservation and water quality protection, at least 3 events per annum **(Accomplished).**

Fifteen seminars, field visits, or education tours were given during Phases I and II of this project. Visitors ranged from college students, staff at Watershed Education for Communities and Officials, Raleigh, NC to visiting scientists and personnel from Chile. An estimate of 40 visitors participated in these outreach activities.
These outreach efforts lead to scientific collaborations to address other research questions related to traditional forestry management practices, species composition and water use, forest soil carbon loss, and watershed hydrological processes. For example, we are now working with other scientists from UNC and NCSU to leverage against the gauged watersheds to:

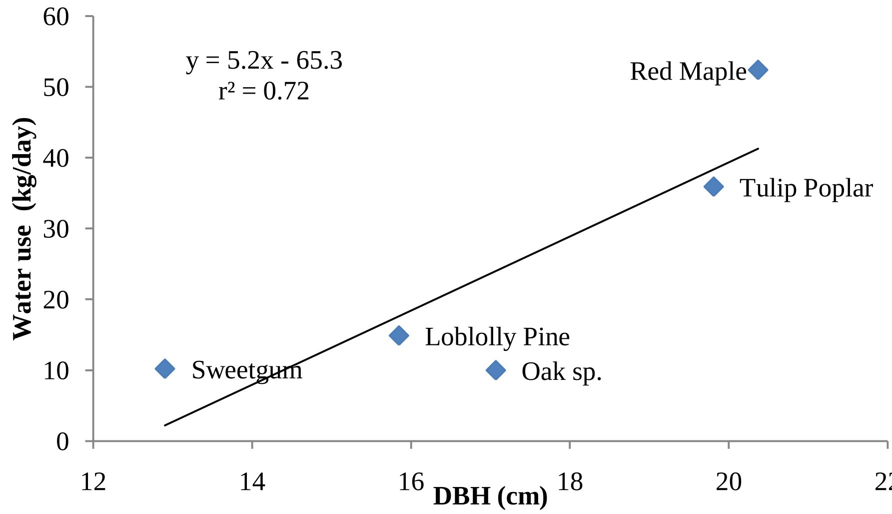
- Monitor sapflow, soil respiration, and energy inputs to further assess streamside buffer effectiveness (e.g., How does buffer tree transpiration change following a clear cut and selective cutting of trees in an upland riparian area? How does forest management impact rates of carbon loss from upland forest soils?).
- Create a model using leaf area index, solar radiation, and vapor pressure deficit to estimate tree and stand transpiration.
- Continue project database development to contribute to Water Supply Stress Index (WaSSI) model validation.

Photo 6. Johnny Boggs (middle), USDA-FS, giving tour to collaborators Dr. April James (left) and Chris Dreps (right), NCSU.

Photo 7. Johnny Boggs, (right), USDA-FS, giving tour watershed hydrology class, NCSU.

Sapflow data from a collaborative project with NCSU were used to determine daily water use of five species located in the upland riparian area of HF1. Red maple used the most water from June – September 2010 and oak sp. used the least with DBH correlating with water use (Figure G). Sapflow monitoring will continue through at least 2013. Sapflow and other support data will ultimately be used to evaluate how species composition and forest management affect water use and the overall water balance in piedmont watersheds.

Figure G. Relationship between DBH and water use.



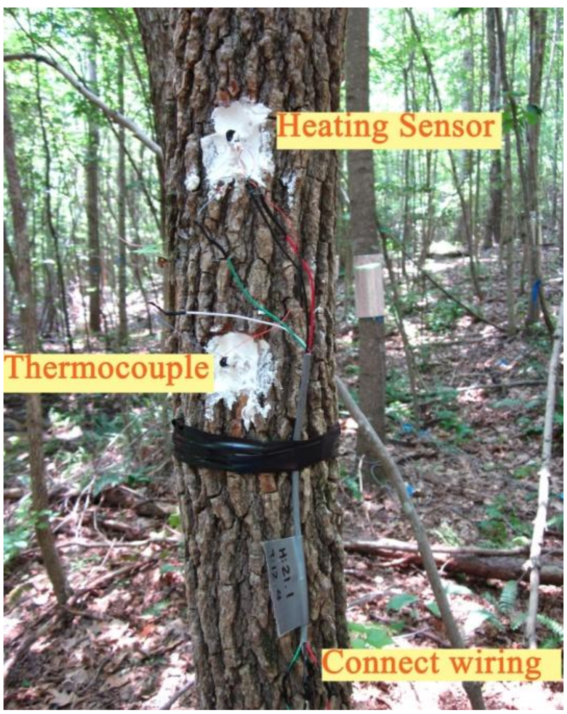


Photo 9. Housing, datalogger, and batteries for sapflow monitoring.

Photo 8. Sapflow sensors installed in sweetgum tree.

7. Provide quarterly reports **(Accomplished)**; Publish research results in peer-review scientific journal(s) and/or professional conferences **(Publication to document pre-harvest data in progress).**

Quarterly progress reports were submitted to summarize findings and update field data surveys and monitoring activities. Two proceedings paper were also written to report pre-harvest watershed hydrology, nutrient concentrations, and stream temperature variability. The papers can be found in the Appendix.

Another report or manuscript will be written three years post-harvest to evaluate if stream quality and watershed hydrology in the treated watersheds have returned to pre-harvest conditions and to explore model development for practical uses in managing and implementing BMPs.

Outcomes & Conclusions

Based upon the task of deliverables, this project was largely successful in its scope:

1. The paired watersheds were successfully calibrated to evaluate treatment effects. Baseline hydrology and water quality data were monitored and processed. Water quality conditions were determined to be within background levels for forests and represent baseline forest conditions.
2. One paired watershed was treated according to the Neuse River Buffer Rules, where upland forest land was clear cut and a 50 foot SMZ was left around the stream channel. The replicate paired watershed will be treated in 2011 to account for site variability.
3. Post-harvest monitoring indicated that stormflow and baseflow have increased. Visual observation of water samples suggests that TSS concentrations were slightly higher post-harvest. The increase in TSS is largely a result of in-channel sediment movement with streambed soil particles being re-suspended. A qualitative buffer survey post-harvest did not reveal any sediment breakthroughs or transport of sediment overland. Three years of additional post-harvest monitoring will occur to explore model development for practical uses in implementing BMPs. In addition, the pre-harvest water quality parameters indicate that forestland is not a significant source of nutrient loading to first order streams in the piedmont, as indicated by the measured contributions of nutrients from each watershed. These measured levels are notably lower than the limit standards described within the Neuse River nutrient management regulations.
4. Preliminary findings indicated that bridgemats coupled with stream bank stabilization and site rehabilitation sufficiently maintained downstream TSS concentrations. Additional site and experimental data will be collected to further quantity the effectiveness of these management activities.
5. Calibration and baseline hydrology and water quality data were presented and published in proceeding papers, abstracts, and posters at a range of scientific meetings and conferences. This report serves as the final grant report.
6. Outreach and service learning projects promoted soil conservation and water quality protection to a broad audience. Research collaborations were also formed to answer other relevant research questions related to traditional forestry management practices, species composition and water use, and forest soil carbon loss.
7. Quarterly reports were submitted to provide project updates and progress.

Lessons Learned

Phase I grant report outlined many challenges with front-end contractual and managerial support and execution that included staff changes, prolonged execution of state contracting processes, and locating long-term access to suitable forest sites. Phase II encountered issues with billing and invoicing and minor equipment failures.

Lesson: Know your soils.
Soils at HF are generally deeper, less erodible, and contain less clay content than soils found in UF. Because of the highly erodible soils at UF, high stormflow rain events caused minor erosion that undercut the flume approach section. Undercutting can reduce flow measurement accuracy as a percent of stream water flows under the flume, bypassing the flow sensor. USDA-FS staff conducted work to reinforce and re-stabilize the flume. This stabilization minimized erosion potential and undercuts. Monitoring for visual signs of undercutting occurred by-weekly. Had the degree of soil erodibility been known at the time of initial installation, the installer could have been directed to make necessary adjustments during flume installation.

Photo 10. USDA-FS summer interns add concrete around flume to stabilize streambed.

Lesson: Field monitoring equipment does fail.
The turbidity meters did not meet expectations in continuously monitoring in-stream suspended sediment. Sensor problems included recalibration issues, and physical and bio fouling that resulted in faulty turbidity readings. Although USDA-FS staff carefully followed the manufacturers suggested protocols for cleaning and mounting meters in shallow streams, these problems were ultimately unavoidable. Thus, in April 2010 all turbidity sensors were removed from the study sites as most of the data were not useful. The water quality dataset was not compromised by dropping turbidity measurements from the sampling survey as TSS data provides similar information.

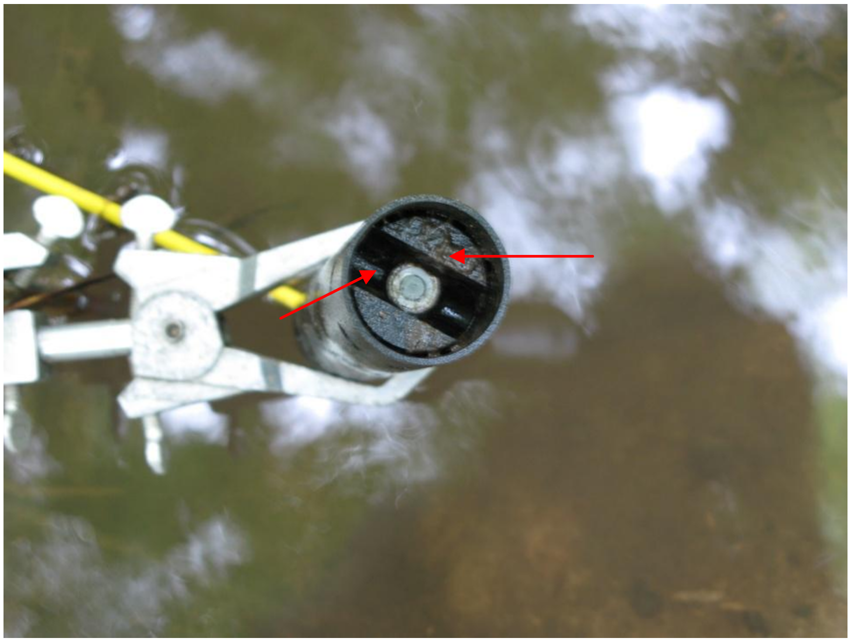


Photo 11. Sediment and algae mixture on the optical surface of turbidity meter.

Lesson: Close coordination is key to a successful timber harvest.
Regular communication between all parties involved (e.g., landowner, timber buyer, logger, study PI's) resulted in a successful harvest treatment that followed study objectives. Pre-harvest planning conducted in advance of the start of operations was an important component of this success. Regular site evaluations also assisted in identifying minor adjustments that were needed before problems occurred.

Management Implications

- Science-based research and monitoring are critically important to assessing the effectiveness of forestry BMPs at preventing nonpoint source pollution on forest harvest sites. The results from this study can provide resource professionals with the information necessary to modify and improve forestry BMPs as needed to protect water quality during forestry operations in North Carolina.
- Evaluating through field study the Neuse River Riparian Buffer Rule as it relates to forestry operations will provide valuable data to assist in determining the validity of the rule's recommendations. These data may also assist resource agency personnel with recommendations for future riparian buffer rules in the state.
- Quantifying water quality protection provided by various stream crossing alternatives will provide valuable data to assist forestry agencies and practitioners in the delivery of sound recommendations to forest landowners interested in conducting a forest harvest.
- Supplemental research conducted on this project will provide additional data on interactions between streamflow, baseflow, soil respiration, and tree transpiration in small headwater catchment riparian areas. More data on the effects of forest harvesting on these interactions will further enable resource professionals to understand the implications of forest management on these ecosystem functions.

Budget

Description	*Amount*	*Fund Source*	*Direct or In-kind*	*Actual or Estimate*
Contracted services (USDA-FS)	$117,000	319-Grant	Direct	Actual
Personnel *(includes time invested by Eastern Forest Environmental Threat Assessment Center staff on this study, but not invoiced)*	$100,000	Cooperating Agencies (NCDFR, NCDACS, NCSU, USDA)	In-Kind	Estimate
Total	***$217,000***			

References

Binkley, D., Brown, T.C. 1993. Forest practices as non-point sources of pollution in North America. Water Resources Bulletin. 29(5): 729–740.

Boggs, J.L., Sun, G., Summer, W., McNulty, S.G., Swartley, W. and Treasure, E. 2008. Effectiveness of streamside management zones on water quality: pretreatment measurements. Proceeding Paper: American Water Resources Association Summer Specialty Conference, June 30 – July 2, 2008, Virginia Beach, VA.

Brooks, K. N., Ffolliott,P.F., Gregersen, H.M, DeBano,L.F. 2003. Hydrology and the Management of Watersheds. 3rd edition. Iowa State University Press, Ames, IA.
Cleland, D.T., Freeouf, J.A., Keys, J.E., Jr., Nowacki, G.J., Carpenter, C., McNab, W.H. 2007. Ecological Subregions: Sections and Subsections of the Conterminous United States [1:3,500,000] [CD-ROM]. Sloan, A.M., cartog. Gen. Tech. Report WO-76. Washington, DC: U.S. Department of Agriculture, Forest Service.

Dreps, C. 2009. Water balance in small piedmont watersheds. Masters of Science, NSCU. Thesis Proposal.

Hewlett JD, Hibbert AR. 1967. Factors affecting the response of small watersheds to precipitation in humid areas, paper presented at International Symposium on Forest Hydrology, Pa. State University, University Park. 275-290.

Ice, G., Stuart, G.W., Waide, J.B. [and others]. 1997. Twenty-five years of the Clean Water Act: how clean are forest practices? Journal of Forestry. 95(7): 9–13.

North Carolina Division of Water Quality. 2005. Identification methods for the origins of intermittent and perennial streams, Version 3.1. North Carolina Department of Environment and Natural Resources, Division of Water Quality. Raleigh, NC.

North Carolina Office of State Budget and Management. 2008. http://www.osbm.state.nc.us (November 3, 2008).

Pru'dhomme, B.A., Greis, J.G. 2002. Chapter 22: Best Management Practices in the South. In: Wear, D.N. and J.G. Greis.(eds). Southern Forest Assessment. Gen Tech. Rep. SRS-53. Asheville, NC. U.S. Department of Agriculture, Forest Service, Southern research Station. 635 p.

North Carolina Division of Forest Resources (NCDFR), 2005. Final Report for the North Carolina Forestry Best Management Practices Implementation Survey 2000-2003. North Carolina Department of Environment and Natural Resources, North Carolina Division of Forest, Raleigh, NC.

Swank, W.T., Vose, J.M., Elliott, K.J. 2001. Long-term hydrologic and water quality responses following commercial clearcutting of mixed hardwoods on a southern Appalachian catchment. Forest Ecology and Management. 143: 163-178.

Weaver, J.C. 1998. Low-flow characteristics and discharge profiles for selected streams in the Neuse River Basin, North Carolina. US Geological Survey, Water-Resources Investigations Report 98-4135.

Wilm, H. G. 1944. Statistical control of hydrologic data from experimental watersheds. Trans Am. Geophys. Union, Pt. 2:616-622.

Wilm, H. G. 1948. How long should experimental watershed be calibrated? USDA Forest Service, Rocky Mountain Forest and Range Experiment Station. Res. Note 2.

Appendix (contact author, Johnny Boggs, 919.513.2973)

- Flow weighted nutrient and TSS concentration data.
- Detail results of benthic macroinvertebrate surveys.
- Proceeding papers 2008 and 2009.
- Poster presentation and class reports.
- Abstracts
- CD computer disk with project photos and related documents (including Appendix items)