Effects of Prescribed Burning on Stream Water Quantity, Quality, and Fuel Loads in a Small Piedmont Watershed in North Carolina

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What do we know?

- In general, prescribed fires usually have minimal hydrologic impact on watersheds because the surface vegetation, litter, and forest floor is only partially burned.

Baker, M.B., 1990

What do we know?

Table 2. Total suspended solid (TSS) concentration in headwater streams with varying disturbance types and severity.

Location	Community	Severity/activity	TSS (mg L^{-1})	References
North Carolina, Mountains	Mesic hardwoods	Low severity, prescribed fire	1-11	Vose, unpublished
East Tennessee and North Georgia, Mountains	Pine/hardwoods	Low severity, prescribed fire	1-6	Elliott and Vose 2005
South Georgia, Coastal Plain	Mixed oak-pine	Military training using tracted vehicles, <7% catchment area disturbed (low severity) >7% catchment area disturbed (high severity)	4 (baseflow) 57-300 (stormflow) 10 (baseflow) 847-1881 (stormflow)	Houser and others 2006
North Georgia, Mountains	Mixed hardwoods	Roads, land-use conversion	1-10 (baseflow) >100 (stormflow)	Riedel and others 2003
W. Oregon	Douglas-fir	Clearcut, slash burn	150	Fredriksen 1971
Montana	Mixed conifer	Wildfire	32	Hauer and Spencer 1998

Elliott and Vose, 2006. In: Second Interagency Conference on Research in the watersheds.

Table 3. Stream nitrate-nitrogen (NO_3^--N) responses following prescribed fire (Rx) and wildfire in the southeastern U.S.

Site location	Treatment	Community	Fire severity	Season	NO_3^--N response (mg L^{-1})	Duration	References
Jacobs Branch, NC	Fell and burn, Rx	Mid-elevation; Pine/hardwood	High intensity, moderate severity	Fall	0.065	30 weeks	Knoepp & Swank 1993
Wine Spring, NC	Restoration, Rx	High elevation; Pine/hardwood	Moderate intensity, low severity	Spring	0	None	Vose and others 1999
Joyce Kilmer, NC	Wildfire	High elevation; old-growth hardwoods	Low intensity, low severity	Fall	0.100	6 weeks	Clinton and others 2003
Hickory Branch, NC	Restoration, Rx	Mid elevation; Pine/hardwood	Moderate intensity, low severity	Spring	0.004	2 weeks	Clinton and others 2003
Conasauga, TN & GA	Understory, Rx	Low elevation; Pine/hardwoods	Low-to-moderate intensity, low severity	Spring	0	None	Elliott & Vose 2005
Robin Branch, NC Roach Mill, GA	Understory, Rx	High elevation; Mesic, mixed oak	Low intensity, low severity	Spring	0	None	Vose and others 2005
Uwarrie, NC	Understory, Rx	Piedmont; pine/hardwoods	Moderate intensity, moderate intensity	Spring	0	None	Vose and others 2005
Croatan, NC	Understory, Rx	Coastal Plain; longleaf pine	Low to moderate intensity, low severity	Winter	0	None	Vose and others 2005

Elliott and Vose, 2006. In: Second Interagency Conference on Research in the watersheds.

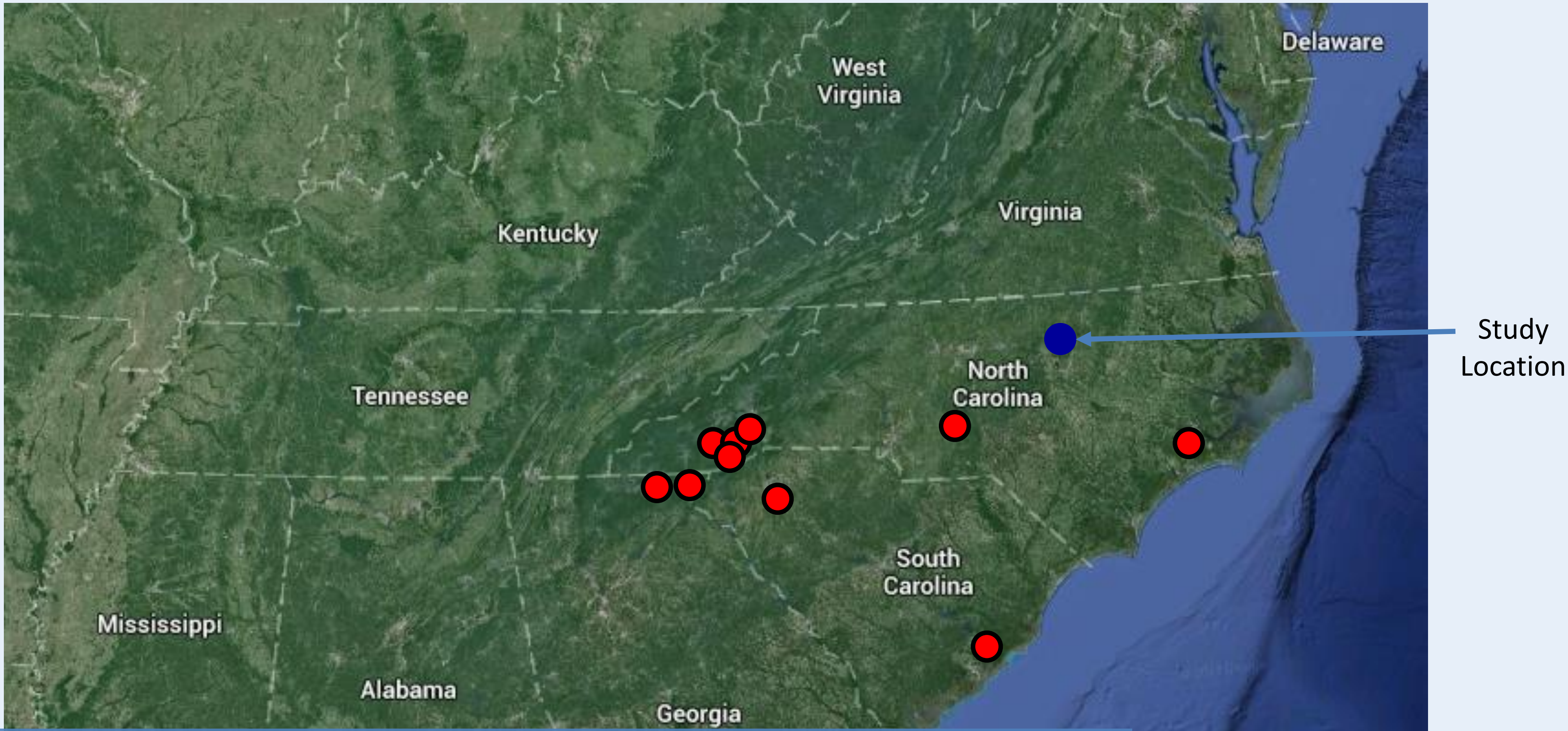
Fine and coarse woody material biomass, and live and dead fuelbed height before and after prescribed fire

Site	Treatment	Fine woody material			Coarse woody material	Live fuelbed height	Dead fuelbed height
		1-hour fuel	10-hour fuel	100-hour fuel			
		($t\ ac^{-1}$)	($t\ ac^{-1}$)	($t\ ac^{-1}$)	($t\ ac^{-1}$)	(ft)	(ft)
CNF-1	Pre-burn	0.07 (0.02)	0.6 (0.1)	1.1 (0.3)	2.2 (0.9)	2.4 (0.2)	2.0 (0.4)
	Post-burn	0.07 (0.01)	0.7 (0.1)	0.7 (0.2)	3.6 (1.3)	2.2 (0.1)	1.6 (0.3)
CNF-3	Pre-burn	0.11 (0.01)[a]	0.5 (0.1)	0.6 (0.1)	1.6 (0.4)	2.9 (0.1)[a]	1.4 (0.1)[a]
	Post-burn	0.09 (0.01)[a]	0.6 (0.0)	0.6 (0.1)	1.5 (0.4)	2.0 (0.1)[a]	2.2 (0.2)[a]
UNF-O	Pre-burn	0.16 (0.01)[a]	0.7 (0.1)[a]	2.2 (0.3)	4.9 (1.2)	1.0 (0.2)	0.5 (0.1)
	Post-burn	0.25 (0.02)[a]	1.0 (0.1)[a]	2.0 (0.2)	5.3 (1.3)	0.8 (0.2)	0.8 (0.2)
UNF-P	Pre-burn	0.11 (0.01)	0.7 (0.1)	2.3 (0.3)	2.6 (0.9)	1.0 (0.2)	0.5 (0.1)[a]
	Post-burn	0.11 (0.01)	0.6 (0.1)	2.6 (0.4)	3.5 (0.5)	0.7 (0.1)	0.1 (0.0)[a]

CNF-Croatan National Forest 1- and 3-year burn cycle, *UNF*-Uwharrie National Forest oak (O) and pine (P) sites
Numbers in parentheses are the standard error of the mean
[a]Within site and fuel class treatment means significantly different, $P<0.05$

Gavazzi and McNulty 2014, International Association of Wildland Fire, Missoula, Montana, USA

Location of Prescribed Fire Studies in the South



Objectives

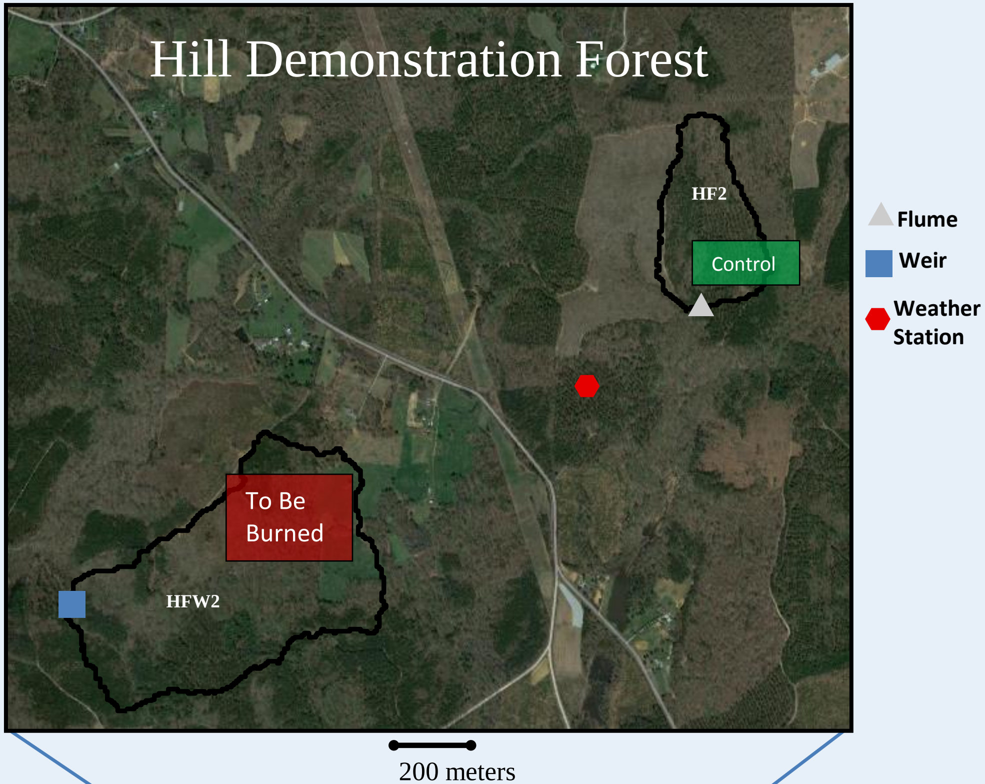
- Quantify responses of discharge, sediment, and nutrient concentrations and loads to prescribed fire in a small Piedmont catchment.

- Quantify fuel load reduction at the watershed scale.

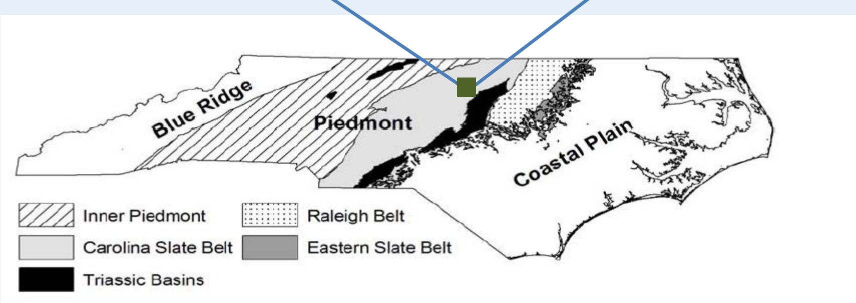
Hypotheses

- Prescribed burning **significantly increases peakflow, total water yield** due to reduction of groundcover, understory and overstory vegetation transpiration, and loss of soil duff and forest floor layers.
- Prescribed burning **does not significantly** increase sediment and nutrient (N, P, NO_3, NH_4) **concentrations**.
- Prescribed burning **significantly increases** sediment and nutrient **loads** due to elevated runoff and reduced plant nutrient uptake.
- Prescribed burning **significantly reduces small, medium, and large fine woody material, litter, and shrub fuel loads** but **does not significantly reduce coarse woody material and overstory biomass**.

Study Watersheds



	Hill Demonstration Forest	
	HF2	HFW2
Watershed size (ha/ac)	12/30	40/99
Stream length (m/ft)	260/853	960/3149
Stand type	Mixed-pine hardwood	
Stand Age (years)	35	
Slope (%)	13	
Geologic Features	Carolina Slate Belt	
Dominate Soil Series	Tatum and Appling	
Soil characteristics	Non expansive clays, no perched water, deep soils, and discharge water slowly throughout the year due to large amounts of stored water in bedrock and topographic control.	



Experimental Design

Paired Watershed

- The experimental design consisted of:
  - a pair of watersheds (reference and treatment)
  - a calibration or pre-burn period
  - a treatment (prescribed fire in this case)
  - a post-burn period.

- In the pre-burn phase (2007-2013), discharge and the water quality parameters from the paired watersheds were calibrated. To calibrate the watersheds, a set of linear relationship/models ($y = mx + b$) between daily discharge and monthly TSS and nutrient concentrations and loads from each pair were generated with all probability values (p) being < 0.05.

- The differences between **measured** and **modeled values** during the post-treatment period (2015-2016) will represent the treatment effect.

Experimental Design

Paired Watershed

- Calibrating the reference watershed to the treatment watershed provided a more accurate assessment of treatment impacts on discharge, water quality data, and cause-effect relationships when compared to referencing the treatment watershed directly.

- The reference watershed also accounts for annual and seasonal climate variability, and will offer predictable and measureable differences between paired discharge and water quality parameters after the burn.

Models developed during calibration period 2008 – 2013.

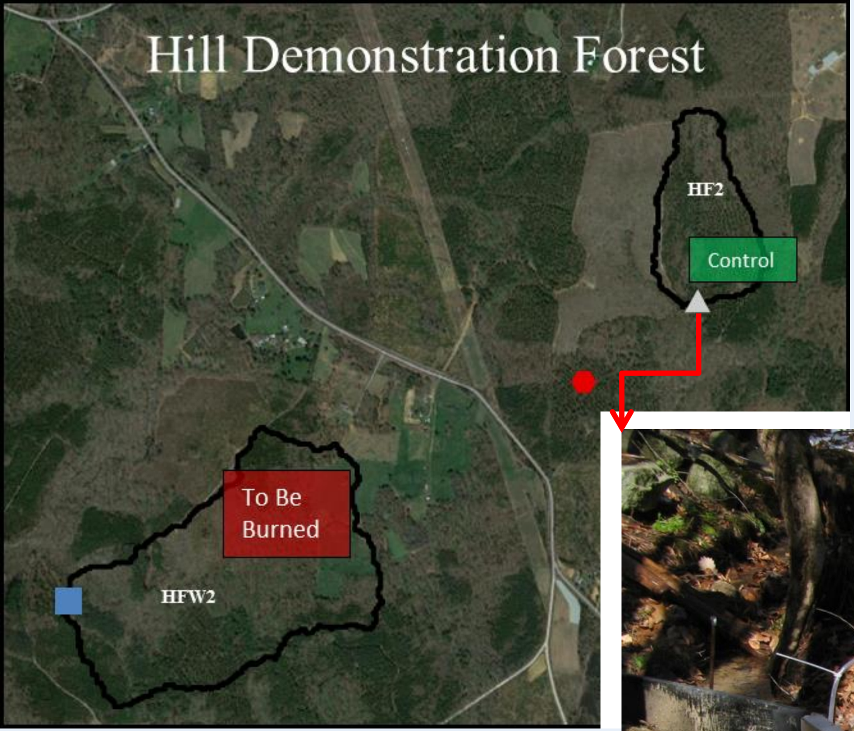
Watersheds	Streamflow (Daily Data)		
HF2 vs HFW2	$y = 1.13x – 0.04$	$r^2 = 0.91$	$p < 0.001$
	Total Suspended Sediment Load (Monthly Data)		
HF2 vs HFW2	$y = 1.16x – 0.9$	$r^2 = 0.62$	$p < 0.001$
	Total Nitrogen (Monthly Data)		
HF2 vs HFW2	$y = 0.03$ $1.03x – 0.01$	$r^2 = 0.50$	$p < 0.001$

Field Data

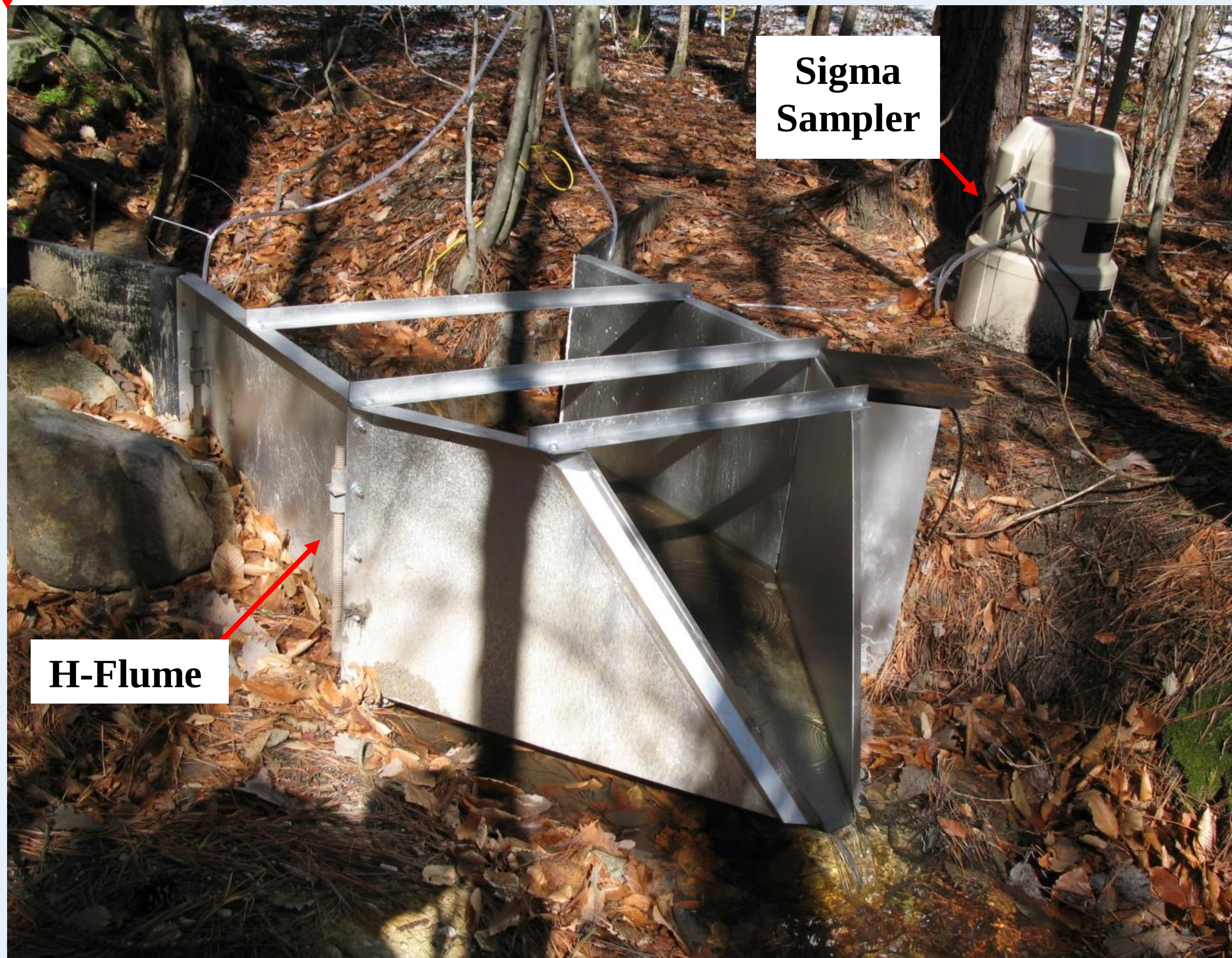
Data categories, parameters, frequency, and methods used to collect data from NC Piedmont paired watersheds.

Data Category	Parameters	Measurement Frequency	Methods
Meteorology	Rainfall, air temp, relative humidity, total solar radiation, wind speed, soil moisture	Sampled every 4 minutes, logged every hour	Hobo micrometeorological station
Stream flow	Water depth, flow rate, flow volume	10 minute intervals	Weirs or flumes and associated water level recorders
Woody Material/Vegetation /Litter/Duff **Fire intensity** **Fire severity**	Fine and coarse woody material (fuel load), Overstory, midstory, shrub & herbaceous cover, litter & duff depth, live and dead fuelbed height.	Pre-burn and/or Post-burn	Forest Inventory Analysis and Chojnacky et al., 2003 Temperature-sensitive paint Matrix of vegetation and soil impacts (Ryan 2002)
Land topography	Digital Elevation Model (DEM)	Once	USGS DEM database
Water quality	TSS, NO3-N, NH4-N, TP, TKN, TOC at the watershed outlets.	During stormflow and baseflow	Grab samples (baseflow) and Sigma sampler programmed for storm event sampling.

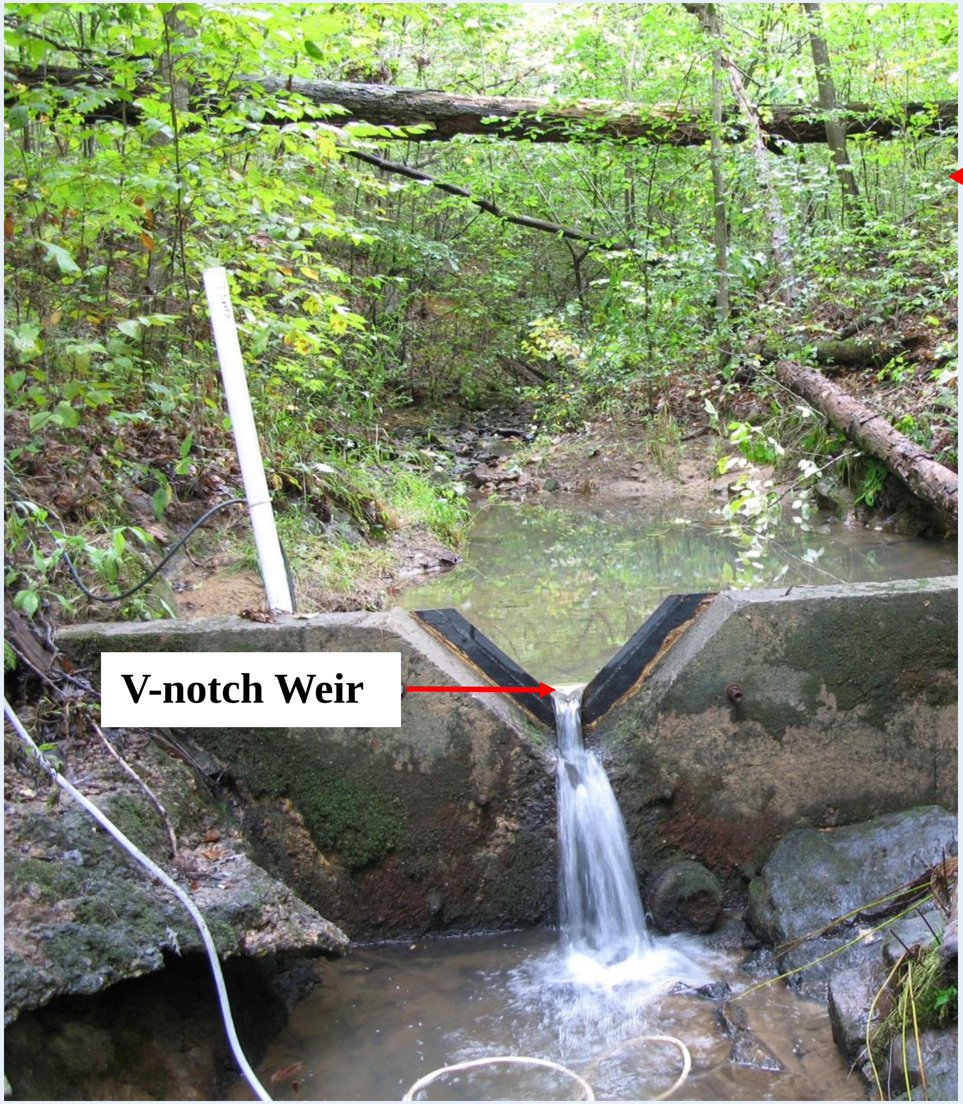

3-cup Anemometer and Wind Vane (Wind Speed and Direction)
Silicon Pyranometer Sensor (Solar Radiation)
Tipping Bucket (Precipitation)
Air Temperature, Dew Point, and Relative Humidity Sensors
Data Logger

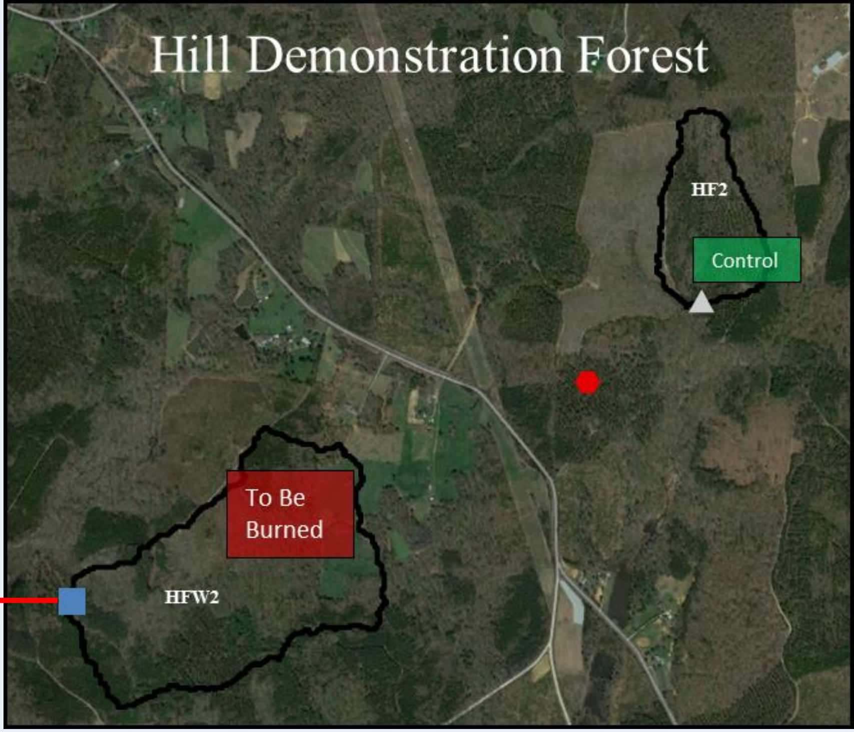


Hill Demonstration Forest
HF2
Control
To Be Burned
HFW2



Sigma Sampler
H-Flume


V-notch Weir


Hill Demonstration Forest
HF2
Control
To Be
Burned
HFW2

Fuel Loads, Overstory, Midstory, and Groundcover Measurements

N

Measurements along each 98.4’ transect:

Coarse Woody Material (≥ 3.0”)

– species, diameter and decay class

Fine Woody material (< 3.0”) Tally one segment and measure other (80’ to 90’)

– small (< 0.25”)

– medium (0.25 – 0.99”)

– large (1.0 – 2.99”)

Measurements at plot center, 32.8’ radius:

Overstory (Woody Vegetation ≥ 5 “)
- species (live and dead), dbh, and canopy openness (fisheye method)

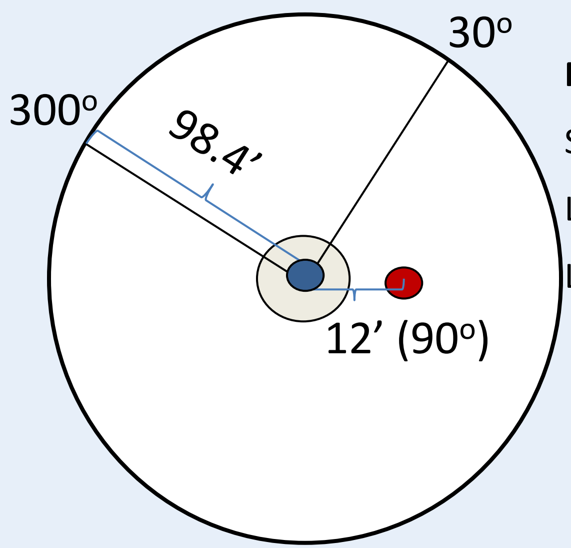
Measurements at plot center, 16.4’ radius:
Midstory (Woody Vegetation 1” to 5”)
- species (live and dead) and dbh

Measurements microplot plot, 6.8’ radius:

Shrub & herbaceous height & percent coverage

Litter & duff depth

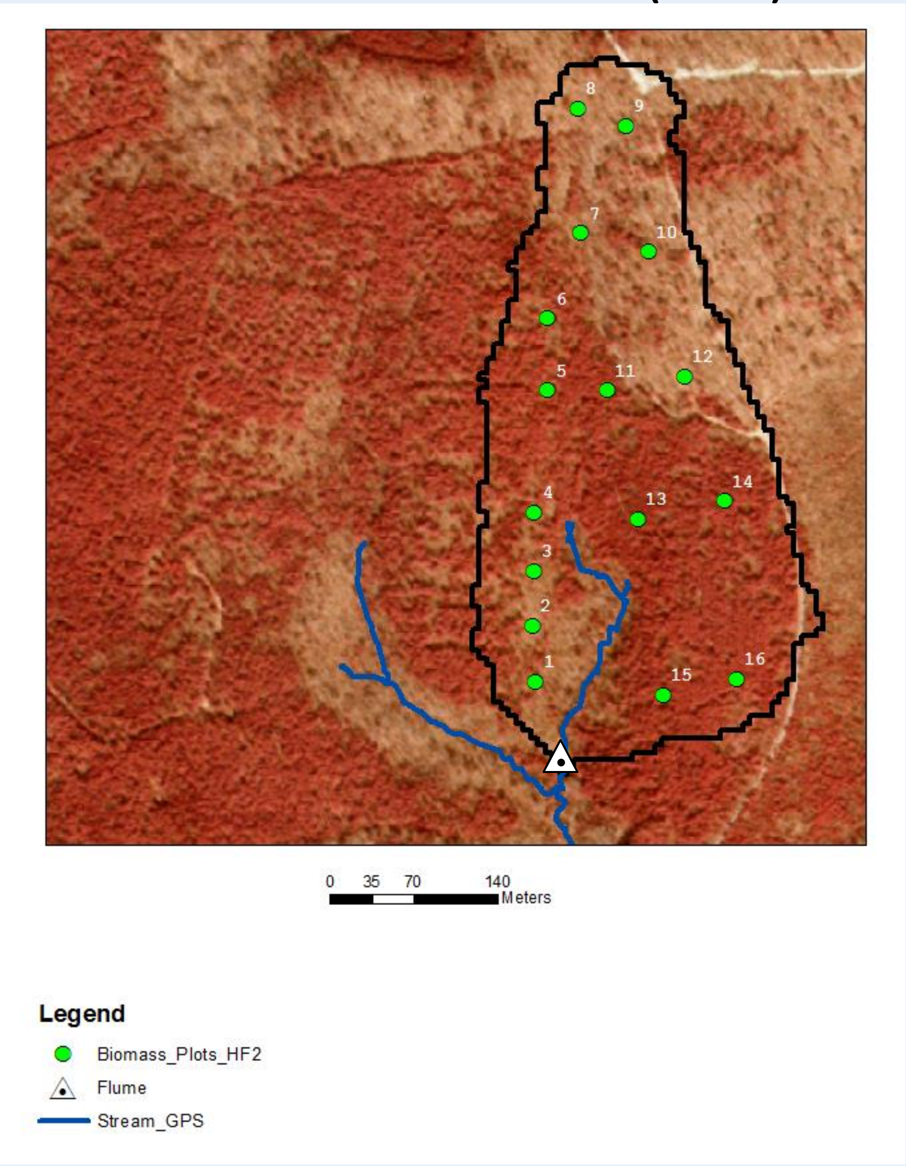
Live and dead fuelbed height



Based on USDA FIA Phase 3 field guide for measuring down woody materials

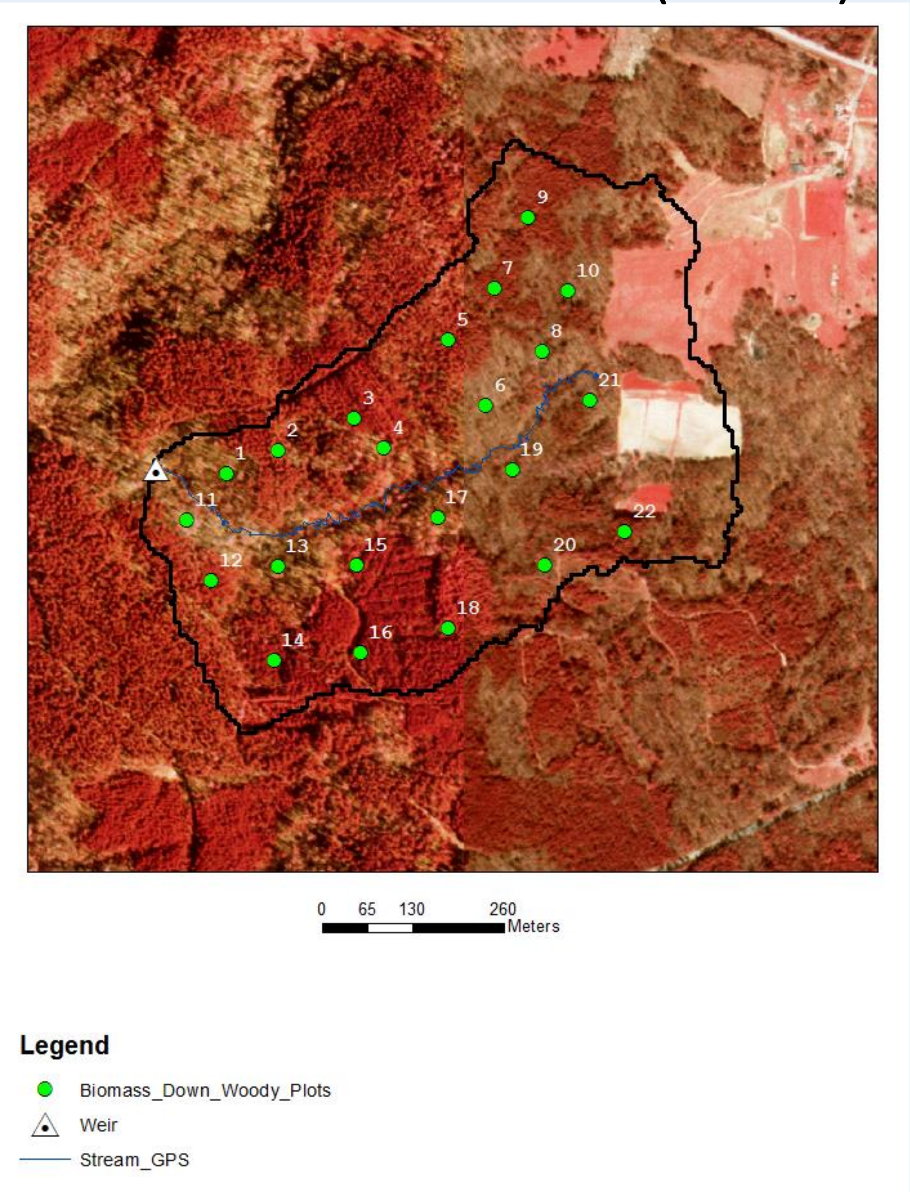
Fuel Load Plot Locations

Control Watershed (HF2)



Fuel Load Plot Locations

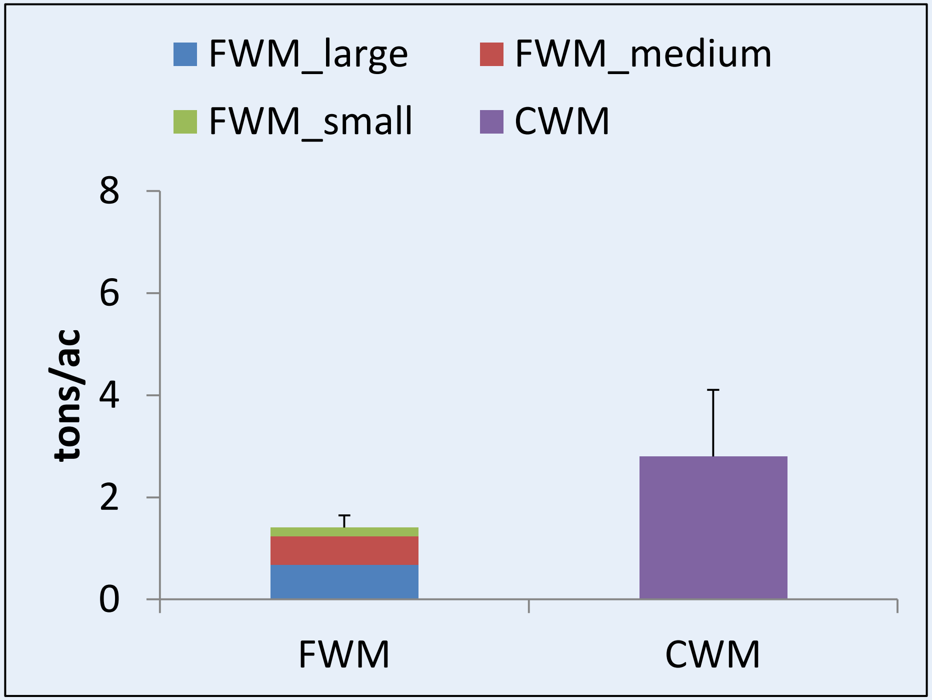
Treatment Watershed (HFW2)



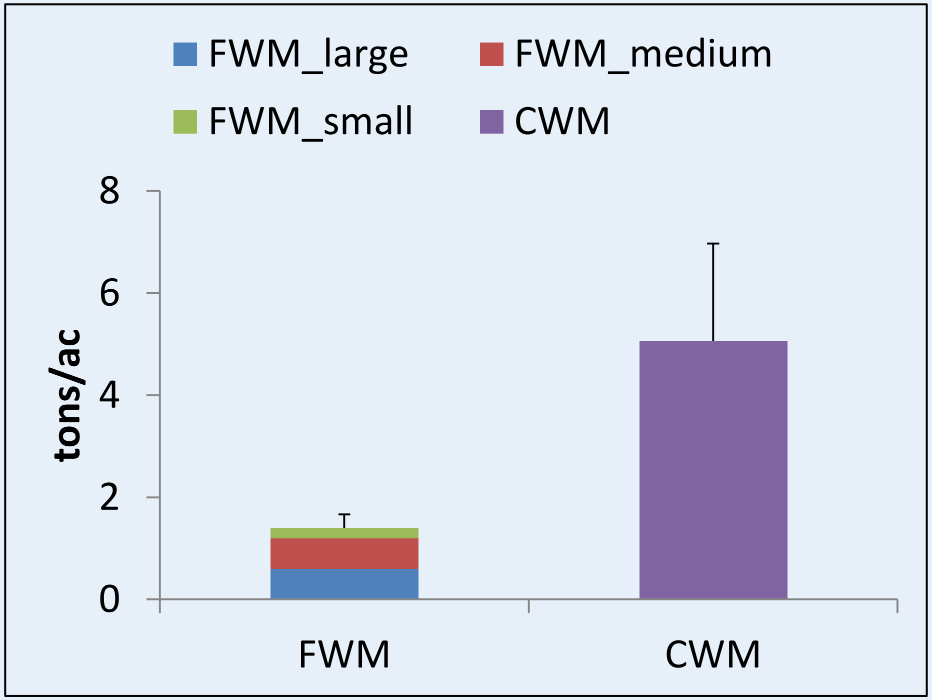
Pre-Burn Results

Pre-Burn Fine Woody Material (FWM) and Coarse Woody Material (CWM)

Control Watershed



Treatment Watershed



Optimum range of CWD that provides an acceptable risk of fire hazard while providing benefits to soil and wildlife

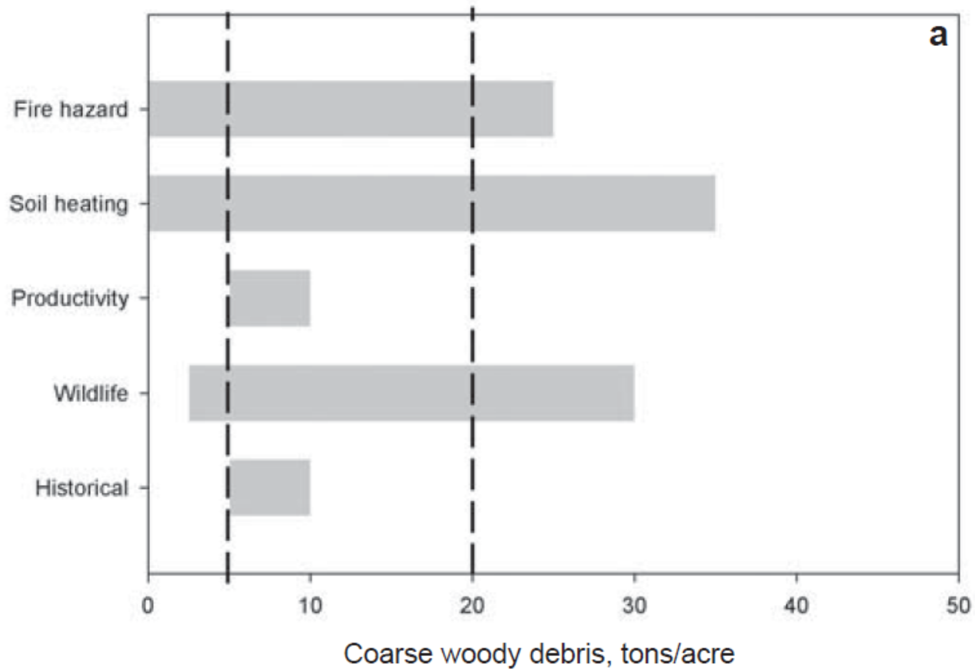
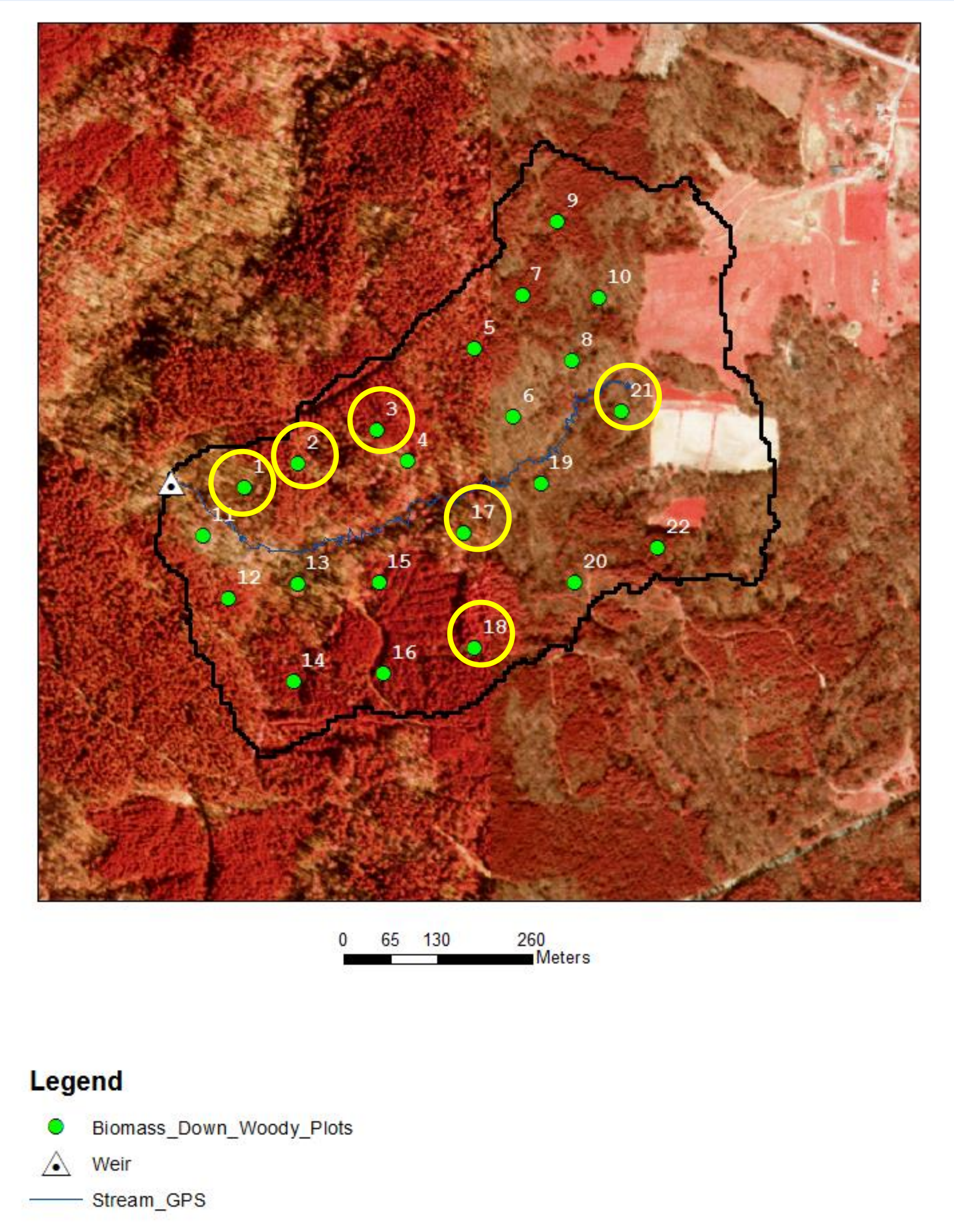
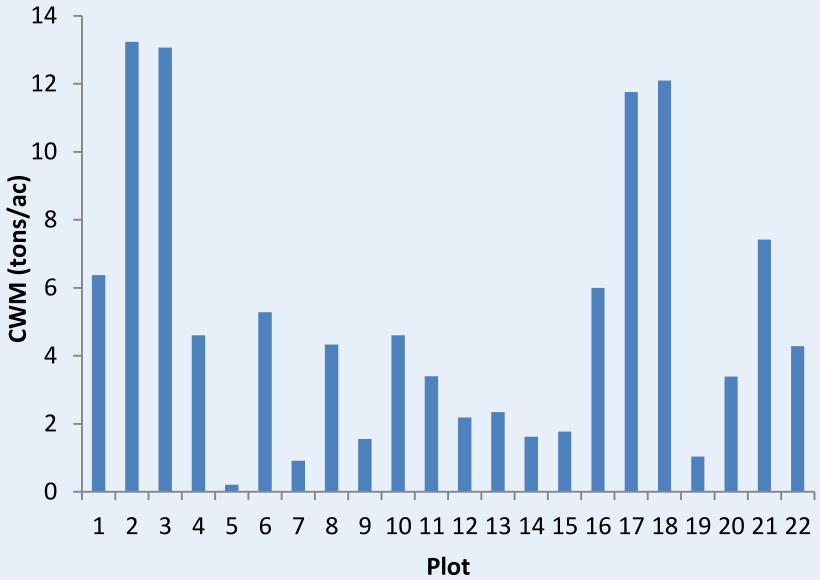


Figure 2—Optimum ranges of coarse woody debris for providing acceptable risks of fire hazard and fire severity while providing desirable quantities for soil productivity, soil protection, and wildlife needs for (a) warm dry forest types Dotted lines show a range that seems to best meet most resource needs: 5 to 20 tons per acre for the warm dry types

USDA Forest Service Gen. Tech. Rep. RMRS-GTR-105. 2003

Fuel load plots in treatment watershed with CWM higher 10 tons/ac (maximum amount to benefit soil productivity). These high fuel areas (yellow circles) could result in greater fire intensity than other areas across the watershed which may lead to a moderate/severe fire severity.





Pre-Burn Discharge and Water Chemistry Concentration

Year	HF2	HFW2	HF2	HFW2	HF2	HFW2
	TSS, mg/l		NO_3, mg/l		Discharge, l/s	
2008	29.8	19.9	0.007	0.056	0.62	1.93
2009	33.7	35.2	0.005	0.040	0.99	3.42
2010	43.7	42.1	0.005	0.024	1.04	2.87
2011	34.5	26.8	0.014	0.008	0.47	0.85
2012	34.5	22.8	0.003	0.018	0.46	0.84
2013	32.2	30.0	0.000	0.027	0.64	2.64
Mean	34.7	29.5	0.006	0.029	0.70	2.09

Pre-Burn Discharge and Water Chemistry Load

Year	HF2	HFW2	HF2	HFW2	HF2	HFW2
	TSS, kg/ha/yr		NO_3, kg/ha/yr		Discharge, l/s	
2008	48.8	30.3	0.011	0.085	0.62	1.93
2009	87.8	94.8	0.013	0.108	0.99	3.42
2010	119.6	95.2	0.013	0.055	1.04	2.87
2011	42.2	17.9	0.017	0.006	0.47	0.85
2012	41.9	15.1	0.004	0.012	0.46	0.84
2013	54.1	62.5	0.000	0.057	0.64	2.64
Mean	65.7	52.6	0.010	0.054	0.70	2.09

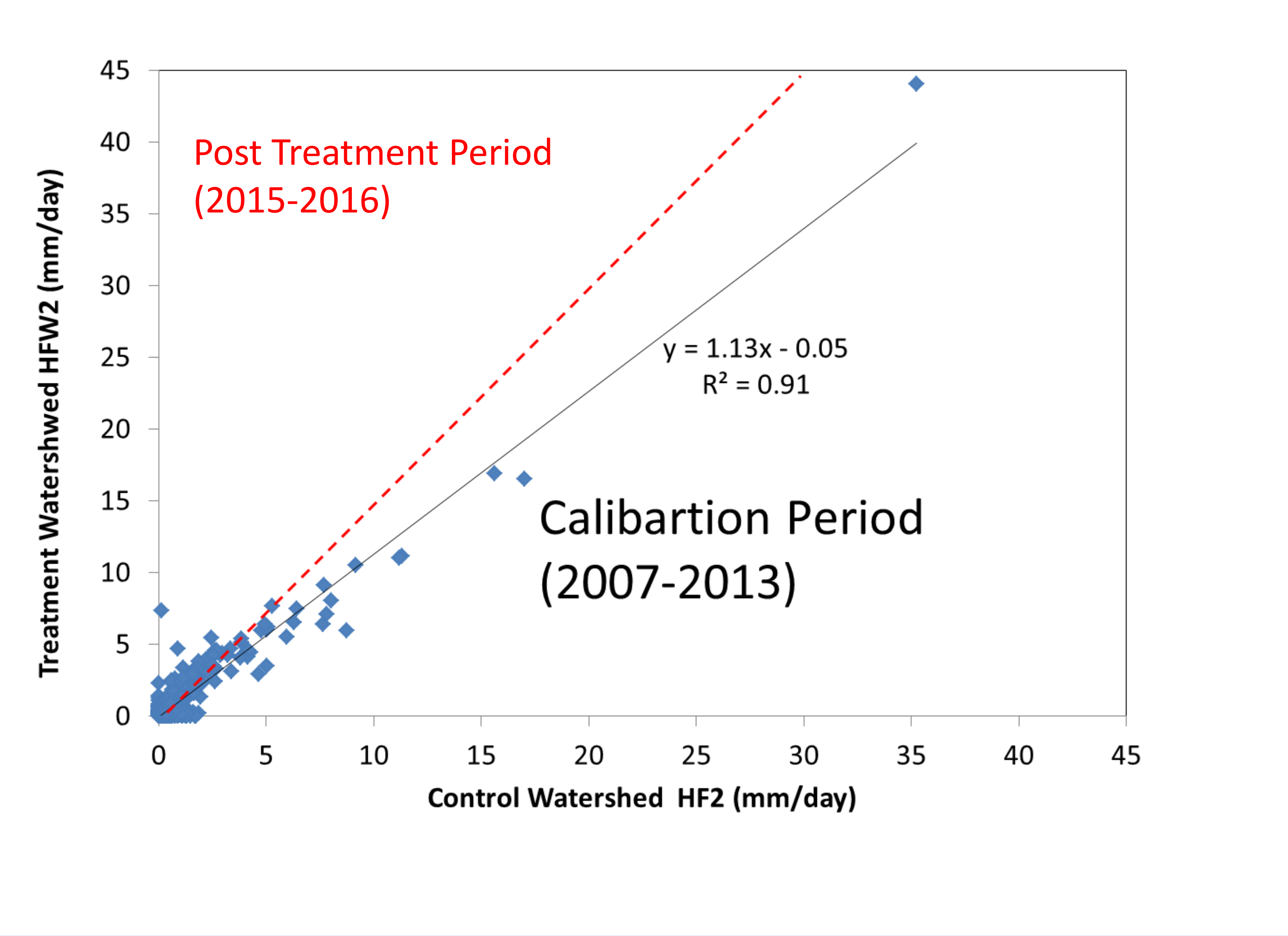
How to detect effects of prescribed burn on fuel loads, water quantity, and quality

Fuel Loads

Watershed	Treatment	Fine woody material Small (t ac^{-1})	Fine woody material Medium (t ac^{-1})	Fine woody material Large (t ac^{-1})	Coarse woody material (t ac^{-1})	Live fuelbed height ft	Dead fuelbed height ft
HF2, 2014	Pre-Burn	0.17	0.56	0.68	2.8	0.5	0.2
HFW2, 2014	Pre-Burn	0.20	0.60	0.60	5.1	2.0	3.0
HF2, 2015	Post-Burn	?	?	?	?	?	?
HFW2, 2015	Post-Burn	?	?	?	?	?	?
HF2, 2016	Post-Burn	?	?	?	?	?	?
HFW2, 2016	Post-Burn	?	?	?	?	?	?

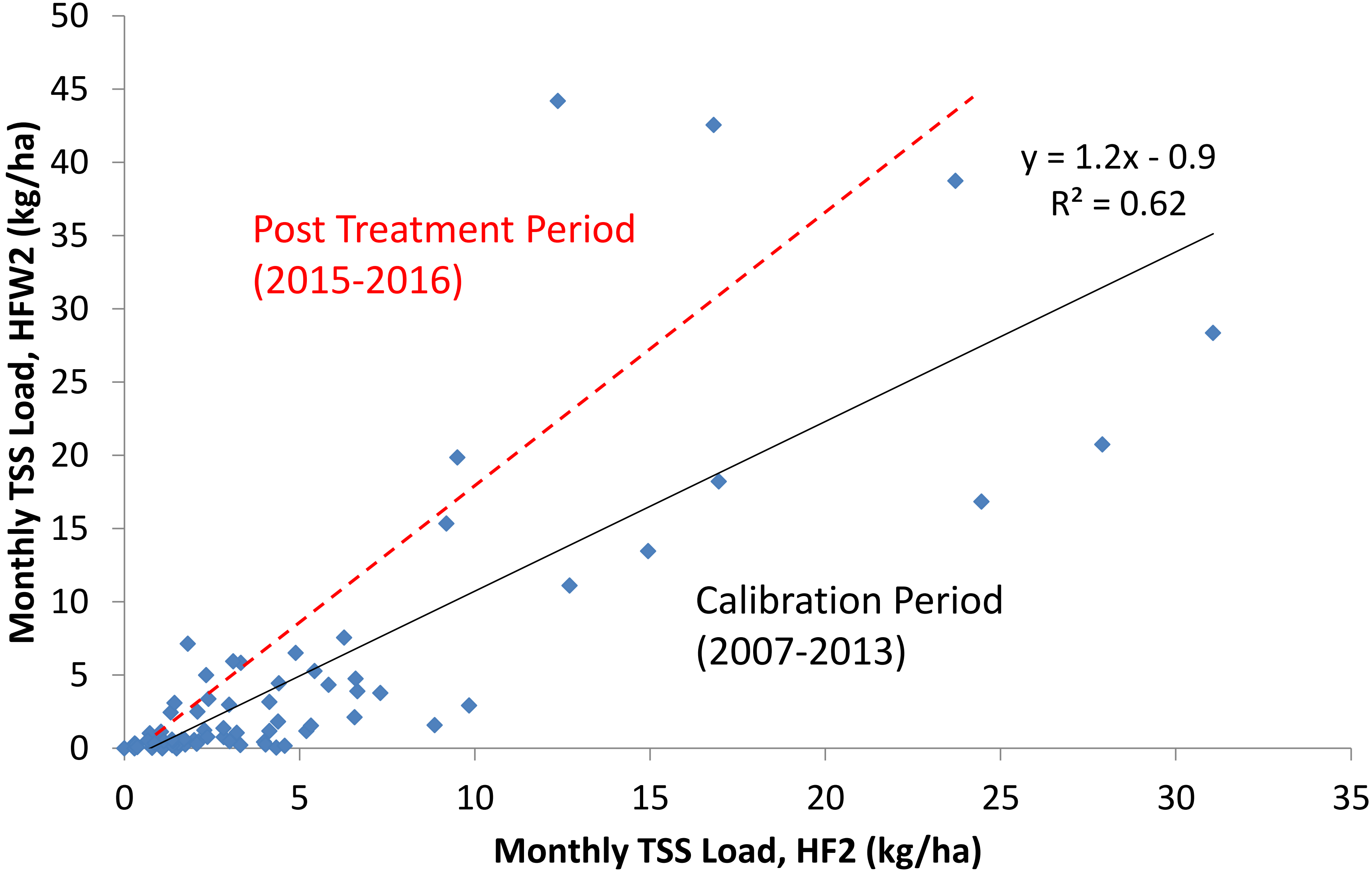
Water Quantity

The red line is hypothetical change after treatment



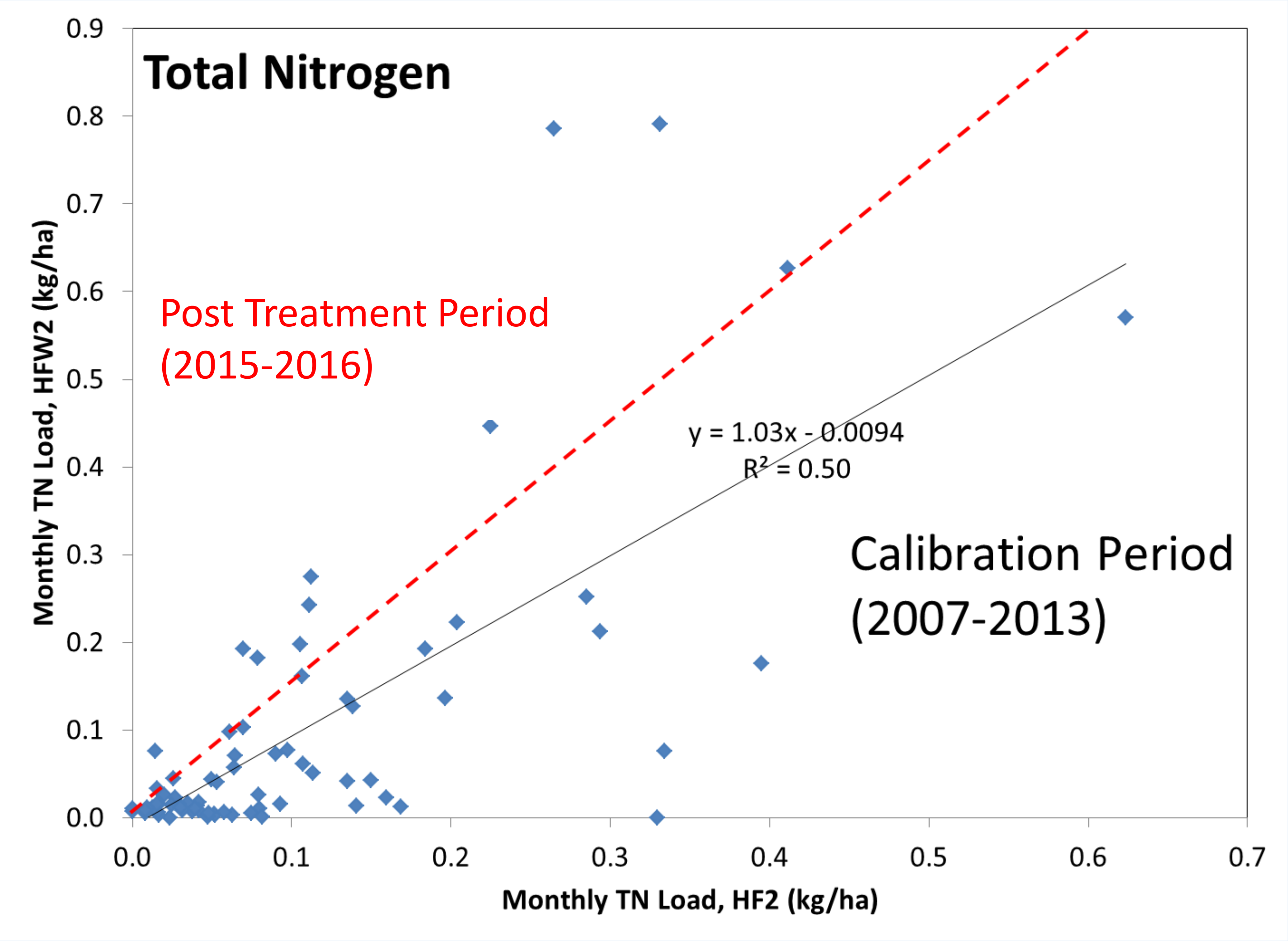
Water Quality, TSS

The red line is hypothetical change after treatment



Water Quality, TN

The red line is hypothetical change after treatment



Water Quality and Discharge Concentration

Year	HF2 (measured)	HFW2 (measured)	HFW2 (modeled)	HF2 (measured)	HFW2 (measured)	HFW2 (modeled)	HF2 (measured)	HFW2 (measured)	HFW2 (modeled)
	TSS, mg/l			NO_3, mg/l			Discharge, l/s		
	Pre-Burn								
2008	29.8	19.9	22.6	0.007	0.056	0.044	0.6	1.9	1.8
2009	33.7	35.2	28.1	0.005	0.040	0.036	1.0	3.4	3.2
2010	43.7	42.1	41.8	0.005	0.024	0.036	1.0	2.9	3.4
2011	34.5	26.8	29.1	0.014	0.008	0.018	0.5	0.9	1.2
2012	34.5	22.8	29.2	0.003	0.018	0.029	0.5	0.8	1.2
2013	32.2	30.0	25.9	0.000	0.027	0.018	0.6	2.6	1.8
Mean	**34.7**	**29.5**	**29.5**	**0.006**	**0.029**	**0.030**	**0.7**	**2.1**	**2.1**
	Post-Burn								
2015	?	?	?	?	?	?	?	?	?
2016	?	?	?	?	?	?	?	?	?

Outcome and Products

- Data on the impacts of prescribed fire on stream water quality and quantity **at a watershed scale** in the Piedmont region
- Demonstration site for active fire management to reduce fuel loads
- Student education, thesis project
- Peer-review publications (1-2)

Ge was awarded a half million project by Joint Fire Science Program to do a 3 year study on wildfire impacts on hydrology (next slide). Our Hill Forest work will contribute to part of the objectives of that study.

H51I-0720

Effects of Wildfires and Fuel Treatment Strategies on Watershed Water Quantity across the Contiguous United States

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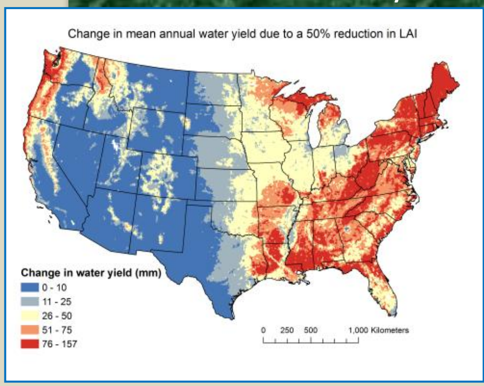
Objectives

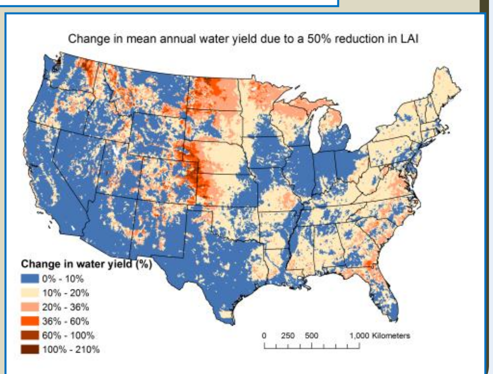
1. to combine historic large wildfire and USGS streamflow records to examine hydrologic impacts of past large wildfires and validate process-based models for regional applications

2. to evaluate the sensitivity of watershed seasonal water yield to fuel management strategies at the basin scale (12 digit Hydrologic Unit Code) across the CONUS using the WaSSI model, and

3. to identify key municipal watersheds that are most vulnerable to wildfires and to quantify potential short and long-term impacts of wildfires on water supply and peakflow rates using a process-based hydrologic model (i.e., MIKE SHE model).

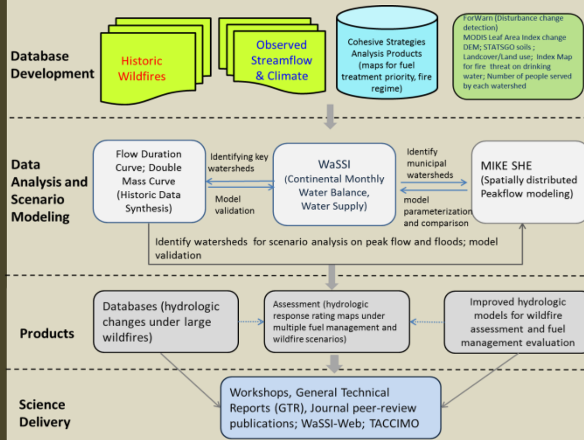
Water Yield Sensitivity to LAI





Simulated by the WaSSI hydrological model

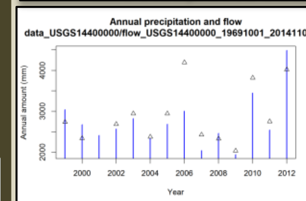
METHODS

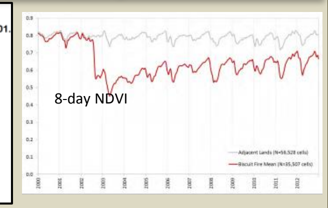


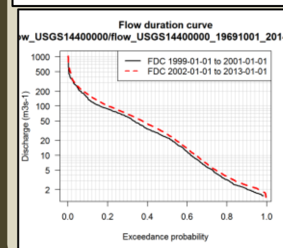
Hypotheses

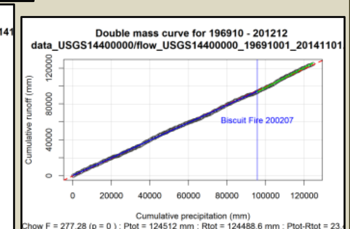
H1: Climatic Regime: Wildfires have higher impacts on total water yield volume in wetter regions (e.g., southeastern U.S., coastal regions) or wetter years than drier regions (interior West) or years.
H2: Fire Severity. Hydrologic responses increase with fire severity, fuel treatment intensity, and decrease with the time interval between the burns and rainfall events.
H3: Threshold Response. detectable/significant only when the area of forest vegetation burned, removed, or thinned exceeds 20-40% of the total area.
H4: Recovery Time In a drier climate it takes longer time to recover than in a wetter climate (e.g., southeast, coastal regions)
H5: Soil Disturbances Significant increases of large peakflows that trigger debris flow after severe wildfires are a result of soil disturbances.

Case Study: 2002 Biscuit Fire, Oregon-California









PRELIMINARY FINDINGS

- There is a large variability in hydrologic response to wildland fires due to climatic, soil, and vegetation differences.

- The 2002 Biscuit fires caused an increase in streamflow for all streamflow percentiles.

- Twenty watersheds have been identified to conduct detailed hydrological analysis across the CONUS.

ACKNOWLEDGEMENT: Project Funded by the Joint Fire Science Program