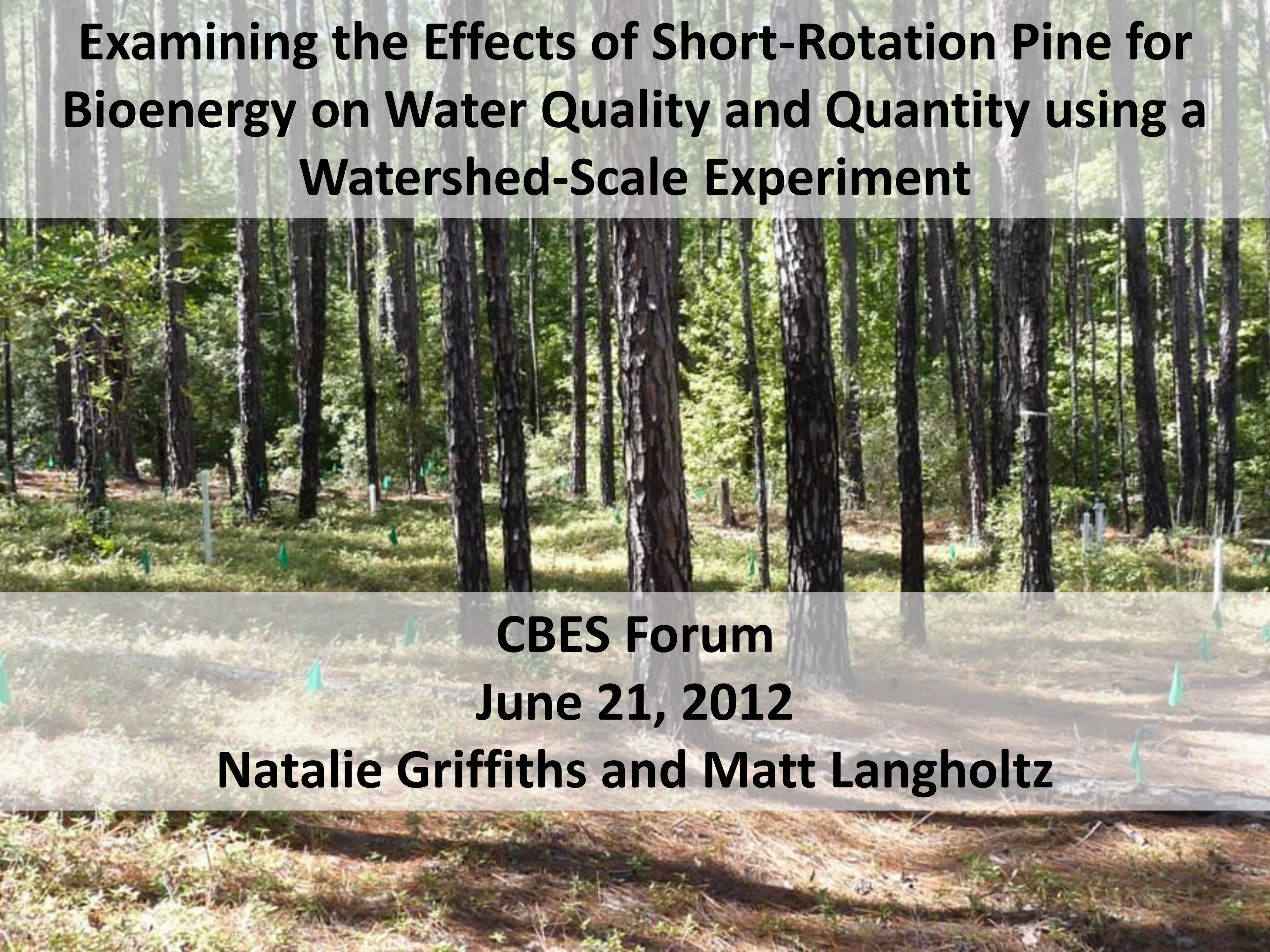
Examining the Effects of Short-Rotation Pine for Bioenergy on Water Quality and Quantity using a Watershed-Scale Experiment



CBES Forum

June 21, 2012

Natalie Griffiths and Matt Langholtz

Bioenergy Production

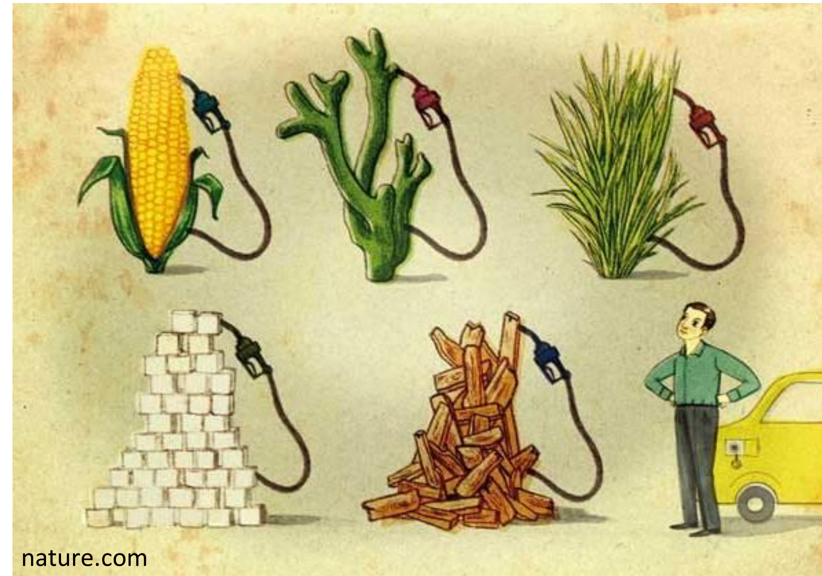
- Growing demand for bioenergy due to issues of energy security and climate change

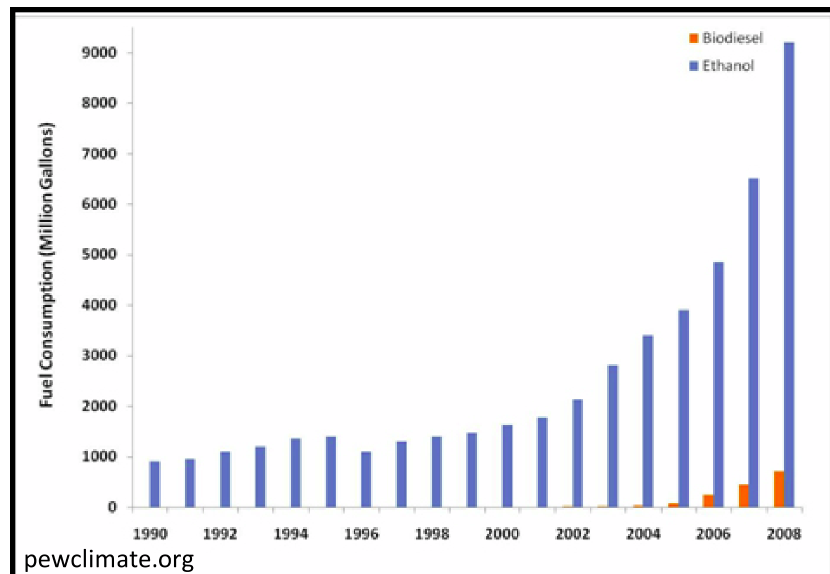
- Variety of feedstocks (e.g., corn, switchgrass, pine) and types of bioenergy (e.g., bioethanol, biodiesel, biomass)

- All aspects of the supply chain (field to consumer) are being assessed

- Sustainability is an important goal in developing bioenergy technologies

- Need to evaluate the environmental sustainability of these practices





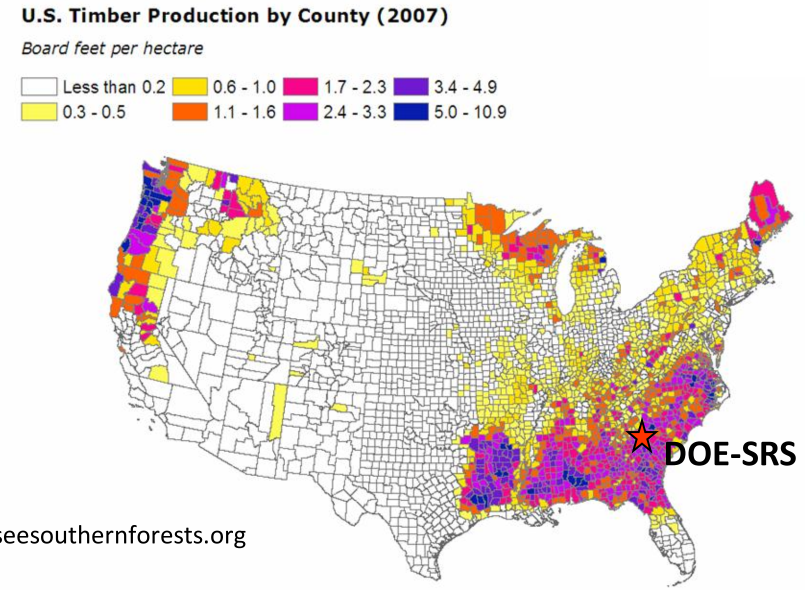
Short-Rotation Woody Biomass Sustainability

- Southeastern US may be a dominant source of pine for bioenergy (e.g., lignocellulose, biomass)

- Practice involves achieving high yields with short rotation (10-12 years) via fertilizer and herbicide applications

- Environmental sustainability (water quality, quantity) needs to be evaluated at the watershed scale

- Collaborative project with U. of Georgia, Oregon State U., and the US Forest Service at Savannah River



seesouthernforests.org

Project Goal and Outcomes

Goal:

- Use watershed-scale experiments along with a distributed catchment modeling approach to evaluate the environmental sustainability (water quality and quantity) of intensive short-rotation pine practices for bioenergy in the Southeastern US.

Outcomes:

- Provide watershed and operational-scale data on woody biomass production for bioenergy

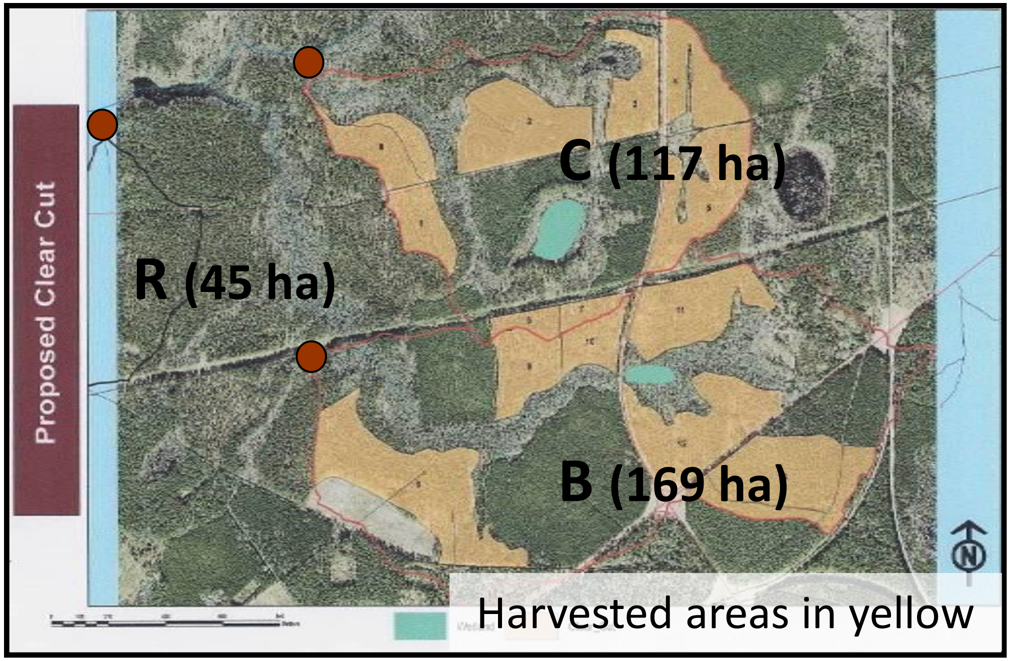
- Determine baselines and targets for water quality and quantity in relation to current Best Management Practices (BMP)

- Modeling effort will expand and generalize results to the Coastal Plains region to estimate hydrological and water quality effects of short-rotation pine in areas with different topography, soils, and vegetation

Watershed-Scale Experimental Design

- BACI design: 1 ref. (R), 2 treatment (B, C) watersheds, currently mixed pine/deciduous forests at Savannah River Site, SC

- Intensive practices planned on 40+% of watersheds B, C and will follow SC forestry BMPs



Timeline:
- 2009-2011: determine baseline hydrology and water quality
- 2012: harvest extant forest
- 2013: plant loblolly pine
- 2014-2018: monitor hydrology and water quality until crown closure

- Hydrologic measurements will inform watershed behaviour and will be used to develop hillslope- and watershed-scale hydrologic models
- Model development will occur in parallel throughout the study

<u>Silviculture Treatment Plan</u>

Lead: Blake (USFS)

- 2 watersheds will each receive one integrated silviculture treatment

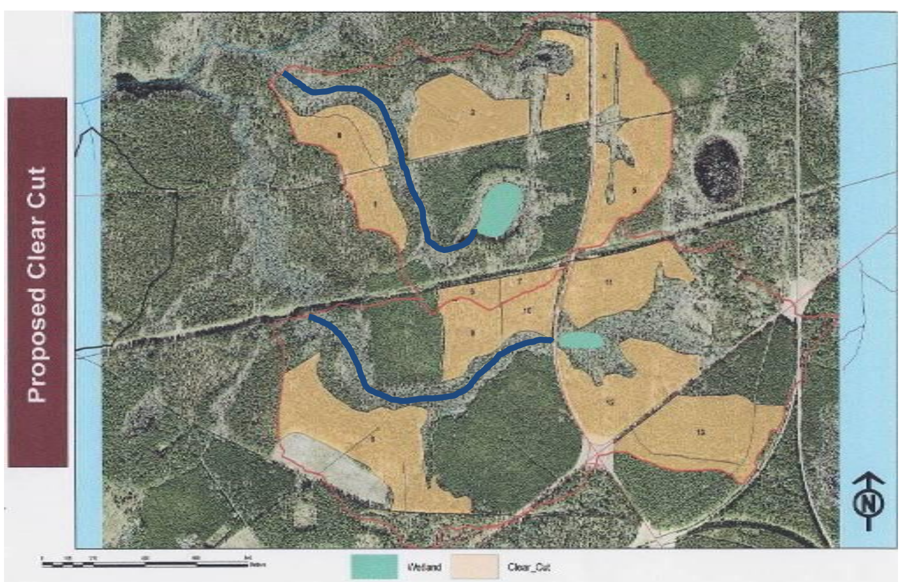
<u>Silviculture Schedule</u>:

- <u>Harvest</u> of 40%+ of extant forest, completed May 2012
- Chemical and mechanical <u>site preparation</u>, summer-fall 2012
- <u>Plant</u> elite genetic loblolly pine in Dec 2012-Feb 2013
- Banded application of <u>herbicide</u> in March 2013 and 2014 for herbaceous control
- <u>Fertilization</u> of planting rows with N and P in May-June 2013, 2014, 2016, 2018, 2022

Silviculture will follow South Carolina BMPs

Simplified Forestry Best Management Practices (BMPs):

1. Minimize bare ground coverage and soil compaction
2. Separate bare ground from surface waters
3. Separate fertilizer/pesticide application from surface waters
4. Inhibit hydraulic connections between bare ground and surface waters
5. Provide a forested buffer around streams
6. Provide stable stream crossings for roads



Soil-Vegetation Nitrogen Cycling Study

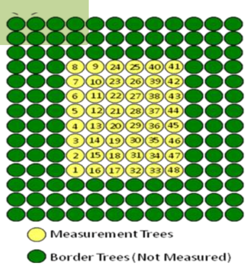
Lead: Kaczmarek (USFS)

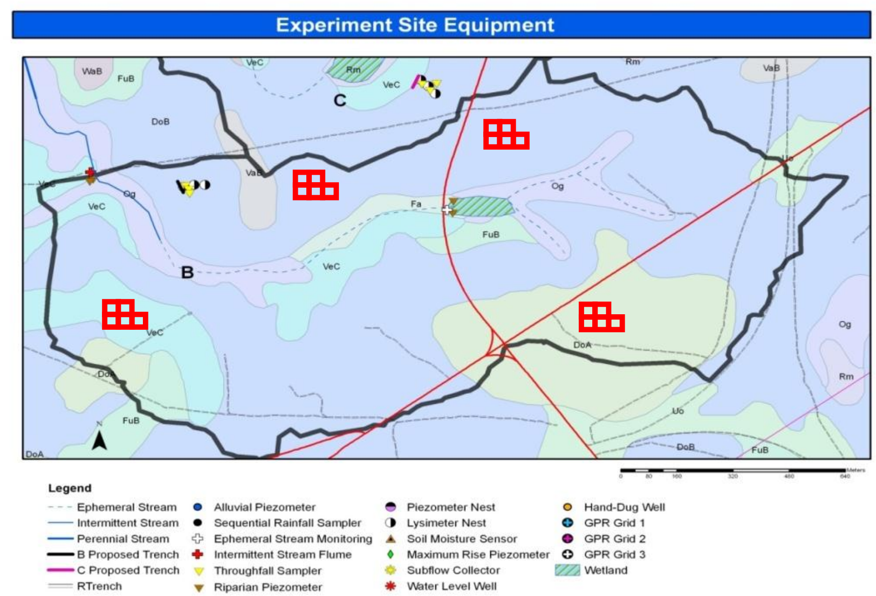
Objectives:

- Quantify soil-vegetation nitrogen budget during pine development
    - N mineralization, N leaching, N use efficiency

- Determine pine nutrient uptake and productivity under changing resource availability using a plot-scale study
    - Study design: 5 treatments, 4 reps per watershed
    - Watershed-level treatment (TRT4) = highest level of management
    - TRT1-3 = less intensive
    - TRT5 = higher density trees

TRT1	TRT2	TRT3	TRT4	TRT5
Elite genetics	Elite genetics	Elite genetics	Elite genetics	Elite genetics
No nutrients	No nutrients	1/2 nutrients	Op. nutrients	Op. nutrients
No herbicides	Op. herbicides	Op. herbicides	Op. herbicides	Op. herbicides
Op. density	Op. density	Op. density	Op. density	High density





Watershed Characterization

Lead: Jackson (UGA)

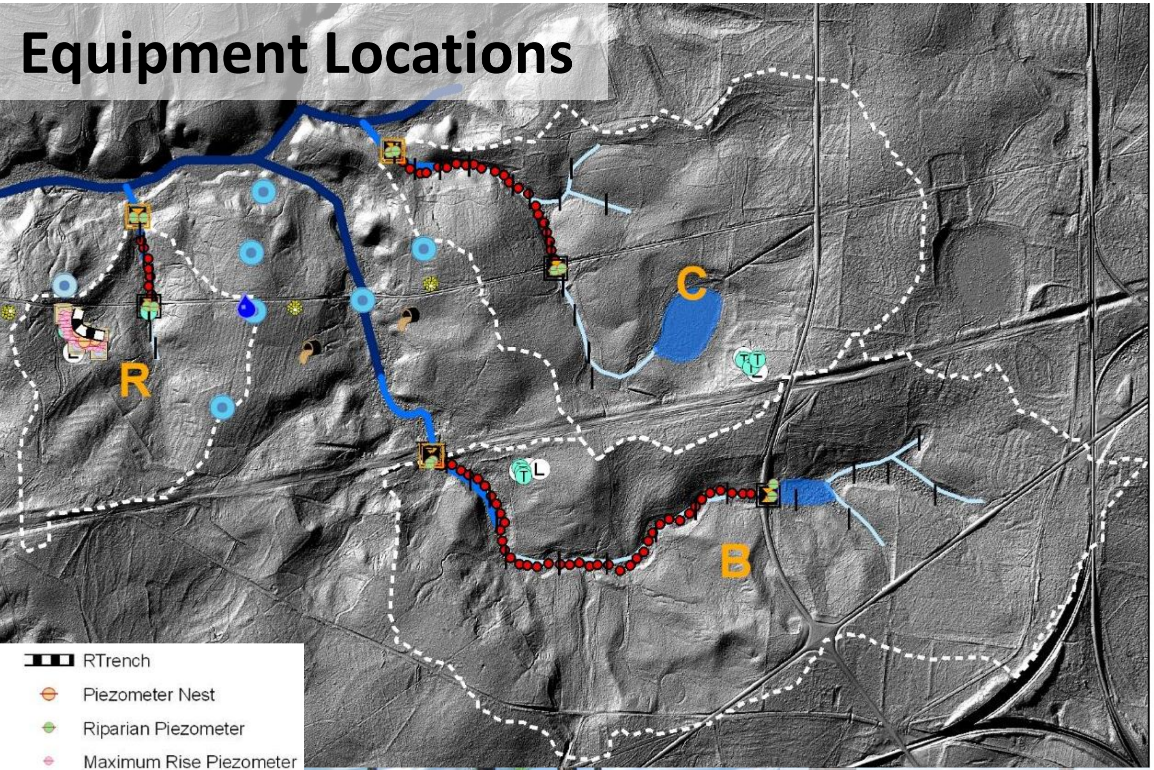
- Instrumented hillslopes and streams in three watersheds

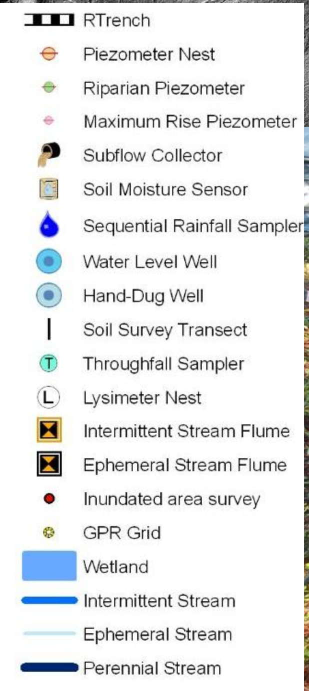
- Installations include:
  - 3 rain gauges, 10 throughfall collectors (precip. water)
  - 104 maximum rise piezometers (soil water dynamics)
  - 9 nests of recording piezometers (soil/groundwater dynamics)
  - 9 lysimeter nests (soil water sampling)
  - 20 soil moisture nests (soil moisture)
  - 15 deep groundwater wells (groundwater dynamics/sampling)
  - 3 interflow interception trenches (soil water flow and sampling)
  - 3 flumes, one at outlet of each watershed (stream flow)
  - 6 automated stream samplers (stream water sampling)

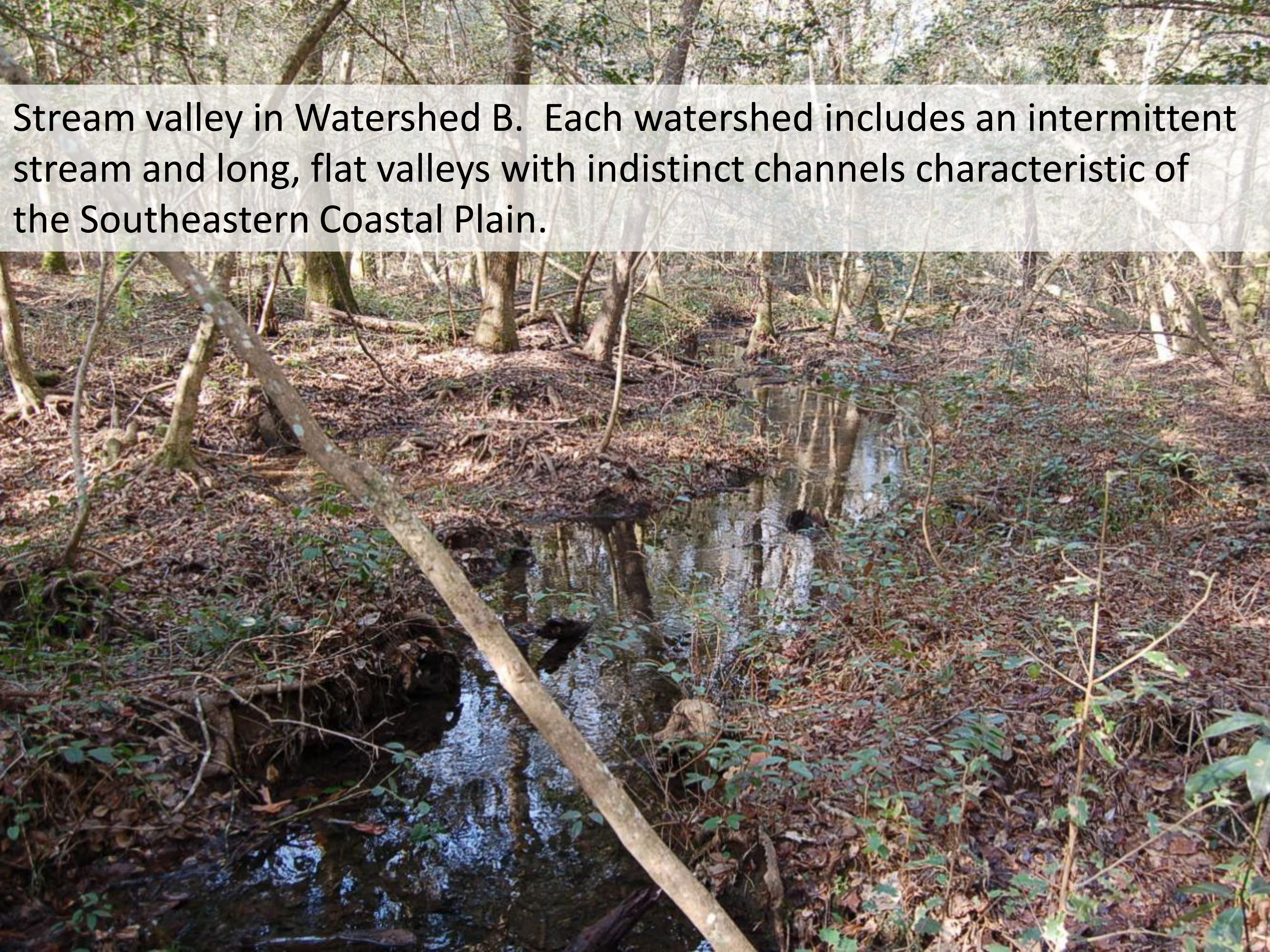
- Hydrologic data will characterize flow behavior in watersheds and parameterize the hillslope and watershed models

Watershed Characterization

Lead: Jackson (UGA)



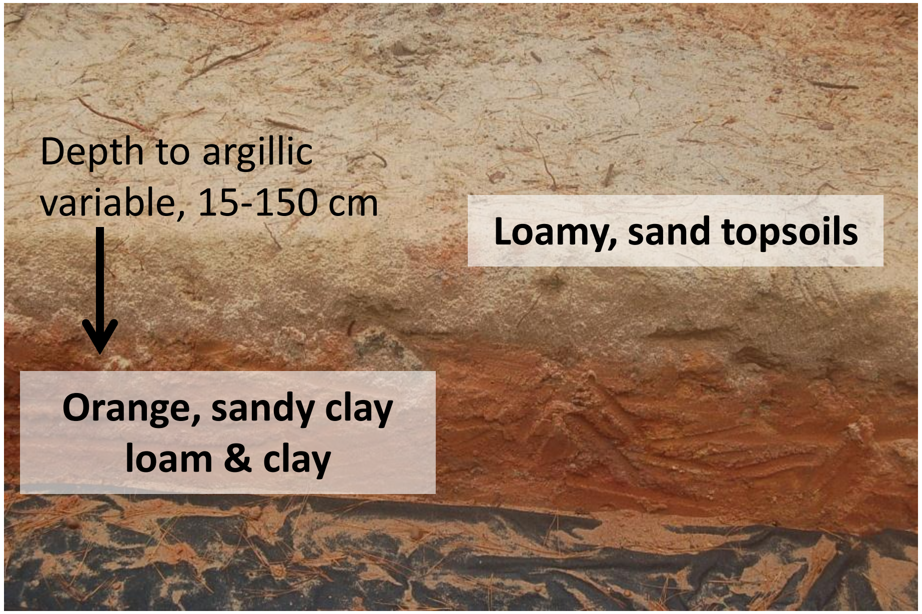


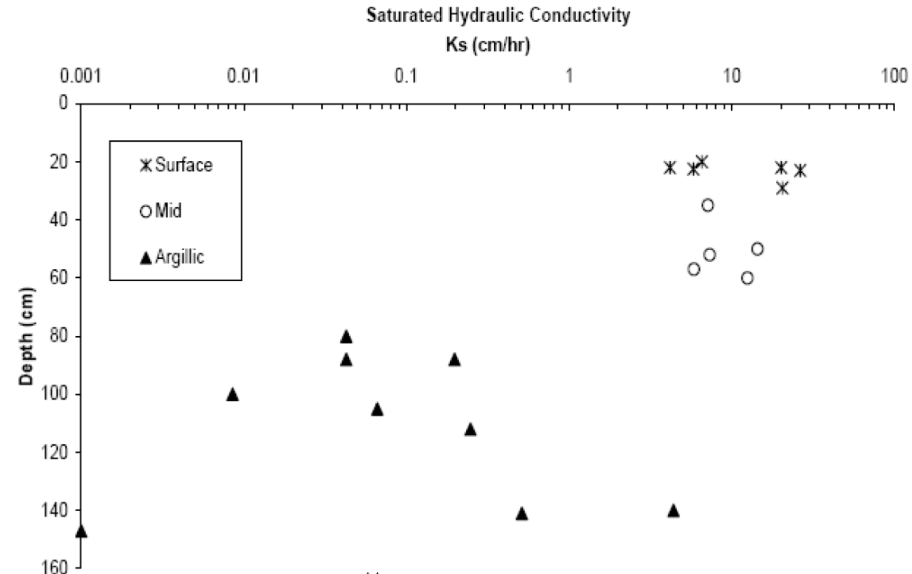


Stream valley in Watershed B. Each watershed includes an intermittent stream and long, flat valleys with indistinct channels characteristic of the Southeastern Coastal Plain.

Watershed Hydrology: Hillslope

Lead: Jackson (UGA)

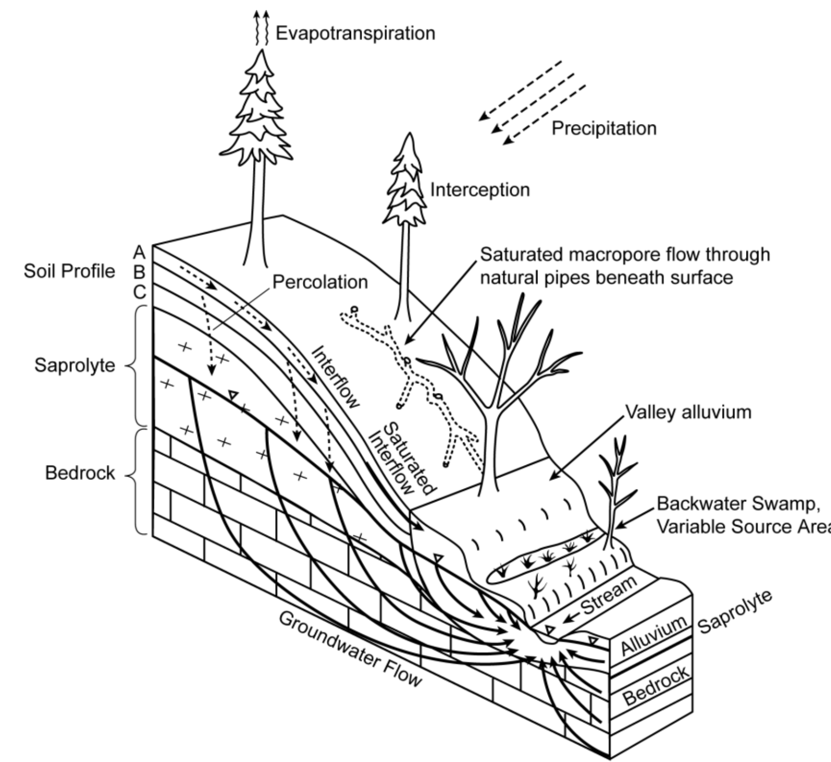




- Topsoils exhibit high hydraulic conductivities (water flow)

- Low conductivities in clay

- Clay layer should impede infiltration, keep water in rooting layer, and cause perching during rainstorms



Watershed Hydrology: Hillslope

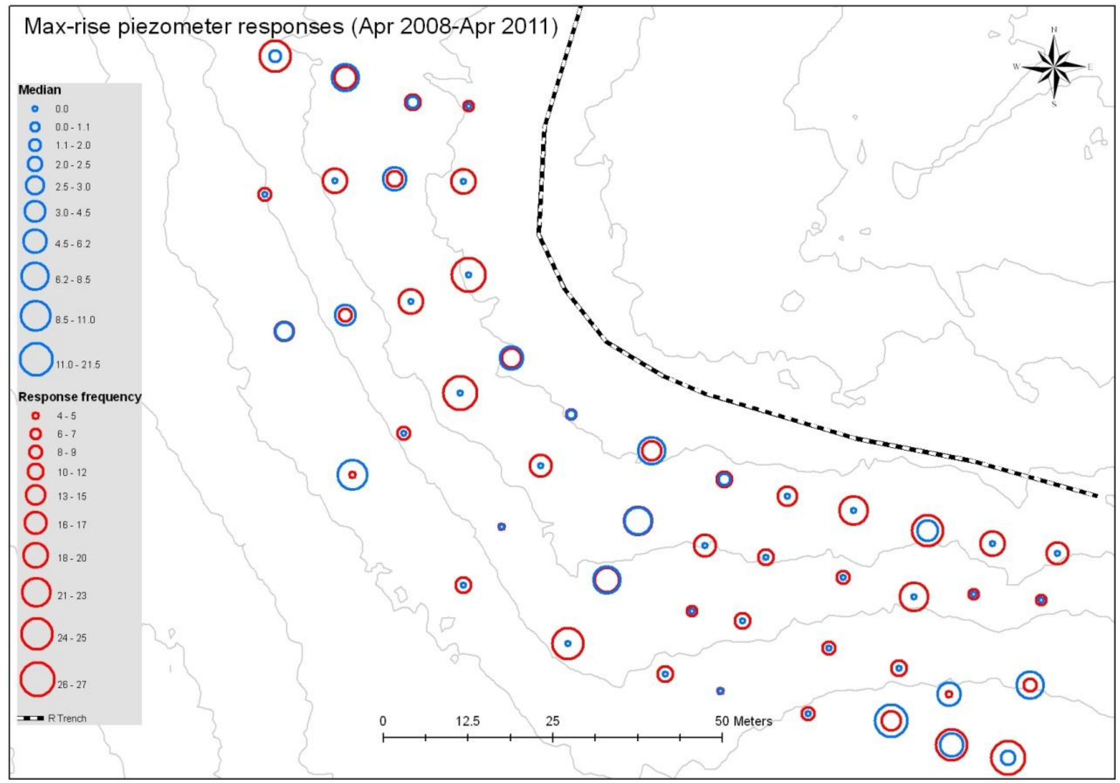
Lead: Jackson (UGA)

- Formation of perched zones above clay layer is common, but large spatial and temporal variation in perching

- Water flow through soils/clay (i.e., trench flows) only occurs with large storms on wet soils

- Lateral macropore (i.e., old root paths, animal burrows) flow has not been observed

- Overland flow over forest soils has not been observed



- Only weak connections between perching events and stream flow response

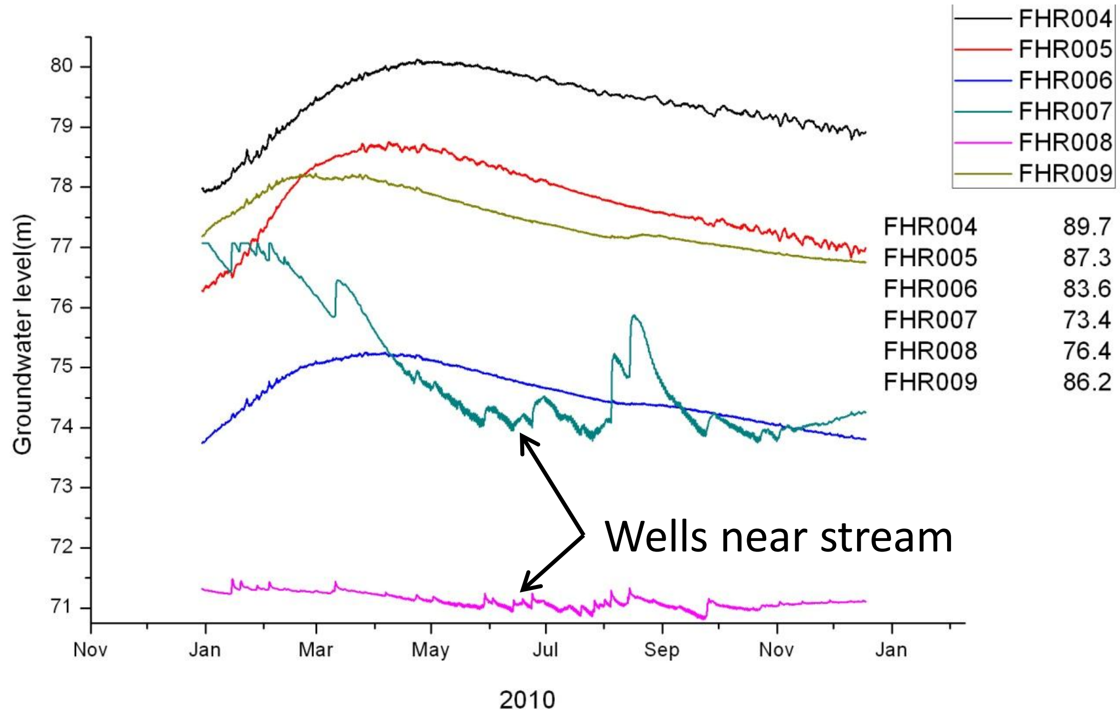
Watershed Hydrology: Groundwater

Lead: Jackson (UGA)

- Deep wells exhibit seasonal variation with little storm responsiveness, but wells near stream valley show more dynamic behaviour

- Seasonal groundwater dynamics appear to control when stream flow begins and ends

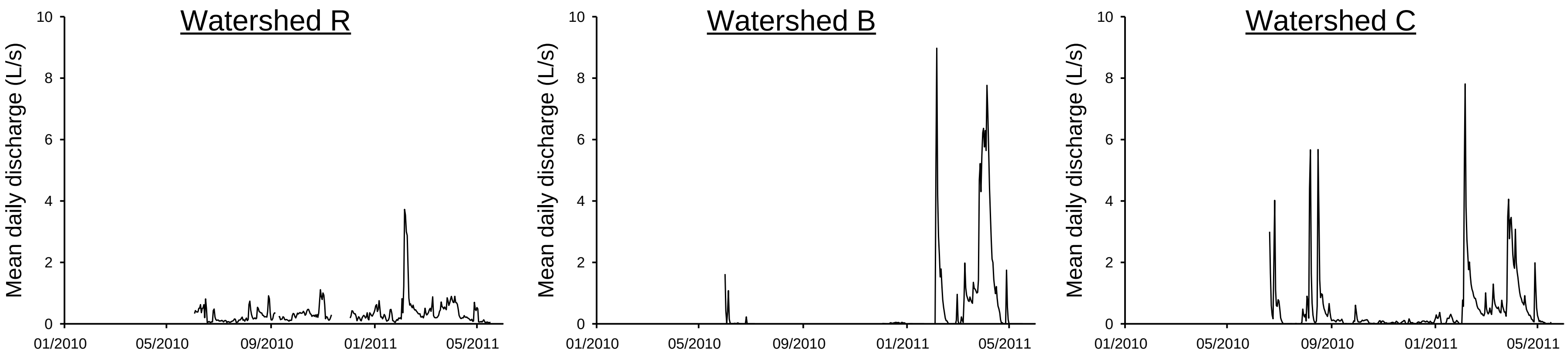
- Models require inclusion of groundwater dynamics to accurately capture stream flow



Watershed Hydrology: Stream Flow

Lead: Jackson (UGA)

- Stream flow seasonality is similar, but peak stream flow and flow durations differ among the 3 watersheds



- Watershed R: flow fairly stable
- Watersheds B and C: 'flashier' flow

- All 3 streams have been dry since May 2011
    - 2010 and 2011 were 3rd & 4th driest years on record
    - 2011 and 2010 were 1st & 3rd hottest summers on record

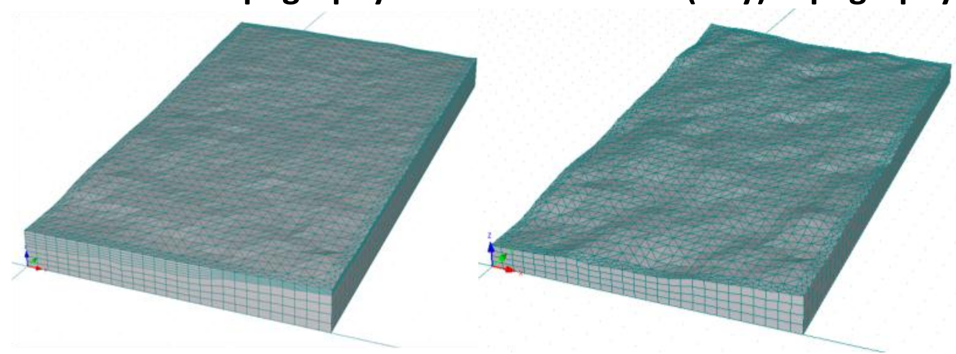
- Hydrologic data are needed to validate the models that predict hillslope and watershed-scale hydrology

Small-Scale Hillslope Modeling

Lead: McDonnell (OSU)

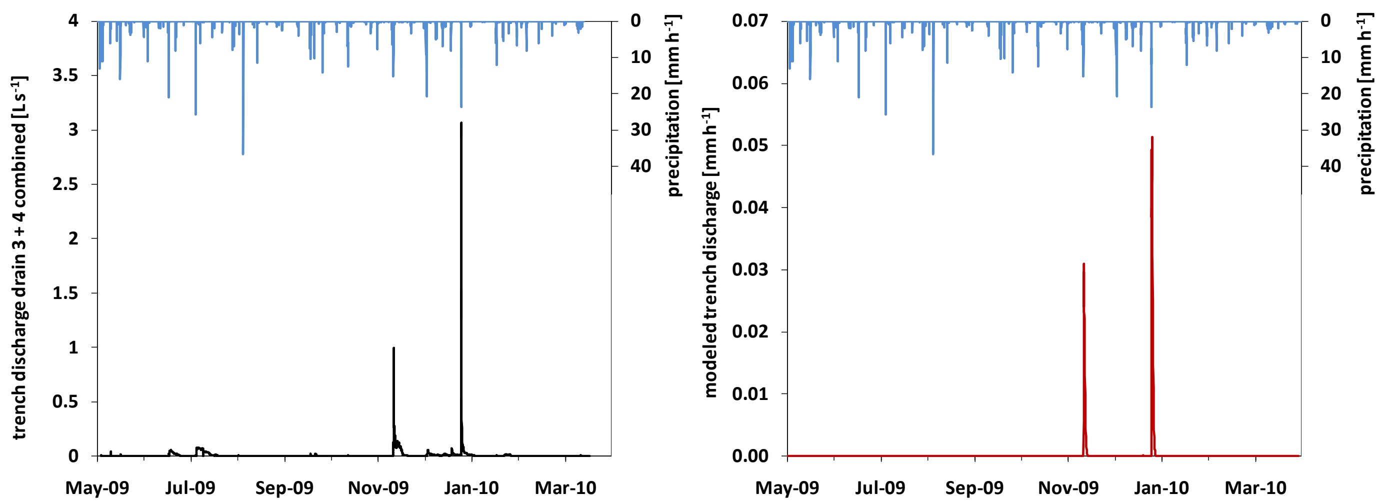
- To better understand the contribution of interflow to stream flow generation in low-relief landscapes

- Hillslope model based on topography, saturated hydraulic conductivities, and moisture release curves at Watershed R



- Initial simulated flow modeled on hourly climate records in 2009 (rain, ET)

- Good agreement between modeled and predicted interflow



Watershed Modeling

Lead: McDonnell (OSU)

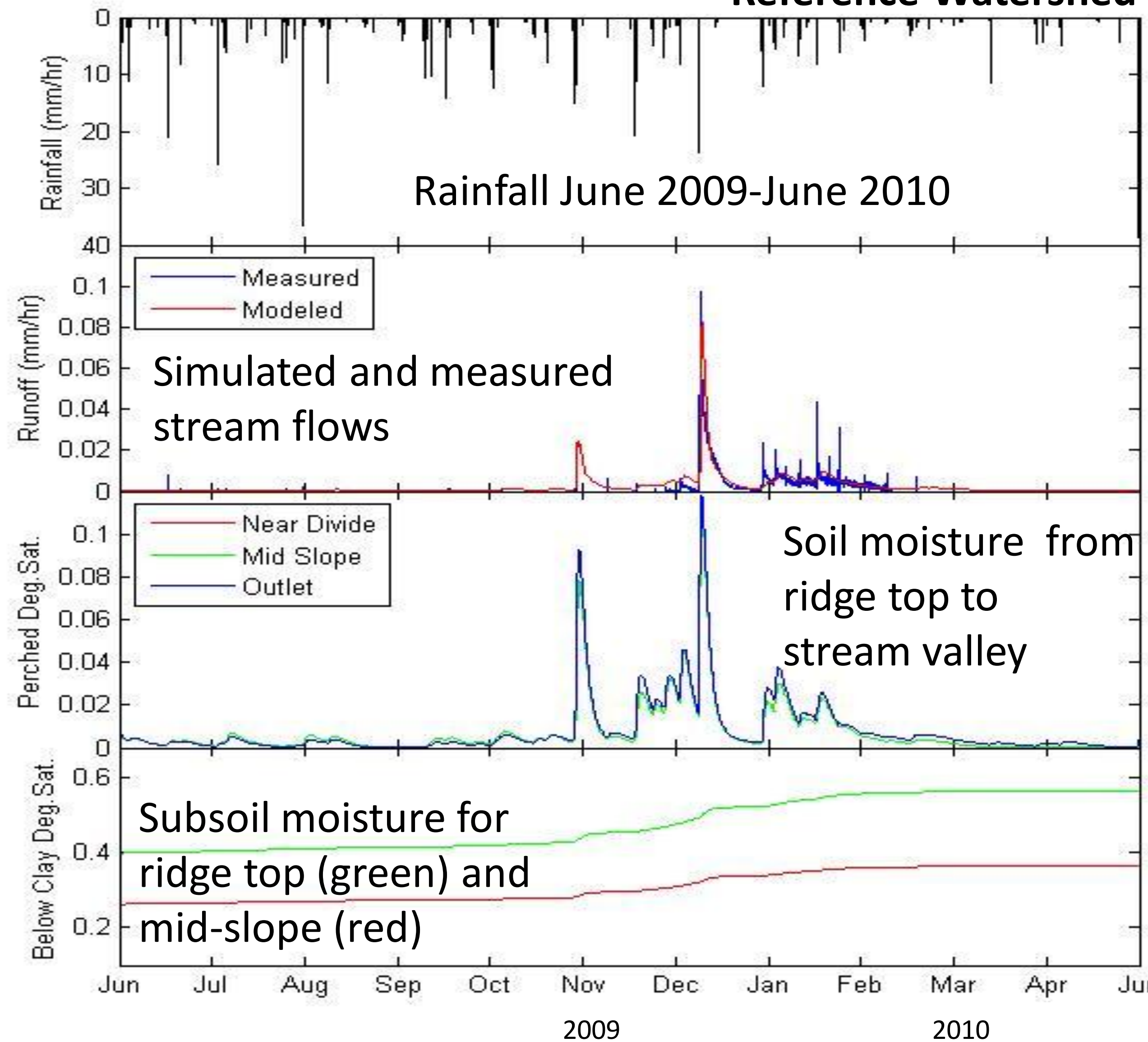
- To develop and evaluate a hydrologic model for the reference watershed (R)

- Simulated and observed stream flows for 2009-2010 show good agreement

- Streamflow only occurs during wet season

- Seasonal groundwater dynamics control streamflow duration

Reference Watershed



Further Model Development

Lead: McDonnell (OSU)

- Hillslope- and watershed-scale modeling complete for Watershed R
- Developing/adapting models to Watersheds B and C
- Will compare the model response in the treatment (B,C) and reference (R) watersheds over time
    - will evaluate the change in runoff behavior, evapotranspiration, and groundwater dynamics following silviculture practices
    - one of the best ways of testing the predictive capability of the OSU models
- Expand model to the Coastal Plains region to areas with different topography, soils, and vegetation

Water Quality: Sampling Design

Leads: Langholtz & Griffiths (ORNL)

Sampling locations:

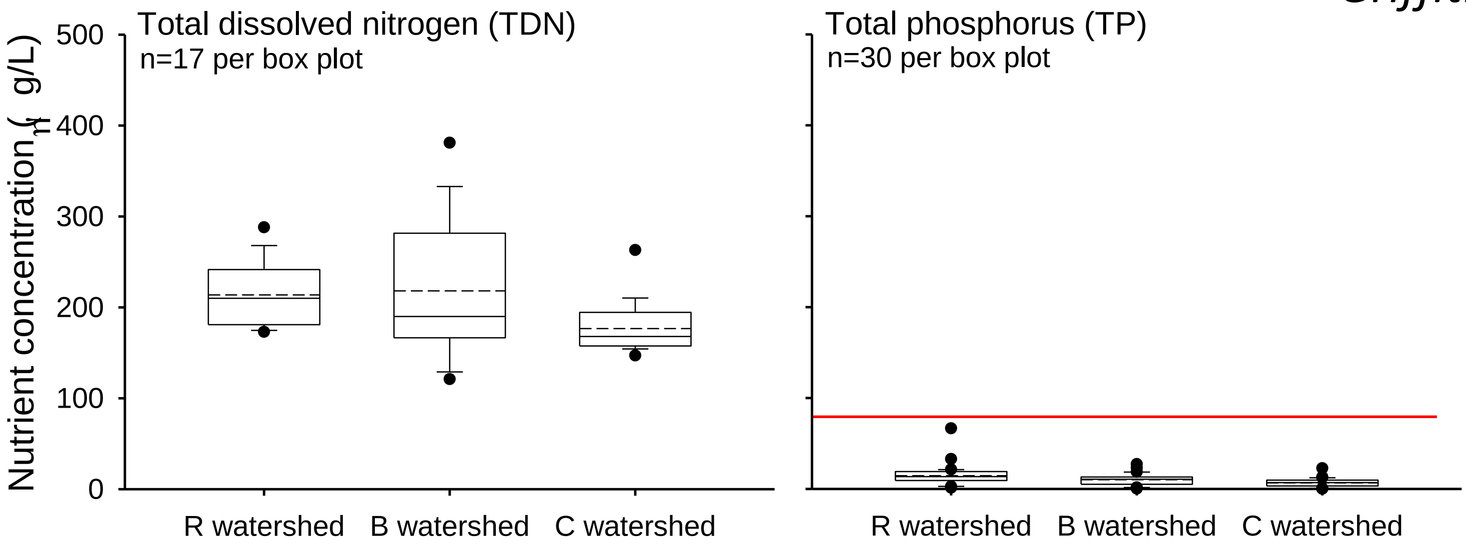
- Intermittent and ephemeral streams
- Throughfall collectors
- Riparian groundwater wells
- Deep groundwater wells
- Tension lysimeters (soil water)
- Interflow interception trenches (flowing soil water)

Measurements:

- Nutrients (N, P), dissolved organic carbon (DOC)
- Herbicides (imazapyr, sulfometuron methyl, glyphosate)
- Isotopic tracers in nitrate (^{15}N, ^{18}O) as an indicator of nitrogen cycling in the watersheds

Baseline Stream Water Quality

Leads: Langholtz & Griffiths (ORNL)



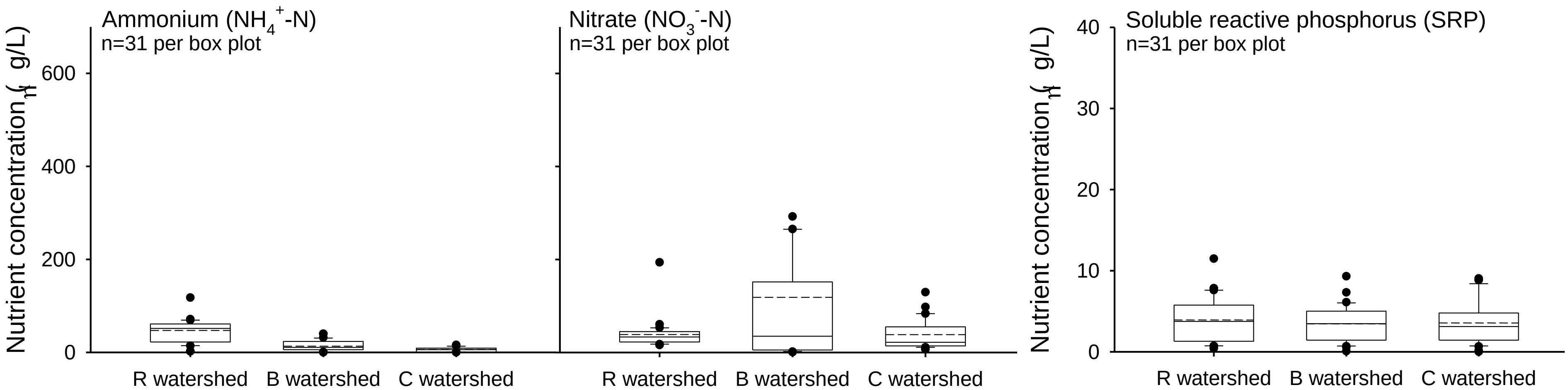
- N and P are biologically-important nutrients, and high concentrations can impair water quality

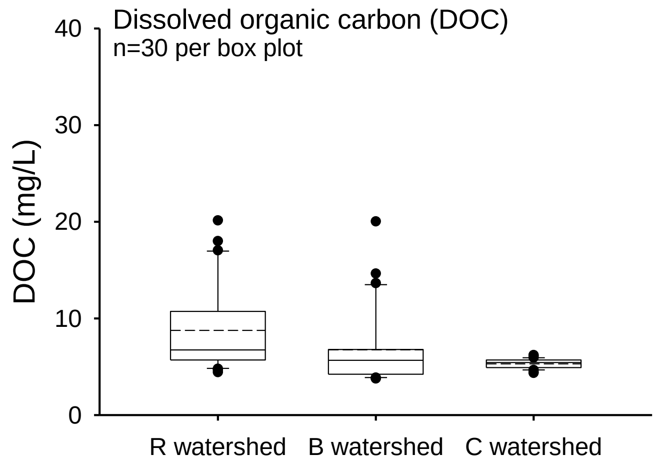
- No water quality standards for streams/rivers in SC
    - Standards for lakes: TN < 1,500 μg/L; TP < 90 μg/L
    - Human health: Nitrate < 10,000 μg/L

- N and P concentrations low in these streams
    - Relatively un-impacted systems, 1950's agriculture
    - All herbicides below detection in streams and groundwater

Baseline Dissolved Nutrients

Leads: Langholtz & Griffiths (ORNL)





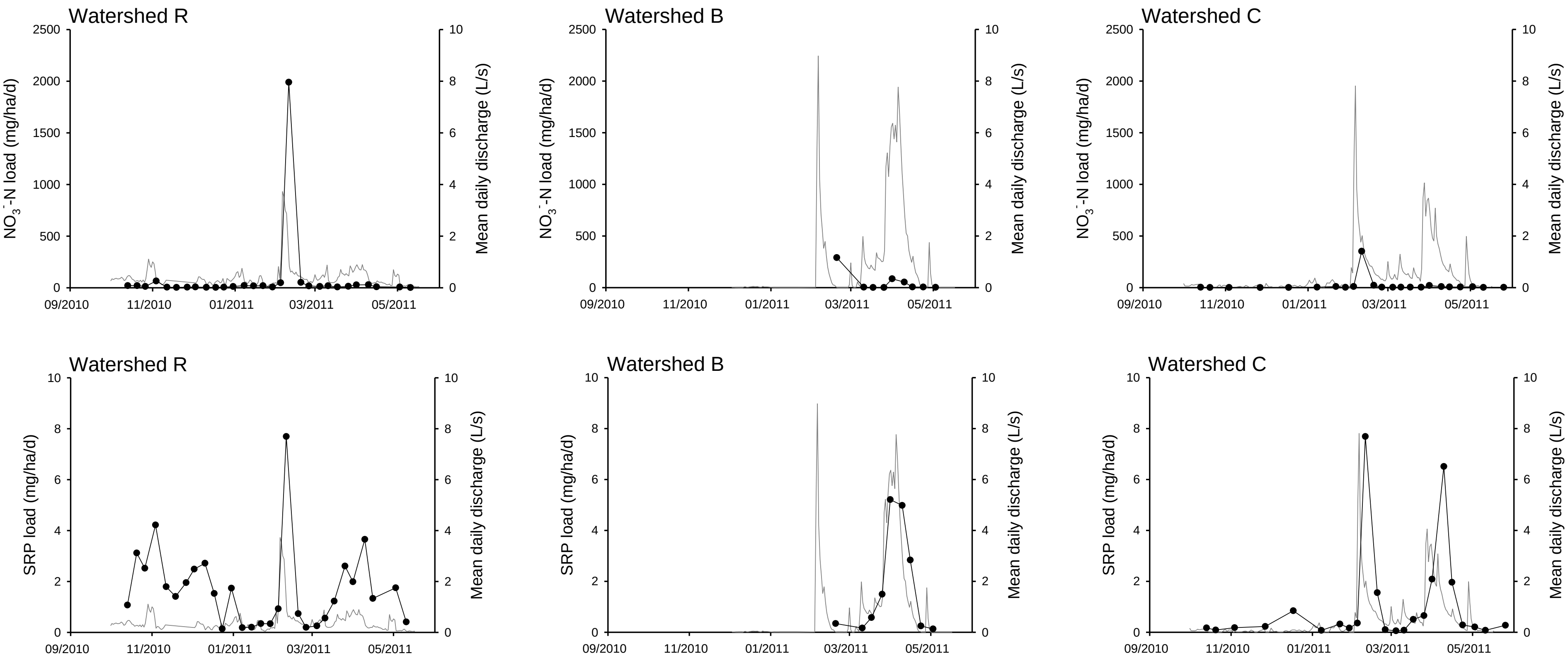
- Stream N, P, DOC concentrations vary among watersheds

- Higher NH_4^+ and DOC in Watershed R suggests anoxic conditions may influence chemistry (little nitrification; $NH_4 \not\rightarrow NO_3$)

- Higher NO_3^- in Watershed B may reflect shallower flowpaths moving nitrate into streams (nitrate = ‘leaky’)

Baseline Nutrient Fluxes

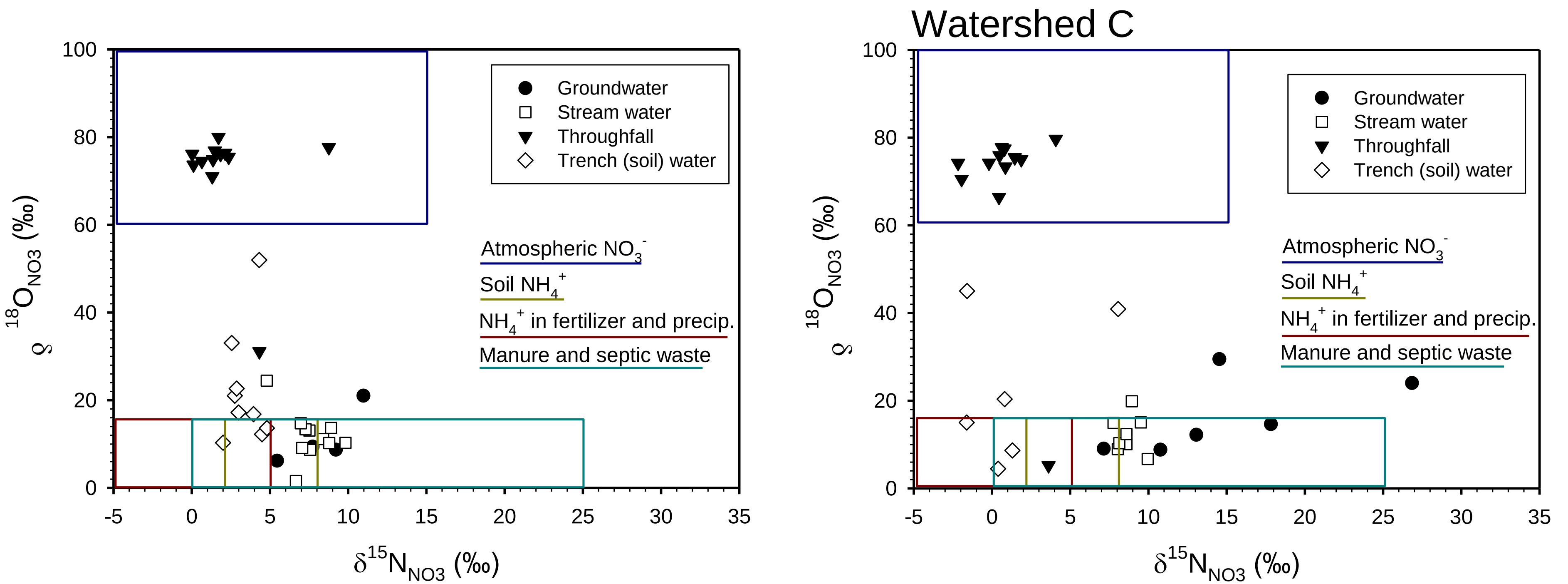
Leads: Langholtz & Griffiths (ORNL)



- Greatest nutrient fluxes during periods of high flow, but nutrients do not consistently respond to storm events

- Linkage between hydrology and water quality (i.e., solute transport) important in understanding fate of nutrients from watersheds

Baseline Watershed Nitrate Cycling



- Stable isotopes of nitrate (^{15}N and ^{18}O) can be used to trace nitrate sources to ecosystems

- In these watersheds, stable isotopes of nitrate suggest that riparian groundwater may be the source of nitrate for stream water

- High $\delta^{15}N$ values likely reflect denitrification occurring in the watershed ($NO_3 \rightarrow N_2$, anoxic, high carbon)

Future Water Quality Work

- 2 years of baseline water chemistry has been collected and analyzed
    - ~1.5 years of stream water chemistry due to drought conditions

- Water samples collected during harvest and will continue to be collected until crown closure (~5 years after planting seedlings)

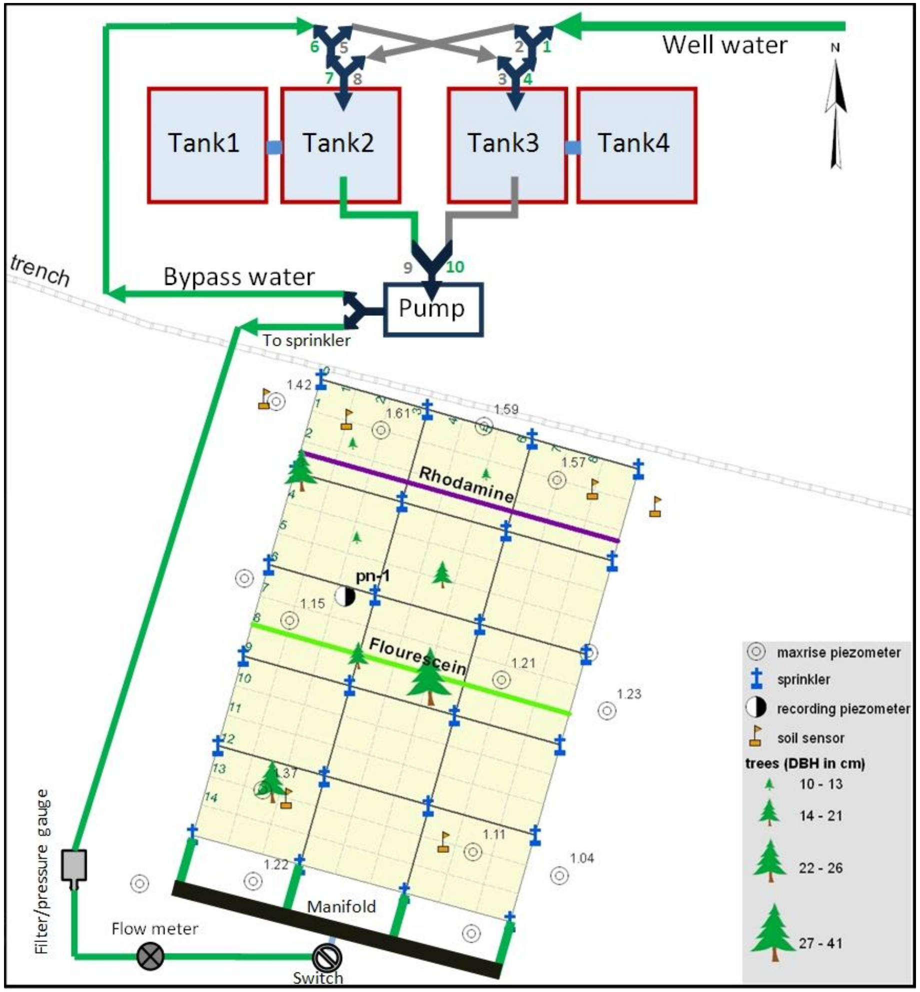
- Stream water nutrient concentrations and fluxes will help determine targets for water quality

- Watershed budgets (input, output) will help inform watershed-scale impacts

Hillslope Irrigation Experiment

How does rainfall and associated nutrients move through the soil?

- How much rainfall is needed to initiate interflow?
- What is the conductivity of the clay layer at the plot scale?
- How long does perching in the clay layer last after a large rain?
- What is the fate of N and P in rainwater?



Irrigation Experiment Methods:

- Irrigated 12x16.5 m hillslope for ~50 hours
- Applied 21,283 gallons of water
- Added dyes (flow velocity), tracers (new/old water mixing), and nutrients

Hillslope Irrigation Experiment

- Flow appeared in trench after 12 h (13 cm irrigation), as predicted from hillslope-scale model

- Estimated conductivity of argillic = 0.3 cm/h (similar to mean K_{sat} of smaller-scale measurements)

- Tracers show pulse of new water initially, then old water, suggesting large storage zone in hillslope

- Awaiting nutrient analyses to examine cycling of N and P in the hillslope

Project Summary and Future Work

- Collaborative project that combines watershed-scale experimental and modeling approaches to determine the environmental sustainability of short-rotation pine for bioenergy in S.E. US.

- 2 years of baseline water quality and hydrologic monitoring of 3 watersheds is complete

- Harvest of ~40% of extant watersheds is complete, site preparation will begin this summer/fall, and planting loblolly seedlings in spring

- Hydrologic and water quality measurements will continue through crown closure (~2018) and model development will occur in parallel

Stay Tuned....