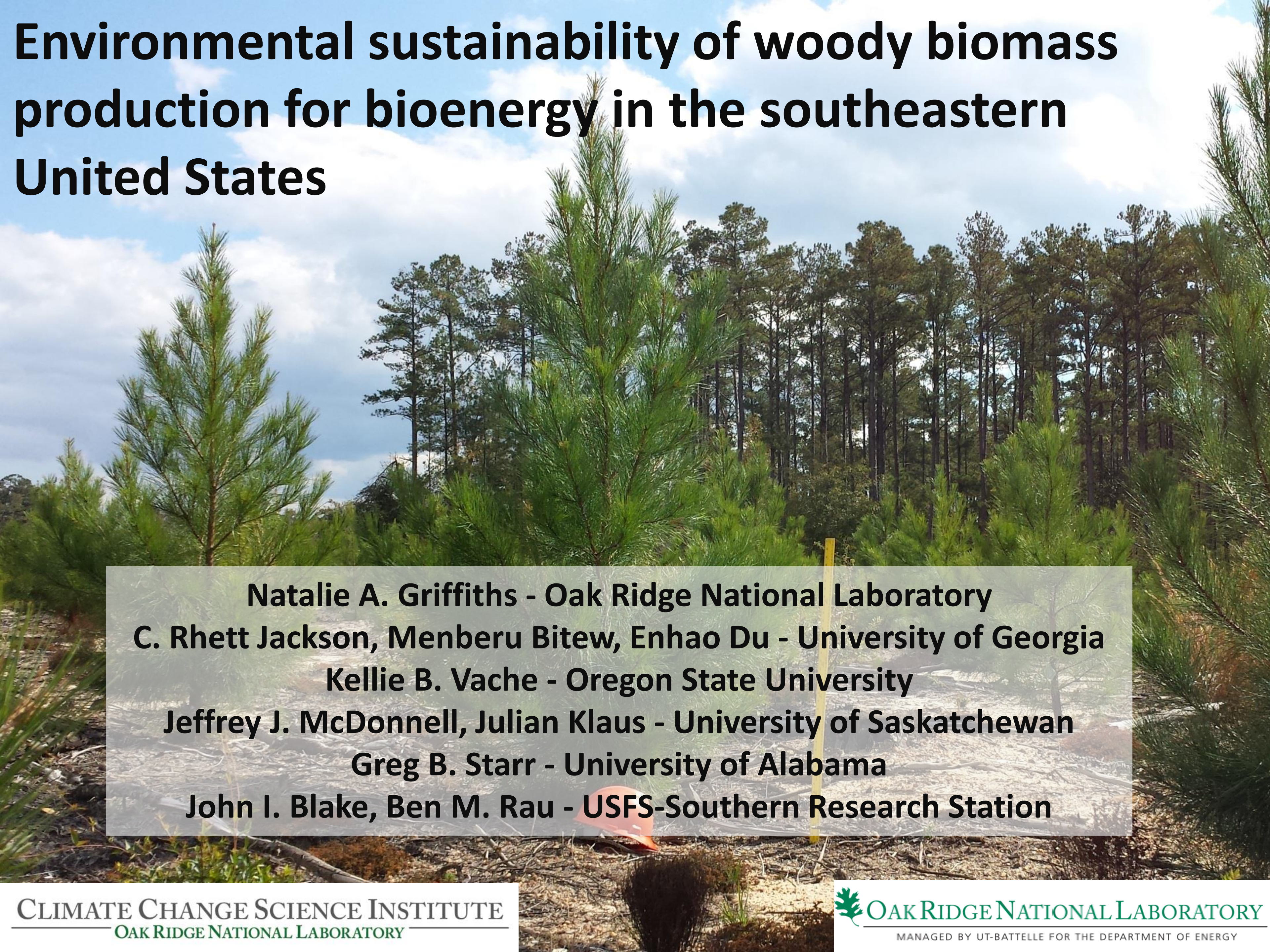


# Environmental sustainability of woody biomass production for bioenergy in the southeastern United States

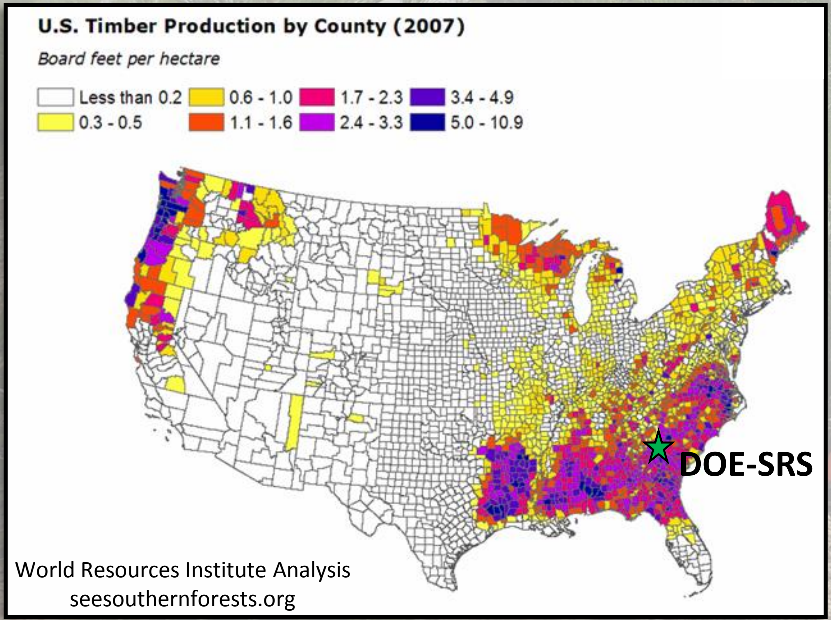
Natalie A. Griffiths - Oak Ridge National Laboratory
C. Rhett Jackson, Menberu Bitew, Enhao Du - University of Georgia
Kellie B. Vache - Oregon State University
Jeffrey J. McDonnell, Julian Klaus - University of Saskatchewan
Greg B. Starr - University of Alabama
John I. Blake, Ben M. Rau - USFS-Southern Research Station

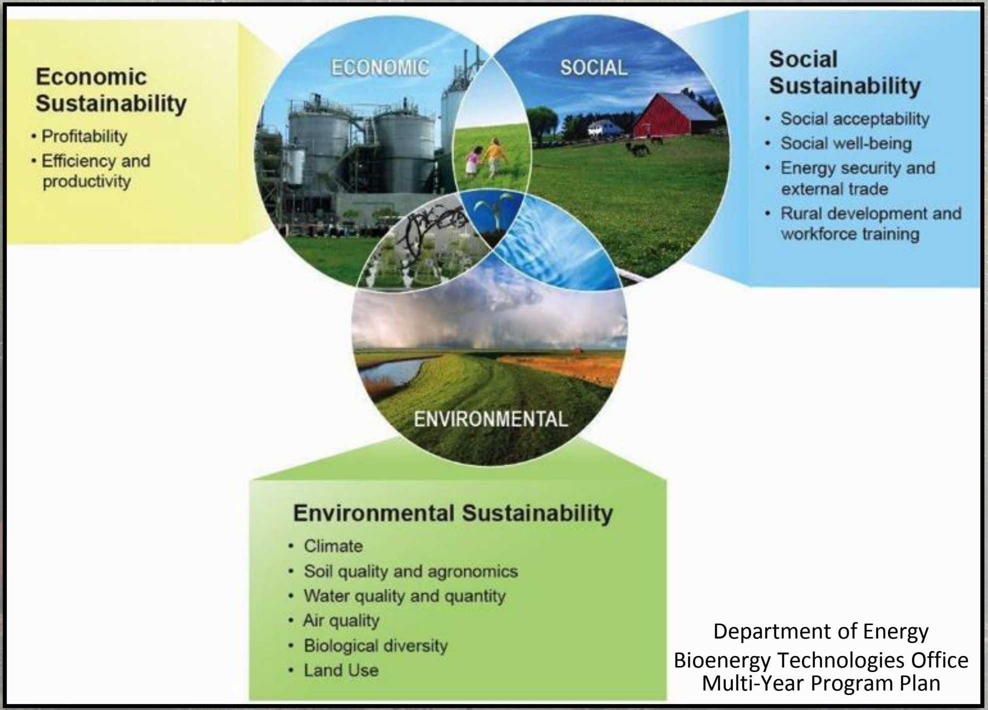
CLIMATE CHANGE SCIENCE INSTITUTE
OAK RIDGE NATIONAL LABORATORY

OAK RIDGE NATIONAL LABORATORY
MANAGED BY UT-BATTELLE FOR THE DEPARTMENT OF ENERGY

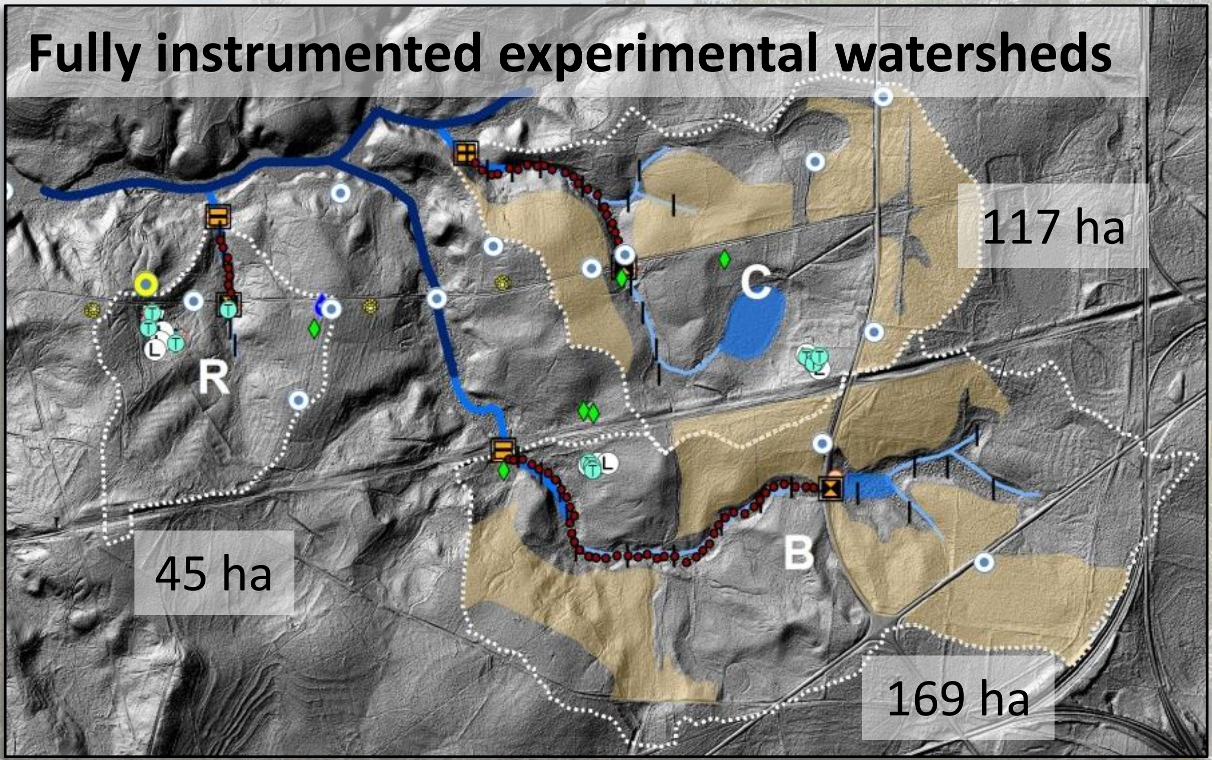
# Woody biomass for bioenergy

- Potential to grow pine trees for bioenergy
    - Wood-fired power plants
    - EISA (2007): increased production of biofuels
    - Wood pellets
- Slightly more intensive than traditional timber management
    - Shorter rotation (8-12 y), fertilizer and herbicide applications



## Multi-year, collaborative project quantifying the environmental sustainability of short-rotation pine for bioenergy using field experiments and watershed modeling



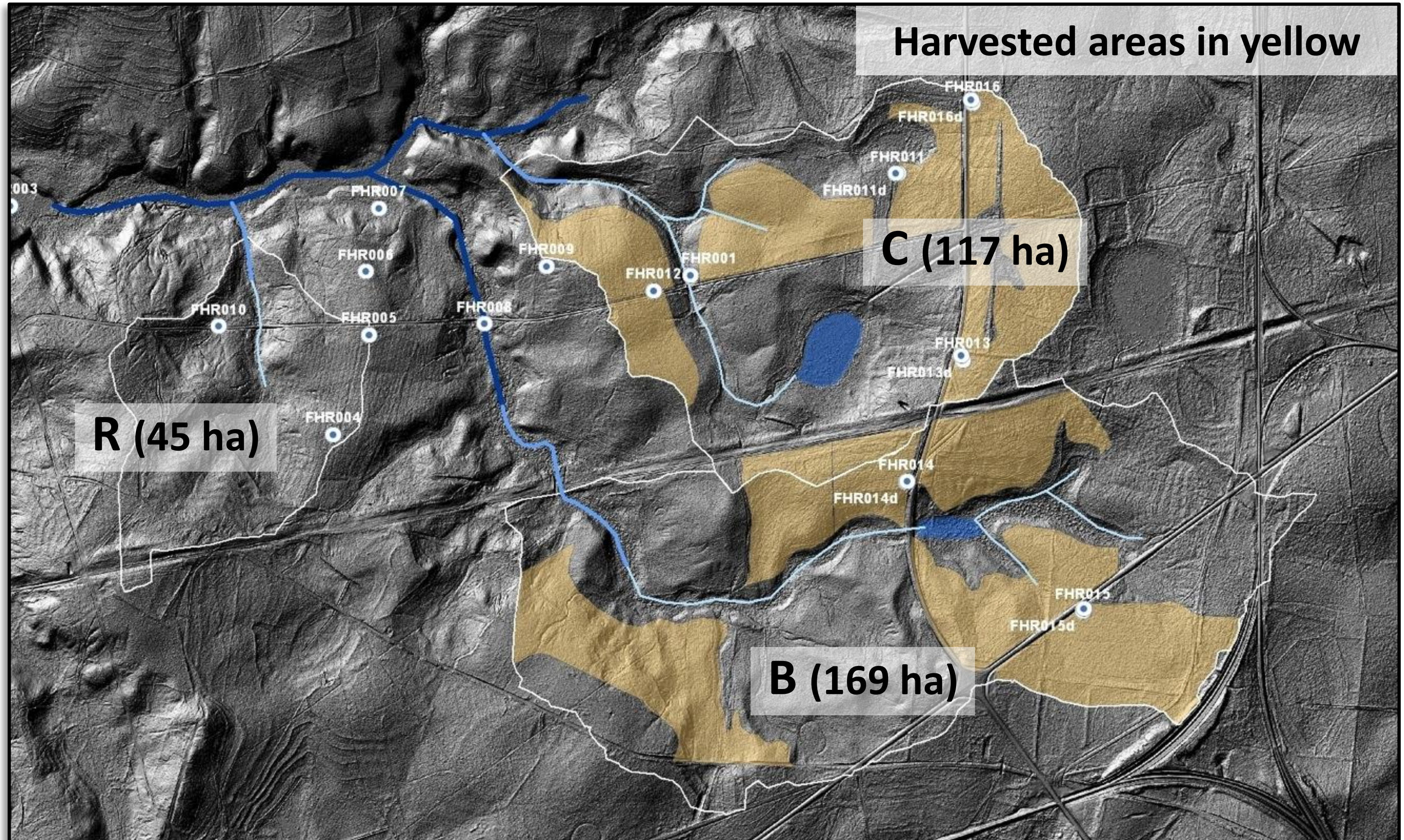

- Water quality
- Hydrology
- Water use
- Watershed modeling
- Soil quality & productivity
- Silviculture

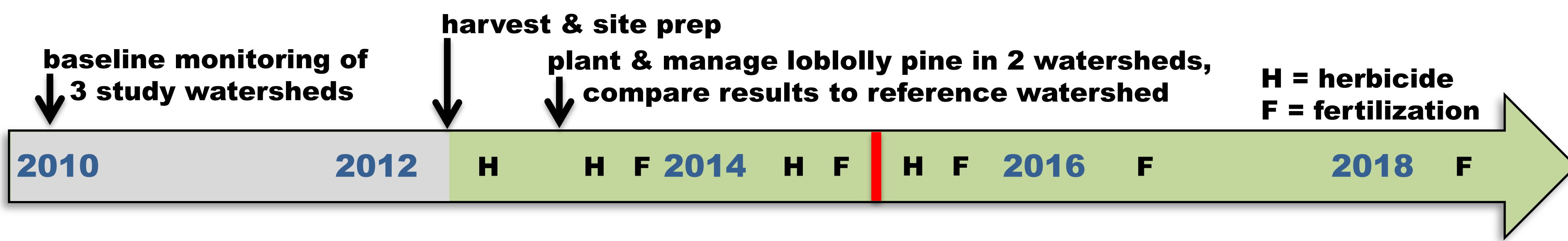
DOE's Savannah River Site, South Carolina. Land managed by USFS for DOE.


- Planted old fields (pine/hardwood)
- Minimally managed (by USFS-SR)
- Low-gradient watersheds
- Sandy soils overlay clay


- Low gradient
- Dense vegetation
- Organic rich
- Intermittent, blackwater streams with indistinct channels

# Watershed-scale experiment

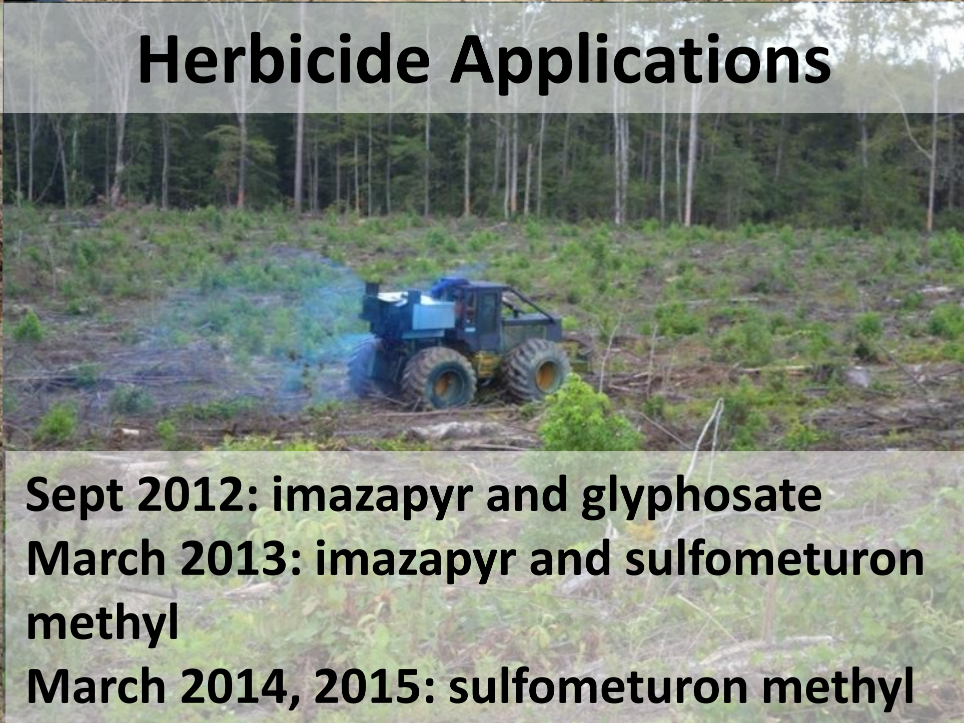



Harvest (Mar-May 2012)
KEEP CLEAR

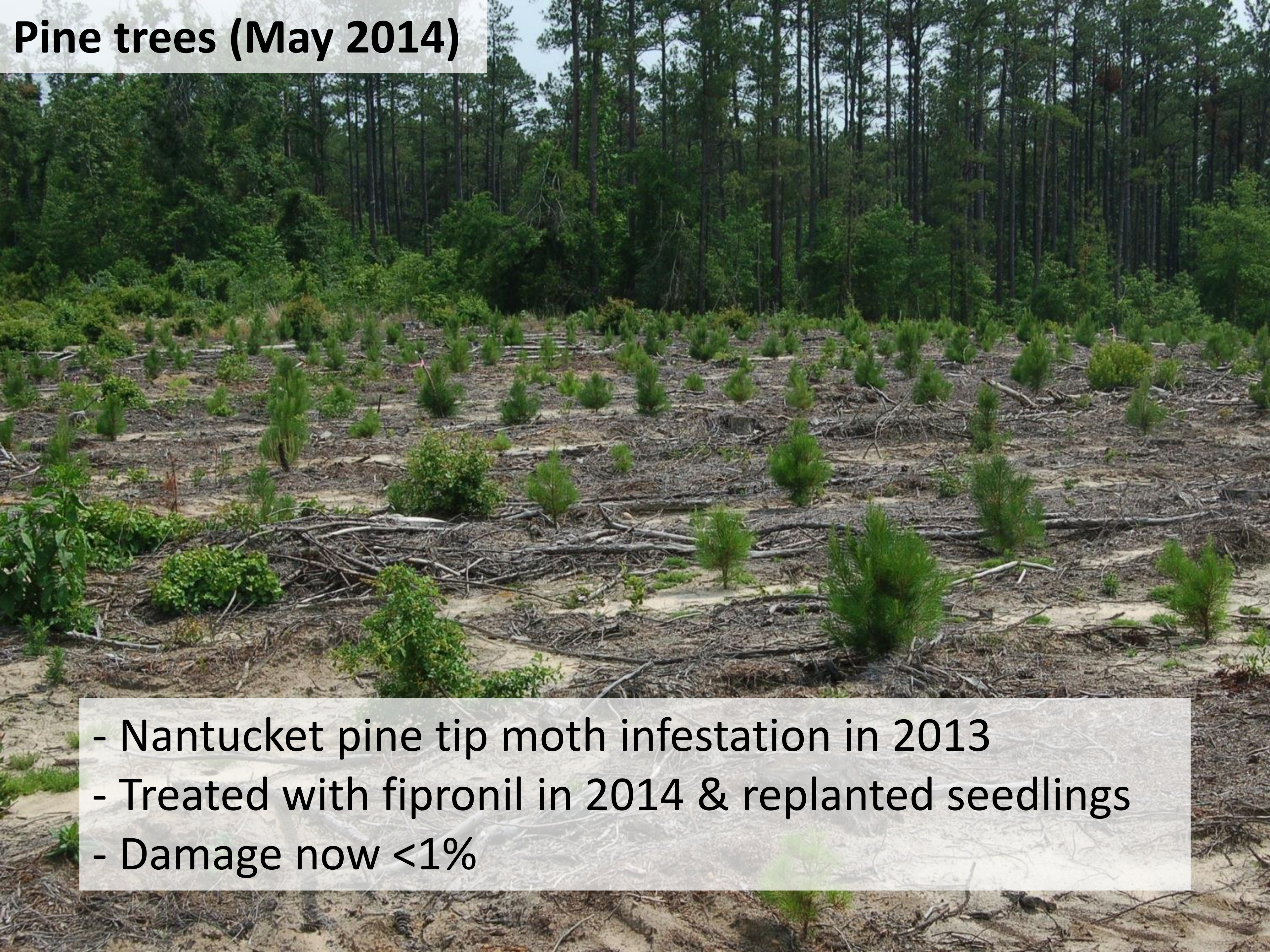

Clear cut with SMZ
Applied South Carolina BMPs plus 50 ft buffers on wetlands


Rip rows (June-Sept 2012)


Herbicide Applications
Sept 2012: imazapyr and glyphosate
March 2013: imazapyr and sulfometuron methyl
March 2014, 2015: sulfometuron methyl

Planted seedlings (Feb 2013)
N cycling and productivity plot (no herbicide treatment)

# Pine trees (May 2014)



- Nantucket pine tip moth infestation in 2013
- Treated with fipronil in 2014 & replanted seedlings
- Damage now <1%

# Pine trees (October 2014)

# Fertilizer Applications

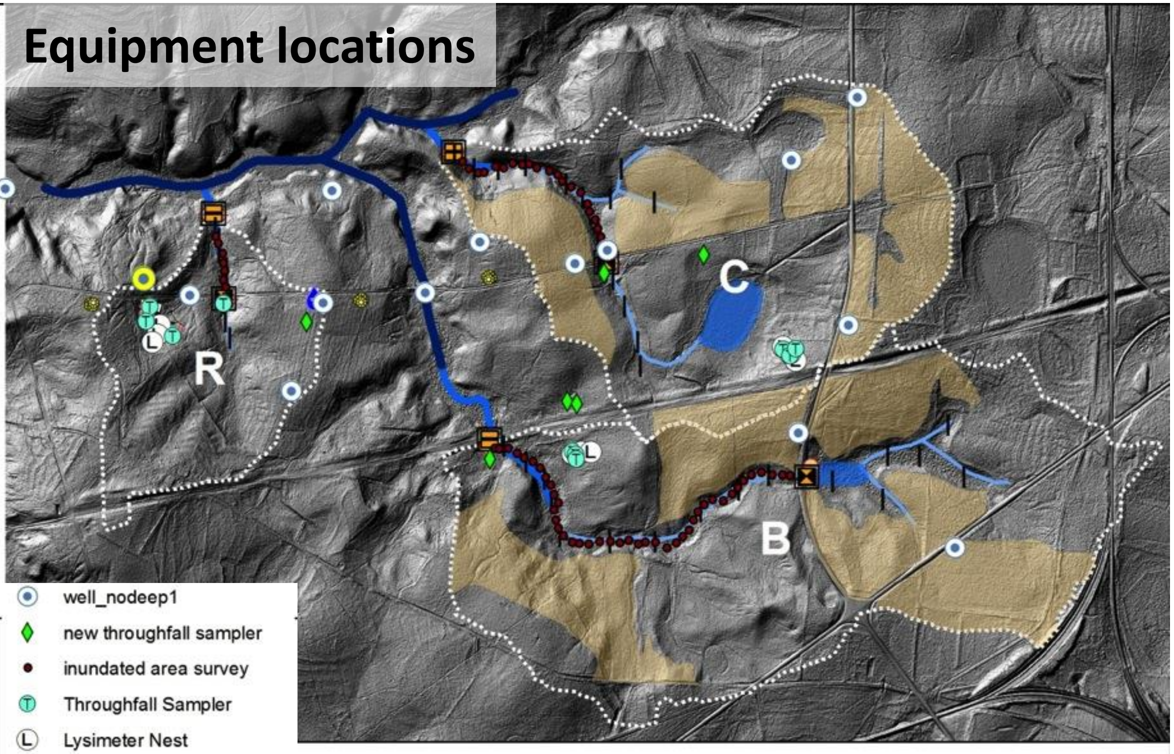
**Spring 2013: Diammonium phosphate (45 lbs-N & 50 lb-P/acre), broadcast**
**Spring 2014: Urea (100 lbs-N/acre), broadcast**
**Spring 2015 (planned): DAP (same as 2013), broadcast**
**Subsequent applications of N will be made every 2 years until harvest**

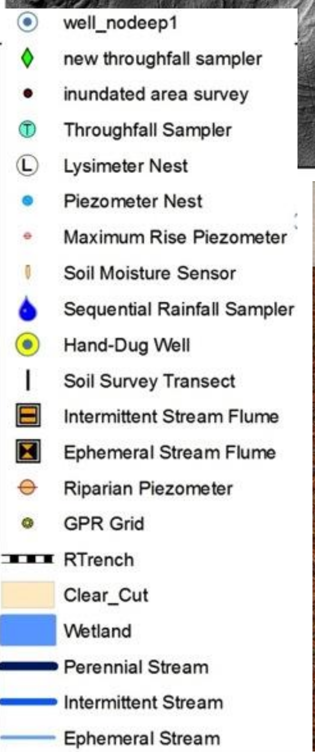
# Pre-harvest (2011)

# Post-harvest (2013)

# Post-planting (2014)

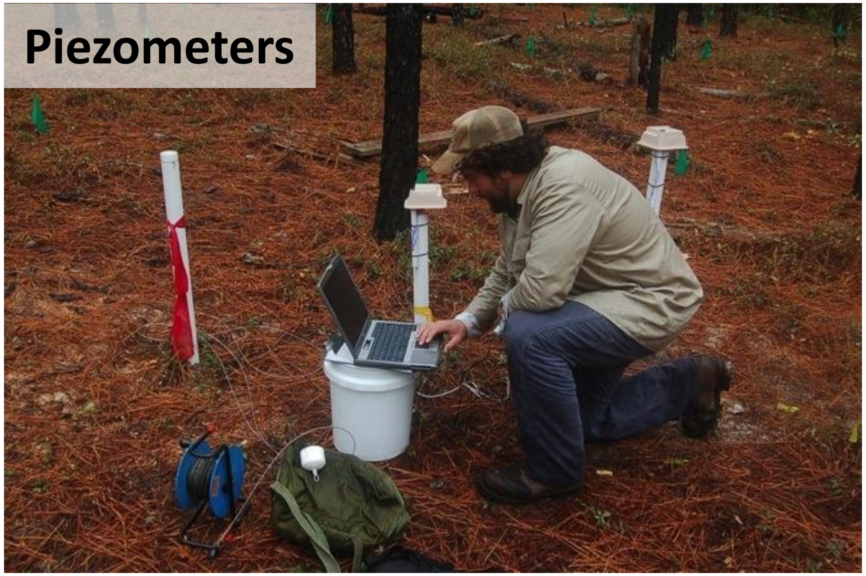
# Field sampling sites and instrumentation



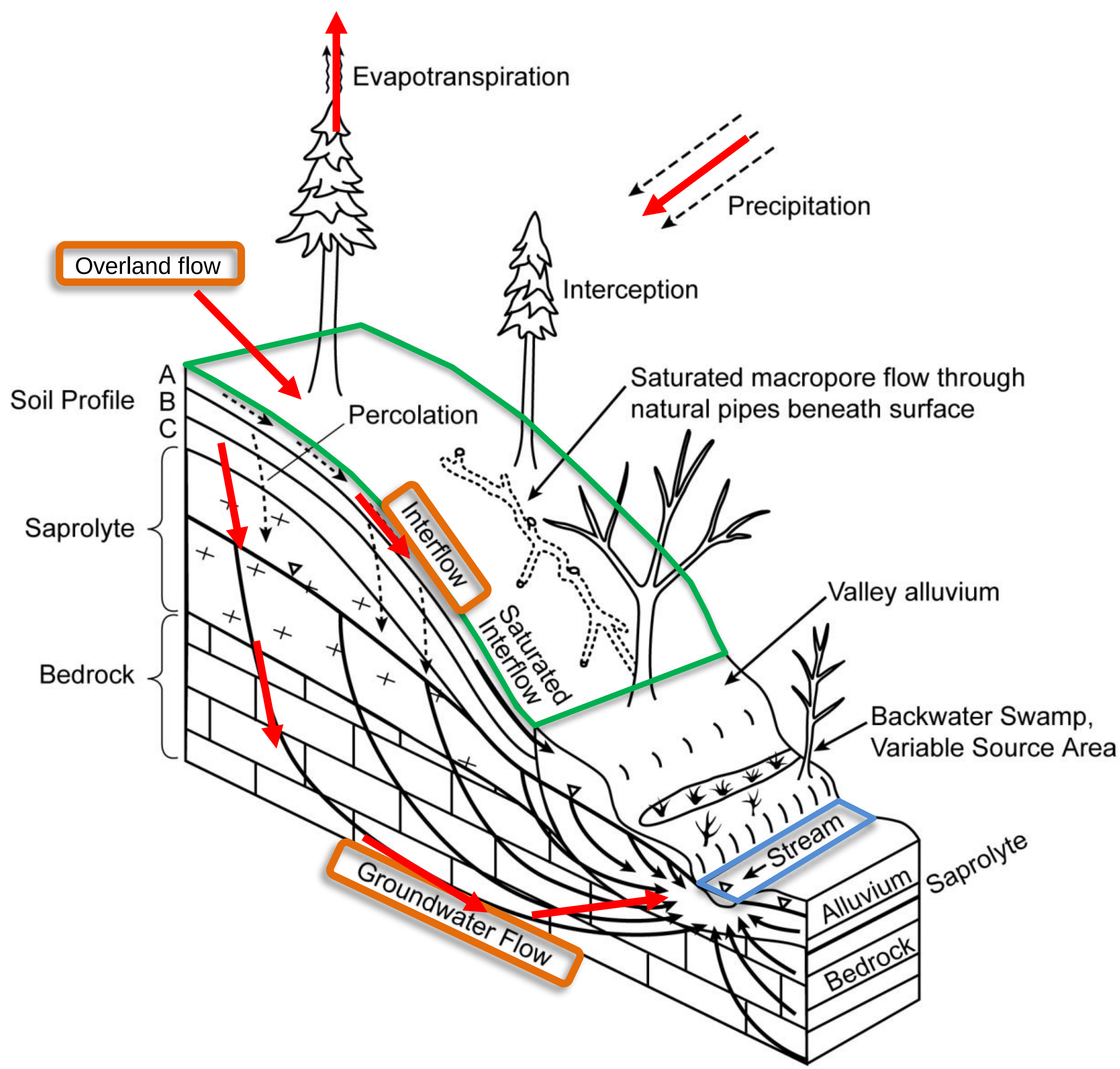









# Research Questions




1) What are the dominant water flowpaths?

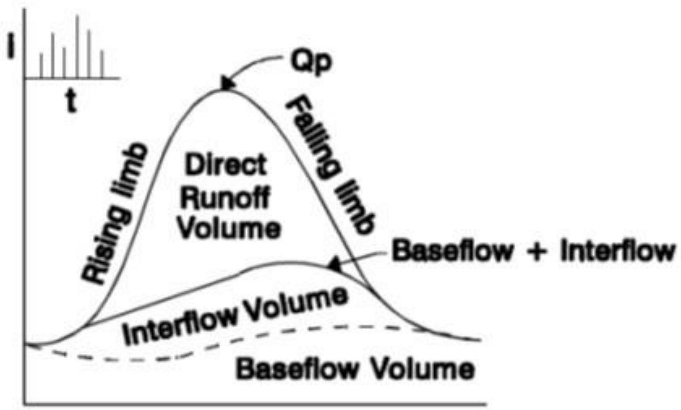
How and when are the hillslopes connected to the stream?

2) What are the short-term effects of pine management on water and soil quality?

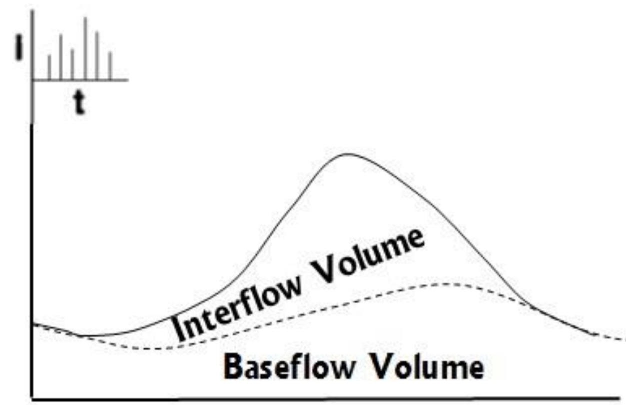
# Hydrology in low-relief watersheds

- Typical hydrograph: baseflow, interflow, runoff.

- Expected hydrograph in low-relief Coastal Plain watersheds: baseflow, interflow.




Standard hydrograph




Expected SE Coastal Plains hydrograph

# Overland flow not observed

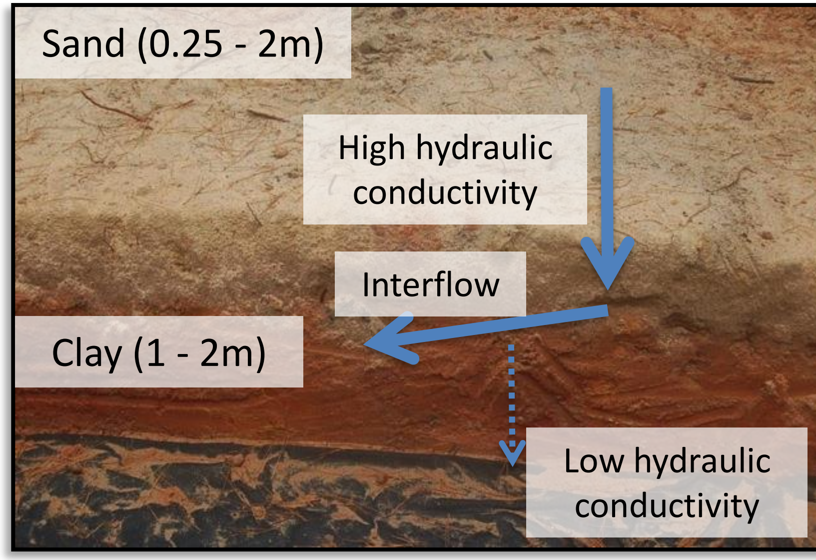
- Seasonal seeps have appeared carrying water and sediments from the plantations to riparian areas.

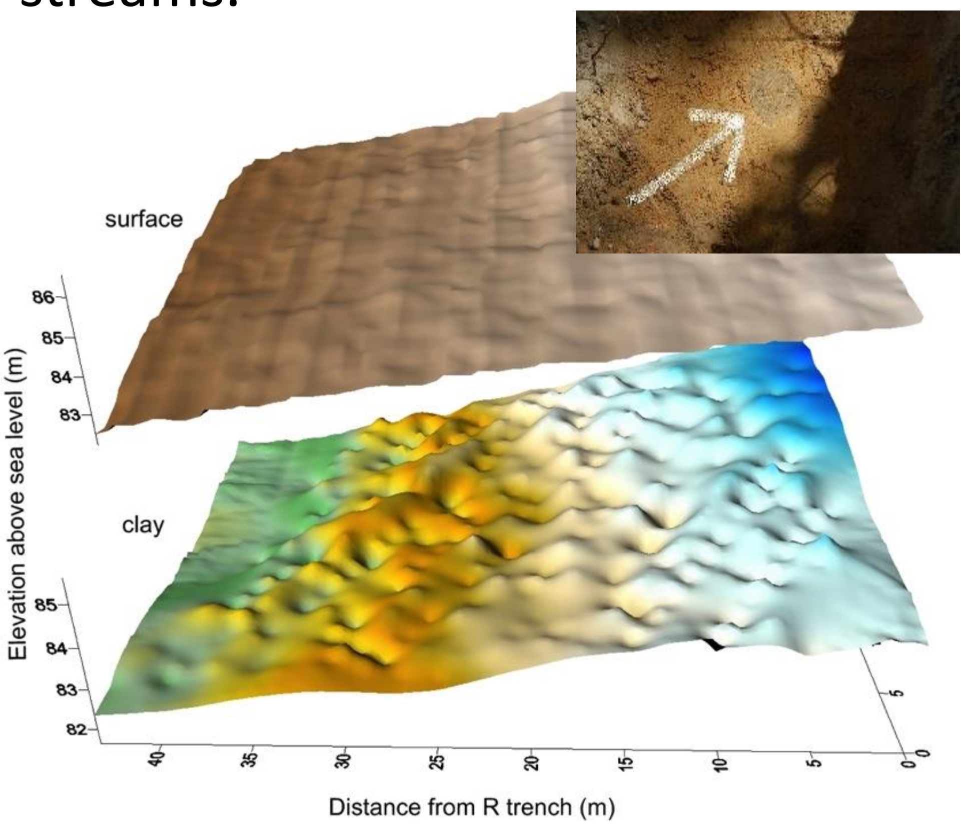
- Water reinfiltrates in the first few meters of the riparian zone.

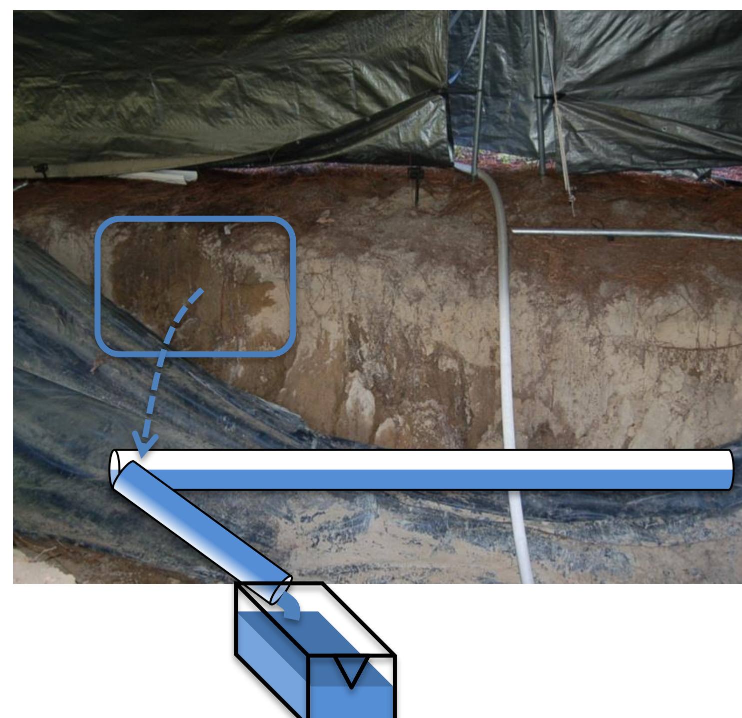
# Short interflow distances

- Interflow observed during storms but high percolation of water through anomalies in the clay.

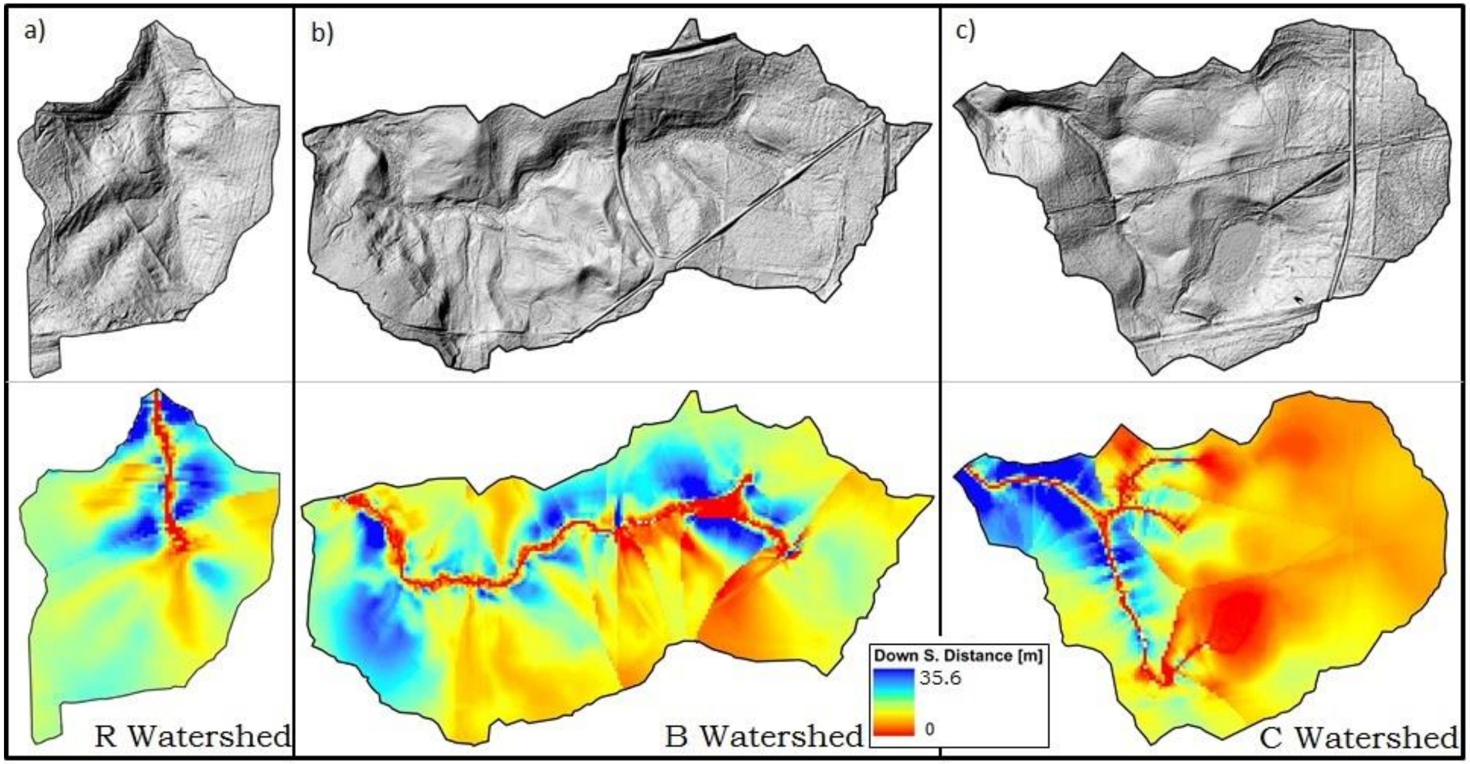
- Hillslopes largely disconnected from streams.



# Short interflow distances

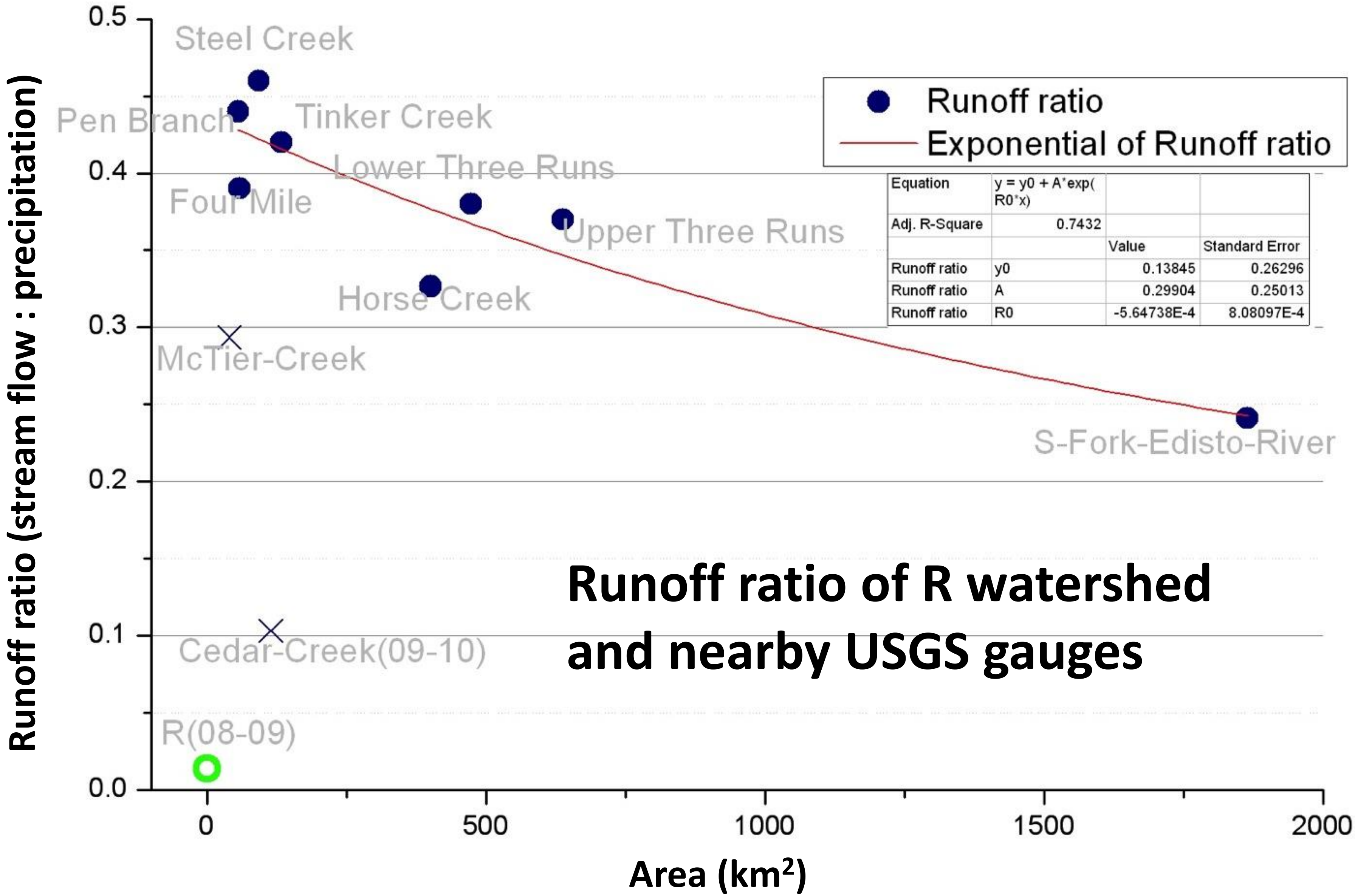



- Because of high percolation rates through the very irregular sandy clay loam argillic layer, interflow travel distances are relatively short, at most 36 m.

- We infer that interflow only delivers solutes from the steeper slopes immediately adjacent to the riparian valleys.

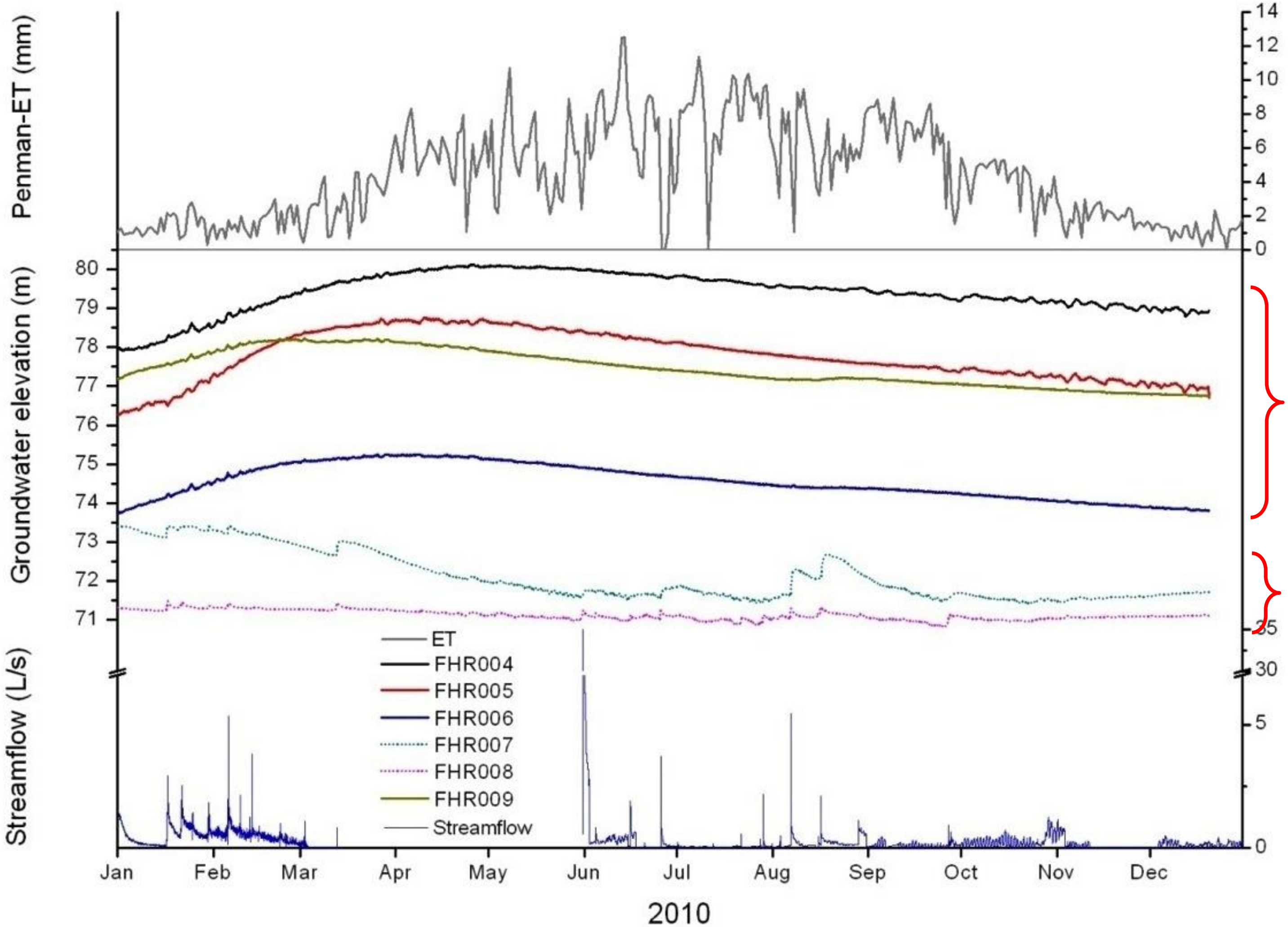
(From Jackson et al. 2014. Hyd. Proc.)

# Groundwater is the dominant flowpath




| Equation | y = y0 + A*exp( R0*x) | | |
|---|---|---|---|
| Adj. R-Square | 0.7432 | | |
| | | Value | Standard Error |
| Runoff ratio | y0 | 0.13845 | 0.26296 |
| Runoff ratio | A | 0.29904 | 0.25013 |
| Runoff ratio | R0 | -5.64738E-4 | 8.08097E-4 |

# Groundwater is the dominant flowpath



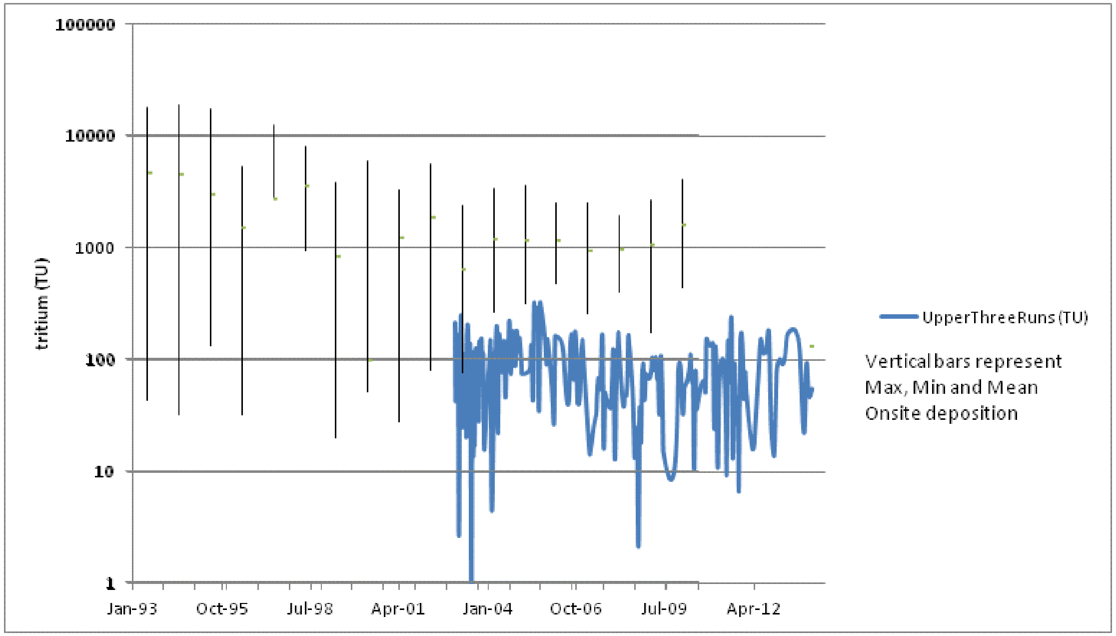

Ridge and mid-slope wells show lagged seasonal fluctuations to water demand (ET)

Riparian wells respond more quickly to ET and are more closely linked to stream flow

- Water and nitrate isotopes also show similarities in stream and groundwater chemistry.

# Next Steps: Water transit time estimates

- Extensive tritium monitoring program at SRS.
- Evaluating the potential for tritium data to provide an independent means to estimate water residence time.
- We will augment the monthly sampling with weekly sampling within Upper Fourmile in 2015.



# Evapotranspiration measurements to begin in 2015

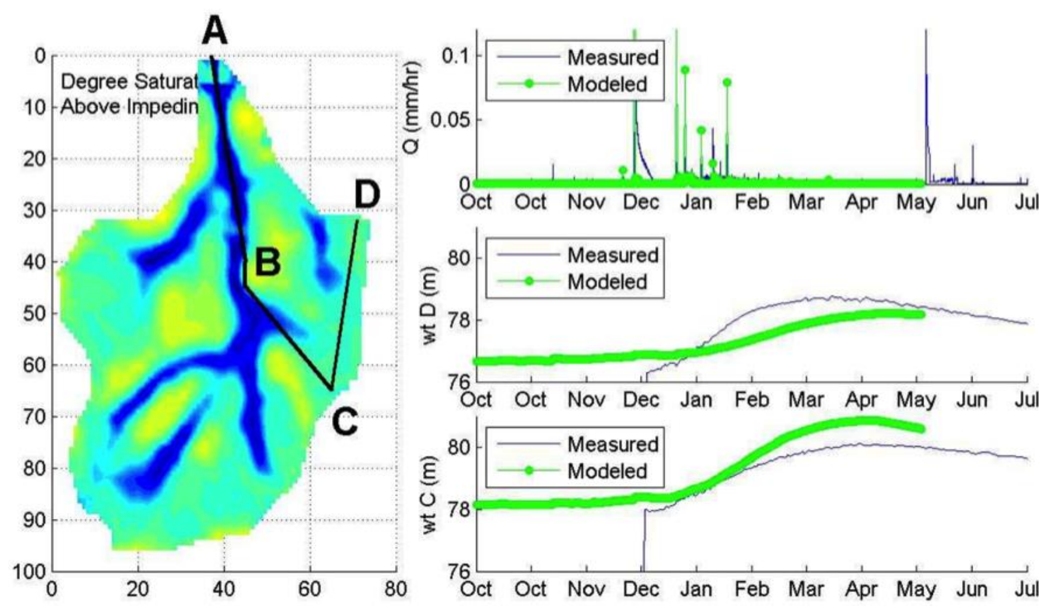
- Eddy flux measurements will provide a large (stand) scale estimate of evapotranspiration (ET) to be used in model parameterization.

- Goal: understand the effects of varying environmental conditions and stand development on the water use efficiency of intensively managed loblolly pine for bioenergy.

- Compare to ET in natural longleaf pine forest at Savannah River.

# Watershed model allows for upscaling results

1) Watershed-scale model developed based on field observations.
   - Model relationships between forest cover, meteorological variables, soil moisture, and groundwater dynamics.
   - Model development and initial calibration complete.
2) Upscaling to broader spatial and temporal scales.
   - Scale to Fourmile watershed and SRS.
   - Run models over multiple rotations and management scenarios to explore long-term impacts.



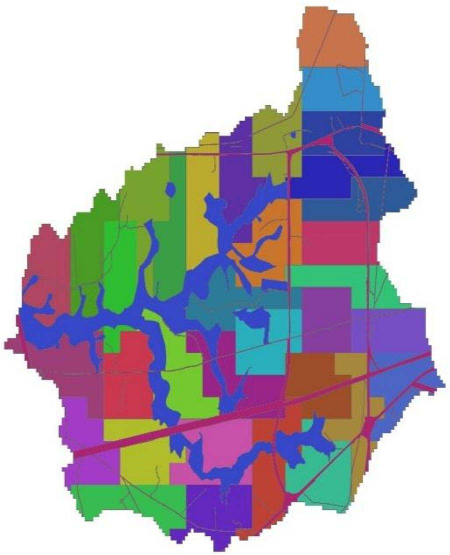
# Next steps: modeling management scenarios

Evaluate hydrologic effects of various forest management scenarios on a mid-sized southeastern Coastal Plain basin (~25,000 ha).

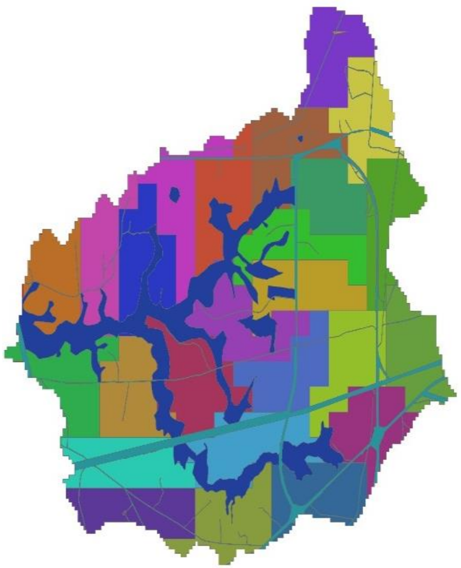
1) Baseline (static forest; no change in LAI or water demand).
2) Low-intensity forest management (35 yr rotation, cut 2.9% of the watershed every year).
3) Low-intensity forest management with mixed use (same as #2, but 50% forest, 20% pasture, 30% crop).
4) Sawtimber/pulp management (25 yr rotation, 12 yr thinning, cut 4% every year).
5) High-intensity woody biomass production (10 yr rotation, cut 10% every year).
6) High-intensity woody biomass production with mixed use (mix of scenarios 3 and 5).

# Next steps: modeling management scenarios

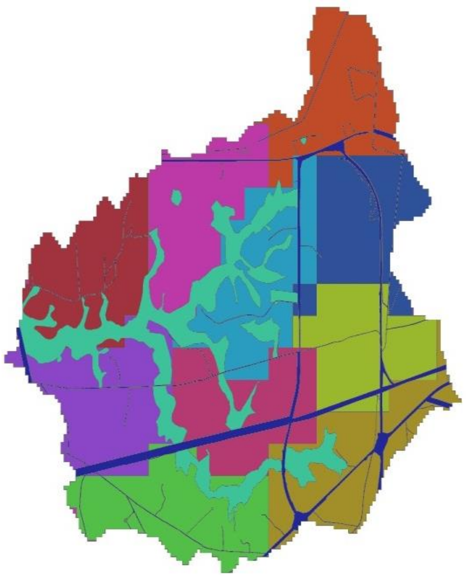
- Polygons of scheduled clear-cut areas for the various scenarios in Upper Fourmile Watershed.
- Non-road and non-SMZs land subdivided into equal areas for clear-cut rotation management.



Low-intensity,
35 yr rotation (#2)



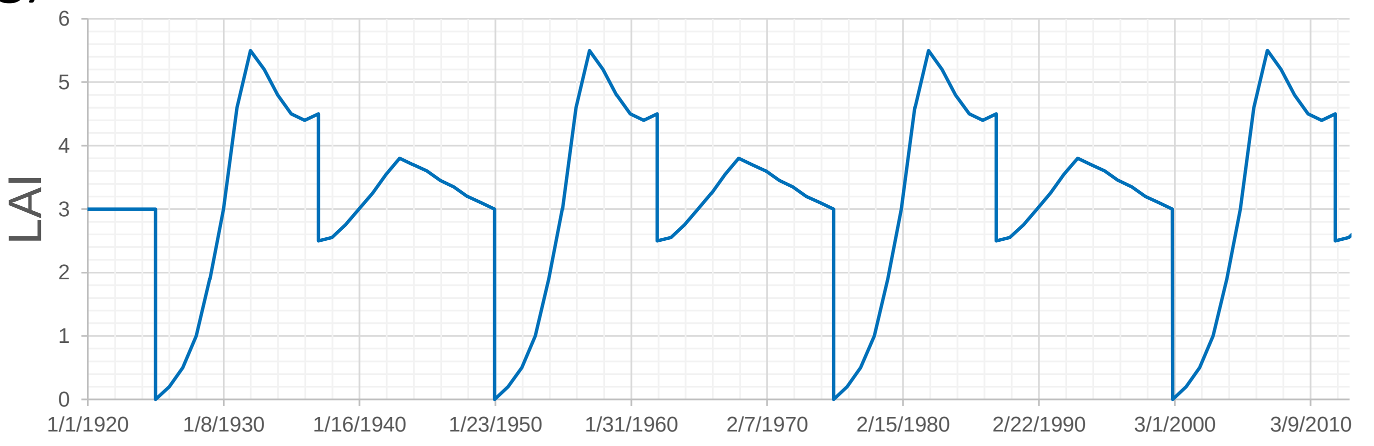
For sawtimber with thinning,
25 yr rotation (#4)



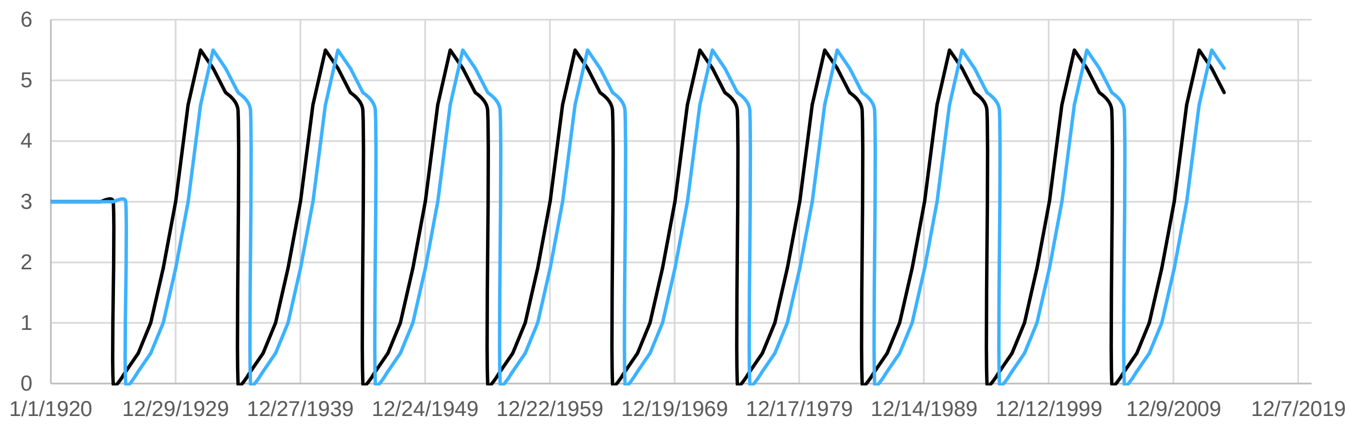
High-intensity for biomass,
10 yr rotation (#5)

# Next steps: modeling management scenarios

- Leaf Area Index (LAI) is an input into the model. Will use OSU, MIKE-SHE, and SWAT models.
- LAI for 25 yr rotation (sawtimber/pulp management with 12 yr thinning).




- LAI for 10 yr short-rotation for biomass scenario.



# Water quality: CFTs and interflow

- Observed higher nitrate concentrations in treatment watersheds (spring 2014):
    - Concentrated Flow Tracts (mean = 0.1 - 1 mg N/L).
    - Interflow draining cut areas (4 - 5 mg N/L).

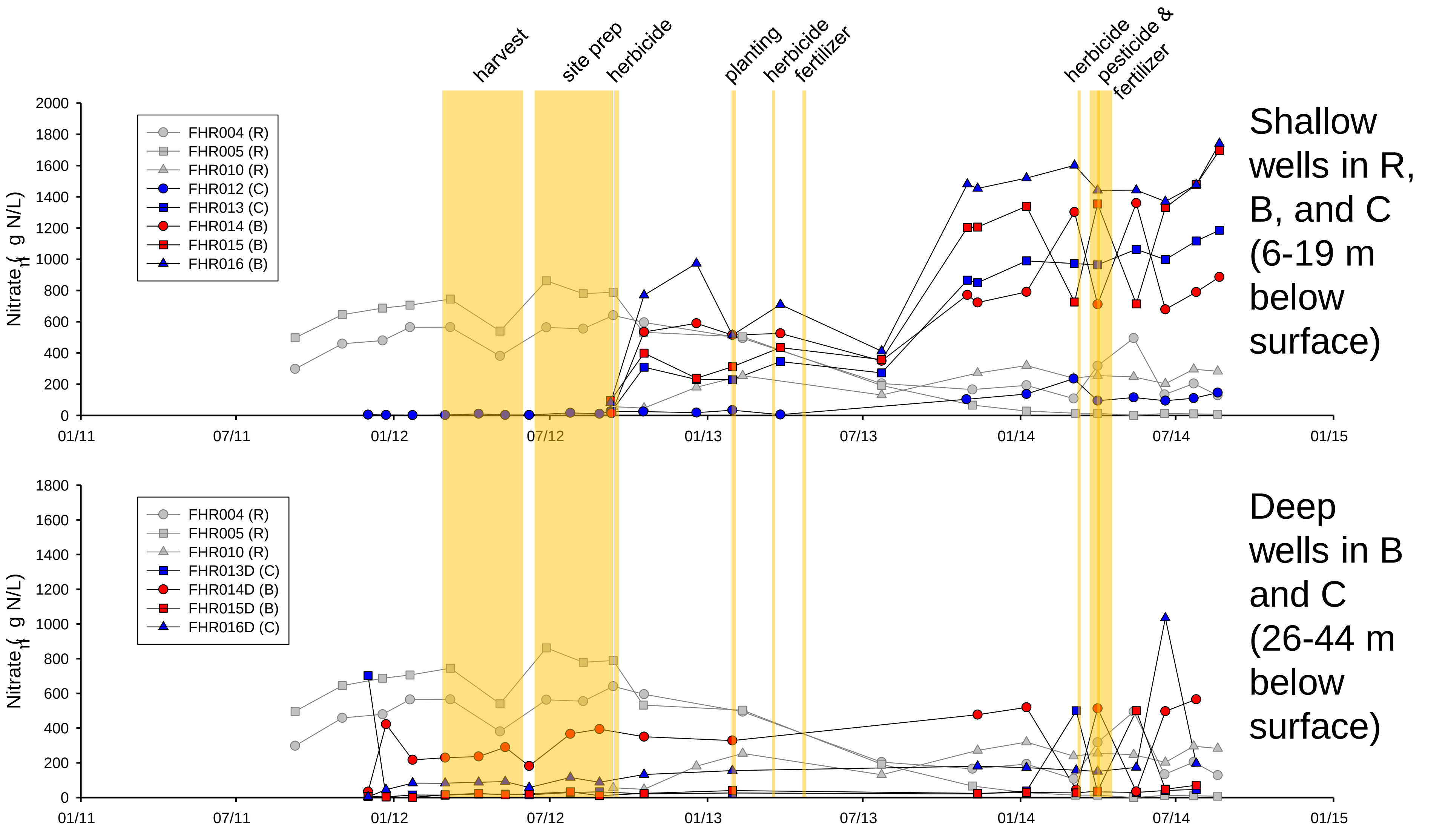
- Nitrate in streams and riparian groundwater not elevated in spring 2014 (water and fertilizers not moving directly to streams).

New interflow interception trench draining B planted area

- All herbicides of interest are below detection limits.

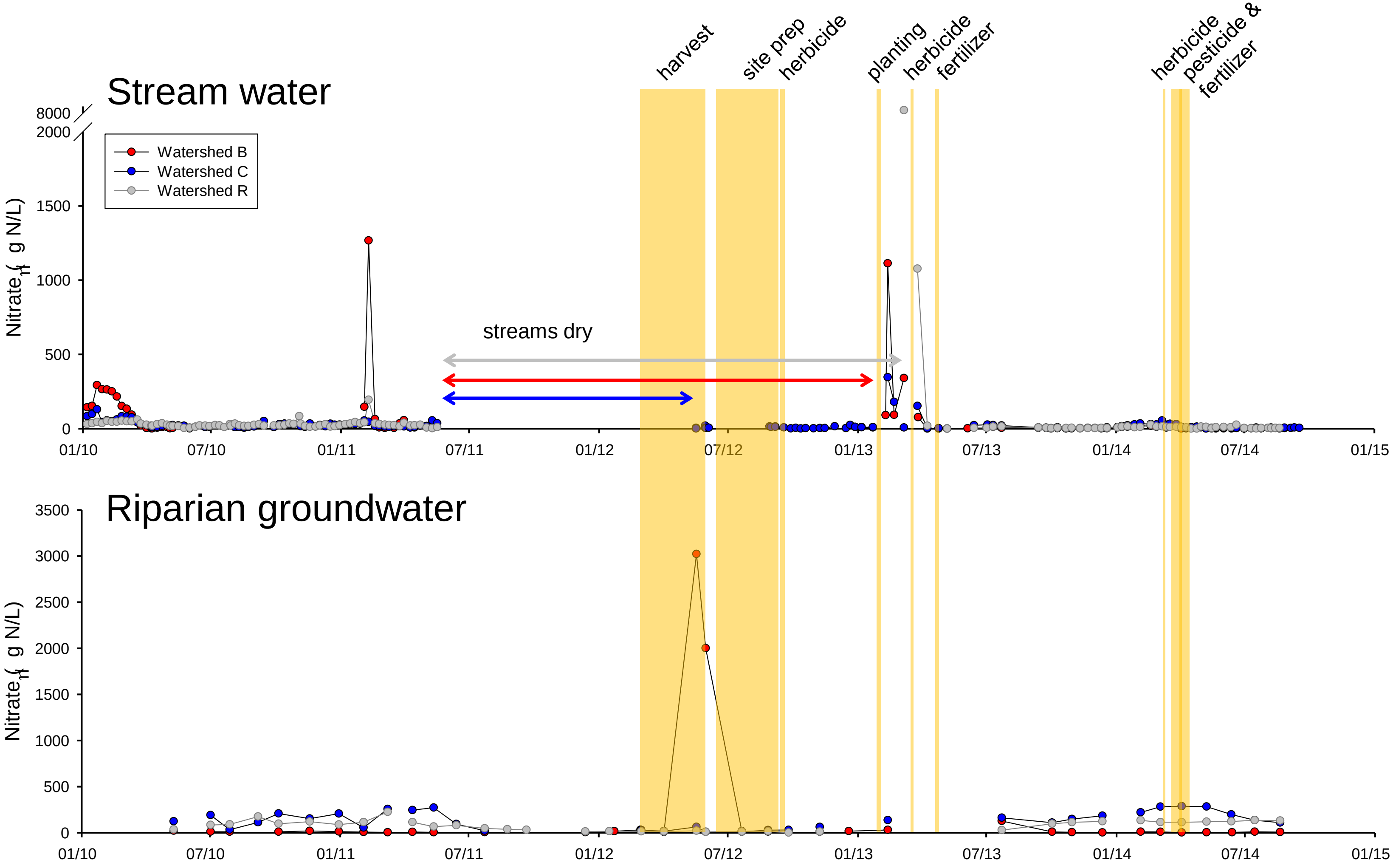
# Water quality: groundwater

- Nitrate concentrations increasing in groundwater;
<2 mg N/L (max contaminant level for nitrate = 10 mg N/L).



# Water quality: stream & riparian water

- Nitrate similar in treatment and control watersheds.
    - Long transit times (years) of groundwater to streams.
    - Possibility for nitrate removal (uptake and denitrification).

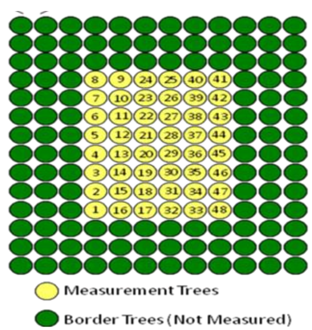


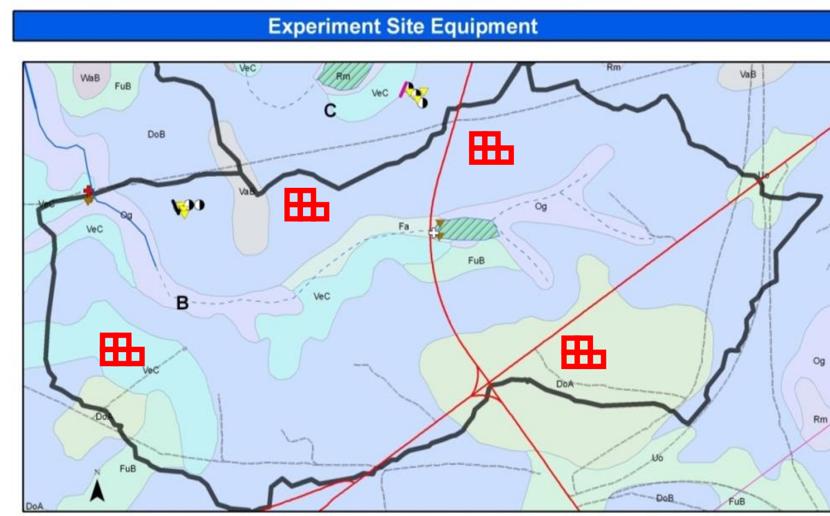
# Soil quality study

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

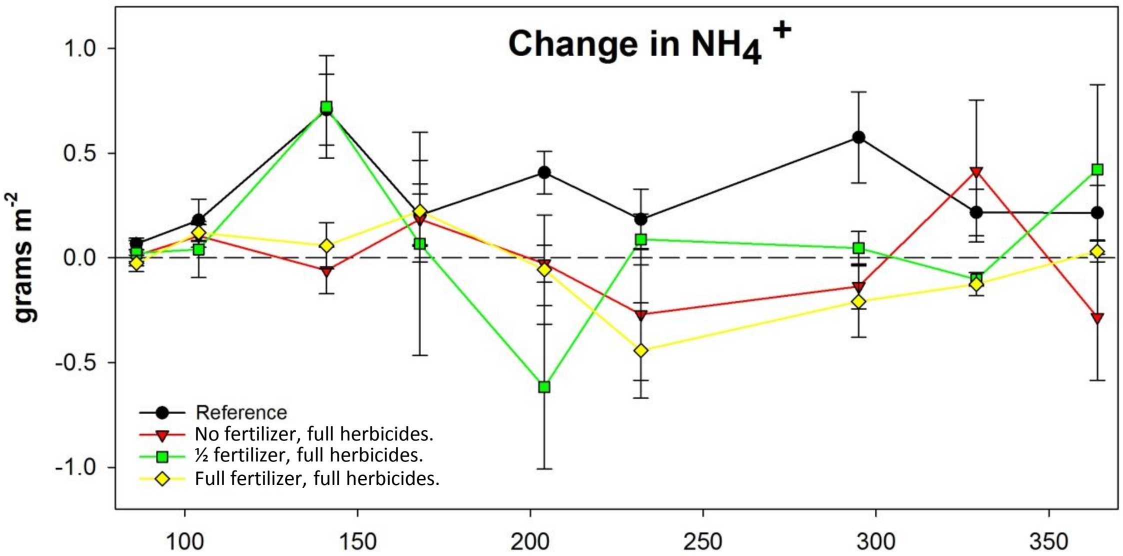
- Study design: 5 treatments, 4 reps per watershed
    - TRT1-3 = less intensive
    - Watershed-level treatment (TRT4) = operational management
    - TRT5 = higher density trees

| 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 |

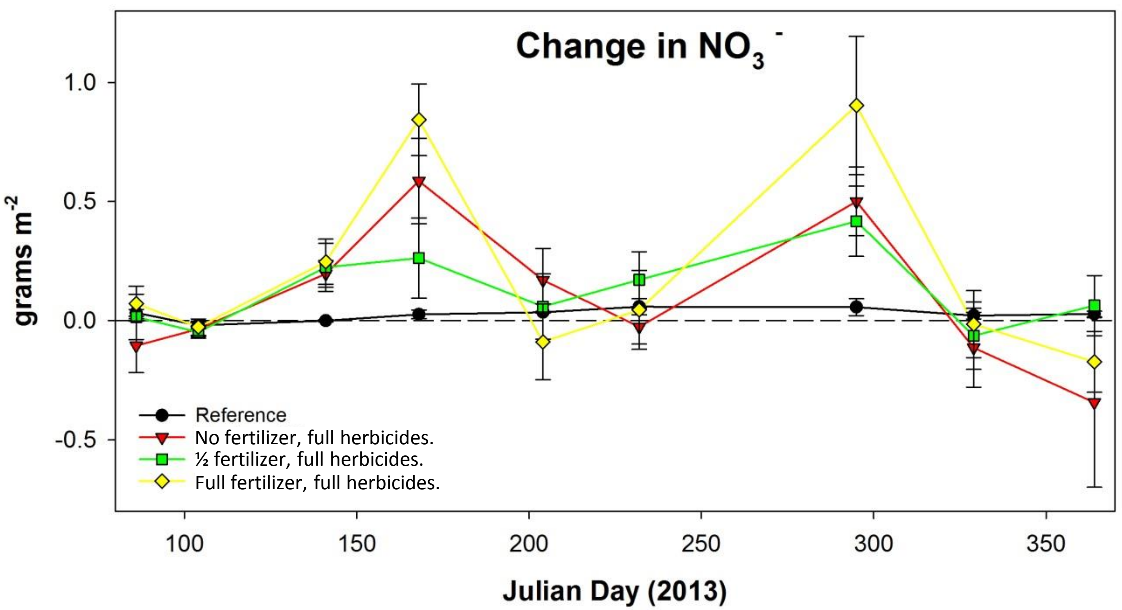


# Soil quality study: N mineralization and nitrification

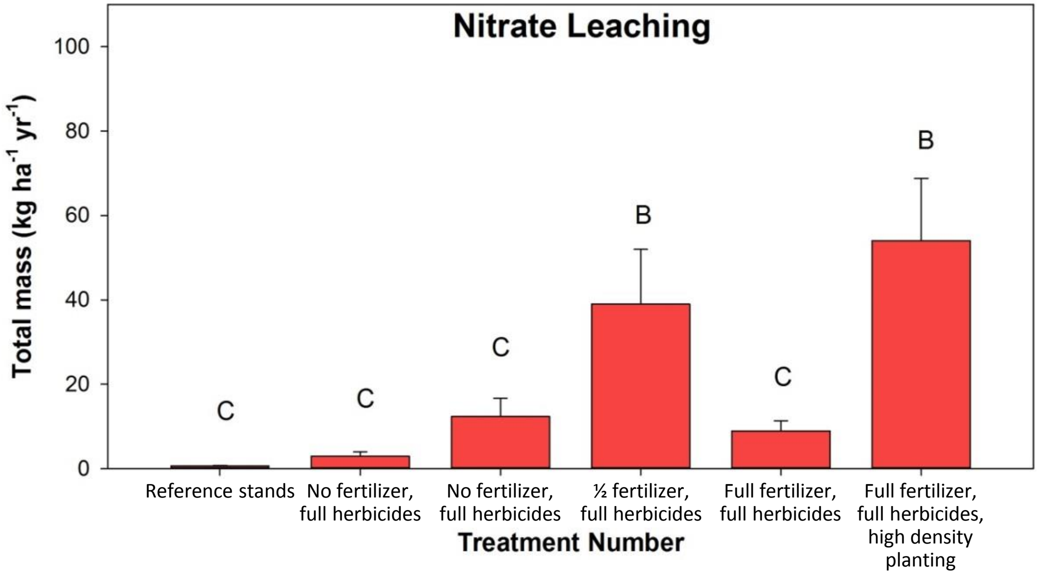



- N mineralization typically higher in reference stands (decomposition of forest floor materials).




- Nitrification higher in treatment stands in spring and autumn (harvest reduced ammonium uptake by pine).

# Soil quality study: N leaching




- Nitrate leaching higher in fertilized treatments except operational treatment (not clear why).
- Nitrate may move to groundwater.

# Summary

- Hydrology:

    - Interflow important in delivering solutes only near the riparian valleys.
    - Some seasonal seeps observed, but disperse in riparian zone.
    - Stream water primarily derived from groundwater; likely route of excess fertilizers to streams is via groundwater.

- Water & Soil Quality:

    - No short-term effects of pine management on stream water quality but increases in nitrate in groundwater consistent with higher nitrate leaching rates.  BMPs appear effective at maintaining stream water quality thus far.

- Watershed-scale model will be used to scale water quality and hydrology results.

# Upcoming Work

- Continue hydrology, water quality, and soil quality measurements through 2018 (canopy closure).

- Investigate transport and fate of nitrate in the riparian zone (denitrification assays, well transects).

- Investigate estimating groundwater residence time via tracers (tritium).

- Work on upscaling model temporally and spatially and modeling effects of various forest management scenarios.

# Acknowledgements


Field sampling: Ben Morris, Kevin Foust, Seth Younger, Bob Bahn

Lab analysis: Kitty McCracken, Allison Fortner, Jana Phillips, Deanne Brice

*Funding: DOE Bioenergy Technologies Office*


U.S. DEPARTMENT OF ENERGY

CLIMATE CHANGE SCIENCE INSTITUTE
OAK RIDGE NATIONAL LABORATORY

OAK RIDGE NATIONAL LABORATORY
MANAGED BY UT-BATTELLE FOR THE DEPARTMENT OF ENERGY