DOE Bioenergy Technologies Office (BETO) 2015 Project Peer Review

Short-Rotation Woody Biomass Sustainability

March 23, 2015
Analysis and Sustainability

Natalie A. Griffiths, Oak Ridge National Laboratory
C. Rhett Jackson, University of Georgia
Kellie Vache, Oregon State University
Jeffrey J. McDonnell, University of Saskatchewan
Gregory Starr, University of Alabama
John I. Blake, Ben M. Rau, USDA Forest Service

U.S. DEPARTMENT OF ENERGY

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

Goal Statements

Overall Project Goals:

- Use a watershed-scale experiment and a distributed watershed modeling approach to evaluate the environmental sustainability (water quality, water quantity, water use, soil quality, and productivity indicators) of intensive short-rotation pine management for bioenergy in the southeastern U.S.
- Determine whether current forestry Best Management Practices (BMPs) are adequate to protect water and soil resources.
- Relevance and outcomes: Woody biomass grown in the southeastern U.S. will be a dominant bioenergy feedstock and understanding the effects of intensive production on water and soils is critical. Research will inform whether bioenergy-specific BMPs are adequate to protect soil and water.

Our project goal aligns with BETO's goals:

- 'Develop commercially viable bioenergy and bioproducts technologies to enable the sustainable, nationwide production of biofuels…' (BETO Strategic Goal, MYPP Nov 2014).
- 'Understand and promote the positive economic, social, and environmental effects and reduce the potential negative impacts of biofuels production activities' (Sustainability Goal, MYPP Nov 2014).

Quad Chart Overview

Timeline

- Project start date: FY10
- Project end date: FY18 (proposed)
- Percent complete: 55%

Budget

	ORNL	University/ USFS-SR	USFS Cost Share	University Cost Share
FY10-12	$659K	$1,016K	$380.5K	$348K
FY13	$255K	$445K	$141.5K	$103K
FY14	$345K	$405K	$103K	$138K
Planned funding (FY15-18)	$1,380K	$1,285K	$71K (FY15)	$138K (FY15)

Barriers

- St-C: Sustainability data across the supply chain. "A fundamental hurdle is the lack of data to evaluate sustainability…"
- St-D: Implementing sustainability indicators. "Remaining challenge is to implement framework to assess and improve sustainability…"
- St-E: Best practices for sustainable bioenergy production. "Few best practices and sustainable systems defined for the bioenergy supply chain…"

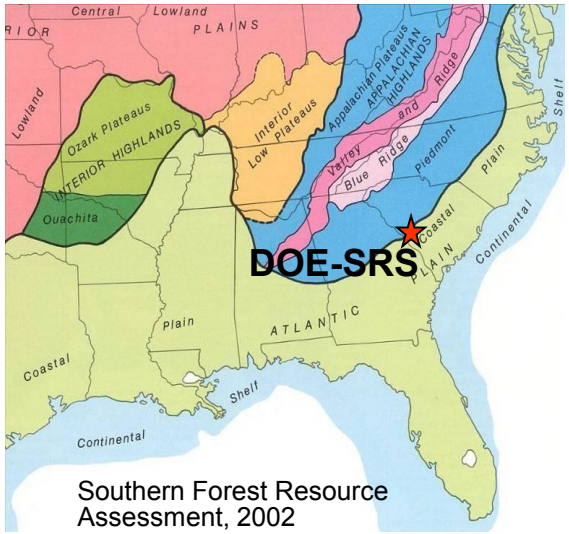
Partners

- Additional project team members:
  - U Saskatchewan: Natalie Orlowski
  - UGA: Menberu Bitew, Kevin Fouts
- Collaborators:
  - ANL: May Wu, Mi-Ae Ha (water footprint analysis)
- Project management: ORNL

Project Overview

- **History:** Project initiated in 2009 at watersheds set aside at the Savannah River Site (SRS) for environmental R&D of intensive biomass.

- **Context:** Southeastern U.S. will be a dominant source of bioenergy feedstocks. Water and soil impacts of intensive silviculture practices (multi-year weed control & fertilization) coupled with advanced genetics have not been evaluated in combination at the watershed scale. Current forestry BMPs have not been tested on practices of this intensity. Woody biomass will likely be utilized at SRS's biomass steam plant.



Southern Forest Resource Assessment, 2002

- **Objectives:**

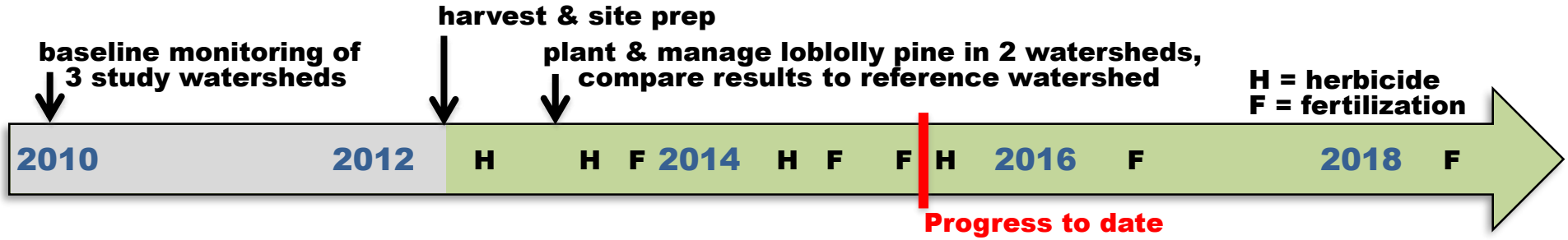
  1) Assess the effects of intensive practices on water and soil sustainability indicators relative to regulatory and narrative standards for forestry.

  2) Integrate dominant hydrologic processes across scales for a complete understanding of watershed-scale effects.

  3) Apply distributed modeling approaches to evaluate effects of short-rotation pine for bioenergy at larger spatial and temporal scales.

Technical Approach: Overview

- Experiment uses a before-after control-intervention (BACI) design of 3 adjacent, highly instrumented watersheds at SRS (1 reference, 2 treatment watersheds).



- Intensive silviculture practices are "state of the art" for woody crops and include sub-soiling, multiple herbicide applications, annual fertilization, and advanced genetic material. Applied South Carolina forestry BMPs.
- Coupled hydrological and biogeochemical measurements assess effects of pine management on water and soil resources at an operational scale.
- Process-level field observations used to develop a watershed model specific to the Coastal Plains area of the southeastern U.S.
- Modeling will upscale results both spatially and temporally to understand long-term effects. Modeling scenarios are being developed with input from stakeholders and industry.

Success Factors and Challenges

- Project success requires collection of high-quality data, scaling results using models, and dissemination of findings to relevant audiences.
  - Data will be published on the KDF. Results published in peer-reviewed journals and presented to industry, state water quality foresters, EPA.
  - Recent project presentations at: Southern Group of State Foresters (2013), Forestry BMP Symposium (2014), Short-Rotation Woody Crops Operations Working Group (2014), Society of American Foresters Convention (planned 2015).
  - Initiated discussions of forest management modeling scenarios with industry (NCASI) and state water quality foresters.

- Results are expected to validate environmental sustainability of high-yield woody crop production technology and provide a baseline for this technology relative to current BMPs based on existing studies.

- Challenges associated with the experiment (i.e., droughts/floods, fire, pests, storms), measurements (i.e., lagged effects on stream water quality), and modeling (i.e., incorporating climate change scenarios) have been identified and solutions have been considered and addressed.

Technical Approach: Management

- **Division of tasks based on scientific expertise:** water quality (ORNL), hydrology (UGA), modeling (OSU), stable isotopes (US), water use (UA), operational forestry practices and soil quality & productivity (USFS-SR).

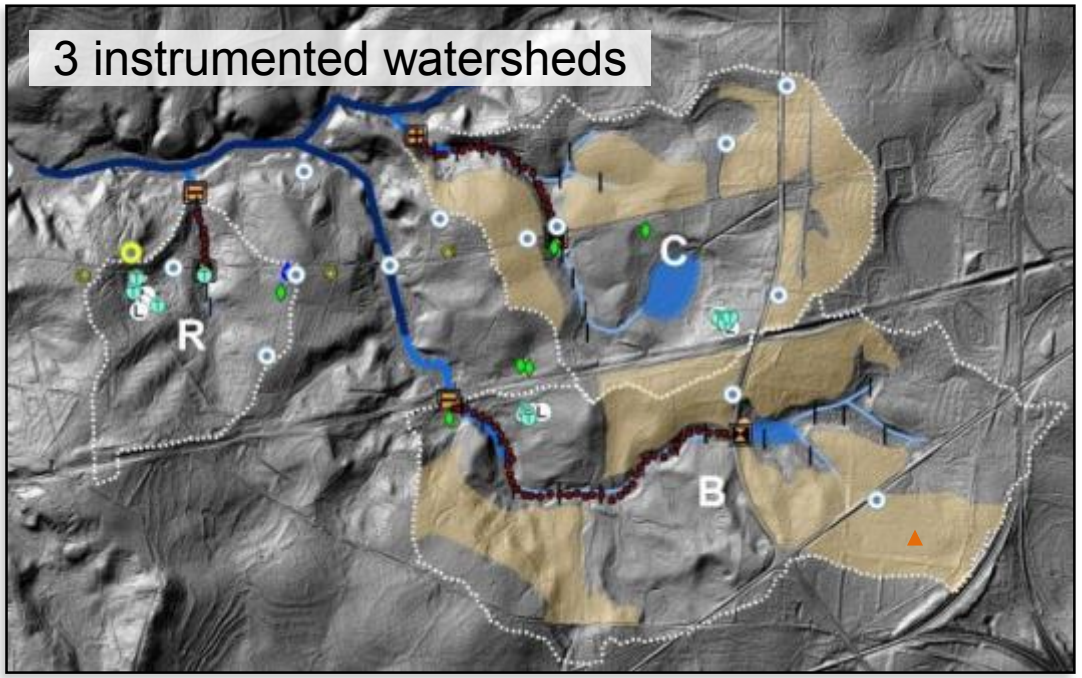
- **Collaborative project requires frequent meetings and on-site researchers:**
  - Monthly conference calls and bi-annual project meetings.
  - On-site field technician (UGA) collects samples and maintains equipment.
  - Post-doc (UGA) and research scientists (USFS-SR staff) based at SRS.

- **Milestones divided by tasks to monitor progress:**
  - All FY13 and FY14 milestones have been completed.
  - FY15 milestones complete (Q1) or on track (Q2-4).

- **Go/No-Go Decision:** If water and soil indicators are consistently near or above regulatory standards by 3/31/16, this suggests the treatment is impairing water and soil resources and would not be an environmentally sustainable practice. If water and soil metrics are below regulatory standards, we will continue the project to examine longer-term impacts.

Progress on Experimental Treatments

- 3 old-field forested watersheds: 1 reference (R; 45 ha) and 2 treatment (B; 169 ha, C; 117 ha).
- Acquired and integrated detailed soils, vegetation, LiDAR topography, groundwater, streams, and meteorological databases.
- Site characteristics: low-relief topography, poor-to-moderate quality sandy soils overlaying clay. Organic-rich riparian zones, intermittent and ephemeral channels. Watersheds typical of those in the southeast Upper Coastal Plain.
- Infrastructure:
  - 3 stream flumes
  - 20 groundwater wells
  - Site weather station and 10 sub-canopy rain gauges
  - 12 stream-side piezometers
  - 5 subsurface trench collectors with hillslope instrumentation
  - 1 eddy flux tower
- 12 nitrogen budget, soil quality, and productivity plots



Intensive pine silviculture for bioenergy on 40% of Watersheds B and C (yellow).

Progress on Silviculture

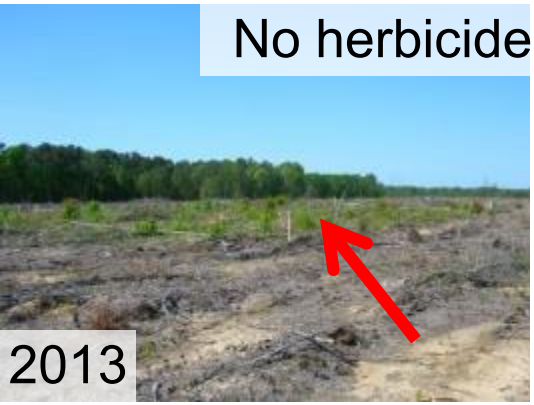
- **All silviculture milestones met. Treatments occurred on schedule:**
  - Jan-May 2012: Harvest 40+% of area, including 20 Mg/ha of residues removed for bioenergy.
  - Summer/fall 2012: Ripping/sub-soiling.
  - Sept 2012: Herbaceous weed control (imazapyr and glyphosate).
  - Jan-Feb 2013: Planting of loblolly pine seedlings (AGM MCP 37 growth is 70% greater than the standard southeast reference).
  - Mar 2013: Herbaceous weed control (sulfometuron methyl and imazapyr).
  - April 2013: Fertilization (diammonium phosphate).
  - March 2014: Herbaceous weed control (sulfometuron methyl) and tip moth control (fipronil).
  - March 2014: Fertilization (urea).
  - March 2015: Fertilization (DAP and urea) and weed control (sulfometuron methyl) scheduled.

Soil Quality and Productivity Study

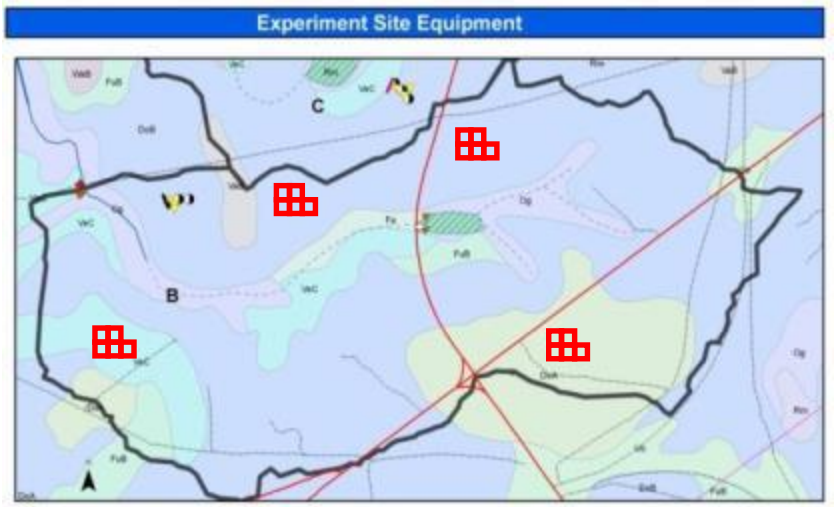
- **Objective:** Measure soil quality and productivity response to varying levels of fertilizer and herbicide.

- **Measurements:** Baseline (2011) & treatment (2012-present) periods. Soil nutrients, N mineralization, nitrification, nitrate leaching, pine growth & mortality.

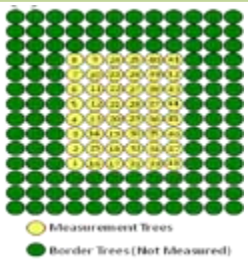
- **Milestones:** Analyzed soil and vegetation samples from baseline and first treatment year. Analysis of year 2 samples is ongoing.



No herbicide treatment plot

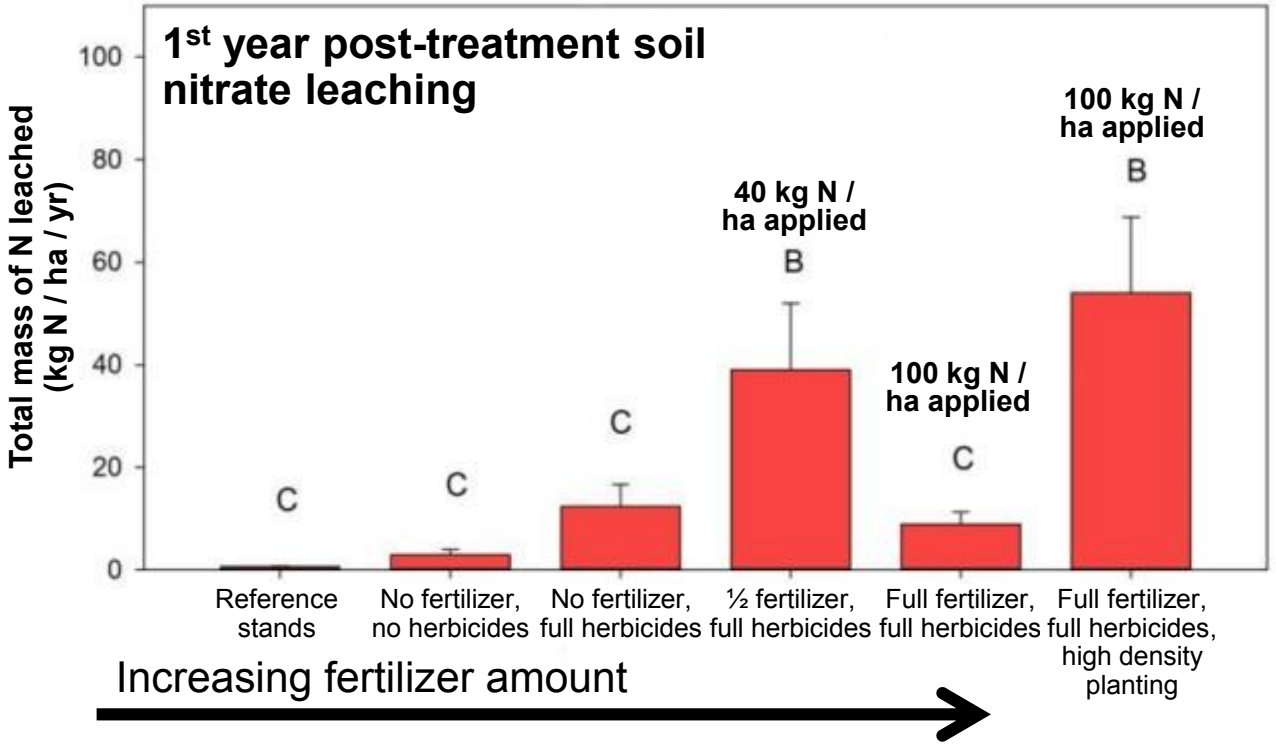


TRT1	TRT2	TRT3
Elite genetics No nutrients No herbicides Op. density	Elite genetics No nutrients Op. herbicides Op. density	Elite genetics 1/2 nutrients Op. herbicides Op. density
TRT4	**TRT5**	
Elite genetics Op. nutrients Op. herbicides Op. density	Elite genetics Op. nutrients Op. herbicides High density	



- 5 fertilizer/herbicide treatments. 4 replicates in both B and C watersheds (8 total) and 4 control plots in R watershed.

Soil Quality and Productivity Study



- Nitrification was higher in intensively managed plantations in spring and autumn due to reduced uptake of ammonium by young pine root systems.
- Nitrate leaching was higher in fertilized treatments than in un-fertilized treatments, except for the operational treatment.
- **Main finding:** Under higher fertilizer application rates, pine nutrient uptake is not 100% efficient. Ammonium can be nitrified and this excess nitrate may leach from plantations to the groundwater and affect groundwater quality.

Field Hydrology Results

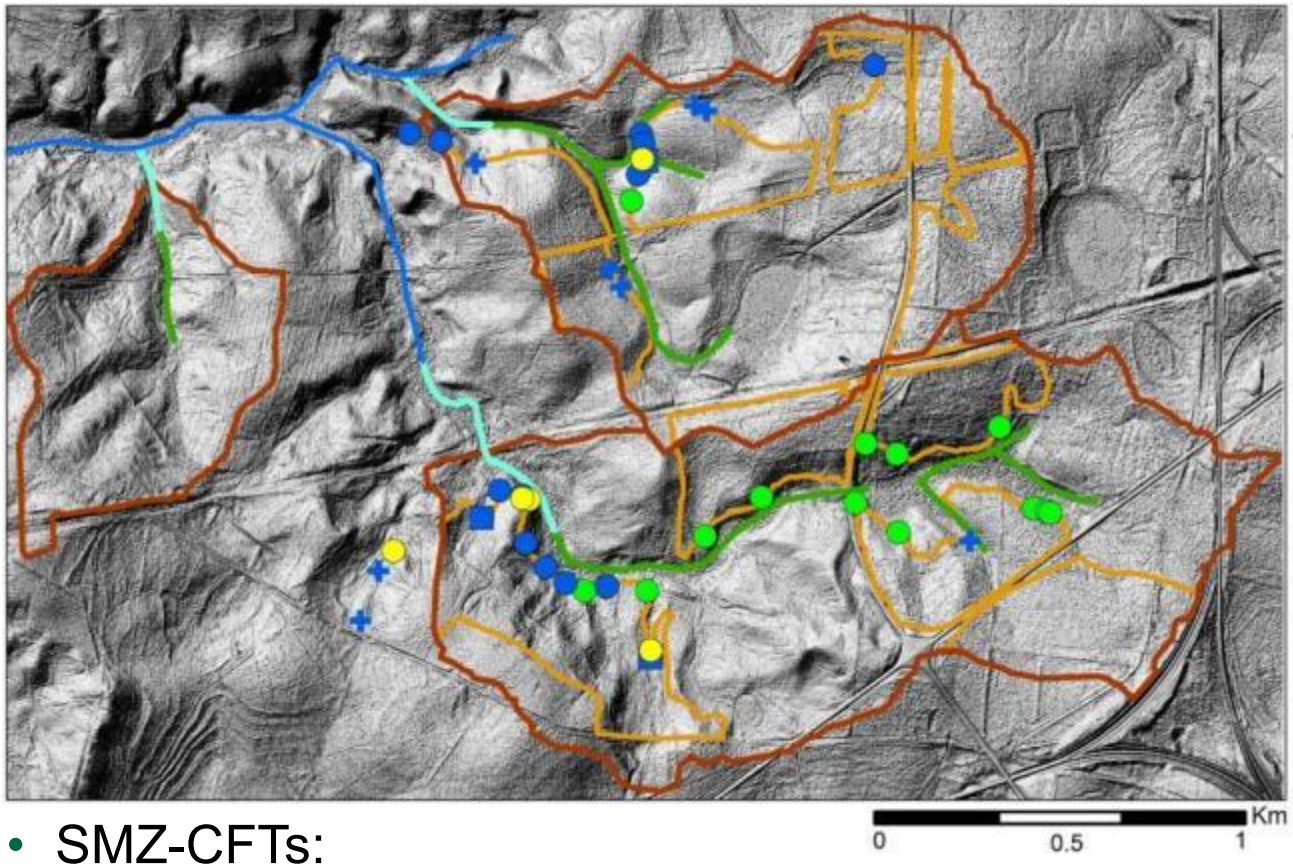
- **Objectives**:
  - Identify and characterize dominant hydrologic processes and streamflow generation pathways.
  - Develop time series of flows, moisture levels, and groundwater levels to inform and test hydrologic models for simulating management scenarios.
  - Use stable isotopes and water chemistry to delineate dominant watershed flowpaths. Use tritium to estimate catchment residence times.

- **All milestones completed.** Two papers published, three submitted, one in preparation.


Stream flume and water sampler


Subsurface trench outflow

Field Hydrology Results

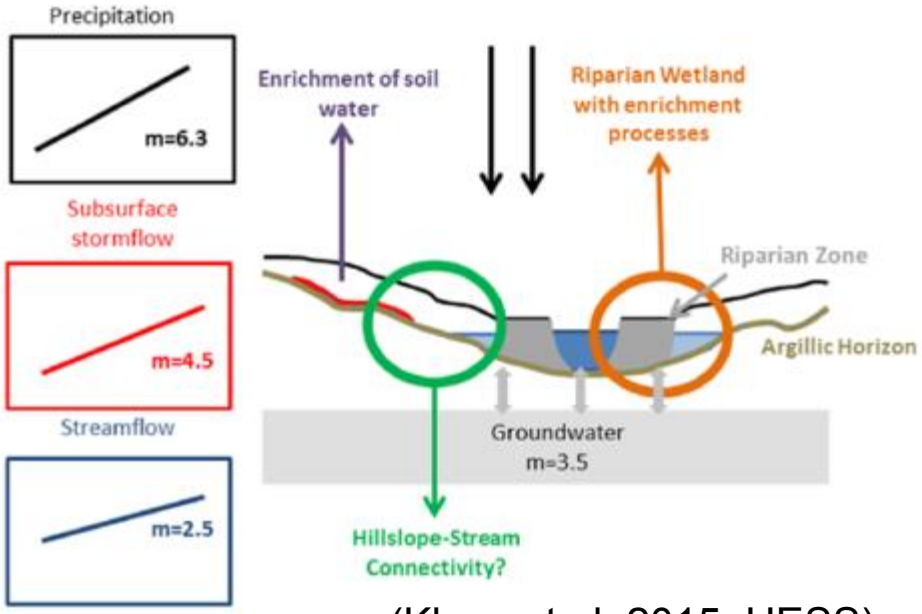


Map showing concentrated flow tracks (CFTs) entering streamside management zones (SMZs) in 2012-2014.

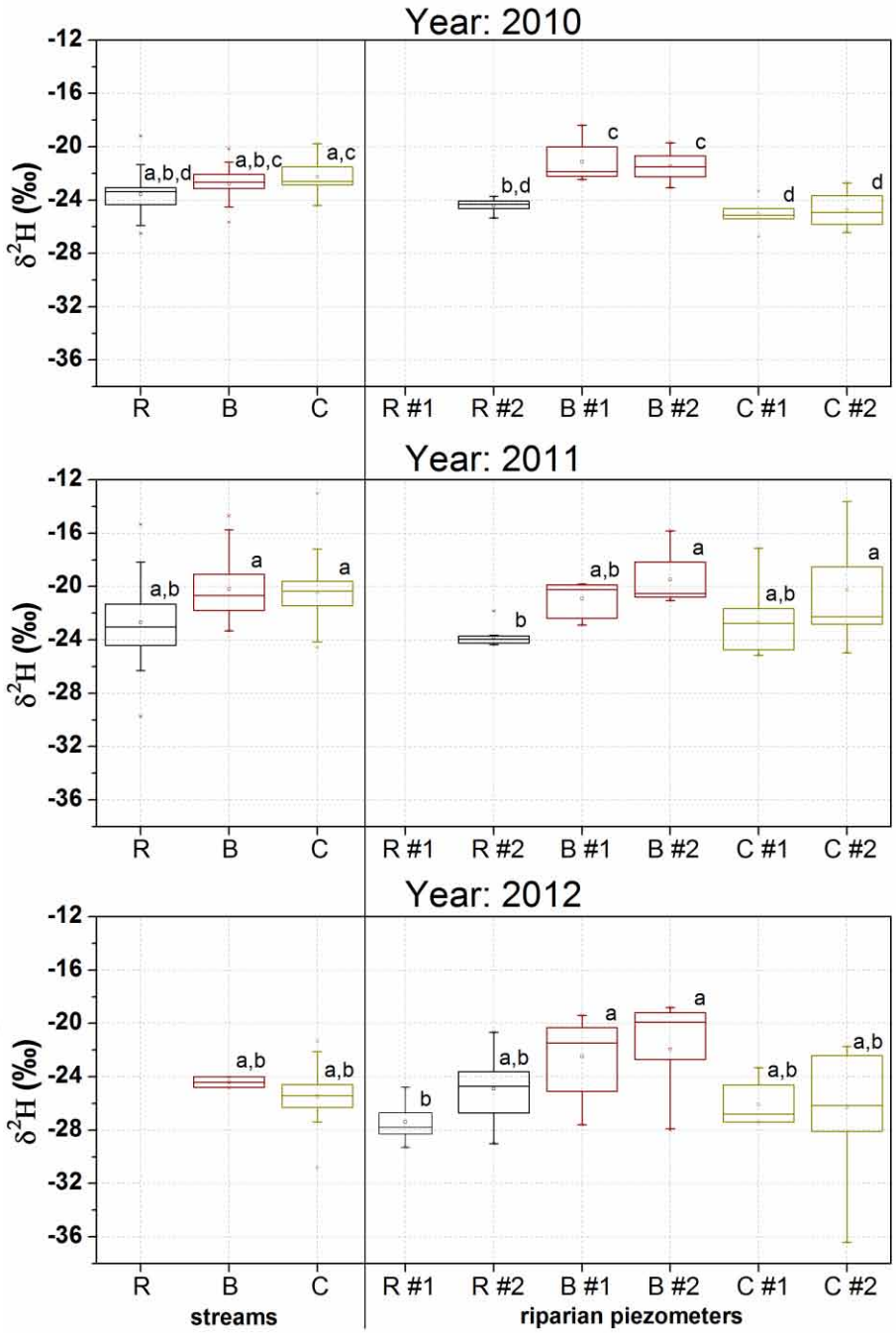
- SMZ-CFTs:
  Cat. 2 – flow and fine sediments reach water bodies.
  Cat. 3 – water without sediment reaches water bodies.
  Cat. 4 – water reinfiltrates in the SMZ.
- **Main finding:** SMZs are working. Horton overland flow is rare. In low areas, water table rises into planted areas during wet periods, forming seasonal seeps.

Field Hydrology Results

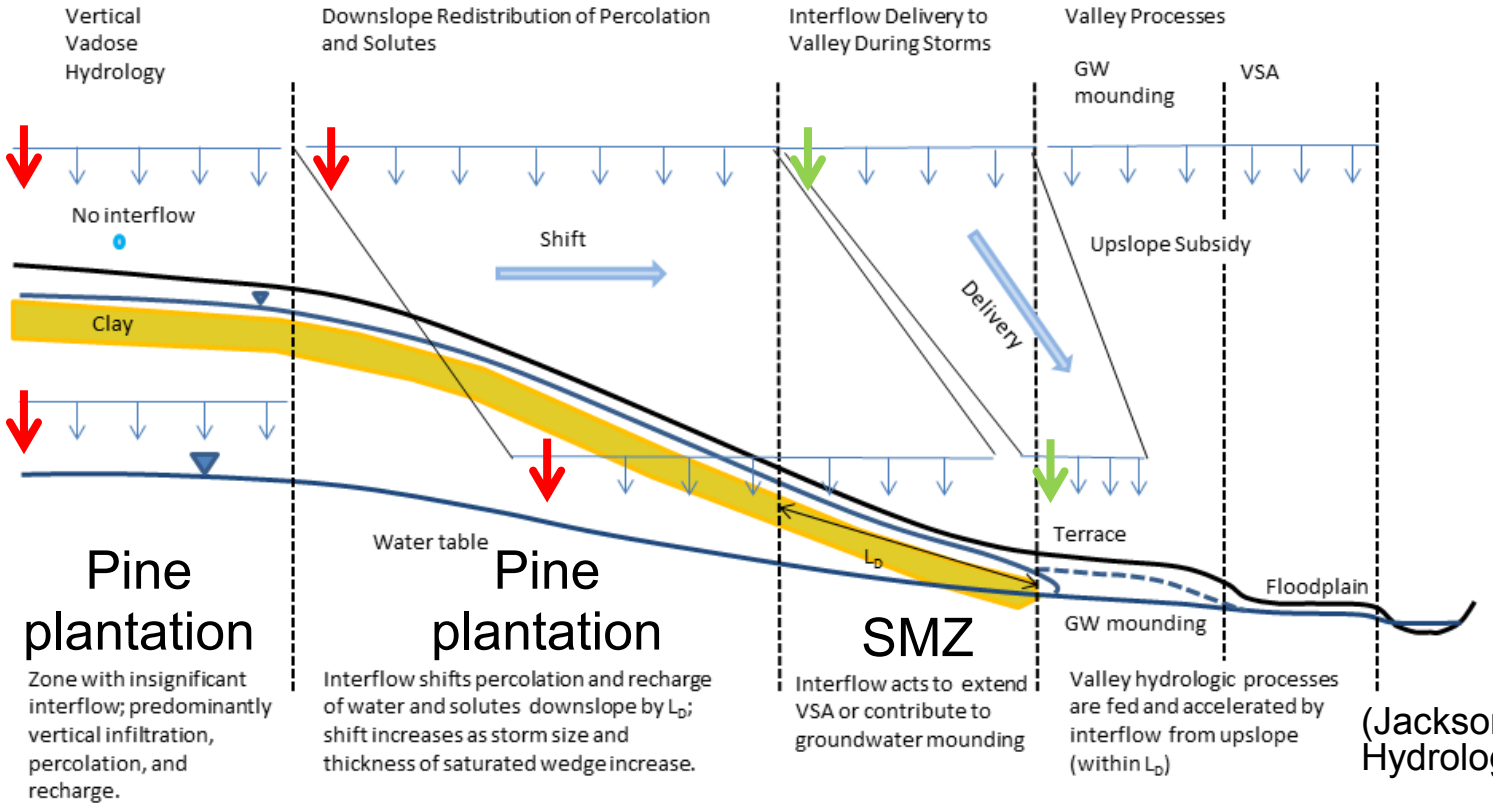
- Water isotope data are used to infer hydrological flowpaths in the study watersheds.
- Spatial statistical analyses revealed isotopic similarities in stream and riparian water (right figure).
- Slopes ('m') of meteoric water lines <u>show a disconnect between hillslope and stream water</u> (bottom figure).



(Klaus et al. 2015. HESS)



Field Hydrology Results



(Jackson et al. 2014. Hydrological Processes)

- All hydrometric, isotope, and water quality data consistently show that interflow delivers water to the valleys only from the immediately adjacent steeper-slope segments.
- **Main finding:** The most likely stream water quality effects will be via a groundwater pathway.

Evapotranspiration Measurements

- New task initiated since 2013 peer review.

- **Objective:** Understand effects of varying environmental conditions and stand development on water use efficiency of intensively managed pine for bioenergy.
- Eddy flux measurements will provide stand scale estimate of evapotranspiration (ET) to be used in model parameterization. ET will be compared to ET of native long-leaf pine from the SRS Ameriflux site.

- **Measurements:** Water and CO_2 fluxes from the loblolly pine stand to calculate ET and net ecosystem exchange (30-min resolution) of the loblolly pine bioenergy feedstock. Footprint ~200-500 m radius from tower.

- **Milestone:** Tower installed and data collection started in Jan 2015.

Eddy flux tower

Water Quality Results

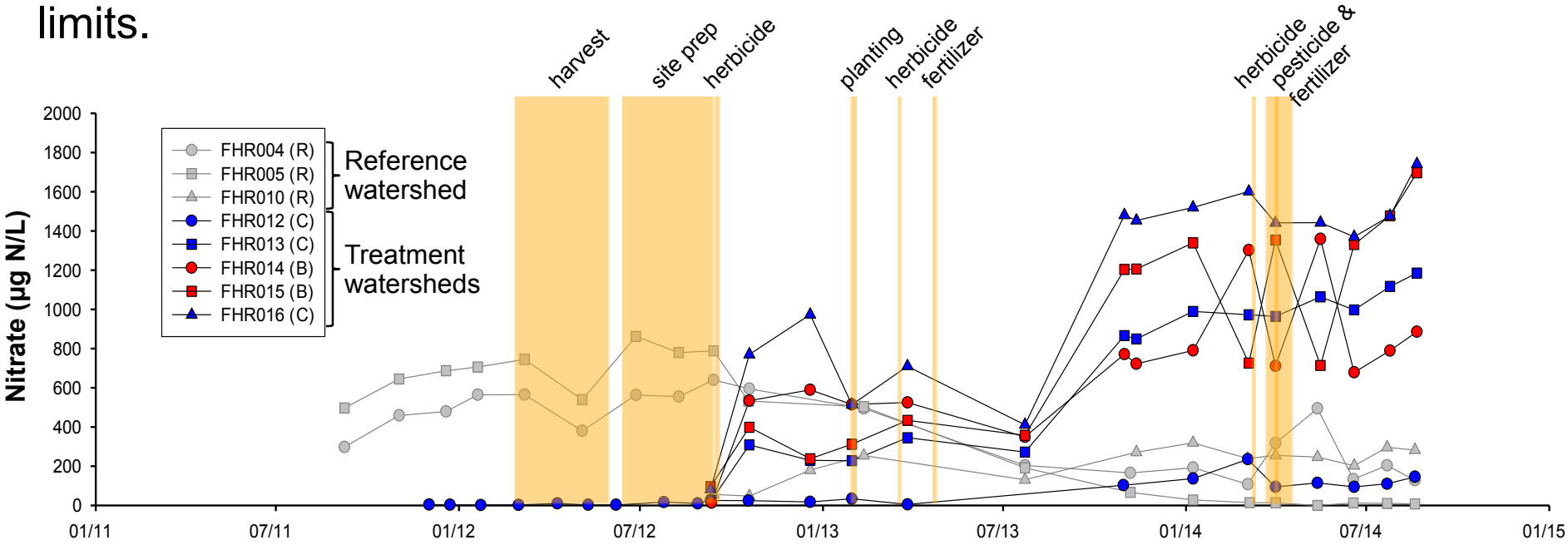
- **Objectives**:
  - Determine baseline water quality in the 3 study watersheds.
  - Examine the short- and long-term effects of conversion to and management of short-rotation woody biomass (i.e., harvest, site preparation, planting) on water quality (nitrogen, stable isotopes of nitrate, phosphorus, dissolved organic carbon, herbicides, pesticides).

- **All milestones completed.** All water samples collected through FY14 have been analyzed, and reports summarizing findings were submitted to BETO. Analysis of FY15 samples in progress. One manuscript in preparation.

Water Quality: Groundwater Nitrate

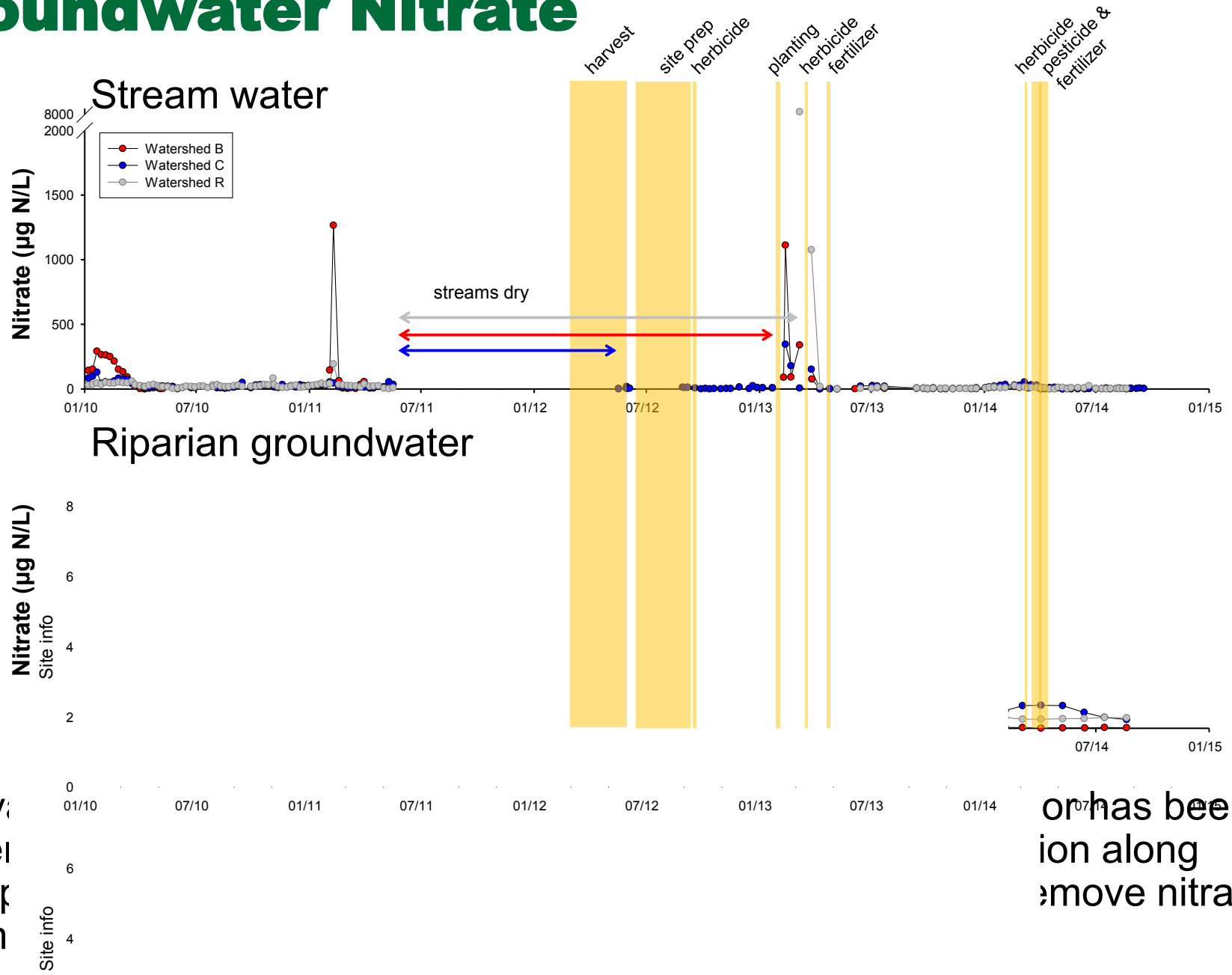
- Nitrate concentrations increasing in shallow (but not deep) groundwater in treatment watersheds in the post-treatment period. Concentrations are <2 mg N/L (drinking water limit = 10 mg N/L).

- No increases in ammonium or soluble reactive phosphorus (SRP) concentrations. All herbicide and pesticide samples are below detection limits.



- **Main finding:** Nitrate is the nutrient of greatest water quality concern. Nutrient uptake is inefficient during early phase due to low pine growth rates and weed control. Results in elevated nitrate concentrations in groundwater.

Water Quality: Stream Water and Riparian Groundwater Nitrate



- Elev
  take
  flowp
  from

or has been
ion along
emove nitrate

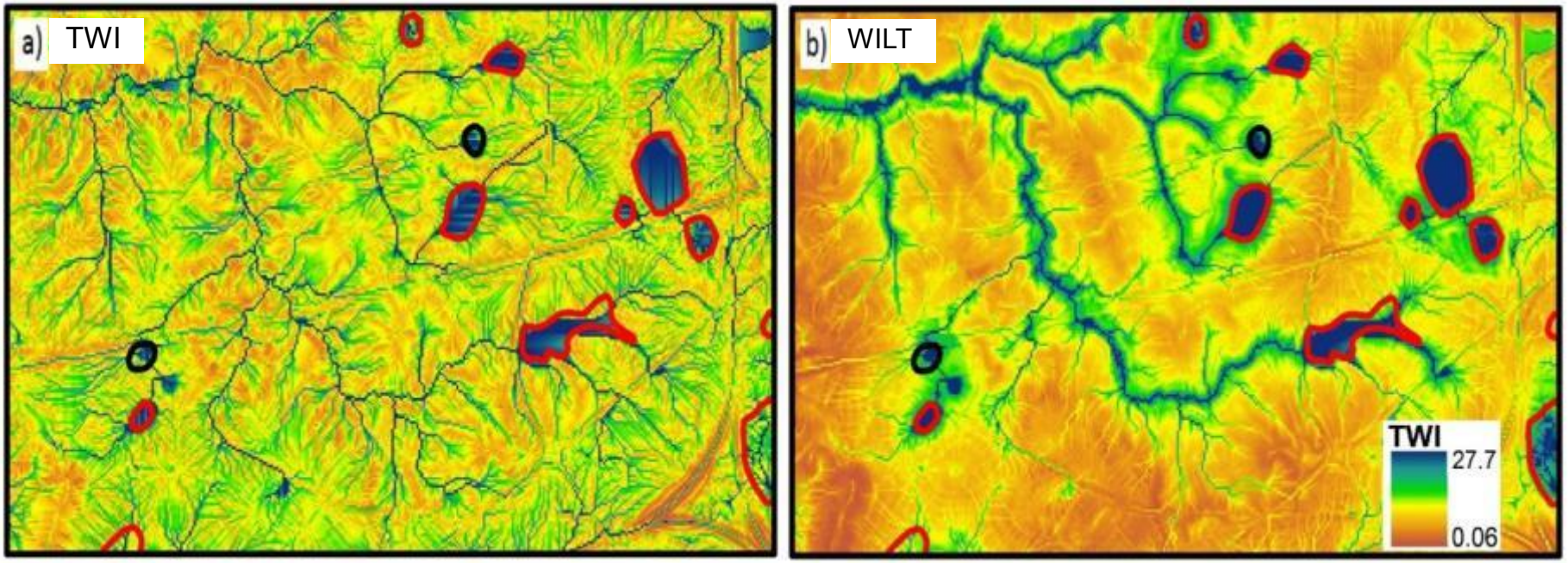
Hydrologic Modeling Results

- **Objectives:**
  - Develop watershed model using functional relationships between vegetation cover, meteorological variables, soil moisture, and groundwater dynamics.
  - Use model to evaluate potential impacts of biomass production and various forest management scenarios across the SRS site.
  - Evaluate influence of biomass crops on the hydrological cycle and nitrogen cycle at local and regional scales.

- **Milestones:** Developed modified version of the OSU-watershed model and included conservative tracer model. Upcoming work focused on forest scenario modeling and transferring watershed model to larger scales.

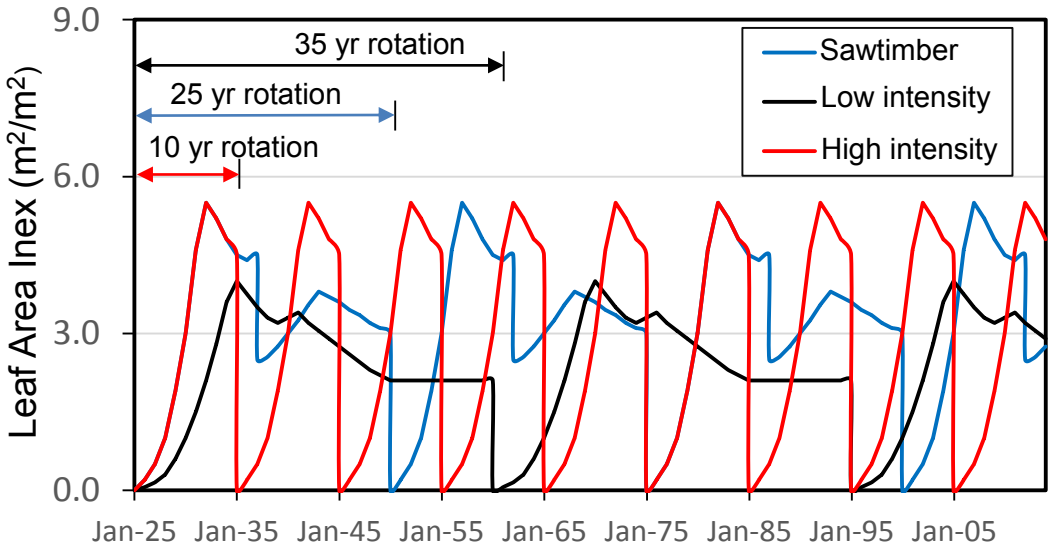
Modeling: SMZ Boundary Delineation

- Developed a Wetness Index based on Landscape and Topography (WILT) to delineate SMZs and predict relative soil moisture and hydrologic responsiveness for low-relief watersheds. WILT modifies the TOPMODEL topographic wetness index (TWI) using proximity to water bodies and estimated depth to groundwater.
- **Main finding:** WILT provides a tool to accurately identified SMZ boundaries in low-relief watersheds. WILT was less sensitive to DEM resolution than the TWI by incorporating landscape attributes and depth to groundwater measurements.



Forest Management Scenario Modeling

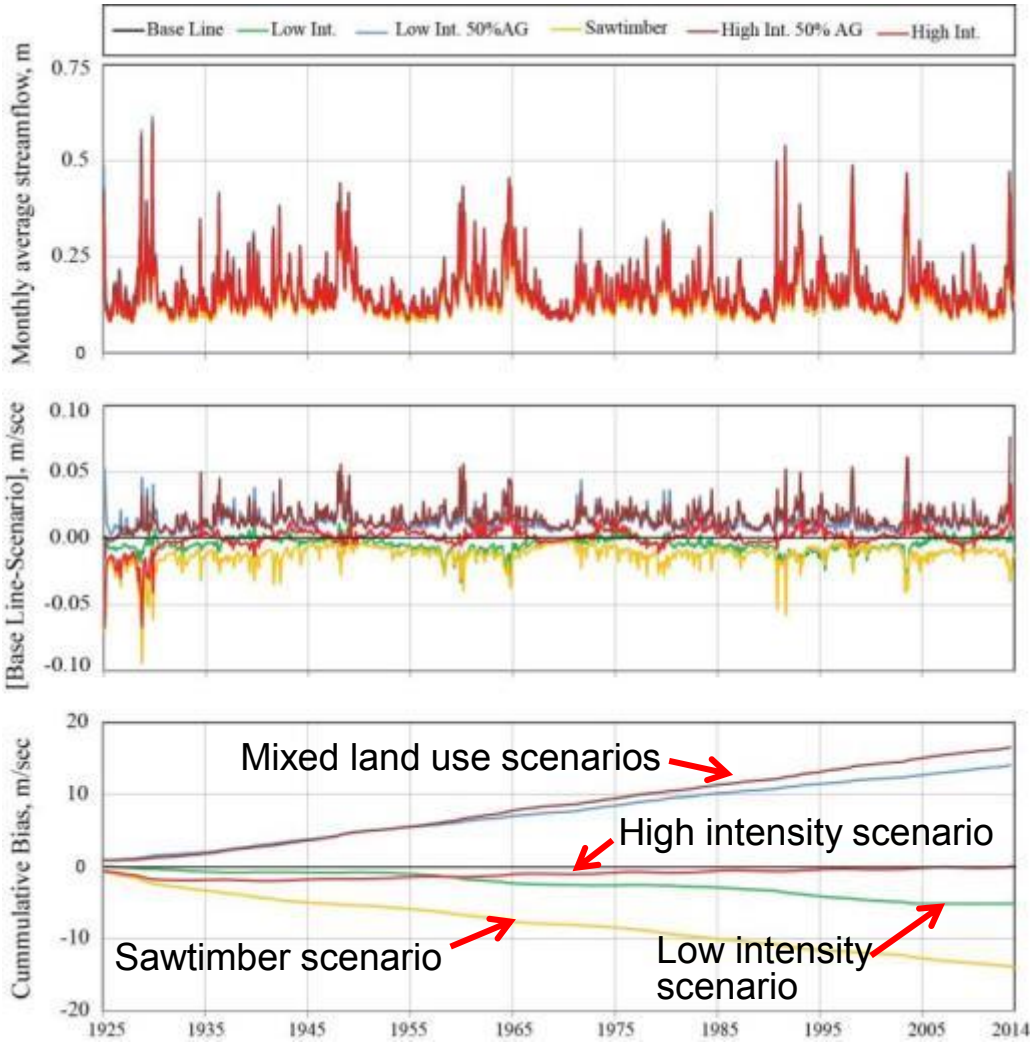
- OSU is developing the watershed model specific to the Coastal Plains region using multi-objective functions comprising several parameters (ET, groundwater elevation, stream flow, soil moisture).
- We are parameterizing standard models (MIKE-SHE, SWAT) for comparison to the OSU watershed model and running forest management scenarios.
- Scenarios suggested to date:
  - Baseline (minimally managed forest based on vegetation condition in R watershed).
  - Low-intensity forest management (35 yr rotation).
  - Low-intensity forest with 50% land in agriculture.
  - Sawtimber/pulp management (25 yr rotation, 12 yr thinning).
  - High-intensity woody biomass production (10 yr rotation).
  - High-intensity woody biomass production with 50% land in ag.



Low- and high-intensity and sawtimber forest production varies based on development of LAI and roots over time.

Forest Management Scenario Modeling using a standard model (MIKE-SHE)

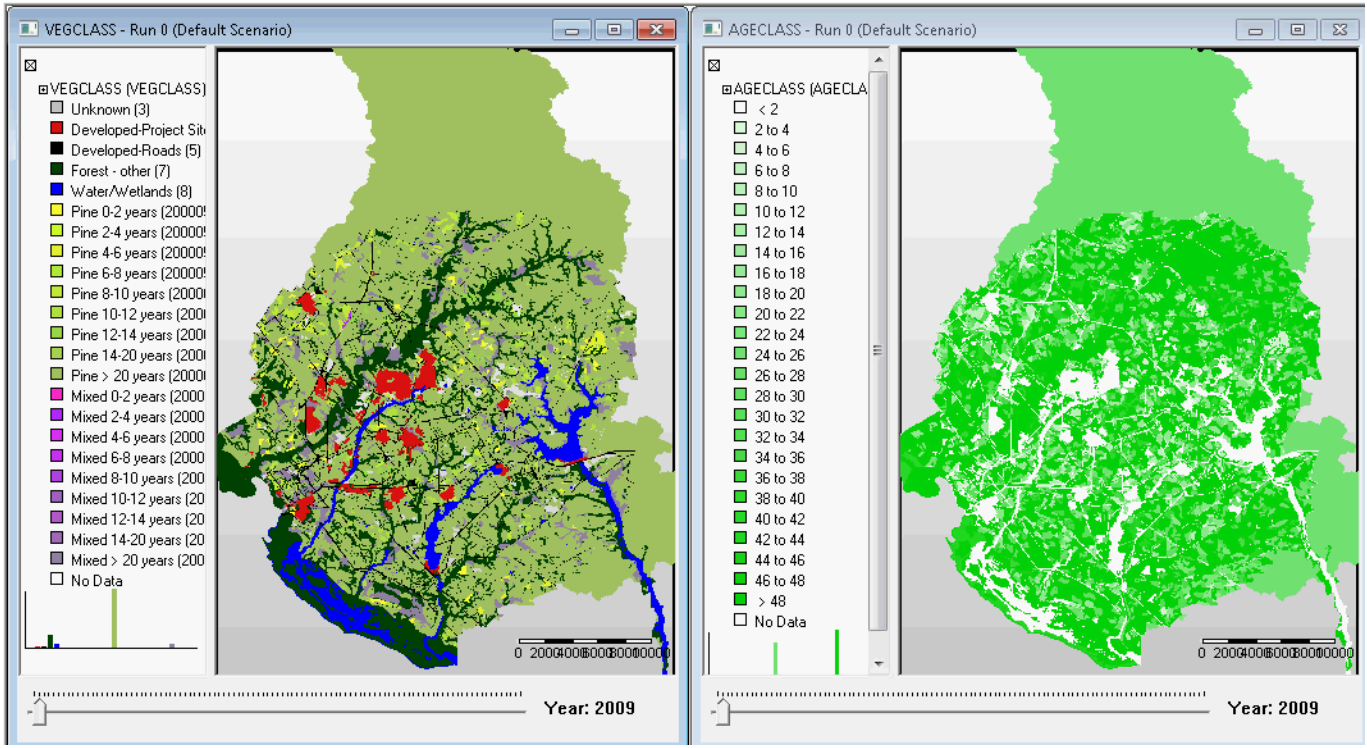
- ET dominated the water budget; stream flow was 20% of total.
- No net change in stream flow under high-intensity (10 yr) pine production for bioenergy. Largest cumulative increases in streamflow were in mixed land use scenarios (50% ag/pasture & 50% forest) and largest cumulative decrease in longer rotation pine (sawtimber).
- **Main Finding:** As a result of harvest and development cycles, short-rotation woody crops for bioenergy will likely use less water than sawtimber scenario.



- Future work will run these scenarios using the OSU model (developed for the southeast Coastal Plain).

Landscape Modeling

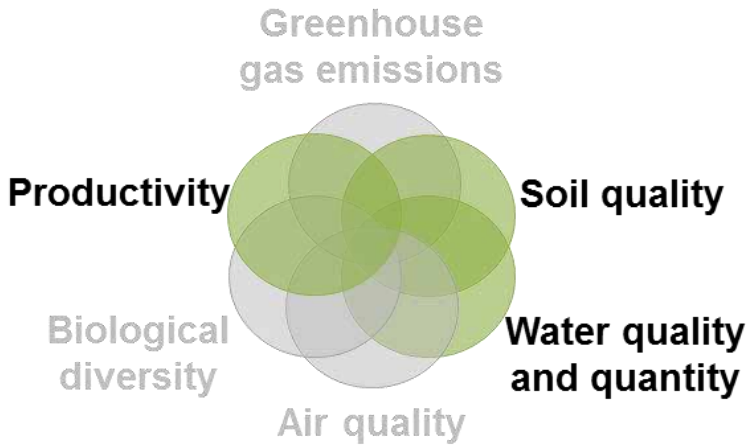
- The OSU watershed model is being parameterized and calibrated with field measurements. Research will apply watershed model to various bioenergy scenarios and at larger temporal and spatial scales.
- Incorporating a landscape simulation approach using the Envision modeling framework (envision.bee.oregonstate.edu).
- Actively engaging stakeholders with relevant insight/interest into these modeling scenarios. Approach is designed to allow stakeholder-based exploration of alternative landscapes.
- Simultaneous modeling of landscape change, hydrology, and water quality, through the Envision framework, is being used to project potential changes associated with different levels and intensities of biomass production.



Relevance

- Maintaining or improving environmental conditions under bioenergy feedstock production is a key goal of BETO. Protection of water and soil quality is critical in the southeastern U.S.

- This project will directly measure key sustainability indicators (water quality, water quantity, water use, soil quality, and productivity) from high-yield woody crops technology using an operational-scale experiment and will compare outcomes to regulatory and narrative standards for forestry.



- This project will demonstrate whether current forestry BMPs are adequate to protect water and soils and will inform industry, state water quality foresters, and the EPA on any potential incremental effects vis-à-vis conventional intensive silviculture.

- This project will upscale and generalize results both spatially and temporally using a distributed hydrologic model and will interpret combined hydrological effects of high-yield woody crops for bioenergy.

Future Work

- **Silviculture**:
  - Complete last herbicide treatment in 2015 and continue periodic fertilizer applications through 2018.
- **Soil quality and productivity**:
  - Measure N leaching & mineralization monthly, and soil chemistry, above and belowground productivity, and nutrient uptake by vegetation annually through 2018.
  - Initiate denitrification measurements along watershed flowpaths to evaluate the fate of elevated nitrate from fertilizer in the treatment watersheds.
- **Hydrology**:
  - Continue measuring watershed hydrology and water stable isotopes through 2018 to gain insights into dominant flow processes and inform the OSU-developed hydrologic model.
  - Investigate tritium sampling to estimate water residence times in the study watersheds.
- **Water use**:
  - Measure ET and NEE of loblolly pine trees throughout the rotation and compare to native long-leaf pine at the SRS Ameriflux site.

Future Work

- **Water quality:**
  - Continue measuring and analyzing water quality data to determine effects of intensive pine management through 2018.
  - Prepare publications on water quality responses to short-rotation pine.
- **Hydrologic modeling:**
  - Validate the functional relationships for partitioning ET, including use of eddy flux observations and data from a USDA-funded water use study.
  - Test transferability of model to other watersheds at SRS.
  - Simulate management scenarios with standard models (MIKE-SHE, SWAT) and compare to OSU-developed model specific to the Coastal Plain.
  - Expand watershed tracer modeling to accommodate nitrogen dynamics.
- **Technology & information transfer:**
  - Validate the effectiveness of current forestry BMPs for short-rotation woody biomass production in the southeast.
  - Coordinate & present results to industry (NCASI), state water quality foresters, EPA. Publish data on the KDF, and publish results in peer-reviewed journals.
  - Carry out economic analysis of production and delivery costs of short-rotation pine for bioenergy and confirm costs at ~$60/dry ton.

Summary

- **Overview**:
  - Data are needed to evaluate the effects of intensive feedstock production for bioenergy on water and soil in the southeastern U.S. and whether current forestry BMPs are adequate to protect these resources.

- **Approach**:
  - Coupled watershed-scale experimental and modeling approaches to assess effects of short-rotation pine plantations at various spatial and temporal scales.

- **Critical success factors and challenges**:
  - Results will provide detailed analysis of key sustainability indicators of intensive short-rotation pine for bioenergy.
  - Project success dependent on high-quality data collection, scaling results using models, and analysis and dissemination of results to relevant audiences.
  - Challenges identified and longer-term scaling issues will be addressed with watershed modeling.

Summary

- **Technical Accomplishments:**
  - Silviculture treatments have occurred as planned.
  - Characterized baseline hydrology and biogeochemistry of these low-relief watersheds. 2 publications, 6 in review/prep, 8 presentations since 2013.
  - Measured initial responses of soil and water quality to short-rotation pine management for bioenergy.
  - Eddy flux tower installed in 2015 and data collection has begun.
  - Parameterized hydrological model and calibrated with field data. Completed forest management scenario modeling with standard model.

Summary

- **Main findings:**
  - No impacts to stream water quality thus far. BMPs are effective at protecting surface water and groundwater for ammonium, SRP, sediments, herbicides, and pesticides.
  - Increasing nitrate in groundwater due to inefficient nutrient uptake by young pine trees, but concentrations are below regulatory limits. More efficient fertilizer applications would reduce groundwater impacts. Longer-term monitoring needed to track fate of groundwater nitrate.
  - Long-term changes in stream flow predicted to be minimal based on modeling with standard model (MIKE-SHE). Will test with OSU model specific to low-relief watersheds.

Summary

- **Relevance:**
  - Woody biomass grown in the southeastern U.S. will be a dominant bioenergy feedstock.
  - Need to evaluate whether current forestry BMPs are adequate to protect water and soils or whether bioenergy-specific BMPs are necessary.
  - Project directly measures key sustainability indicators and aligns with BETO's MYPP goals and targets dates.

- **Future work:**
  - Continue monitoring to assess short and longer-term impacts of forest conversion on hydrology and water quality, compare impacts to baseline values and the reference watershed, and use results to evaluate existing BMPs and compare to narrative and regulatory standards.
  - Continue modeling effort to explore long-term implications of higher intensity management and extend the modeling effort to the Coastal Plains to broaden regional context of the study.

Additional Slides

Responses to 2013 Reviewer Comments

Comment: The project performers did not really address critical success factors for the project. They just stated what they expect their results to be, and what the benefits of those results will be.

Response: There may have been confusion regarding how to identify critical success factors within the context of this project. Critical success factors may be clear for certain platforms (e.g., conversion, by achieving XYZ, gallon/ton yields can be increased from A to A+B). In the context of this project, the goal is to objectively evaluate sustainability, rather than achieve it. Broadly interpreted, this project can be considered successful if soil quality is not impaired, if water quality and quantity impacts of this intensive silvicultural system are demonstrated to not exceed regulatory standards associated with current forest BMPs and are within the range expected from conventional sustainable forestry practices, and if productivity yields are 7-10 Mg per hectare. In the event that water or soil impacts are beyond levels consistent with conventional southern pine silviculture, this project would still be successful in identifying these conditions. If this is the case, both the field measurements and the modeling component can be used to develop and inform short-rotation woody crop-specific BMPs. The challenges associated with this project include unanticipated operational conditions, extreme climate events (e.g., drought/floods) that could constrain interpretation of results, the integration of complex operational treatments within the study design, and equipment failures that may compromise data collection. Further, this project may not be successful if it is underfunded in the future or ended prematurely. We will maximize likely success by constantly monitoring site and infrastructure conditions and status, and quickly attending to any problems that arise. We will be successful in this project by collecting high-quality data and scaling our results using models to ultimately inform whether short-rotation woody crop production for bioenergy is environmentally sustainable in the southeastern U.S.

Comment: Weakness is the need to discuss and plan for wider applicability and use of the scaled up model and the development of a SOPs to enable its broader use.

Response: This summer, Dr. Vache has begun work to scale up our findings to the entire Savannah River Site and then to the Upper Coastal Plain by incorporating the ENVISION (http://envision.bioe.orst.edu/) modeling platform into the OSU catchment model in combination with extensive vegetation, soils, and water resource databases. Forest biogeochemistry will also be incorporated into the ENVISION/FLOW modeling framework.

Comment: Plan for dissemination and coordination with other technical communities and regulators needs to be better described and elaborated.

Response: Dr. Jackson regularly interacts with the water quality committee of the Southern Group of State Foresters, an organization that coordinates BMP revisions across the southeast, and the National Council for Air and Stream Improvements, the research organization of the timber and wood products industries. Dr. Jackson and other project participants will continue to present research findings to these groups and continue to coordinate technology transfer with BETO. Dr. Jackson's past BMP research has been used in updating BMP recommendations in several southeastern states. Additionally, Dr. Vache works closely with EPA staff that are using the ENVISION model in their work. Adoption of this common modeling platform as part of our work going forward is designed to facilitate the dissemination of the models themselves.

Publications and Presentations

Published:

- Jackson, C.R., M. Bitew, and E. Du. 2014. When interflow also percolates: Downslope travel distances and hillslope process zones. Hydrological Processes 28:3195-3200.
- Klaus, J., J.J. McDonnell, C.R. Jackson, E. Du, and N.A. Griffiths. Where does streamwater come from in low-relief forested watersheds? A dual isotope approach. 2015. Hydrology and Earth System Sciences 19:125-135.

In Review:

- Du, E., C.R. Jackson, J. Klaus, J.J. McDonnell, N.A. Griffiths, M.F. Williamson, J.L. Greco, and M. Bitew. More fill, less spill: interflow behavior over a low-angle argillic layer. In Revision at the Journal of Hydrology.
- Drover, D.Y., C.R. Jackson, M. Bitew, and E. Du. Effects of DEM scale on the correlation of topographic wetness indices to watershed and soil characteristics. In Review at Hydrological Processes.
- Bitew, M., S. Younger, C.R Jackson, E. Du, and D. Drover. Wetness Index based on Landscape and Topography (WILT): A modification of the TOPMODEL topographic wetness index incorporating landscape position relative to water bodies. In Review at the Journal of Hydrology.
- Vache, K., and J.J. McDonnell. On the bi-modality of transit time distribution and the hidden streamflow challenge. In Review at Hydrological Processes.

In Preparation:

- Jackson, C.R., E. Du, J. Klaus, N.A. Griffiths, J.J. McDonnell, and M. Bitew. Hillslope irrigation using a multi-tracer approach reveals complicated hydrologic behavior in an apparently simple slope. In preparation for Water Resources Research.
- Griffiths, N.A., C.R. Jackson, J.J. McDonnell, J. Klaus, E. Du, and M.M. Bitew. Nitrogen dynamics in low-gradient Coastal Plain watersheds using a dual nitrate isotope approach. In preparation for JGR-Biogeosciences.

Presentations:

- Griffiths, N.A., C.R. Jackson, M.M. Bitew, E. Du, K. Vache, J.J. McDonnell, J. Klaus, and B.M. Rau. Evaluating the effects of woody biomass production for bioenergy on water quality and hydrology in the southeastern United States. Interagency Conference on Research in the Watersheds, Charleston, SC, March 2015. Oral presentation.
- Griffiths, N.A., C.R. Jackson, J.J. McDonnell, M.M. Bitew, E. Du, and J. Klaus. Water quality response after two years of short-rotation pine management for bioenergy in the southeastern U.S. American Geophysical Union (AGU) fall meeting, San Francisco, CA, December 2014. Poster presentation.
- Bitew, M.M., C.R. Jackson, J.J. McDonnell, K. Vache, and N.A. Griffiths. Dynamic downslope travel distance modeling: Interflow modeling from bottom of slope upwards. AGU fall meeting, San Francisco, CA, December 2014. Poster presentation.
- Jackson, C.R., L. Hopp, J.J. McDonnell, M. Bitew, E. Du, J. Klaus, and N.A. Griffiths. Interflow moving over leaky impeding layers: how far can we expect it to go? AGU fall meeting, San Francisco, CA, December 2014. Poster presentation.
- Griffiths, N.A., C.R. Jackson, M. Bitew, E. Du, K.B. Vache, J.J. McDonnell, J. Klaus, and C.C. Trettin. Environmental sustainability of woody biomass production for bioenergy in the southeastern United States. Short-Rotation Woody Crops Operations Working Group Meeting, Seattle, WA, July 2014. Oral presentation.
- Griffiths, N.A., C.R. Jackson, M. Bitew, E. Du, K.B. Vache, J.J. McDonnell, J. Klaus, and J.I. Blake. Assessing BMP effectiveness for woody biomass production for bioenergy in groundwater-dominated Coastal Plain watersheds. Symposium on Forestry Best Management Practice (BMP) Effectiveness in the Eastern U.S., Blacksburg, VA, May 2014. Oral presentation.
- Vache, K.B., C.R. Jackson, M. Bitew, J. Blake, J.J. McDonnell, and N.A. Griffiths. Potential impacts of intensive cellulosic biofuel production on water quality and quantity in the Upper Coast Plain. AGU fall meeting, San Francisco, CA, December 2013. Poster presentation.
- Jackson, C.R. BMP research at UGA. Southern Group of State Foresters Annual Meeting, Savannah, GA, June 2013. Oral presentation.

Abbreviations

AGM MCP 37 – Loblolly pine seedling family
ANL – Argonne National Laboratory
BETO – Bioenergy Technologies Office
BMPs – Best Management Practices
CFT – Concentrated Flow Track
DAP – Diammonium phosphate (fertilizer)
DEM – Digital Elevation Model
DOE – Department of Energy
EPA – Environmental Protection Agency
ENVISION – Alternative scenarios modeling framework (http://envision.bioe.orst.edu/)
ET – Evapotranspiration
Fourmile – Larger watershed that encompasses our 3 study watersheds
^{2}H – Stable isotope of hydrogen (water stable isotope measurement)
KDF – Knowledge Discovery Framework
LAI – Leaf Area Index
LiDAR – Remote sensing technology
MIKE-SHE – Integrated hydrological model (surface and groundwater)
MYPP – Multi-Year Program Plan
NCASI – National Council for Air and Stream Improvement
NEE – Net Ecosystem Exchange
N – Nitrogen
^{18}O – Stable isotope of oxygen (used to measure water and nitrate cycling)
Op. – Operational
ORNL – Oak Ridge National Laboratory
OSU – Oregon State University
SMZ – Streamside Management Zone (50 ft buffer between planted areas and stream; hardwood riparian zone)
SRP – Soluble reactive phosphorus
SRNL – Savannah River National Laboratory
SRS – Savannah River Site
SWAT – Soil and Water Assessment Tool
TOPMODEL – Hydrologic model based on topography
TWI – Topographic Wetness Index
UA – University of Alabama
UGA – University of Georgia
US – University of Saskatchewan
USDA – United States Department of Agriculture
USFS-SR – USDA Forest Service – Savannah River
Watersheds B and C – Treatment watersheds (locations of clear cuts)
Watershed R – Reference (unmanipulated) watershed
WILT – Wetness Index based on Landscape and Topography (modified version of TOPMODEL)

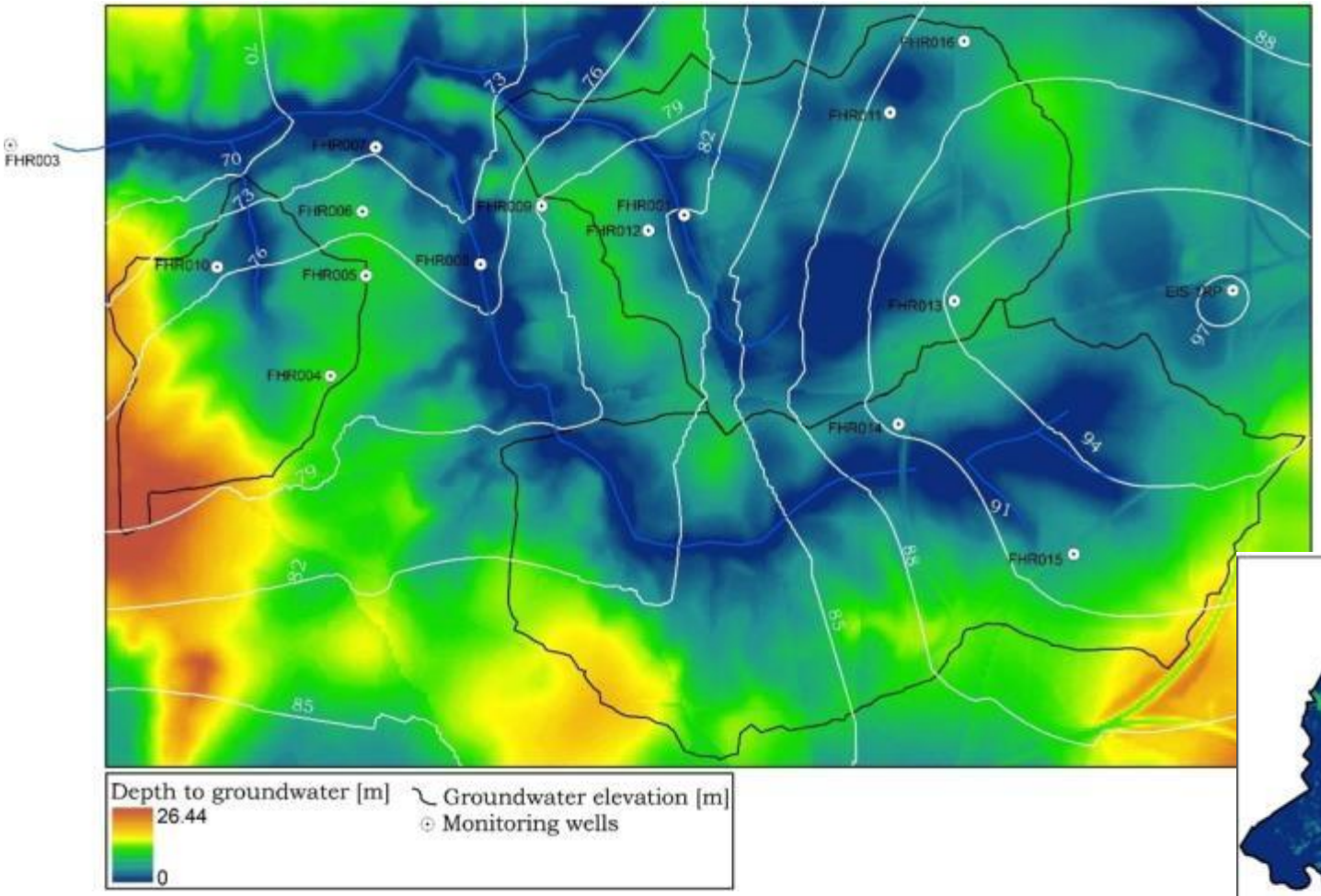
Challenges:

- Drought and floods could constrain interpretation of results. Interactions between water use impacts and climate change need to be considered.
  - Watershed models will be run with long-term climate data, SRNL climate change scenarios, and a variety of management scenarios to help understand these impacts.
- Effects of short-rotation pine on water quality may be lagged past the proposed end date of project.
  - If it is worthwhile to continue monitoring past FY18, we will explore possible funding options to continue sampling and analysis for the full rotation. Modeling effort will be run over longer time scales and will provide some insight into possible lagged effects.
- Forest fires could affect productivity, hydrology, and water and soil quality.
  - USFS-SR has a large full-time fire staff and few fires occur on site. The risk should be minimal during the first 3 years of growth due to the openness of the canopy.
- Decreased growth and mortality of planted pine seedlings.
  - Pine was infested with Nantucket tip moth in 2014. Treated with soil-injected pesticide and replanted seedlings, and damage is now <1%. We will continue to monitor conditions and implement remedial actions as necessary.

FY15 Milestones:

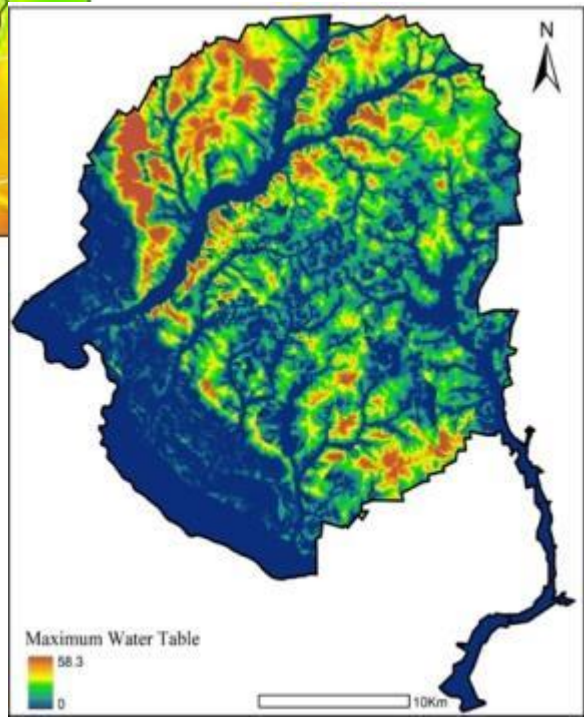
Milestone:	Due:	Group(s):	Status:
Complete analysis of water quality samples collected in FY14.	1/31/15	ORNL	100% complete
Complete forest management scenario modeling of Fourmile Creek watershed using MIKE-SHE.	3/31/15	UGA	80% complete
Complete fertilization application in treatment watersheds and analysis of FY14 soil quality and productivity samples.	6/30/15	USFS-SR	50% complete
Complete analysis of stable isotope data collected in the 2014 water year, transfer of watershed models to larger SRS watersheds, and first year monitoring and analysis of water flux data.	9/30/15	USask/OSU/UA	20% complete

Depth to Groundwater Maps



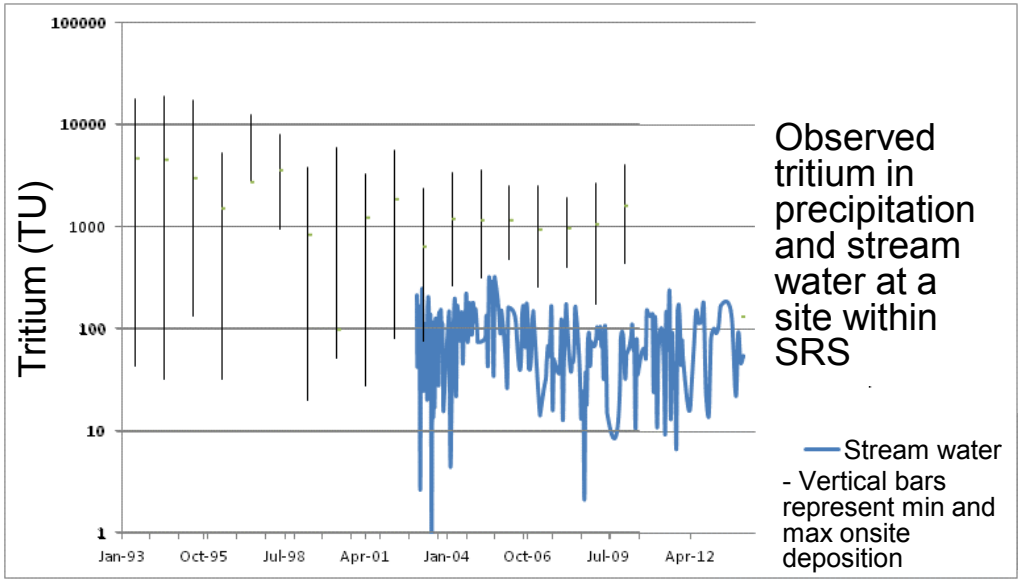
- Depth to groundwater for the 3 study watersheds (above) based on data from monitoring wells, streams, wetlands, and the DEM. Streams and wetlands were considered as an extension of the regional groundwater table.

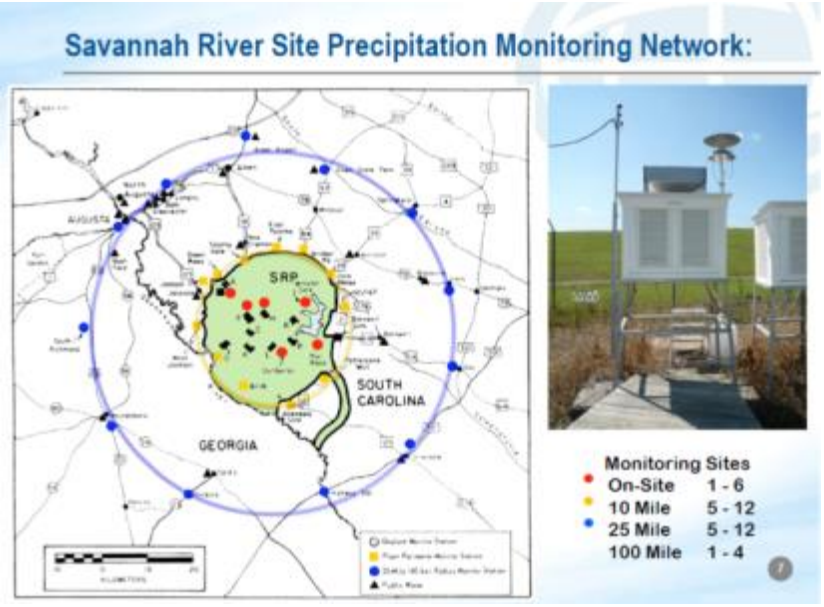
- Maximum water table depth for the SRS site (below). In this groundwater-dominated area, depth to groundwater is an important input for understanding hydrological processes.

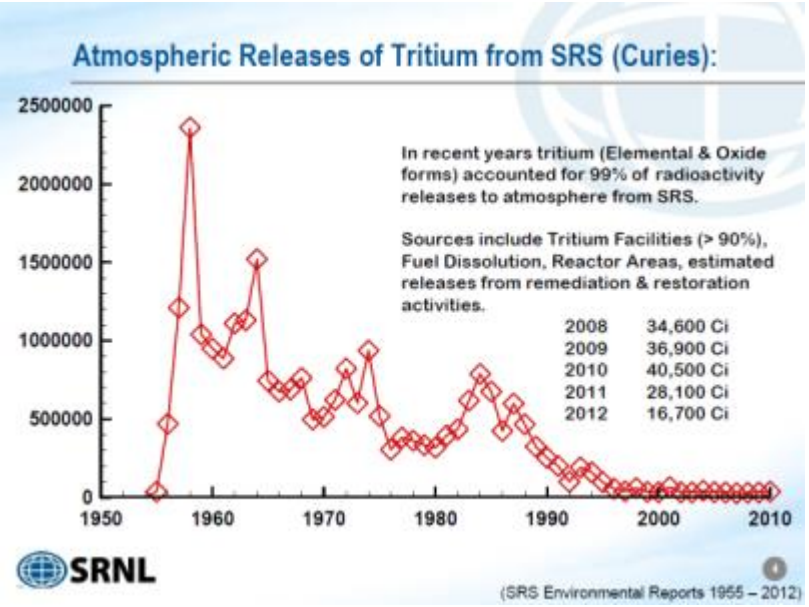


Field Hydrology: Tritium Sampling

- We are investigating the potential for tritium data (in precipitation, stream water, ground water) to provide an independent means to estimate water residence times in these watersheds.
- We will augment the monthly sampling done by SRNL with weekly sampling within Upper Fourmile. Weekly sampling will commence in 2015.
- Residence time data will be important in parameterizing the watershed model.







USDA Water Use Project

- USDA-funded project to compare water use of loblolly pine and eucalyptus as bioenergy feedstocks. Sub-plots established in watersheds B and C. Doug Aubrey (Georgia Southern U), Rhett Jackson, and Jeffrey McDonnell are PIs. This mutually beneficial experiment is leveraging our project's watershed-scale experiment and results will be used to inform our watershed model.
- **Objectives:** measure water consumption & hydrologic cycling to parameterize process-based watershed model.
- 6 eucalyptus plots within watersheds B and C. Compare to 6 pine plots.