US DOE BETO 2017 Project Peer Review

Short-Rotation Woody Biomass Sustainability

March 9, 2017
Analysis and Sustainability

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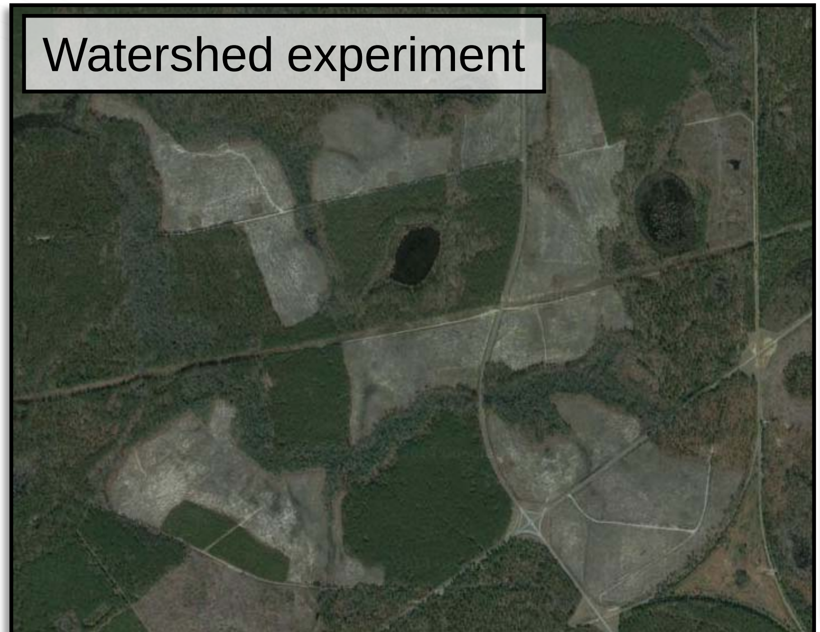
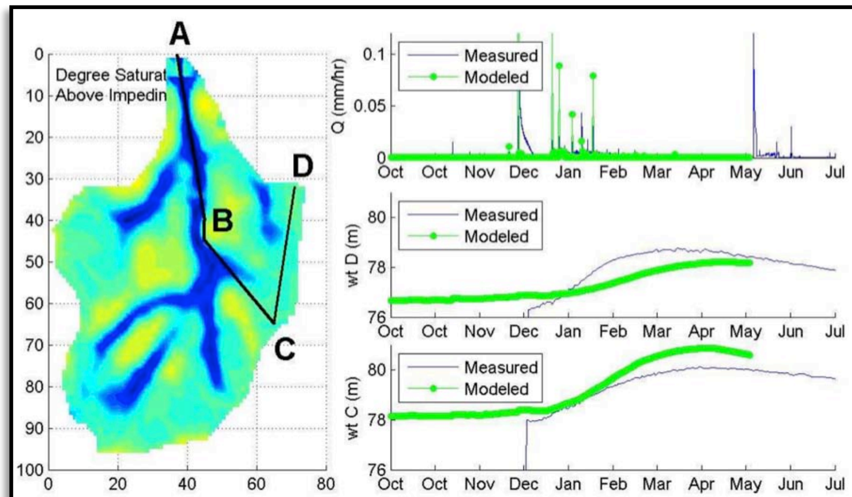
Goal Statement

- Use a watershed-scale experiment and a distributed watershed modeling approach to evaluate the environmental sustainability (water, soil, and productivity indicators) of intensive short-rotation loblolly pine management for bioenergy in the southeastern US.
- Determine whether current forestry Best Management Practices (BMPs) are adequate to protect water and soil resources.



Watershed models



- **Impact:** Findings will be used by state water quality foresters and industry in developing guidelines for SRWC BMPs for bioenergy (if needed) and to minimize environmental effects when implementing this SRWC technology across the southeastern US.

Quad Chart Overview

Timeline

- Project start date: FY10
- Project end date: FY18
- Percent complete: 85%

Budget

	Total Costs FY12-FY14	FY15 Costs	FY16 Costs	Total Planned Funding (FY17-FY18)
DOE BETO Funded:				
ORNL	713K	330K	345K	690K
University/ USFS-SR	1,226K	370K	310K	620K
Collaborator Cost Share:				
Universities	361K*	125K	129K	188K
USFS	438K	85K	0K	86K

*for FY13-14

Barriers

- St-C: Sustainability data across the supply chain.
- St-D: Implementing sustainability indicators.
- St-E: Best practices for sustainable bioenergy production.
- MYPP technical target: evaluate environmental indicators of bioenergy production systems.

Partners

- Project lead and management: ORNL.
- Collaborators: USFS-SR, U. of Georgia, U. of Alabama, Oregon SU, U. of Saskatchewan.

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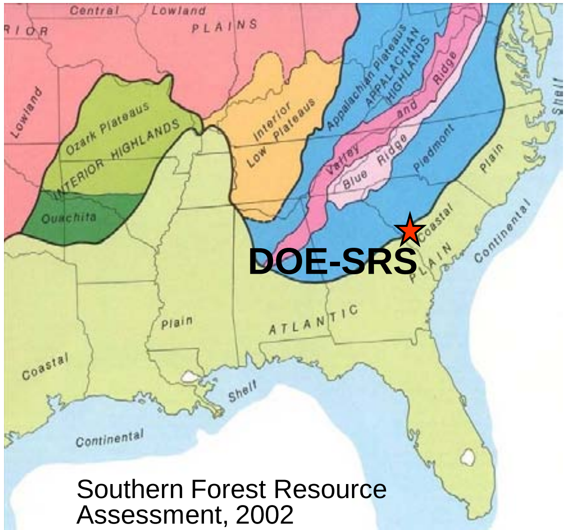
Project Overview

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

Context:

- Southeast will be a dominant source of bioenergy feedstocks.
- SRS biomass steam plant utilizes feedstocks.
- Water and soil impacts of intensive silviculture coupled with advanced genetics have not been evaluated at the watershed scale.
- Current forestry BMPs not tested for bioenergy.



Objectives:

- Assess effects of intensive SRWC production on water and soil indicators relative to regulatory and narrative standards for forestry.
- Evaluate effectiveness of current forestry BMPs for SRWC production.
- Apply distributed modeling approaches to evaluate effects of SRWC at larger spatial and temporal scales.

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Approach (Management)

Division of tasks based on scientific expertise:

Water quality	Hydrology	Water use	Modeling	Soil quality	Forestry
Oak Ridge National Laboratory	University of Georgia University of Saskatchewan	The University of Alabama	Oregon State University OSU University of Georgia	Forest Service U S Department of Agriculture	Forest Service U S Department of Agriculture

Collaborative project requires frequent team meetings, on-site researchers, and communication with BETO:

- Monthly conference calls.
- Bi-annual project meetings.
- On-site, full-time field technician.
- Post-doc and research scientists based at SRS.
- Quarterly reporting and update calls with BETO technology manager.

Milestones divided by tasks to monitor progress:

- All FY15 milestones completed.
- All but one FY16 milestone completed (USFS-SR milestone 90% complete: awaiting analytical results from external laboratory).
- FY16 Go/No-Go complete (Result: Go).
- FY17 milestones complete (Q1) or on track (Q2-4).

Approach (Technical)

Coupled Experimental-Modeling Approach:

- Before-after control-intervention operational-scale watershed experiment.
- Intensive practices are state-of-the-art:
  - Sub-soiling, multiple herbicide and fertilizer applications, advanced genetic material.
- Evaluating effectiveness of South Carolina forestry BMPs.
- Process-level field observations used to develop a watershed model specific to the Upper Coastal Plain.
- Modeling will upscale results spatially and temporally. Modeling scenarios developed with input from stakeholders and industry.

Riparian buffer/stream side management zone

Go/No-Go: Determine water quality, quantity, and soil quality metrics relative to regulatory standards.

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Approach (Technical)

Success Factors:

- Implementing silviculture treatments on schedule.
- Rapidly addressing field issues (e.g., instrument failures, storms).
- Collecting high-quality data.
- Scaling field results using models.
- Disseminating findings to relevant audiences, including publishing data on the Bioenergy KDF and results in peer-reviewed journals.
- Engaging industry (NCASI) and state water quality foresters on forest management modeling scenarios.

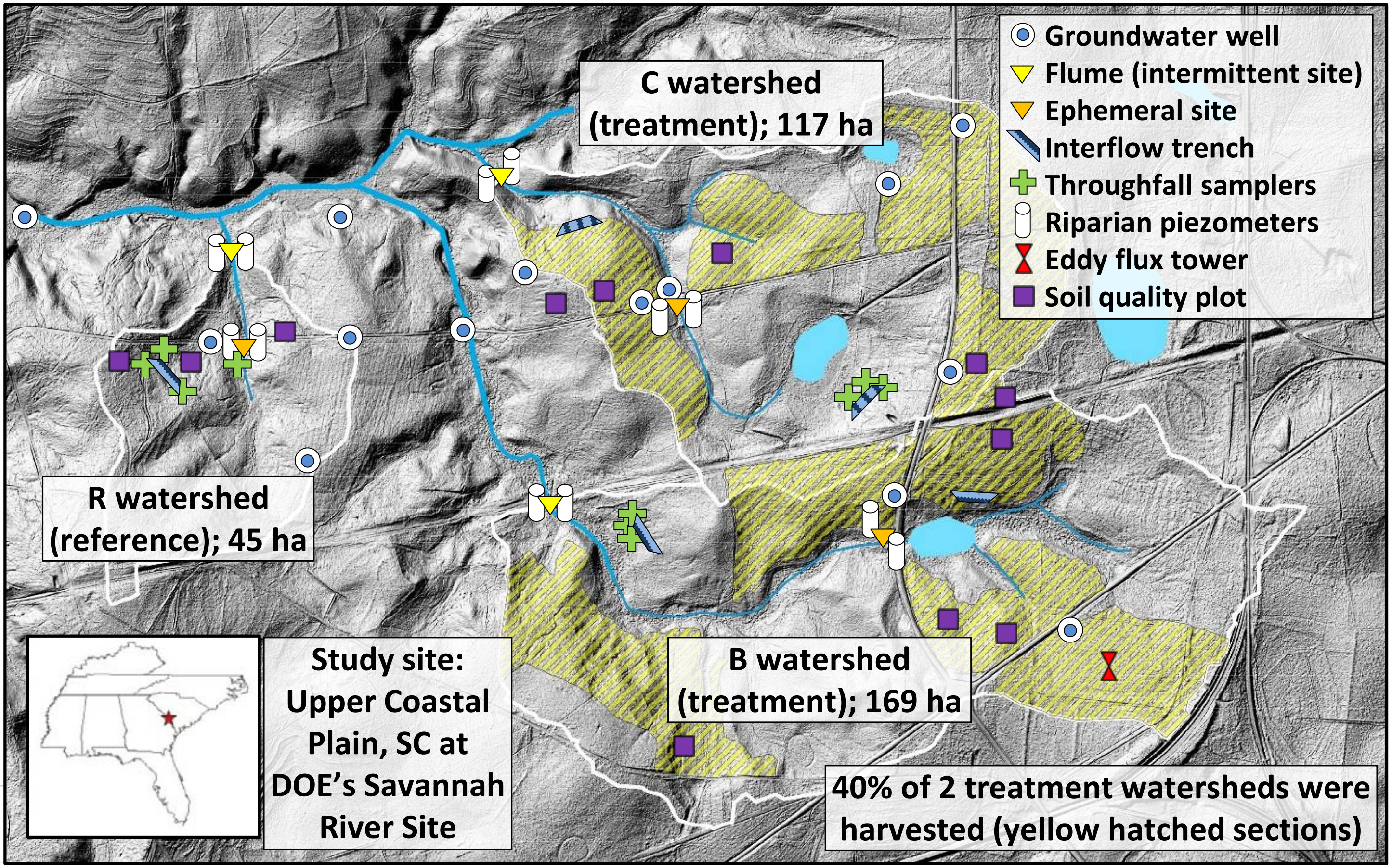
- Results expected to validate environmental sustainability of SRWC production technology and provide a baseline relative to current BMP studies.

Challenges:

- Experimental design (i.e., droughts/floods, fire, pests, storms).
- Measurements (i.e., groundwater transit times, instrument failures, analytical backlogs, eddy flux calculations with rapidly growing trees).
- Modeling (i.e., including climate change scenarios, flexibility of standard model frameworks for simulating dynamic landscapes over time).

Accomplishments: Experimental Treatments

- 3 highly instrumented forested watersheds: 1 reference and 2 treatment.
- **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.



Accomplishments: Silviculture

Harvest: 40% of treatment watersheds, 20 Mg/ha residues for bioenergy

Planting: loblolly pine seedlings at 545/acre (AGM MCP 37 growth is 70%> than SE reference)

Fertilizer: DAP

Fertilizer: DAP
Herbicide: sulfometuron methyl

Pre-treatment (2010-2012) — **Post-treatment (2012-2018)**

2010 — 2012 — 2014 — 2016 — 2018*

*1/2 way through rotation

Site prep: ripping/sub-soiling

Herbicide: imazapyr and glyphosate

Herbicide: sulfometuron methyl and imazapyr

Herbicide: sulfometuron methyl
Pesticide: fipronil (tip moth)
Fertilizer: urea

Fertilizer: urea (aerial application)

All milestones completed:
Task complete. No additional silvicultural activities planned.

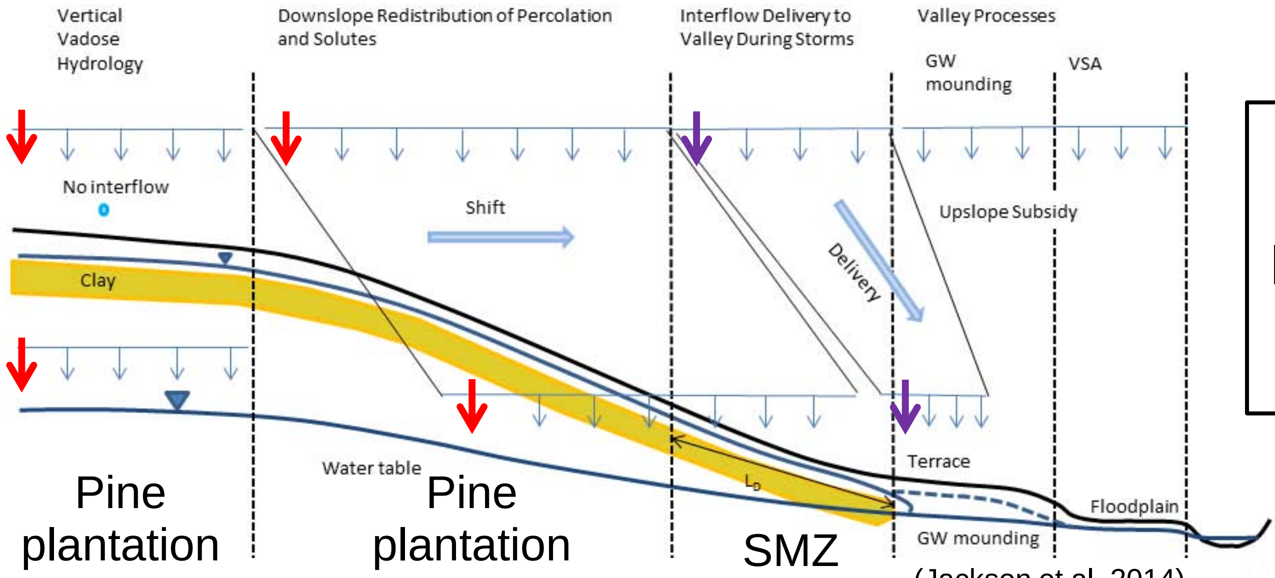
Accomplishments: Field Hydrology

Objectives:

- Characterize dominant hydrologic processes.
- Collect time series hydrologic data to inform and test hydrologic models.

Results:

- Multiple lines of evidence demonstrate that groundwater is the dominant hydrologic pathway (Jackson et al. 2014, 2016, Du et al. 2016).
- Stream water is isotopically and chemically distinct from hillslope water (Klaus et al. 2015, Griffiths et al. 2016). **The most likely stream water quality effects will be via a groundwater pathway.**



(Jackson et al. 2014)

All milestones completed: 5 papers published on hydrologic and biogeochemical flow paths.

Accomplishments: Evapotranspiration (ET)

Objective: Understand effects of varying environmental conditions and stand development on C flux and ET of intensively managed pine and inform models.

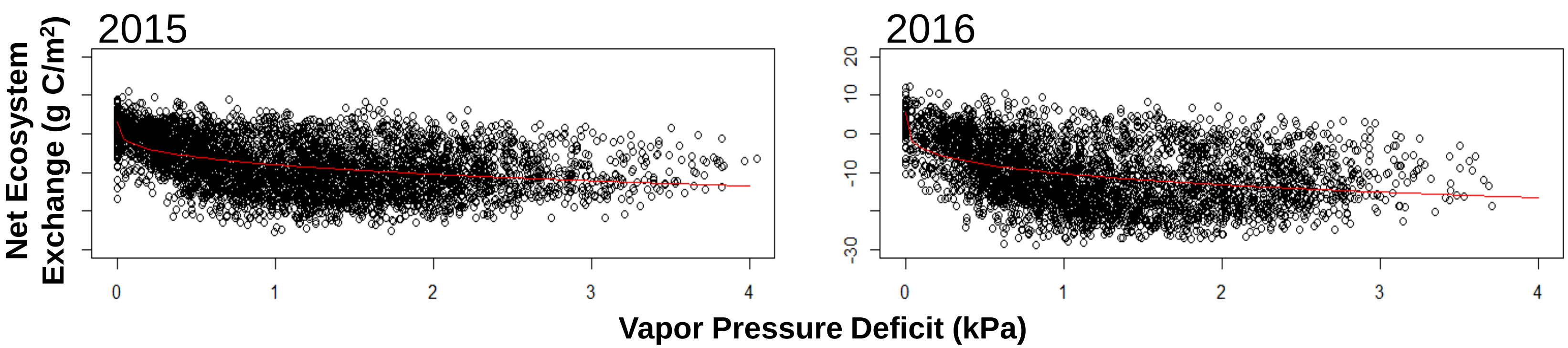
Results: 2 y of eddy covariance data collected.

- Initial estimate of C flux suggests that pine is ~2 y ahead in development compared to standard timber plantations.
- Sites with open canopy show no stomatal limitations during early growth (not water limited).
- ET rates comparable to 4-6 y loblolly pine stand in NC (Sun et al. 2010).
- **C and H_2O fluxes are as projected by physiological activity. They are advanced by ~2 y compared to traditional plantations.**

2015 C flux and ET:

NEE	GEE	Reco	ET
-95.7	-2202.4	2106.8	537

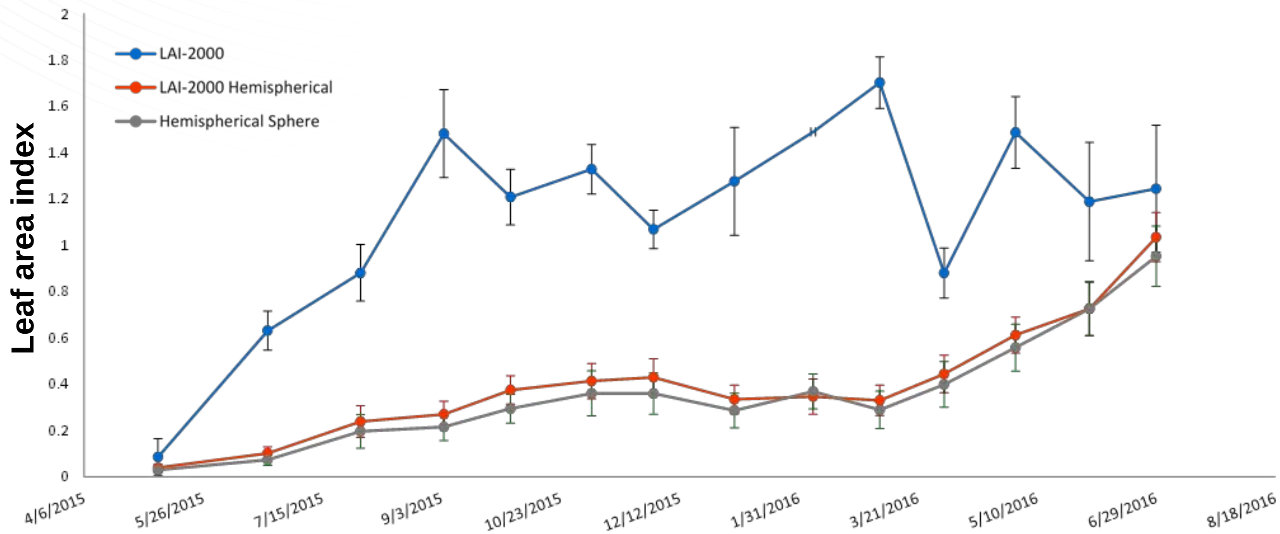
Net Ecosystem Exchange (NEE), Gross Ecosystem Exchange (GEE), and Ecosystem Respiration (R_{eco}) for year one (Feb 2015-Jan 2016).
Units: g C m^2 y^{-1}, ET in mm y^{-1}.



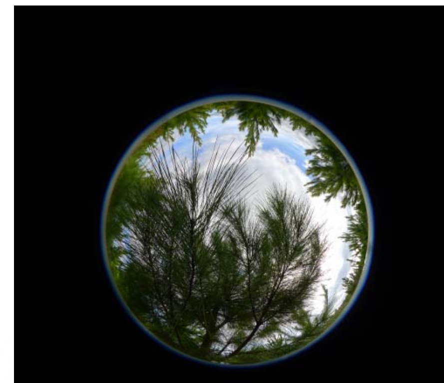
No evidence of water limitation based on relationship between NEE and VPD.

Accomplishments: Evapotranspiration (ET)

- Leaf area is continuing to expand at rapid rates.
- Due to rapid growth, standard gap filling techniques for eddy flux lead to instability in gap filling. More advanced gap techniques are being used to ensure statistically sound annual estimates of carbon and water exchange.




06-21-2014


03-04-2015

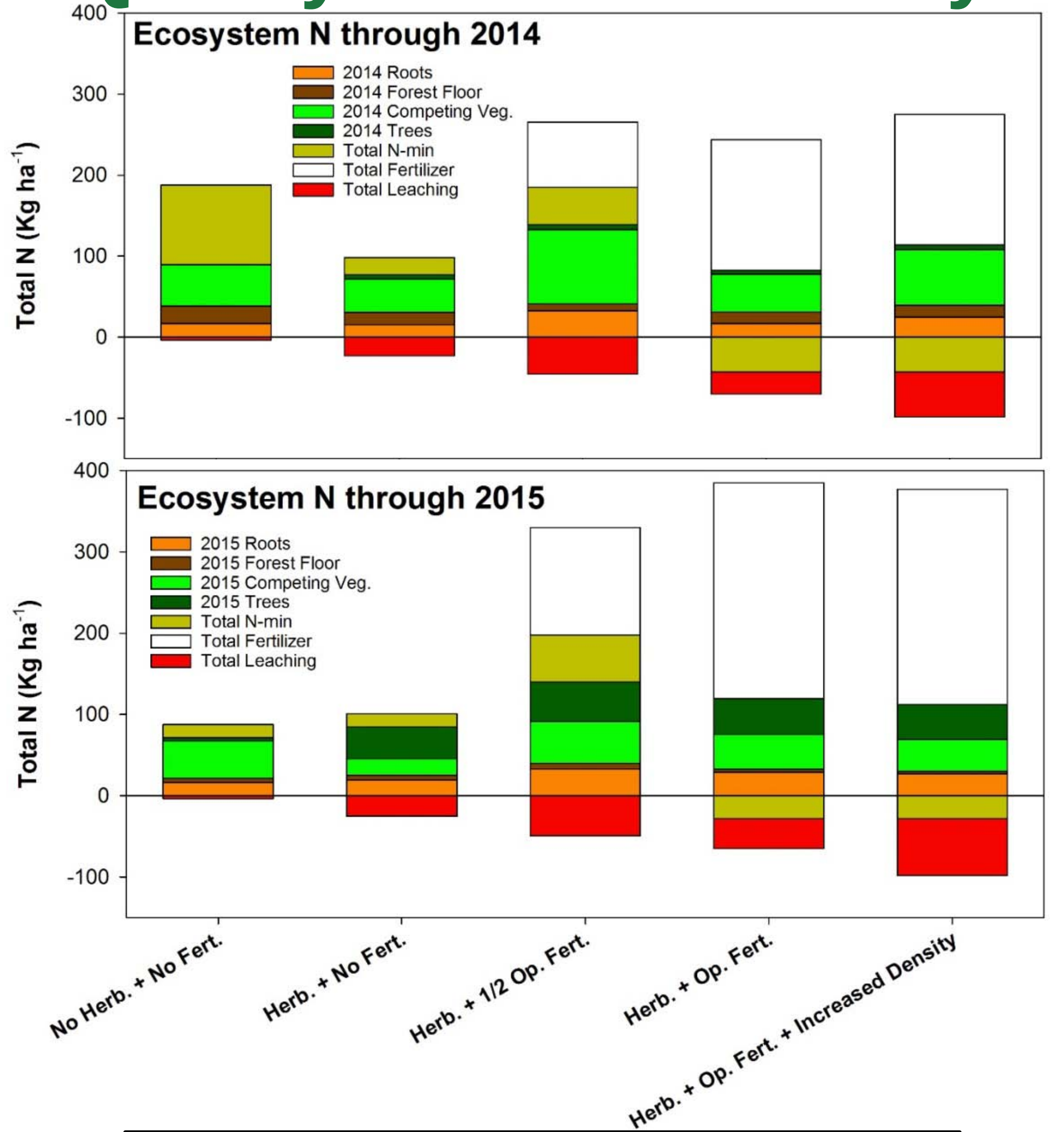
All milestones completed: First year of C flux and ET data analyzed. Second year analysis will be completed in early 2017. Manuscript on C flux/ET in preparation.

Accomplishments: Soil Quality and Productivity

Objective: Measure soil quality and productivity responses to varying levels of fertilizer and herbicide at the plot scale.

Results:

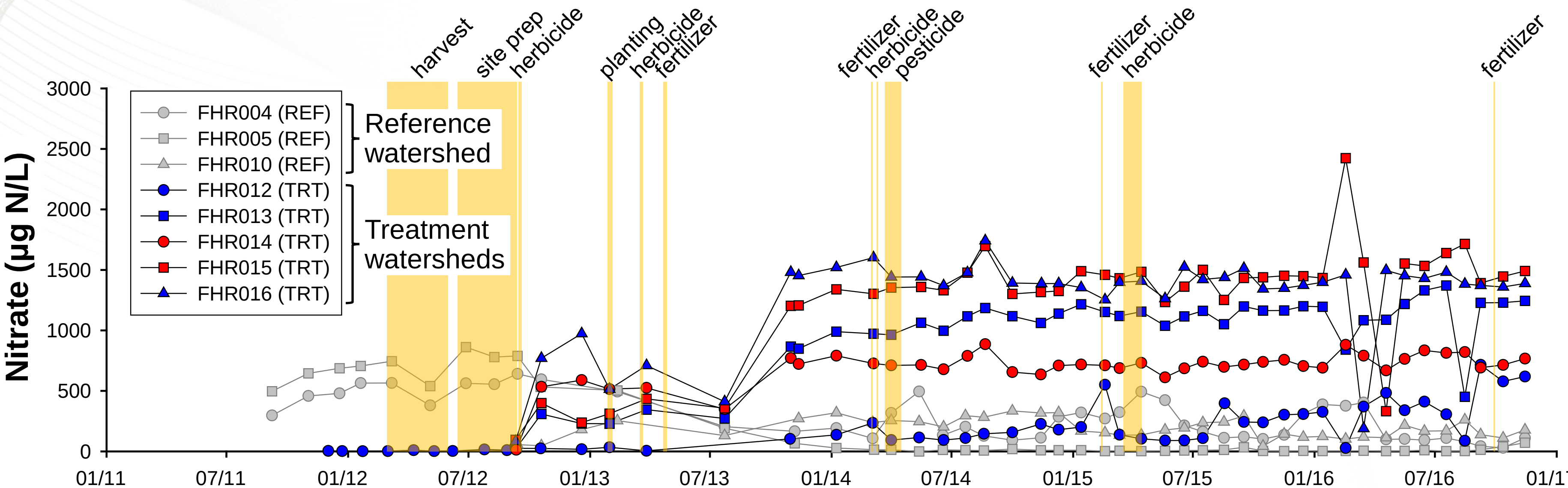
- N-uptake by pine was low through 2014, and lower than competing veg. Pine N uptake increased in 2015.
- Pine N-uptake could have been satisfied by N-mineralization. Control of competing veg. could free up N.
- Leaching was high in 2013, decreased in 2014 and 2015.
- **Through 3 growing seasons, no fert. or ½ op. fert. appear to satisfy pine N demand and minimize leaching.**



Milestones: FY15 milestone complete. FY16 milestone 90% complete (awaiting lab results).

Accomplishments: Water Quality

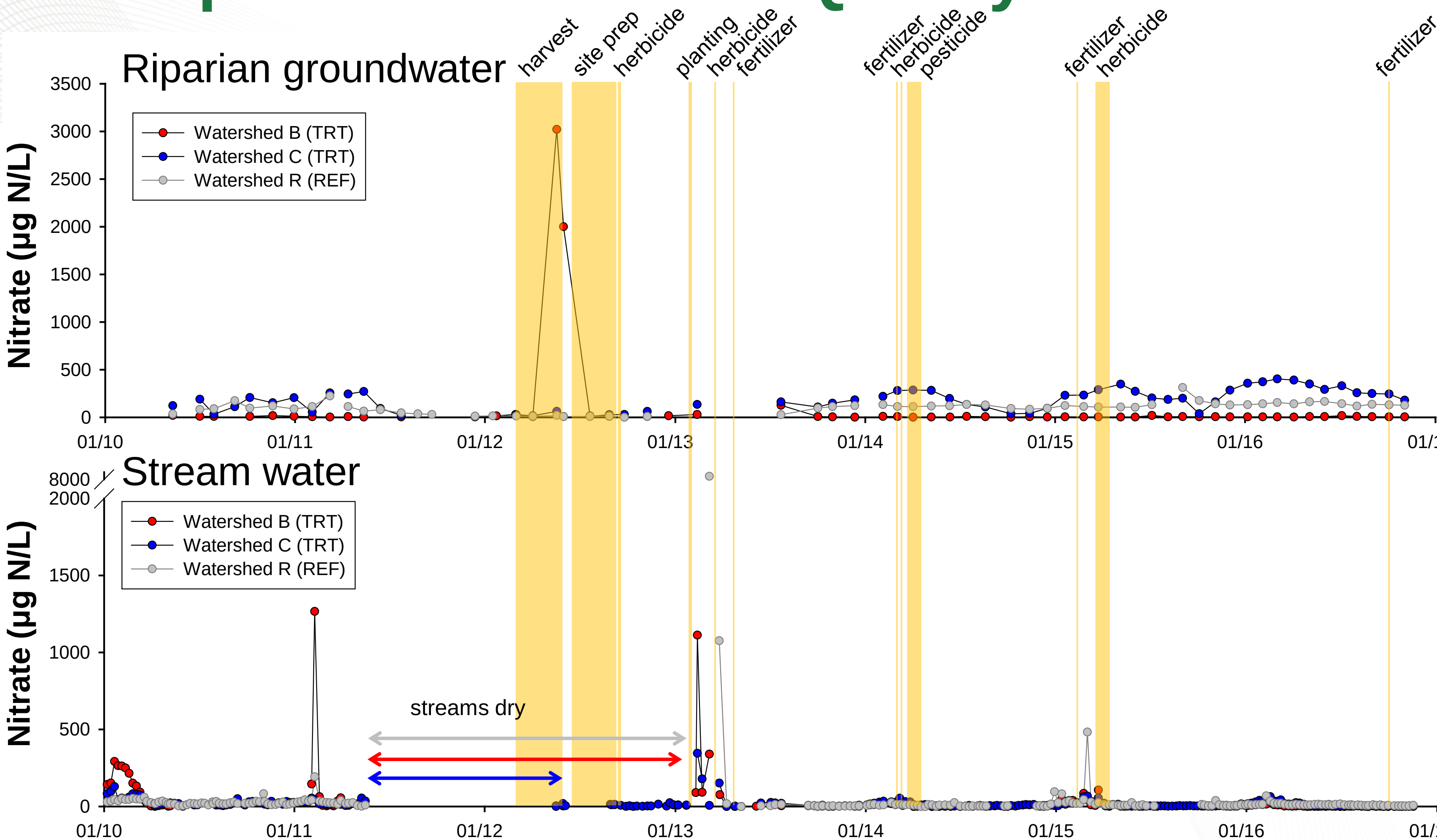
Objective: Examine the short- and long-term effects of short-rotation pine production on water quality.



Results:

- Nitrate concentrations increased in groundwater in treatment watersheds. Concentrations are <2 mg N/L (drinking water limit = 10 mg N/L).
- No increases in ammonium or soluble reactive phosphorus (SRP) concentrations. Herbicide and pesticide samples below detection.
- **Nutrient uptake is inefficient resulting in leaching to groundwater.**

Accomplishments: Water Quality



- Elevated groundwater nitrate has not reached riparian areas or has been taken up/transformed. BMPs appear to protect surface water quality. Will measure denitrification and use groundwater models to estimate transit times.

All milestones completed: Chemical analyses completed through FY16. Pre-treatment data on Bioenergy KDF. Initial effects manuscript drafted.

Accomplishments: Hydrologic Modeling

Objectives:

- Develop a watershed model using functional relationships between vegetation cover, meteorological variables, soil moisture, and groundwater dynamics.
- Use model to evaluate potential impacts of various forest management scenarios across the SRS site. Models developed with input from foresters and industry.
- Evaluate influence of SRWC production on hydrology and nitrogen cycling at local and regional scales.

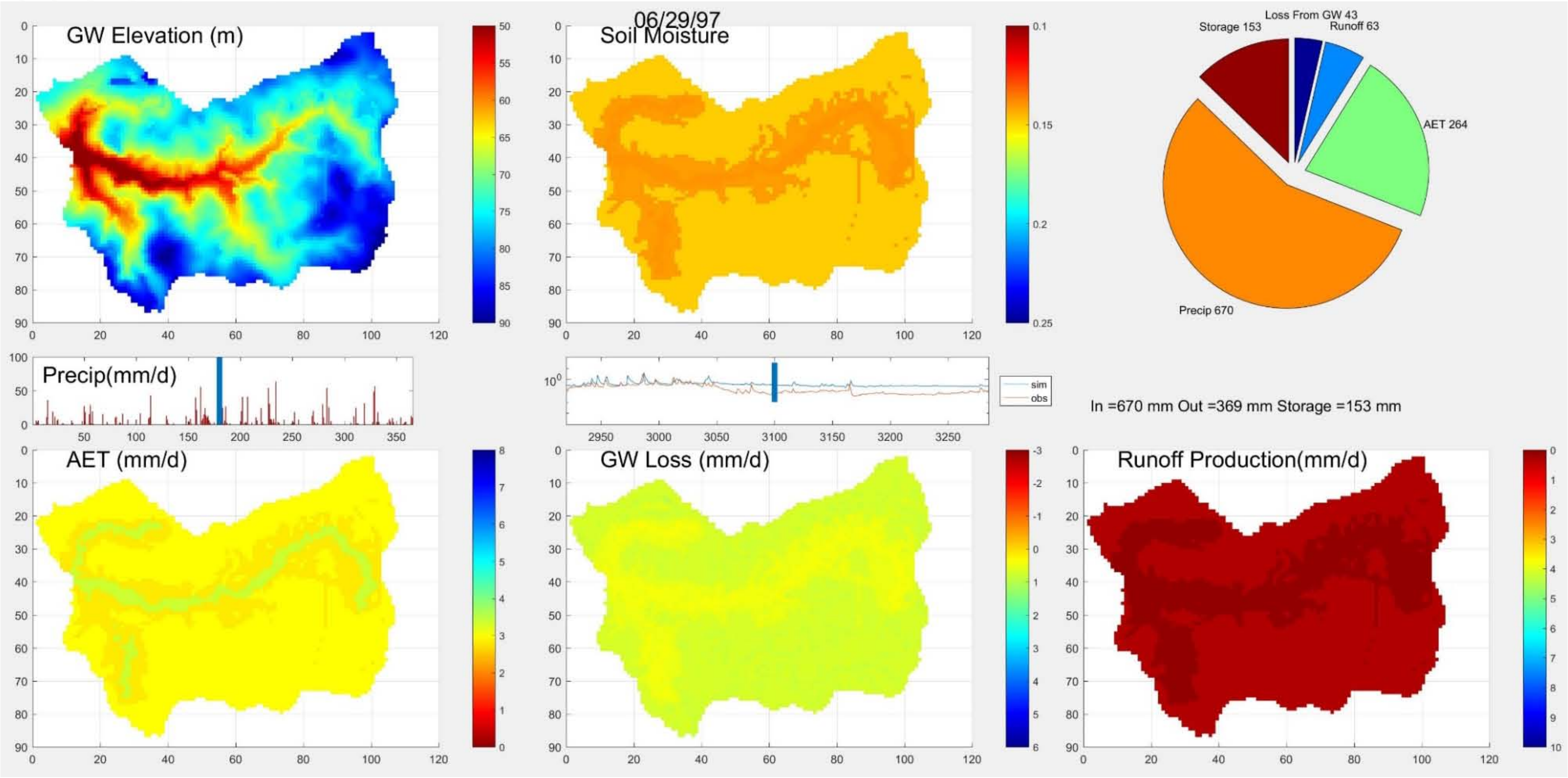
All milestones completed:

Initial forest management scenario model runs completed with the OSU model and standardized models MIKESHE and SWAT.

Initiated inclusion of conservative and non-conservative (nitrogen) tracking in watershed models.

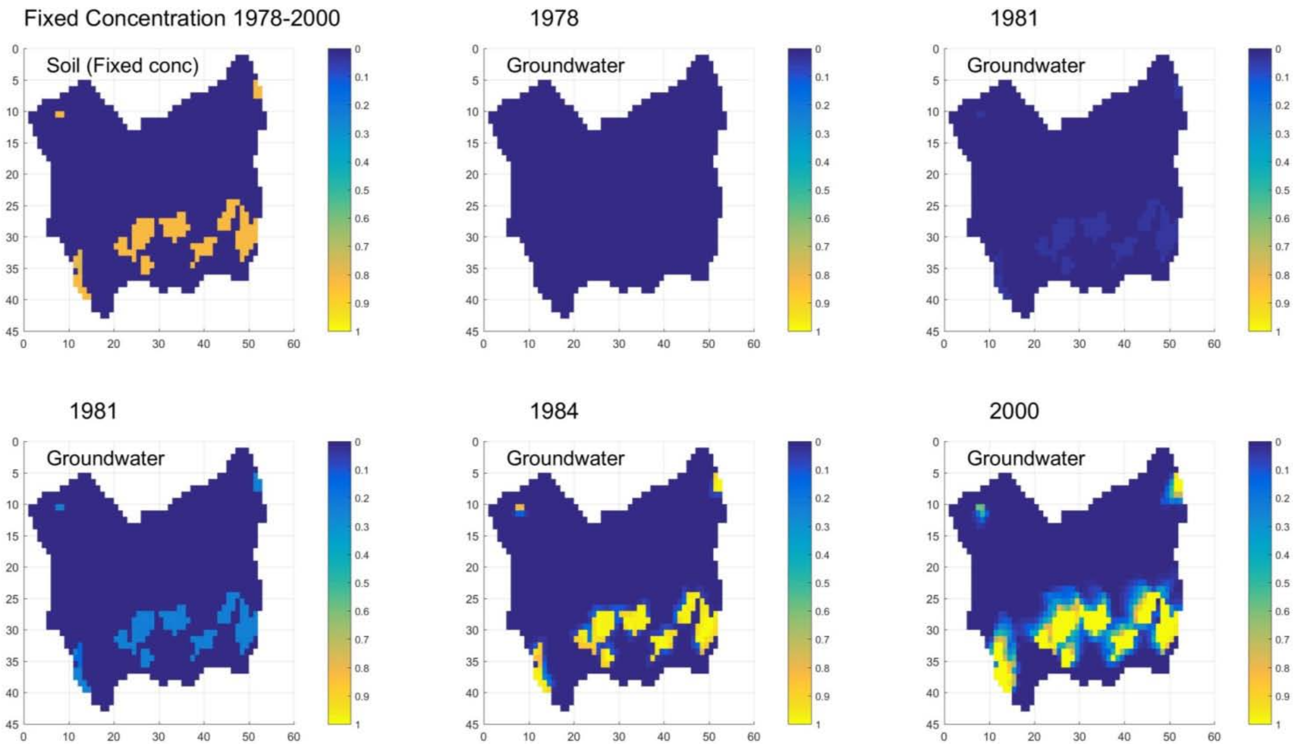
Accomplishments: Hydrologic Modeling

- OSU developed a watershed model specific to the Coastal Plains region using multi-objective functions comprising several parameters (ET, groundwater elevation, stream flow, soil moisture).
- A key feature is the capacity to simulate spatial and temporal patterns of parameters. It allows for evaluation of the influence of spatial patterning of SRWC production on water quality and quantity.

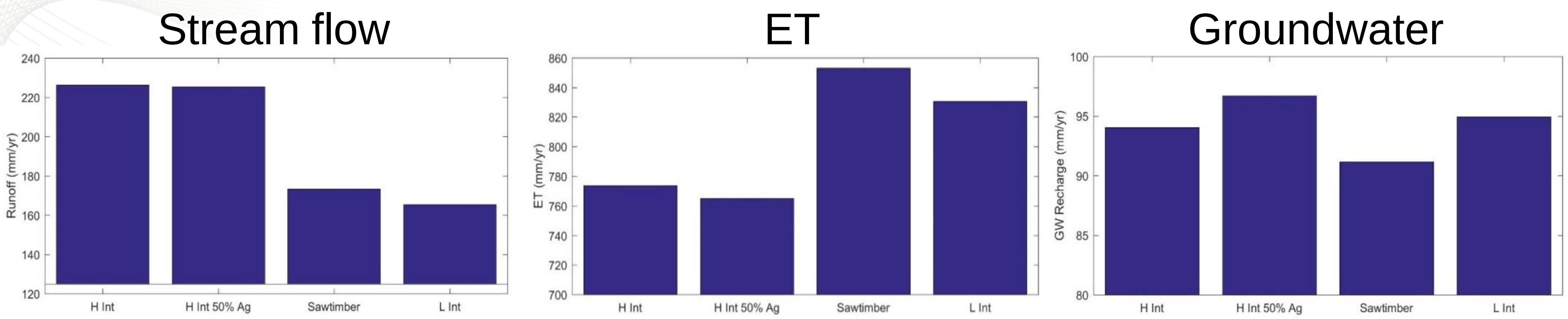


Accomplishments: Hydrologic Modeling Tracers

- OSU included conservative tracer mass balances to facilitate evaluation of source area tracking and estimation of residence time distributions.
- Model run from 1978-2000, with fixed concentration of conservative (non-reactive) tracer at surface (upper left figure).
- Individual maps depict concentration of tracer in deeper groundwater between initial application (1978) and the end of the model run (2000).
- **Movement of tracer indicates flow patterns and rates of flow in groundwater.**



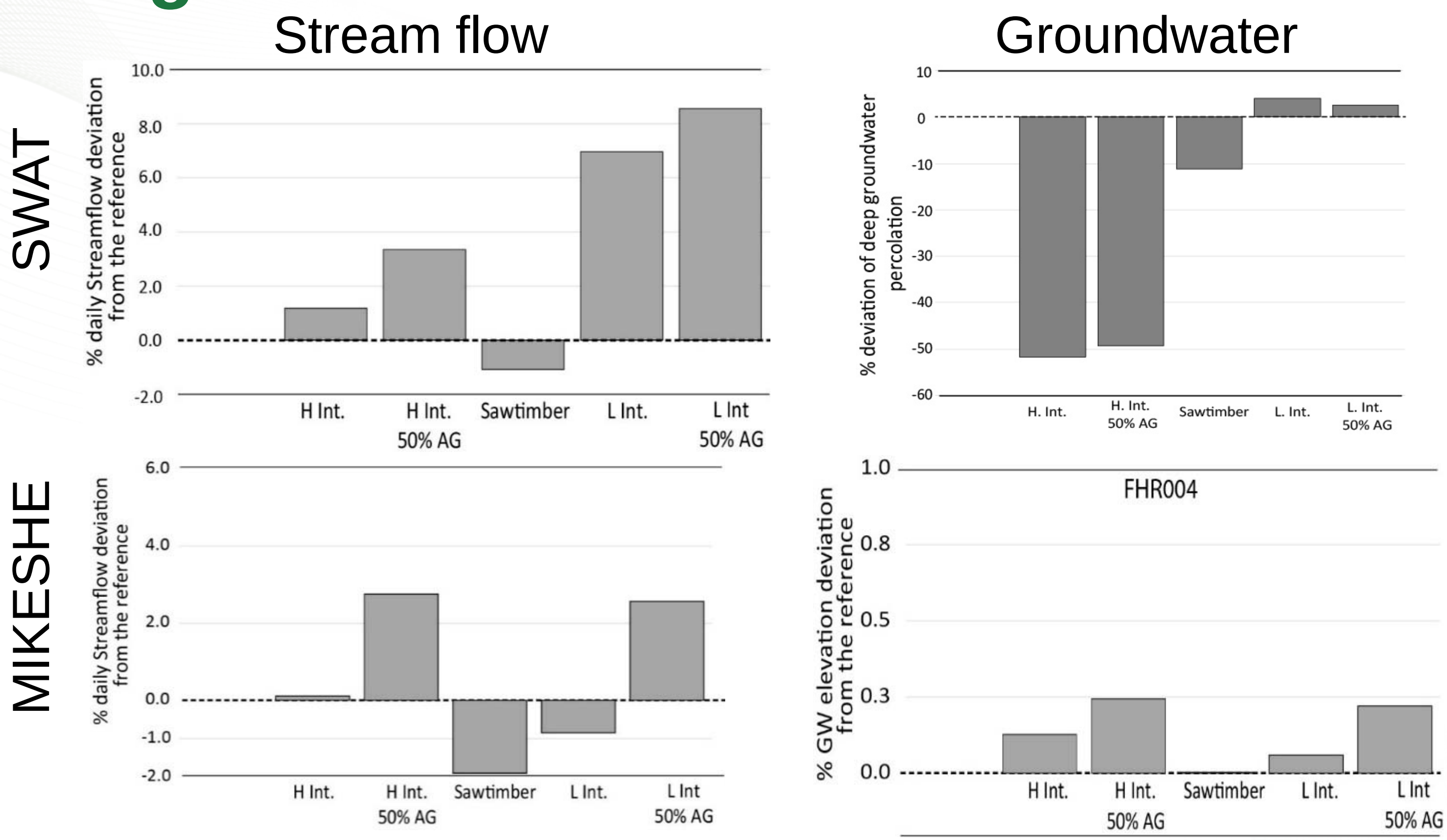
Accomplishments: Forest Management Scenario Modeling - OSU Model



Treatments (L→R: high-intensity, high-intensity with 50% ag, sawtimber, low-intensity)

- Cross-scenario comparison of water balance components.
- Shorter rotations resulted in reduced ET, with a maximum difference of 73 mm (9% decrease).
- Decreased ET resulted in increased runoff.
- Groundwater recharge was minimally impacted.

Accomplishments: Forest Management Scenario Modeling - MIKESHE and SWAT

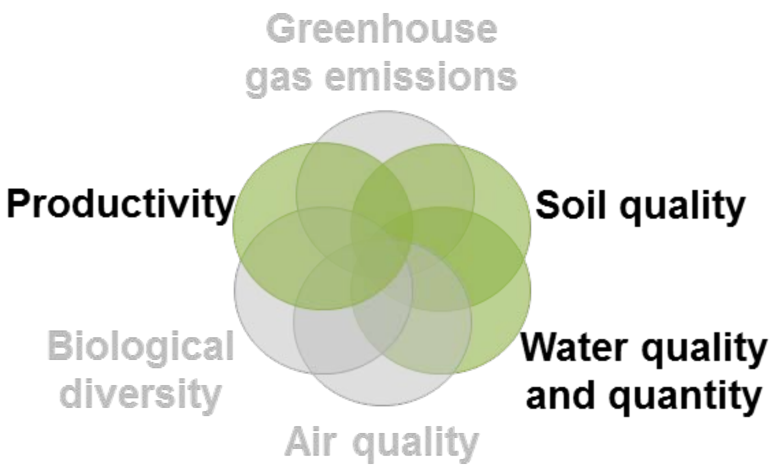


- MIKESHE showed negligible effects on water balance with high-intensity production, SWAT showed modest impacts on water balance. Both show largest effects with 50% agriculture.

- **Structural differences in models cause deviations in some predictions.** SWAT predicts large amounts of surface runoff and low GW recharge from clearcuts and plantations – does not reflect observations for pine plantations.

Relevance

- Maintaining or improving environmental conditions under bioenergy feedstock production is a key goal of BETO. Protection of water and soils is critical.
- Measuring key sustainability indicators in an operational-scale SRWC experiment.
- Comparing outcomes to regulatory and narrative standards for traditional forestry.
- Will demonstrate whether current forestry BMPs are adequate to protect water and soils and will inform industry, state water quality foresters, and regulators.
- Will upscale and generalize results both spatially and temporally using a distributed hydrologic model.
- Advancing scientific understanding of watershed hydrology and biogeochemistry in Coastal Plains.



Future Work

Field measurements:

- Continue measuring hydrology, water use, C flux, soil quality, and water quality through 2018 to gain insights into potential lagged effects and longer-term responses to SRWC production.
- Compare ET and C flux of loblolly pine to native long-leaf pine at SRS site.
- Initiate denitrification measurements along watershed flow paths to evaluate the fate of elevated nitrate from fertilizer.
- Investigate options for continuing low-frequency water quality measurements past 2018 given the long estimated transit times for transporting groundwater nitrate to streams.

Hydrologic modeling:

- Expand watershed tracer modeling to accommodate nitrogen dynamics.

All tasks:

- Prepare publications, including a review paper on considerations for monitoring and modeling environmental effects of SRWCs.

Future Work

Technology & information transfer:

- Synthesize results to evaluate the effectiveness of current forestry BMPs for SRWC production for bioenergy in the southeast.
- Present results to industry (e.g., NCASI southern regional meeting).
- Organize a special session at the Society of American Foresters or similar meeting on bioenergy BMPs.
- Publish on the Bioenergy KDF and in peer-reviewed journals.

Future directions past 2018:

- Take advantage of highly instrumented and well-studied watersheds.
- Explore use of drones for spatially resolved measurements of sustainability indicators.
- Evaluate changes in water use efficiency as plantation changes from an open canopy, rapidly growing system to a closed canopy, more mature plantation. Important for future projections of rotation lengths and production.
- Evaluate effectiveness of additional fertilizer applications on pine growth.
- Examine effects of biomass harvest on soil and water quality.

Summary

Overview:

- Data are needed to evaluate the effects of SRWC for bioenergy on water and soils in the southeast US and effectiveness of current forestry BMPs.
- Findings will be used by state water quality foresters and industry in developing guidelines for SRWC BMPs for bioenergy (if needed) and to minimize environmental effects when implementing this SRWC technology in the southeastern US.

Approach:

- Coupled watershed-scale experimental and modeling approaches to assess effects of SRWCs at various spatial and temporal scales.

Critical success factors and challenges:

- Success depends on implementing treatments, collecting high-quality data, scaling results using models, disseminating results to relevant audiences.
- Challenges identified and scaling issues will be addressed with modeling.

Summary

Technical Accomplishments and Main Findings:

- Silviculture treatments occurred as planned; all treatments completed.
- Disseminated results: 4 publications, 17 presentations since 2015.
- No impacts to stream water quality thus far. BMPs effective at protecting surface water.
- Increasing nitrate in groundwater due to inefficient N uptake, but concentrations below regulatory limits. Publication on water quality drafted.
- No fertilizer or ½ operational fertilizer treatments appear to satisfy pine N demand and minimize leaching.
- Due to rapid growth, pine is ~2 y ahead in development compared to standard timber plantations. Publication on ET in prep.
- Completed forest management scenario modeling with OSU model and standardized models.
- Models showed negligible to modest hydrologic impacts with bioenergy. SWAT has limitations for examining forest land uses. OSU and MIKESHE models mostly agree, but ET differences need further examination.
- Off-the-shelf models have some limitations for forest management questions.

Summary

Relevance:

- Woody biomass grown in the southeastern US will be a dominant bioenergy feedstock.
- Critical 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 field measurements through 2018 to assess longer-term impacts.
- Use results to evaluate existing BMPs and compare to narrative and regulatory standards.
- Expand watershed tracer modeling to accommodate N dynamics.
- Focus on dissemination of project results through presentations and publications, including review paper in 2017.
- Explore possible future research directions that take advantage of rich datasets at these field sites.

Additional Slides

Response to 2015 Peer Review Comments

<u>Comment</u>: I would have liked to see the silvicultural system incorporate more diverse species, versus a monoculture. Or, at least a buffered monocultured system? Also, I would like to have seen analysis of biodiversity and habitat. I suppose that would have been a stretch, assuming that even water quality information is not available for these types of SRWCs (surprising that industry has not undertaken these types of studies!). Perhaps a slide in the beginning explaining the rationale for choosing this type of project would have been helpful.

I like how the project used lidar information that related the soils composition to water quality movements. It seems like all of the modeling studies that this project looked at/executed would be useful to forest management and improvement of water quality.

Why is it that you are studying whether BMPs are adequate? Why assume they are not? I would have liked to have had more explanation of why existing BMPs are being questioned.

<u>Response</u>: Regarding the comment on the silvicultural system, we chose a loblolly pine monoculture because pine is what southeastern foresters grow. The wood production infrastructure is focused on pine - there is plentiful nursery stock, silvicultural knowledge, contractors who know how to harvest, plant, and apply chemicals, and markets for products. The tree is hardy and quite reliable. It has been the dominant commercial tree of the southeast for over half a century, and there is no sign of that changing.

However, pine has not been grown on a 10-12 year rotation, because there has not been a market for wood that small. Traditional forestry does not disturb the ground as much, remove as much product, or apply as many chemicals (fertilizer and herbicides) as would be done if the bioenergy market created demand for short rotation pine biomass. Thus, studies of BMP effectiveness for traditional forestry do not encompass the site conditions associated with short rotation biomass production. One of our goals is to determine if current BMPs are adequate for short rotation woody biomass production given these differences in management.

We felt that making the design any more complex than current would make interpretation of the results more difficult. In addition, extensive experience in operational settings by several of the PIs suggests that the logistics of establishing and managing complex species and structure arrays is prone to failure. It is one thing to prepare, plant, and manage a single crop in a limited area, but adding additional species/structure is very difficult on a large scale.

Regarding the comment on an analysis of biodiversity and habitat, researchers with the USFS at Savannah River Site have validated BIRDHAB and created empirical models for other groups that can serve as predictive models of habitat conditions under normal low intensity forestry practices. These models can be used to test the degree of impact these systems may have on biodiversity. However, we have no funding for this type of analysis for our watershed study.

Regarding the comment on the adequacies of BMPs, none of the BMP studies in the last few decades employed a combination of intensive weed control and fertilization during the early phase of establishment and few studies have assessed the impacts to groundwater. When practices are combined to create and maintain bare soil for an extended period under intensive crop management and existing BMPs are followed (that were not developed for these intensive regimes), the effects on nutrient and herbicide transport is not clear. It is often stated that vegetation cover recovery after clearing and planting mitigates many of the potential environmental problems.

Go/No-Go 3/31/2016

Go/No-Go Description:
Determine water quality, quantity, and soil quality metrics relative to regulatory standards.

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

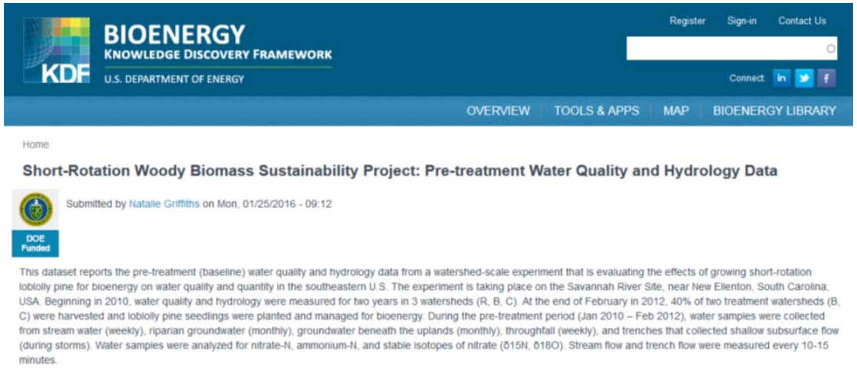
Summary from Go/No-Go Report:
A report was completed summarizing the findings from our study so far, including impacts to water quality, soil quality, hydrology, and evapotranspiration. Overall, our field and modeling results suggest that the effect of short-rotation pine for bioenergy on water and soils is minimal thus far. Changes in hydrology and water use are similar to other systems and pine management practices, and water quality metrics (nitrate) are below regulatory standards.

Publications and Presentations

Published:

- Du, E., C.R. Jackson, J. Klaus, J.J. McDonnell, N.A. Griffiths, M.F. Williamson, J.L. Greco, and M. Bitew. 2016. Interflow dynamics on a low relief forested hillslope: lots of fill, little spill. Journal of Hydrology 534:648-658.
- Griffiths, N.A., C.R. Jackson, J.J. McDonnell, J. Klaus, E. Du, and M.M. Bitew. 2016. Dual nitrate isotopes clarify the role of biological processing and hydrologic flow paths on nitrogen cycling in subtropical low-gradient watersheds. JGR-Biogeosciences 131:422-437.

Pre-treatment data were published on the Bioenergy KDF:



https://bioenergykdf.net/content/short-rotation-woody-biomass-sustainability-project-pre-treatment-water-quality-and

- Jackson, C.R., E. Du., J. Klaus, N.A. Griffiths, M. Bitew, and J.J. McDonnell. 2016. Interactions among hydraulic conductivity distributions, subsurface topography, and transport thresholds revealed by a multi-tracer hillslope irrigation experiment. Water Resources Research 52:6186-6206.
- Klaus, J., J.J. McDonnell, C.R. Jackson, E. Du, and N.A. Griffiths. 2015. Where does streamwater come from in low-relief forested watersheds? A dual isotope approach. Hydrology and Earth System Sciences 19:125-135.
- 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.

In Review:

- Vache, K., J. Bolte, C. Schwartz, and J. Sulzman. A flexible framework to support socio-hydrological scenario analysis. In review at Environmental Modeling and Software.

In Preparation:

- Griffiths, N.A., C.R. Jackson, M.M. Bitew, A.M. Fortner, K.L. Fouts, K. McCracken, and J.R. Phillips. Initial water quality effects of short-rotation pine management for bioenergy feedstocks in the southeastern United States. In Preparation for Forest Ecology and Management.

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Publications and Presentations

Presentations:

- Bitew, M.M., C.R. Jackson, K.B. Vache, N.A. Griffiths, G. Starr, J.J. McDonnell, B. Rau, S. Younger, and K. Fouts. Water quantity and quality impacts of intensive woody biomass feedstock production in the southeastern U.S. American Geophysical Union fall meeting, San Francisco, CA, December 2016. Poster presentation.
- Vache, K., M. Bitew, C.R. Jackson, and J.J. McDonnell. Observation-based model development for groundwater dominated catchments. American Geophysical Union fall meeting, San Francisco, CA, December 2016. Oral presentation.
- Rau, B.M., N.A. Griffiths, C.R. Jackson, and J. Blake. Nitrogen cycling in short rotation pine. Soil Science Society of America annual meeting, Phoenix, AZ, November 2016. Oral presentation.
- Bitew M.M., C.R. Jackson, J.J. McDonnell, K. Vache, N.A. Griffiths, G. Starr, S. Younger, K. Fouts, and B. Rau. Modeling hydrologic impacts of intensive woody biomass feedstock production in the Southeastern US. Short-Rotation Woody Crop Operations Working Group conference, Ft. Pierce, FL, October 2016. Poster presentation.
- Griffiths, N.A., C.R. Jackson, M. Bitew, E. Du, K. Vache, J.J. McDonnell, N. Orlowski, J. Klaus, G. Starr, S. George, and B.M. Rau. Examining the effects of woody biomass production for bioenergy on water quality, soil quality, and hydrology in the southeastern United States. Symposium on Watershed Scale Sustainability of Forest-Based Bioenergy Production, Raleigh, NC, September 2016. Oral presentation.
- Griffiths, N.A., C.R. Jackson, M. Bitew, A.M. Fortner, J.R. Phillips, K. McCracken, and K.L. Fouts. Evaluating the water quality effects of short-rotation pine production for bioenergy using a watershed-scale experiment. Ecological Society of America conference, Fort Lauderdale, FL, August 2016. Oral presentation.
- Aubrey, D.P., C.R. Jackson, J.J. McDonnell, C.F. Minat, and P.V. Caldwell. Hydrologic budgets for short rotation loblolly pine and sweetgum. Ecological Society of America conference, Fort Lauderdale, FL, August 2016. Poster presentation.
- Jackson, CR. Influence of soils on vertical and lateral movement of water. Workshop on hydrologic connectivity: bridging terrestrial and aquatic systems in a karst landscape. Joseph Jones Ecological Research Center, July 2016. Invited Presentation.
- Jackson, C.R. Forest Hydrology and Water Quality: Grand Challenges in the U.S. NCASI Southern Regional Meeting, June 2016, Chattanooga, TN, Invited Presentation.
- Jackson, C.R., N.A. Griffiths, and B. Rau. Evaluating the environmental sustainability of woody biomass production for bioenergy in the southeastern US. Southeastern US bioenergy study tour sponsored by DOE and Oak Ridge National Laboratory, Savannah River Site, SC, April 2016. Invited Presentation.
- Jackson, C.R., M.M Bitew, E. Du, N.A. Griffiths, L. Hopp, J. Klaus, J.J. McDonnell, and K.B. Vache. Headwater streams in porous landscapes: what's the contributing area? American Geophysical Union fall meeting, San Francisco, CA, December 2015. Oral presentation.
- Younger, S. and C.R. Jackson. Comparison of evapotranspiration and forest cover type in the southeast United States: a long-term water budget approach. American Geophysical Union fall meeting, San Francisco, CA, December 2015. Poster presentation.
- Jackson, C.R. Forest hydrology: grand challenges in the USA. Forest Hydrology Science Symposium and Workshop, Portland, OR, December 2015. Invited presentation.
- Griffiths, N.A., C.R. Jackson, M. Bitew, E. Du, K. Vache, J.J. McDonnell, N. Orlowski, J. Klaus, G. Starr, S. George, J.I. Blake, and B.M. Rau. Examining the effects of woody biomass production for bioenergy on water quality and hydrology in the southeastern United States. Third annual National Bioenergy Day, October 2015. Webinar presentation.
- Griffiths, N.A., C.R. Jackson, J.J. McDonnell, M.M. Bitew, E. Du, and J. Klaus. Effects of short-rotation pine management or bioenergy on water quality in the southeastern U.S. University of Tennessee Watershed Symposium, Knoxville, TN, September 2015. Poster presentation.
- Griffiths, N.A., C.R. Jackson, J.J. McDonnell, M. Bitew, E. Du, and J. Klaus. Effects of short-rotation pine management for bioenergy on water quality in the southeastern United States. Society for Freshwater Science conference, Milwaukee, WI, May 2015. Oral presentation.
- Hopp L., K.B. Vache, C.R. Jackson and J.J. McDonnell. Modeling subsurface stormflow initiation in low-relief landscapes. European Geophysical Union Annual Meeting, Vienna, Austria, April 2015. Poster presentation.

Abbreviations

Ag – Agriculture
AGM MCP 37 – Loblolly pine seedling family
BETO – Bioenergy Technologies Office
BMPs – Best Management Practices
DAP – Diammonium phosphate (fertilizer)
DOE – Department of Energy
EC – Eddy Covariance
EPA – Environmental Protection Agency
ET – Evapotranspiration
Fert. – Fertilizer
Fourmile – Larger watershed that encompasses our 3 study watersheds
GEE – Gross Ecosystem Exchange
KDF – Knowledge Discovery Framework
LAI – Leaf Area Index
MIKESHE – 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
N-min – Nitrogen mineralization
Op. – Operational
ORNL – Oak Ridge National Laboratory
OSU – Oregon State University
Reco – Ecosystem respiration
REF – Reference watershed
SE – Southeastern US
SMZ – Streamside Management Zone (50 ft buffer between planted areas and stream; hardwood riparian zone)
SRP – Soluble Reactive Phosphorus
SRNL – Savannah River National Laboratory
SRWC – Short-Rotation Woody Crops
SRS – Savannah River Site
SWAT – Soil and Water Assessment Tool
TRT – Treatment watershed
UA – University of Alabama
UGA – University of Georgia
U of S – University of Saskatchewan
USDA – United States Department of Agriculture
USFS-SR – USDA Forest Service – Savannah River
Veg. – Vegetation
VPD – Vapor Pressure Deficit
Watersheds B and C – Treatment watersheds (locations of clear cuts)
Watershed R – Reference (unmanipulated) watershed

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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.
  - We will explore possible funding options to continue lower-frequency 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.

FY17 Milestones:

Milestone:	Due:	Group(s):	Status:
Complete aerial fertilization of planted areas in the treatment watersheds.	12/31/2016	USFS-SR	100% complete
Complete analysis of water quality samples collected in FY16.	12/31/2016	ORNL	100% complete
Evaluate the ability of MIKESHE and the OSU model to evaluate pollutant transport and travel times using conservative particle tracking or nutrient dynamics algorithms.	3/31/2017	UGA/OSU	UGA: 75% complete OSU: 40% complete
Complete analysis of stable isotope samples collected in 2016 water year.	6/30/2017	U of S	50% complete
Complete analysis of water and energy flux of pine trees, leaf area, and fisheye photography for the first 22 months of measurements.	6/30/2017	UA	85% complete
Complete analysis of all soil quality and productivity study samples collected in FY16.	9/30/2017	USFS-SR	35% complete
Complete draft manuscript on eddy flux studies of water use efficiency.	9/30/2017	UA	65% complete
Provide a draft manuscript to BETO detailing the SRWC issues in the US and ideas for measuring and modeling environmental effects of SRWCs.	9/30/2017	All	10% complete

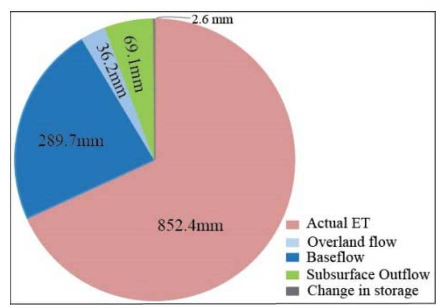
Forest Management Scenario Modeling: Reference model for MIKESHE and SWAT

Objective: Develop a reference model simulation that represents the hydrologic processes in Fourmile Watershed.

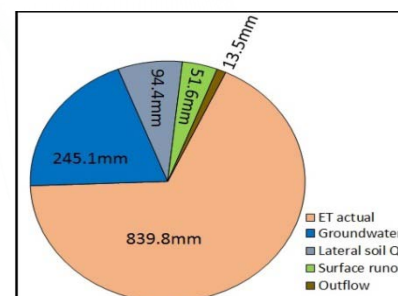
- To evaluate potential impacts of biomass production on watershed hydrology, a reference simulation using mixed pine-hardwood forest was developed and calibrated using multi-objective functions.
- Simulation evaluated streamflow, groundwater elevation, and soil moisture at multiple locations in Fourmile Watershed.
- Both MIKESHE and SWAT captured the hydrologic processes in Fourmile.

USGS Stations	Evaluation Statistics	Model	
		SWAT	MIKE SHE
Site#3	Correlation coefficient	0.602	0.703
	Nash efficiency Coeff	**0.356**	**0.410**
	RMSE	0.202	0.193
	% Bias	-3.178	-3.138
Site#6	Correlation coefficient	0.669	0.743
	Nash efficiency Coeff	**0.413**	**0.546**
	RMSE	0.207	0.182
	% Bias	3.516	-0.678
Site#7	Correlation coefficient	0.627	0.752
	Nash efficiency Coeff	**0.390**	**0.513**
	RMSE	0.607	0.542
	% Bias	4.794	-5.114
Fourmile	Correlation coefficient	0.636	0.635
	Nash efficiency Coeff	**0.401**	**0.356**
	RMSE	0.969	1.006
	% Bias	-6.962	-14.380

MIKESHE



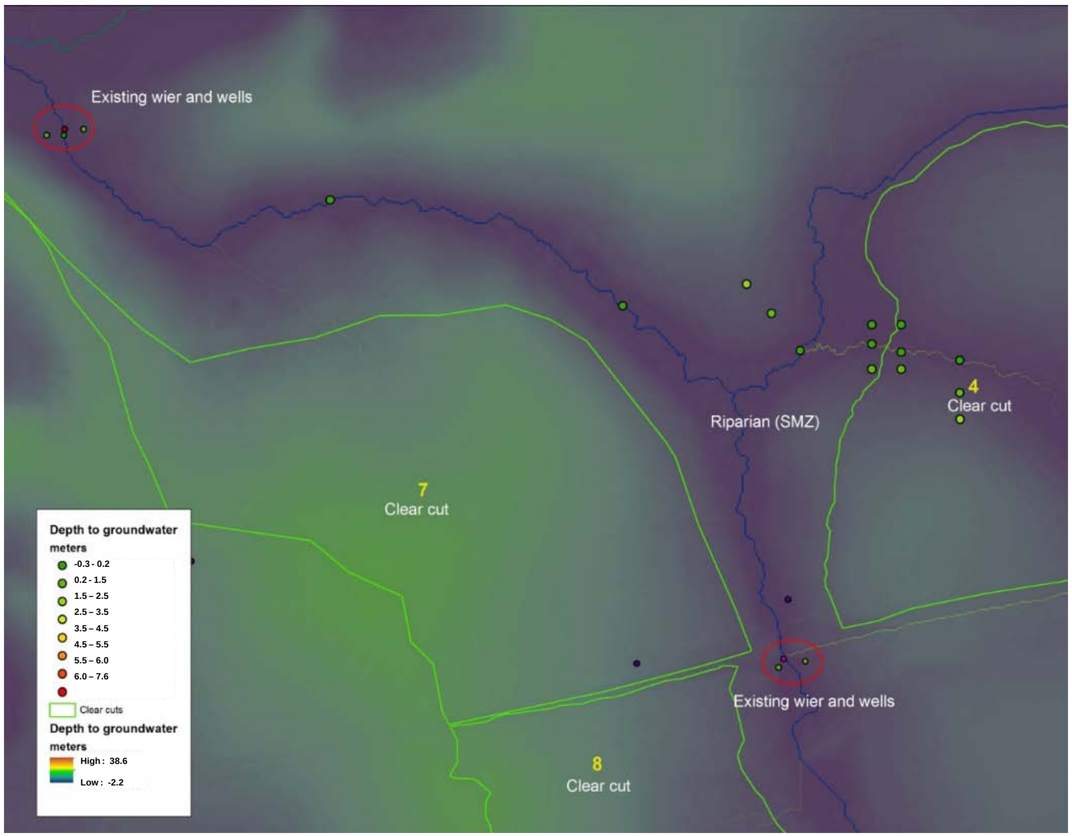
SWAT



Reference water budgets for 2 standard models

In-situ Riparian Denitrification Estimates

Background: Denitrification is a microbial process that converts NO_3 to N_2 (with some N_2O produced), serving as a natural pathway for NO_3 loss in the system before reaching surface waterways.



Objectives:

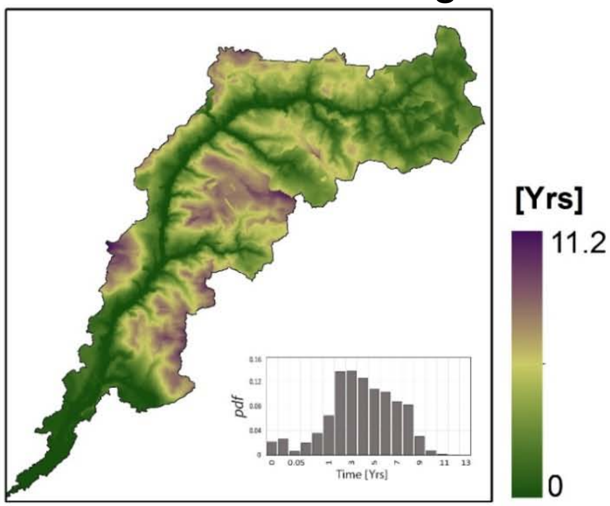
- Quantify denitrification rates along groundwater flowpaths from loblolly pine plantation through SMZ.
- Investigate correlations between denitrification rates and shallow groundwater temperature and chemical characteristics.

Measurements:

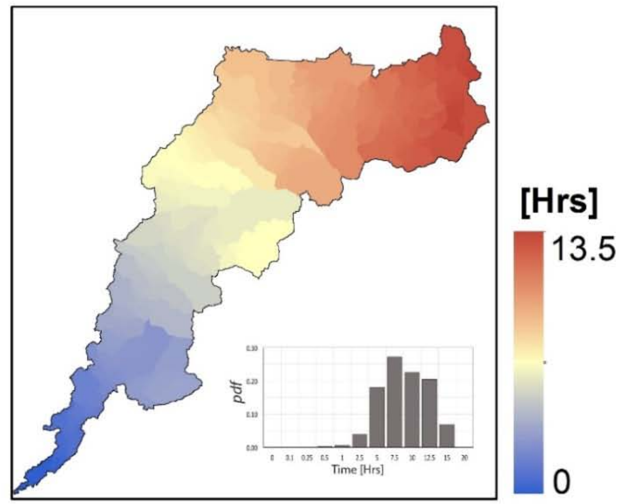
- Established 20-well monitoring network, sampling and analysis protocols.
- Samples collected monthly for 1 y starting winter 2017.
- Total denitrification rates calculated from dissolved N_2 and N_2O concentrations.

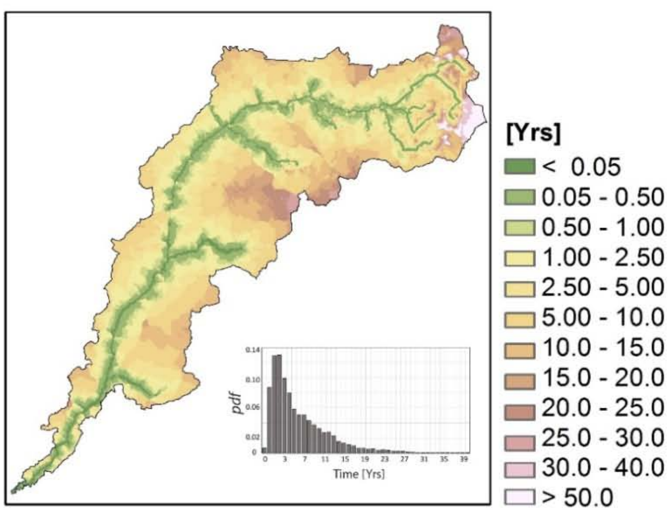
How long might nitrate take to reach streams?
Estimating travel time distributions using groundwater models.

Unsaturated flow lag

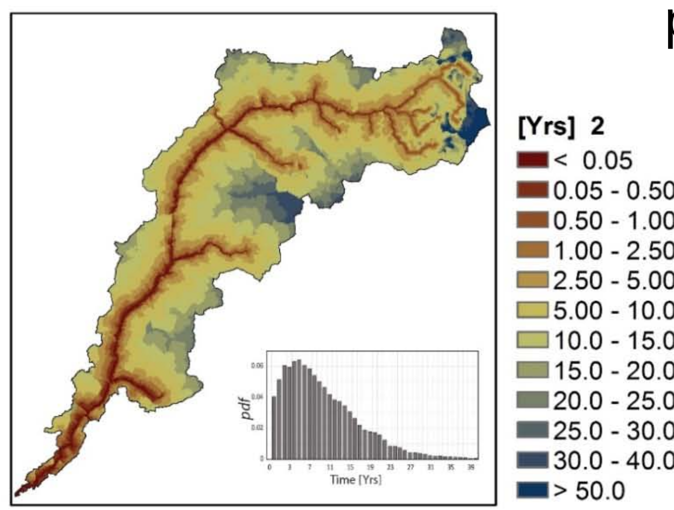


Channel flow travel time





Saturated flow travel time



Total travel time

Preliminary results: Don't quote us yet: early estimates suggest median travel times in the range of 10 years. This has implications for monitoring plans.

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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 (UGA), 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 models.
- **Objectives:** measure water consumption & hydrologic cycling to parameterize process-based watershed models.
- 6 eucalyptus plots within watersheds B and C. Compare to 6 pine plots.