2015 DOE Bioenergy Technologies Office (BETO) Project Peer Review

Forecasting Water Quality & Biodiversity

March 25, 2015

Cross-cutting Sustainability Platform Review

Principle Investigator: Dr. Henriette I. Jager
Organization: Oak Ridge National Laboratory

This presentation does not contain any proprietary, confidential, or otherwise restricted information

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Goal Statement

Regional-scale river basin modeling to support decisions (e.g., when and where to plant crops and apply conservation practices) to promote sustainability indicators that measure feedstock production, water quality, water quantity, and biodiversity.

Addresses the following MYPP BETO goals:

- Advance scientific methods and models for measuring and understanding bioenergy sustainability [across the supply chain].
- Develop landscape design approaches that increase bioenergy production while maintaining or enhancing ecosystem and social benefits.
- Understand and promote the positive economic and environmental effects of biofuels production activities and reduce potential negative impacts.
- Assess current and future environmentally sustainable biomass availability.
- Increase the volume of sustainable, quality feedstock available.
- Highlight the role that a thriving bioeconomy plays in benefitting the environment.

Quad Chart Overview

Timeline

Project start date: FY09
Project end date: FY17
Percent complete: 61%

Barriers

- Mm-A Lack of understanding of environmental/energy tradeoffs
- St-B Consistent and science-based message on bioenergy sustainability
- St-D Implementing indicators and methodology for evaluating and improving bioenergy
- St-E Best practices and systems for sustainable bioenergy production
- St-G Land-use and innovative landscape design proactively design and manage landscapes to enhance benefits and minimize negative impacts

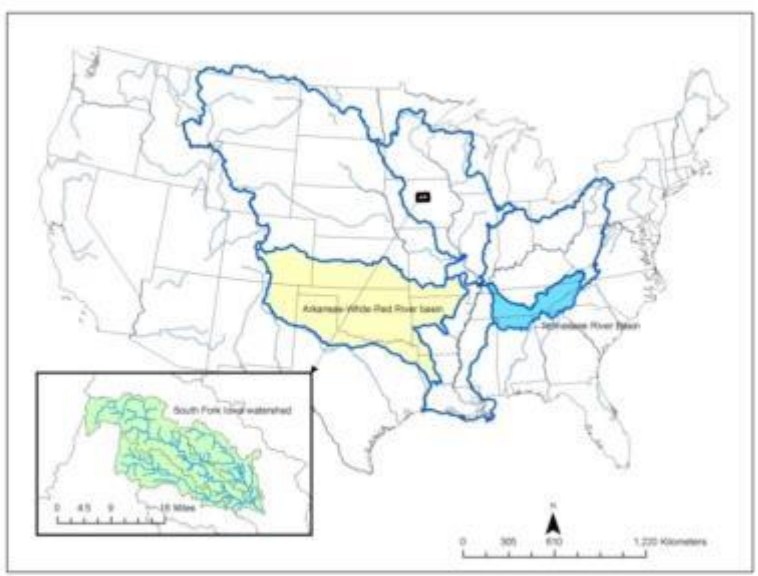
Budget

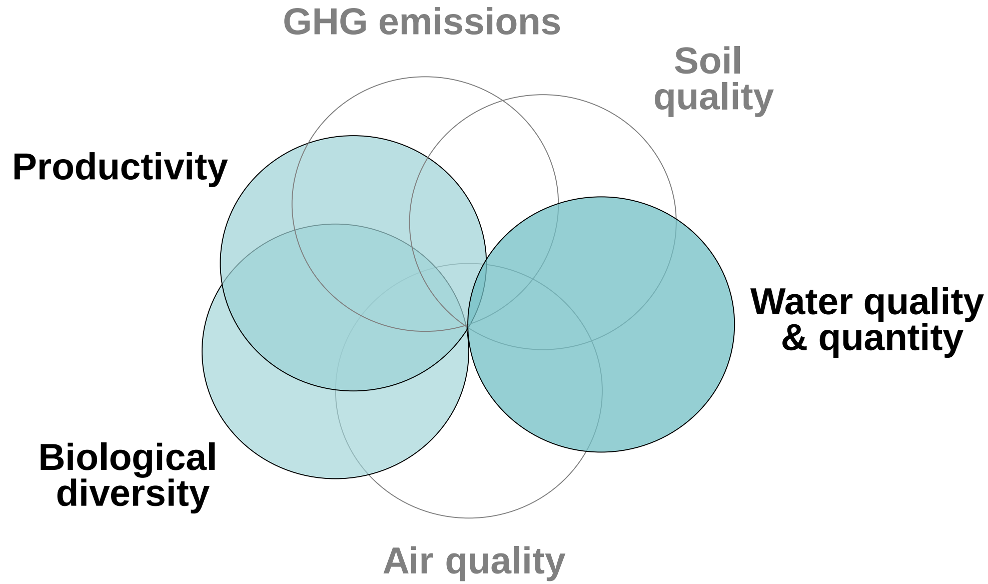
- Total project funding $1,400K
  - DOE share (100%)
  - Contractor share (0%)
- FY10-12: $600K ($200K x 3y)
- FY13: $225K
- FY14: $325K
- FY15-16: $650K

Partners

- DOE labs: ANL (Wu), INL (Bonner / Jacobsen)
- Tennessee Valley Authority (Tyler Baker)
- Universities: Joint Bioenergy Institute, UC Berkeley), Center for Native Grasslands Management, U. Tenn.
- USDA (Tomer, Srinivasan)
- Forest Service (Trettin)

1 - Overview





FY13 Task	FY14 Task	FY15 Task	Spatial scale / location	Collaborators
Forecasting water quality (75%)	Forecasting water quality (57%)	Regional opportunity assessment	Large river basins	ANL (Wu)
Forecasting biodiversity (25%)	Forecasting biodiversity (20%)	Regional opportunity assessment	Large river basins	Universities
	Pathways to Sustainable Design (12%)	<on hold>	Regional and farm / South Fork Watershed, Iowa	INL (Jacobsen), ANL (Wu), USDA (Tomer)
		Billion-Ton Sustainability	(1) National (biodiversity) (2) River basin (water quality)	ORNL Resource Assessment (Langholtz, Efroymson); ANL (Wu); Forest Service

2 – Approach (Technical)

Major Challenges	Critical Success Factors
Large-scale river basin modeling to represent bioenergy crops	• Modeling team with depth and experience with biogeochemical, hydrologic, and crop modeling
Representing non-target, region-specific features	• Engaged TVA to represent reservoirs in Tenn. • Engaged USDA collaborator to advise on tile drains in Iowa
Inferring responses to future cellulosic crops from limited data	• Employed process-based models • Developing statistical methods to infer wildlife responses from available data

2 – Approach (Management)

– ***Core Team:***
  - Henriette (Yetta) Jager, ecological modeler & PI
  - Latha Baskaran, watershed modeler & geographer
  - Gangsheng Wang, watershed modeler & climate scientist
– ***Supplemental team***
  - ORNL colleagues in Resource Analysis & Sustainability
  - Scientists at other DOE Labs
  - Post-graduate researchers (Jasmine Kreig, Nate Sutton)
  - University partners
  - USDA, Forest Service

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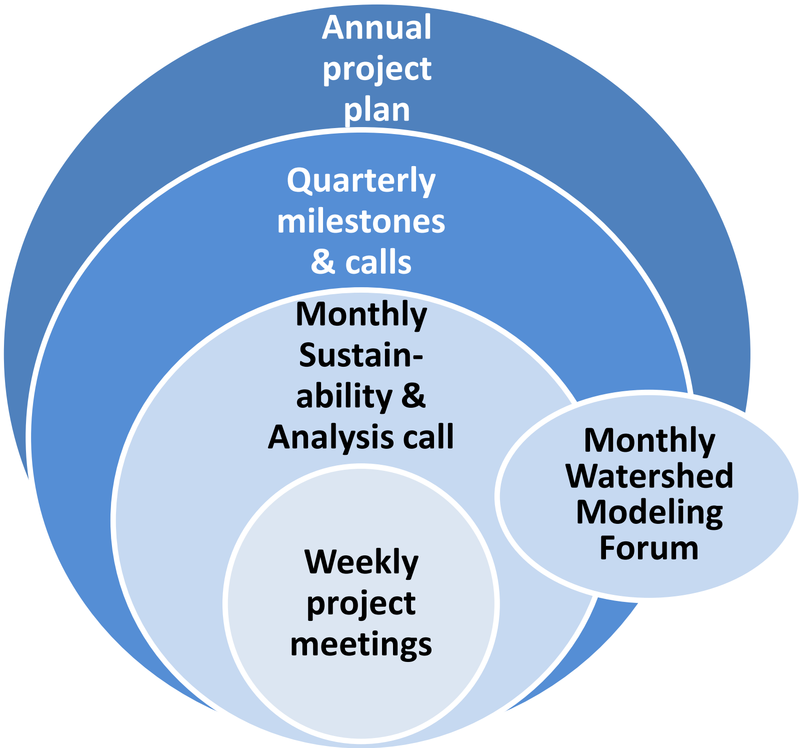
2 – Approach (Management)

Critical Success Factors

- Available data for large-scale modeling
- Coordination with other groups
  - Argonne National Laboratory (Task A)
  - Tennessee Valley Authority (Task A)
  - INL, USDA, Watershed Alliance (Task C)
  - Resource Analysis, University partners (Billion Ton)

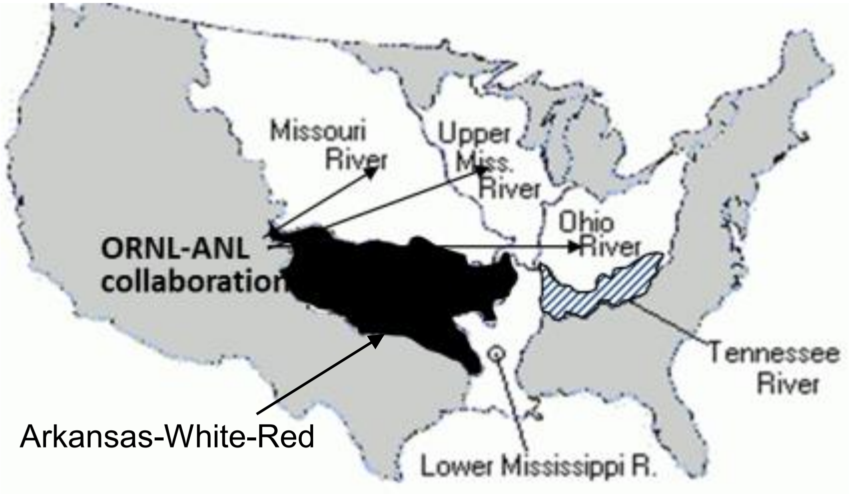
Risks defined & addressed

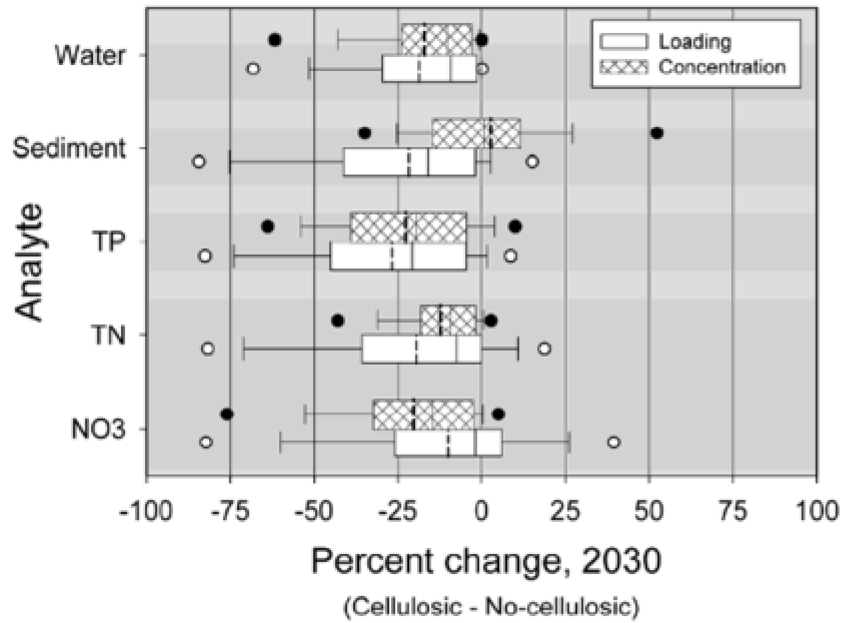
- BETO encourages ambitious goals
- Back-up plans mitigate risk



3-Technical Accomplishments

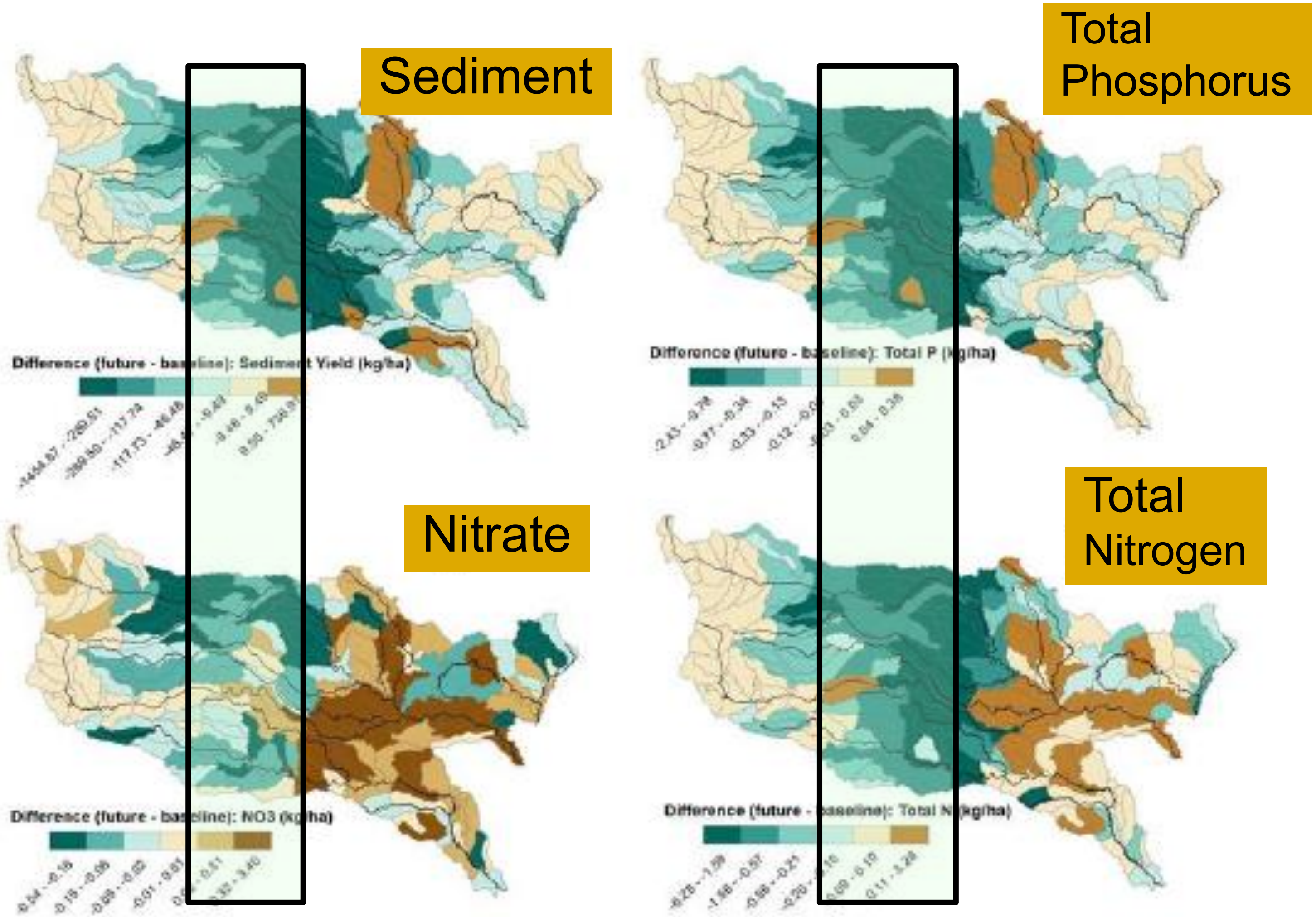
Reduced flow and median decreases in loadings and concentrations of nutrients and sediment in the Arkansas-White-Red River basin.





Task A. Regional Opportunity Assessment

3-Demonstrated water quality benefits East of 100th meridian, Arkansas-White-Red River basin.

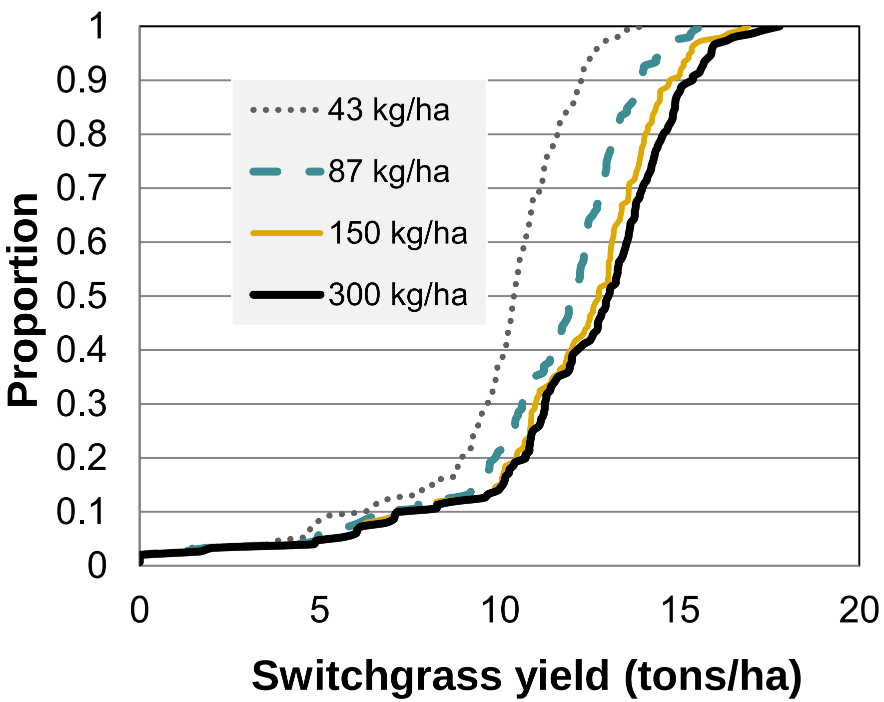


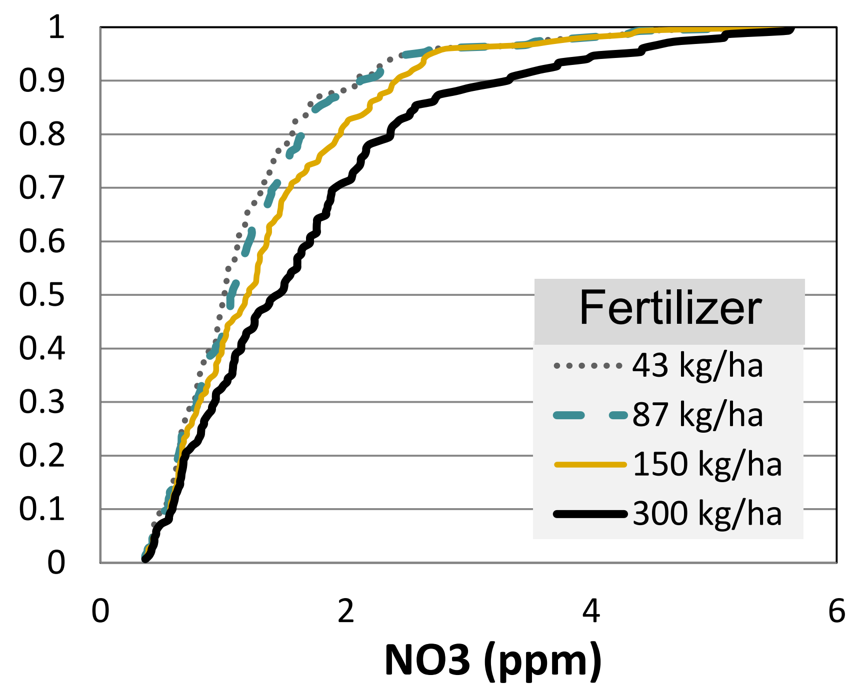
Increasing precipitation →

Task A. Regional Opportunity Assessment

3-Understand trade-offs among sustainability indicators

Applying fertilizer in excess of 87 kg/ha to switchgrass was counter-productive in the Arkansas-White-Red River basin.





Task A. Regional Opportunity Assessment

3-Technical Accomplishments

Dissemination of results

Progress toward Evaluating the Sustainability of Switchgrass as a Bioenergy Crop using the SWAT Model

L. Baskaran, H. I. Jager, P. E. Schweizer, R. Srinivasan

ABSTRACT. *Adding bioenergy to the U.S. energy portfolio requires long-term profitability for bioenergy producers and long-term protection of affected ecosystems. In this study, we present steps along the path toward evaluating both sides of the sustainability equation (production and environmental) for switchgrass (Panicum virgatum) using the Soil and Water Assessment Tool (SWAT). We modeled production of switchgrass and river flow using SWAT for current landscapes at a regional scale. To quantify feedstock production, we compared lowland switchgrass yields simulated by SWAT with estimates from a model based on empirical data for the eastern U.S. The two produced similar geographic patterns. Average yields reported in field trials tended to be higher than average SWAT-predicted yields, which may nevertheless be more representative of production-scale yields. As a preliminary step toward quantifying bioenergy-related changes in water quality, we evaluated flow predictions by the SWAT model for the Arkansas-White-Red river basin. We compared monthly SWAT flow predictions to USGS measurements from 86 subbasins across the region. Although agreement was good, we conducted an analysis of residuals (functional validation) seeking patterns to guide future model improvements. The analysis indicated that differences between SWAT flow predictions and field data increased in downstream subbasins and in subbasins with higher percentage of water. Together, these analyses have moved us closer to our ultimate goal of identifying areas with high economic and environmental potential for sustainable feedstock production.*

Keywords. *Bioenergy, Functional validation, River flow, Sensitivity analysis, Sustainability, Switchgrass, Water quality.*

Long-term sustainability of the nascent bioenergy industry is influenced by several factors. These include economic feasibility and concerns over environmental impacts (Simpson et al., 2008; Simpson, 2009). Switchgrass (*Panicum virgatum* L.) is a native grass that has high potential as a sustainable dedicated

sential to provide more accurate spatial estimates of bioenergy resource potential. Because they extrapolating to new location models are well-suit McMaster

GCB Bioenergy (2014), doi: 10.1111/gcbb.12169

Forecasting changes in water quality in rivers associated with growing biofuels in the Arkansas-White-Red river drainage, USA

HENRIETTE I. JAGER[1], LATHA M. BASKARAN[1], PETER E. SCHWEIZER[1], ANTHONY F. TURHOLLOW[1], CRAIG C. BRANDT[1] and RAGHAVAN SRINIVASAN[2]
[1]Oak Ridge National Laboratory, Oak Ridge, TN, 37831-6036, USA, [2]Texas A&M University, College Station, TX, USA

Abstract

Excess nutrients from agriculture in the Mississippi River drainage, USA have degraded water quality in freshwaters and contributed to anoxic conditions in downstream estuaries. Consequently, water quality is a significant concern associated with conversion of lands to bioenergy production. This study focused on the Arkansas-White-Red river basin (AWR), one of five major river basins draining to the Mississippi River. The AWR has a strong precipitation gradient from east to west, and advanced cellulosic feedstocks are projected to become economically feasible within normal-to-wet areas of the region. In this study, we used large-scale watershed modeling to identify areas along this precipitation gradient with potential for improving water quality. We compared simulated water quality in rivers draining projected future landscapes with and without cellulosic bioenergy for two future years, 2022 and 2030 with an assumed farmgate price of $50 per dry ton. Changes in simulated water quantity and quality under future bioenergy scenarios varied among subbasins and years. Median water yield, nutrient loadings, and sediment yield decreased by 2030. Median concentrations of nutrients also decreased, but suspended sediment, which is influenced by decreased flow and in-stream processes, increased. Spatially, decreased loadings prevailed in the transitional ecotone between 97° and 100° longitude, where switchgrass, *Panicum virgatum L.*, is projected to compete against alternative crops and land uses at $50 per dry ton. We conclude that this region contains areas that hold promise for sustainable bioenergy production in terms of both economic feasibility and water quality protection.

Keywords: bioenergy, biofuels, cellulosic feedstocks, land-use change, *Panicum virgatum*, POLYSYS, Soil Water Assessment Tool, sustainability, water quality

Received 5 December 2013 and accepted 3 January 2014

Introduction

Historical shifts in land use and land cover have caused, and may continue to cause, large-scale shifts in the health of rivers and streams of the Great Plains region

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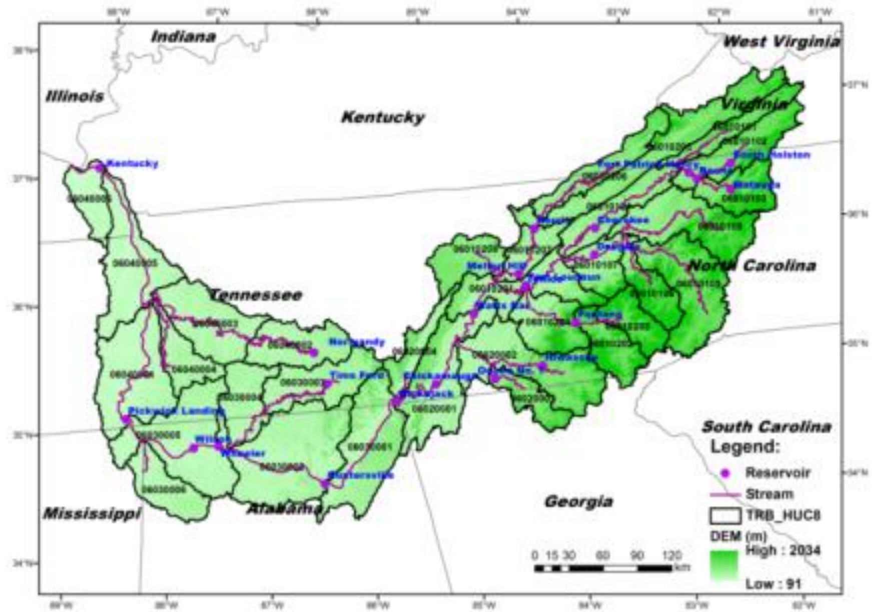
Task A. Regional Opportunity Assessment

3-Technical Accomplishments
Tennessee River Basin: A region with many reservoirs

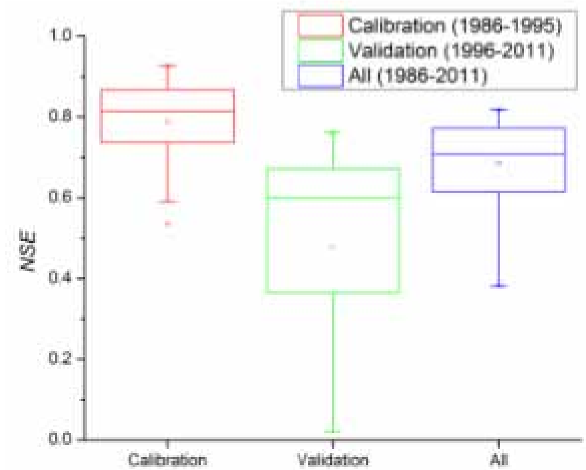
- TVA provided reservoir data
- Simulated 55 sub-basins and 32 8-digit USGS hydrologic unit code watersheds.
- Incorporated optimization / calibration algorithm into SWAT
- Calibrated all subbasins against USGS runoff
  - Spin-up: 1-yr: 1985
  - Calibration: 10-yr: 1986–1995
  - Validation: 16-yr: 1996–2011

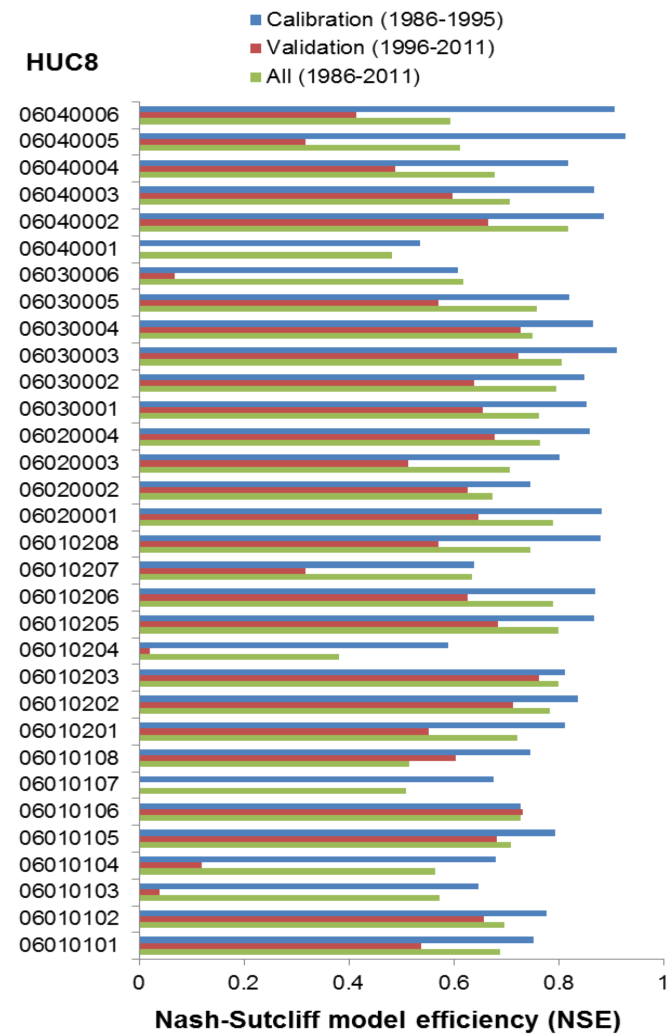
Drainage Area: 105,859 km^2 (40,890 mi^2)



Task A. Regional Opportunity Assessment

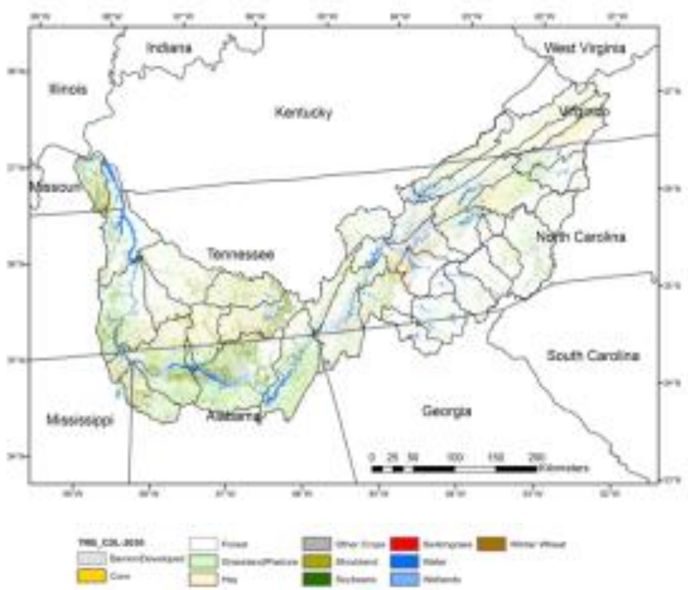
3-Modeled Hydrology for Tennessee River Basin Compared Well with Data

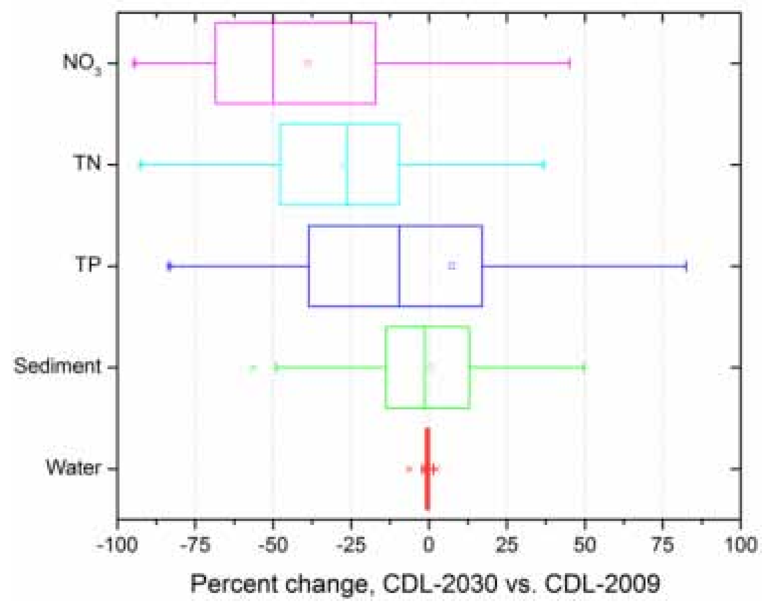


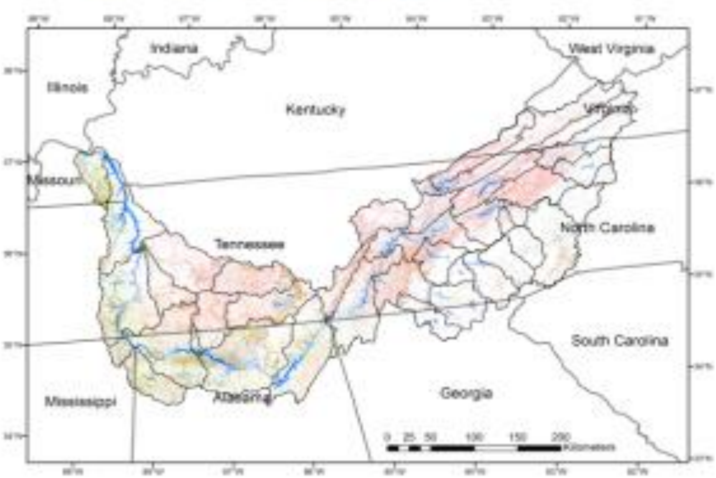


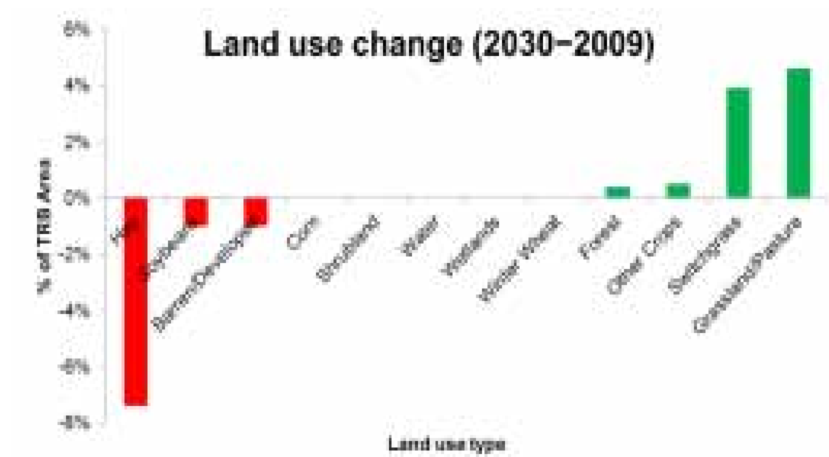
Task A. Regional Opportunity Assessment

3-Technical Accomplishments
Preliminary changes in water quality

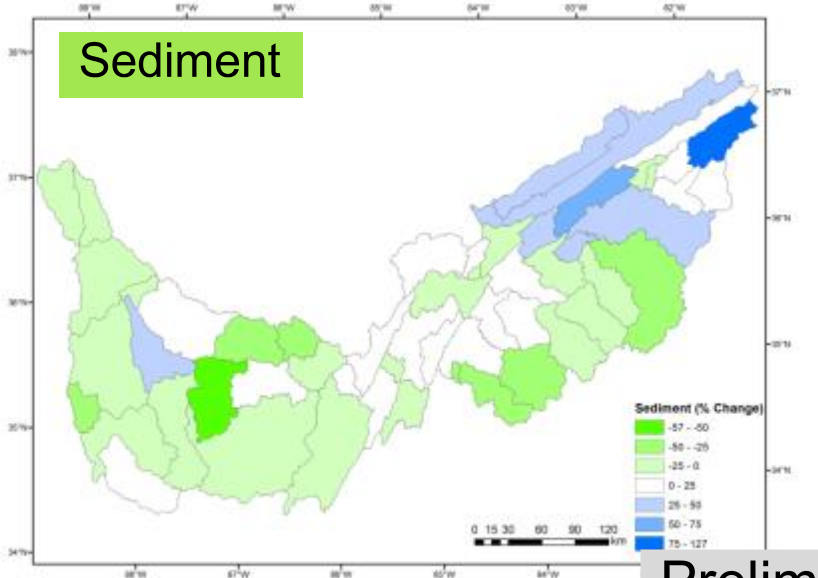


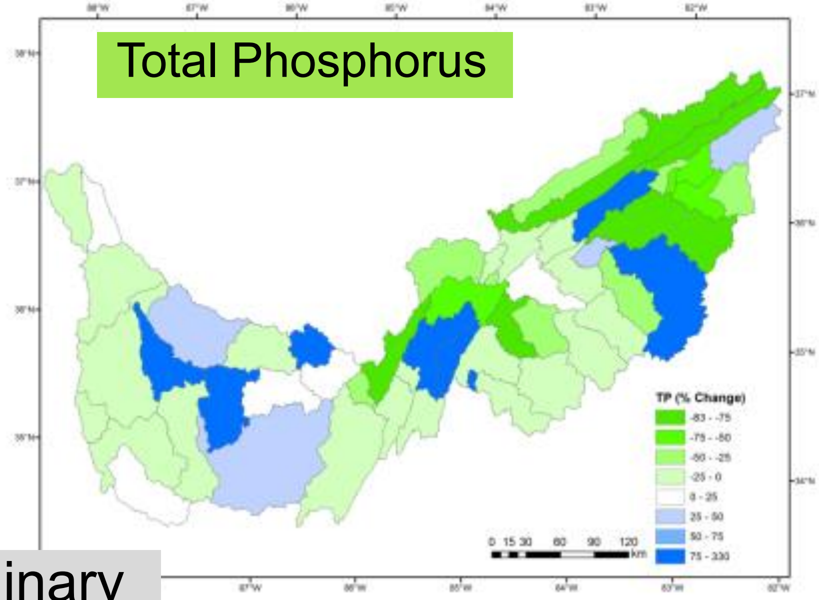




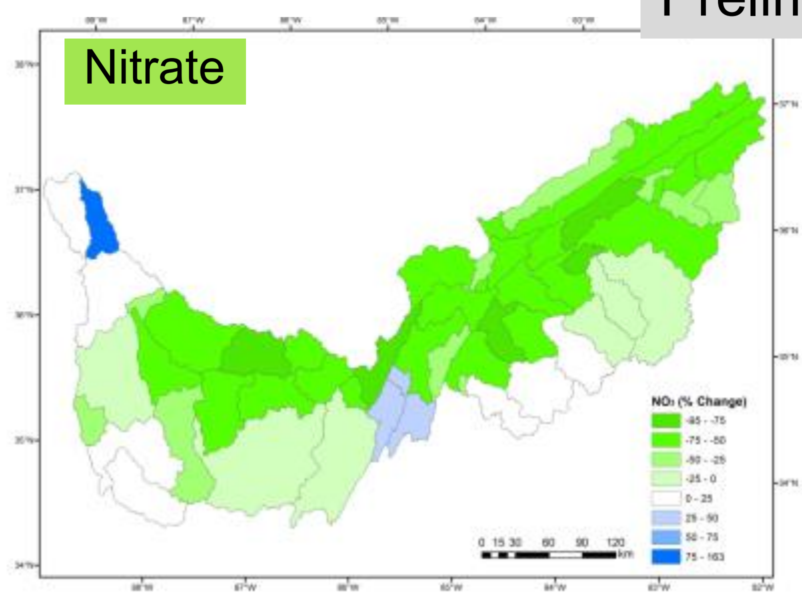


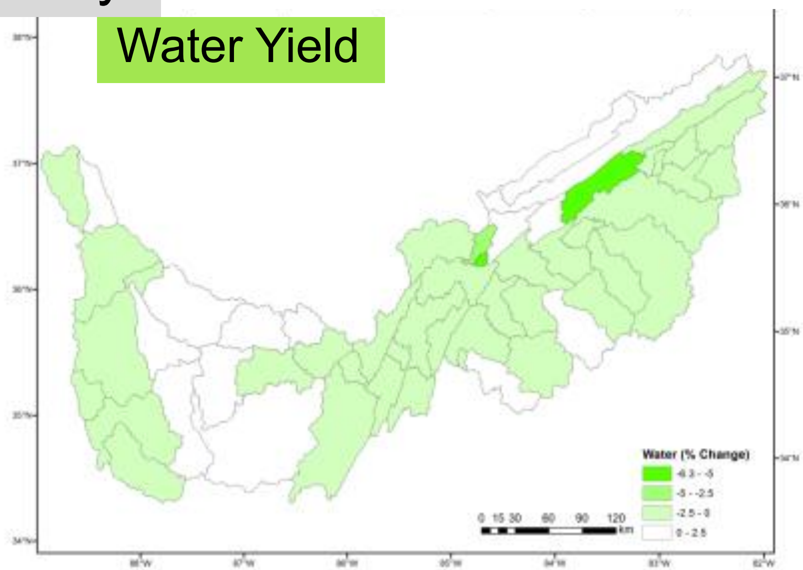
3-Opportunities to Improve Water Quality





Preliminary





3-Technical Accomplishments

FY14 Milestones Task B. Forecasting Biodiversity:

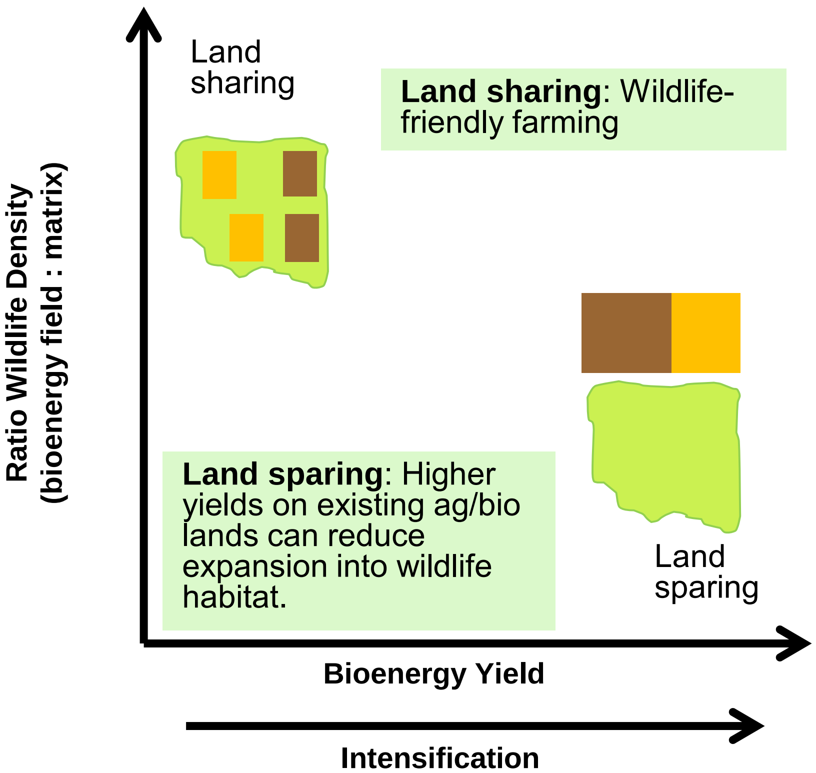
- Bibliography of papers documenting how bioenergy crops influence wildlife. Disseminated via Knowledge Discovery Framework
- Extended outline of a review paper

Additional Products:

- Presentation and Webinar (Watershed Modeling Forum)
- Jager, Krieg, Sutton & Efroymson. "Designing Landscapes to Produce Bioenergy and Wildlife" Will be submitted to Ecology Letters

Task B. Forecasting Biodiversity

3-Technical accomplishments



- Identified wildlife-friendly management practices.
- Identified landscape patterns that promote wildlife. i.e, a land-sparing design is preferred over land-sharing:

1. Intensive crop production
2. Area-sensitive species present
3. Wildlife movement dangerous
4. Wildlife productivity in bioenergy lands << that in surroundings

Tasks B & C. Forecasting Biodiversity & Pathways to Sustainable Landscape Design

3 - South Fork Watershed, Iowa

Task C. Pathways to Sustainable Design

- Visited South Fork Iowa
  - Hosted by USDA
  - Met with S. Fork Watershed Coalition
- Landscape design workshops
  - New Bern, NC, Argonne, IL
- Milestones:
  - Coordination plan (INL & ANL)
  - Evaluation of APEX model
- Management decisions
  - Landscape designs to improve water quality should consider tile drainage

3-Technical accomplishments

'Designing Bioenergy Landscapes to Protect Water Quality' (collaborative publication).

- Spatial decisions about agricultural drainage (Jager, ORNL)
- Spatial decisions about inter-planting (Negri, ANL)
- Spatial decisions about fertilizer application (Sokhansan, ORNL)
- Spatial decisions about harvest and stover removal
- Spatial decisions about riparian buffers
- Spatial decisions about wetland restoration and ponds

Task C. Pathways to Sustainable Design

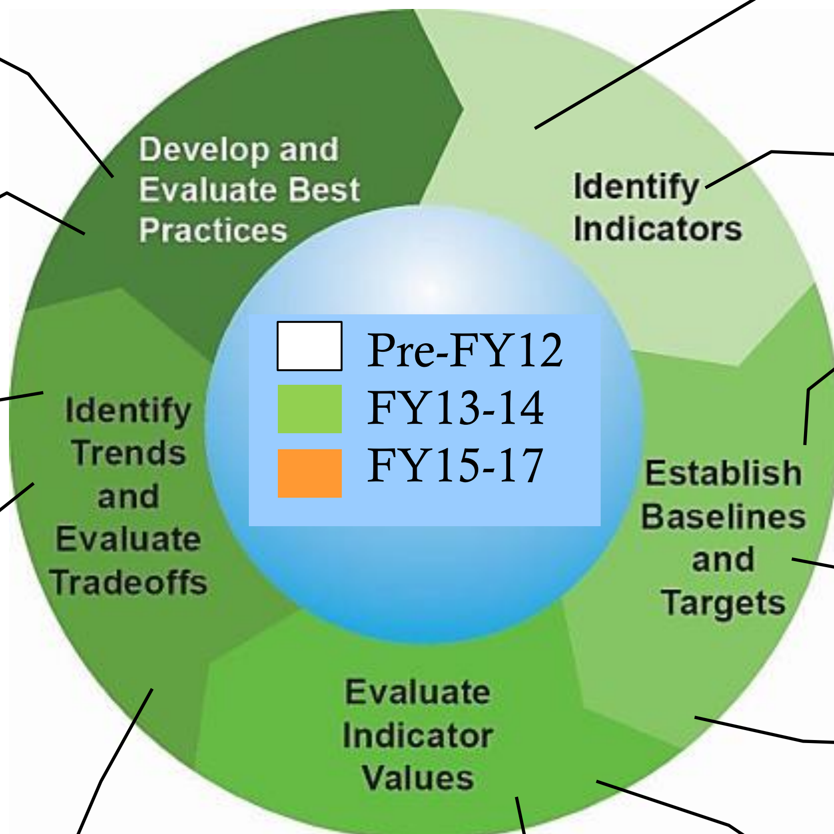
4 - Relevance

BTS: Identify regions where conservation practices are most effective.

Publish spatial design guidelines to promote bioenergy, water quality, biodiversity

Evaluated fertilizer effects on trade-off between water quality and yield for bioenergy crops.

Evaluated tillage effect on trade-offs between water quality and yield for stover crops



Defined water quality indicators (McBride et al 2011)

Tailored water quality indicators for large, regional context.

Established regional-scale water quality baselines, BT2 targets for AWR river basin.

Establishing regional-scale water quality baselines, BT2 targets for Tenn. River basin.

BTS: Defining bio-diversity indicators and assessment methods

BTS: Evaluate crop allocation to promote wildlife diversity

BTS: Evaluate regional-scale water quality & quantity.

BTS: Minimize trade-offs between water indicators and feedstock supply.

BTS=Billion Ton Sustainability

4-Relevance

Project addresses the following MYPP BETO goals:

- Advance scientific methods and models for measuring and understanding bioenergy sustainability [across the supply chain].

  This project has developed regional-scale modeling methods for measuring and understanding trade-offs and complementarities between cellulosic feedstock production and water quantity and quality indicators. Previously, we developed methods for assessing aquatic biodiversity indicators. For BTS, we are developing methods for assessing terrestrial biodiversity for endpoints of interest to the public.

- Develop landscape design approaches that increase bioenergy production while maintaining or enhancing ecosystem and social benefits.

  Two synthesis papers (in progress) will provide guidelines for sustainable bioenergy landscape design, one focusing on water quality and the other on biodiversity (wildlife).

4 - Relevance

Project addresses the following MYPP BETO goals (cont.):

- Understand and promote the positive economic and environmental effects of biofuels production activities.

  We identified spatial win-win opportunities to improve water quality where cellulosic crop is economically viable in AWR region. We are finding similar opportunities in the Tenn. River basin.

- Assess current and future environmentally sustainable biomass availability, and
- Increase the volume of sustainable, quality feedstock available.
- Highlight the role that a thriving bioeconomy plays in benefitting the environment.

  For BTS, we are evaluating ability to benefit wildlife and water quality while providing economically sustainable future biomass. This addresses three MYPP goals above.

5-Next steps

FY15-17 Tasks

Gulf of Mexico / Regional Opportunity Assessment

- Complete Tennessee River Basin, FY15
- Integrate ORNL and Argonne subbasins
- Bioenergy => Water quality & quantity => aquatic biodiversity

Billion Ton Sustainability

- Quantify sustainable feedstock production
- Minimize trade-offs: productivity & water quality
- Distribute feedstock production to enhance biodiversity

Pathways to Sustainable Design

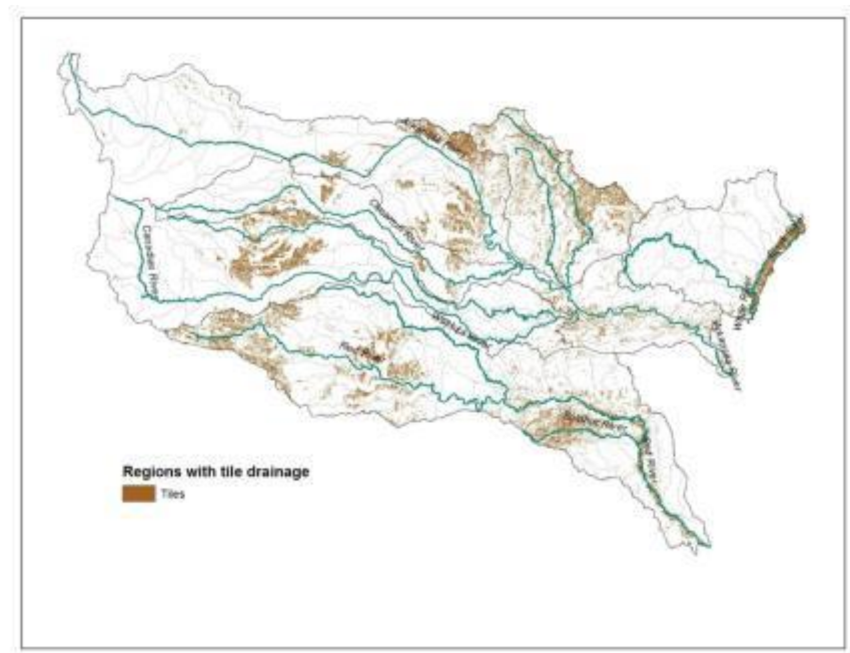
- Assess feasibility of representing tile drains.
- Design optimal harvesting guidelines for wildlife

5-Next Steps

Continue progress in representing linkages between feedstock production and water quality

Miscanthus as a feedstock in the next Billion Ton Report

Role of tile drained areas as sources of nutrients and sediment

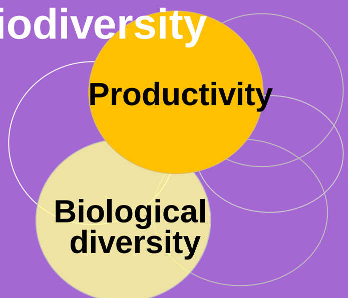


5-Next steps

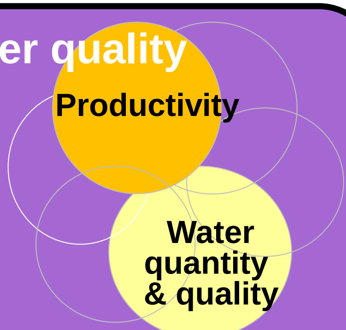
Billion Ton Sustainability

1. Feedstock supply

2. Biodiversity



3. Water quality



1. Maximize **biodiversity** (habitat for wildlife species of concern) while **producing** BT16 levels of feedstock supply.

2. Minimize trade-offs between **production** and **water indicators** (quality & quantity) via smart spatial allocation of conservation practices (Fertilizer, Tillage, Cover crop. Stover removal, Mitigation of artificial drainage)

5-Next steps

Billion Ton Sustainability (Biodiversity)

National-scale wildlife presence data

Relative densities of wildlife in other v. bioenergy lands

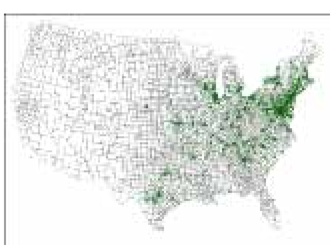
County-level BT16 future feedstock production

Model current species distributions based on climate & current landuse

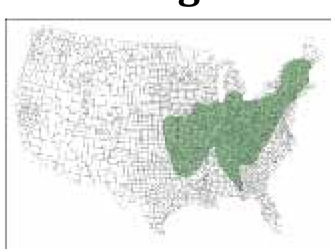
Estimate model coefficients for future bioenergy crops.

Maximize wildlife habitat for CLU parcels, while maintaining BT16 feedstock production

Species records

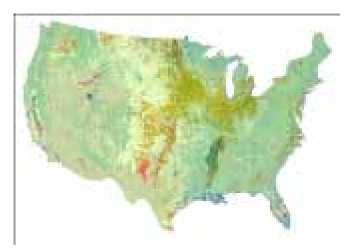


Species range



Environmental covariates

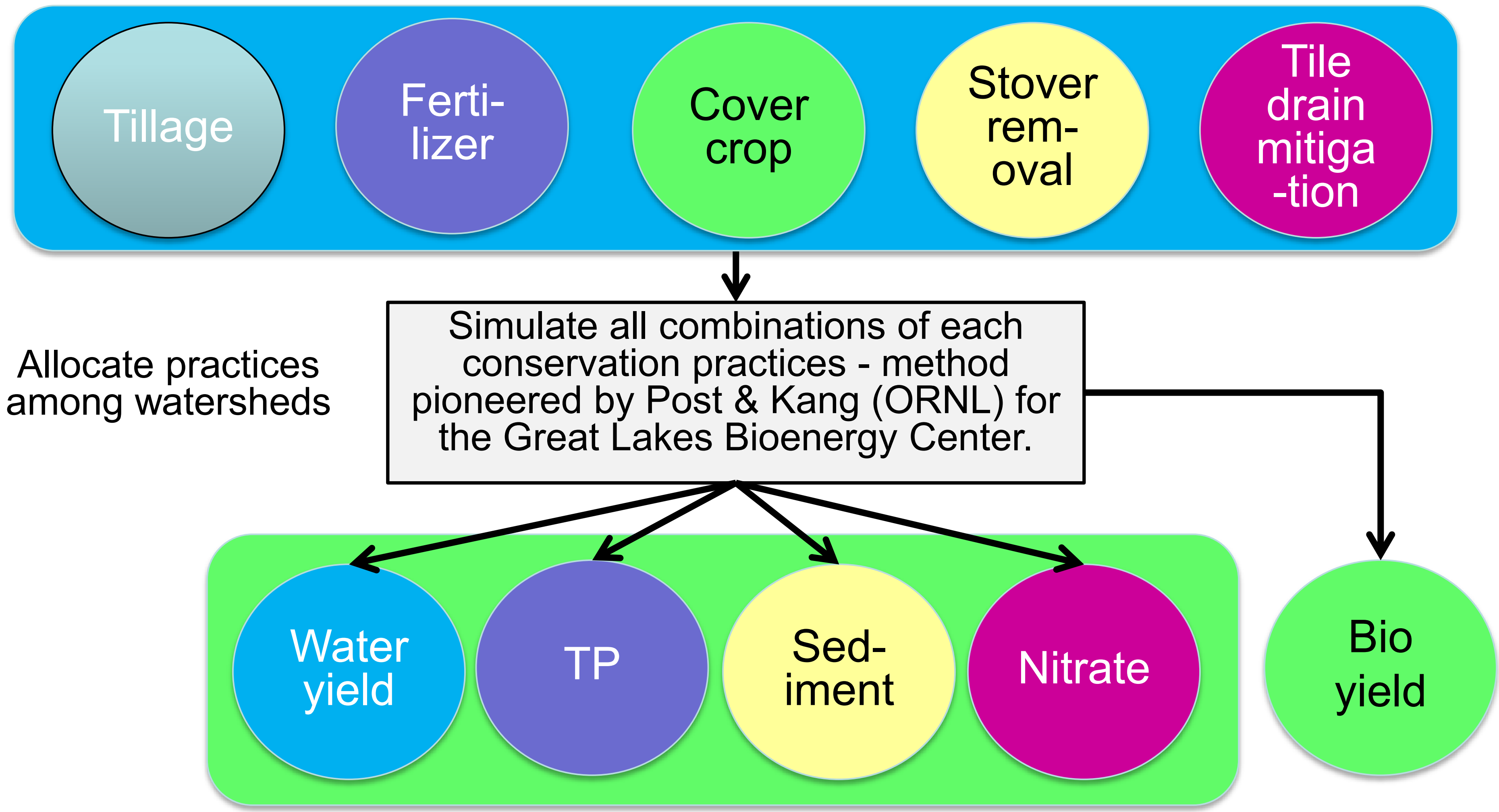
Land use



Social covariates

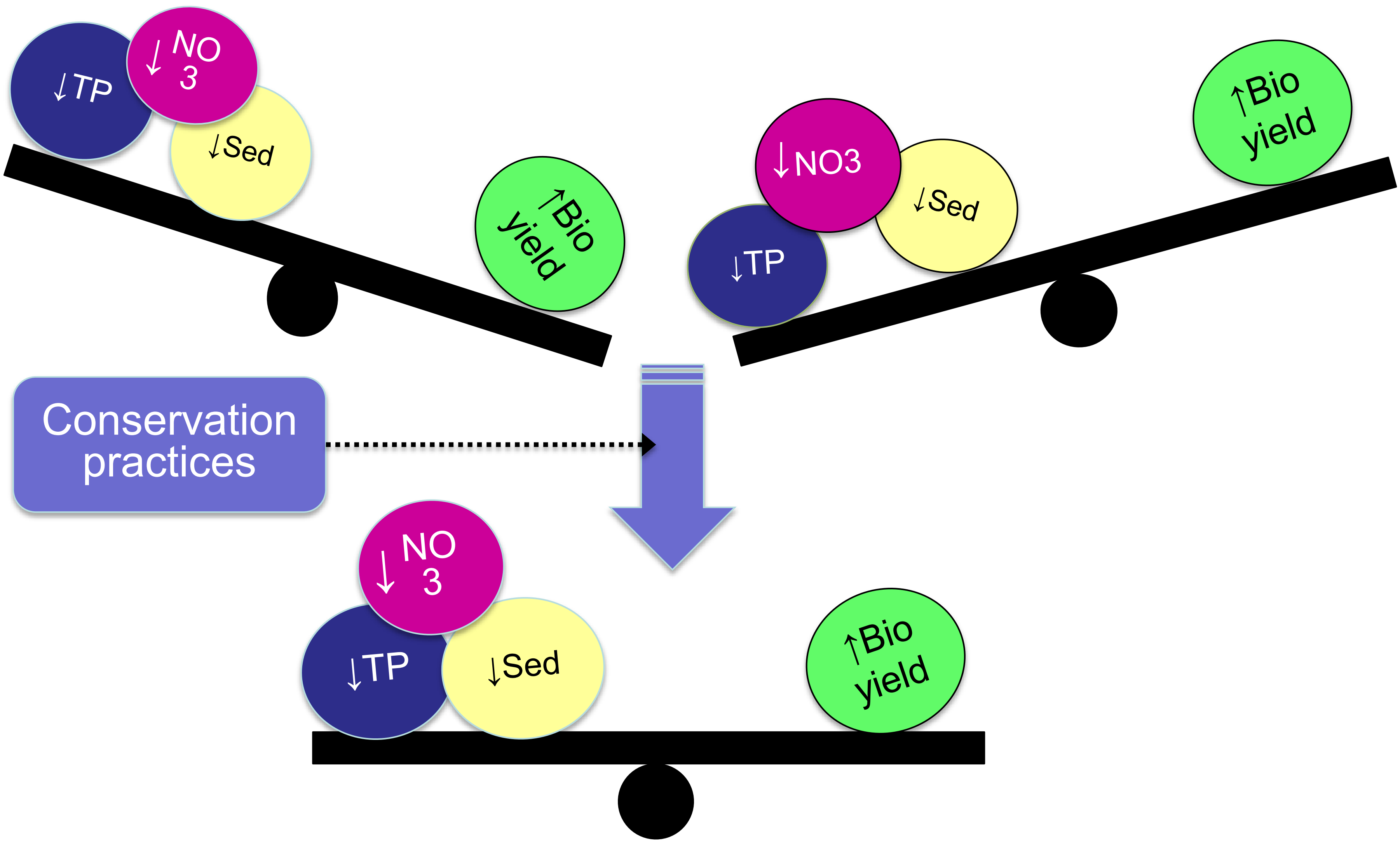
5-Next steps

Billion Ton Sustainability (Water indicators)



5-Next steps

Minimize trade-offs between loadings & biomass yield



6-Summary

Criterion	Project approach
Approach(es)	Regional-scale river-basin modeling to support decisions (e.g., when and where to plant crops and apply conservation practices) to promote increased sustainability as measured by indicators for feedstock production, water quality, water quantity, and biodiversity
Technical accomplishments	▪ Demonstrated and published median decreases in nutrient and sediment loadings in Arkansas-White-Red river basin ▪ Preliminary Tennessee River basin results also show median mproved water quality ▪ Two manuscripts describing landscape design principles are in progress
Relevance	Increase acceptance of bioenergy by: ▪ Finding win-win opportunities for water quality improvements in river basins ▪ Demonstrating how spatial decisions (conservation practices, crop placement) can promote wildlife and water indicators with minimal reductions in feedstock supply (BTS)
Critical success factors & challenges	▪ Working at a large, regional scale ▪ Integration with other labs ▪ Short timeline for Billion Ton report
Future work	▪ Complete Tenn. River basin ▪ Gulf of Mexico loadings and basinwide biodiversity assessment ▪ Support Billion Ton Sustainability effort
Technology transfer	Disseminated results via organized sessions, reports (e.g., BTS), & scientific publications

Additional Slides

Progress FY13 – FY14+

Publications (in progress)

- Jager, HI, E. Parish, L. Baskaran. In progress. Ecosystem sustainability of perennial grass-based biofuel production in southern landscape in the U.S. In Webber and Wu, eds. Current Sustainable/Renewable Energy Reports.
- Jager, HI, RA Efroymson. In progress. Designing landscapes to produce bioenergy and wildlife habitat.
- Jager, HI, J. Kreig, C. Negri, H. Ssesane, I. Chaubey, M. Tomer and others. In Progress. Designing bioenergy landscapes to improve water quality

Publications (accepted or published)

- Jager, HI, LM Baskaran, PE Schweizer, A Turhollow, CC Brandt, and R Srinivasan. In Press, Feb. 2015. *Forecasting changes in water quality in rivers associated with growing biofuels in the Arkansas-White-Red river drainage, USA*. Global Change Biology: Bioenergy.
- Ridley, CE, HI Jager, RA Efroymson, C Kwit, DA. Landis, ZH Leggett, DA Miller, CM Clark. 2013. *Debate: Can bioenergy be produced in a sustainable manner that protects biodiversity and avoids the risk of invaders*? Ecological Society of America Bulletin 94(3): 277-290.

Progress FY13 – FY14+

Reports

- Baskaran, L.M., H.I. Jager, A. Turhollow, and R. Srinivasan. 2014. *Understanding shifts in agricultural landscapes: context matters when simulating future changes in water quantity and quality*. ORNL/TM-2013/531, Oak Ridge, TN.
- Wang, Gangsheng, et al. 2014. *Hydrologic Modeling of the Tennessee River Basin.* ORNL/TM-2014/566. Oak Ridge, TN

Progress FY13 – FY14+

Presentations & Posters

- Wang, G. et al. March, 2015. *Hydrologic Modeling of the Tennessee River Basin*. 4th Annual Watershed Symposium. University of Tennessee, Knoxville.
- Langholtz, M., R. Efroymson, H. Jager. Jan, 2015. *Billion Ton 2016*. Presentation to Center for Bioenergy Sustainability, Oak Ridge, TN
- Jager, HI. Nov. 17, 2014. *Designing Bioenergy Landscapes for Wildlife*. Webinar presentation to BETO Hydrology/Water Quality Modeling Forum.
- Jager, HI. et al. April, 2014. *In Search of Spatial Opportunities for Sustainable Bioenergy Production*. Presentation to Center for Bioenergy Sustainability, Oak Ridge, TN
- Jager, HI, et al. 2014. *Pathways to Sustainability: Designing Bioenergy Landscapes to Improve Water Quality & Biodiversity*. South Fork, Iowa
- Gorelick, D., HI Jager, LM Baskaran. 2014. *Spatial optimization of bioenergy feedstock introductions in the Arkansas White-Red River Basin: trade-offs between nutrient loadings and farm profit.* ORISE Student Poster session. Oak Ridge, TN.
- Smedsmo, J L., et al. July 25—27, 2013. *The sustainability of cellulosic biofuel crop production in a changing climate.* 2013 Annual Program Review / DOE Computational Sciences Graduate Fellows Poster Session, Arlington, VA, Virginia, USA.

Responses to Previous Reviewers' Comments

Comment: *A better understanding of the watershed impacts of bioenergy seems like necessary work to support BETO's efforts. Beginning to transition from estimation of impacts to prioritization and protection of sensitive areas is important. This project offers the potential to conduct improvement analyses to determine the places most sensitive to changes in management practices and the extent of water quality improvements possible.*

Our BTS effort seeks to identify where different types of conservation practices are most needed and to quantify potential water quality improvements associated with implementing these practices where they are most needed.

Comment: *This effort made good use of the Billion-Ton Update scenarios to better understand the water quality and biodiversity impacts. Its focus on the optimization of planting and BMPs selection is a strength. Collaboration is likewise a strength, but could be made more robust by coordinating with other optimization efforts regarding the criteria, tools, and ability to inform user decisions.*

Our efforts are tightly integrated with the BTS resource assessment. We have also invited other lab partners to contribute to a synthesis paper that summarizes guidelines for spatial decisions relevant to bioenergy production and water quality to help inform decisions, and working collaboratively with May Wu (Argonne) on a special issue..

Responses to Previous Reviewers' Comments

Comment: *This is an interesting project where results and project outcomes will be optimized when viewed through the lens offered by the complementary SWAT modeling projects, which extend down to the field scale and up to the scale of the greater Mississippi River watershed. This should include standardized approaches or best practices and sensitivity analyses for model calibration/validation to strengthen the overall portfolio of results. For BETO to realize the best return on their water quality modeling investment, Sustainability and Analysis SWAT PIs should be encouraged and facilitated in an active collaboration with an eye toward linking to the broader USDA and academic communities dedicated to water quality modeling.*

In response to this, BETO Pis have participated in a Watershed Modeling and Landscape Design Forum over the past year. The purpose of the forum has been to coordinate our efforts and allow us to share methodologies and results. In addition, several Pis are collaborating on a manuscript summarizing spatial design principles for water quality.

Responses to Previous Reviewers' Comments

Comment: *This project developed good tools to develop a biofuel feedstock strategy that has a positive impact on water quality. The team developed a detailed model with good spatial resolution. Expansion of approach to other river basins and dissemination of findings will be critical to fully capture the value created by this project.*

We have made considerable progress toward implementing a similar analysis in the Tennessee River Basin. Our plan, with Argonne, is to begin the full Gulf of Mexico assessment in FY16.

Comment: *There seems to be a case to be made that the choice of watershed (AWR basin) makes sense from the vantage point of potential for switchgrass production, but there was little context for understanding the ultimate value of achieving 10% changes in nutrient release (as determined in this project) in the larger context of the Mississippi River watershed, nor how much bioenergy production is represented in this area.*

Agriculture in the corn belt contributes the majority of nitrate and phosphorus to the Gulf of Mexico (e.g., Upper Mississippi River basin). However, the opportunities to reduce nutrient impacts may be stronger in regions where perennial feedstocks will be economically viable (e.g., AWR & TRB).