Forecasting Water Quality and Aquatic Biodiversity

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http://www.esd.ornl.gov/~zij/

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Oak Ridge National Laboratory

2011 Platform Review

Annapolis, MD

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Goal

Answer question: *"Will EISA targets for 2nd generation bioenergy crops maintain/improve water quality and aquatic biodiversity?"*

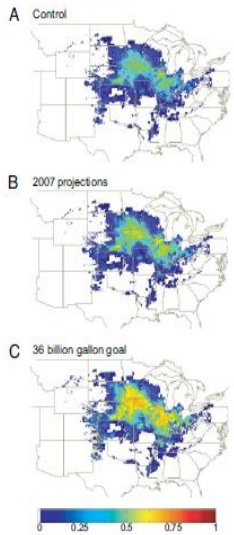

Fig. 2. Fractional area of each 5′ × 5′ grid cell planted in corn in the 2004–2006 control (*A*), the 2007 projections (*B*), and the 36 billion gallon goal scenario (*C*). The area is expressed as a fraction of the total grid cell area.

Donner and Kucharik

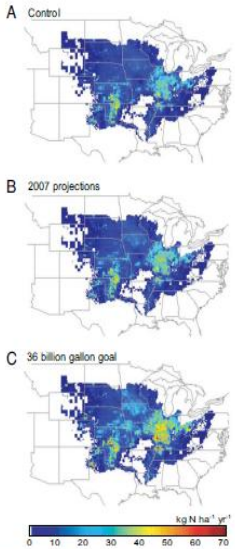

Fig. 5. Simulated dissolved inorganic nitrogen leaching (kg·ha^{-1}·yr^{-1}) from land across the Mississippi–Atchafalaya River Basin in the 2004–2006 control (*A*), the 2007 projections (*B*), and the 36 billion gallon goal scenario (*C*).

Our water quality research builds on Donner '03, Nelson et al. '05:

- River basin-wide US assessment
- Improved hydrologic & geochemical modeling of terrestrial-aquatic interface
- Represents EISA mandates for 2nd generation feedstocks

No previous research of changes in aquatic biodiversity. A recent PNAS study of bird richness used a similar approach.

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Project Overview - I

History

- Project commenced in FY09. ORNL focus on Arkansas-White-Red river basin:
  - High potential for cellulosic perennial (switchgrass) production
  - Successful fish biodiversity modeling efforts to build on.
- DOE expressed interest in understanding effects of bioenergy crop production on the Gulf of Mexico dead zone.
- In late 2010, we joined forces with Argonne to quantify these relationships for the entire Mississippi River basin. Collaboration promises several benefits.

ORNL-ANL Mississippi River basin-scale collaboration

Project Overview - II

ORNL Team

This project

- Latha Baskaran, geographer and watershed modeler
- Peter Schweizer, post-doc fish biologist

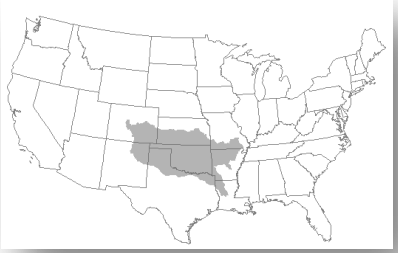
Integration with Resource Analysis project

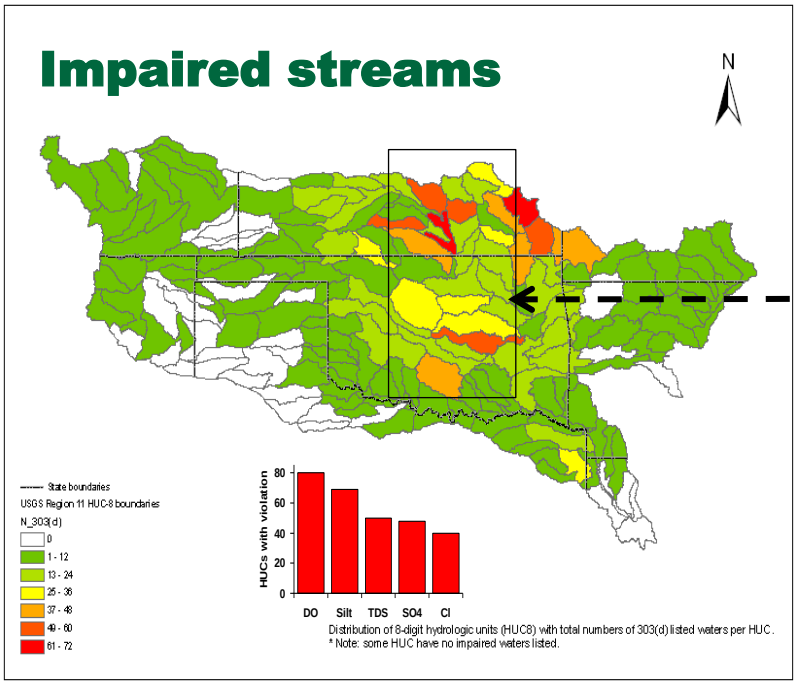
- Craig Brandt, statistician, data downscaling
- Laurence Eaton, resource economist, POLYSYS liason
- Bob Perlack, PI, agricultural & resource economist

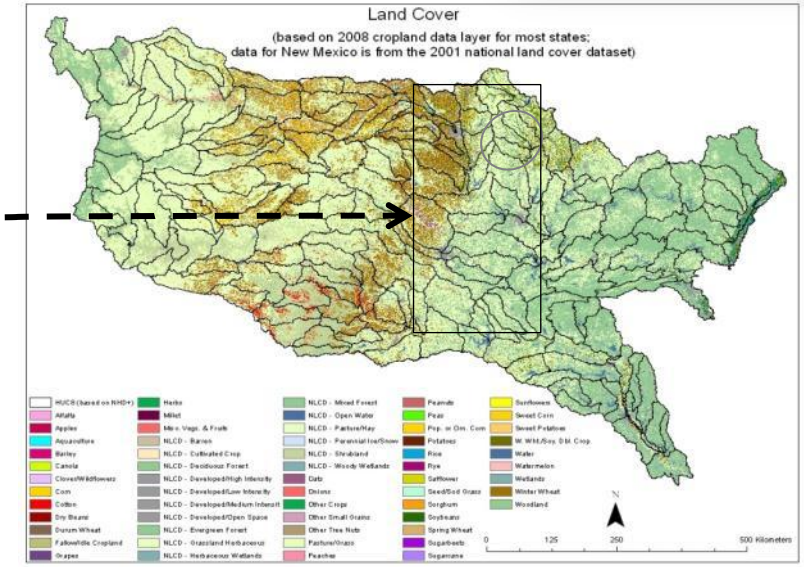
Coordination

- Robin Graham, forestry, bioenergy, biomass program manager

Project Overview - III







Winter wheat
Grass-shrubland-pasture
Forest
Corn
Other crops

Hypotheses

Where switchgrass replaces agriculture

- Nutrient inputs to streams will decrease
- Sediment input to streams will decrease
- Fish diversity will be maintained or increased

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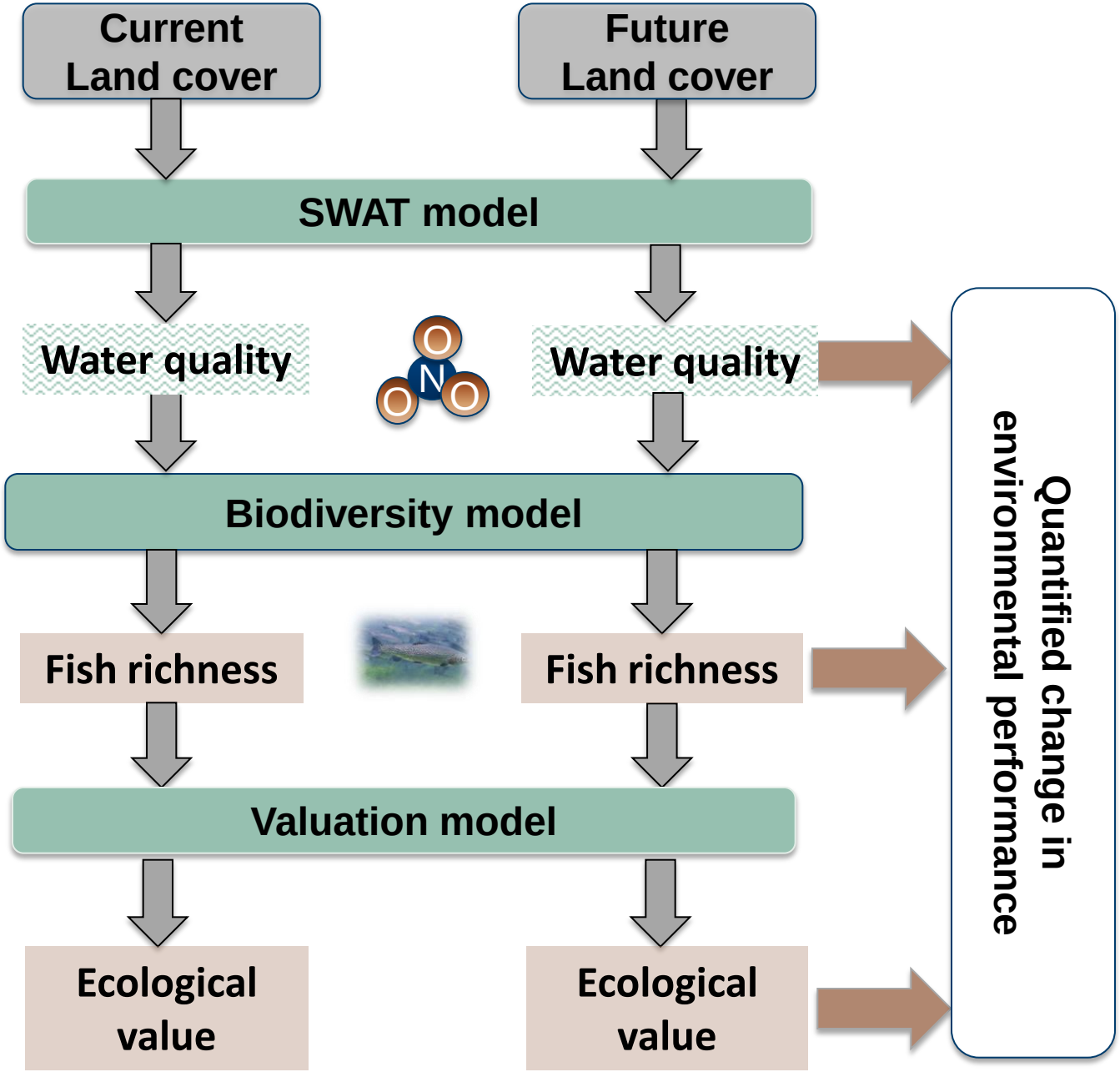
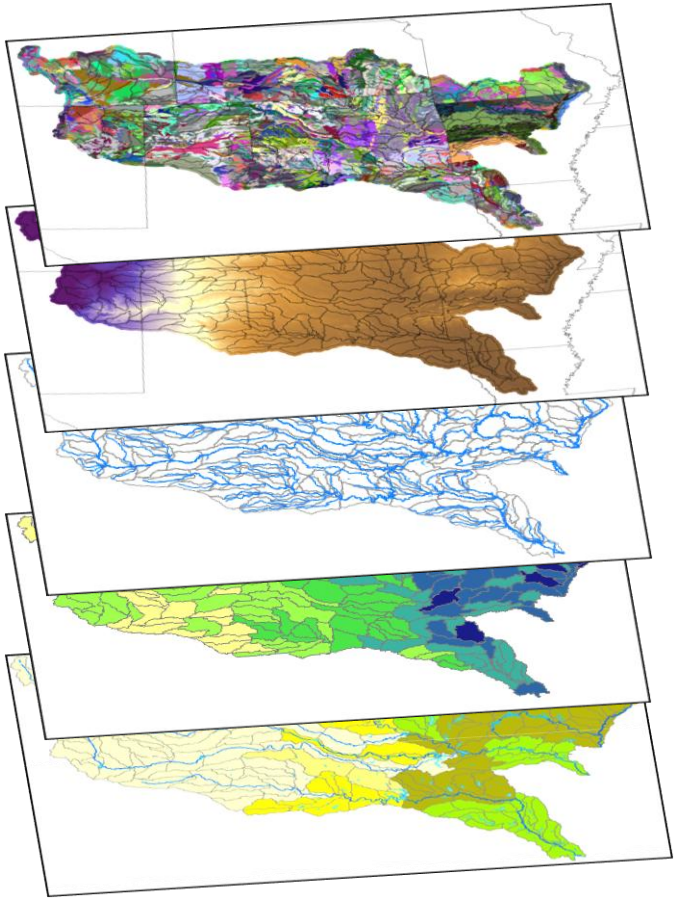
Approach


Current Land cover
Future Land cover
SWAT model
Water quality
Water quality
Biodiversity model
Fish richness
Fish richness
Valuation model
Ecological value
Ecological value
Quantified change in environmental performance

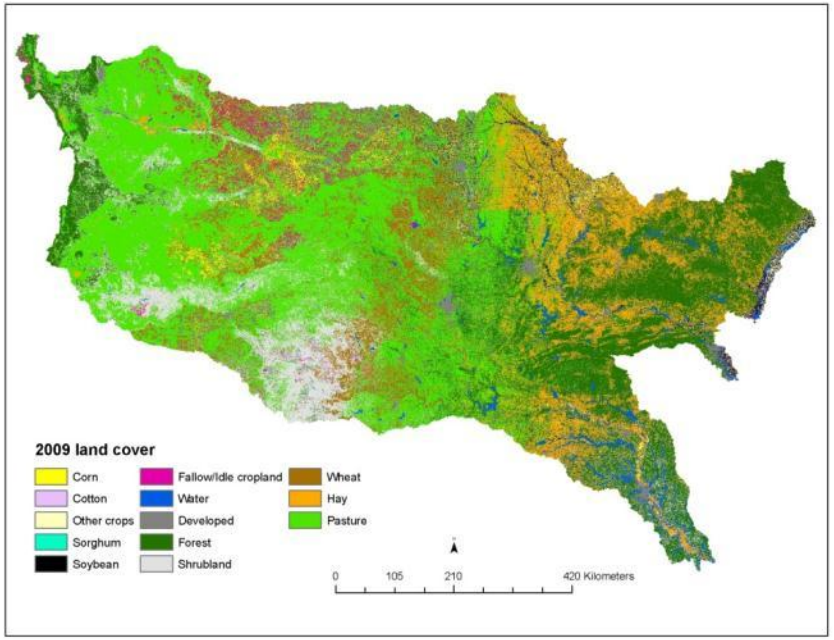
Technical Accomplishments

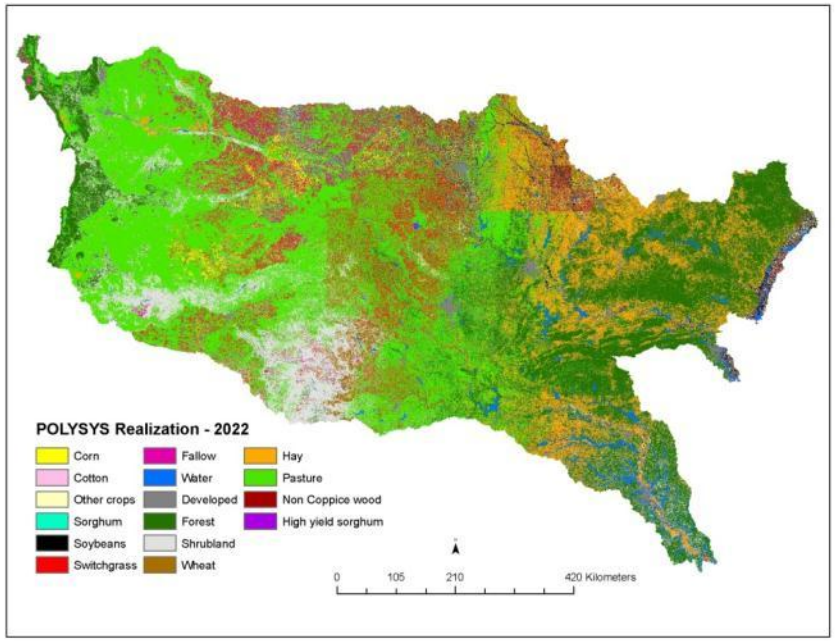
1. OBP-POLYSYS futures
2. River-basin modeling
3. Fish biodiversity modeling
4. Ecological valuation



1. OBP-POLYSYS Futures

EISA Scenario:
$50 farmgate price for switchgrass
1% annual yield increase





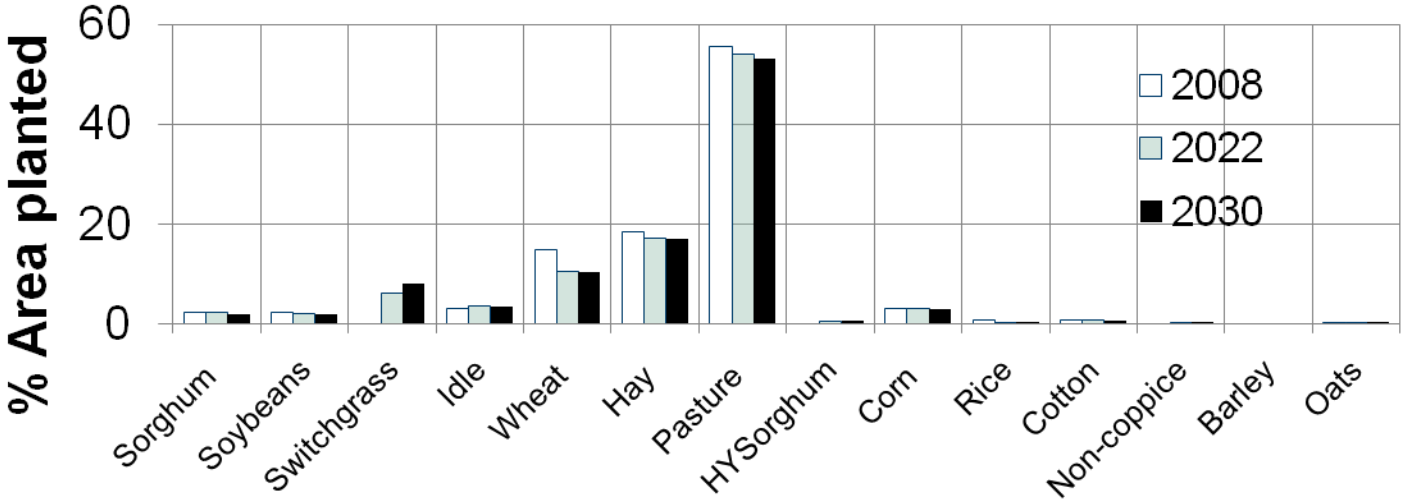
Our approach depends on comparing environmental performance of pre-cellulosic-bioenergy landscapes with that of future bioenergy landscapes.

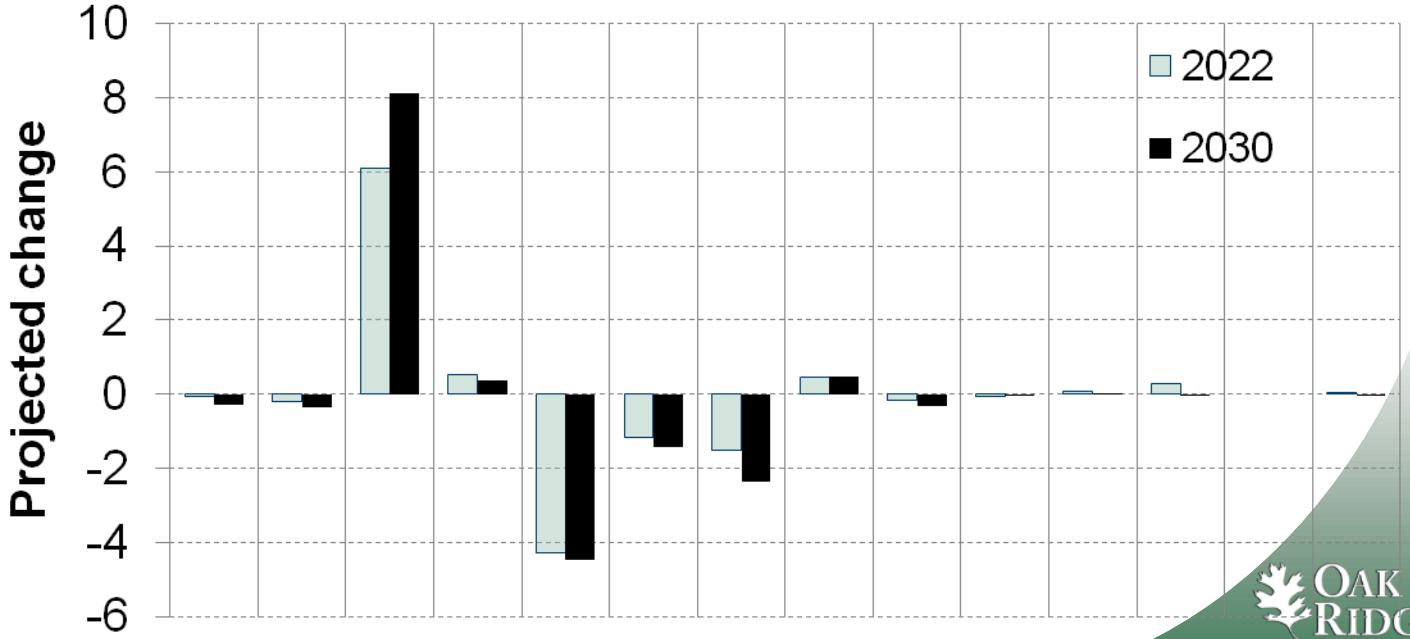
We developed a method for downscaling county-level OBP-POLYSYS forecasts to 56-m pixels using county-level transition probabilities.

1. OBP-POLYSYS Futures

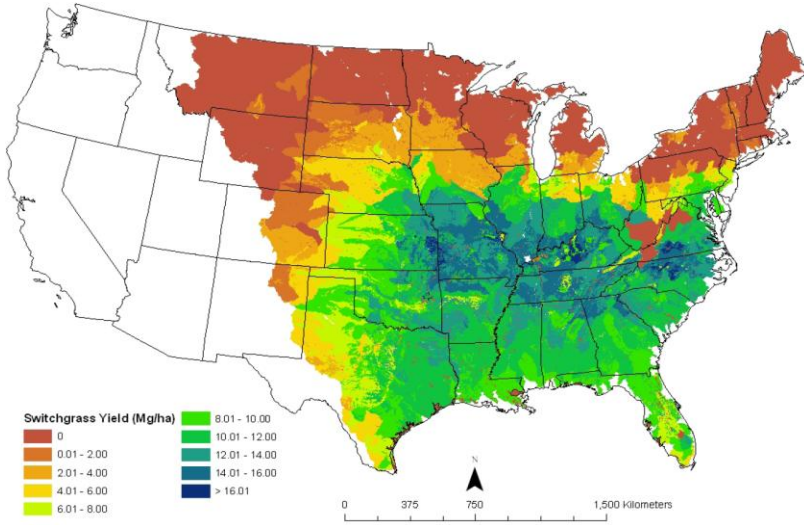
Switchgrass replaced pasture, hay, & wheat

- ***$50 farmgate price for SWG***
- ***1% annual yield increase***





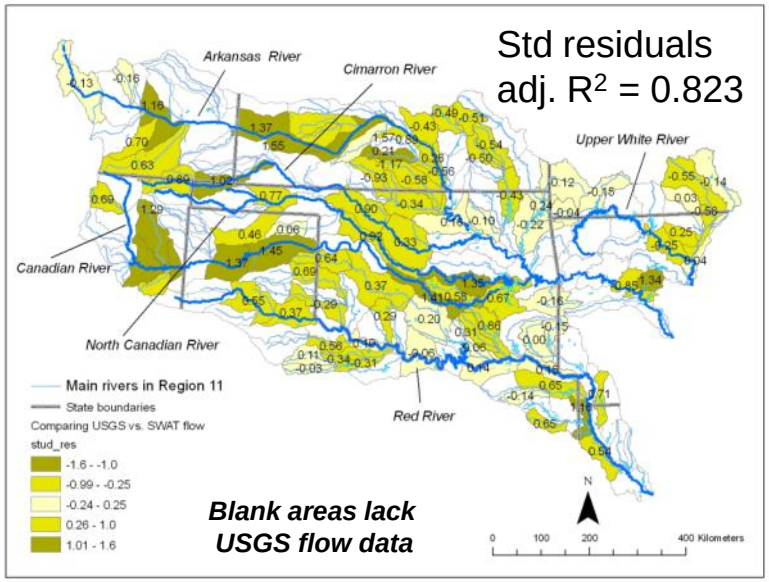
2. River-basin Modeling

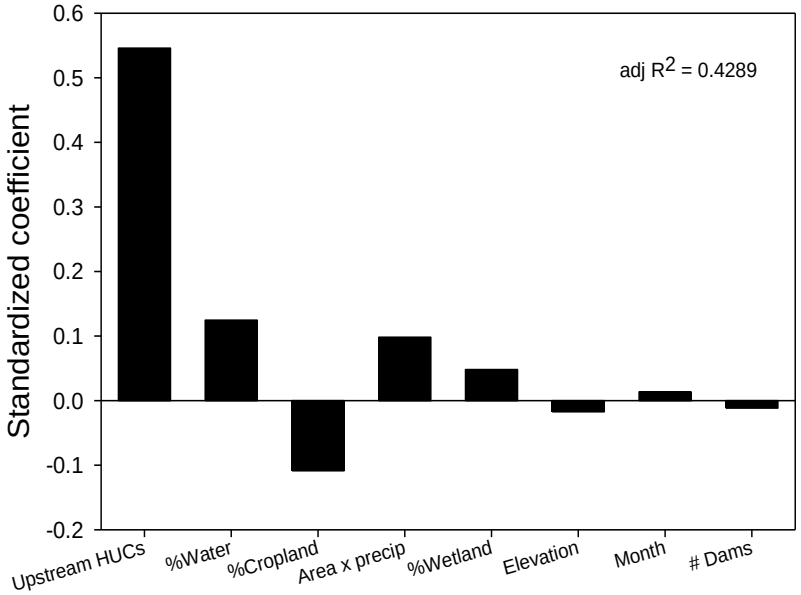


Crop type	Current	Alternative futures
Cellulosic bioenergy	None	Rotations Fertilizer specified Specified %no-till
Conventional	No stover removal Lower %no-till	Stover removal Higher %no-till
Pasture	Fertilized	Intensification

2. River-basin Modeling

Constructive validation of SWAT showed agreement with measured flows.

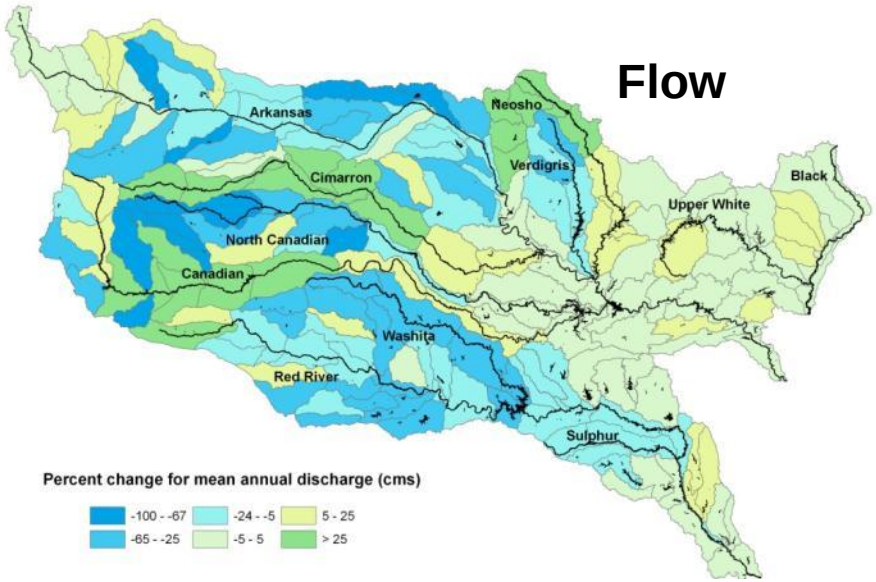


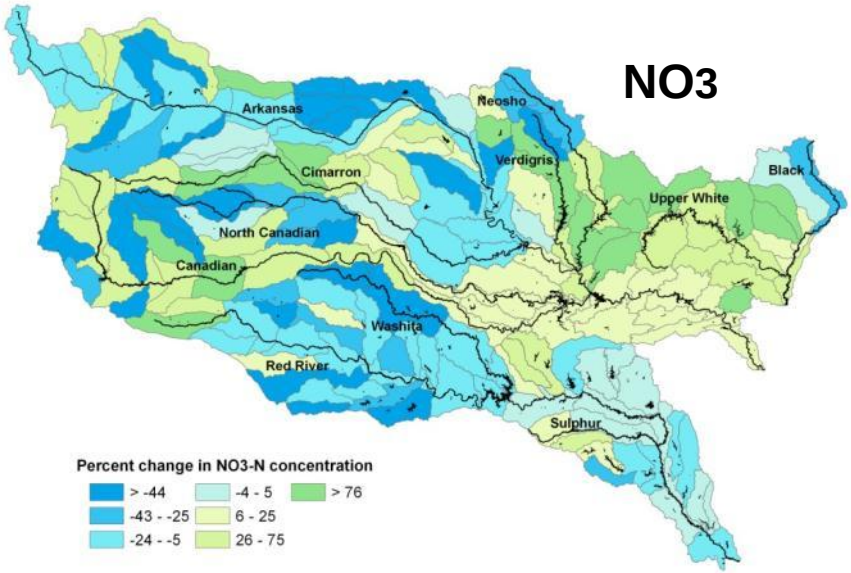


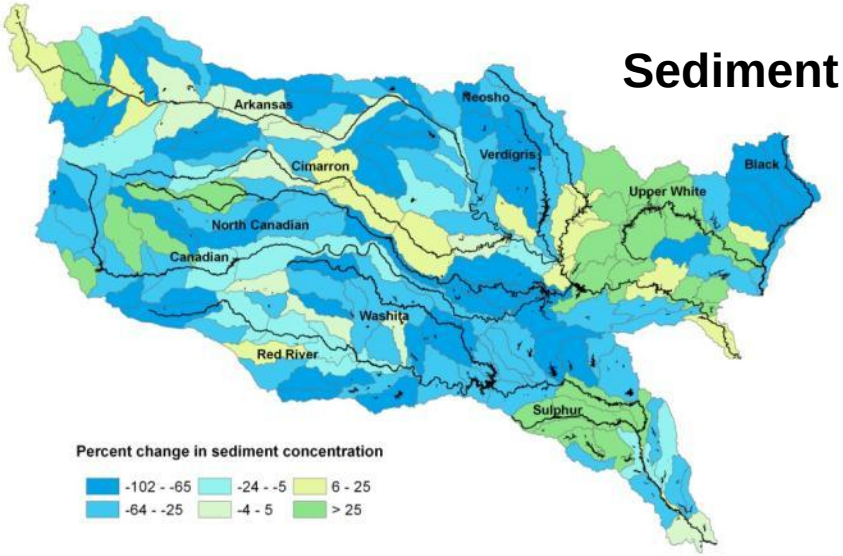
- SWAT-predicted and observed USGS monthly river flows, all residuals <2 SD from 0. See Baskaran et al. 2010.
- Patterns in residuals: SWAT predicted best in watersheds with cropland, worst in downstream subbasins, hi %water. Largest residuals (dark) along Canadian and upper Arkansas mainstems.
- We have assembled water quality data from 16 gages.

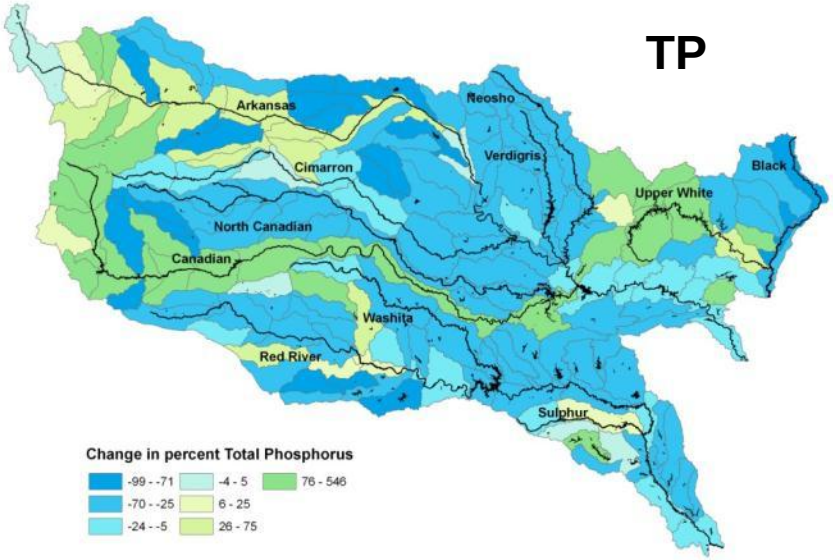
2. River-basin Modeling

Sediment, TP, and NO3 decreased on average (increases in some subbasins)



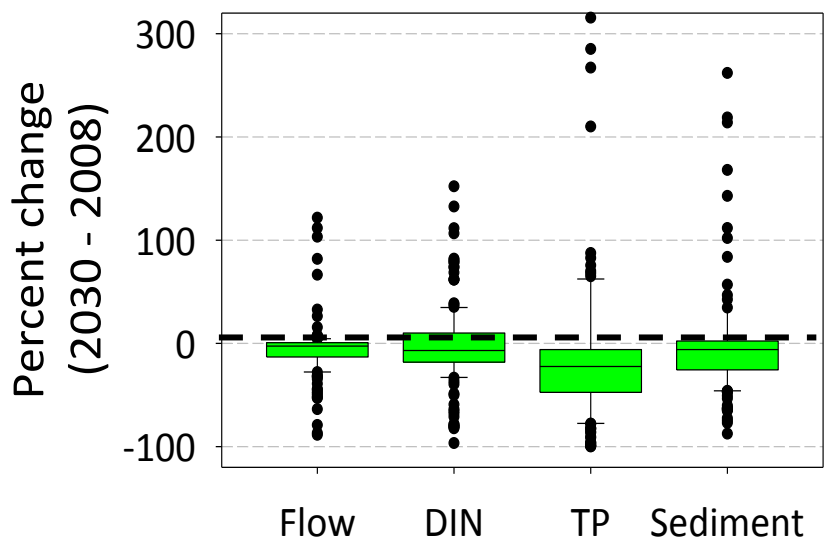


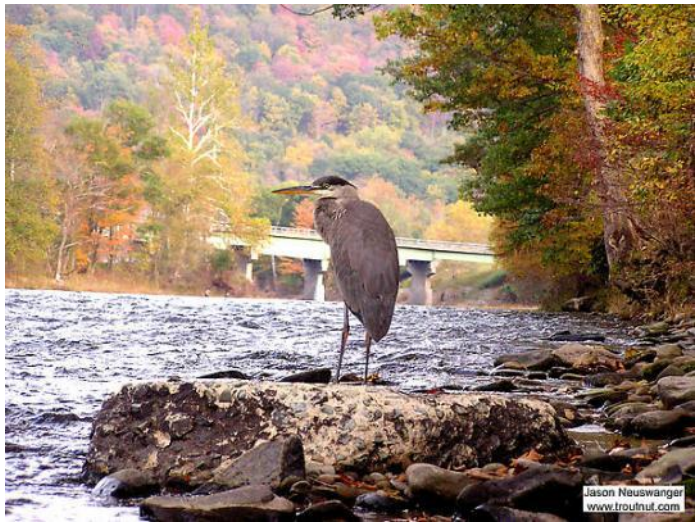




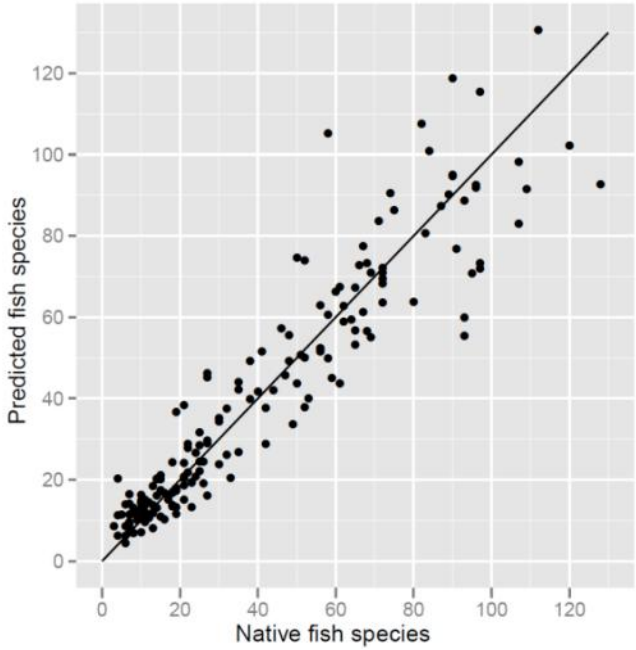
2. River-basin Modeling

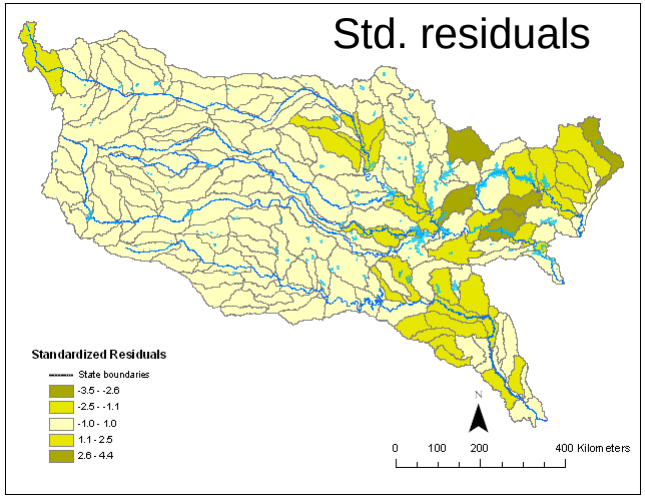
Water quantity	Overall decrease Increase where switchgrass replaced agriculture Decrease where switchgrass replaced pasture/hay
Sediment	Overall decrease Increase where pasture/hay was replaced
Nitrate	Overall decrease Increase where pasture/hay was replaced
Total phosphorus	Overall decrease (correlated with sediment)





3. Fish Biodiversity Modeling





- **Fish Richness = F(subbasin, flow, elevation, TP, %forest, %shrubland, sediment, NO_3, # dams)**
- **Results will help to identify performance goals for 2nd generation energy crops that prevent loss of fish diversity. (MYPP goal 2.6.2)**

Schweizer, PE & HI Jager. Accepted. Modeling regional variation in riverine fish biodiversity in the Arkansas-White-Red River basin. Transactions of the American Fisheries Society.

4. Ecological Valuation

What is the relationship between fish richness and fishing activity?

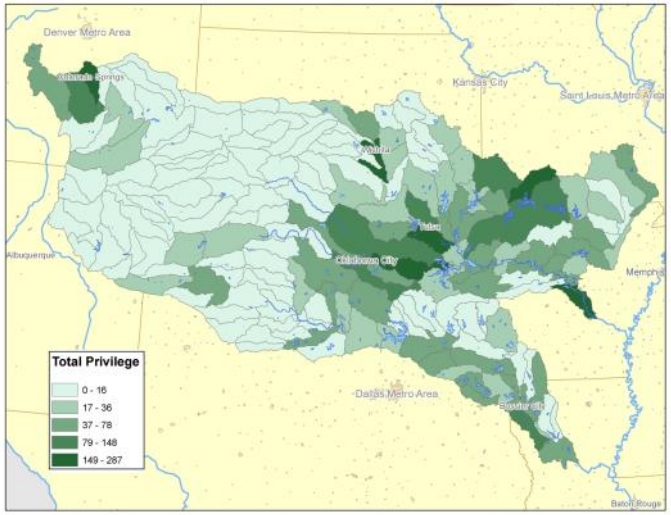
- **Compiled data on activity days and license sales**
- **Modeled activity days in each HUC8 based on:**
  - **Biophysical final goods**

    (lakes, rivers with high quality water/habitat)
  - **Ecological final goods**

    (total or game fish richness – highly correlated)
  - **Capital infrastructure or access**

    (roads, human population)

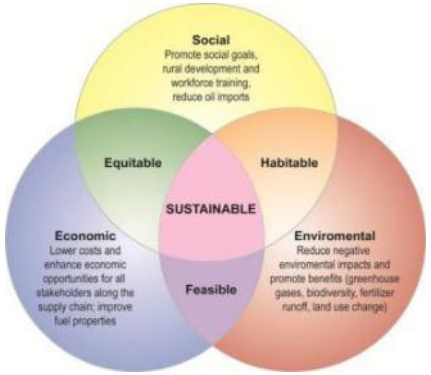
Parameter	Estimate	P
Intercept	9.5127	<.0001
Human population	0.0017	0.0943
# Game fish	0.0417	<.0001
Sediment (mg/kg)	-0.0003	0.0027
Roads (km)	0.0002	<.0001
% Water	0.0794	<.0001



Relevance

DOE's Sustainability research portfolio as described in the Multi-year performance plan (2010).

- **Sustainability strategic goal is MYPP "grow a biofuels industry in a way that protects our environment". Our project contributes to three sub-objectives:**
  - **Maintaining or improving water quality**
  - **Conserving biological diversity**
  - **Minimizing negative land use change impacts**



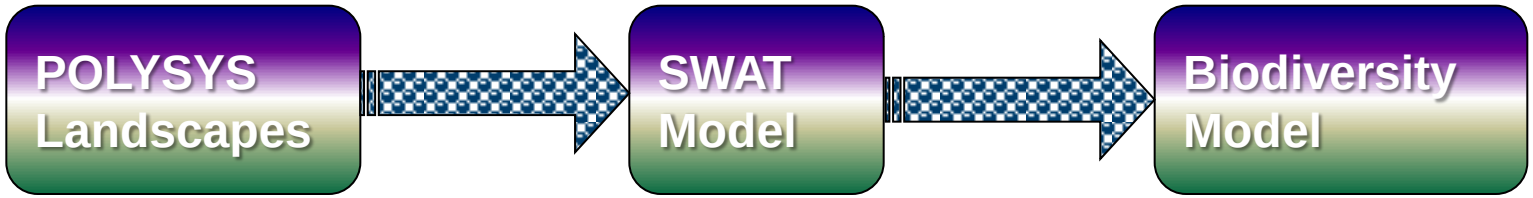
- **Our project's role is to develop and use scientifically defensible methods to answer the question:**

  "How will 2nd generation feedstock production influence water quantity, water quality, and aquatic biodiversity?"

- **Our project has successfully applied these methods in one regions for a OBP-POLYSYS scenario that meets EISA targets for cellulosic feedstocks.**

Users of Data and Results

- **<u>Argonne National Laboratory</u> –** ORNL-ANL collaboration to assess water quality and biodiversity in the Mississippi River Basin.



- **Collaborations and data/SWAT modeling support**:
  - USDA project at Purdue U./U. of Arkansas (Chaubey)
  - Virginia Polytechnic Institute (Christopher),
  - U. of Kentucky (Lhotka)
  - Feedback to Resource Analysis task (ORL)

Benefits and Expected Outcomes

- Our tools provide regional estimates of changes in water quantity, quality, biodiversity, & ecological value.
- After completing analysis of the latest POLYSYS scenario, we will better understand circumstances under which 2nd generation bioenergy production maintains fish biodiversity in the Arkansas-White-Red basin.
- Generalize models to the Mississippi River basin. Outcomes will include:
  - **Estimated changes in nutrient inputs to the Gulf of Mexico**
  - **Projected river-basin-scale changes in freshwater biodiversity**
  - **What functional groups of fish & mussels are gained or lost**
  - **Understanding how differences in crop replacement among river subbasins influence water quality and biodiversity**
- Understand how different simulated outcomes depend on:
  - **Which landuse or crop is replaced by which cellulosic feedstock**
  - **What management practice is used (fertilization, tillage, tile drainage, rotations).**

Summary

- AWR basin has highest potential for switchgrass, replacing pasture, hay & wheat.
- Our results suggest that 2nd generation bioenergy production will not lead to increases in sediment or P in this region. We expect similar results for NO_3, including areas where switchgrass replaces fertilized pasture.

- Future goals:
  - **Will EISA mandates protect fish biodiversity in river basins draining to the Gulf of Mexico?**
  - **Diagnose simulated ecological responses to introducing 2nd generation bioenergy crops.**
  - **Contribute environmental performance measures to those wishing to incorporate ecological values into cropland allocation & management decisions.**

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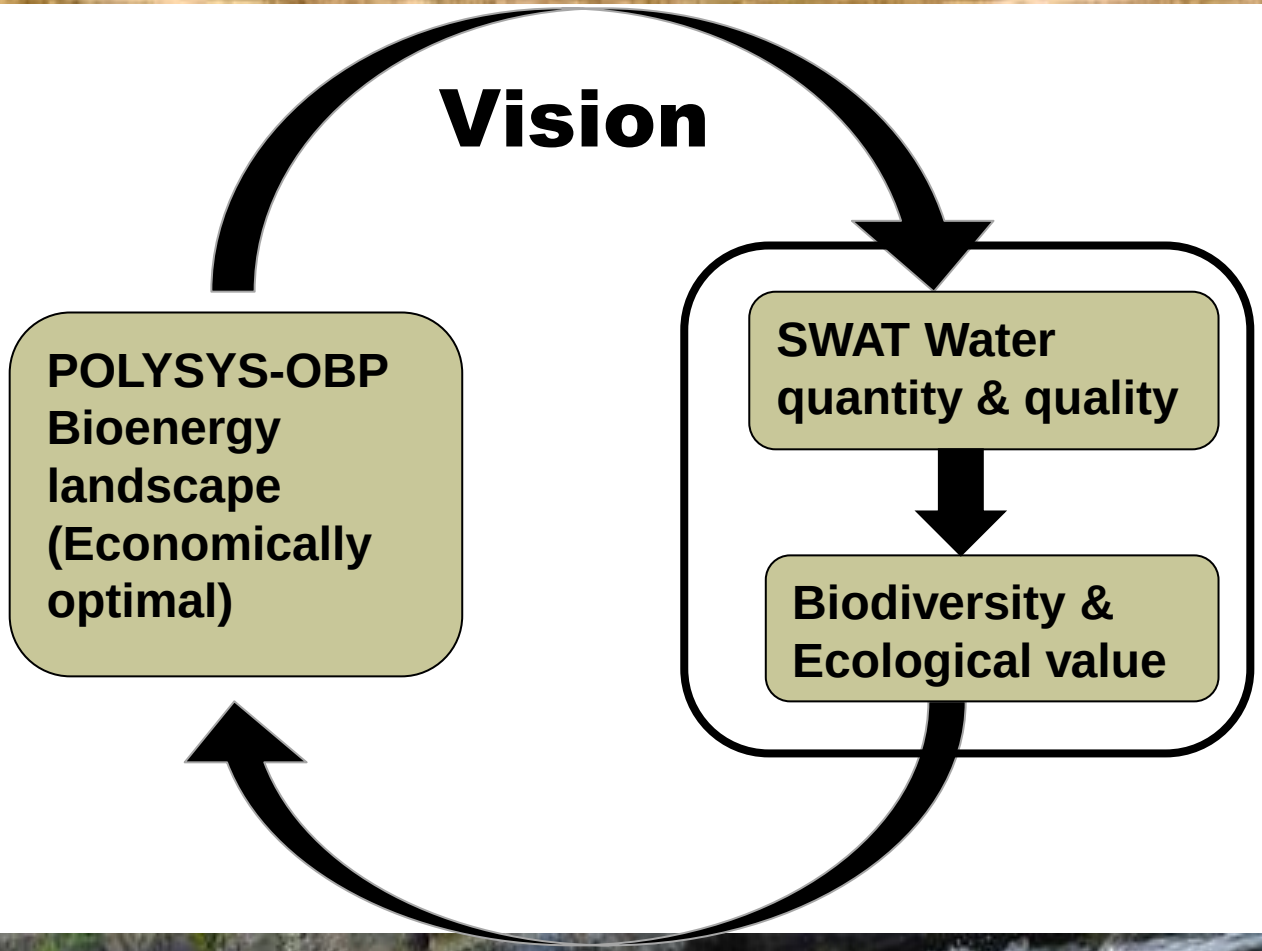
Vision
SWAT Water quantity & quality
Biodiversity & Ecological value
POLYSYS-OBP Bioenergy landscape (Economically optimal)

Additional Slides

Publications and Presentations

See www.esd.ornl.gov/~zij/pubs.html

Nov

Jan

Mar

May

Jul

Sep

FY09

- Baskaran, L., Jager, H., Schweizer, P. 2009. An Approach to Spatial Assessment of Aquatic Habitat Response to Biomass Feedstock Production. Report to DOE 6/2009. **Milestone 6/09**
- Baskaran L, Jager HI, Schweizer P, Srinivasan R. 2009. Use of the SWAT model to evaluate the sustainability of switchgrass production at a national scale. 2009 International SWAT Conference Proceedings, Boulder, CO.

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Publications and Presentations

FY10

Nov

- Jager, H.I., L. M. Baskaran, C. C. Brandt, E. B. Davis, C. A. Gunderson, S. D. Wullschleger. 2010. Empirical geographic modeling of switchgrass yields in the United States. Global Change Biology: Bioenergy 2: 248-257

Jan

- Presentation to EPA Watershed Workshop in Oak Ridge,Jan.'10, Jager.

Mar

- Organized full-day symposium April '10 annual meeting of the International Association of Landscape Ecologists, "Shifting Landscapes: Bioenergy and Biodiversity." www.esd.ornl.gov/~zij/IALE_symposium/index.htm **Milestone 6/10**. Two ORNL presentations:

May

  - Schweizer, P.E., L.M. Baskaran, H.I. Jager, C.C. Brandt. *Predicting changes in aquatic biodiversity from proposed biofuel crop production in the Arkansas-White-Red River basin*

Jul

  - Eaton, L.M., H.I. Jager, P.E. Schweizer. *Valuing services of fish communities to assess watershed benefits of bioenergy crops*

Sep

- Presentation to quarterly USDA Biofeedstock PI meeting, Purdue U., April 2010; Quarterly web-conferences thereafter.
- USDA/ARS Stakeholder Workshop on Water Availability and Watershed Management, Chicago, Sept 2010.

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Publications and Presentations

FY11

Nov

Jan

Mar

May

Jul

Sep

- Eaton, L.M., P.E. Schweizer, H.I. Jager. Dec '10 *The economic effects of biofuel feedstock production on gamefish distribution ,* Presentation to A Conference on Ecosystem Services (ACES) 2010, Phoenix, Arizona. **Milestone 12/10**
- Baskaran, L.M., H.I. Jager, P. E. Schweizer, R. Srinivasan. 2010. Progress toward evaluating the sustainability of switchgrass production at a regional scale. American Society of Agricultural and Biological Engineers 53(5): 1547-1556. **Milestone 6/10**
- McBride, A.C, V.H. Dale, L.M. Baskaran, and others. In Press. Indicators to support environmental sustainability of bioenergy systems. Ecological Indicators.
- Presentation to Environmental Engineering Seminar, March 9, U. Tennessee, Knoxville, Dr. John Schwartz (host)
- Schweizer, P.E. and H.I. Jager. Accepted 3/11. Modeling regional variation in riverine fish biodiversity in the Arkansas-White-Red River basin. Transactions of the American Fisheries Society. **Milestone 9/11**

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Publications and Presentations

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FY12 – Future plans

Papers in progress

- Jager, H.I., L.A. Baskaran, P.E. Schweizer, C.C. Brandt. In prep. Forecasting the effects of future biomass energy landscapes on water quality in rivers of the Arkansas-White-Red river basin, USA.
- Schweizer, Jager, Baskaran, Brandt. In prep. Forecasting changes in riverine fish biodiversity associated with bioenergy production in the Arkansas-White-Red River basin.
- Baskaran, L.M., Jager, Dale, others. In prep. Representation of switchgrass (*Panicum virgatum*) in the Soil Water Assessment Tool model.

Collaborative papers, EPA-ORNL Watershed Workshop

- Smith, E., R. Efroymson**,** H.I. Jager, and others. In prep. Review of ecosystem service impacts across the biofuels supply chain. Environmental Management.
- Parish, E.S., T. Johnson, V. Dale, R. Efroymson, J.M. Bielicki, M.R. Hilliard R. Dodder, and H.I. Jager. In prep. Scale-dependent effects of bioenergy. Environmental Management.

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