Forecasting Water Quality and Aquatic Biodiversity

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ORNL Team

This project

- **Latha Baskaran**, geographer and watershed modeler extraordinaire
- 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

“Will EISA targets for 2nd generation bioenergy crops maintain / improve water quality and aquatic biodiversity?”

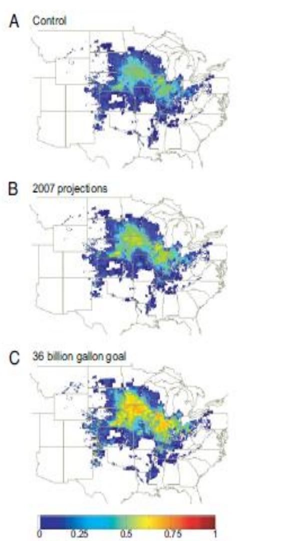


Fig. 2. Fractional area of each 5′ × 5′ grid cell planted in corn in the 2004–2006 control (*A*), the 2007 projections (*B*), and the 36 billion gallon goal scenario (*C*). The area is expressed as a fraction of the total grid cell area.

Donner and Kucharik

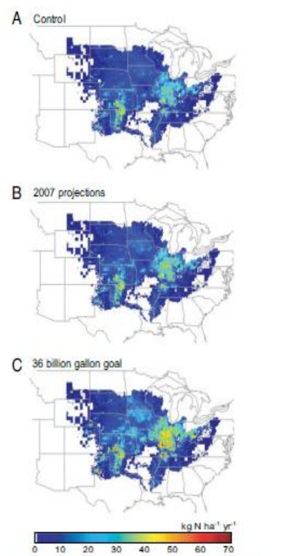


Fig. 5. Simulated dissolved inorganic nitrogen leaching ($kg{\cdot}ha^{-1}yr^{-1}$) from land across the Mississippi–Atchafalaya River Basin in the 2004–2006 control (*A*), the 2007 projections (*B*), and the 36 billion gallon goal scenario (*C*).

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

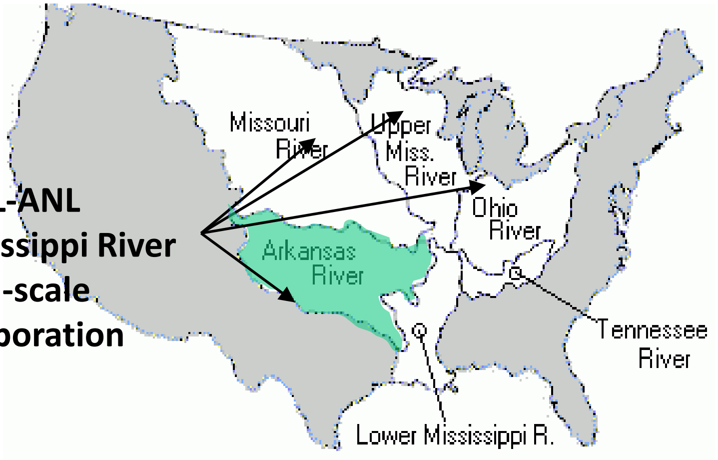
- River basin-wide US assessment
- Improved hydrologic & geochemical modeling of terrestrial-aquatic interface
- Represents EISA mandates for 2nd generation feedstocks

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

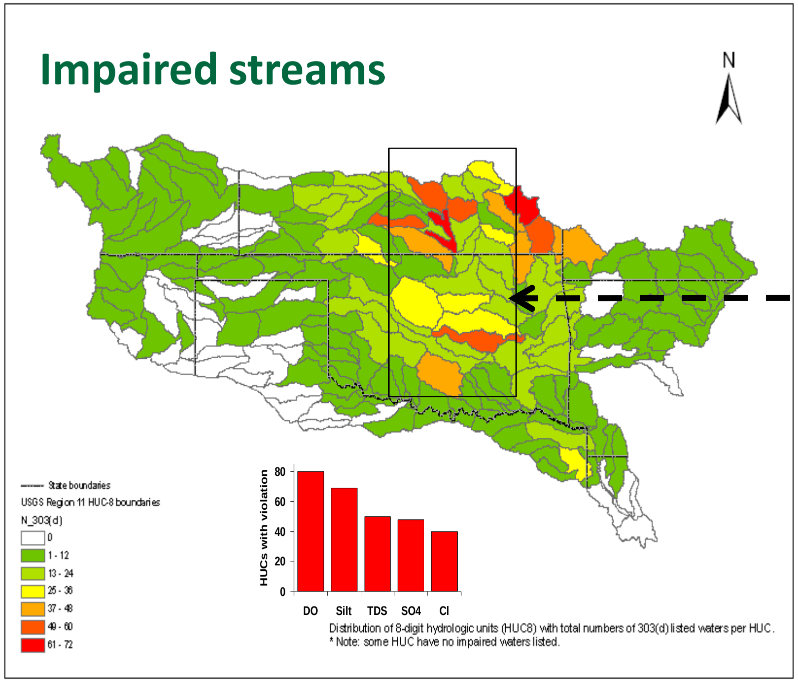
History

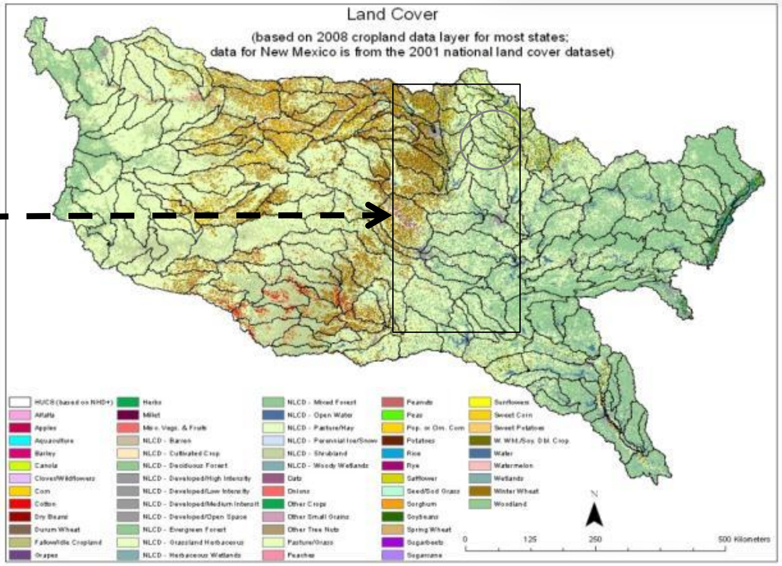
- ORNL focus on Arkansas-White-Red river basin:
  - High potential for cellulosic perennial (switchgrass) production
  - Successful fish biodiversity modeling efforts to build on.
- Interest in understanding bioenergy effects on Gulf of Mexico
- Joined forces with Argonne to quantify relationships for the entire Mississippi River basin

ORNL-ANL Mississippi River basin-scale collaboration



Hypotheses





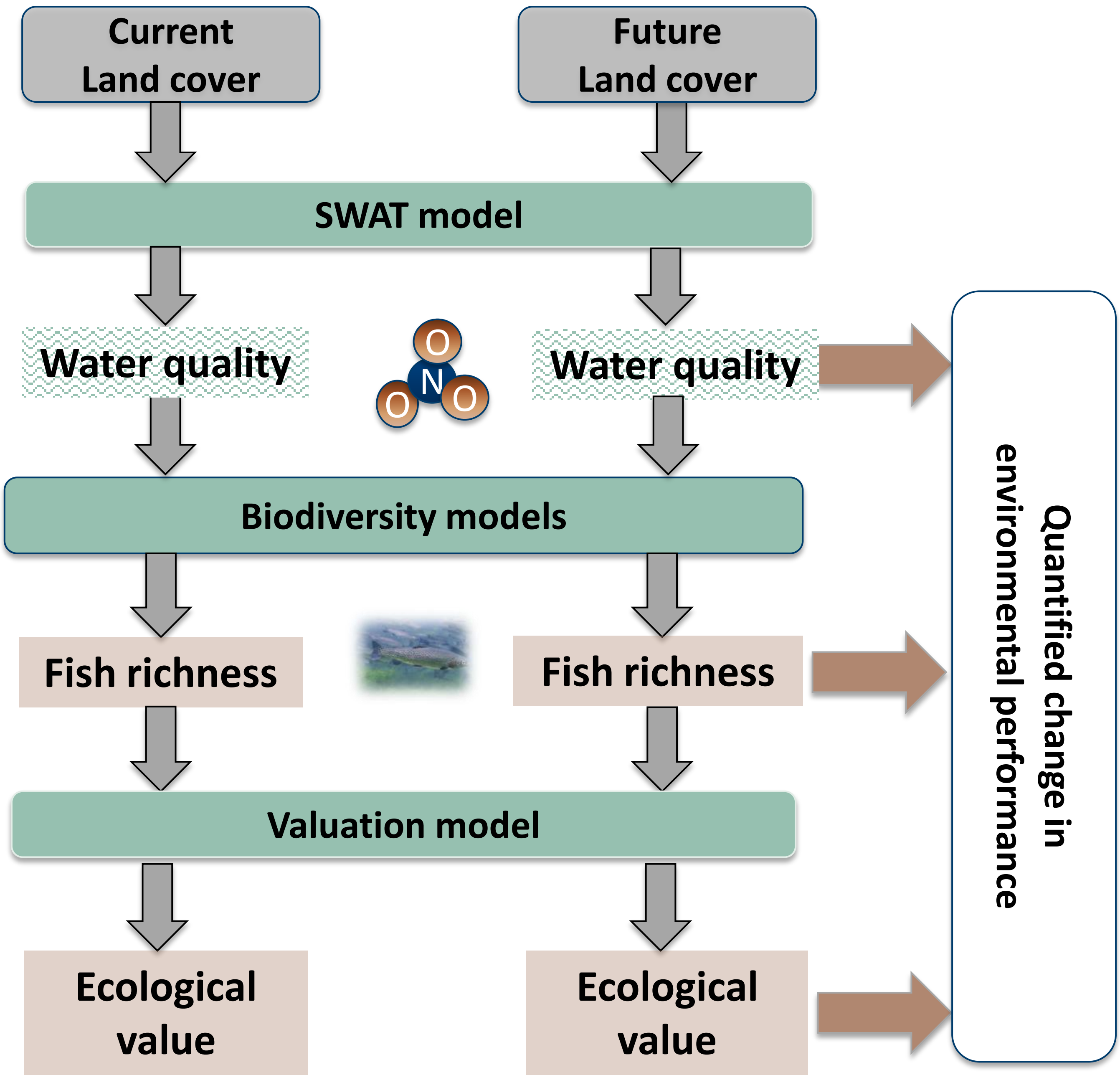
Winter wheat
Grass-shrubland-pasture
Forest
Corn
Other crops

Hypotheses

Where switchgrass replaces conventional crops...

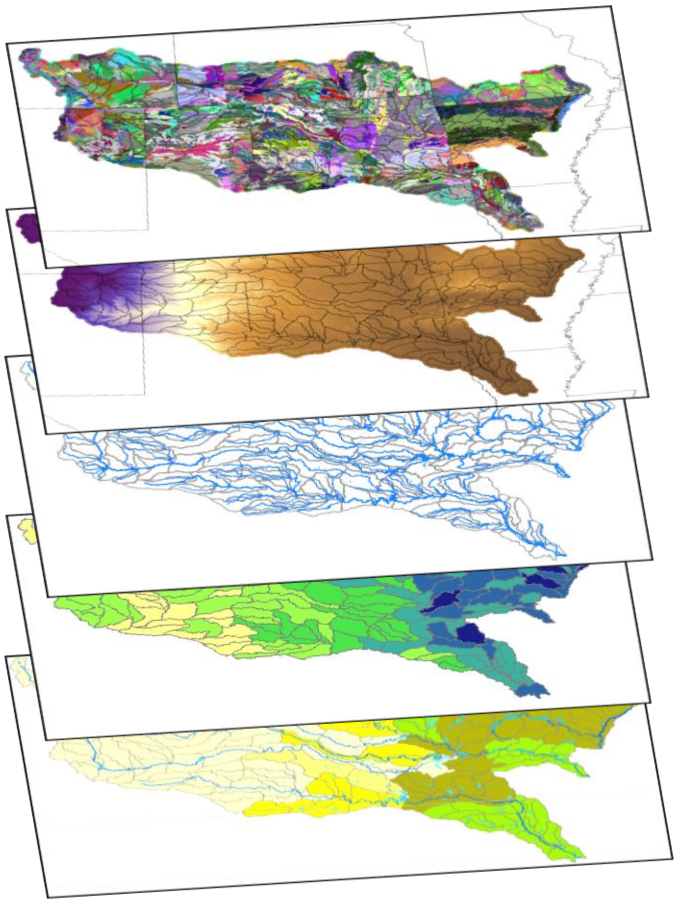
- Nutrient inputs to streams will decrease
- **Sediment input to streams will decrease**
- Enhanced fish diversity and recovery of ag-impacted species

Approach


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

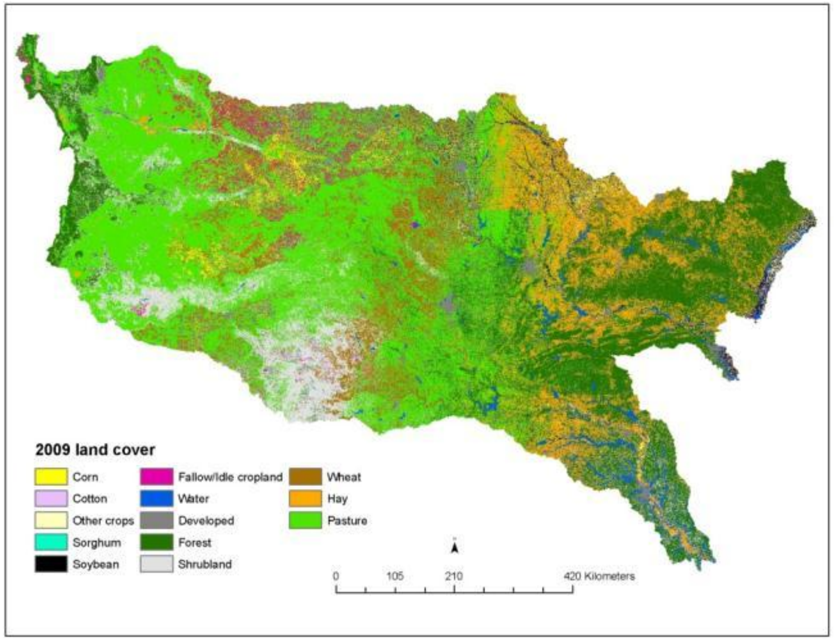
Outline

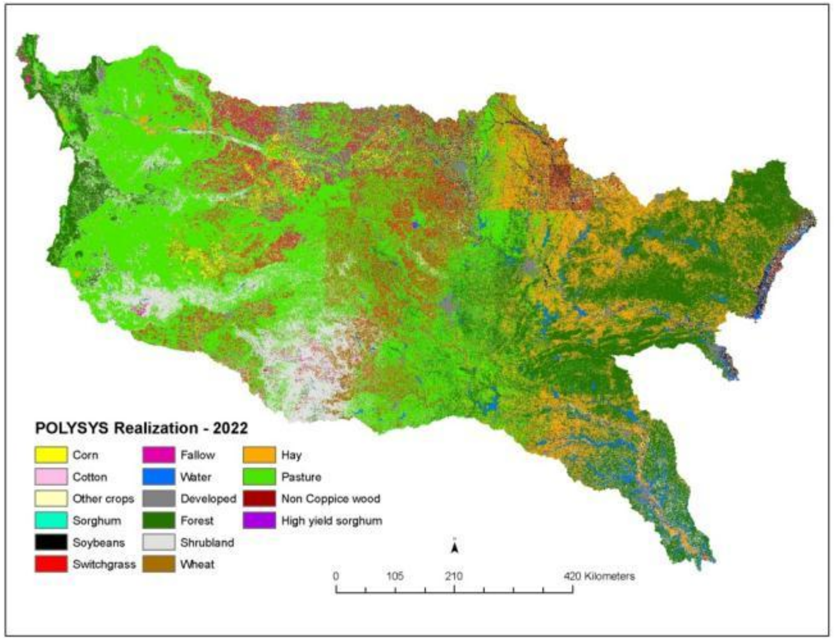
1. OBP-POLYSYS futures
2. River-basin modeling
3. Fish biodiversity modeling
4. Ecological valuation



OBP-POLYSYS Futures

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

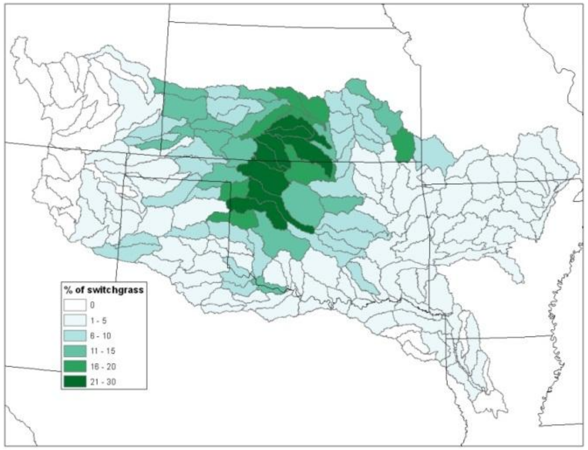


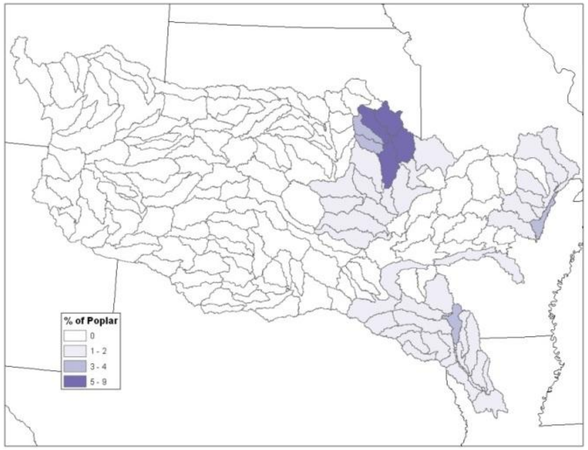


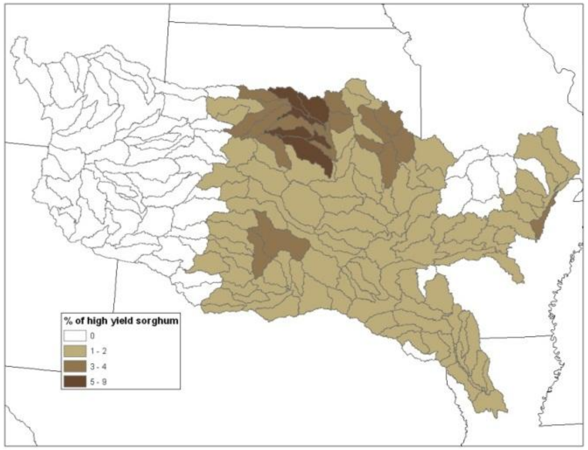
Our approach depends on comparing environmental performance of pre-cellulosic-bioenergy landscapes with that of future bioenergy landscapes.

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

Switchgrass dominant bioenergy crop in most-recent POLYSYS (2030)



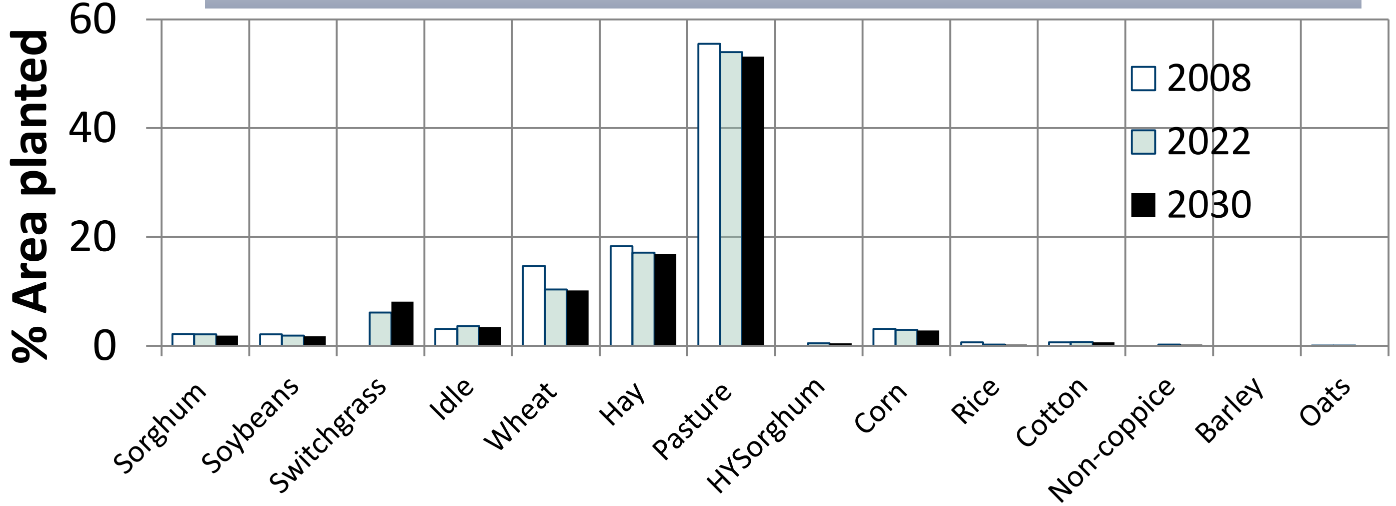


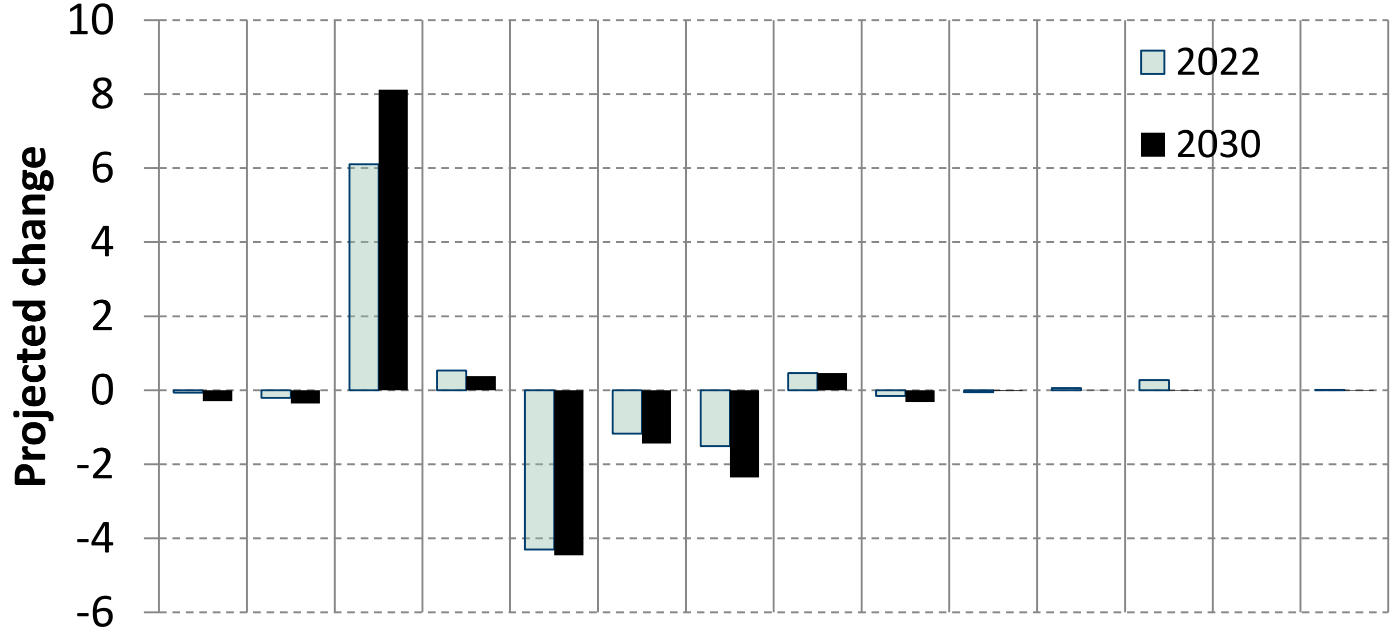


OBP-POLYSYS Futures

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

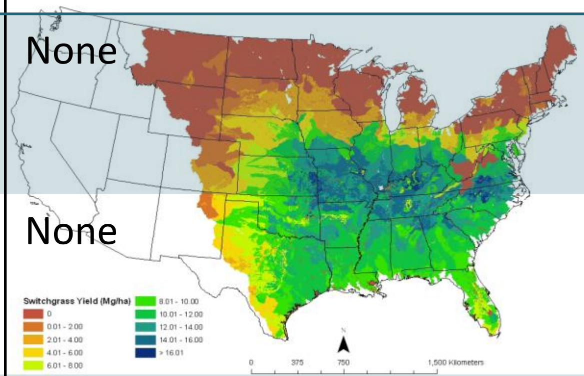
Switchgrass replaced pasture, hay, & wheat





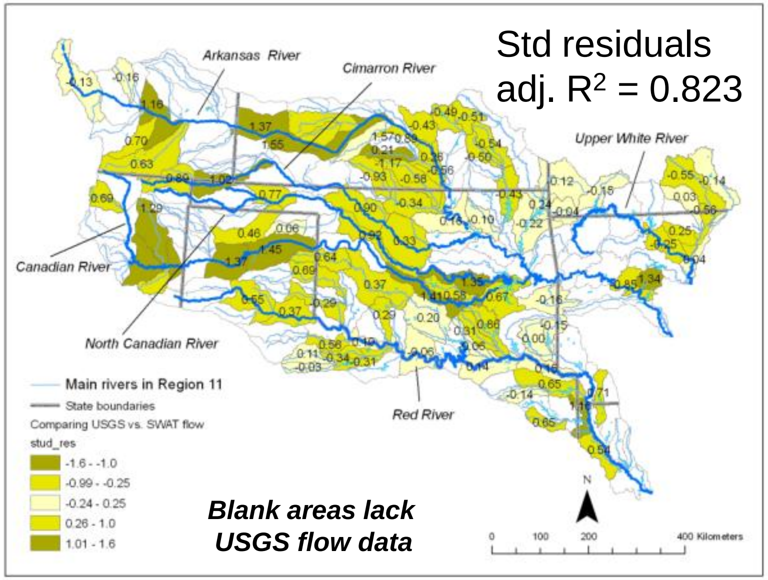
River-basin Modeling

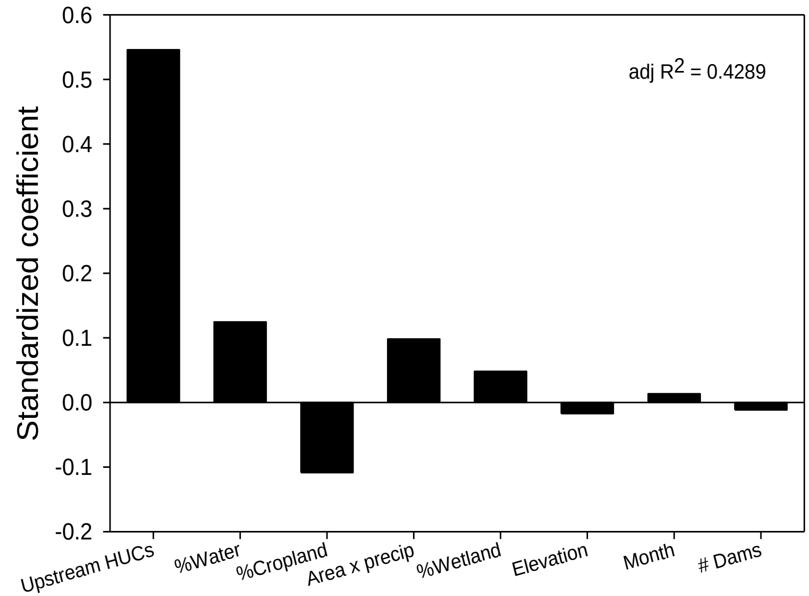
Crop type	Current	Alternative futures
Switchgrass	None	10-y rotation 80 lbs/acre/y N from year 2 40 lbs/acre/y P
Poplar	None	8-y rotation 90 lbs/acre N in year 3 & 6 15 lbs/acre P in year 3
Hi-yield sorghum	None	50 lbs/acre N 60 lbs/acre P
All conventional	No stover removal Lower %no-till	Stover removal Higher %no-till
Hay	Auto-fertilized up to 200 lbs /acre; 3-cut harvest	Auto-fertilized up to 200 lbs/acre; 3-cut harvest
Winter wheat	Auto-fertilized up to 40 lbs/acre /application	Auto-fertilized up to 40 lbs/acre /application
Pasture	Fertilized	Intensification



River-basin Modeling

Constructive validation of SWAT showed agreement with measured flows

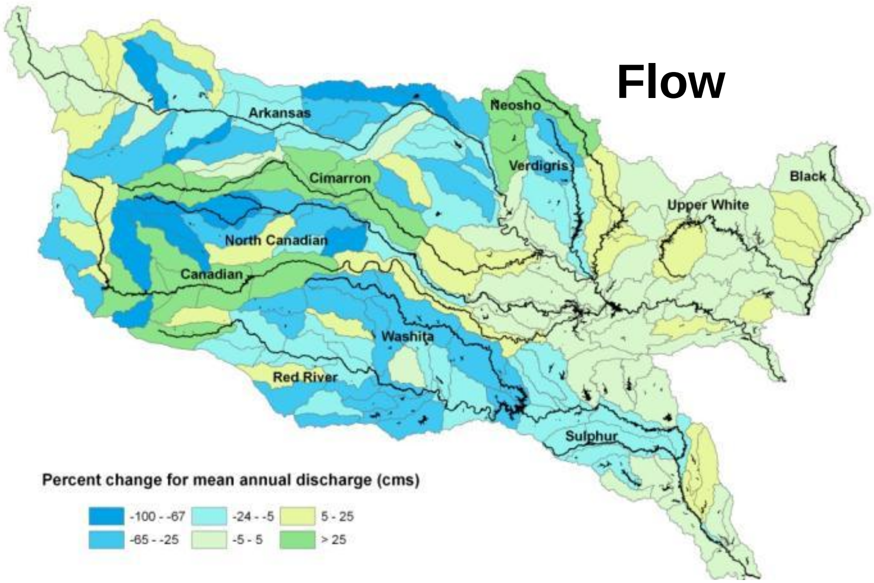


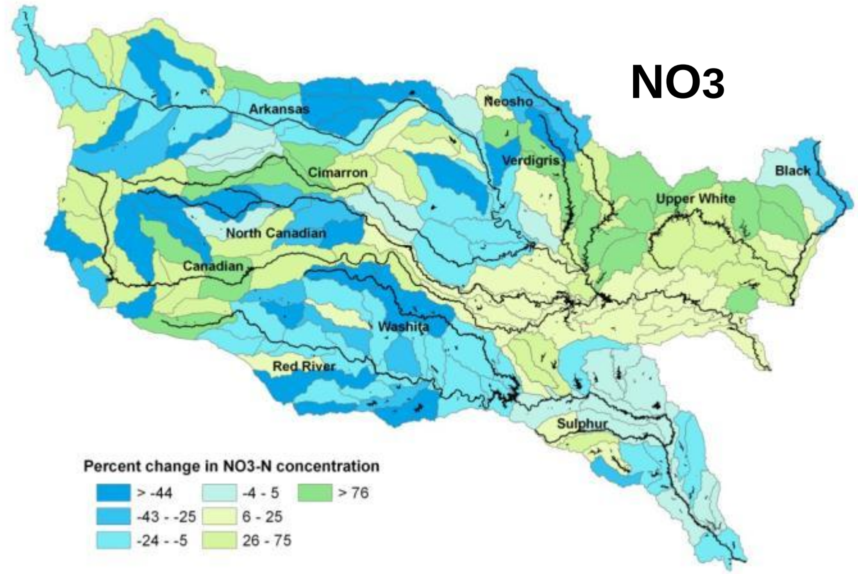


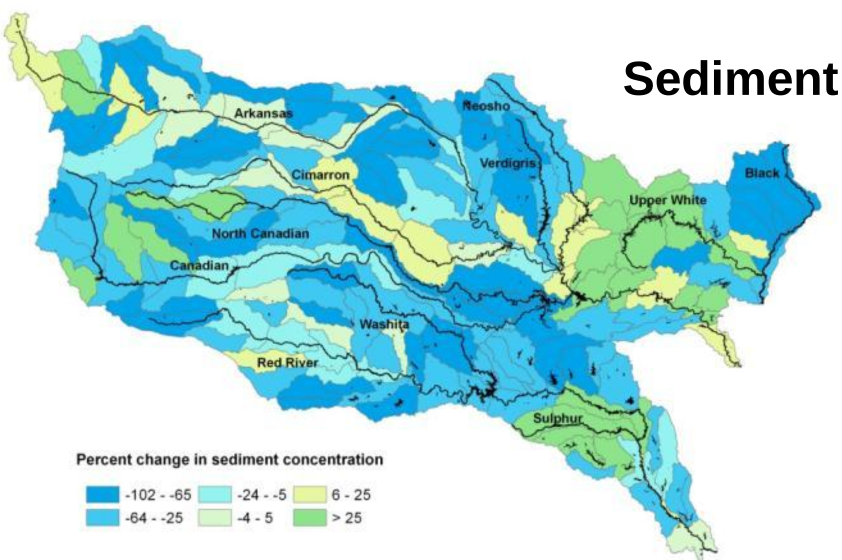
- SWAT-predicted and observed USGS monthly river flows, all residuals <2 SD from 0. See Baskaran et al. 2010.
- Patterns in residuals: SWAT predicted best in watersheds with cropland, worst in downstream subbasins, hi %water. Largest residuals (dark) along Canadian and upper Arkansas mainstems.
- We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

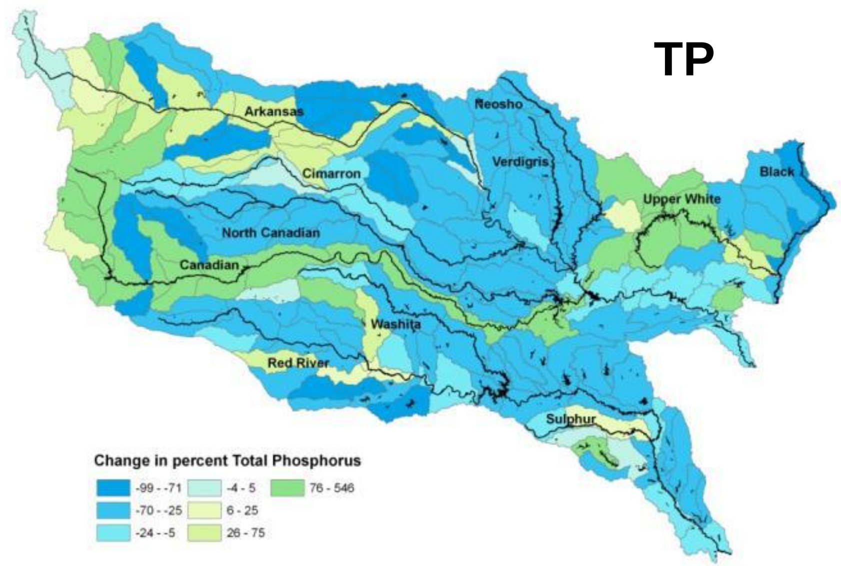
River-basin Modeling

Sediment, TP, and NO_3 decreased on average (increases in some subbasins)

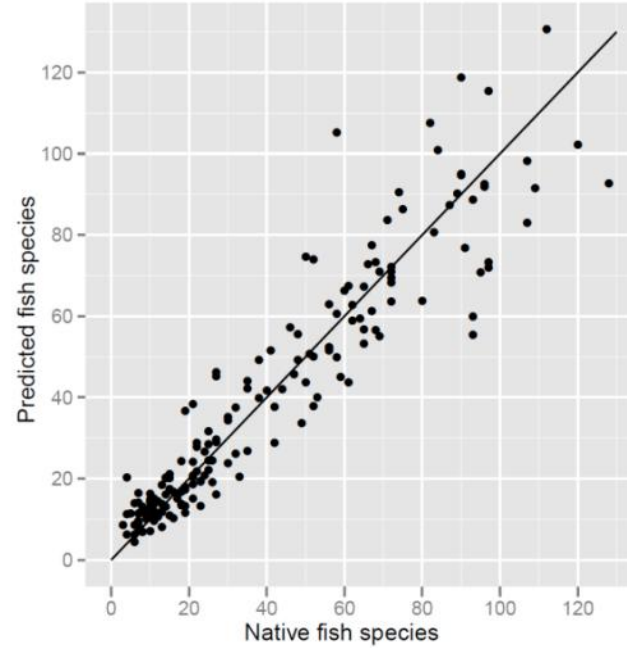


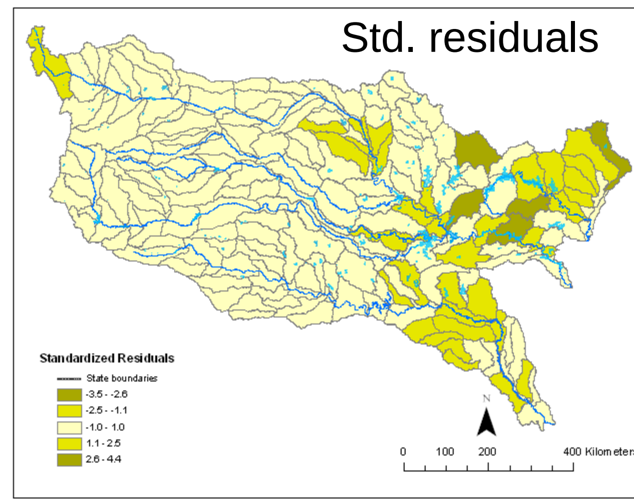






Fish Biodiversity Modeling





- **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.**

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

Opportunities for recovery

- **Fishes are impacted by conventional agriculture**
- **Missing species sought**
- **Modified indicator species analysis**

Ecological Valuation

What is the relationship between fish richness and fishing activity?

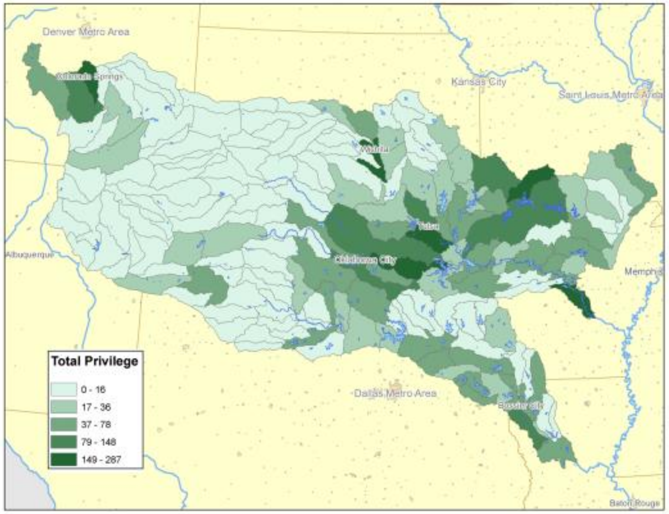
- **Compiled data on activity days and license sales**
- **Modeled activity days in each HUC8 based on:**
  - **Biophysical final goods**

    (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 2010 Multi-year performance plan

- **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?"

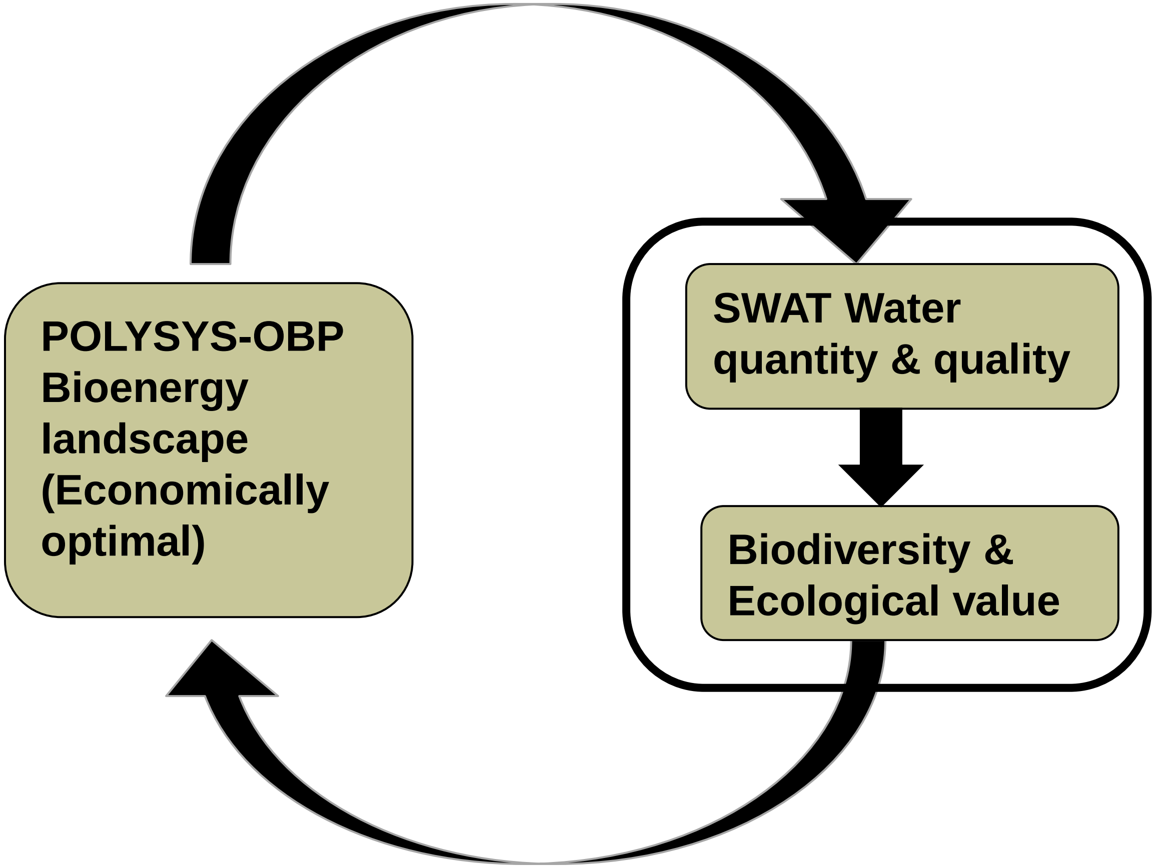
- **Our project has successfully applied these methods in one regions for a OBP-POLYSYS scenario that meets EISA targets for cellulosic feedstocks.**

Vision

- Understand how differences in crop replacement among river subbasins influence water quality and biodiversity
  - Which landuse or crop is replaced by which cellulosic feedstock
  - What management practice is used (fertilization, tillage, tile drainage, rotations).
- Project changes in water quality
- Project changes in freshwater biodiversity
- Potential for recovery of indicator species

ORNL-ANL Mississippi River basin-scale collaboration

Vision



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