Water for Biofuels: Implications for Energy, Food and Environment

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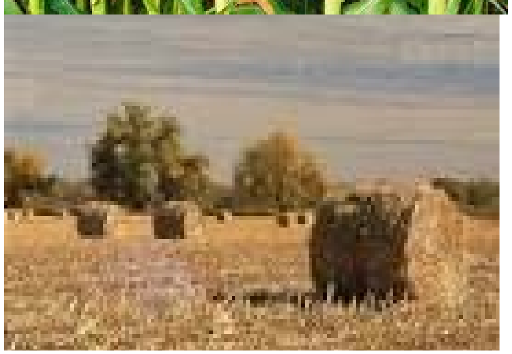

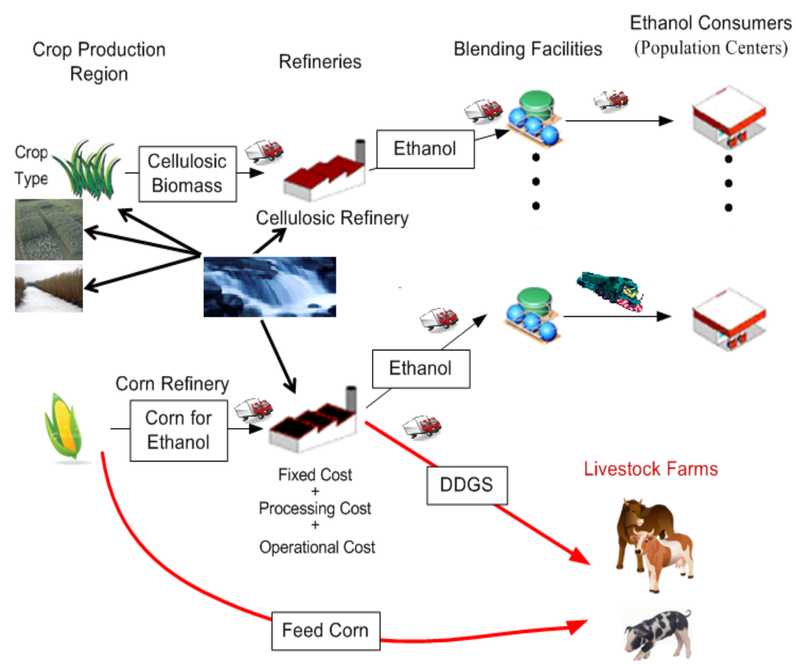

Water for Biofuels

- Background
- Issues
- Outlook for research

Background of Biofuels

- Renewable energy and cleaner energy than gasoline

- New opportunity for agriculture and economic development

- 1st and 2nd generation of biofuel crops
    - 1st: Corn, corn stover, sugarcane
    - 2nd: Cellulosic crops, e.g., Miscanthus, switchgrass

Corn-based Ethanol Increased Corn Production

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MARKETPLACE

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Ethanol powers farmland market

Some worry that producers just starting will get priced out

By MONICA DAVEY
N.Y. TIMES NEWS SERVICE

DEKALB — While much of the nation worries about a slumping real estate market, people in Midwestern farm country are experiencing exactly the opposite. Take, for instance, the farm here — nearly 80 acres of corn and soybeans off a gravel road in a universe of corn and soybeans — that sold for $10,000 an acre at auction this spring, a price that astonished even the auctioneer.

"If they had seen that day, they would have never believed it," Penny Layman said of her sister and brother-in-law, who paid $32,000 for the entire spread in 1962 and whose deaths led to the sale.

Skyrocketing farmland prices, particularly in states such as Illinois, Iowa and Nebraska, giddy with the promise of corn-based ethanol, are stirring new optimism among established farmers. But for younger farmers, already rare in this graying profession, and for small farmers with dreams of expanding and grabbing a piece of the ethanol craze, the news is oddly grim. The higher prices feel out of reach.

"It's extremely frustrating," said Paul Burrs, who farms about 400 acres near Dixon and says he regularly bids on new farmland in the hopes of renting it. Mostly, he said, he loses out to higher bidders. "I crunch t
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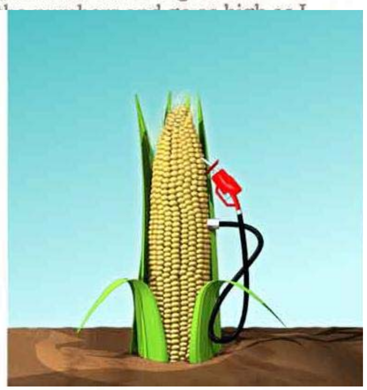
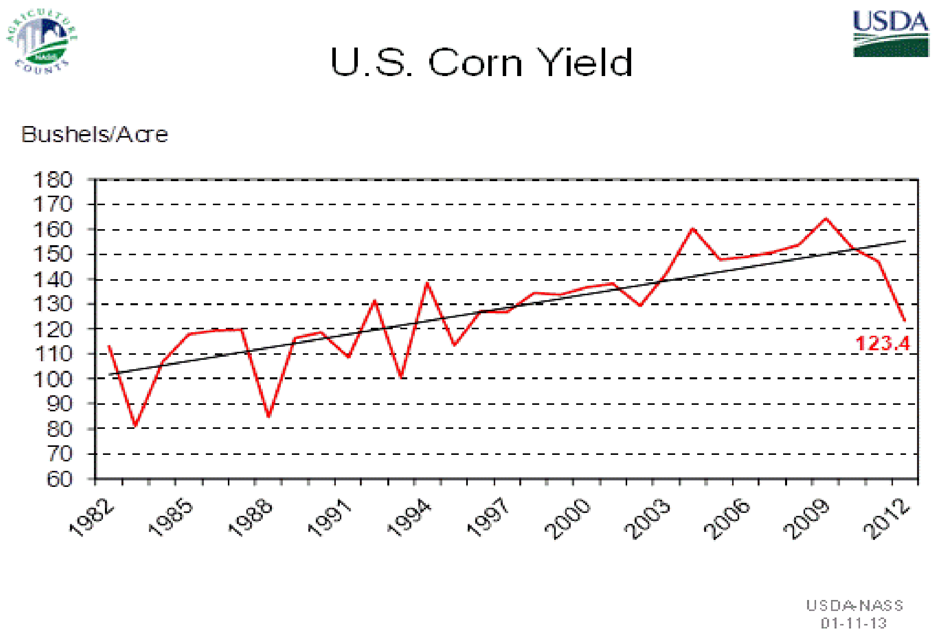
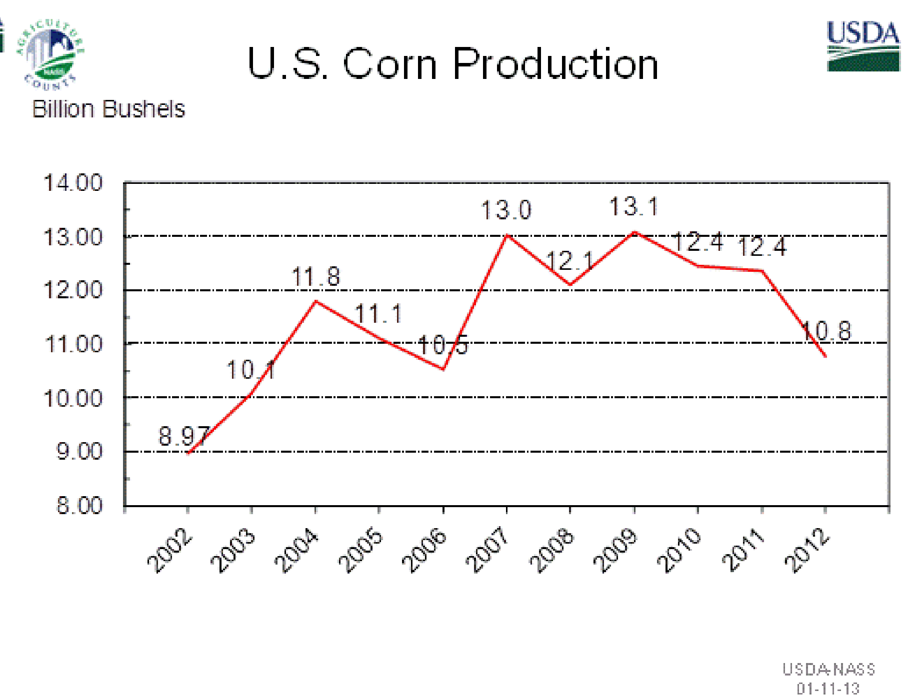


Corn-based Ethanol Increased Corn Production





In 2012, U.S. growers planted a record 94 million acres of corn for animal feed, ethanol fuel, and food products

Concern: High yield and production might have caused increased N load and soil erosion

US Biofuel Mandates

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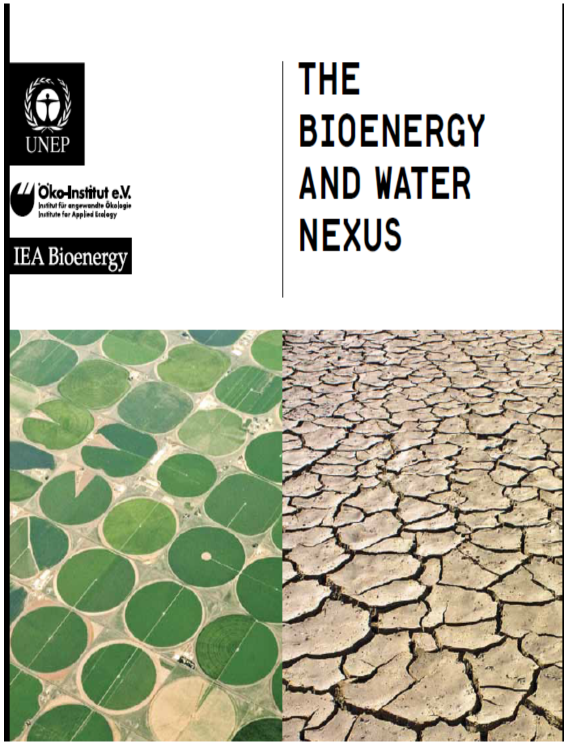
Bush signs energy bill

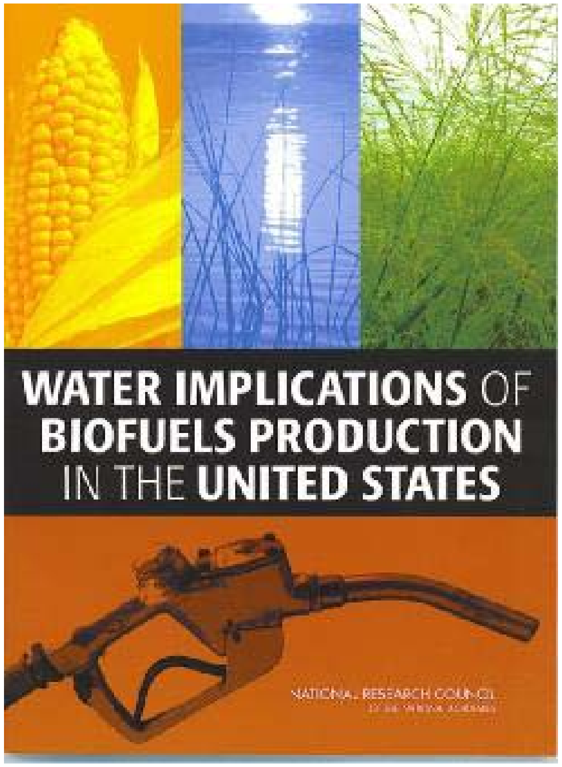
Raises fuel economy standards for the first time in 30 years and boosts biofuel use, but leaves out new taxes on Big Oil.

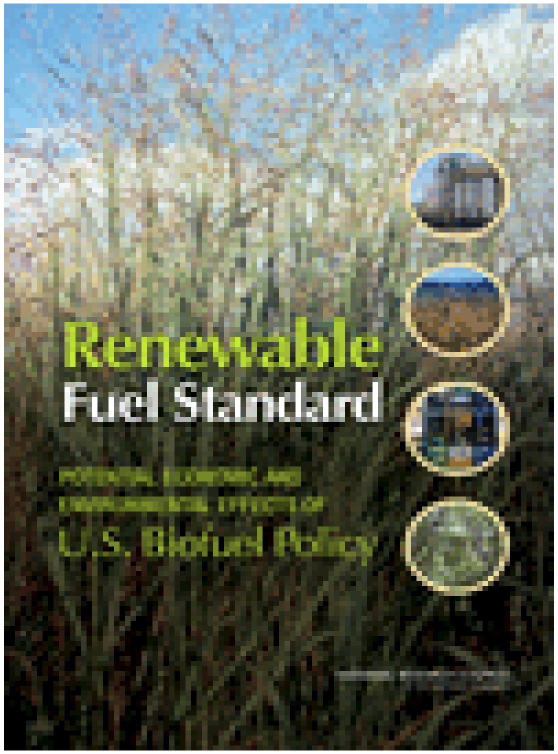
- Energy Security & Independence Act (EISA) requires 36 billion gal of biofuels by 2022

- EPA Renewable Fuel Standard (RFS) requires 25% replacement of vehicle gas in 2022, about 50% of the biofuel will be generated from cellulosic feedstock.

State-of-the-Art of Studies on Water and Biofuel



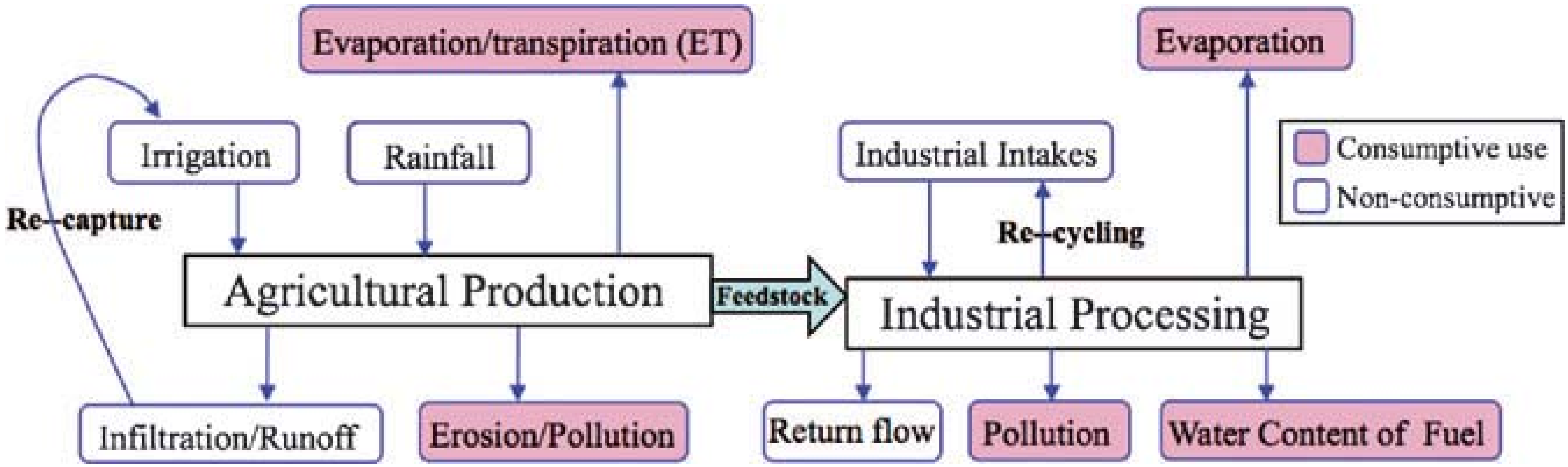




Issues

- Water requirement and impact on hydrology
- Impact on water quality
- Economic and environmental tradeoffs
- Food vs. fuel (competing for resources)

Water Requirements for Biofuels and the Environmental Impacts



(Sources: Fingerman et al., 2011, *Biofpr*)

Water Requirements for Biofuel

- It takes an average of roughly 2,500 liters of water to produce 1 liter of liquid biofuel
- Water consumption for energy production in the US will jump two thirds between 2005 and 2030,and about half of the increase is due to growing biofuels (Service, 2000)
- Replacing 10% of global energy consumption with 1st generation biofuel would double agricultural water withdrawals in the world (Source: The World Economic Forum: Water Initiative)

Bioenergy is the biggest water consumer compared to other energies

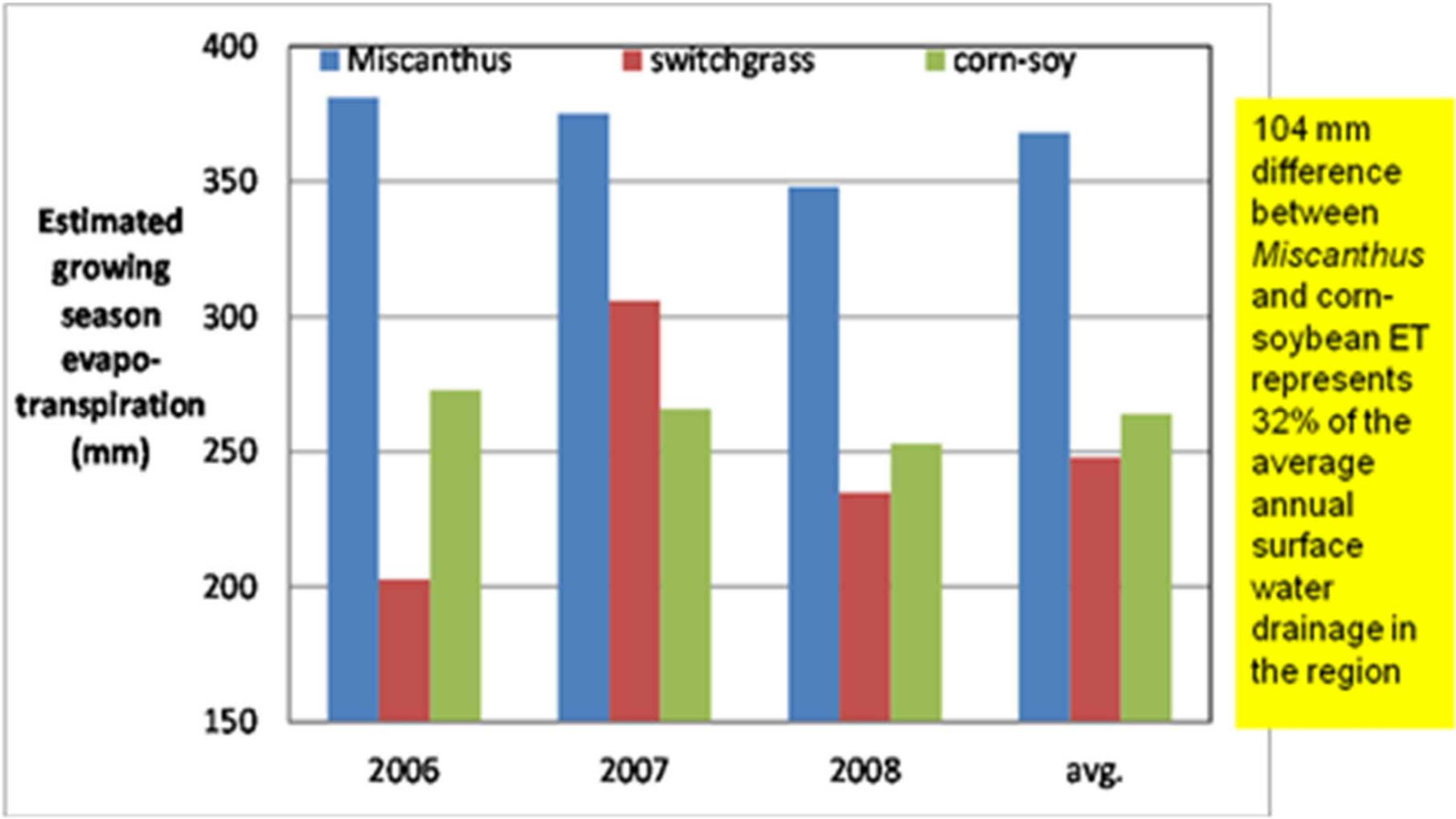
WATER REQUIREMENTS FOR ENERGY PRODUCTION (Liters per megawatt hour)

Petroleum Extraction	10-40
Oil Refining	80-150
Oil shale surface retort	170-681
NGCC* power plant, closed loop cooling	230-30,300
Coal integrated gasification combined-cycle	~900
Nuclear power plant, closed loop cooling	~950
Geothermal power plant, closed loop tower	1900-4200
Enhanced oil recovery	~7600
NGCC*, open loop cooling	28,400-75,700
Nuclear power plant, open loop cooling	94,600-227,100
Corn ethanol irrigation	2,270,000-8,670,000
Soybean biodiesel irrigation	13,900,000-27,900,000

*Natural Gas Combined Cycle

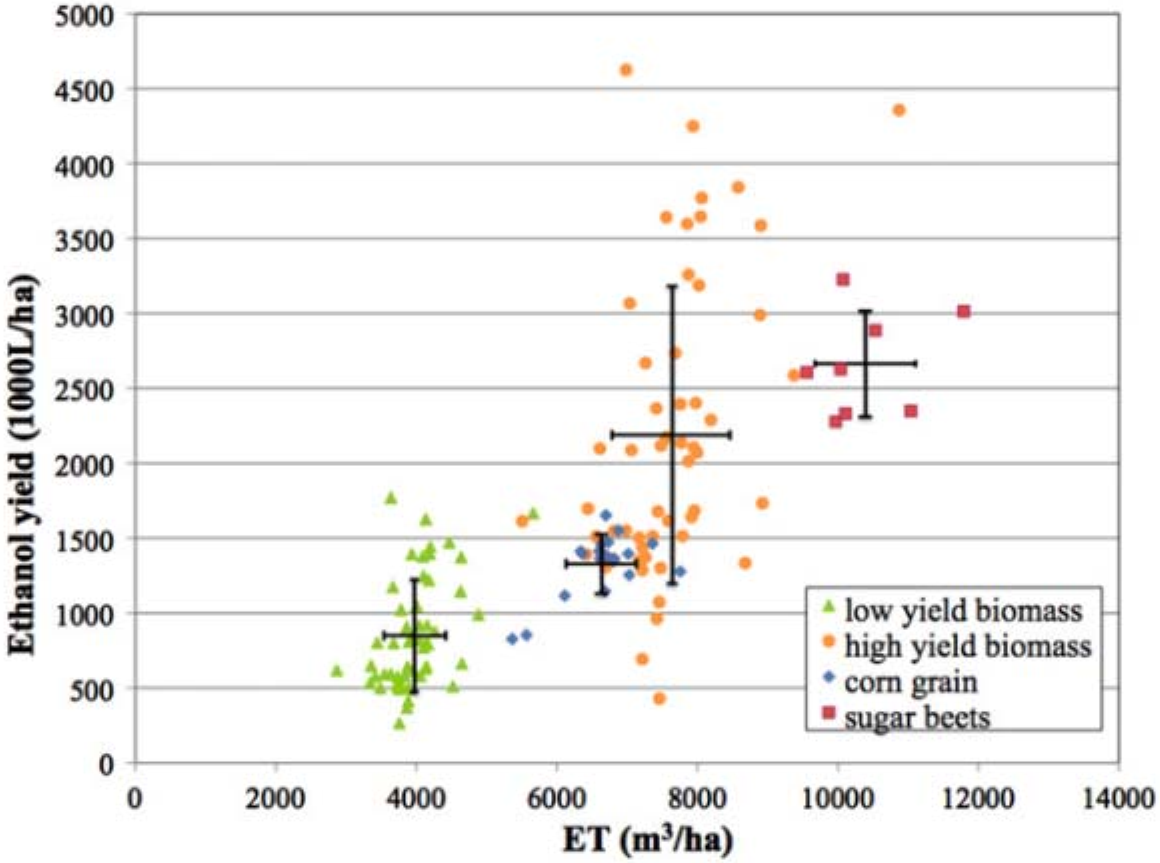
(Source: Service, 2009, *Sci.*)

Water Requirement and Impact on Hydrology



(Source: McIsaac et al., 2010).

Water Requirement and Impact on Hydrology



ET and yield for counties in California

- High-yield biomass: dedicated energy crops such as Miscanthus
- Low-yield biomass: grassy fodder crops

(Source: Fingerman et al., 2010, ERL)

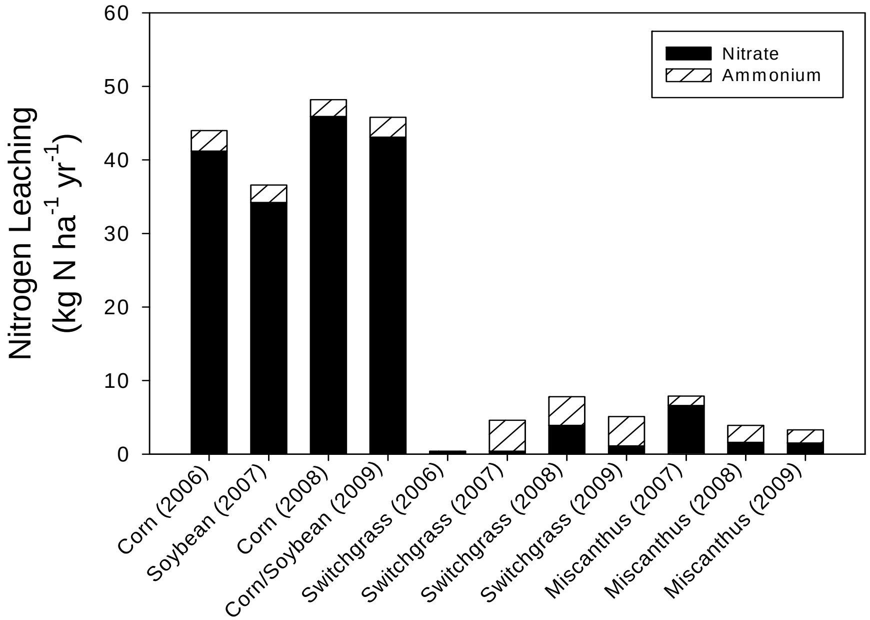
Water requirement for biofuel processing

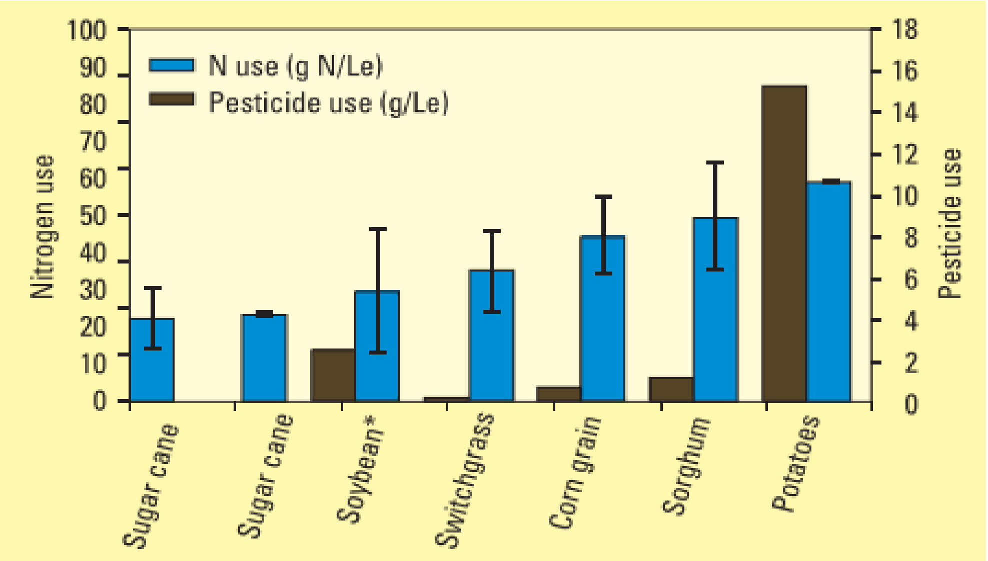
- The range of processing water requirements for a typical ethanol refinery is 2-10 Lw/Le
- By average, 100 million gallon/year corn ethanol plant uses 600 million gallons of water, the equivalent of a town of ~ 7000 people
- Local water problems (such as aquifer drawdown) can be caused or enhanced by biofuel production

Impact on Water Quality

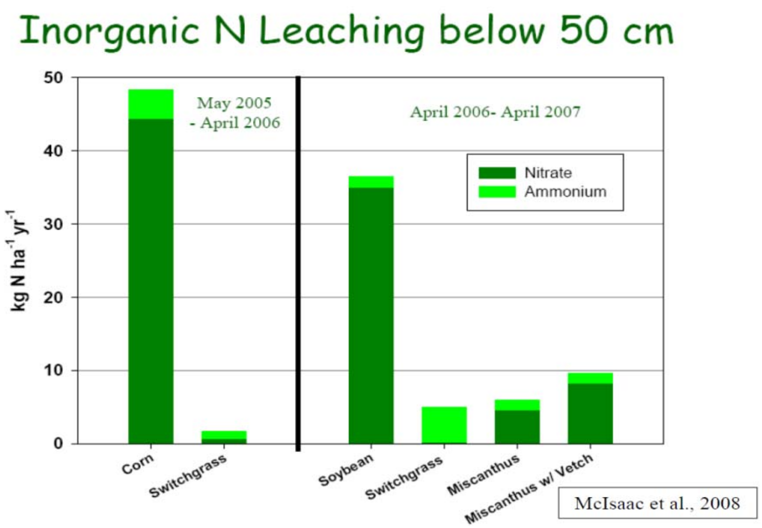
- Corn-based biofuel production can cause 8 g N exported to Gulf of Mexico and 20-40 lb of soil eroded per gal ethanol (Credit: Jerry Schnoor)
- Farmers switched land from conservation reserve program (CRP) for biofuel production, which potentially increase chemical leaching and sediment erosion risk
- Cellulosic feedstocks have considerable potential to sequester nutrients in its root system, and require less fertilization than corn, thus resulting in a low nutrient runoff, e.g., 50% land change to Miscanthus can lead to decrease in nitrate load of 30% (Ng et al., 2010, EST)

Impact on Water Quality





Nitrogen and pesticide requirements for producing 1 L of ethanol (if fertilized) from different crops. Source: Dominguez-Faus, 2009, EST

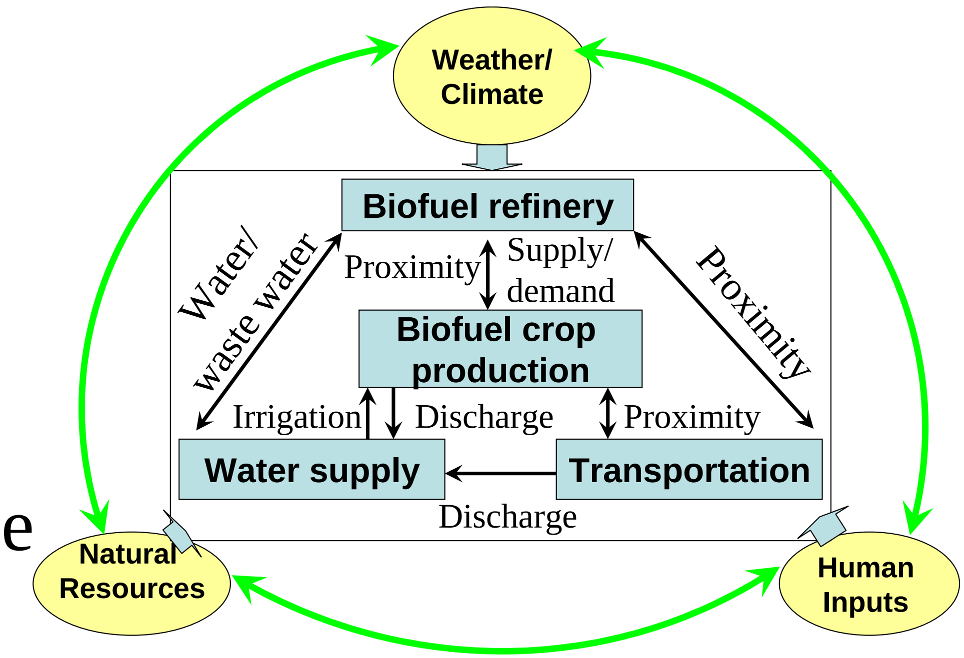


Impact on Water Quality

Discharges from the refinery plants may cause potential chemical, biological, and thermal pollution to aquatic systems (regulation on 0-discharge)

Case study I: A "system of systems" model for infrastructural support for biofuel development

- Transportation
- Refineries
  - Location of refineries
  - Expansion over years
  - Refinery and water use
- Land use
- Water supply and quality
  - Stream flow
  - Nitrate load



Interdependence of infrastructures and interactions with the society and environment

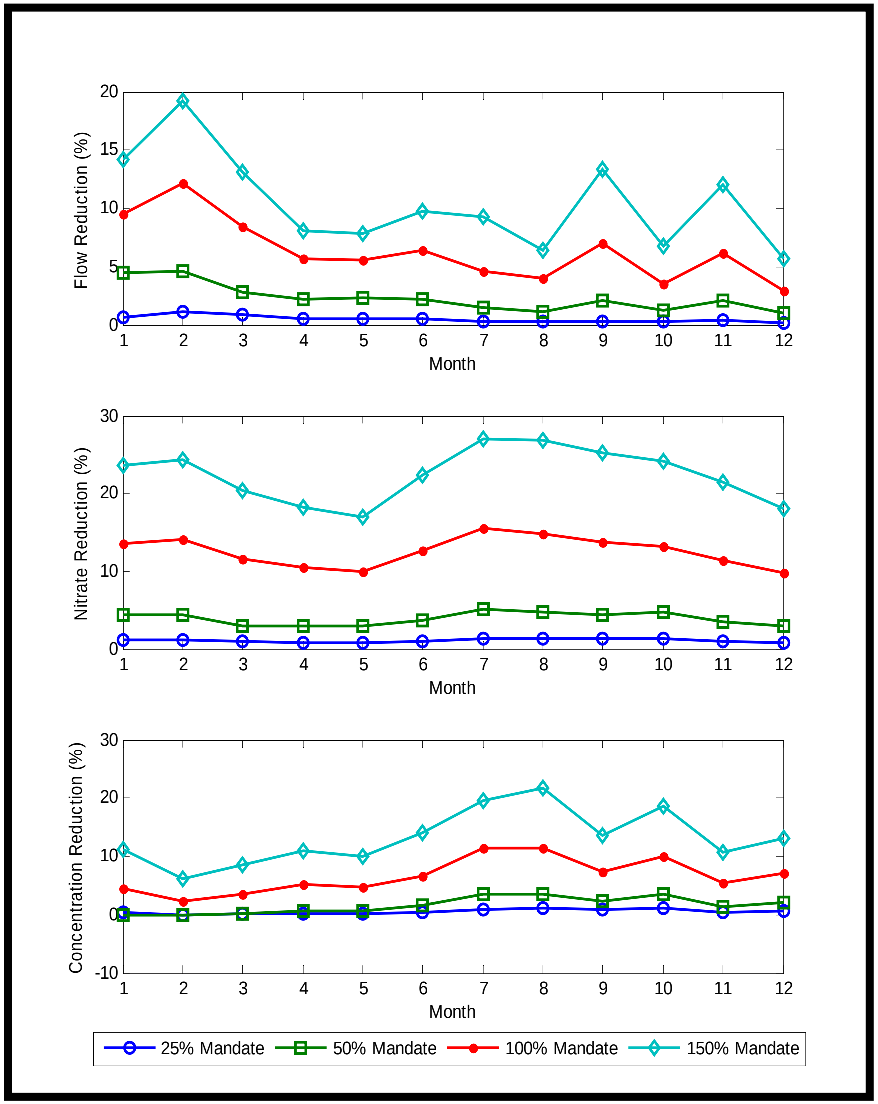
(Source: X. Cai group)

Impact of Different Levels of Mandate

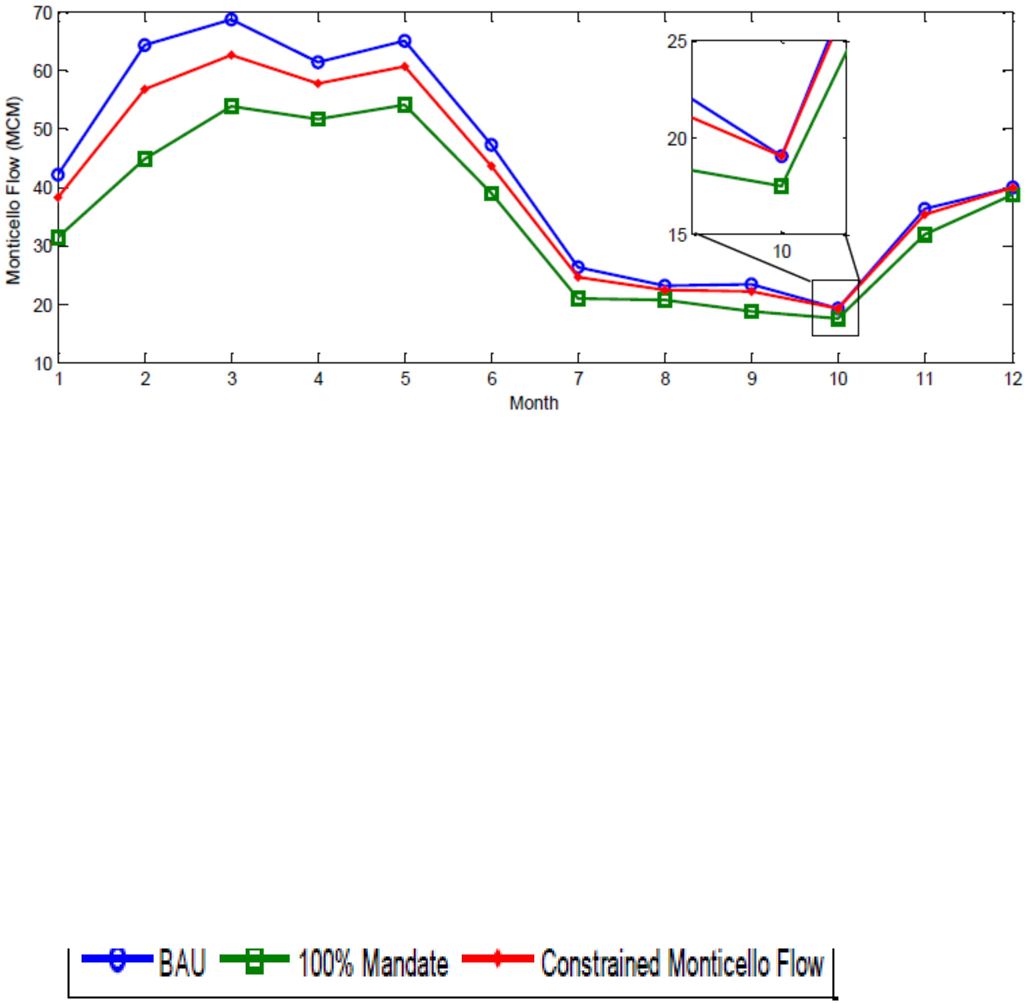
- Up to 50% of mandate the watershed experiences a modest change in flow/nitrate load regimes and slight change in concentration.

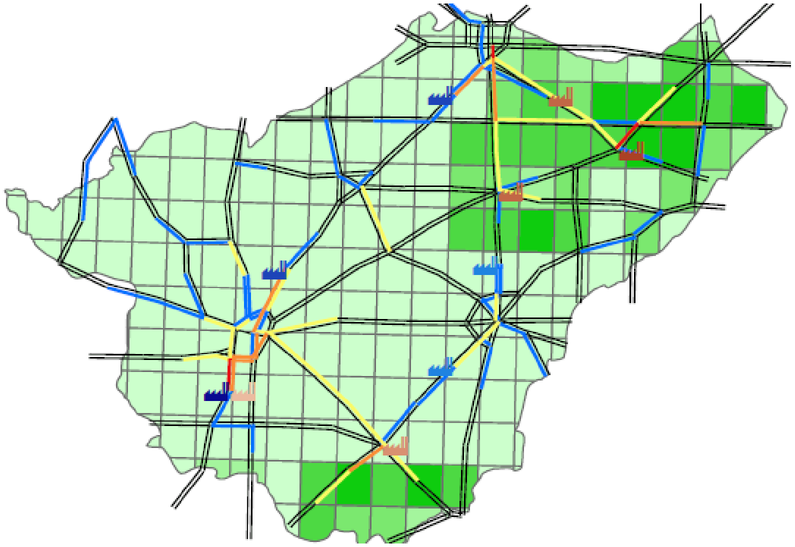
- Nitrate reduction level exceeds the flow reduction level

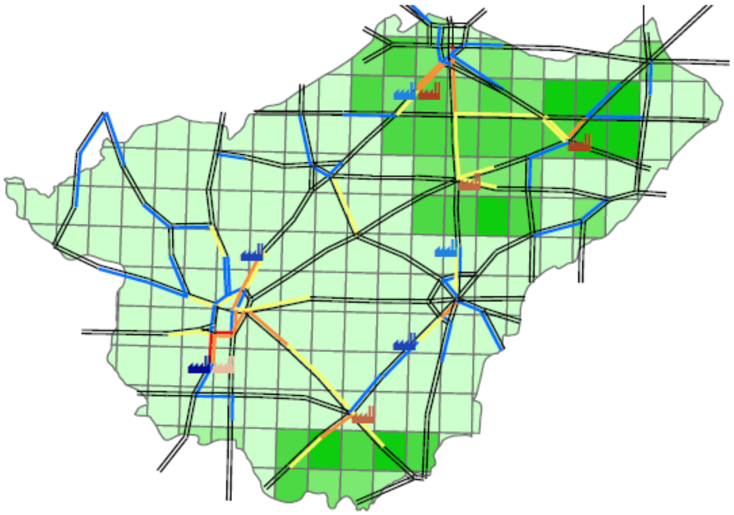
Monthly Flow regime curves and nitrate load



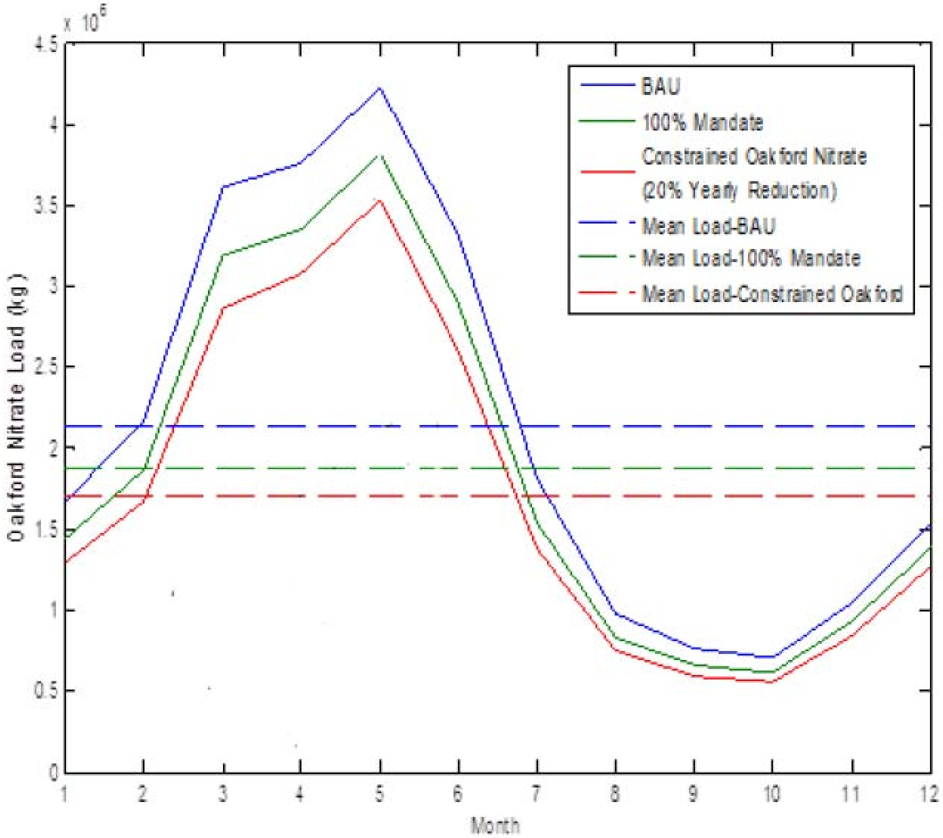
Impact of Streamflow Constraints

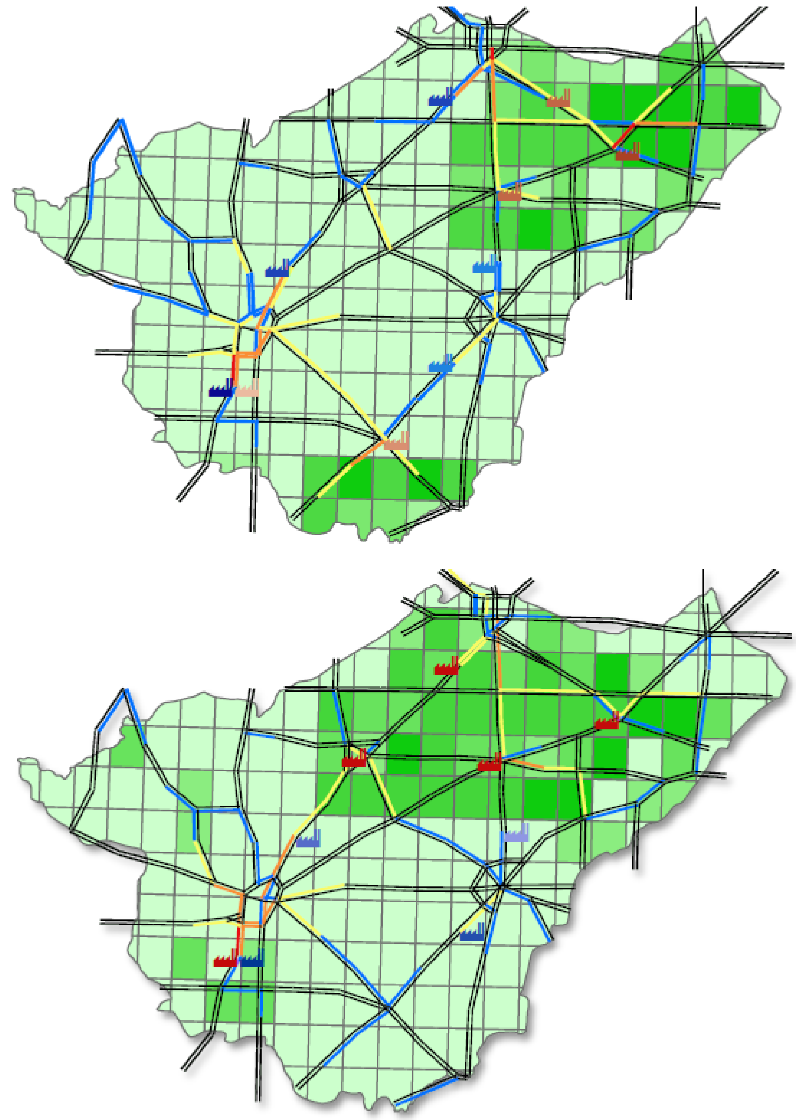






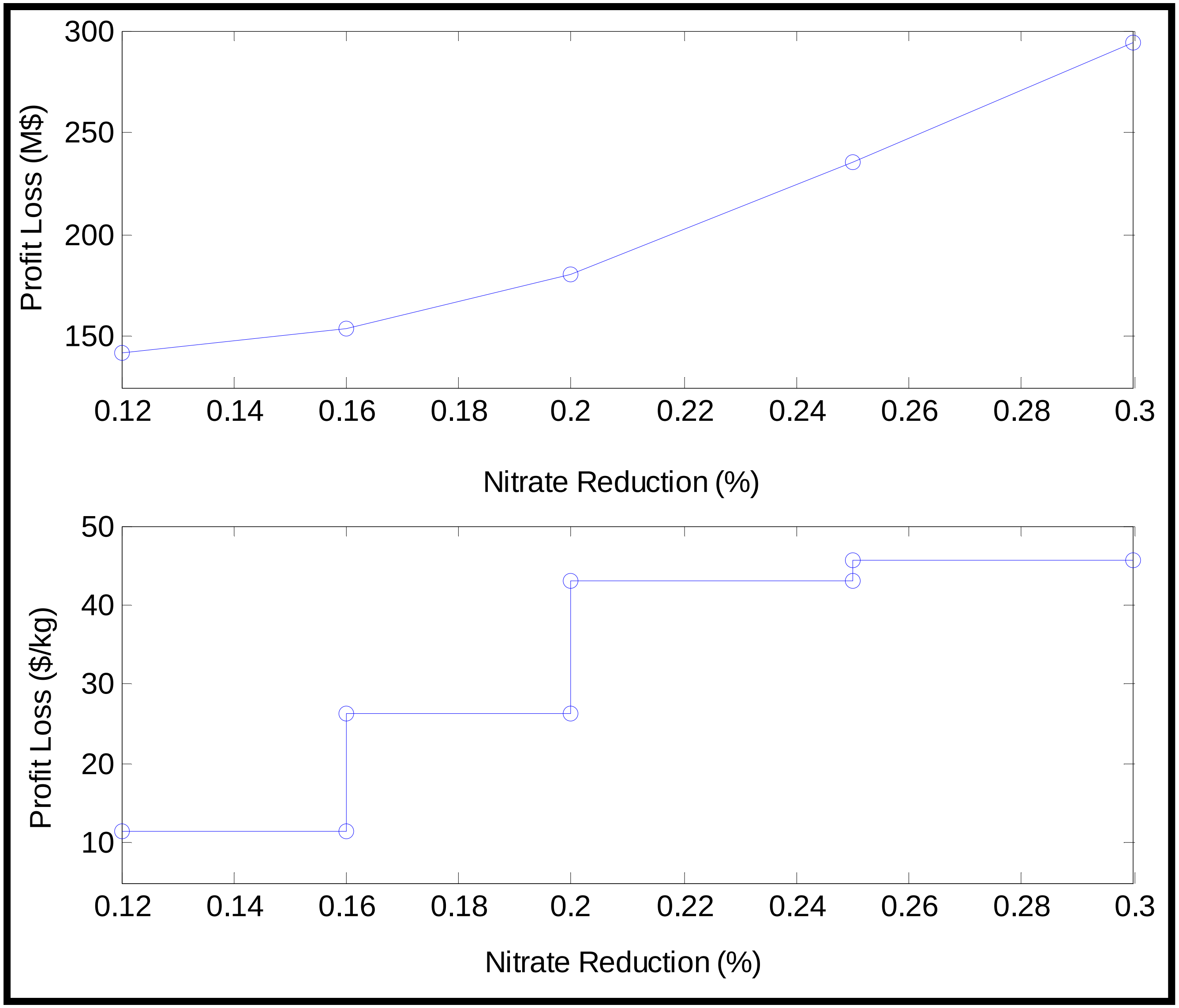
Impacts of Water Quality Constraints (to insure 20% annual N reduction)





Economical Impacts of Environmental Policies

Imposing different levels of nitrate reduction to examine profit loss



FOOD OR FUEL?

Nearly a billion people will go hungry tonight, yet this year the U.S. will turn nearly 5 billion bushels of corn into ethanol. That's enough food to feed 412 million people for an entire year.

8 BUSHELS OF CORN = 21.6 GALLONS OF ETHANOL FUEL OR ENOUGH FOOD TO FEED A PERSON FOR A WHOLE YEAR

DOING THE MATH...

5 billion bushels / 8 bushels of corn (enough calories to feed a person for a year) = sufficient calories to support 625 million people, minus one-third to account for distiller's grain (DDG) = 412 million

8 bushels of corn (feeds a person for a year)
X 2.7 gallons of ethanol per bushel
= 21.6 gallons of ethanol per bushel

SOURCES

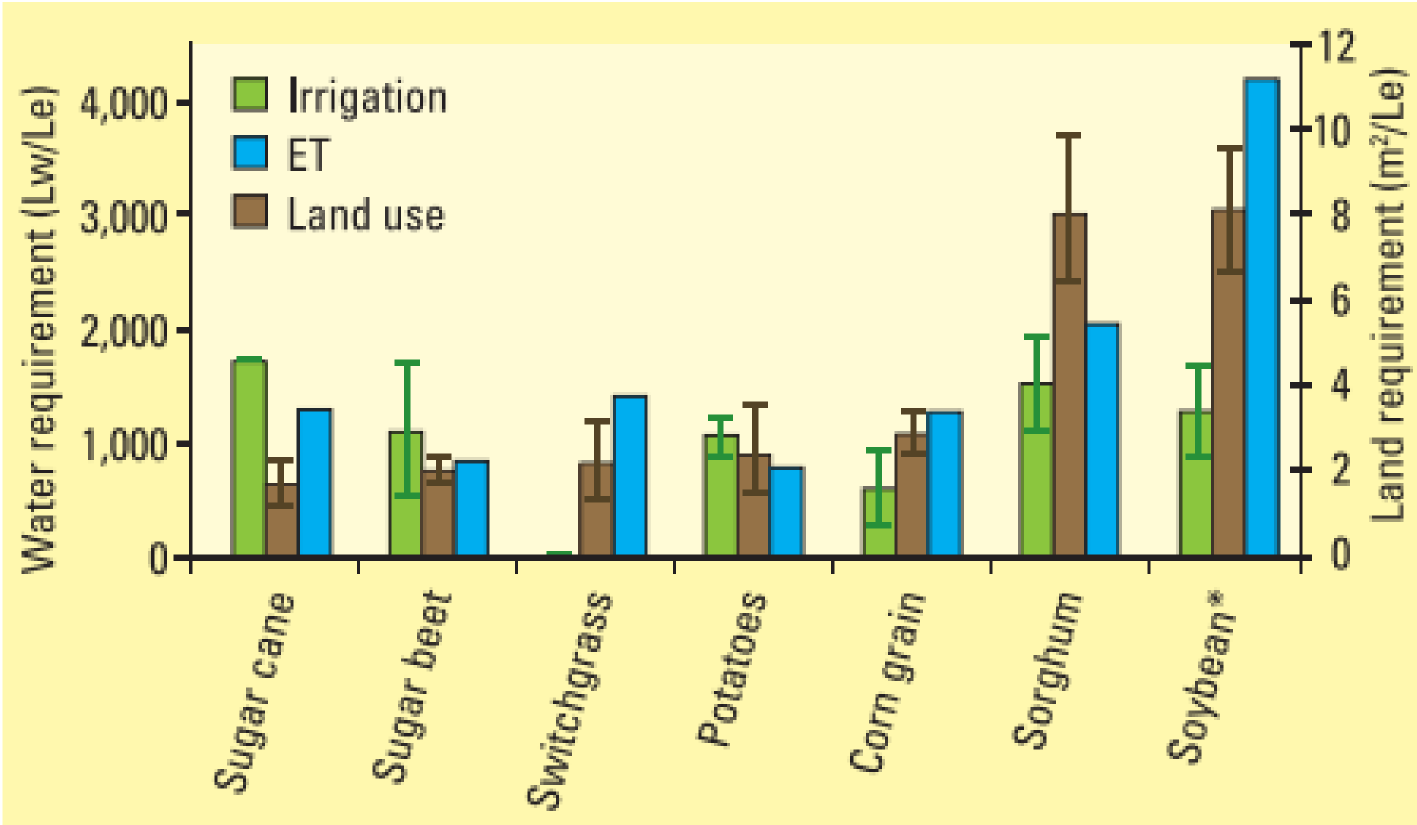
450 pounds of corn supplies enough calories for one person for a year
(http://www.foreignaffairs.com/articles/62609/c-ford-runge-and-benjamin-senauer/how-biofuels-could-starve-the-poor)

About 5 billion bushels of U.S. corn production is slated for ethanol production
(http://www.usda.gov/oce/commodity/wasde/latest.pdf)

One bushel of corn produces 2.7 gallons of ethanol
(Purdue Extension, "How Fuel Ethanol is Made From Corn," http://www.extension.purdue.edu/extmedia/ID/ID-328.pdf)

resource media

Food and Fuel Competing for Land and Water



Evapotranspiration, irrigation, and land requirements to produce 1 L of ethanol in the U.S. from different crops

(Source: Dominguez-Faus, 2009, EST)

Food vs. Fuel

Although the impact is extremely difficult to assess, bioenergy production is estimated to have caused up to 70%-75% of the rise in the global prices of some food stocks, including approximately 70% of the increase in maize prices. This can lead to:

- More irrigation for producing both food and fuel by using marginal land with inadequate precipitation
- More use of fertilizer and pesticide to increase yield
- Land use expansion: Marginal lands require even higher fertilizer application and are more susceptible to erosion

Economic and Environmental Tradeoffs

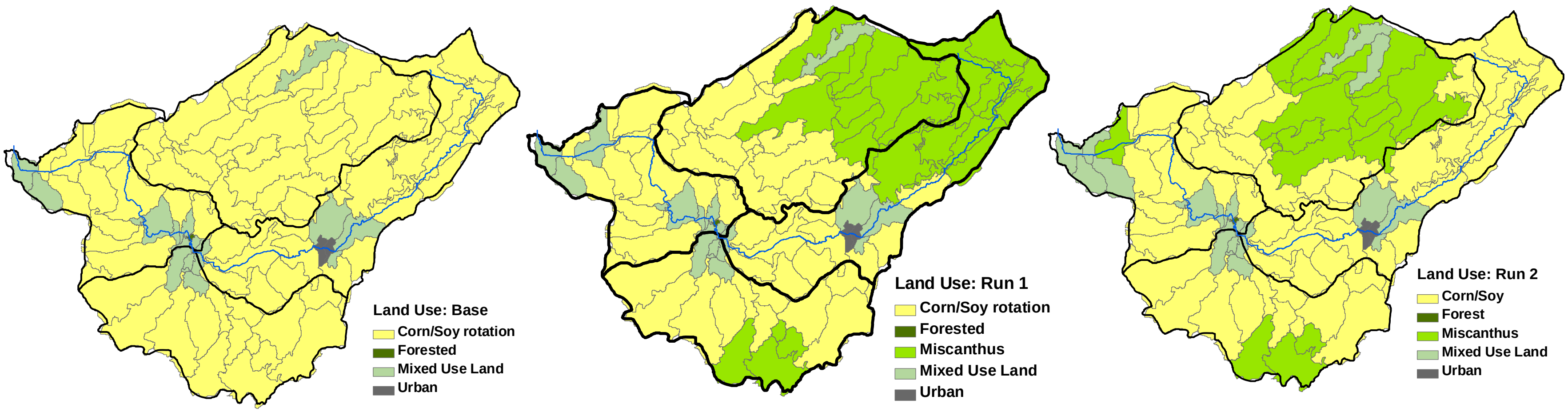
- Different feedstocks differentiate in term of biomass productivity, economic efficiency, carbon emission reduction and impact on water quantity and quality

- 1^{st} generation crops (e.g., corn) have lower costs, higher carbon emission and higher nitrate load

- Cellulosic biofuel crops have higher cost, lower carbon emission, lower nitrate load, and higher water requirement

- Which biofuel crop is more sustainable?

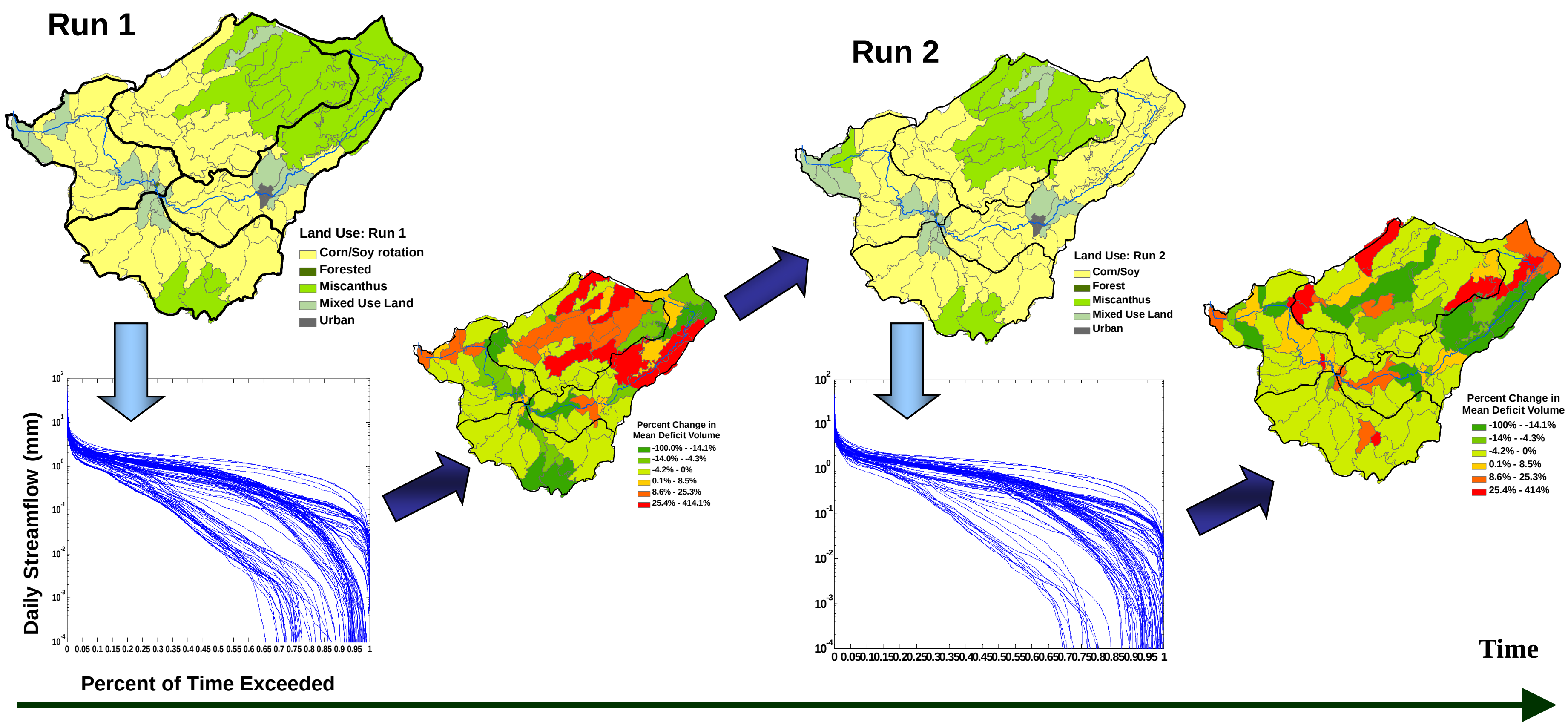
Case Study II: Price, Feedstock Choice and Impact on Flow and Water Quality



- **Base** run is the optimized land use case under current prices and conditions (*left*)
- **Run 1** represents an increase of 15% in the price of ethanol (*center*)
  - **Economic change that causes *Miscanthus* to become a profitable crop**, and thus areas of high *Miscanthus* yield switch to the new crop.
- **Run 2** represents a minimum flow requirement ("historical" minimum; here, the Base case) placed at the Monticello gauge (*right*).

(Source: X. Cai group)

Coupled System Trajectory



- Shifting the location of Miscanthus within the basin (Run 1 to Run 2) reduced deficit volumes relative to Run 1 (variable response)
  - Effect is shown as percent change in mean deficit volume using Q85 threshold.
- In the south, Miscanthus did not appear to have a large effect on the headwater streams in which it was planted.
  - Effects showed up downstream.

Outlook for Research

- Examining local suitability: Land, water and infrastructure, followed by considering the scale of economy
- Feedstock choice: dealing with multiple-aspect of tradeoffs and uncertainty with cellulosic crops. Which one is more sustainable?
- Integrated economic-environmental analysis: Considering the loss/gain of environmental value
- Water reallocation among food, fuel, and environment
- Conducting more careful studies on the effects of biofuel water use on environmental flow, regional climatic variability, and local and regional water stress

Outlook for Research

- Taking into account possible beneficial effects/synergies (UNEP, 2011), e.g. for food and fuel production through combined systems, irrigation using water with marginal quality, or using marginal land (Cai et al., 2011, EST)

- Exploring global opportunities in virtual resources trade (water and land) in the world

- Exploring policy and economic incentives for 2nd and even more advanced biofuel crops (specifically for tradeoff management)

Outlook for Research

- Adopting drought-tolerant or less-water consumptive feedstock with reasonable productivity

Low-input high-diversity (LIHD) mixtures of native perennials (Tilman, 2006, SCI)

Hydrogen production, green algae as source of energy