

# Development of an Intelligent Digital Watershed for sustainable Agro economy in the US Midwest

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# Introduction

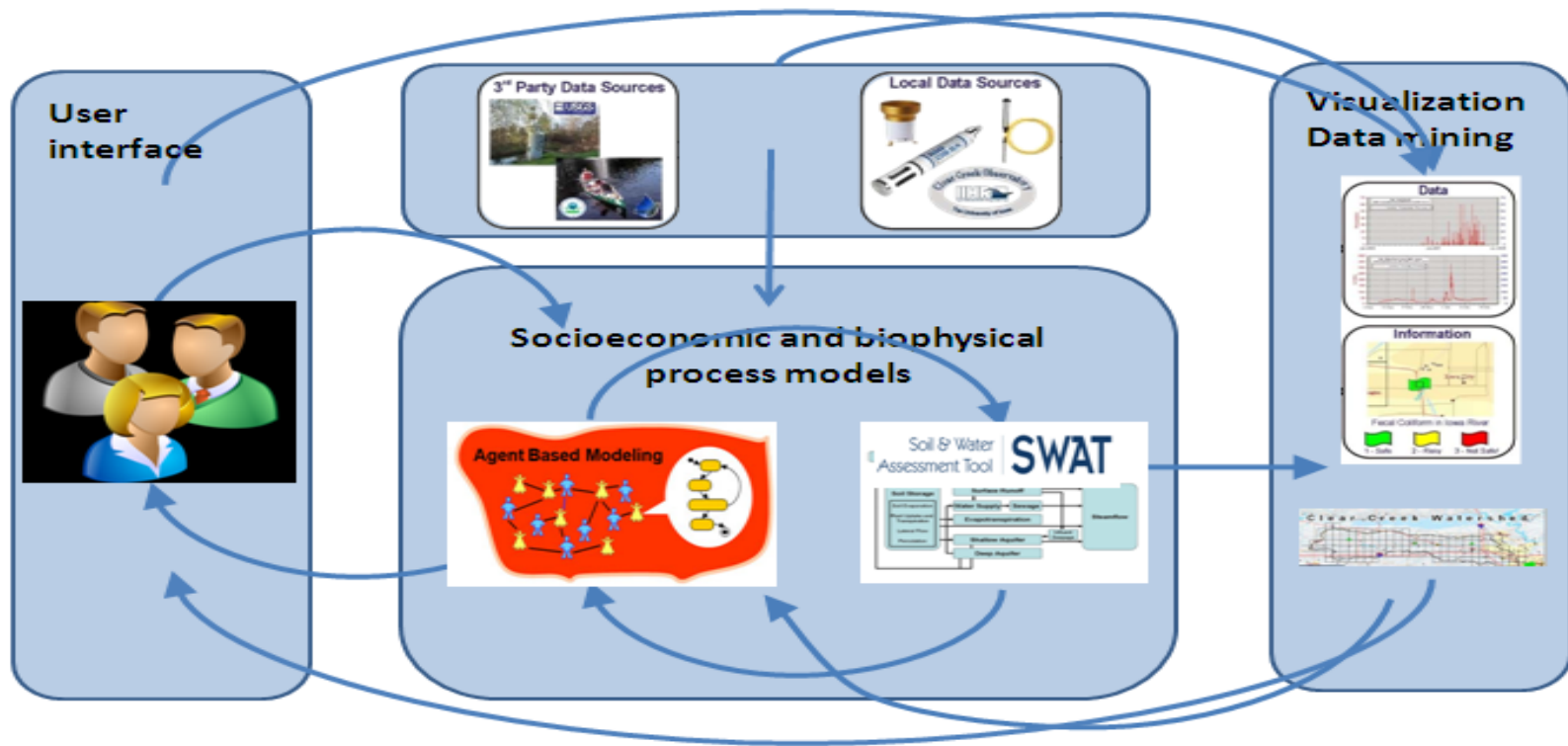
## Why CNH?

- Human activity is intricately linked to the quality and quantity of water resources. Although many studies have examined human-water dynamics, the complexity of such coupled systems is not well understood.
- Do decision-makers understand the tradeoffs among economic return and environmental impact given alternative assumptions about the application of nutrients? Does such understanding change the way farmers manage the landscape or regulators set policies?

## **Objectives:** Built framework of linked socioeconomic and biophysical processes:

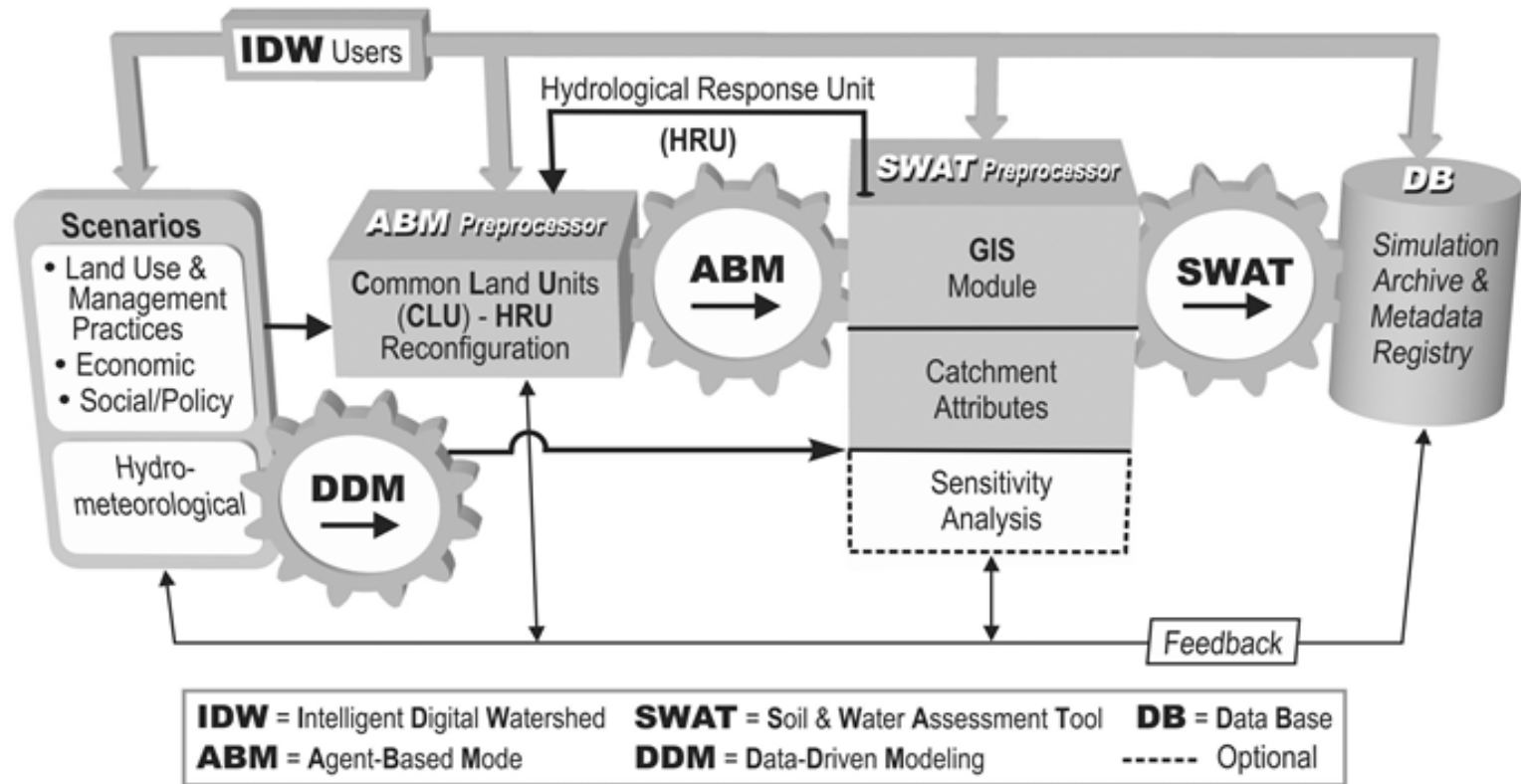
1. Understand the connections that exist between the expanding biofuel economy, land management, and water quality impacts
2. Develop CI-enabled technologies to assist:
  - researchers transform data into knowledge about interrelated socioeconomic and biophysical processes
  - stakeholders transform data into more informed decision-making through an understanding of these processes

# Approach: Linking socioeconomic and biophysical processes



- Land-use models that simulate decision-making under alternative scenarios about:
  - Agricultural and environmental policies
  - Market forces associated with biofuel production
  - And to a lesser degree climate change
- Modeled decisions are linked to an existing watershed simulation model to understand the impact these scenarios may have on indicators of water quality (nitrate, phosphate, dissolved oxygen)

# Framework



# Workflows

- **ABM workflow:** ABM simulates actions and interactions of heterogeneous autonomous agents in complex adaptive systems. Agents in the system make decisions and behave based on specific decision-making heuristic, learning and adaption rules. The ABM developed by this research team is focused on land use modeling. It was developed **to capture and represent:** 1) the heterogeneous set of driving forces on land-use decisions, 2) the interactions among agents, and between agents and environment, and 3) the complex feedback mechanisms and non-linear dynamics.

**SWAT workflow:** SWAT is a widely used semi distributed watershed model for predicting the impact of land management practices on water, sediment, and agricultural chemical yields in large, complex watersheds with varying soils, land use, and management conditions over long periods of time. This workflow entails the preparation of the static data as described above using mostly freely-available data. The dynamic data, i.e., stream flow, weather data, and water quality are stored in the IDW using the workflows described above.

**Feedback workflow:** The user can choose to run SWAT or SWAT alone or connected back-to-back as illustrated in Figure. Moreover user can visualize, interact and generate report for each unique simulation. More relevant in the present context is the capability of the repeated simulations to reciprocally inform the two domain models on **extrogeneous driving forces** or imposed thresholds not included in the individual simulations (e.g., the impact of environmental regulation on farmer decision-making). The feedback from SWAT to ABM allows to **parameterize the optimization models** by farmer agents.

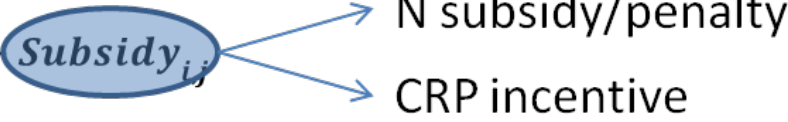
# Agents' decision-making processes

## ➤ Decision variables

- Crop : corn, soybean, stover, switchgrass, CCRP, GCRP
- Tillage: conventional, mulch, no
- Fertilizer: N, P, K

## ➤ Objective: maximize farm total profit over planning horizon

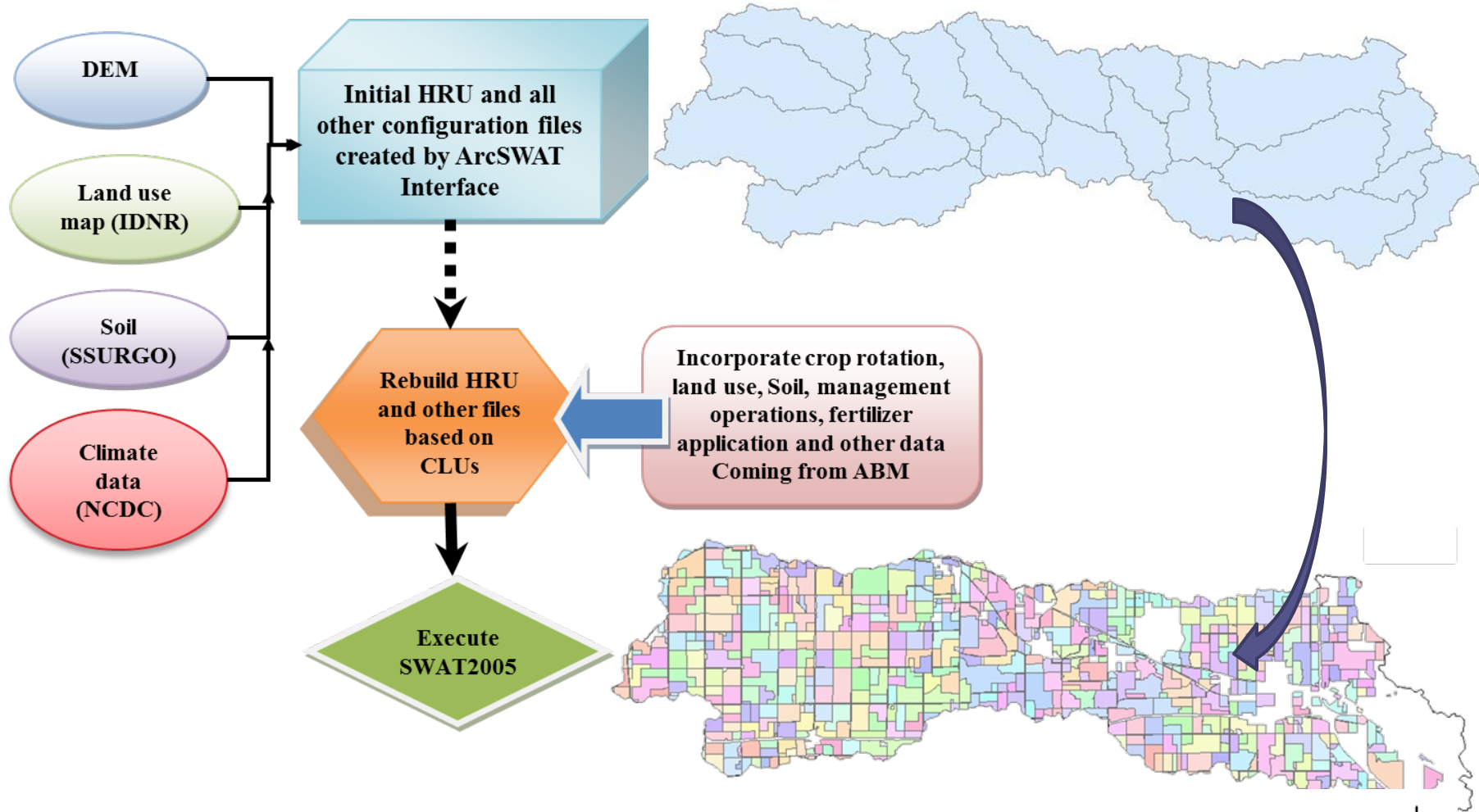
$$\max TPT = \sum_{i=1}^N \sum_{j=1}^n Sale_{i,j} - Cost_{i,j} + \text{Subsidy}_{i,j}$$



## ➤ Subject to constraints

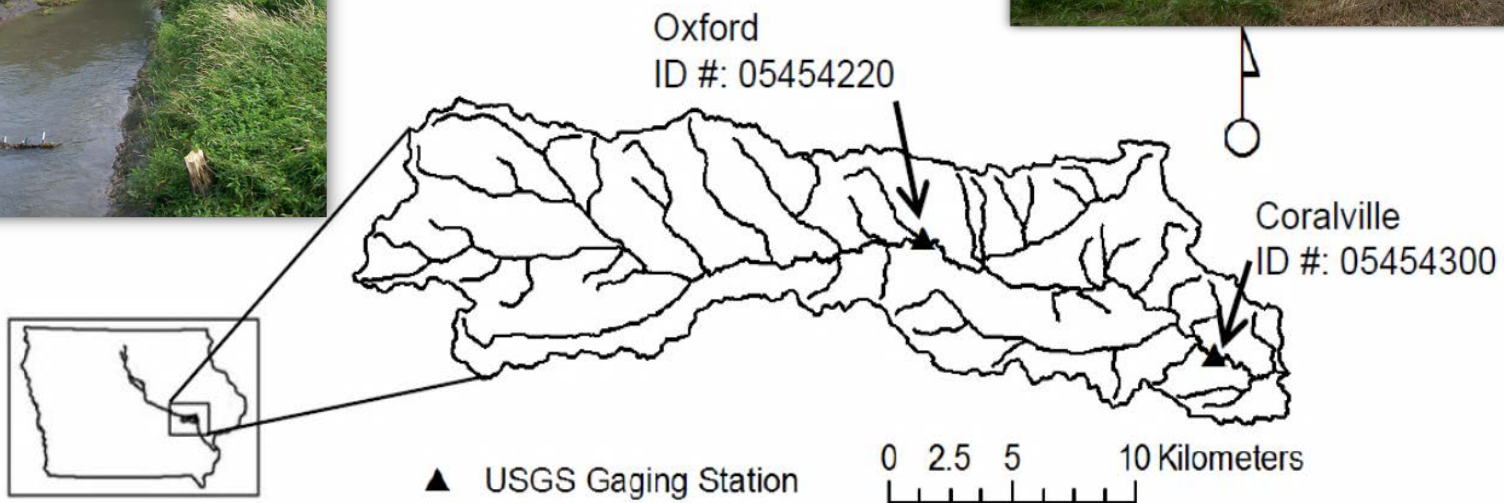
- Crop Decision (corn, soybean, stover, fallow, switchgrass, GCRP, CCRP)
  - One and only one type of crop or land cover must be chosen for each CLU
  - Stover is associated with corn
  - Switchgrass and CRP has to be kept throughout the whole planning horizon

# SWAT workflow



# Study area

- **Clear Creek watershed:**
- CCW is a 267 km<sup>2</sup> HUC 10 (Hydrologic Unit Code 10) located in east-central Iowa Approximately 85% of the land cover is agricultural or grassland (pastureland). 3 sampling stations (near real-time)





# Survey to define “Agents”

6. How many more years do you plan to farm?

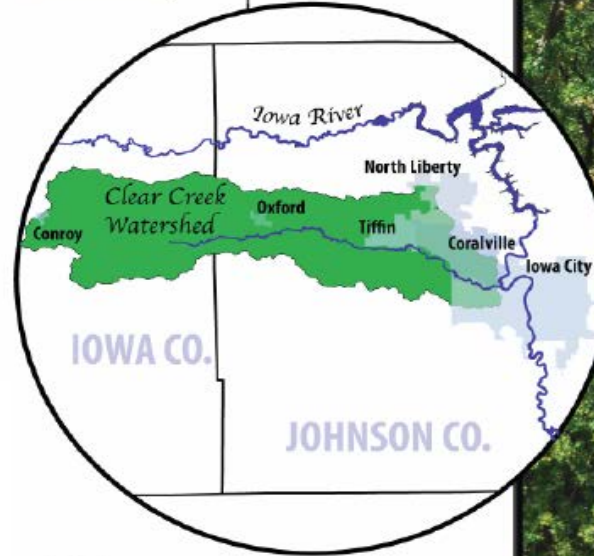
- \_\_\_\_\_ years
- I am already retired from farming
- I do not farm

7. Considering all sources of agricultural income (including government payments), what was the total gross value of your agricultural income in 2008?

- None
- \$ 1–\$ 24,999
- \$ 25,000–\$ 99,999
- \$100,000–\$249,999
- \$250,000–\$499,999
- \$500,000–\$999,999
- \$1,000,000 and over

8. In the past five years, approximately what percent of your household income has come from farming?

- 0%
- 1–25%
- 26–50%
- 51–75%
- 76–100%



## Questions on biofuel production

38. Do you sell any of your corn to an ethanol plant?  Yes  No

39. Have you ever invested in the ethanol industry?  Yes  No

40. How knowledgeable are you about the harvesting and marketing of

Corn stover (stem residue)	1	2	3	4	5
	(not at all knowledgeable)			(very knowledgeable)	
Switchgrass	1	2	3	4	5
	(not at all knowledgeable)			(very knowledgeable)	

41. In 2009, did you harvest and sell any corn stover?

- Yes  No

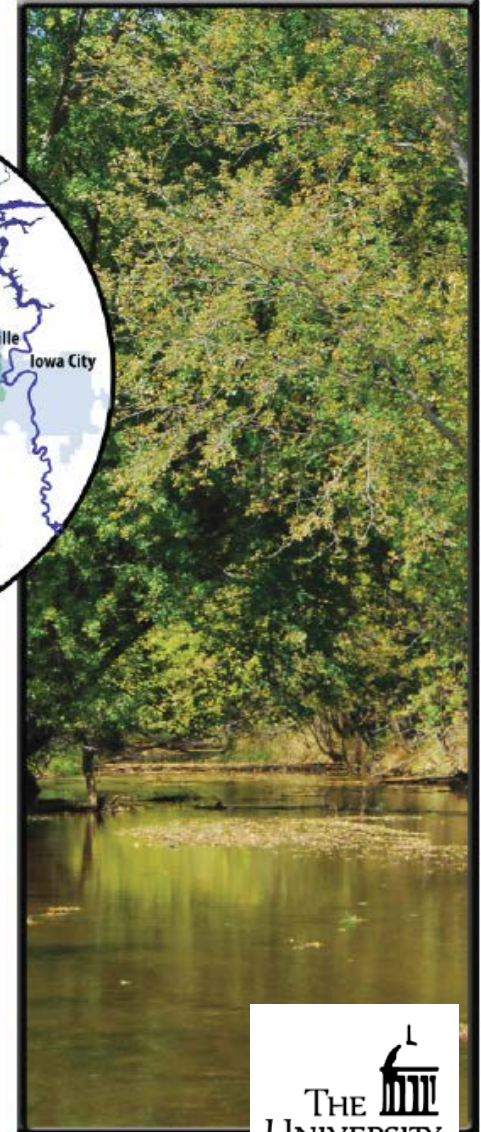
42. In the past 5 years, have you harvested or hired someone to harvest your hay?

- Yes  No  No hay harvested in past 5 years

c. government subsidies	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
d. Special insurance to lower the risk	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
e. bank financing	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
f. Using a co-op to handle delivery arrangements	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

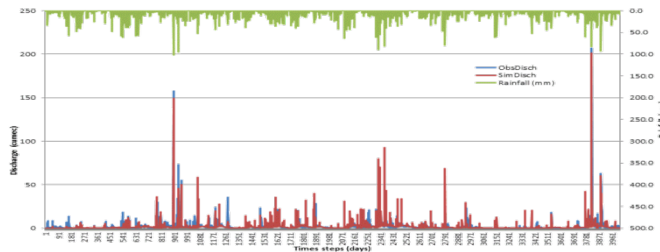
# Clear Creek Watershed

## 2010 Agricultural Land Survey

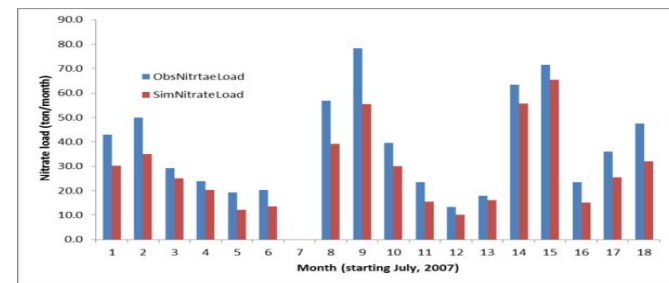
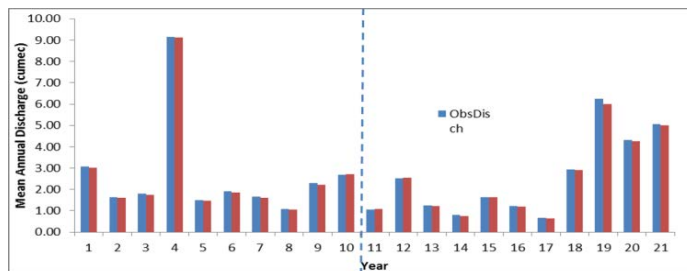
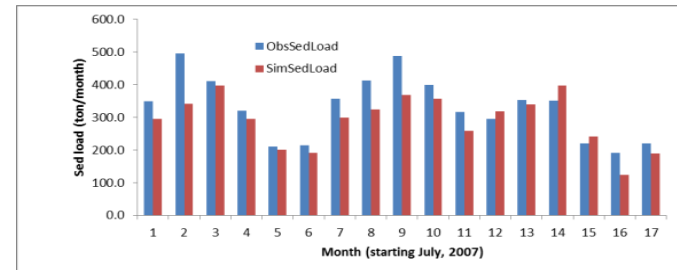
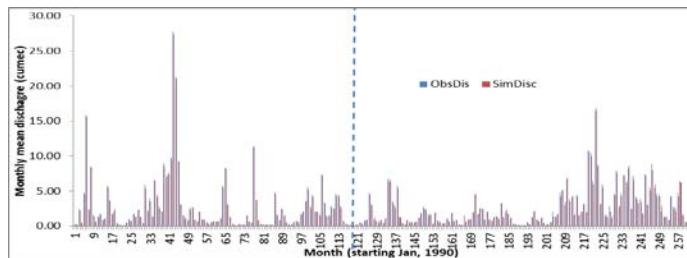


# SWAT calibration and Validation

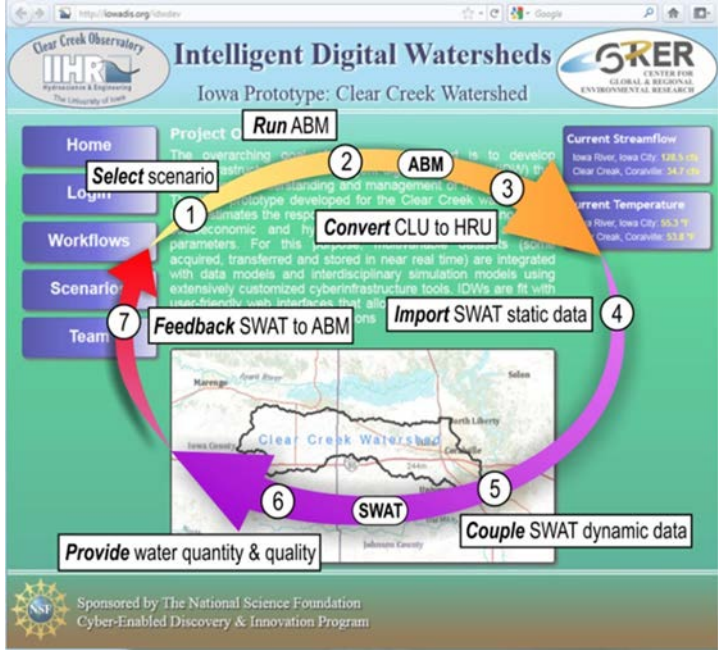
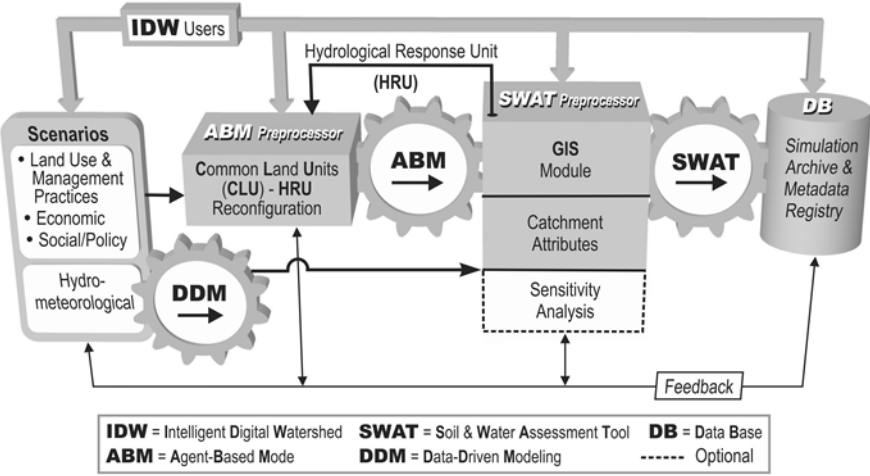
- SWAT model was set up with 5% contributing source area (CSA) which resulted into 21 sub basins. Discharge and other water quality parameters were calibrated at the watershed outlet at Clear Creek. Regression coefficient ( $R^2$ ) obtained for monthly discharge was 0.85 and for yearly it was 0.91. For sediment  $R^2$  obtained for monthly simulation was: **0.78** and for Nitrate  $R^2$  obtained for monthly simulation was: **0.72**.



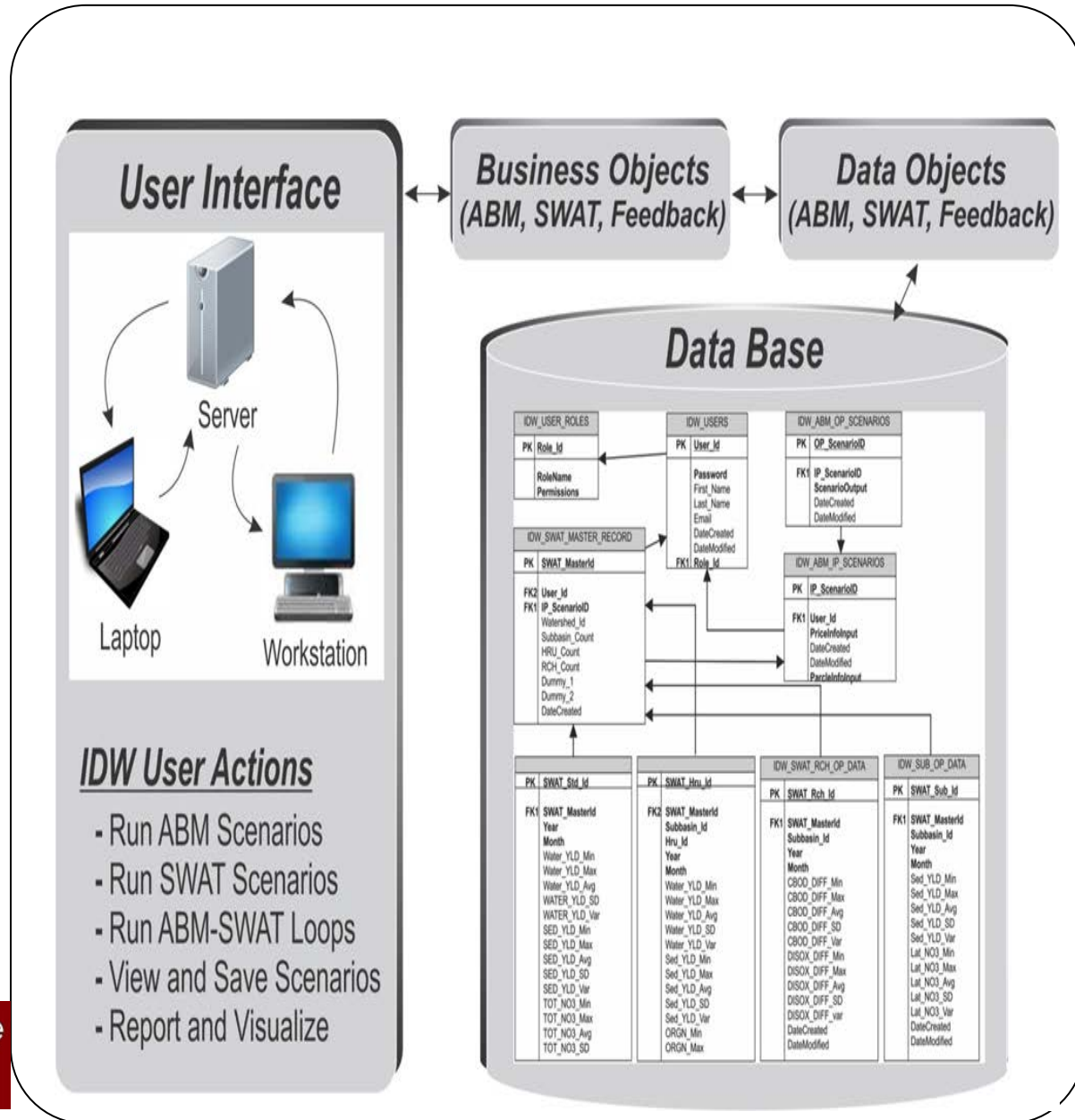
Time step	Regression Correlation coefficient ( $R^2$ )	
	Calibration	Validation
Daily	0.78	0.76
Monthly	0.85	0.83
Yearly	0.91	0.90



# Intelligent Digital Watershed



# IDW operational flux



# Clear Creek Intelligent Digital Watershed

Intelligent Digital Watersheds  
Iowa Prototype: Clear Creek Watershed

Current Streamflow  
Iowa River, Iowa City: 198.5 cfs  
Clear Creek, Corvallis: 34.7 cfs

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**Project Workflows**

**Agent-Based Modeling**  
Agent-based models (ABM) simulate actions and interactions of individuals or autonomous agents in complex adaptive systems. Agents in ABM are based on specific decision-making logic. Agent ABM developed by this research team is focused on land use, water and wetland. It is heterogeneous set of flows in the subwatershed among agents, and between agents and landscape characteristics and land flow systems.

**SWAT Modeling**  
The Soil Water Assessment Tool (SWAT) is a semi-distributed watershed model that simulates the impact of land management practices on water quality in large, complex watersheds with varying soils, topography and land cover, over long periods of time. SWAT model can assess existing water resources and model future pollution prevention and conservation measures across the globe.

**Fully Coupled ABM-SWAT Model**  
The user can choose to run SWAT-ABM back-to-back. Most of the capabilities of the traditional watershed model are preserved. The integration of the two models allows for the simulation of the interaction between the two models and the management practices using the coupled ABM-SWAT model.

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Intelligent Digital Watersheds  
Iowa Prototype: Clear Creek Watershed

Current Streamflow  
Iowa River, Iowa City: 198.5 cfs  
Clear Creek, Corvallis: 34.7 cfs

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**SWAT Modeling**

**SWAT Settings**  
The model was built using a 30m DEM from the Iowa DNR and 2001 USDA, National and SSURGO soil data. Calibration and validation was performed for the period 2000 and 2010.

Select Precipitation Time Series  
Select a site: 134101 Iowa City  
Begin Date: 1/1/2000  
End Date: 9/30/2011

Select Alternative Weather Scenario  
Time Series Scaling Factor: 1.0

Download Data

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Intelligent Digital Watersheds  
Iowa Prototype: Clear Creek Watershed

Current Streamflow  
Iowa River, Iowa City: 198.5 cfs  
Clear Creek, Corvallis: 34.7 cfs

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**SWAT Simulation**

Selected Simulation Attributes  
Simulation Start Date: 1/1/2009 12:00:00 AM  
Simulation End Date: 9/30/2010 12:00:00 AM  
Weather Station Code: Iowa City - 134101  
Weather Scenario Generated: Measured Precipitation

Simulation Output Options  
Print pesticide output?   
Print soil chemical output?

Run SWAT

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Intelligent Digital Watersheds  
Iowa Prototype: Clear Creek Watershed

Current Streamflow  
Iowa River, Iowa City: 198.5 cfs  
Clear Creek, Corvallis: 34.7 cfs

Current Temperature  
Iowa River, Iowa City: 58.3 F  
Clear Creek, Corvallis: 53.8 F

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**Model Output**

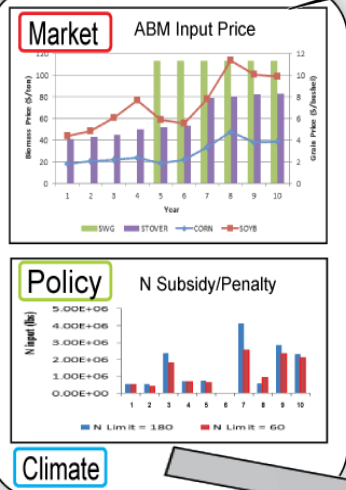
```
SWAT2010
Soil & Water Assessment Tool
PC Version
Program reading from file.cio . . . executing
Executing year 1
Executing year 2
Executing successfully completed
```

View the completed simulation files: [here](#)

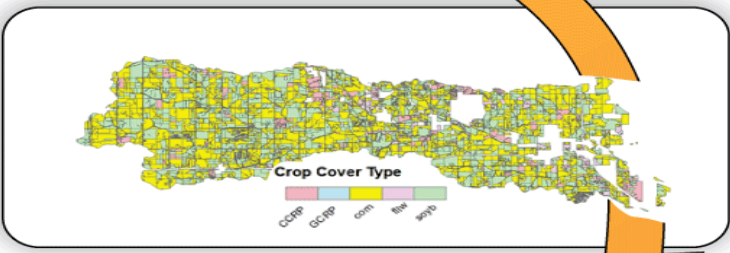
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Indian Institute of Technology Delhi  
New Delhi, India

**Select Scenario** ①



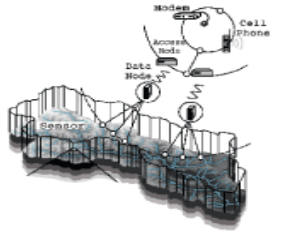
**Run ABM** ②



**Convert CLU to HRU** ③

**Observation System & Network**

Weather data (NCDC, INWS, Daymet, HydroNEXRAD)



Surface water quantity/quality data (USGS, EPA, local sources)

**SWAT Repository**

Management dataset (static)  
Land use  
Crop rotation  
Tillage practice

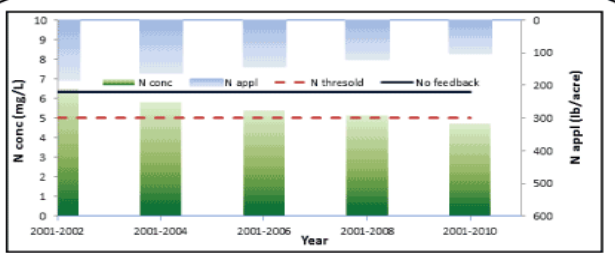
**Import Static Data** ④

Hydrometeo dataset (dynamic)  
Precipitation, solar radiation, temperature, humidity

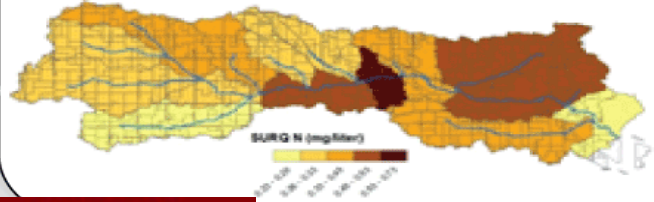
**Couple Dynamic Data** ⑤

Hydrographic dataset  
SWAT Preprocessor

**Feedback SWAT to ABM**

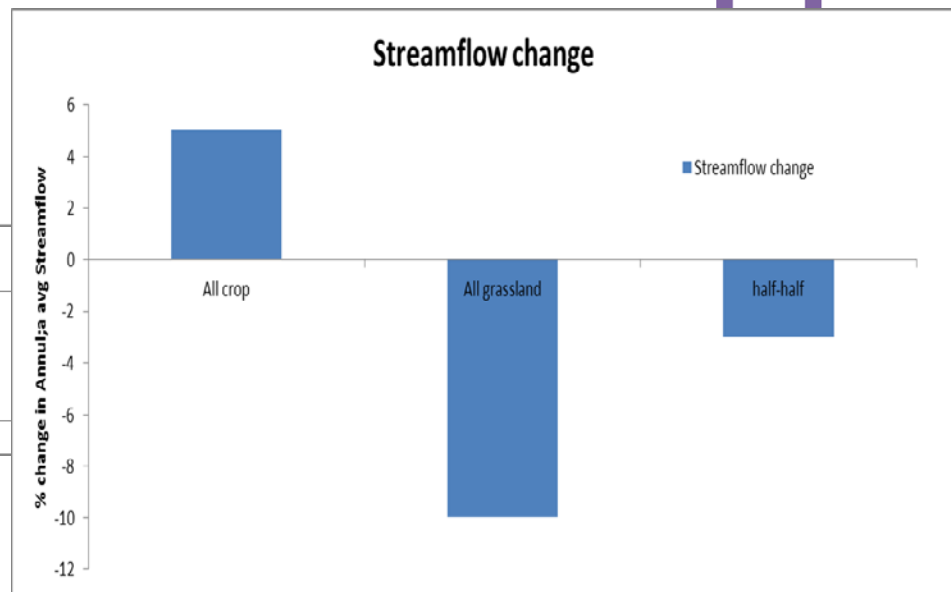
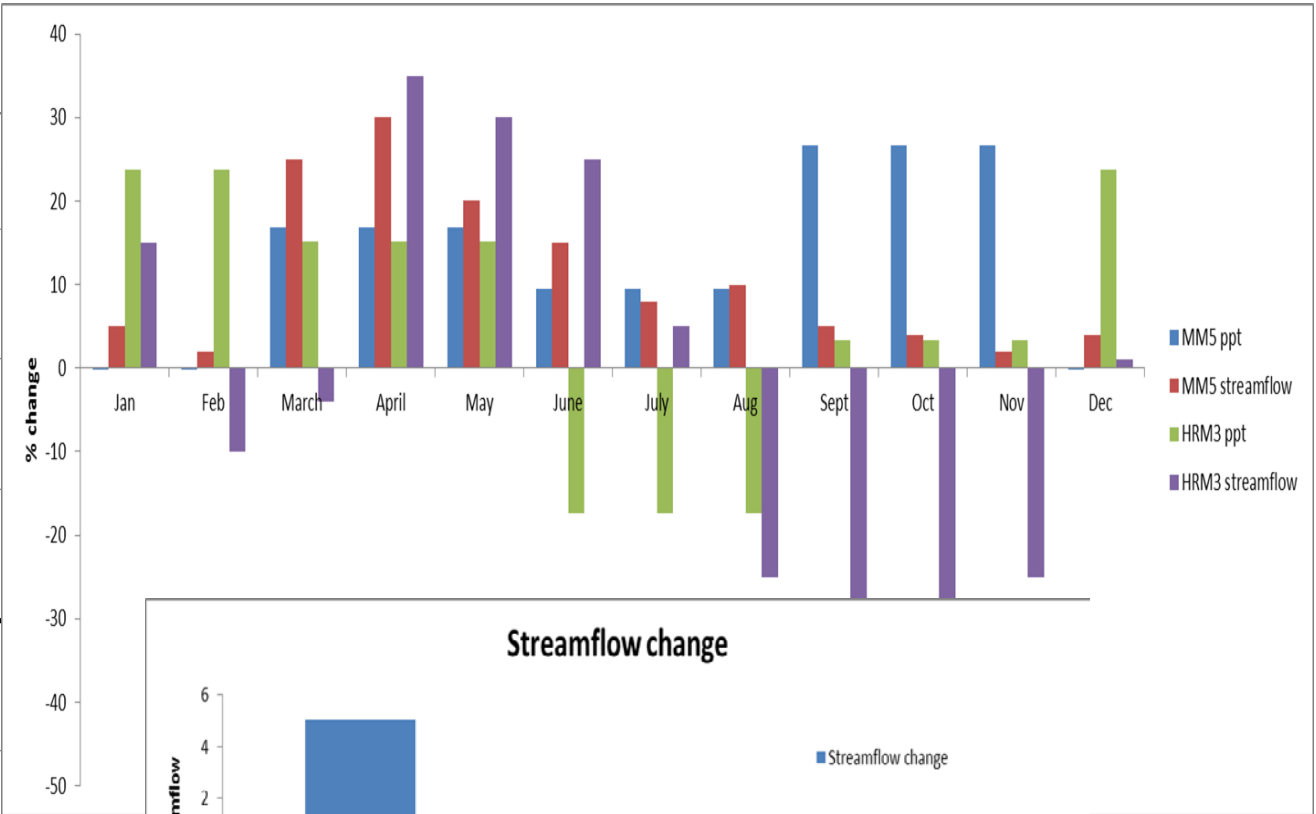
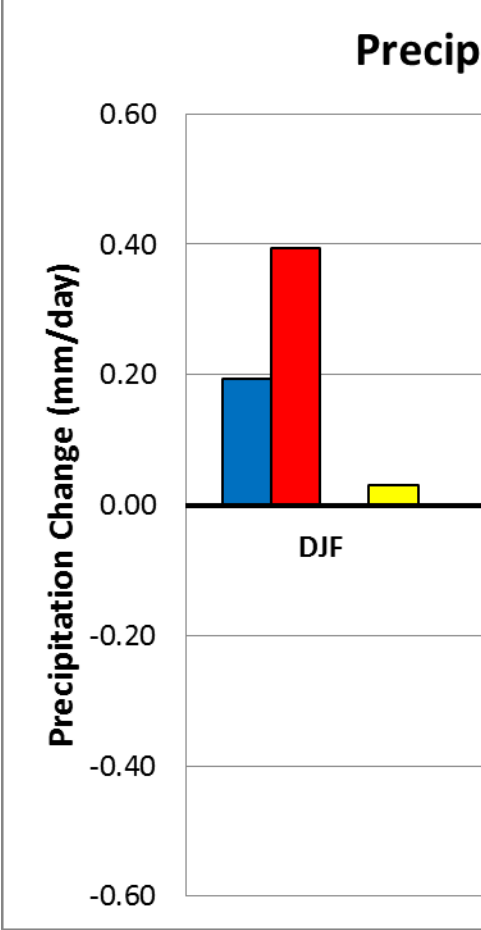


**SWAT Output** (e.g. N in surface runoff at subbasin level)



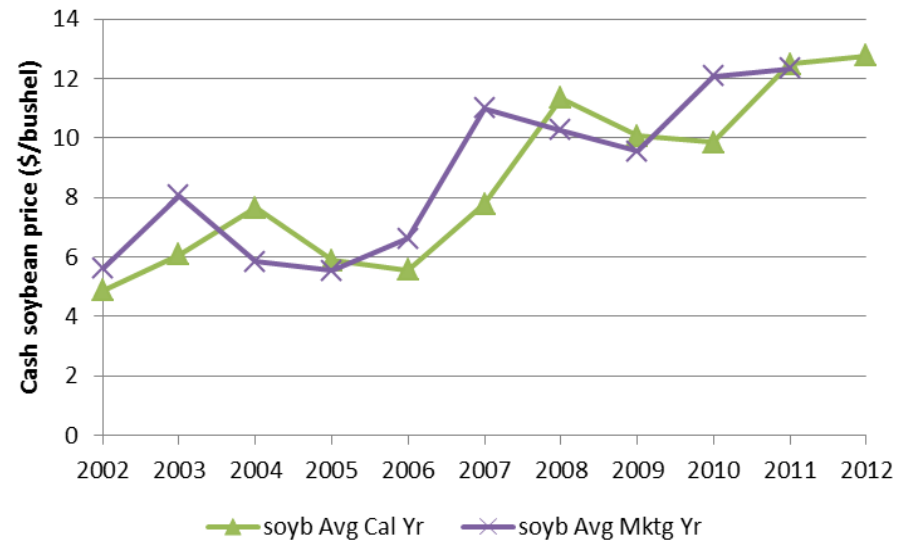
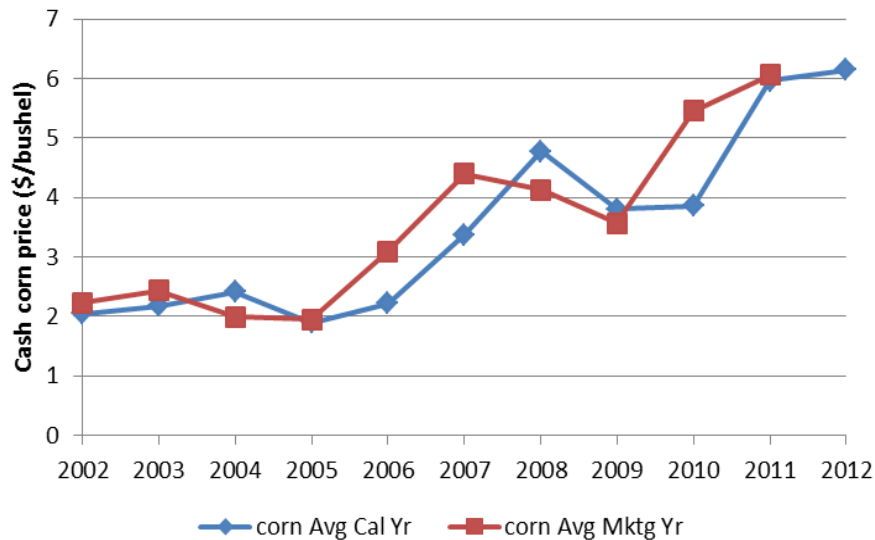
**Run SWAT** ⑥

# Building weather scenarios:



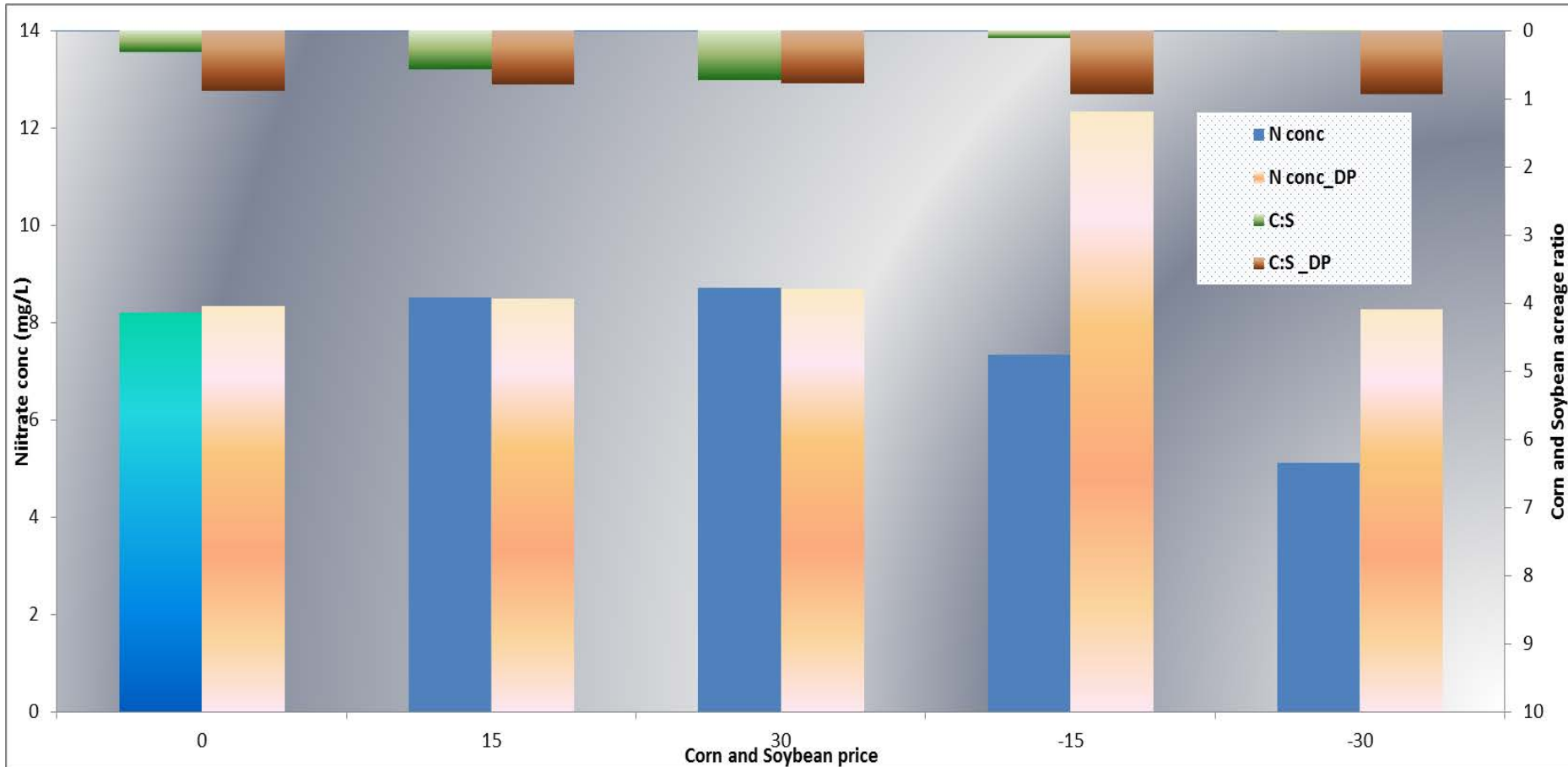
# Market scenarios:

Scenario	Corn and Soybean prices	Direct payment and counter-cyclical payment	Switchgrass and corn stover	N tax	Fertilizer and fuel prices
Price0	Historical prices	No payment	No market	No tax	Historical prices
PriceInc15	increased by 15%	No payment	No market	No tax	Historical prices
PriceInc30	increased by 30%	No payment	No market	No tax	Historical prices
PriceDec15	decreased by 15%	No payment	No market	No tax	Historical prices
PriceDec30	decreased by 30%	No payment	No market	No tax	Historical prices
Price0_DCP	Historical prices	All payment*	No market	No tax	Historical prices
PriceInc15_DCP	increased by 15%	All payment*	No market	No tax	Historical prices
PriceInc30_DCP	increased by 30%	All payment*	No market	No tax	Historical prices
PriceDec15_DCP	decreased by 15%	All payment*	No market	No tax	Historical prices
PriceDec30_DCP	decreased by 30%	All payment*	No market	No tax	Historical prices



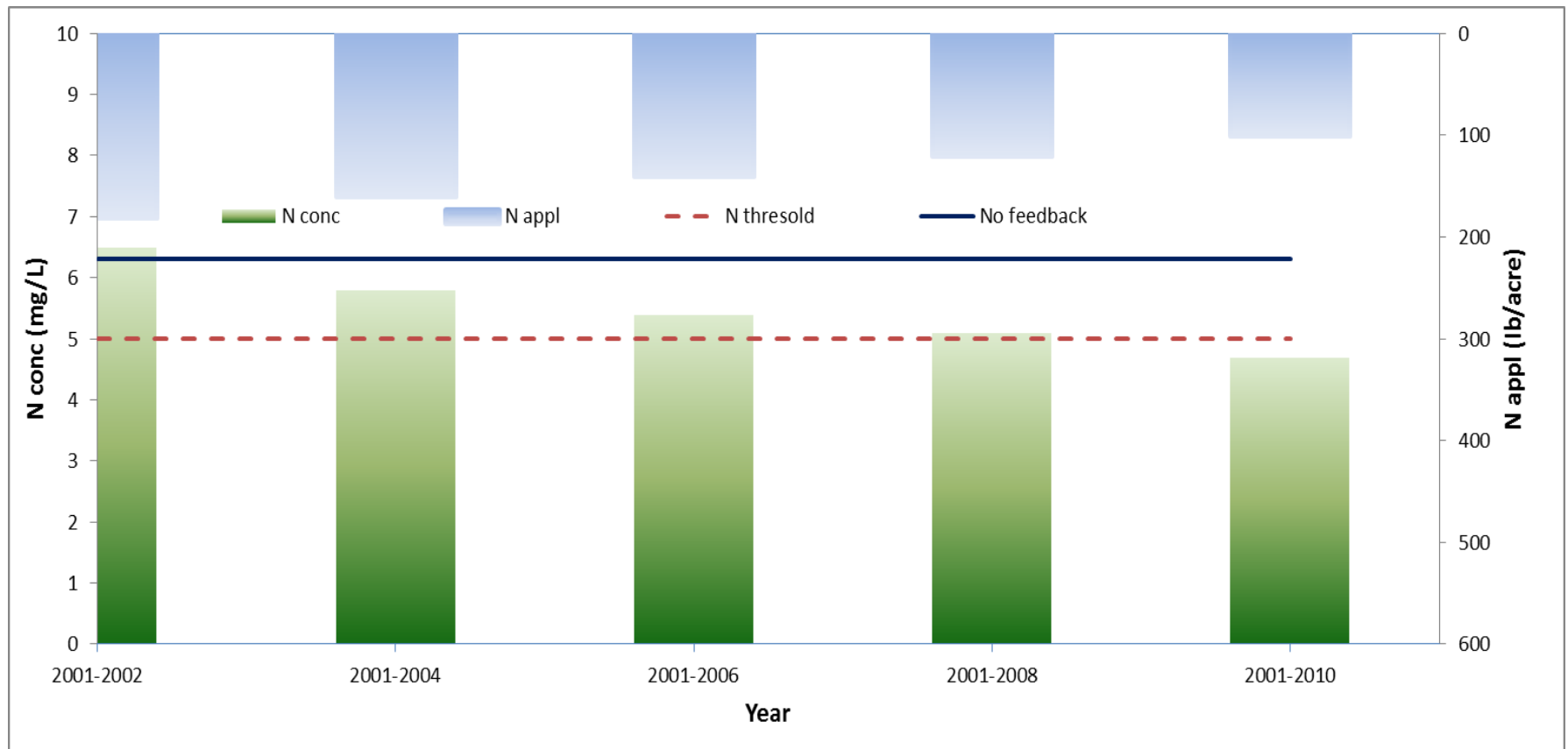


# Contd...



Direct payment and counter-cyclical payment are commodity subsidy programs stated in Farm Bills 2002 and 2008. Basically, when effective prices (max(market price, national loan rate) + direct payment) is lower than the target price, farmers can get cyclical payments from government if they plant corn or soybean. I simply replace the cash corn (soybean) prices with the target prices when the former are lower. Target prices are specified in Farm Bills 2002 and 2008.

# Policy implication: N subsidy or penalty



Determine how the rates will be adjusted according to water quality dynamics both spatially and temporally.

# Expected outcomes

- Through the exploration of this database users can identify conditions that lead to desirable socio-economic outcomes with preservation of water quantity and quality in the watershed streams. Using this “intelligent” CI system, managers can find answers to such questions as :
  - What is the **response of the hydrologic system to shifts in economic drivers** (e.g., in response to changes in the ethanol content of gasoline) or emerging technologies (the development of economically viable cellulosic ethanol production)?
  - **What motivates individuals** as they make decisions that affect land management?
  - What **planning horizon** is important to decision-makers, how does this vary based on public policy, economic condition, or available technology?
  - What impact does improved knowledge about environmental effects of decisions have on the **decision-making process**?

Thank you