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

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Introduction

Why CNH?

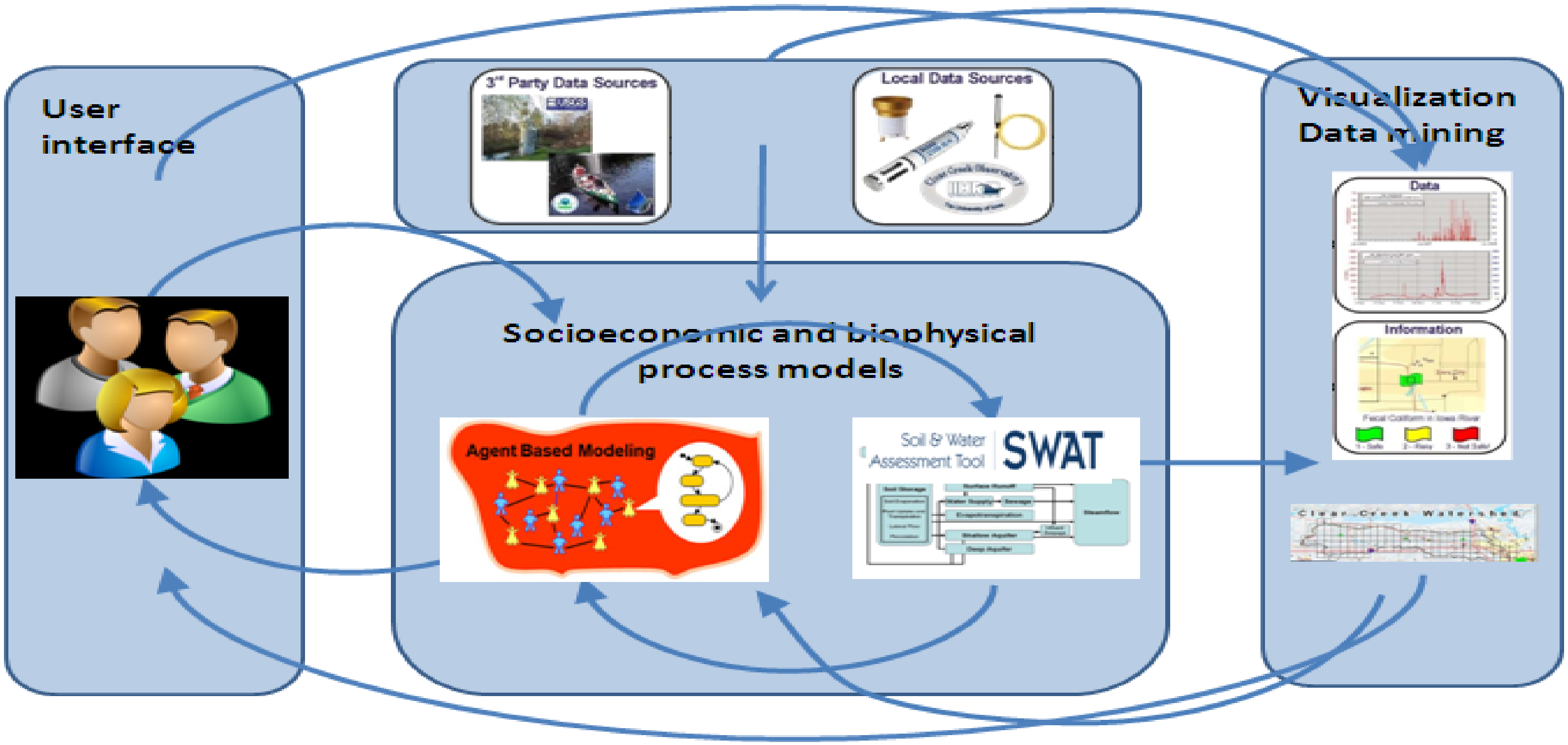
- Human activity is intricately linked to the quality and quantity of water resources. Although many studies have examined human-water dynamics, the complexity of such coupled systems is not well understood.
- Do decision-makers understand the tradeoffs among economic return and environmental impact 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

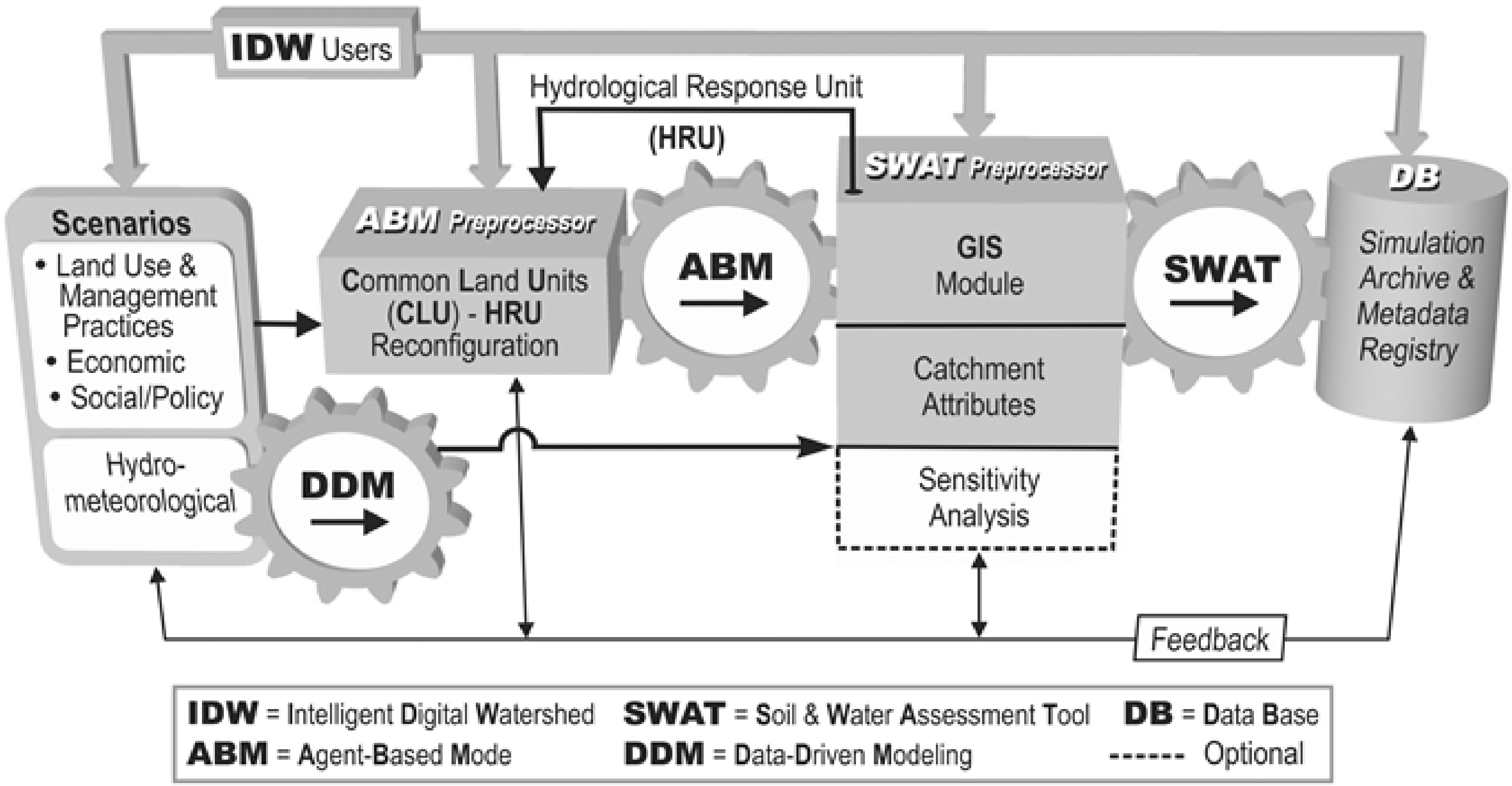
Approach: Linking socioeconomic and biophysical processes



- 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


IDW Users
Hydrological Response Unit
(HRU)
Scenarios
• Land Use & Management Practices
• Economic
• Social/Policy
Hydro-meteorological
ABM Preprocessor
Common Land Units (CLU) - HRU Reconfiguration
ABM
DDM
SWAT Preprocessor
GIS Module
Catchment Attributes
Sensitivity Analysis
SWAT
DB
Simulation Archive & Metadata Registry
Feedback
IDW = Intelligent Digital Watershed
SWAT = Soil & Water Assessment Tool
DB = Data Base
ABM = Agent-Based Mode
DDM = Data-Driven Modeling
------ Optional

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

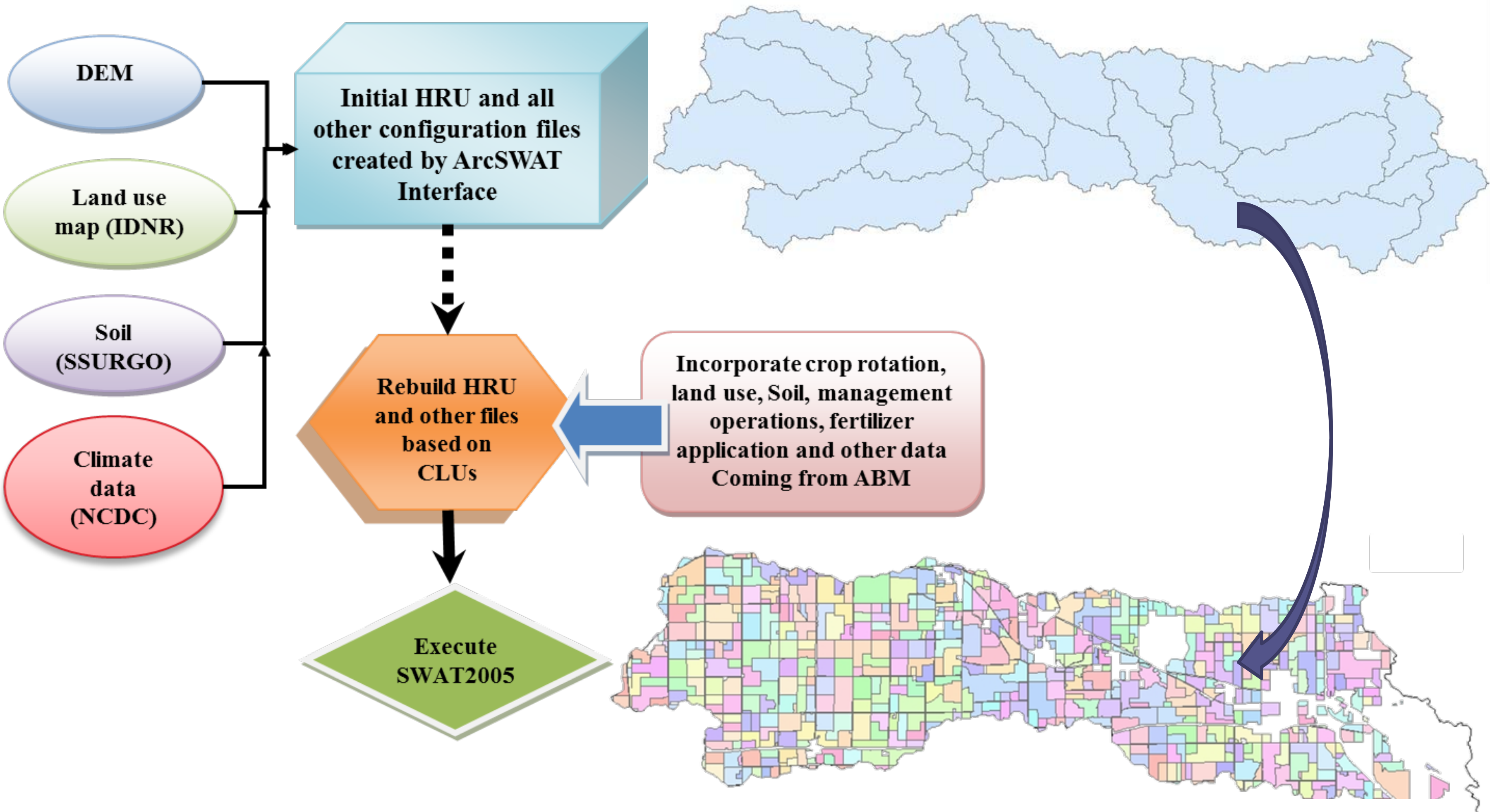
- Decision variables
  - Crop : corn, soybean, stover, switchgrass, CCRP, GCRP
  - Tillage: conventional, mulch, no
  - Fertilizer: N, P, K
- Objective: maximize farm total profit over planning horizon

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

$Subsidy_{i,j}$ → N subsidy/penalty; CRP incentive

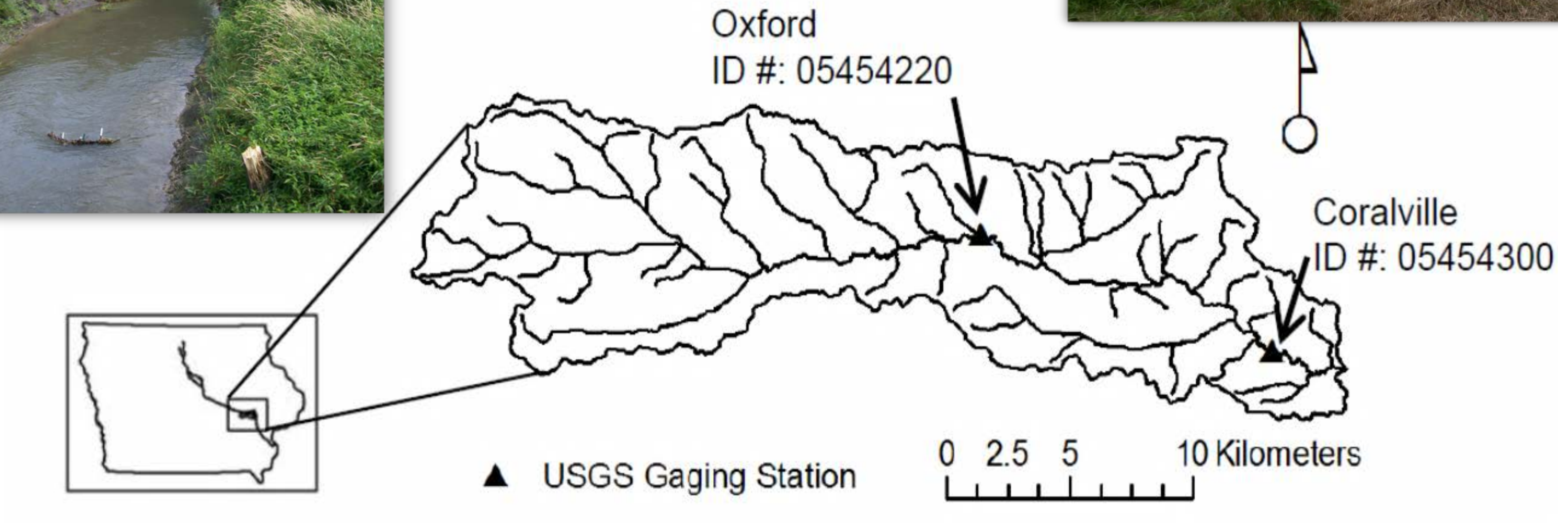
- Subject to constraints
  - Crop Decision (corn, soybean, stover, fallow, switchgrass, GCRP, CCRP)
    - One and only one type of crop or land cover must be chosen for each CLU
    - Stover is associated with corn
    - Switchgrass and CRP has to be kept throughout the whole planning horizon

SWAT workflow



Study area

- **Clear Creek watershed:**
- CCW is a 267 km^2 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)



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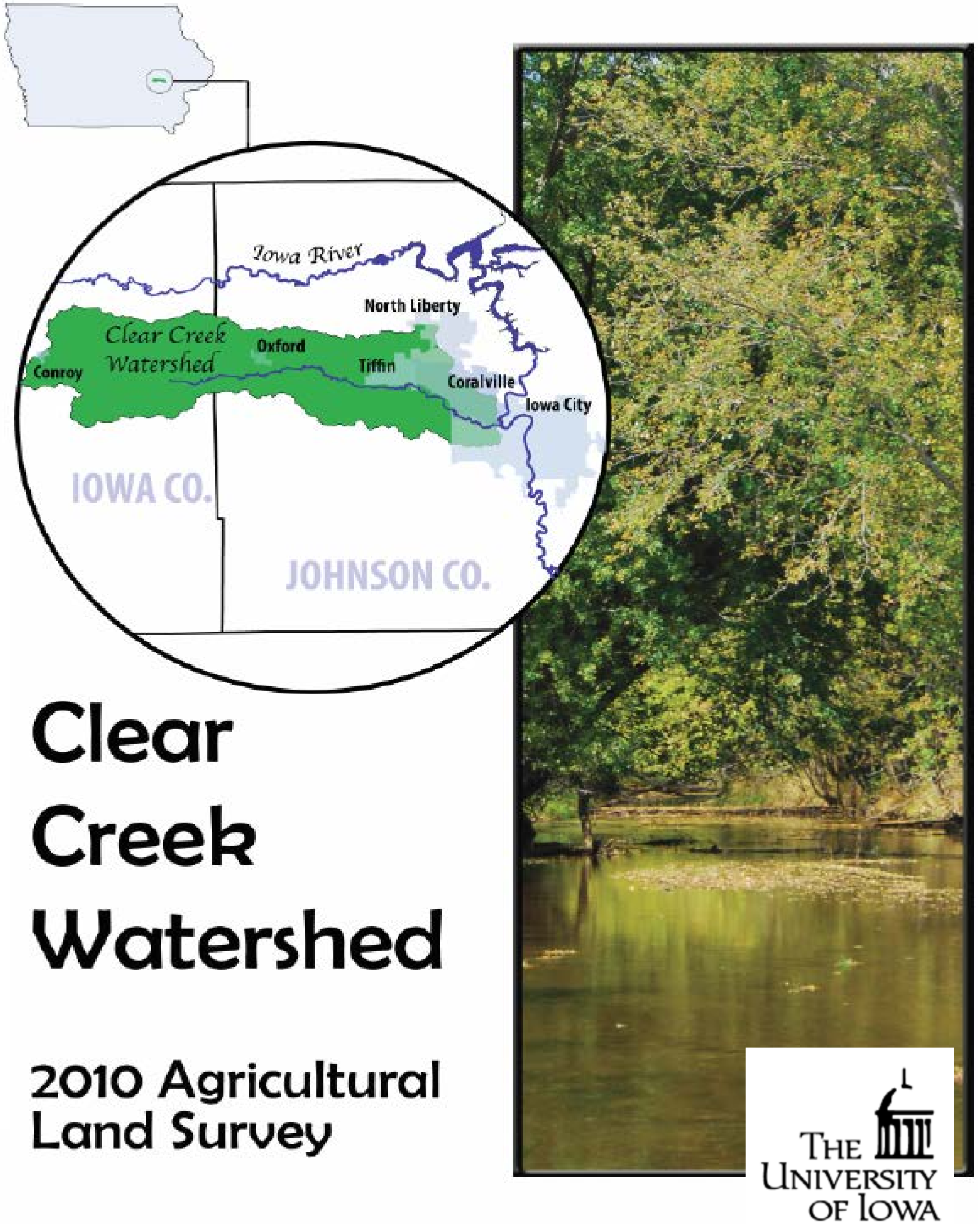
Survey to define "Agents"

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

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

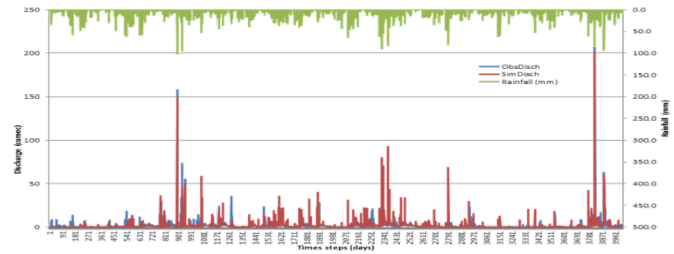
41. In 2009, did you harvest and sell any corn stover?
   ❐ Yes ❐ No

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

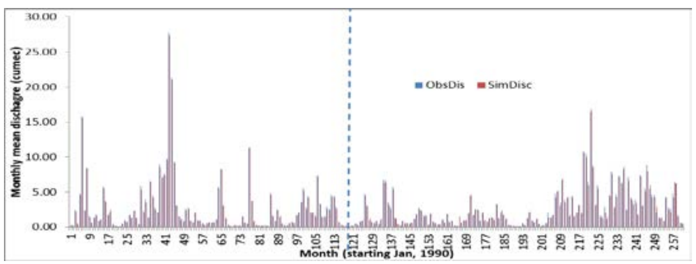
c. Government subsidies	❐	❐	❐	❐	❐	❐
d. Special insurance to lower the risk	❐	❐	❐	❐	❐	❐
e. Bank financing	❐	❐	❐	❐	❐	❐
f. Using a co-op to handle delivery arrangements	❐	❐	❐	❐	❐	❐

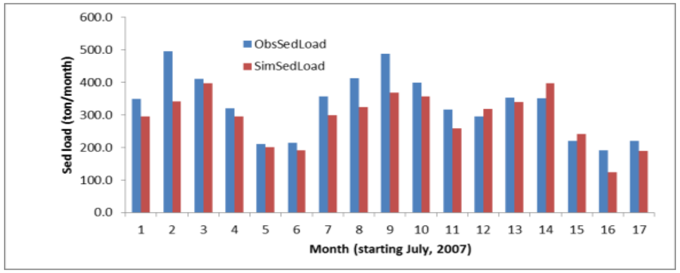
SWAT calibration and Validation

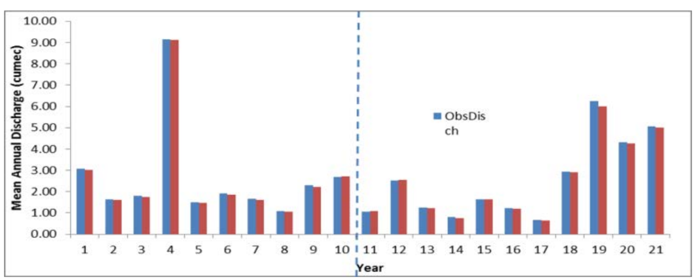
- SWAT model was set up with 5% contributing source area (CSA) which resulted into 21 sub basins. Discharge and other water quality parameters were calibrated at the watershed outlet at Clear Creek. Regression coefficient (R^{2}) obtained for monthly discharge was 0.85 and for yearly it was 0.91. For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

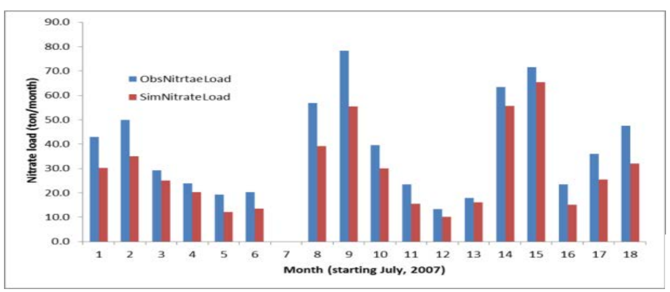


Time step	Regression Correlation coefficient (R^2)	
	Calibration	Validation
Daily	0.78	0.76
Monthly	0.85	0.83
Yearly	0.91	0.90

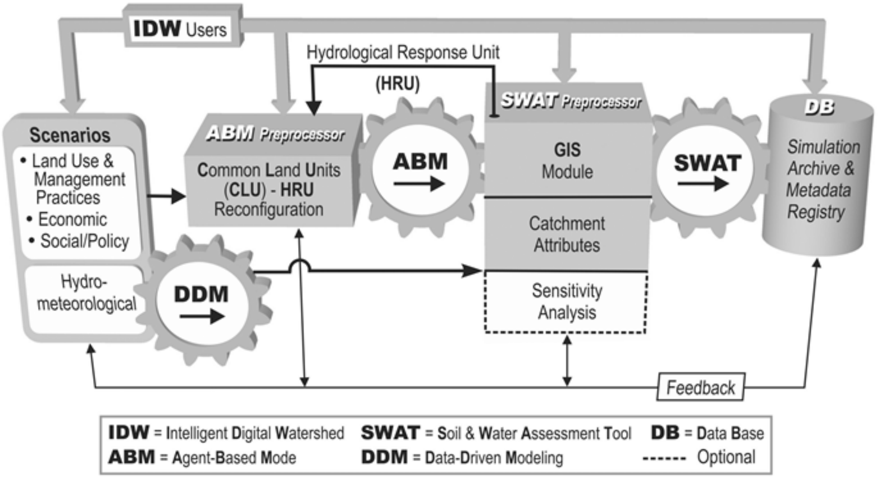


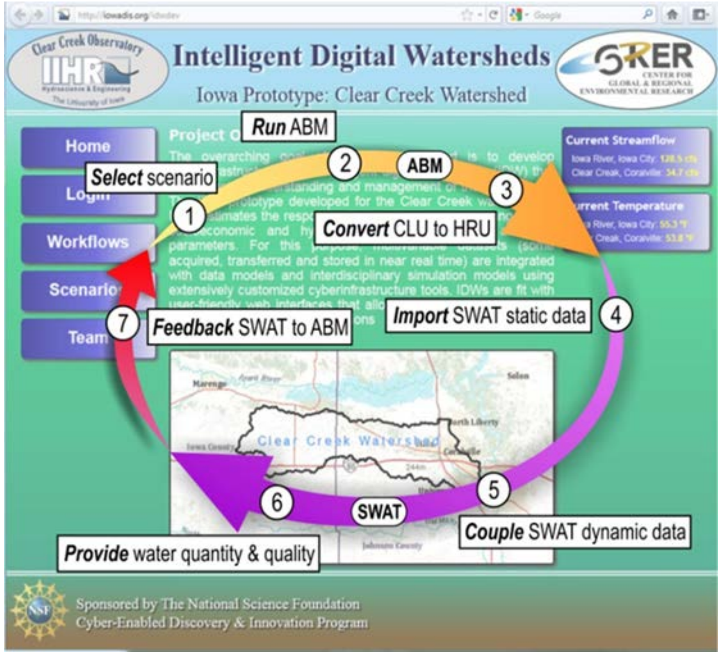






Intelligent Digital Watershed





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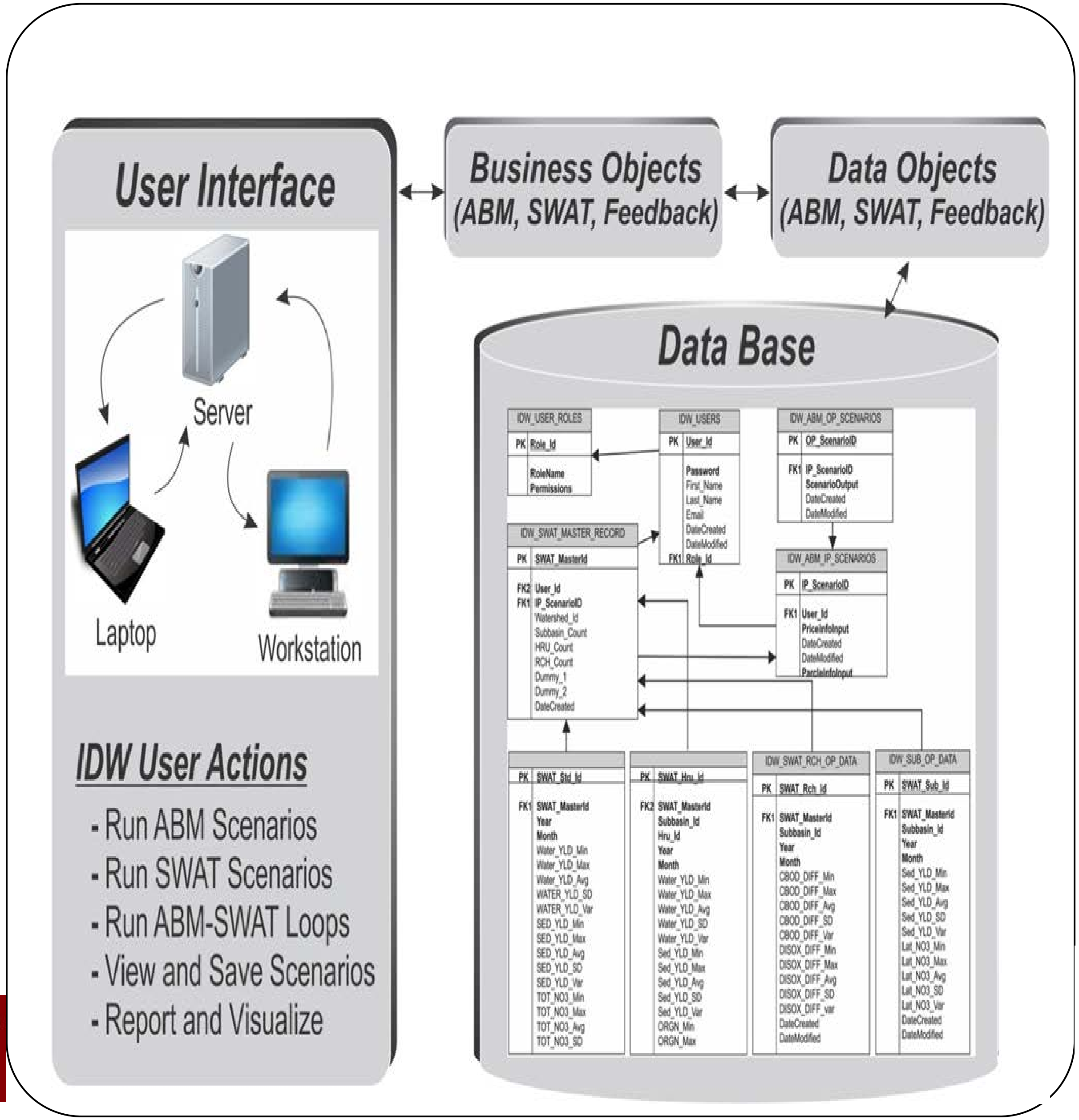
IDW operational flux



Clear Creek Intelligent Digital Watershed

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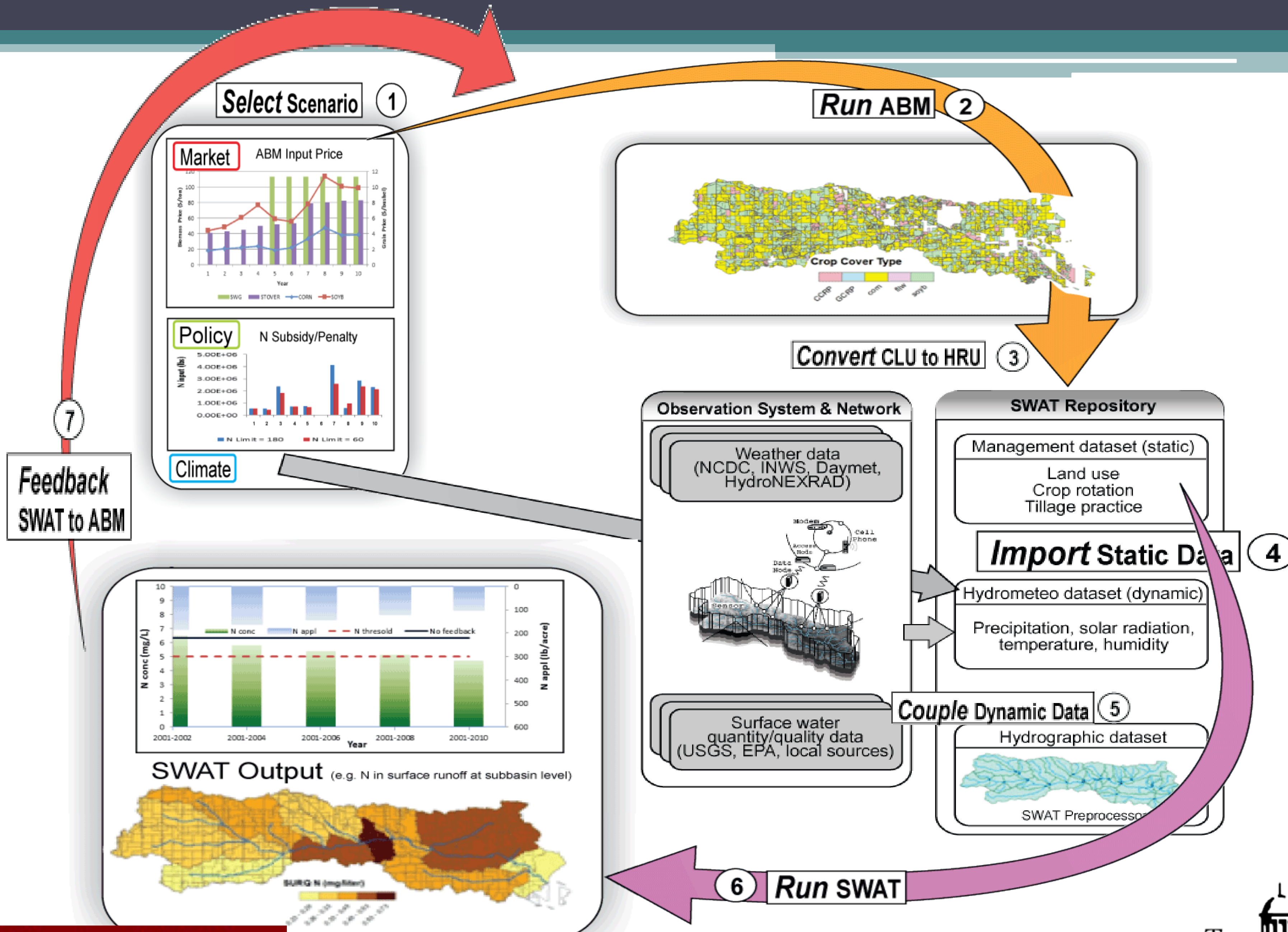

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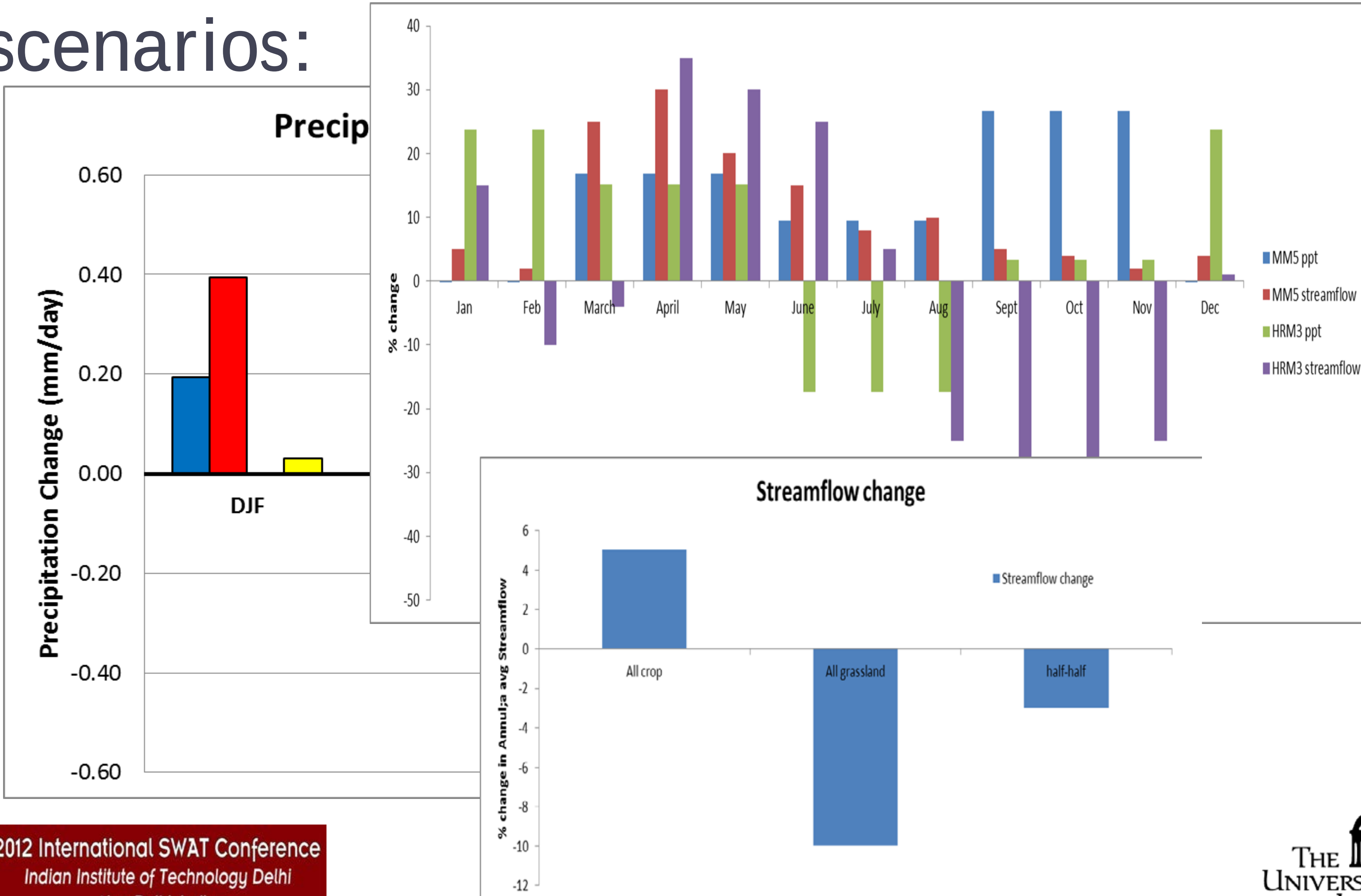
Building weather scenarios:



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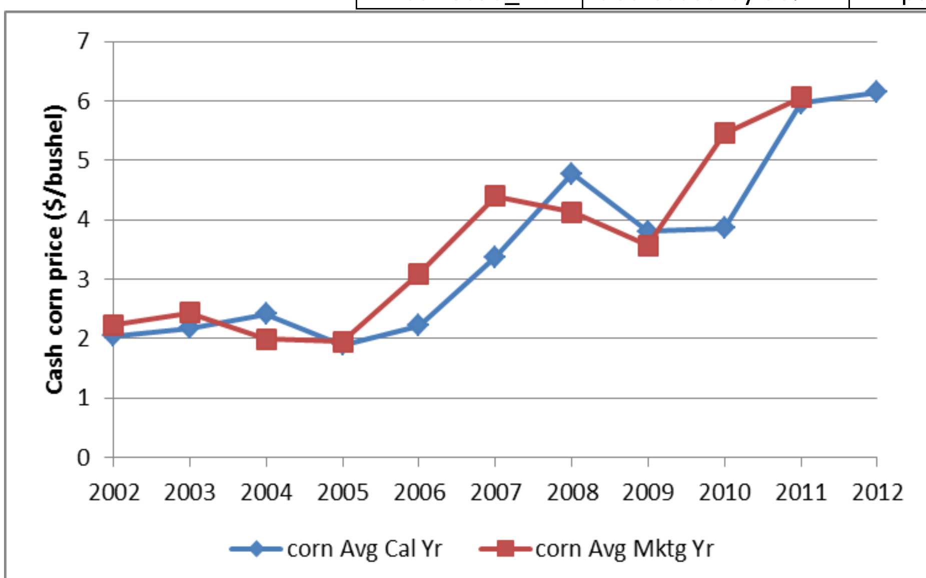
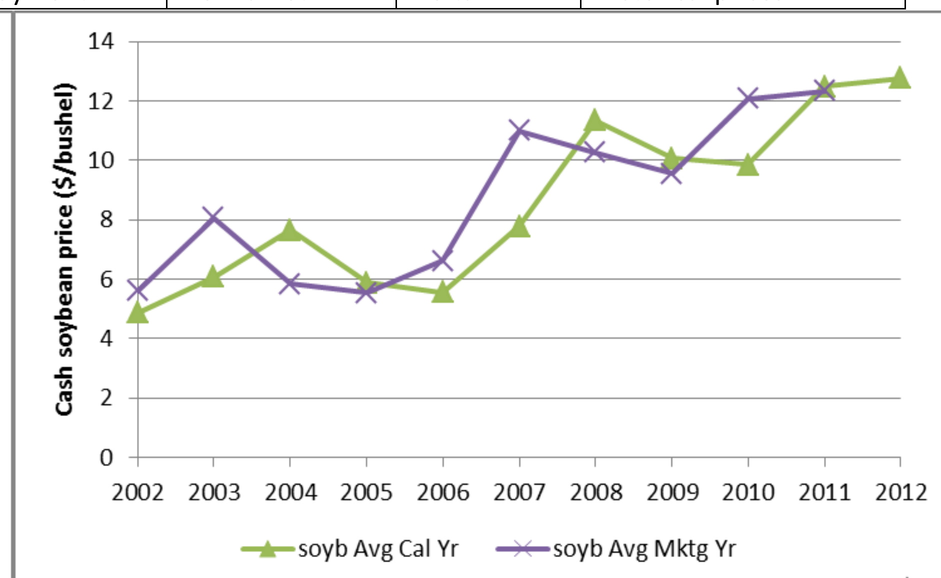
Market scenarios:

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





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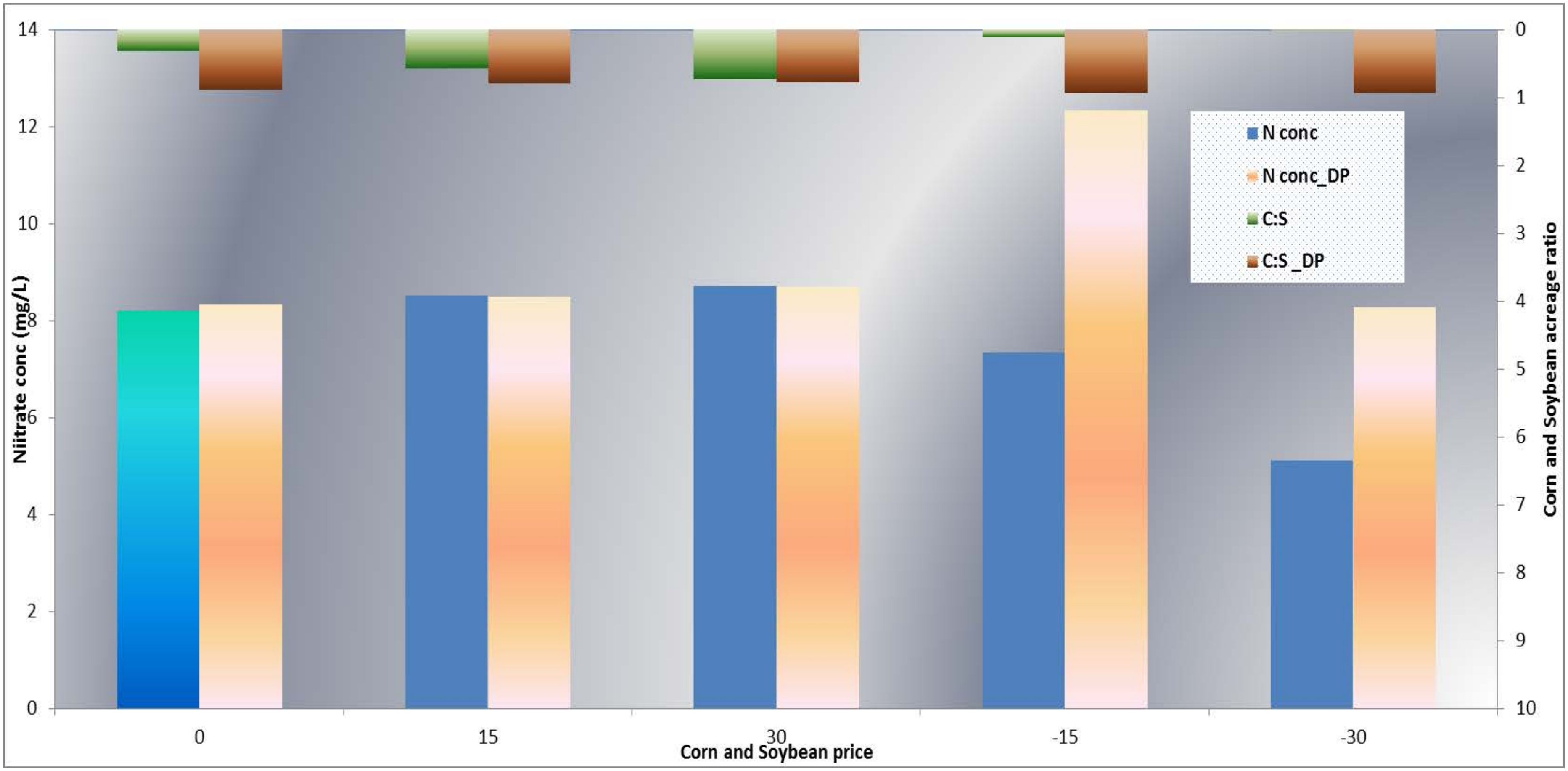
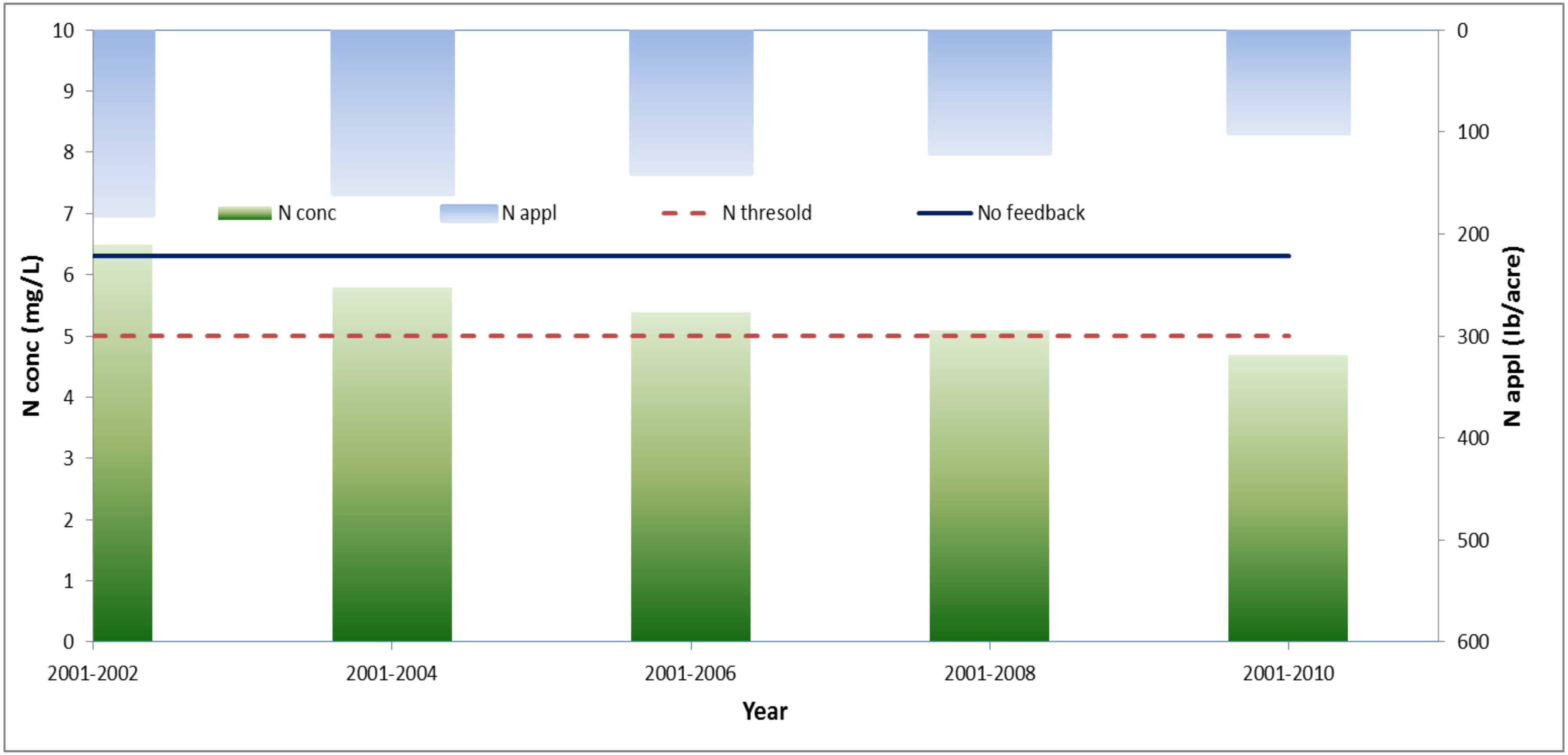


Direct payment and counter-cyclical payment are commodity subsidy programs stated in Farm Bills 2002 and 2008. Basically, when effective prices (max(market price, national loan rate) + direct payment) is lower than the target price, farmers can get cyclical payments from government if they plant corn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