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Watershed Management Tool for Evaluating BMPs : Case Studies in the Mackinaw and Upper Sangamon River Watersheds

By

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Outline

- Background
- Watershed Monitoring
- Watershed BMP Evaluation Tool
  - Coupled optimization-watershed model
- Watershed Case Studies
- Decision support System
- Summary

Background

- Nine states in the Midwest (including Illinois) contribute 75% of nutrient fluxes to the Gulf of Mexico (predominantly agricultural sources)
- Hypoxia in the Gulf and resulting in increased “Dead zone” - 8000 sq. mi. in 2008 (Alexander et. al, 2008)
- Local impacts include impairment of drinking water supply sources, reduced habitat quality and biodiversity in rivers and streams, inefficiencies in nutrient management
- Best Management Practices (BMPs) could serve as crucial control measures to reduce nutrient impacts, increase sustainable farming and be cost effective

Background (contd.)

- BMPs can be either structural or non-structural conservation practices that help control loads at their source or transport to receiving water bodies
- Implementation of BMPs should focus on critical source areas contributing significant loads
- Selection of locations for BMPs should take into account not only ecological benefits but also associated implementation costs
- This presentation discusses watershed management tools for evaluating BMPs - watershed case studies in Mackinaw and Upper Sangamon River watershed

Watershed monitoring

- Watershed characterization
  - Geology, soils, landscape, vegetative cover, land management, urban cover/runoff, climate, etc.
- Hydrologic and water quality data collection
  - Streamgaging for continuous streamflow discharge
  - WQ sampling throughout the year and during rainfall events
  - Computing nutrient loading
  - Provides:
    - data needed for calibration and verification to a particular watershed
    - relationships that can be applied to similar watersheds

Watershed BMP Evaluation Tool

- Objectives
  - optimal selection and placement of BMPs in a watershed for maximum removal of nonpoint source pollutants such as sediment and nutrients
  - Striking a balance between ecological benefits and BMP implementation costs

- Accomplish using Integrated Modeling Approach
  - Formulating the problem as multiobjective optimization
  - Develop watershed simulation model
  - Couple the watershed model with optimization algorithm
    - Selection/placement of BMPs as a function of NPS reduction and implementation costs.

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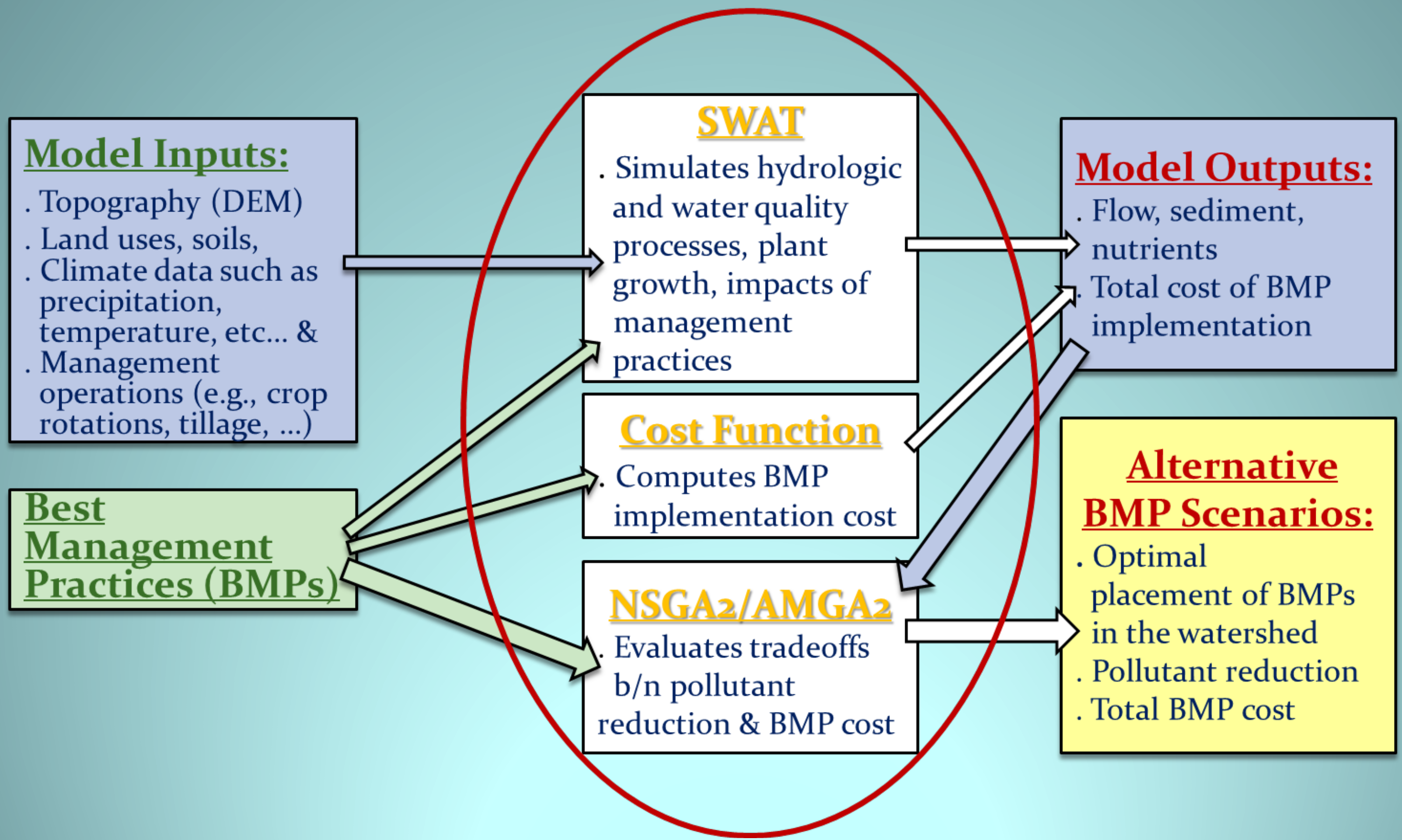
Integrated Modeling Framework



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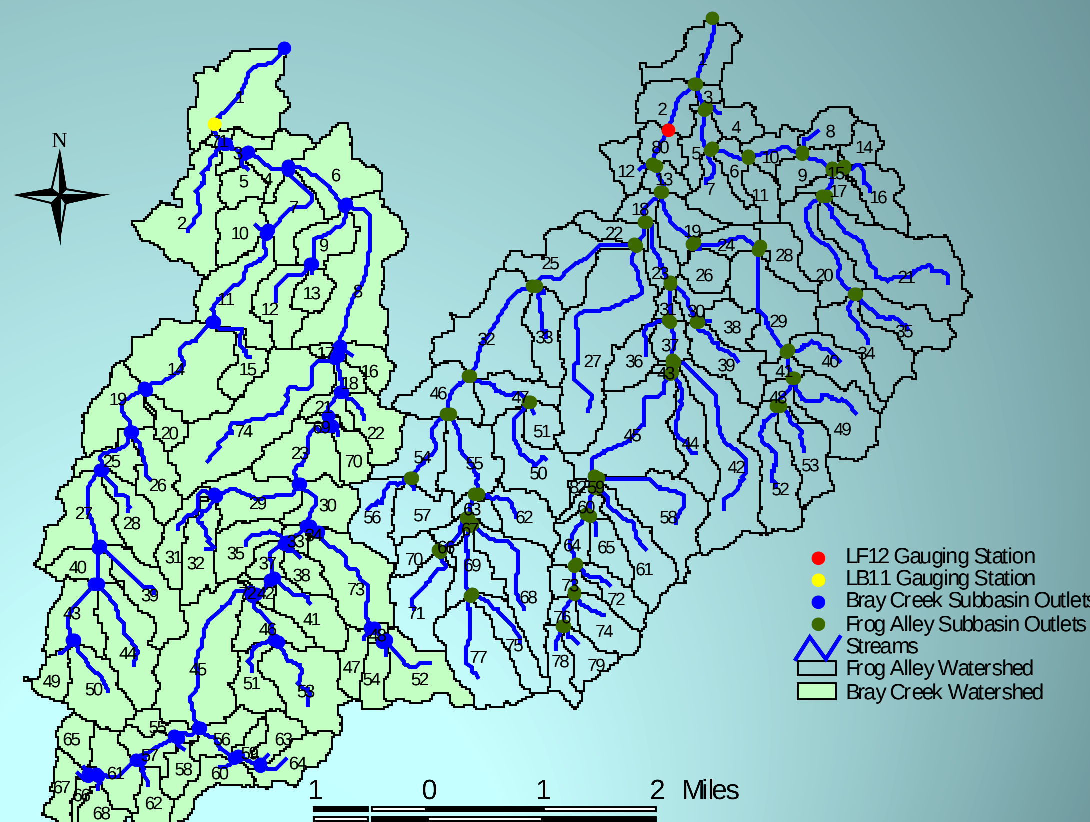
Case Study: Mackinaw River Watershed

- Bray Creek and Frog Alley Watersheds – tributary watersheds of Mackinaw River
- Drainage area of 15 and 17 sq. mi., respectively and both are agriculturally dominated with extensive tile drainage



Case Study: Mackinaw… (cont'd)

- Subject of TNC's paired watershed study (1999-2006), measuring the effectiveness of filter strips and grassed waterways and outreach programs on implementation of those BMPs
  - No significant change in water quality was exhibited as a result of implementing the BMPs
- Testing of constructed wetlands was found to be effective in removal of pollutants
- Identifying areas for placement of constructed wetlands is critical to improve the water quality at the watershed scale

Bray Creek and Frog Alley Watershed Models

- Model input data
  - DEM for watershed delineations; land uses & soils for HRU definitions; climate, hydrologic and water quality data for watershed model calibrations
  - less frequent water quality data (4% and 12% of simulation period for TP and TSS, respectively)
- Calibration (2002-2005)
  - stream flows (NSE 0.5-0.6)
  - TSS, TN &TP (bias < 6%)

Average Values (2000-2005)	*Bray Creek Watershed* *Observed*	*Bray Creek Watershed* *Simulated*	*Frog Alley Watershed* *Observed*	*Frog Alley Watershed* *Simulated*
Flow (m^3/s)	0.44	0.44	0.51	0.47
TSS (*tons/d*)	2.28	2.4	2.32	2.44
TN (*kg/d*)	369.1	379.6	371.2	383.4
TP (*kg/d*)	4.29	4.44	3.93	3.85

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Application of BMP Evaluation Tool

- Constructed wetlands
  - simulated as a water body within a subbasin draining a fraction of its area
  - simple mass balance for sediment transport into and out of a wetland
  - TSS removal by settling
  - nutrient removal using empirical equations that employs apparent settling velocity
  - No simulation of transformation between different pools of nutrients

Application of BMP … (cont'd)

- Wetland specification including sediment and nutrient removal efficiencies are based on TNC's study on Franklin Farm experimental watershed
  - Ratio of wetland surface to watershed drainage area (HRU) is 0.5
  - The minimum threshold wetland drainage area is fixed at 5 hectares (0.02 sq mi.)
  - Implementation cost including maintenance is $3,000 per acre excluding land value

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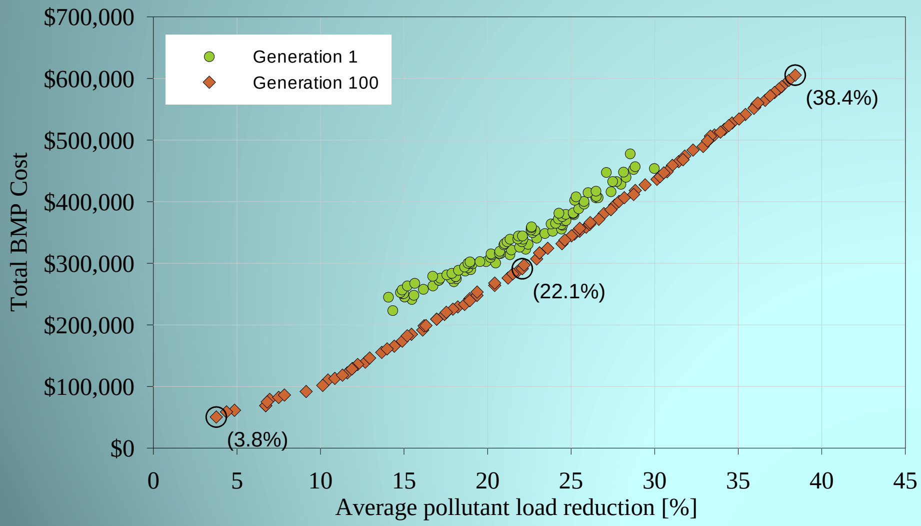
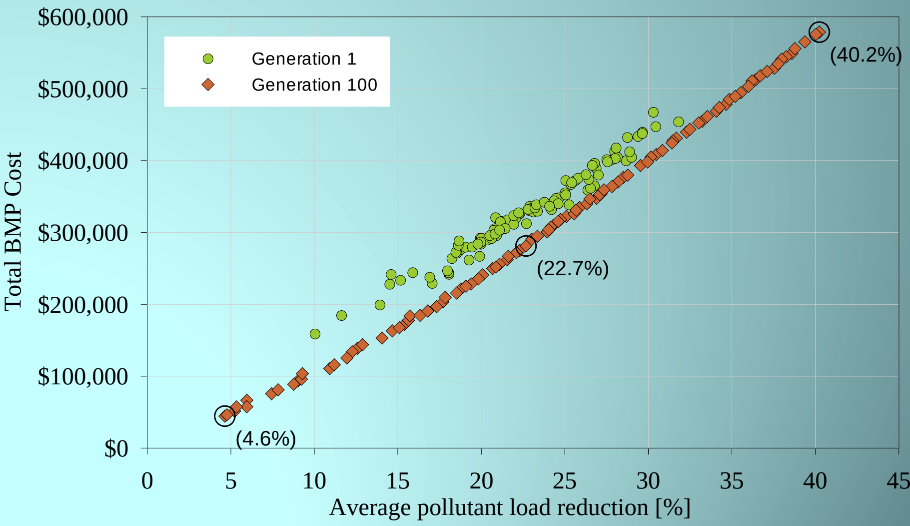
Application Results

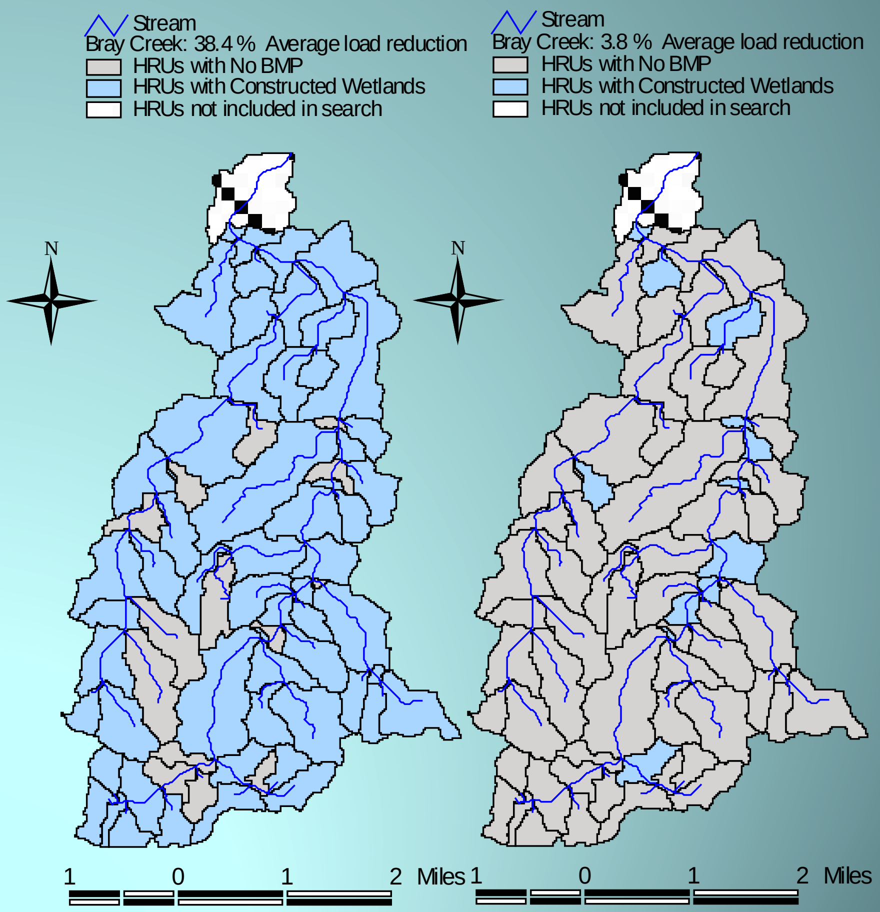
- Optimal tradeoff plots for Bray Creek (left) and Frog Alley (right) watersheds showing average water quality reduction versus total BMP implementation cost for 1st and 100th generations
  - average % reduction of TSS, TN and TP loads
  - illustrates the performance of the optimization algorithm





Application Results – Bray Creek Watershed

- Maximum reduction (left) and minimum cost (right) solutions
  - maximum load reduction is 38.4% and it costs $605,000
  - requires placement of constructed wetlands in most of the HRUs – draining about half of the watershed
  - minimum cost solution results in a marginal water quality reduction of 3.8% ($50,000)
  - both solutions provide the best reduction possible for the estimated implementation cost



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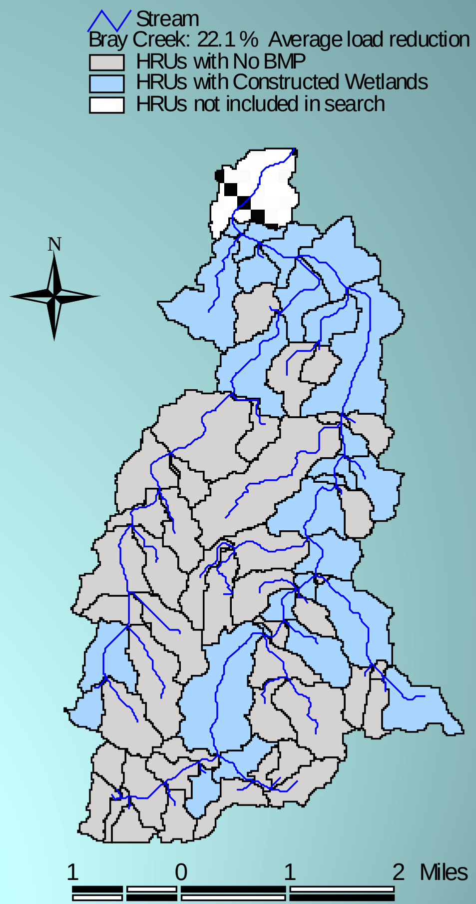
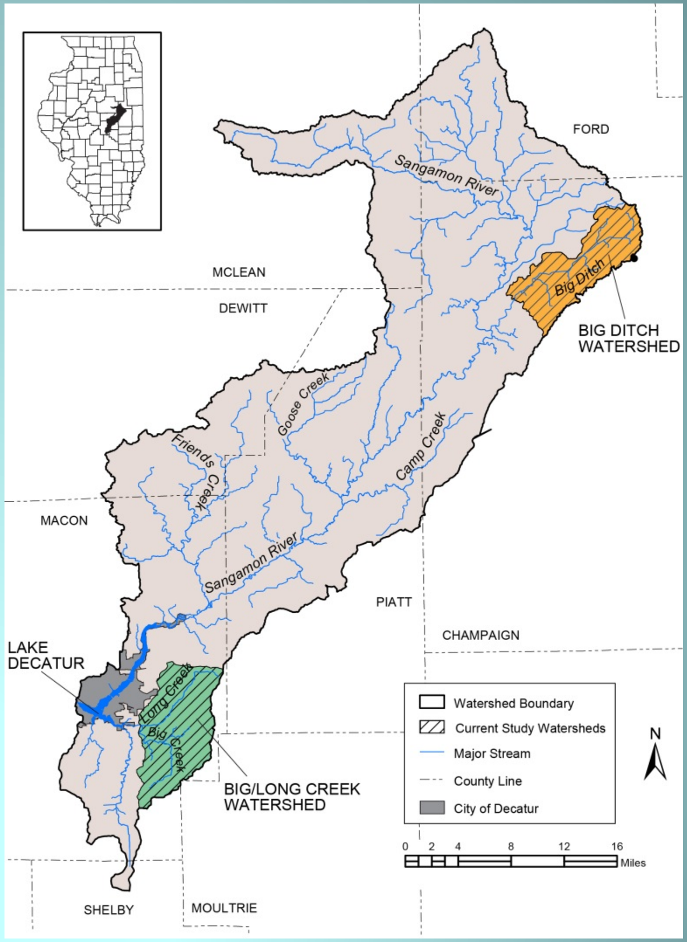
Application Results – Best Tradeoff

- Best tradeoff solution for Bray Creek watershed
  - optimal placement of constructed wetlands in Bray Creek watershed, draining only 21% of the total watershed area
  - resulted in an average load reduction of 22.1% (i.e., TSS, TN and TP load reductions of 11.7%, 28.3% and 26.2%, respectively)
  - more effective in TN and TP load reductions
  - estimated total placement cost of $290,000



Case Study: Upper Sangamon River Watershed

- Lake Decatur is the major source of public water supply for the City of Decatur
- Included in the 2004 Section 303(d) list - impaired for NO_3 and TP (IEPA, 2004)
- ISWS is tasked with developing decision support models (DSM) to evaluate the water quality impacts of best management practices (BMPs) in Big Ditch and Big-Long Creek watersheds (see Figure) of Lake Decatur watershed



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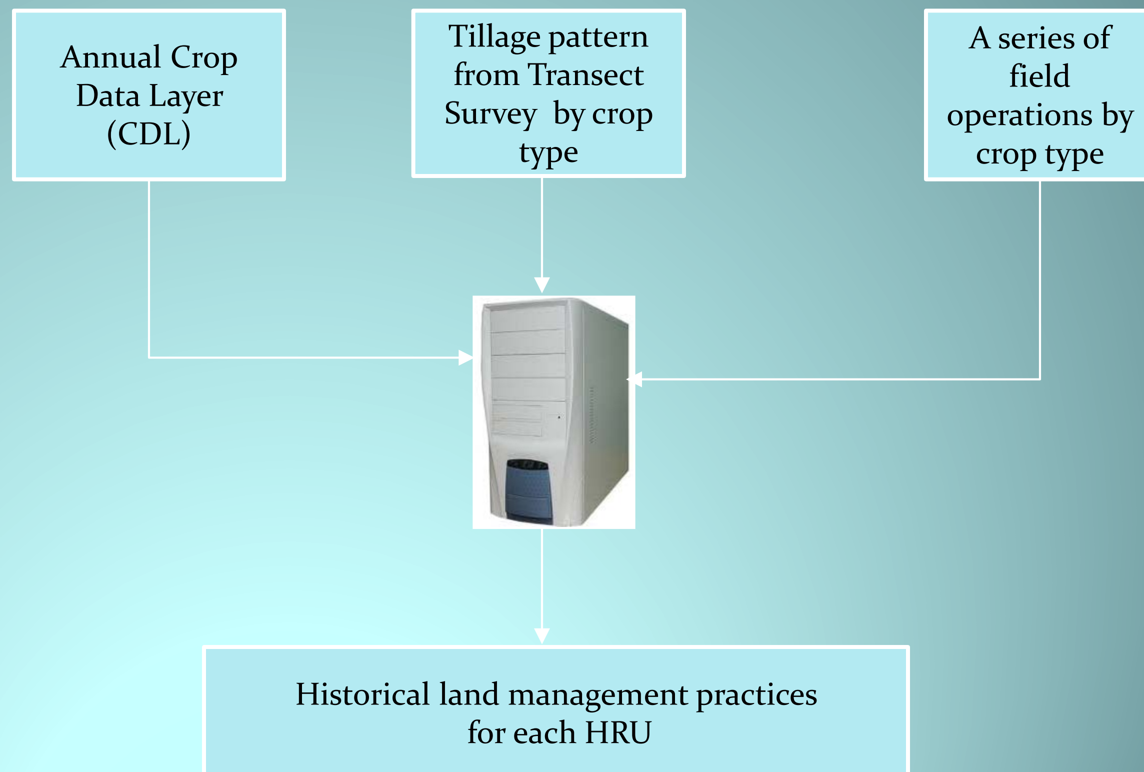
Case Study: Upper Sangamon... (cont'd)

- Big Ditch and Big-Long Creek Watersheds have drainage areas of 41 and 48 sq.mi., respectively.
- Both are agriculturally dominated with 90% in corn-soybean rotation and extensive tile drainage

- Unlike, Mackinaw watershed, there exists more extensive hydrologic and nutrient data available for use in the modeling
  - 1993 -2008 (Keefer, et al., 2010 – City of Decatur)
  - 2005 – 2008 (Keefer and Bauer, 2010 – IEPA, AWI)
- Watershed models are developed for both watersheds
- Hydrologic and water quality model calibration has been completed.

Case Study: Upper Sangamon... (cont'd)

- Detailed representation of <u>land management operations</u> improves hydrologic and water quality simulation
- Preparation of detailed land management operation in the model using a suite of algorithms



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Decision Support System

Decision Support System for BMP Evaluation

Select Watershed: Big Ditch | Select Subbasin: 3 | Select BMP: Constructed Wetland (CW)

Agricultural HRUs in selected Subbasin

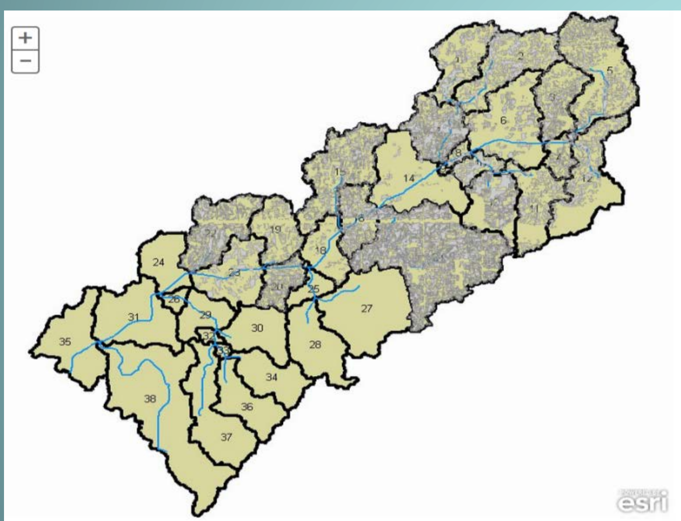
Assign BMP for HRU | Clear BMPs | Submit

Selected Subbasins for BMP: Subbasin 3: FS-0% ,GW-0% ,CW-89.16% ,BR-0% ,CC-0% ,DM-0% ,SB-0% ,NM-0% ,PC-0% | Remove BMP | Cost per hectare for BMP (USD): Constructed Wetland (CW)

1 | Assign Cost

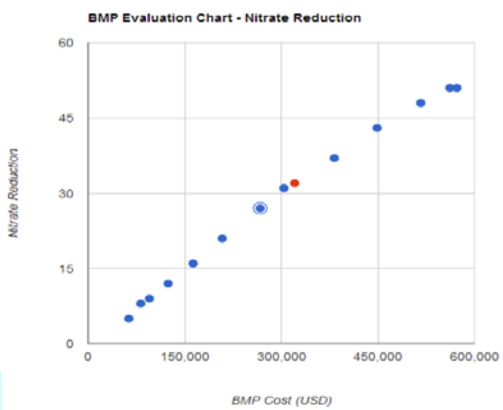
Evaluate

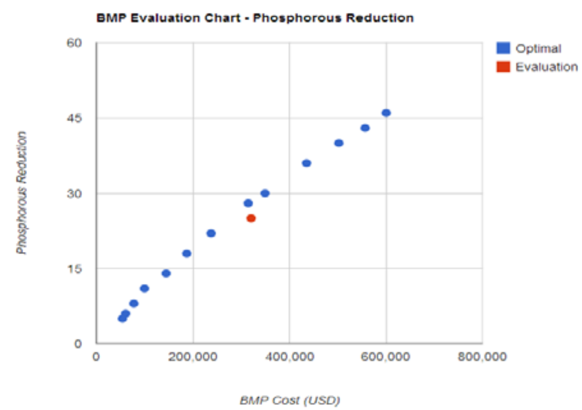
Start Again



BMP Evaluation Result - Cost : 320802.1484 USD

Nutrient	Reduction Value	% Reduction
Sediment	258.78	30.27
Nitrate	255.59	32.68
Phosphorous	260.21	25.83





Summary

- Coupled model which locates areas for BMPs with optimal water quality reduction and implementation costs
- Develop BMP efficiencies from recent studies (test novel BMPs)
- Monitoring data tailors results to particular watershed for "custom" results but
  - Has application in other agriculturally dominated watersheds in Illinois
- Development of DSS allows stakeholders in modeled watershed make decision for their situation