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

By

Laura Keefer ¹ and Elias G. Bekele ²

¹ Fluvial Geomorphologist, Illinois State Water Survey; ² Research Hydrologist, Surface Water Hydrology and Hydraulics Section, Illinois State Water Survey, Prairie Research Institute
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
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.
Integrated Modeling Framework

**Model Inputs:**
- Topography (DEM)
- Land uses, soils
- Climate data such as precipitation, temperature, etc... &
- Management operations (e.g., crop rotations, tillage, ...)

**Best Management Practices (BMPs)**

**SWAT**
- Simulates hydrologic and water quality processes, plant growth, impacts of management practices

**Cost Function**
- Computes BMP implementation cost

**NSGA2/AMGA2**
- Evaluates tradeoffs b/n pollutant reduction & BMP cost

**Model Outputs:**
- Flow, sediment, nutrients
- Total cost of BMP implementation

**Alternative BMP Scenarios:**
- Optimal placement of BMPs in the watershed
- Pollutant reduction
- Total BMP cost
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%)

<table>
<thead>
<tr>
<th>Average Values (2000-2005)</th>
<th>Bray Creek Watershed</th>
<th>Frog Alley Watershed</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Observed</td>
<td>Simulated</td>
</tr>
<tr>
<td>Flow ($m^3/s$)</td>
<td>0.44</td>
<td>0.44</td>
</tr>
<tr>
<td>TSS ( tons/d )</td>
<td>2.28</td>
<td>2.4</td>
</tr>
<tr>
<td>TN ( kg/d )</td>
<td>369.1</td>
<td>379.6</td>
</tr>
<tr>
<td>TP ( kg/d )</td>
<td>4.29</td>
<td>4.44</td>
</tr>
</tbody>
</table>
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
**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

![Graphs showing optimal tradeoff plots for Bray Creek and Frog Alley watersheds.](image)
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
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.
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 land management operations improves hydrologic and water quality simulation
- Preparation of detailed land management operation in the model using a suite of algorithms

- Annual Crop Data Layer (CDL)
- Tillage pattern from Transect Survey by crop type
- A series of field operations by crop type
- Historical land management practices for each HRU
Decision Support System
**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