Development of a multi-objective optimization tool for the selection and placement of BMPs for nonpoint source pollution control

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Different strategies used for NPS pollution control using BMPs

☐ Random placement of BMPs

☐ Targeting the BMPs

☐ Optimization
Optimization

- Global optimization algorithm: ecologically and economically effective solution
  - Genetic algorithms
  - Simulated annealing
  - Tabu search
Objective functions for optimization

Objective Functions

\[ \sum_{hru=1}^{m} \sum_{bmp=1}^{n} \text{Eff}_{bmp} \times \text{TP}_{hru} \times \text{Area}_{hru} : \text{Total Pollution Reduction} \]

\[ \sum_{hru=1}^{m} \sum_{bmp=1}^{n} \text{Cost}_{bmp} \times \text{Area}_{hru} : \text{Cost Increase} \]

Total phosphorus (TP) is the water quality parameter evaluated in this study

Cost\(_{bmp}\) includes BMP placement, maintenance, opportunity, and crop yield rates
Objectives

☐ Developing a multi-objective optimization model that optimizes the two objectives of maximum TP load reduction and minimize the cost increase, due to the implementation of BMPs.

☐ A tradeoff (pareto-optimal front) between these two objectives was obtained with the best cost effective solution for TP load reduction
Literature review

Chatterjee, A. (1997)
Srivastava et al. (2002)
Veith et al. (2003)
Gitau et al. (2004)
Bekele et al. (2005)
Arabi et al. (2006)

Used Genetic Algorithms combined with a watershed simulation model.
Simultaneous single objective optimization used to optimize the two objective functions
Research focus

- Multi-objective optimization

- BMP selection and placement on a large watershed (8 digit watersheds)
  Multi-objective optimization to optimize the two objective functions

Bekele et al. (2005)
Methodology

- SWAT used to get the initial TP loads
- Multi-Objective GA with objectives:
  1) Maximize pollution (TP) reduction in the watershed
  2) Maximize the returns from the watershed (in $) due to the implementation of the BMP
- A BMP tool is used to obtain TP efficiencies of the management practices
- An allele set with all possible BMPs that can be applied in a field
- Cost of BMP
Case Study (L’Anguille River Watershed, AR)

- Mississippi delta region of eastern Arkansas
- Drainage area of 2520 km²
- Predominately agricultural watershed
  - Rice: 26%, Soybean: 46%
- NPS pollutants are sediment and nutrients
- Included in the list of impaired water bodies by ADEQ
Soil and Water Assessment Tool (SWAT)

- Delineate the watershed into subbasins, which are further discretized into Hydrological Response Units (HRUs) based on the land use and soil distributions

- Simulate the sediment and nutrient losses in the watershed
BMP effectiveness tool

- SWAT is used to simulate the different BMP scenarios in the entire watershed (Total of 54 scenarios) with 433 HRUs (approx. as farms)

<table>
<thead>
<tr>
<th>BMP</th>
<th>Scenarios</th>
<th>Rice</th>
<th>Soybean</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Nutrient management plan</td>
<td>P (33 kg/ha)</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>P (22 kg/ha)</td>
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<td></td>
<td>P (16.5 kg/ha)</td>
<td></td>
<td></td>
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<tr>
<td>2) Buffer strips</td>
<td>0m, 5m, 10m</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>3) Tillage practice</td>
<td>Conservation till</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>No till</td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>
BMP effectiveness tool and cost estimation

- Effectiveness of a particular BMP in the reduction of pollutant of concern

- $\text{Eff}_{\text{bmp}} = \frac{(\text{TP}_{\text{bmp}} - \text{TP}_{\text{base}})}{\text{TP}_{\text{base}}} * 100$

- Effective set of BMPs for soybean: 73.1%
  - 10 m buffer strip
  - 16.5 kg/ha P fertilizer application
  - No till
Allele set preparation

- BMPs are land use and land cover specific
- Sets of BMPs are called allele sets
  - e.g., consider two farms that grow rice and soybean and the various sets of BMPs that are feasible in the two farms are
    - Allele1 (rice) : [NM1 NM2 NM3]
    - Allele 2 (soybean) : [NM1 NM2 NM3 Till1 Till2 FS1 FS2]
      - NM-Nutrient Management Plan
      - FS-Filter strip
      - Till-Tillage practice
Cost Estimation

Total unit cost ($/ha): $C_{\text{placement}} (\$/ha) + C_{\text{yield}} (\$/ha)$

Placement cost:

- Includes the implementation, maintenance, and opportunity costs of the BMPs

Agricultural yield cost:

- Includes the unit market selling price for the crop
Genetic Algorithm

- **reproduction**
  - parents
  - population
    - evaluated children
    - discarded members
  - children
  - modification
    - modified children
- **evaluation**
  - population
  - discard
Chromosome structure

Chromosome (Represents the set of BMPs in the watershed)

- Population 1: (1 0 1 1 0 1 1 1 0)
- Population 2: (0 1 1 0 0 1 1 0)

Genes (Represents BMP in a field)
Sensitivity analysis and estimation of GA parameters

- Parameters
  - Population
  - No. of generations
  - Mutation probability
  - Crossover probability
Sensitivity analysis of the parameters of NSGA-II

- Population
  - Population 10
  - Population 50
  - Population 100
  - Population 200
  - Population 400

- Generation
  - Generation 100
  - Generation 1000
  - Generation 10000
  - Generation 40000

- Crossover
  - Crossover 0.1
  - Crossover 0.4
  - Crossover 0.5
  - Crossover 0.7
  - Crossover 0.9

- Mutation
  - Mutation 0.0001
  - Mutation 0.001
  - Mutation 0.01
  - Mutation 0.1
GA parameters used for optimization

- Population = 100
- No. of generations = 20,000
- Crossover probability = 0.9
- Mutation probability = 0.001

45 minutes on an CentrinoDuo@2.16GHz
Pareto-optimal front after the optimization

A : 33% reduction in the TP for a cost increase of $14 millions

B : <15% reduction in TP for an implementation cost of $0.4 million

Routing

A : 20% reduction in TP at the watershed outlet
Conclusions

- An optimization algorithm is applied to solve the BMP selection and placement problem which generally requires millions of solutions to be searched.
- Multi-objective genetic algorithm (NSGA-II) is used to optimize the two objective functions simultaneously.
- The dynamic link connecting the water quality model is replaced by the BMP tool which facilitates BMP placement in a very large watershed (~2500 km²).
- A tradeoff is obtained between the two objective functions, which can help the watershed modelers in TMDL development. This also helps in estimating the corresponding cost for the placement of BMPs for a given TMDL goal.
Thank You

QUESTIONS???