Designing Practice Based Approaches for Managing Agricultural Nonpoint-Source Water Pollution

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U.S. Water Quality: Lakes

• Lakes, Reservoirs, Ponds:
  – 42% assessed, 65% inadequate water quality to support uses
  – Over 11 million acres are “impaired”
  – Agriculture third highest source of impairment

The diverse aquatic vegetation found in the Littoral Zone of freshwater lakes and ponds.

A cyanobacteria bloom in a Midwestern lake.
Water Quality: Rivers & Streams

- Rivers and Streams:
  - 26% assessed, 50% inadequate water quality to support designated uses
  - Nearly ½ million stream miles are “impaired”
  - Agriculture leading source of impairment (identified as cause of 22% unknown second highest)
Time trend

Assessed Waters of United States

Figure 1. US waters assessed as impaired

Source: EPA National Summary of Assessed Waters Report
What abatement options exist? Examples from U.S. Agriculture

• In field Management Practices
  – Reduced (no) tillage
  – Manure, fertilizer management/reduction
  – Cover crops, rotation changes
  – Land retirement

• Structural Practices
  – Buffers
  – Grassed Waterways
  – Denitrification, controlled drainage
  – Wetland restoration
Conservation practices

Photos courtesy of USDA NRCS
Land Retirement

Panoramic view of gamma grass-big blue stem planting

http://www.fsa.usda.gov/Internet/FSA_Image/ia_767_15.jpg
Wetlands Restoration

Photo courtesy Missouri NRCS
Efficacy and Cost of Practices

• Vary by
  – Pollutant
  – Field characteristics
  – Land use in watershed
  – Provision of other ecosystem services

• Ideally, all of these factors considered in efficient policy design
In sum, have to deal with all of these aspects

- Enormous number of farm fields/decision makers

- Each: one or more land use/conservation practices
  Retire land (e.g., CRP), Reduce tillage, Terraces, Contouring, Grassed Waterways, Reduce fertilizer, better timing, etc.

- Costs and effectiveness vary across locations

- HOW? Use models to guide policy
Soil and Water Assessment Tool

• Watershed-scale simulation model developed by USDA - Agricultural Research Service

• Predicts ambient (instream) water quality associated with a spatially explicit set of land use/conservation practices

• Gassman et al. (2007) identify over 250 publications using SWAT
• 13 Fields, 4 land use/abatement options: a, b, c, d

• SWAT simulates water quality under alternative land use, abatement activities

SWAT: N, P, and Sediment
Least Cost Problem

• What is the optimal placement of conservation practices?

• Brute force strategy:
  – Using water quality/hydrology model, analyze all the feasible scenarios, picking cost-efficient solutions
  – But, if there are N abatement possibilities for each field and there are F fields, this implies a total of possible NF configurations to compare
  – 30 fields, 2 options \(\rightarrow\) over 1 billion possible scenarios!
Strength Pareto Evolutionary Algorithm

Search technique to approximate pareto optimal frontier

– Integrate Evolutionary Algorithm with water quality model
– Search for a frontier of cost-efficient nutrient pollution reductions

“Individual” = specific assignment of practices to fields

“Population” = set of individual watershed configurations
SPEA2 Applied to Optimal Watershed Design

Step I: Generate initial population

Step II: Run SWAT and compute costs

Step III: Identify best individuals

Step IV: Evaluate stopping rule

Step V: Choose parents

Step VI: Create offspring

Pareto frontier
• Strength $S(i) = \#$ of individuals $i$ dominates
• Raw fitness $R(i) = \sum$ of strengths of individuals that dominate $i$
• Low value best: $R(i)=0$ means $i$ is on the frontier
Boone River Watershed Iowa

- ~586,000 acres
- tile drained, 90% corn and soybeans
- 128 CAFOs (~480,000 head swine)
Natural Environment: Boone

- Some of the highest N loads in Iowa
- TNC priority area biodiversity
- Iowa DNR Protected Water Area
Common Land Unit Boundaries

• 16,430 distinct CLUs

• Detailed data related to:
  land use,
  farming practices,
  production costs,
  slope,
  soils,
  CSRs, etc.

• Weather station data
The Land use/Abatement Set

• For each CLU
  – Current practice
  – Land retirement
  – No tillage
  – Reduced fertilizer (20%)
  – Cover crops
  – Sensible combinations
## Gains from Optimal Placement

<table>
<thead>
<tr>
<th>Practice Allocation (%)</th>
<th>Cost ($1000 dollars)</th>
<th>% N</th>
<th>% P</th>
<th>NT</th>
<th>NT, RF</th>
<th>CC, RF</th>
<th>CC</th>
<th>NT RF</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cover Crops, Red. Fert</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<td></td>
<td>15,380</td>
<td>29</td>
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<td></td>
<td>100</td>
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<td>Same N reductions</td>
<td>2,778</td>
<td>29</td>
<td>44</td>
<td>84</td>
<td>13</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td>3</td>
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<tr>
<td>Same Cost</td>
<td>15,365</td>
<td>47</td>
<td>45</td>
<td>8</td>
<td>23</td>
<td>&lt;1</td>
<td>64</td>
<td>5</td>
<td></td>
</tr>
</tbody>
</table>
Boone Individual 0001
N 4,837,160.0
Phosphorus 187,888.0
Cost $0.00

Baseline
NT
Cover Crop
Cover Crop NT
RF
NT RF
Cover Crop RF
Cover Crop NT RF
CRP
## Least Cost for N and P Reductions

<table>
<thead>
<tr>
<th>Target % Decrease</th>
<th>Cost ($1,000)</th>
<th>Cost ($/acre)</th>
<th>Reduction (%)</th>
<th>Watershed practices (counts of HRUs)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>P</td>
<td>Baseline</td>
<td>NT</td>
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<tr>
<td>80</td>
<td>80</td>
<td>89</td>
<td>4</td>
<td>8</td>
</tr>
</tbody>
</table>
Per acre average costs of abatement actions needed to achieve equal percent reductions in N and P

![Graph](chart.png)
Policies to Attain Nutrient Reductions

• Taxes (or subsidies)

• Voluntary Approaches (may be with financial incentives)

• Regulations
  – Technology requirements
  – Standards (permits)
  – Permit trading, “cap-and-trade,” “offsets”
  – Other (compliance requirements, labeling requirements)
Regulation types

• Technology Requirements: required to adopt specific method of production or technology catalytic converters,
• Standards: required to have a permit to cover their emissions or meet a standard zoning requirements
• Firms may be allowed to buy and sell permits from one another
• Compliance Requirements
Property rights with polluters

- Cost share programs - voluntary
  - Conservation Reserve Program,
  - Environmental Quality Improvement Program,
  - Conservation Security Program, and
  - Wetlands Reserve Program, etc.

- Reverse auctions

- Offsets (baseline and trade)

- Labeling, consumer information programs

- Conservation compliance
Property rights with society

• Approach for many pollutants
  – Industrial sources air pollution
  – Point sources water pollution
  – Smoking bans, etc.

• Policies that are consistent with:
  – Cap and trade (capped sectors)
  – Regulatory requirements
BMPs: Everglades Agricultural Area

- 718,000 acres (40 acre fields)

- Everglades Regulatory Program
  - goal 25% P reduction overall
  - mandatory BMPs, 1995
  - Implemented via points
    - flexibility in BMPs, 25 points/farm
    - expert judgment set point values
    - must implement and monitor WQ

Wikipedia
EAA Regulatory Program

• Property Rights: with citizens

• First 3 years: 55% P load reduction (SFWMD, 1998)

• Unable to find information on costs
  – Direct cost of BMPs
  – Lost profit
  – Cost of monitoring
  – Cost of program implementation
Comments and Questions Welcome!