A Phosphorus Credit Trading Program in an Agricultural Watershed

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1. Introduction

**Study Area**

- **Uses:** water supply, flood control, irrigation, and recreation.

- **Threats:** Land use changes and excessive nutrient (phosphorus) loads.

- **Solution:** Adoption of a phosphorus Total Maximum Daily Load (TMDL) of 140 mtons/yr.

Drainage area: 11,914 km$^2$
1. Introduction (cont.)

Case Study: S191 Basin
1. Introduction (cont.)

Case Study: S191 Basin

- Direct discharge to Lake Okeechobee.

- **73% of the basin is composed by agricultural land, 22% natural areas, and 5% urban.**

- **485 km\(^2\) - 4% of the Lake Okeechobee Watershed (LOW) area.**

- Annual average Total Phosphorus (TP) load of 85 mtons* - **17% of TP load to the Lake.**

*From 2002 to 2009.
2. Objective

Assess the environmental and economic benefits of a phosphorus credit trading program compared with a command-and-control approach
3. Methodology

**Phase 1**

**Hydrology and Water Quality Modeling**
Where phosphorus sources are located? How much is their annual average load? What are the trading ratios?

**Phase 2**

**Economic Modeling**
What is the optimal cost-effective Best Management Practices (BMPs) to be implemented at each source in order to achieve a basin-load reduction target?

**Phase 3**

**Phosphorus Credit Trading Scenario Analysis**
What is the net cost savings of a trading program compared with a command-and-control approach?
3. Methodology (cont.)

Phase 1: Hydrology and Water Quality Modeling

WAM is a GIS based model aimed to:

- Simulate the water quantity and quality for existing conditions in a watershed.
- Develop nutrient strategies while identifying existing nutrient sources by land use and region.
- Analyze the impacts of different best management practices on the watershed.

Source: SWET (2011)
3. Methodology (cont.)

Phase 2: Economic Modeling

Least-Cost Abatement Model:

\[
\text{Min } Z = \sum_{i} \sum_{k} \sum_{j} c_{i,k,j} \times X_{i,k,j}
\]

Subject to:

\[
\sum_{i} \sum_{k} \sum_{j} L_{i,j} \times r_{k,j} \times X_{i,k,j} \geq \text{Target}_P \_\text{Red}
\]

\[
\sum_{k} X_{i,k,j} = 1 \quad \forall i, k, j
\]

This optimization model will be solved using the General Algebraic Modeling System (GAMS) software.

Indices:
- \(i\): zones
- \(j\): land use types
- \(k\): BMP types

Given Data:
- \(C_{i,k,j}\): annual abatement cost, $/yr
- \(L_{i,j}\): TP load, kg/yr
- \(r_{k,j}\): BMP TP load reduction efficiency, %
- \(\text{Target}_P \_\text{Red}\): basin-wide minimum TP load reduction target, kg/yr

Decision Variable:
- \(X_{i,k,j}\): binary variable, 1 if BMP is implemented, 0 otherwise
3. Methodology (cont.)

Best Management Practices (BMPs) for Phosphorus Reduction

**BMP type I – Owner type**
- Non-structural

Fertilizer type  | Fertilizer amount  | Record keeping

**BMP type II – Typical type**
- Structural

Fencing  | Wetland restoration

**BMP type III – Alternative type**
- Structural

Chemical treatment
3. Methodology (cont.)

**Phase 3: Phosphorus Credit Trading Scenario Analysis**

**Step 1**
- Determination of the cap
- Allocation of the cap per source

**Step 2**
- Estimation of the costs of the command-and-control and the least-cost abatement approaches

**Step 3**
- Determination of the credit price
- Identification of the buyers and sellers of credits

**Step 4**
- Estimation of the number and cost of the credits traded

**Step 5**
- Estimation of net costs savings
4. Results

Phase 1: Hydrology and Water Quality Modeling

Identification of Total Phosphorus (TP) Sources in the S191 Basin

Land use and TP loads spatial distribution

Total area: 485 km²
56% Improved Pastures
5% Dairies

Total load: 91 mtons yr⁻¹
56% Improved Pastures
23% Dairies
5. Results (cont.)

Phase 1: Hydrology and Water Quality Modeling

Trading Ratios (TR)

TR are used to equalize the TP loads at the basin outlet from trading sources located at different distance from the Lake

\[
TR = \frac{(1 - \text{Buyer's attenuation factor})}{(1 - \text{Seller's attenuation factor})}
\]

<table>
<thead>
<tr>
<th>Seller</th>
<th>zone 1</th>
<th>zone 2</th>
<th>zone 3</th>
<th>zone 4</th>
<th>zone 5</th>
<th>zone 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>zone 1</td>
<td>1.00</td>
<td>1.02</td>
<td>1.04</td>
<td>1.06</td>
<td>1.09</td>
<td>1.14</td>
</tr>
<tr>
<td>zone 2</td>
<td>0.98</td>
<td>1.00</td>
<td>1.02</td>
<td>1.04</td>
<td>1.07</td>
<td>1.11</td>
</tr>
<tr>
<td>zone 3</td>
<td>0.96</td>
<td>0.98</td>
<td>1.00</td>
<td>1.02</td>
<td>1.04</td>
<td>1.09</td>
</tr>
<tr>
<td>zone 4</td>
<td>0.94</td>
<td>0.96</td>
<td>0.98</td>
<td>1.00</td>
<td>1.02</td>
<td>1.07</td>
</tr>
<tr>
<td>zone 5</td>
<td>0.92</td>
<td>0.94</td>
<td>0.96</td>
<td>0.98</td>
<td>1.00</td>
<td>1.05</td>
</tr>
<tr>
<td>zone 6</td>
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<td>0.90</td>
<td>0.92</td>
<td>0.94</td>
<td>0.96</td>
<td>1.00</td>
</tr>
</tbody>
</table>
4. Results (cont.)

Phase 3: Phosphorus Credit Trading Scenario Analysis (step 1)

- Trading Program Cap: TP Reduction Target

\[
\text{Min } Z = \sum_{i} \sum_{k} \sum_{j} c_{i,k,j} \times X_{i,k,j}
\]

Subject to:
\[
\sum_{i} \sum_{k} \sum_{j} L_{i,j} \times r_{k,j} \times X_{i,k,j} \geq \text{Target}_{\text{P}_{\text{red}}}
\]
\[
\sum_{k} X_{i,k,j} = 1 \quad \forall i, k, j
\]

Current load (attenuated to the nearby stream): 87.9 mtons yr\(^{-1}\)

Target load: 61.5 mtons yr\(^{-1}\)

Individual allocation: 1.6 kg ha\(^{-1}\) yr\(^{-1}\)
4. Results (cont.)

Phase 3: Phosphorus Credit Trading Scenario Analysis (step 2)

- Identification of Best Management Practices per Land Use and Zone

**Command-and-Control**

![Command-and-Control Chart](chart1.png)

- Zone 1
- Zone 2
- Zone 3
- Zone 4
- Zone 5
- Zone 6

**Least-Cost Abatement**

![Least-Cost Abatement Chart](chart2.png)

- Zone 1
- Zone 2
- Zone 3
- Zone 4
- Zone 5
- Zone 6

Reduction Target: 30%

Actual Reduction: 41%

Cost: $ 5.0 million

Reduction Target: 30%

Actual Reduction: 41%

Cost: $ 3.4 million
4. Results (cont.)

Phase 3: Phosphorus Credit Trading Scenario Analysis (step 3)

- **Credit Price**: Marginal Abatement Cost (MAC) Curve

Reduction achieved after BMP implementation (41%)
4. Results (cont.)

Phase 3: Phosphorus Credit Trading Scenario Analysis (step 4)

- Identification of Sellers and Buyers
4. Results (cont.)

Phase 3: Phosphorus Credit Trading Scenario Analysis (step 5)

- Cost of Credits Sold/ Bought per Land Use and per Zone ($ in thousands)

<table>
<thead>
<tr>
<th>Zone 1</th>
<th>Zone 2</th>
<th>Zone 3</th>
<th>Zone 4</th>
<th>Zone 5</th>
<th>Zone 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Citrus</td>
<td>568</td>
<td>284</td>
<td>665</td>
<td>9</td>
<td>8</td>
</tr>
<tr>
<td>Improved Pastures</td>
<td>493</td>
<td>730</td>
<td>415</td>
<td>0.8</td>
<td>7</td>
</tr>
<tr>
<td>Dairies</td>
<td>272</td>
<td>24</td>
<td>6</td>
<td>0.2</td>
<td>9</td>
</tr>
<tr>
<td>Ornamental</td>
<td>8</td>
<td>81</td>
<td>0.8</td>
<td>0.4</td>
<td>2</td>
</tr>
<tr>
<td>Sod</td>
<td>8</td>
<td>5</td>
<td>0.4</td>
<td>0.8</td>
<td>0.2</td>
</tr>
<tr>
<td>Urban</td>
<td>1</td>
<td>5</td>
<td>0.2</td>
<td>0.8</td>
<td>0.8</td>
</tr>
</tbody>
</table>

Total credits traded: 9,579
4. Results (cont.)

Phase 3: Phosphorus Credit Trading Scenario Analysis (step 5)

- Cost Savings per Land Use and per Zone ($ in thousands)

<table>
<thead>
<tr>
<th>Zone 1</th>
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<td>Dairies</td>
<td>Ornamental</td>
<td>Sod</td>
<td>Urban</td>
</tr>
<tr>
<td>196</td>
<td>602</td>
<td>48</td>
<td>23</td>
<td>6</td>
<td>3</td>
</tr>
</tbody>
</table>

Total cost savings: $1.3 million (27%)
5. Conclusions

- Phosphorus Credit Trading in the S191 Basin would provide 41% reduction in TP loads into Lake Okeechobee with a 27% in cost savings when compared to a command-and-control approach.

- This TP load reduction represents 10% of the total reduction needed to meet Lake Okeechobee TMDL.

- Higher TP reductions could be achieved by implementing a trading program to other sub-watersheds.
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