

Searching for Solutions: Cost-Efficient Pollution Control on a Watershed Scale

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Introduction

- Finding cost-efficient solutions to agricultural nonpoint source water quality problems is difficult:
 - there are numerous conservation practices that can be implemented on any field, each with different levels of effectiveness and costs
- Solving for the least-cost solution requires comparison among a very large number of possible land use scenarios

Introduction

- If there are N conservation practices possible for adoption on each field and there are F fields, this implies a total of possible N^F configurations to compare.
- In a watershed with 20 fields, if we consider only two possible options: implement a BMP or leave it alone, we would have to evaluate 2^{20} possibilities (over 1 million)
 - With 30 fields would need to evaluate over 1 billion possibilities

Approach

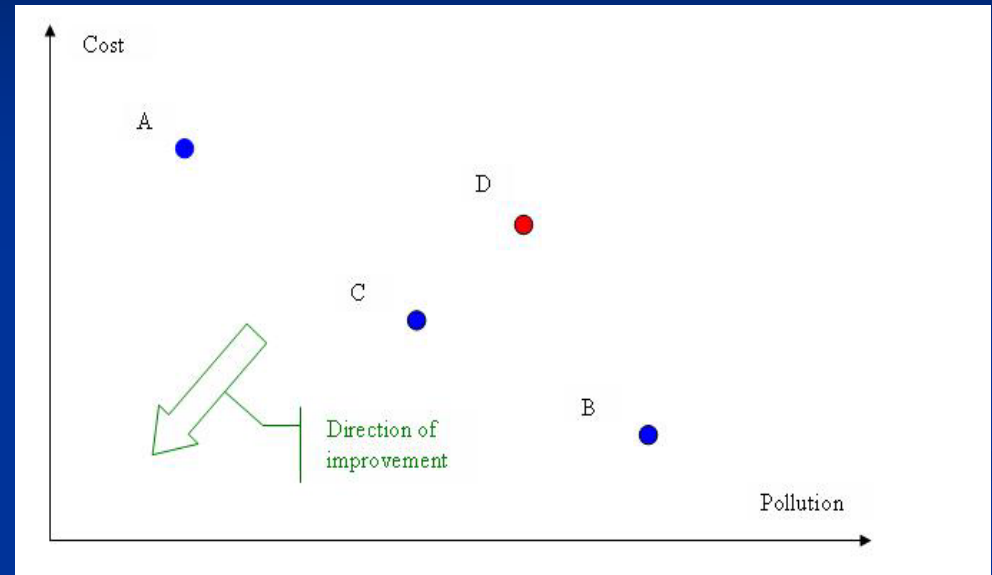
- Evolutionary algorithms provide one search strategy
 - mimic the power of evolution, which, in effect, is a method of searching for solutions among an enormous amount of possibilities (Mitchell, 1999)
- Integrate modern evolutionary algorithm with economic and water quality modeling to search for cost-efficient nitrogen pollution reduction solutions for a watershed
 - Similar attempts: Srivastava et al. (2002); Veith et al. (2003); Muleta and Nicklow (2005); Whittaker et al. (2006)

Cost-Pollution Tradeoff and Pareto Optimality

- In many environmental problems reducing pollution can only be achieved at higher costs
 - reducing nitrogen pollution is increasingly costly
- Given this tradeoff, one would like to identify the set of watershed-level solutions which result in the lowest cost of achieving any given pollution reduction
- This set of costs and pollution reductions defines the **Pareto-optimal** frontier

Pareto Optimality

- Point A is not clearly preferred to point B (since B has lower costs, but higher pollution)
- A reallocation of conservation practices that yields lower pollution (cost) levels for the same level of cost (pollution) ought to be a preferred solution
- Thus, point C ought to be preferred to point D (since D exhibits both lower costs and lower pollution levels)



Why a Pareto frontier?

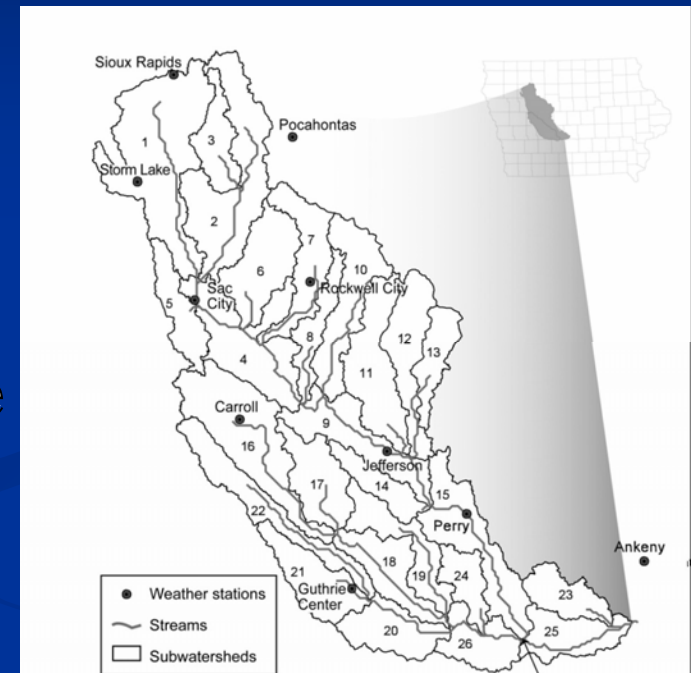
- While a Pareto-optimal frontier by itself does not indicate the solution that the public should choose, it allows for two important questions to be answered:
 1. What is the minimum cost of achieving a certain level of pollution, and
 2. What is the minimum level of pollution that can be achieved with a given conservation budget?

Application

- Our goal: approximate a Pareto-optimal frontier for nitrogen pollution in Raccoon River Watershed in Iowa
- Employ SWAT to model water quality
- Utilize a search algorithm SPEA2 (Strength Pareto Evolutionary Algorithm 2)
 - evaluates alternatives based on pollution and cost levels
 - selects those that are preferred
 - subsequently attempts to create better solutions through the process of recombination and mutation

Study Area

- The Raccoon River Watershed is an intensively farmed watershed in West-Central Iowa, impacted by sediment, phosphorus, and nitrogen pollution
- Nitrates are of particular concern, nitrate export from the watershed is among the highest in the United States
- The Raccoon River is a major source of drinking water for over 370,000 residents of Iowa



Land use options considered

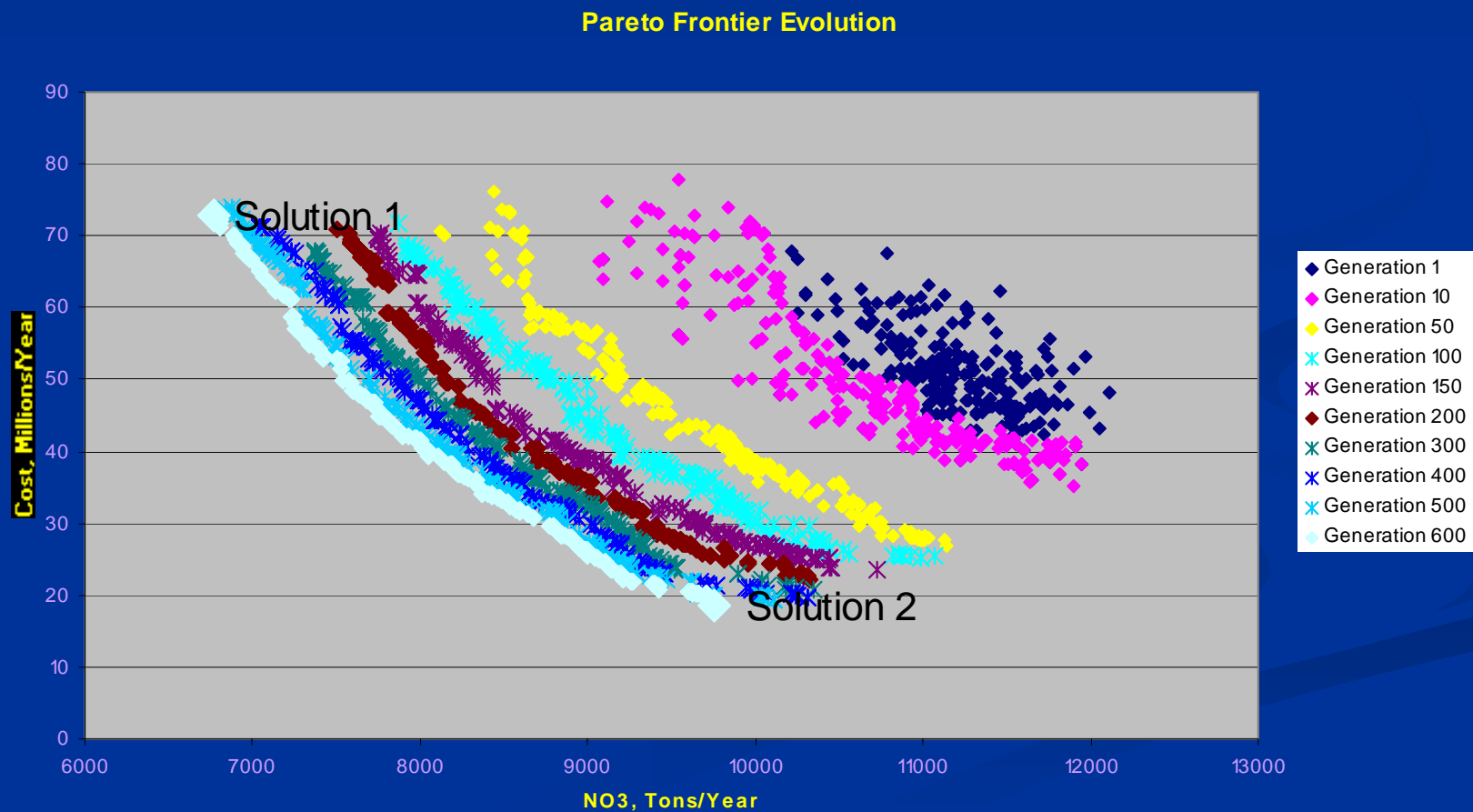
<i>Option number</i>	<i>Option description</i>
1	<i>Land retirement</i>
2	<i>Corn-Soybeans, Conventional Tillage</i>
3	<i>Corn-Soybeans, Conventional Tillage, 20% Fertilizer Reduction</i>
4	<i>Corn-Soybeans, No-Till</i>
5	<i>Corn-Soybeans, No-Till, 20% Fertilizer Reduction</i>
6	<i>Corn-Soybeans, Conventional Tillage, Terracing</i>
7	<i>Corn-Soybeans, Conventional Tillage, Terracing, 20% Fertilizer Reduction</i>
8	<i>Corn-Soybeans, No-Till, Terracing</i>
9	<i>Corn-Soybeans, No-Till, Terracing, 20% Fertilizer Reduction</i>
10	<i>Corn-Soybeans, Conventional Tillage, Contouring</i>
11	<i>Corn-Soybeans, Conventional Tillage, Contouring, 20% Fertilizer Reduction</i>
12	<i>Corn-Soybeans, No-Till, Contouring</i>
13	<i>Corn-Soybeans, No-Till, Contouring, 20% Fertilizer Reduction</i>

Results

- Economic data on the costs of these practices have been collected and are used as inputs in the optimization process
- Run a population of 250 potential solutions through 600 generations
- Each point on the frontier is a distinct pollution reduction solution associated with a unique combination of conservation practices in each subwatershed

Results

- The following chart highlights the functioning of the algorithm: it pushes the Pareto-optimal frontier toward the origin

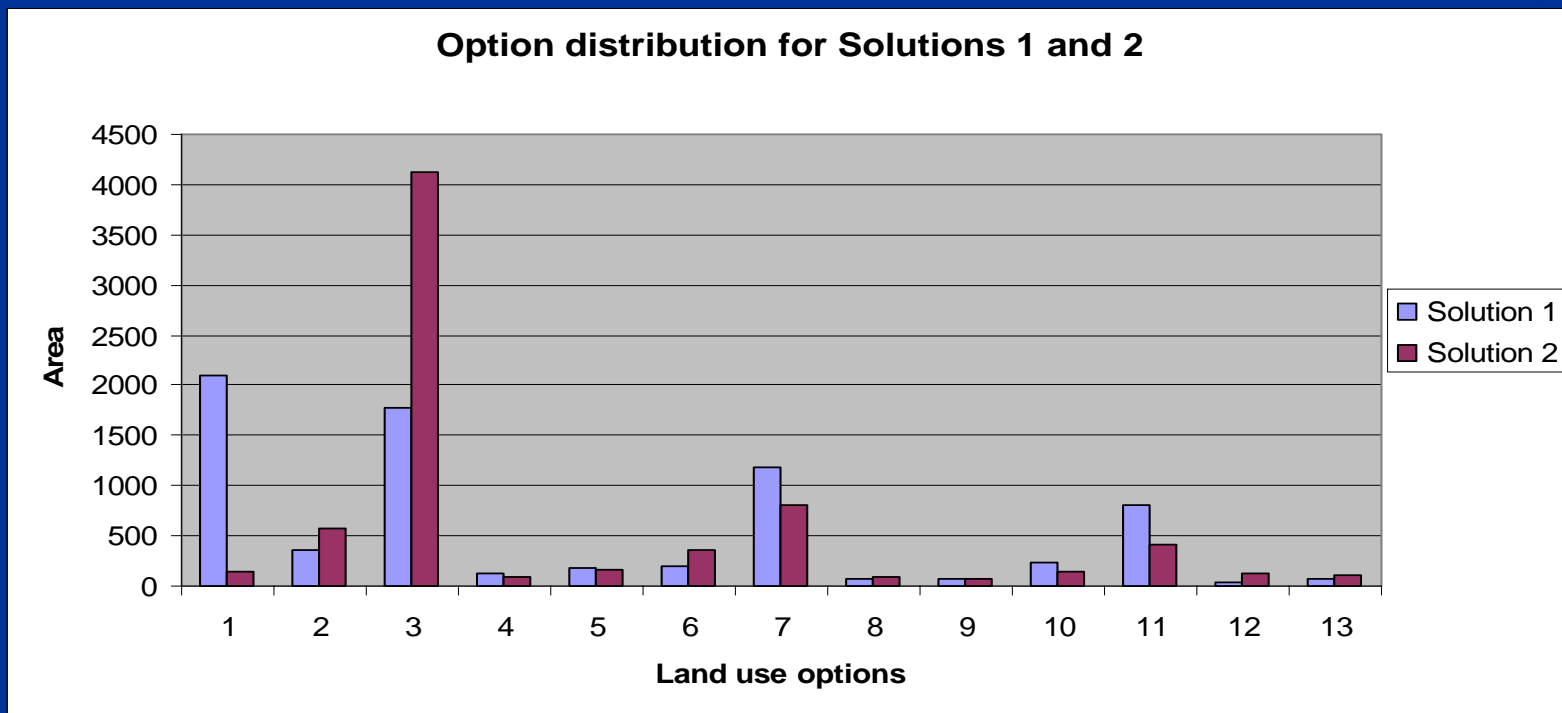


Results

- Solution 1 is predicted to reduce annual loadings of NO_3 to 6.8 thousand tons at a cost of \$75 million annually
- Solution 2 is the least expensive solution (\$18 million), but yields 9.8 thousand tons of NO_3
 - Both solutions represent dramatic reductions from current loadings, estimated at 15 thousand tons
- Model-predicted average daily concentrations are 2.53 mg/L for Solution 1 and 3.52 mg/L for Solution 2

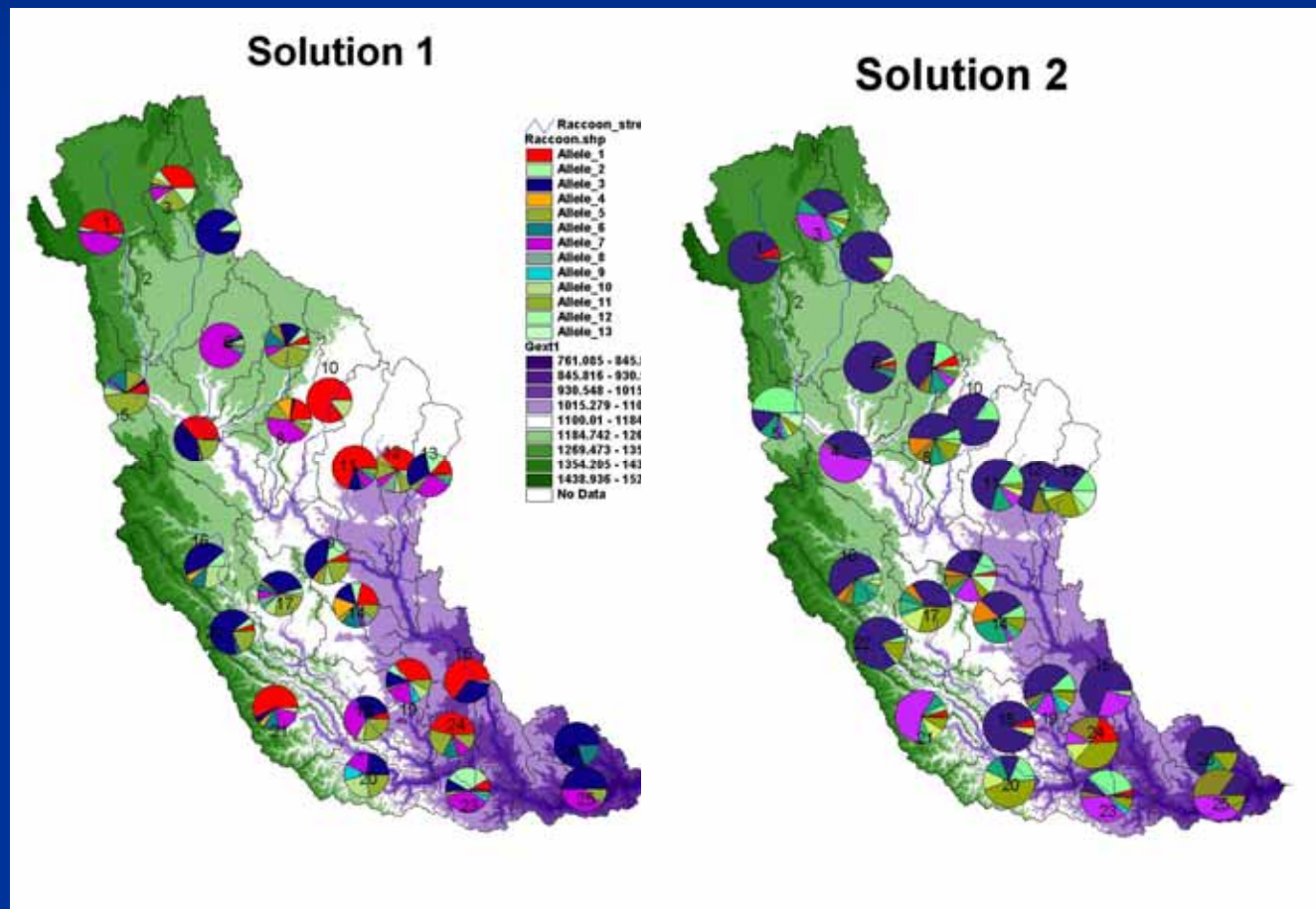
Results

- Land retirement and reduced nitrogen fertilizer application are the preferred options for nitrate reductions
- Solution 1 utilizes the expensive land retirement option extensively
- Solution 2 utilizes the relatively cheaper fertilizer reduction option



Solutions 1 & 2 Mapped

- The maps provide a detailed view of these two solutions
- Highlight the importance of geographic placement of conservation practices



Importance and Caveats

- Our approach represents one reasonable way of searching for pollution reduction solutions
- By employing the concept of Pareto-efficiency we are able to provide decision-makers with a menu of solutions
- Further, our approach allows us to derive watershed-level marginal abatement cost curve
 - indispensable in designing an inter-watershed pollution trading program
- Current research can be improved by
 - incorporating finer-scale land use data
 - including additional relevant conservation options
 - recognizing additional environmental objectives