Economic Incentives to Improve Water Quality in Agricultural Landscapes:

Some New Variations on Old Ideas

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AAEA, Denver, 2010

Topics

- Introduction
  - Water quality snapshot
  - Current policy
- Policy: abatement actions, point-based
- Tools: evolutionary algorithms
- Case study: Boone River Watershed

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.

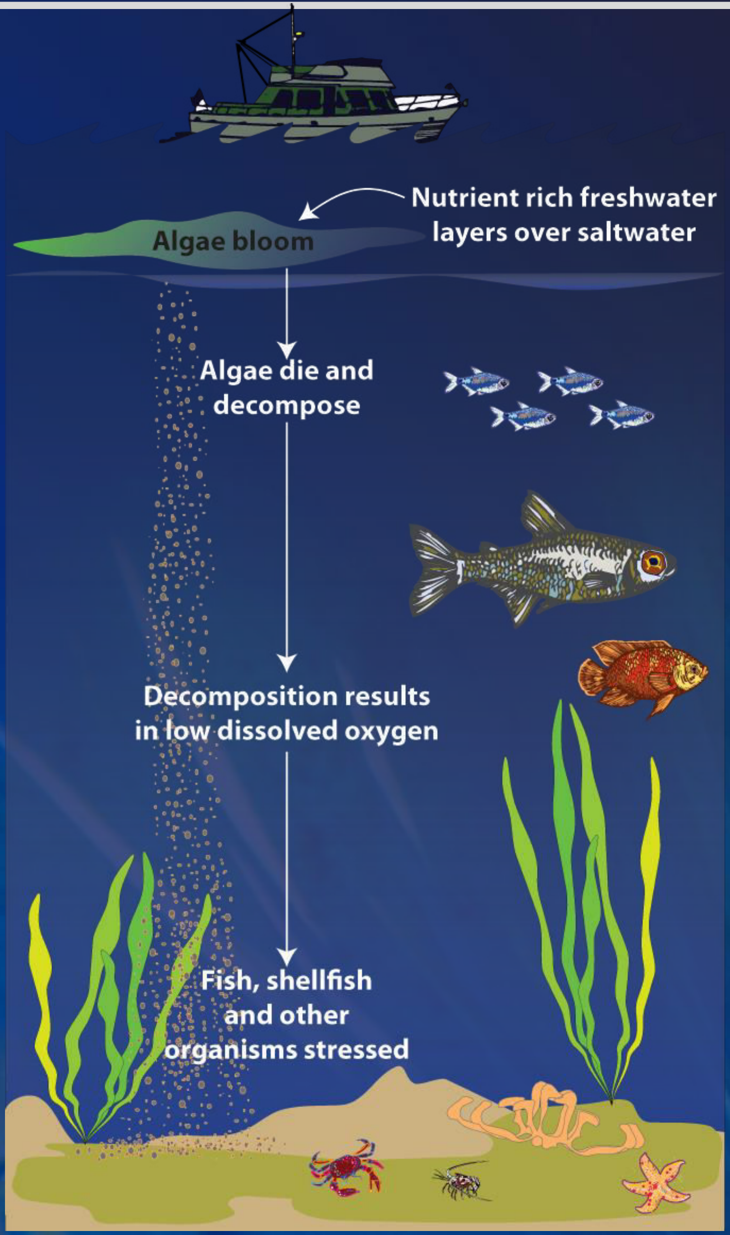
A cyanobacteria bloom in a Midwestern lake.

Water Quality: Rivers & Streams

Photos courtesy Iowa DNR

- 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)

Hypoxia = Dead Zone



- Depleted oxygen creates zones incapable of supporting most life
- 400 worldwide
- Stressed marine and estuarine systems, mass mortality and dramatic changes in the structure of marine communities (Diaz and Rosenberg, 1995).
- In other words ….

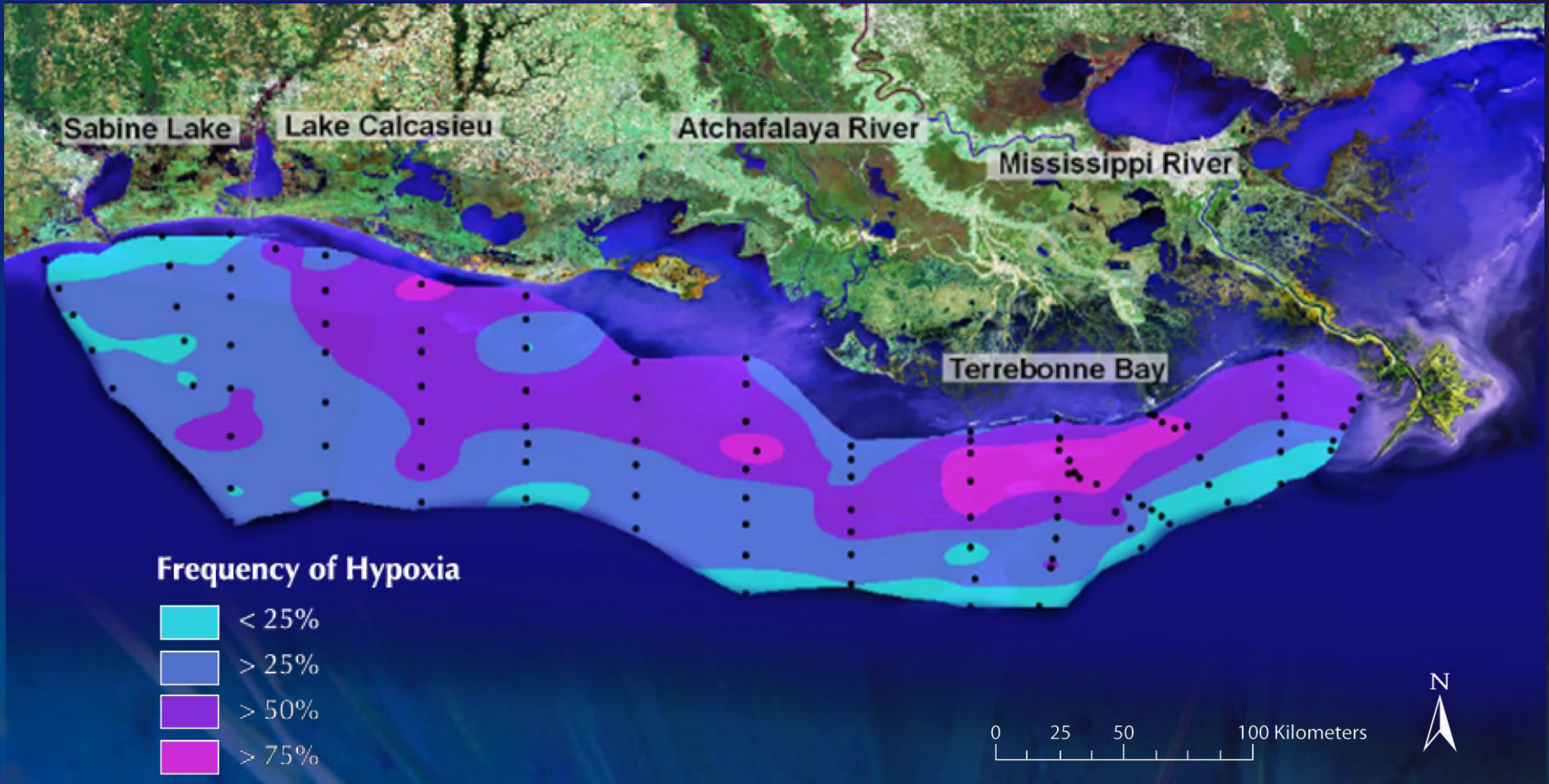
Hypoxic Zone in the Gulf of Mexico

Nutrients and sediments from the Mississippi River enrich the water making it brown.

Over 400 hypoxic Areas worldwide
(Diaz and Rosenberg, 2008)

Image courtesy of Nancy Rabalais (Louisiana Universities Marine Consortium) and can be found on the Southern Regional Water Program web site.

Frequency and Size: 1985-Present



What abatement options exist?

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

Panoramic view of gamma grass-big blue stem planting
http://www.fsa.usda.gov/Internet/FSA_Image/ia_767_15.jpg

What abatement options exist?

- Structural Practices
  - Buffers
  - Grassed Waterways
  - Denitrification, controlled drainage
  - Wetland 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

Agricultural Water Pollution Characteristics

- Nonpoint (Segerson, Shortle and Dunn, etc.)
  - Measurement: costly to trace nutrients to source
  - Randomness: stochastic events (weather) have large effect on damages
- Spatial Aspect (Montgomery, Baumol and Oates)
  - Location of release affects damages
  - Damages are non-separable between fields

Current Policy Milieu

Clean Water Act, 1972

- States required to have water quality “standards” identifying goals for water
- Point sources required to obtain a discharge permit
- Nonpoint sources have no such obligations
  - Total Maximum Daily Loads are not a standard
  - Identify sources

Programs to Support Policy

- Cost share programs - voluntary
  - EPA's 319 program,
  - Conservation Reserve Program,
  - Environmental Quality Improvement Program,
  - Conservation Security Program, and
  - Wetlands Reserve Program

- Water Quality Trading
  - Lack of standards on agriculture
  - ~ 475 of 700 watersheds agriculture contributes 90%+ of N loads! (Ribaudo et al. 2008)

Bottom Line

- Current policy approach
  - Voluntary
  - Property rights with polluters
- Fundamentally different than pollution control other sectors
- Nonpoint source nature
  - Makes reversing property right seem hard
  - Don't know how much externality generating activity is attributable to each source

An Alternative ?

- Reverse property rights
- Focus on practices (abatement actions)
  - Imperfect, but may still be welfare enhancing
  - Example: Abatement Action Permit System

An Abatement Action Permit System (AAPS) Based on Points

- Assign each practice/land use a point
- Set total points for watershed and allocate
- Allow trading
- Choose enforcement mechanism
- Adopt adaptive management
- Include innovation options

Features

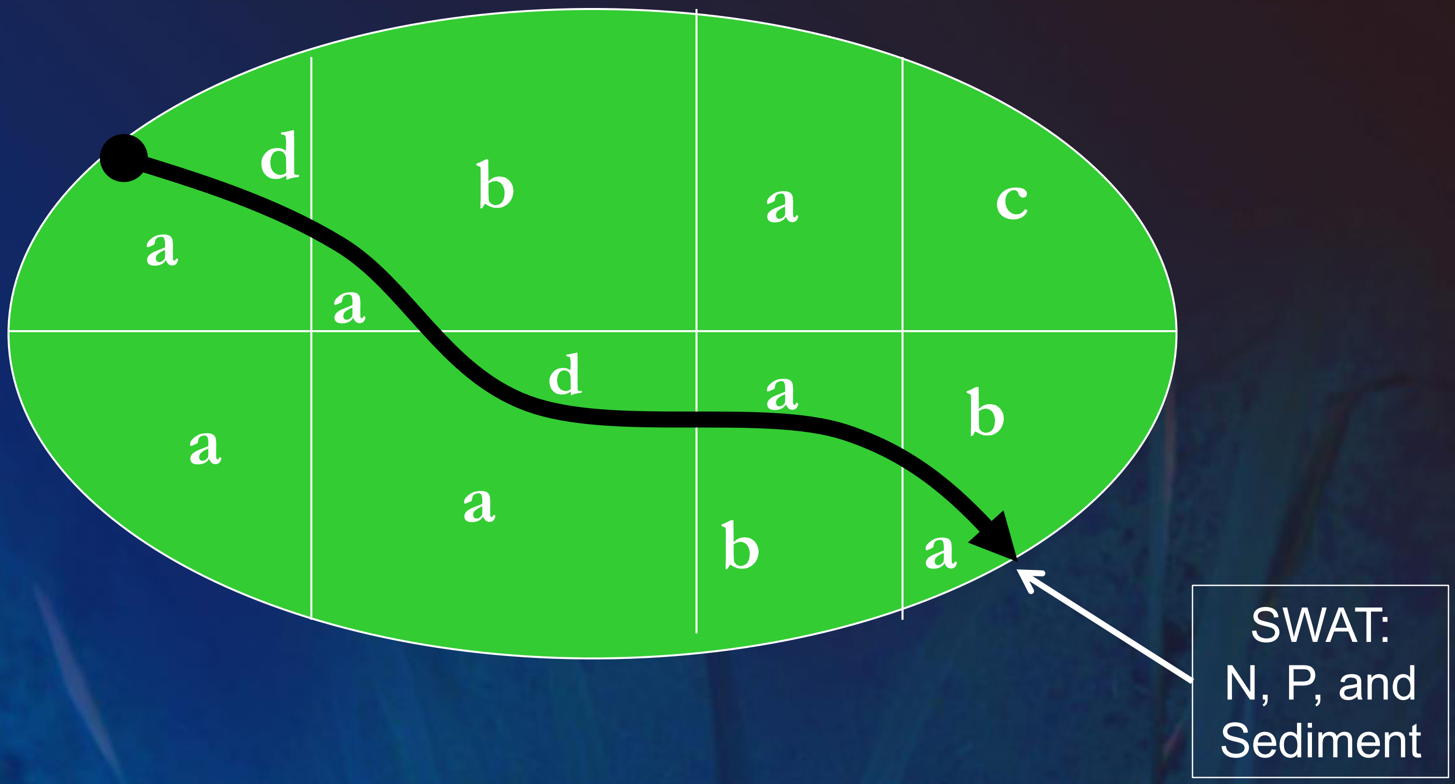
- Puts property rights to clean water in hands of society
- Addresses fairness – early adopters rewarded
- Base on readily observable practices
- Not perfect, but a way to move forward?

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

SWAT Team

Watershed



- 13 Fields, 4 land use/abatement options: a, b, c, d
- SWAT simulates water quality under alternative land use, abatement activities

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 → over 1 billion possible scenarios!

Evolutionary Algorithm --- SPEA2

– Zitzler, Laumanns, and Thiele. “SPEA2: Improving the Strength Pareto Evolutionary Algorithm,” TIK-Report 103, May 2001, Errata added September, 2001

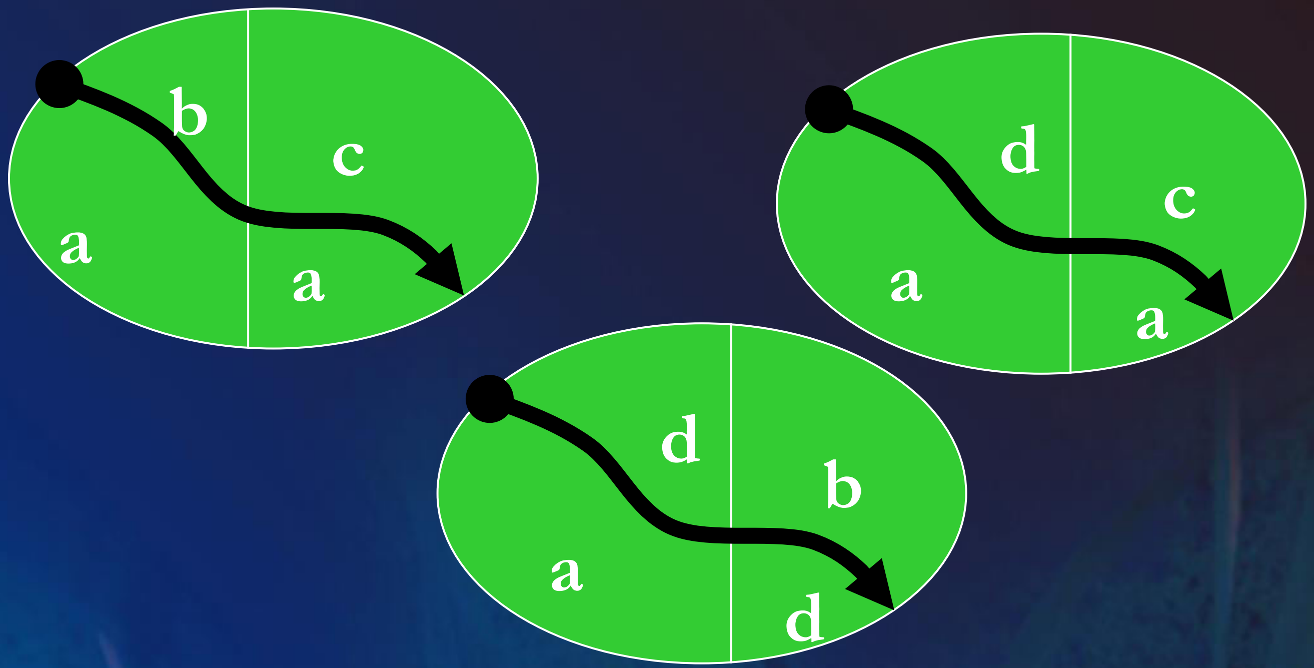
– Other water quality applications: Srivastava et al. (2002); Veith et al. (2003); Muleta and Nicklow (2005); Lant et al. (2005), Arabi et al. (2006)

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

Terminology



"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

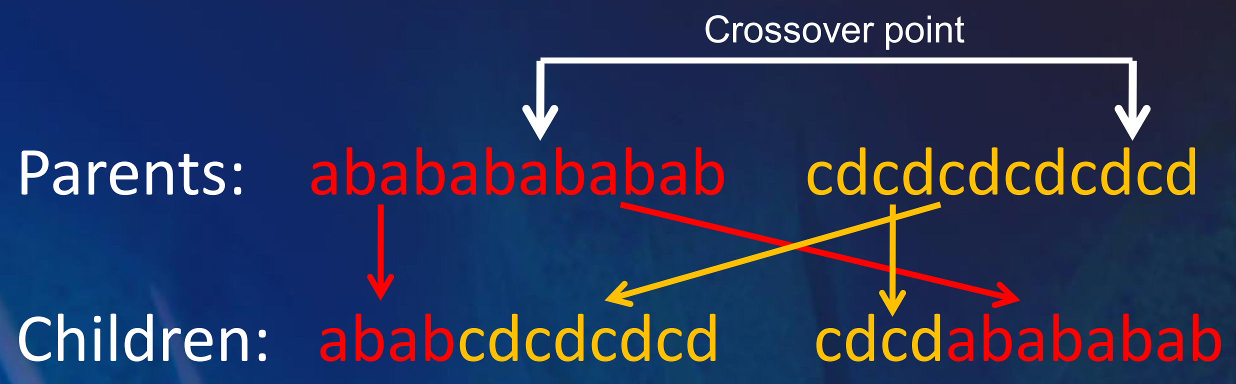
Step IV: Evaluate stopping rule → **Pareto frontier**

Step V: Choose parents

Step VI: Create offspring

Creating Offspring by Crossover

- Choose random position for cross
- Swap "heads" and "tails"



- Other variations: multiple points, random points, etc.

Mutation

Randomly replace an abatement option with another

Example

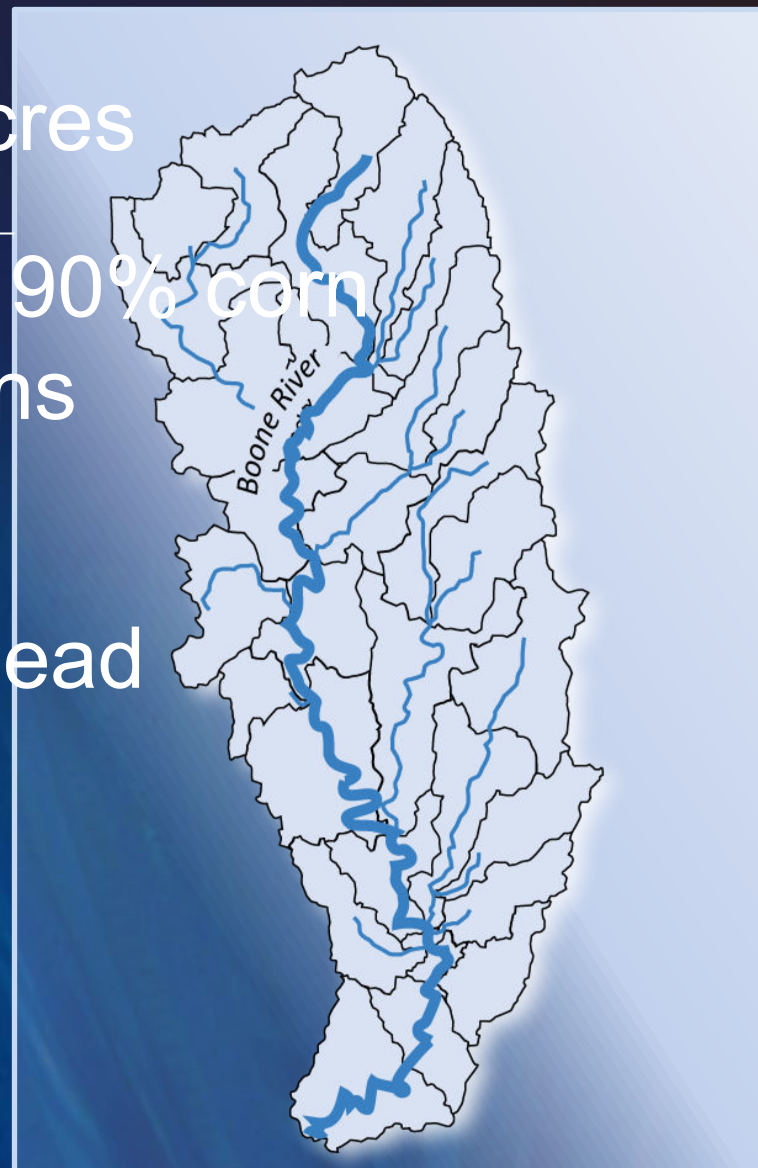
Child1: ababcdcdcdcd

might become: ababacdcdcd

Usually use a low mutation rate ~ .003

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

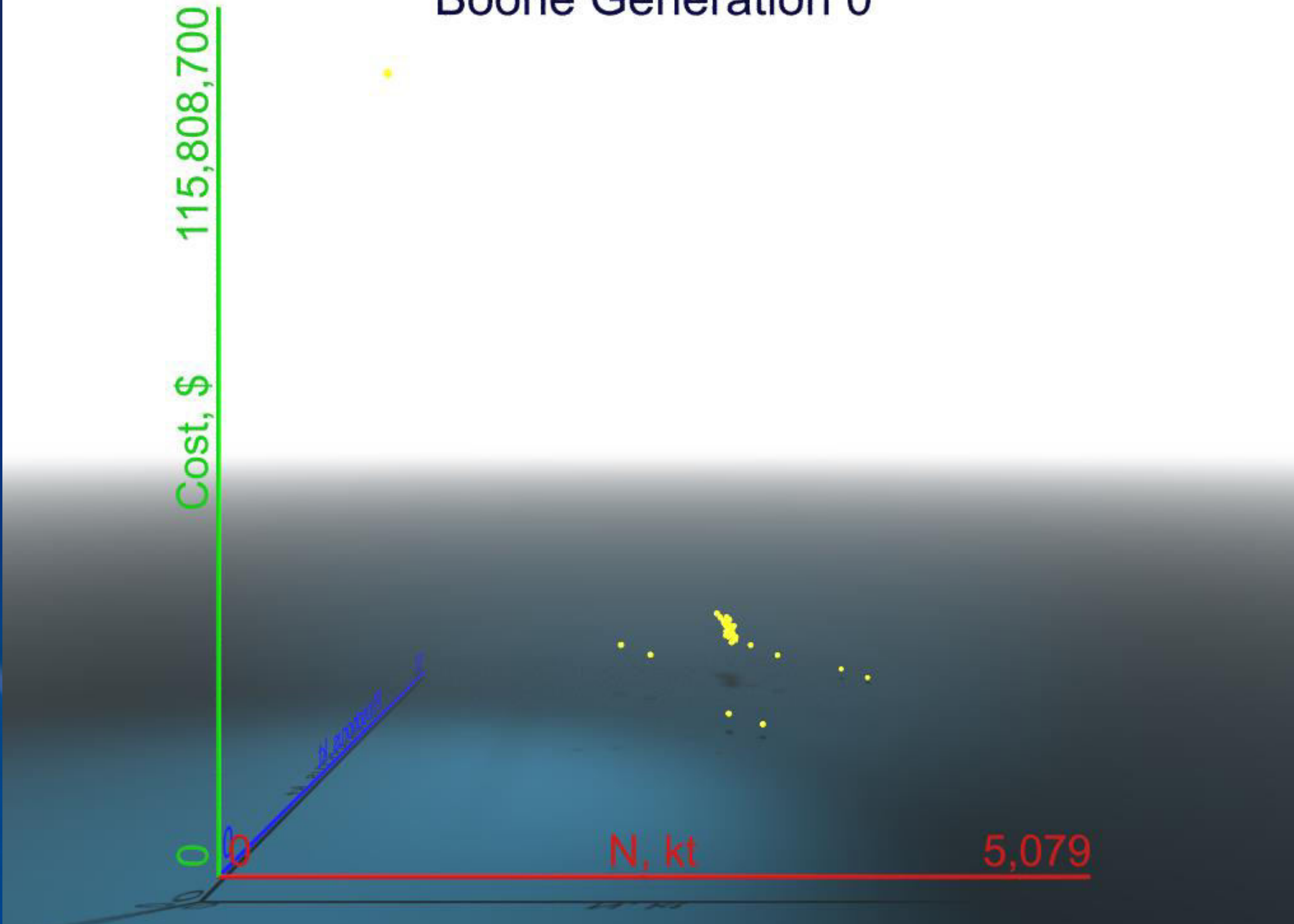
The Land use/Abatement Set

- For each CLU
  - Current practice
  - Land retirement
  - No tillage
  - Reduced fertilizer (20%)
  - Cover crops
  - Sensible combinations

Evolutionary Algorithm: Uniform Seeds

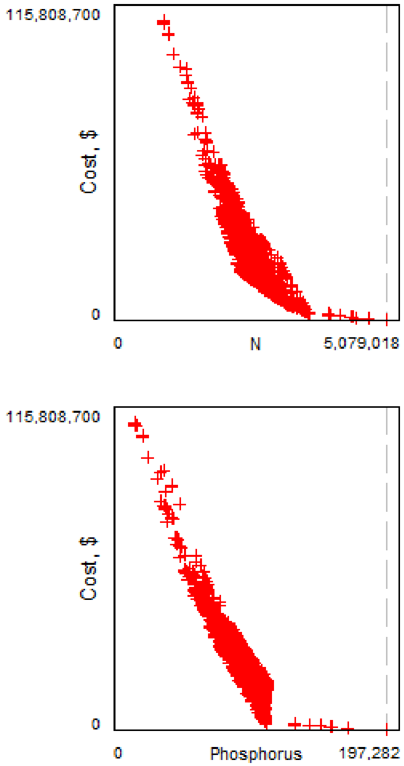
Description/ Uniform Seed	Cost ($1000)	% N Reduction	% P Reduction
Baseline	0		
Reduced Fertilizer	2,199	6	0
No till	2,589	28	44
NT, RF	4,788	34	45
Cover Crop	13,181	24	32
CCr,RF	15,380	29	32
CCr, NT	15,770	48	42
CCr,NT, RF	17,969	53	43
Land Retirement	110,294	82	92

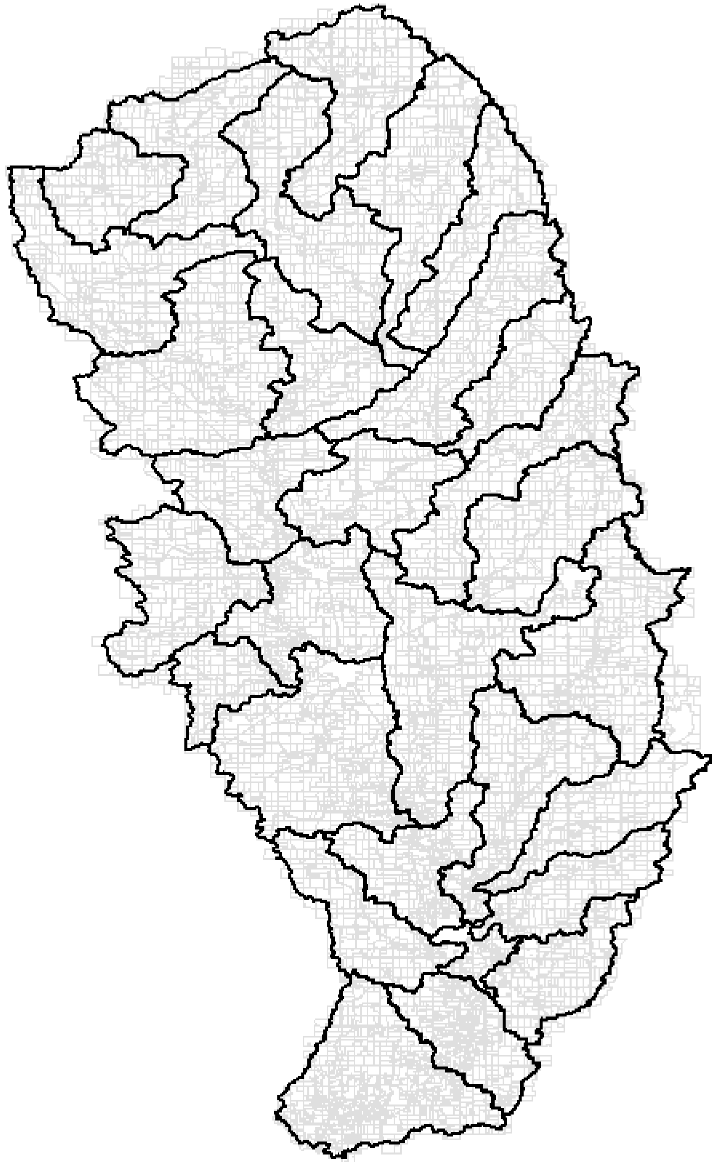
Boone Generation 0



Gains from Optimal Placement

				Practice Allocation (%)				
	Cost ($1000 dollars)	% N	% P	NT	NT, RF	CC, RF	CC NT RF	Other
Cover Crops, Red. Fert	15,380	29	32			100		
Same N reductions	2,778	29	44	84	13	<1	<1	3
Same Cost	15,365	47	45	8	23	<1	64	5



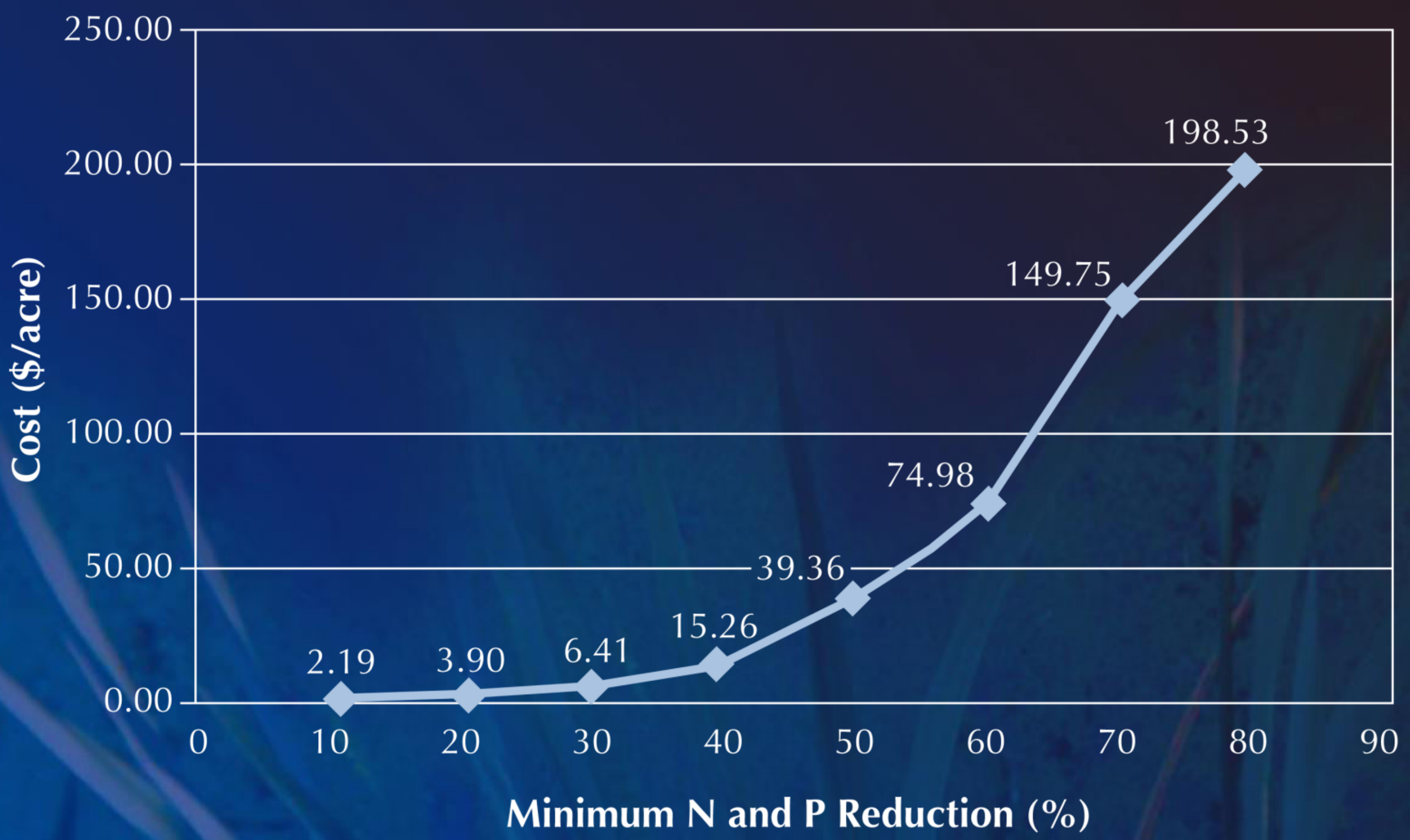


Boone Individual 0001

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

Per acre average costs of abatement actions needed to achieve equal percent reductions in N and P



Thanks for your attention!

Much appreciation to Todd Campbell, Phil Gassman, Manoj Jha, Becky Olson, Sergey Rabotyagov, and Adriana Valcu for superb research and presentation support and to Marca, Silvia, Lyubov and loads of other thoughtful people too numerous to mention for insightful discussions. Financial support from the U.S. Environmental Protection Agency under their targeted watersheds grant program, the USDA Conservation Effects Assessment Program, and CSREES is very gratefully acknowleged.