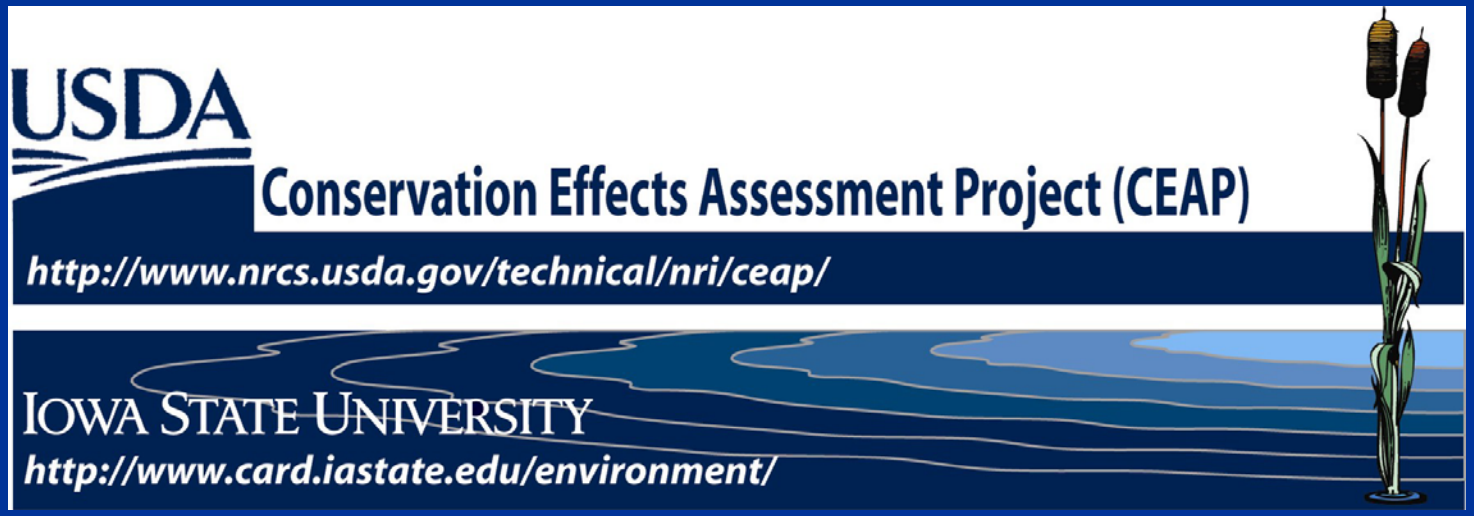
Efficient Placement of Conservation Practices in the Walnut and Squaw Creek Watersheds



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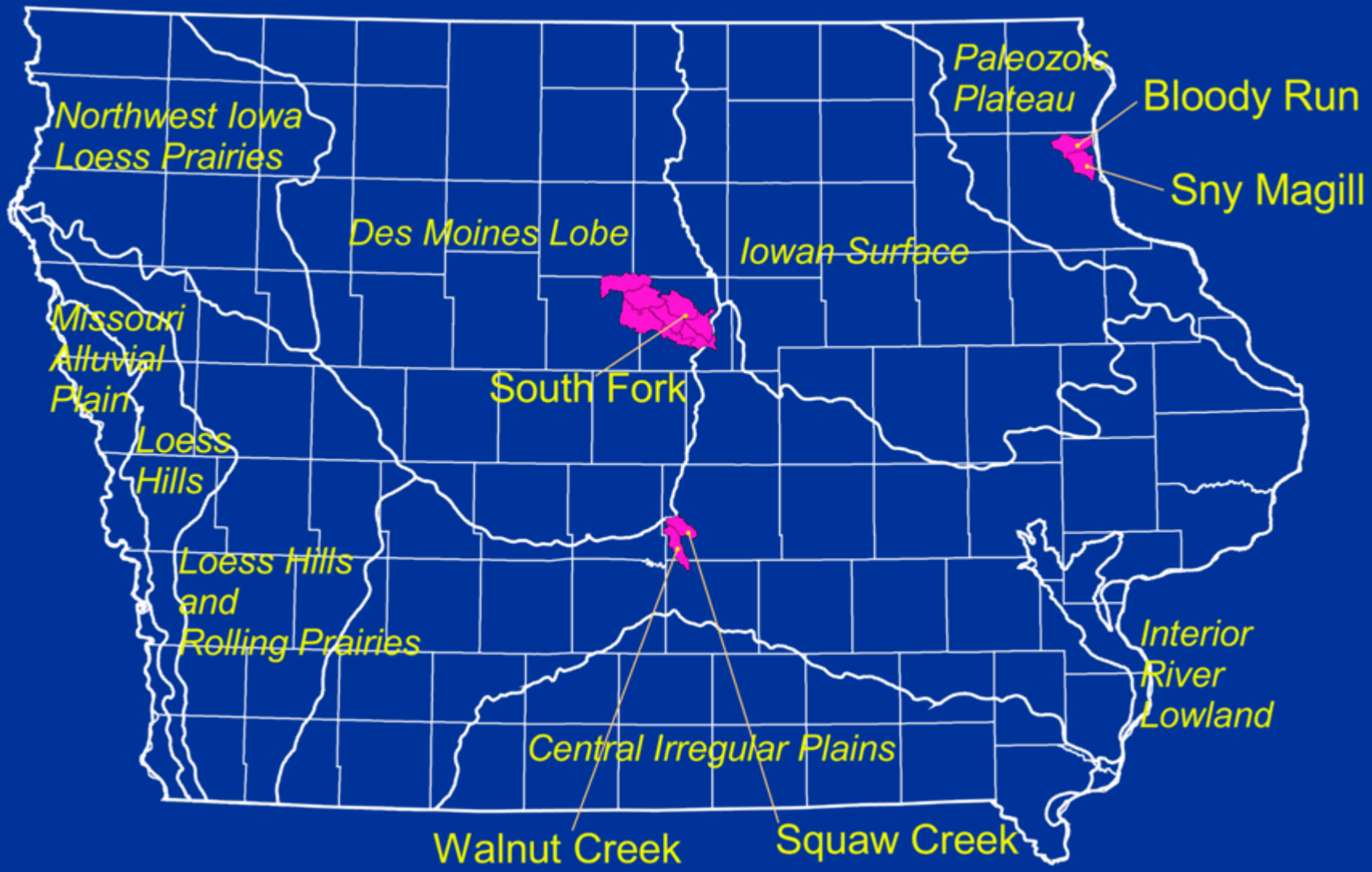
CEAP Project: Study Watersheds in Iowa



Objectives of Overall Study

I. Assemble data to use/develop water quality and economic models of conservation practices.

II. Calibrate SWAT using current conditions for three different watersheds in Iowa, each with differing land use history, physical characteristics, etc.

III. Compare SWAT results to analytic-element groundwater-surface water model (GFLOW) and sediment delivery based on MUSLE.

IV. Using fully developed modeling system, approximate optimal placement of practices to achieve local water-quality goals

Today's talk

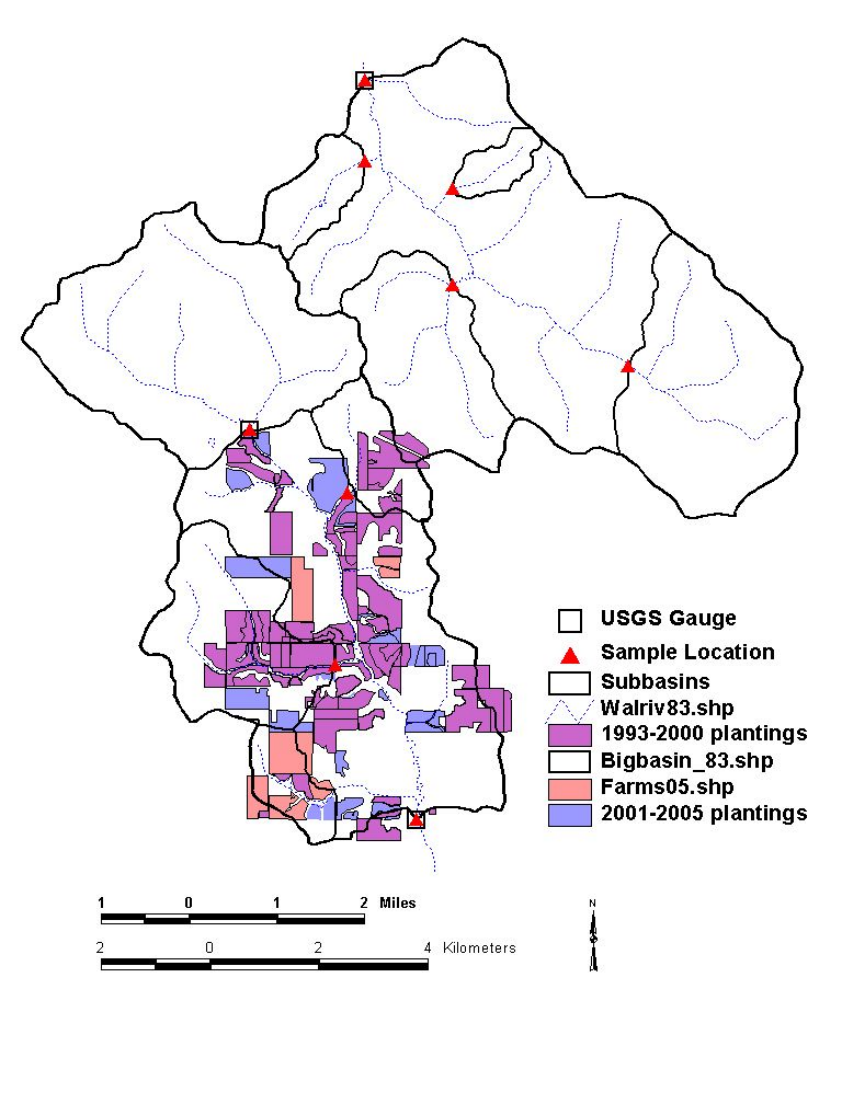
- Focus on Walnut and Squaw Creek
- Describe integrated economic-watershed modeling component: optimal placement of practices using *evolutionary algorithms*
- Present preliminary results

Walnut Creek Watershed Restoration

- The project was established in 1995 in relation to watershed restoration activities at Neal Smith National Wildlife Refuge located near Prairie City, Iowa
- Large areas of the Walnut Creek watershed have been converted from row crop to native prairie by the US Fish and Wildlife Service
- Paired watershed approach - Walnut Creek is 12,890 ac (treatment watershed) and Squaw Creek is 11,714 ac (control watershed)
- Watersheds share a basin divide and have similar basin characteristics

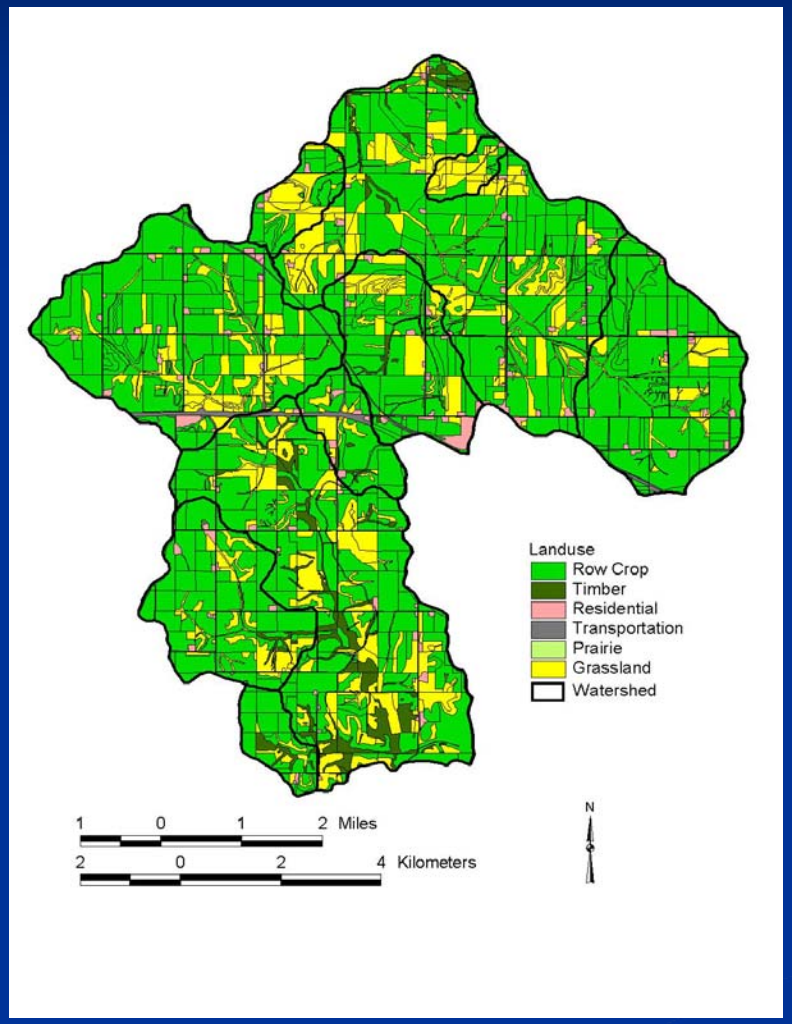
Watershed Info

- Since 1993, 3,023 ac of prairie planted in Walnut Creek watershed – most located in core of watershed between two stream gauges (23% of watershed)
- 3.7% of watershed – rented to area farmers
- From 1992 to 2005: row crop land use decreased from 69 to 54% in WC and increased from 71 to 80% in Squaw Creek
- Nitrogen applications reduced 21%; Pesticide use reduced by 28%



1990 Land Cover

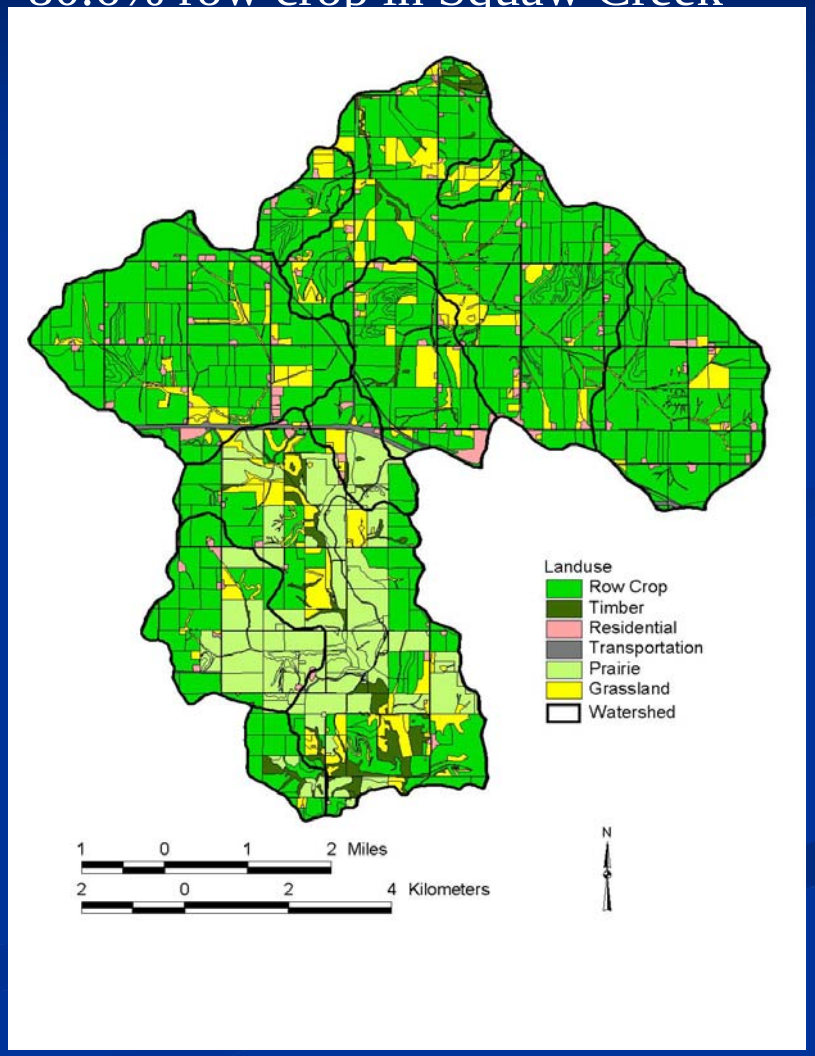
69-71% row crop



2005 Land Cover

54.5% row crop in Walnut Creek

80.6% row crop in Squaw Creek



Study Objectives

- Couple spatially-detailed watershed model with economic information (costs) to assess "optimal" placement of additional conservation practices to meet improved water quality goals
- Use detailed field-scale data to calibrate water quality model and to consider placement of conservation practices
- BASIC QUESTIONS:
  - Where to put conservation practices so as to meet water quality improvement objectives at least cost?
  - What are the trade-offs between costs and water quality improvements?

What conservation practices?

- **Terraces**: an earth embankment, or a combination ridge and channel, constructed across the field slope (USDA-NRCS)
- **Grassed waterways**: natural or constructed channel with suitable vegetation
- **Contour farming**: tillage, planting, and other farming operations performed on or near the contour of the field slope
- **No-till**: managing the amount, orientation and distribution of crop and other plant residue on the soil surface year round while limiting soil-disturbing activities to only those necessary to place nutrients, condition residue and plant crops
- **Land retirement** (CRP): remove land from working production, plant with perennial grasses or other appropriate vegetation
- **Nutrient management**: reduced fertilization, N (20% reduction)

Conservation practices

- Photos courtesy of USDA NRCS

The conservation practices set

- For each hydrologic unit in the watershed, consider 1 of 33 mutually exclusive options
- One is land retirement
- Obtain the rest of options by interacting 4 tillage types (CT, RT, MT, NT) with
  - Practices:
    - Terraces
    - Contouring
    - Grassed Waterways
  - 20% N fertilizer reduction
- Baseline conservation practices impose a set of constraints
  - In this application, algorithm only allowed to add practices

Watershed Model: Soil and Water Assessment Tool (SWAT)

- A hydrologic and water quality model developed by the U.S. Department of Agriculture's Agricultural Research Service (USDA-ARS)
- A long-term continuous watershed-scale simulation model that operates on a daily time step and is designed to assess the impact of different management practices on water, sediment, and agricultural chemical yields
- Gassman et al. (2007) identify over 250 publications using SWAT

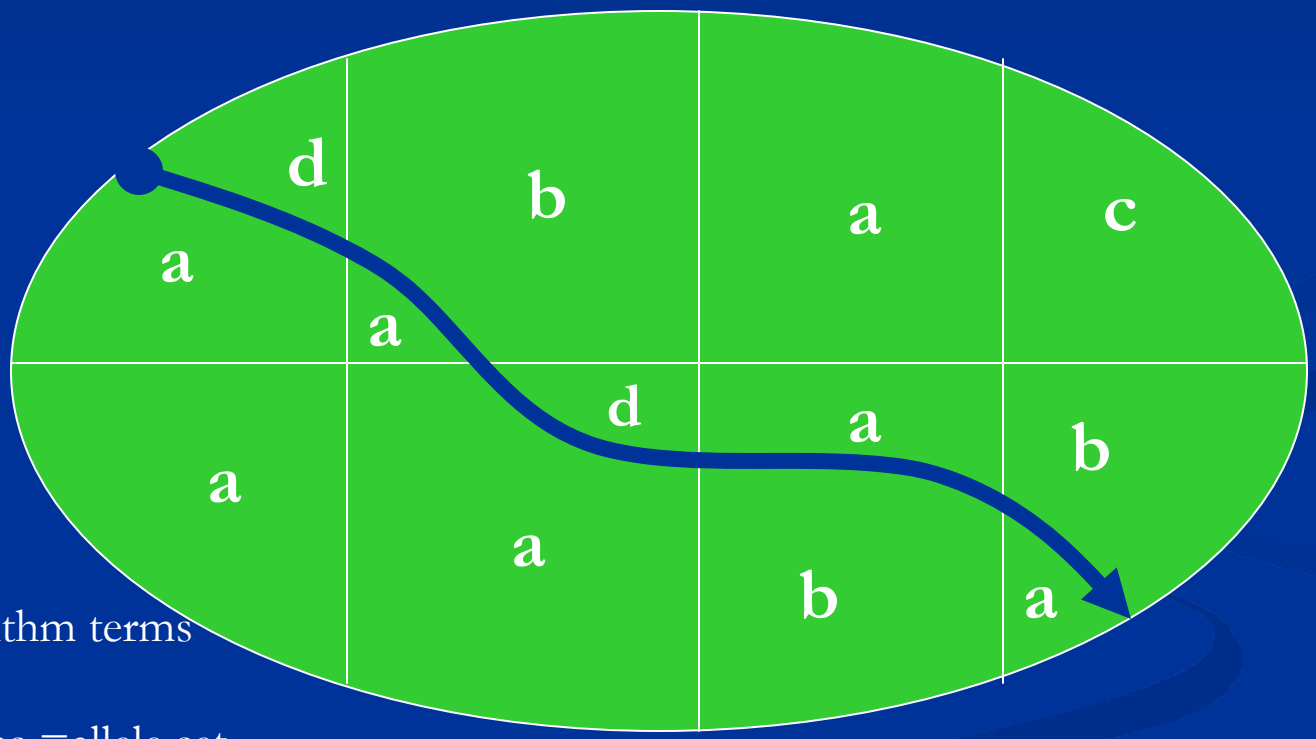
Costs of practices

- Sources of information on the cost of CP's:
  - Terraces, Grassed Waterways, Contouring, No-Till:
    - EQIP: Federal Conservation Program
    - IFIP: State Conservation Program
    - CRP: Federal Conservation Program
  - Land retirement: 2007 Iowa Cash Rental Rates Survey
- Costs of CP's vary by subbasin in each watershed
- Develop a cost estimate for fertilizer reduction
  - Approximate cost=Yield reduction*Corn price ($4.98/bu)

Least Cost Problem

- One field's contribution affected by choices on other fields
  - no exogenous "delivery coefficients"
  - non-mutually exclusive CP's can be implemented on any field, different effectiveness and costs
  - precludes any simple spatial optimization schemes
- Brute force
  - using hydrologic model, analyze all the feasible scenarios, picking cost-efficient solutions
  - But, 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
  - 30 fields, 2 options → over 1 billion possible scenarios

One possible watershed configuration



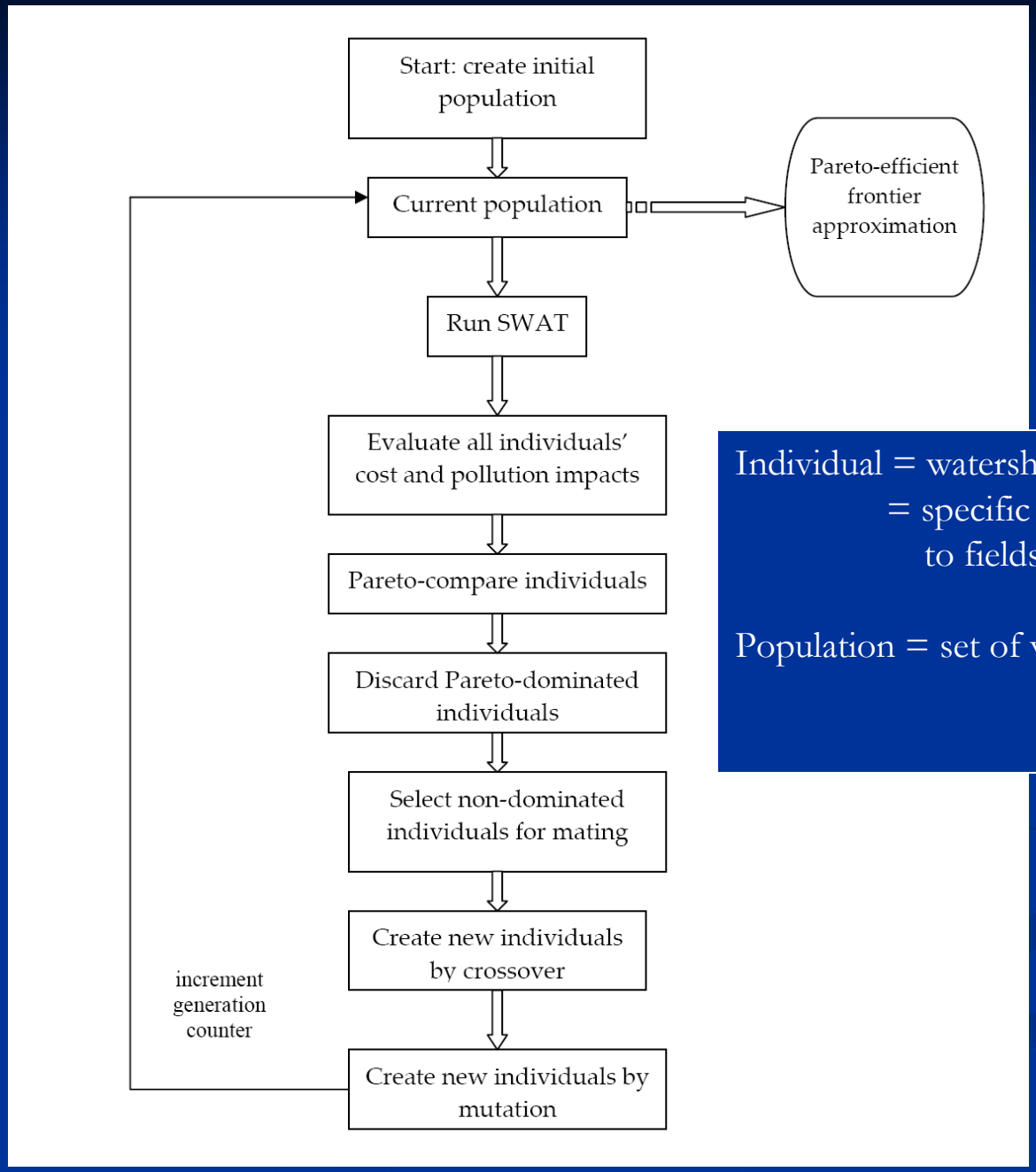
Genetic Algorithm terms
Field = gene
Practice options =allele set
watershed configuration = individual (described by set of genes)
Population = set of configurations

13 Fields
4 conservation practices
13^4=28561 possible configurations

Algorithm implementation

- To implement the algorithm, need values of objectives
- Of the two objectives to be minimized (N, Cost), only cost can be easily computed for a particular scenario
- Nutrient loadings need to be simulated
- Combine:
  - An evolutionary algorithm, SPEA2
  - Hydrologic model, Soil and Water Assessment Tool (SWAT)
- Sometimes referred to as *simulation-optimization* framework

Algorithm flow diagram

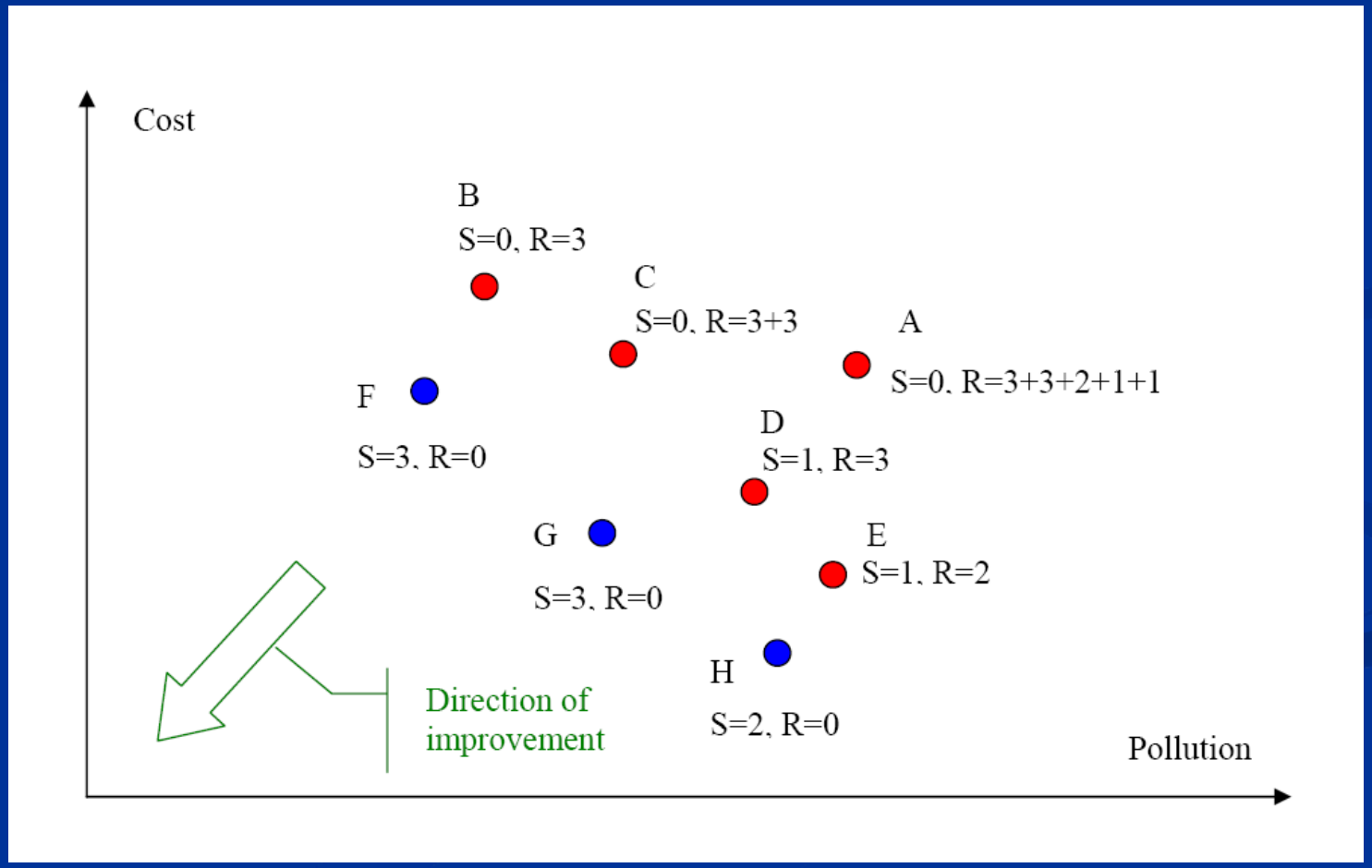


Individual = watershed configuration
= specific assignment of practices to fields

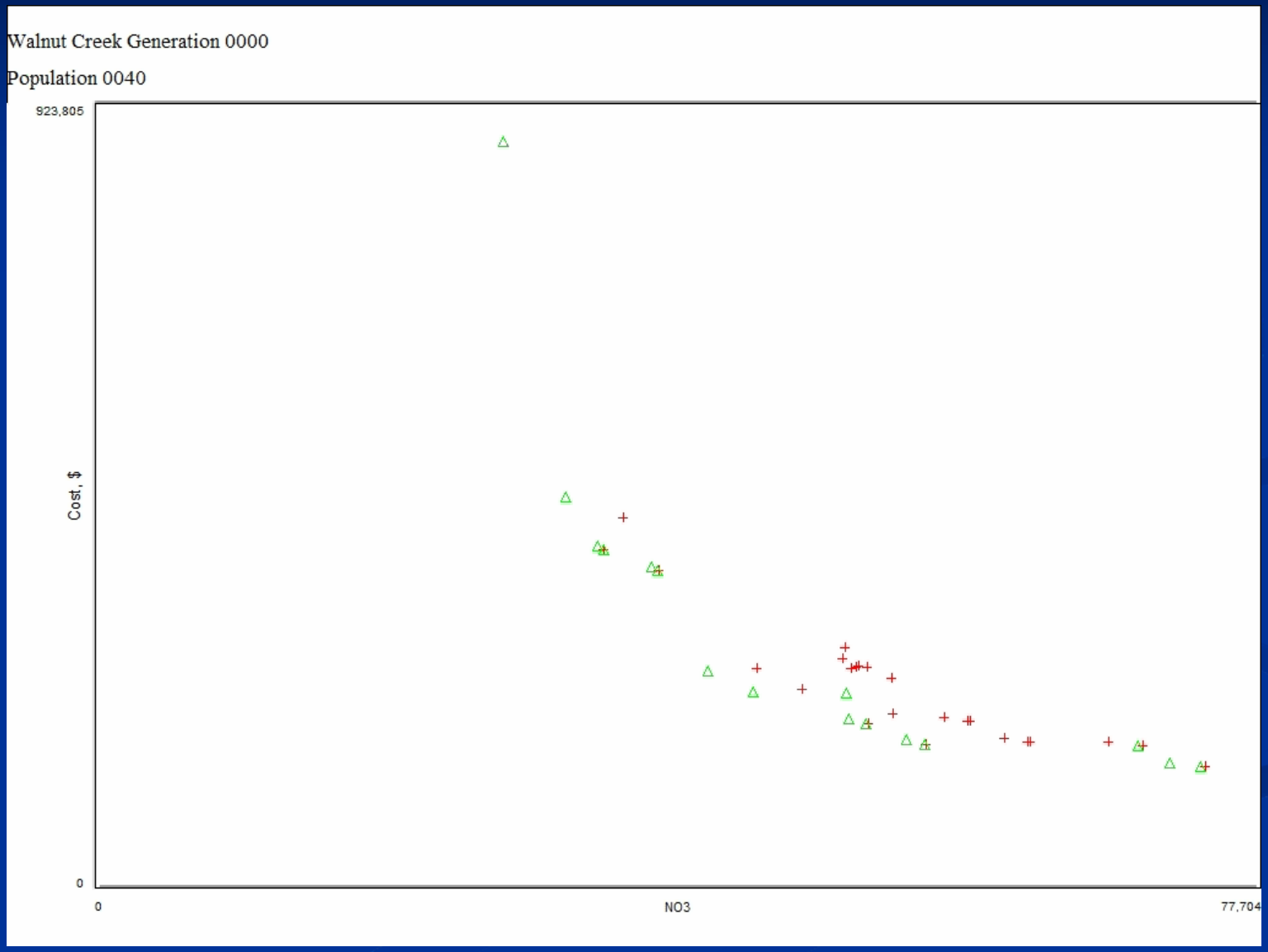
Population = set of watershed configurations

Fitness assignment example

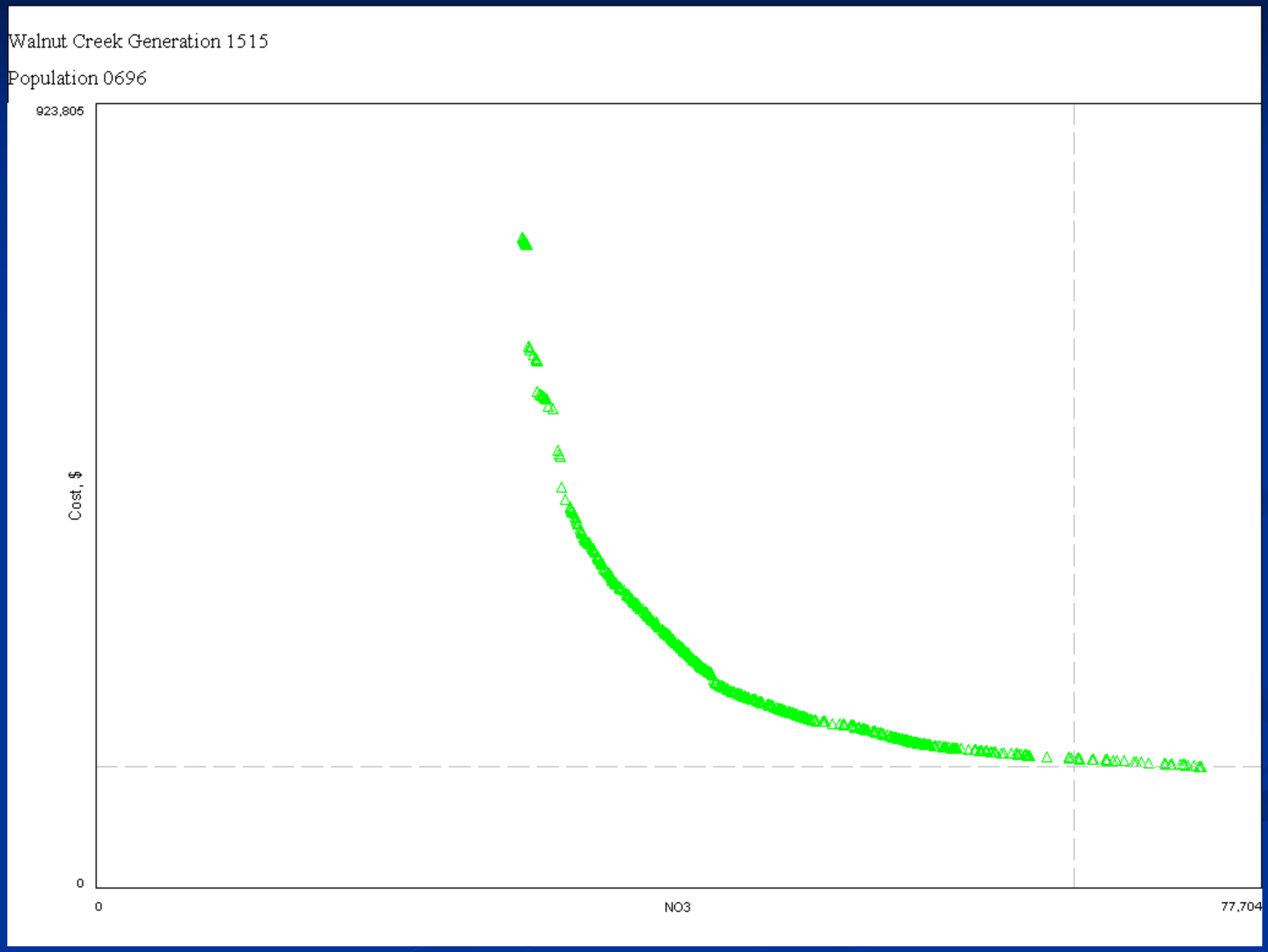
- Strength S(*i*)= # of individuals *i* dominates
- Raw fitness R(*i*)= sum of strengths of individuals that dominate *i*



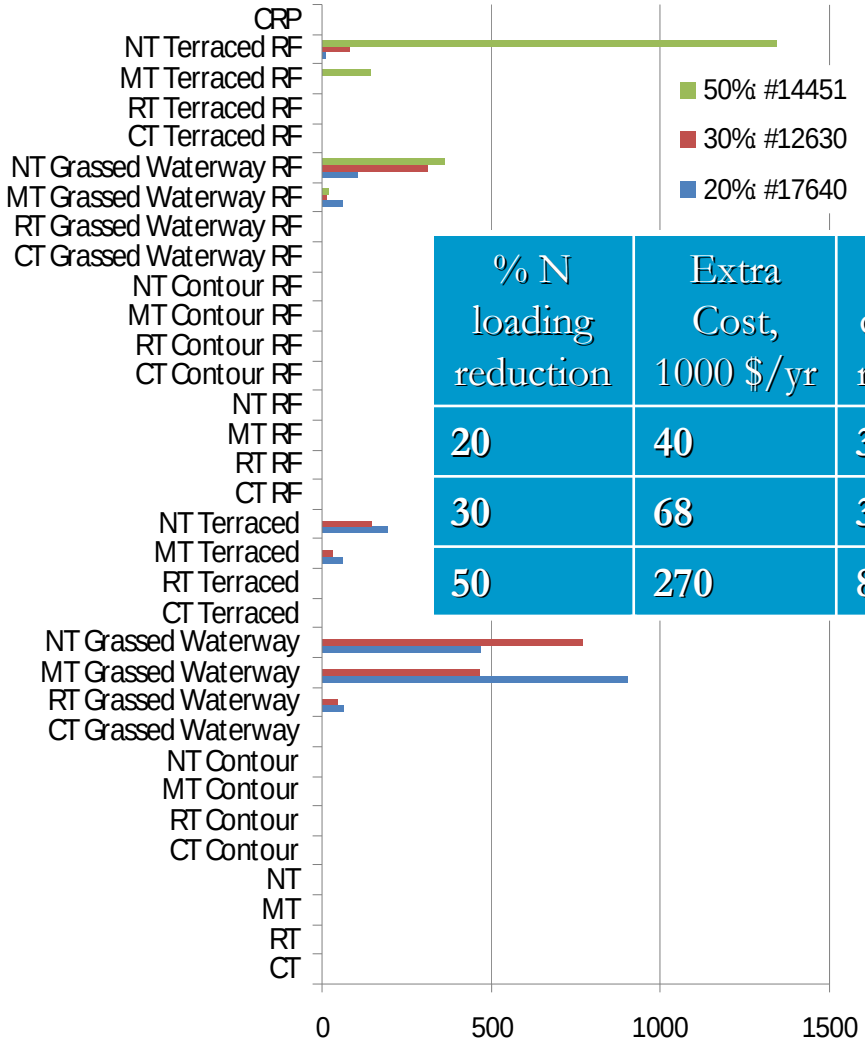
Algorithm progression



Nitrate-Cost Frontier

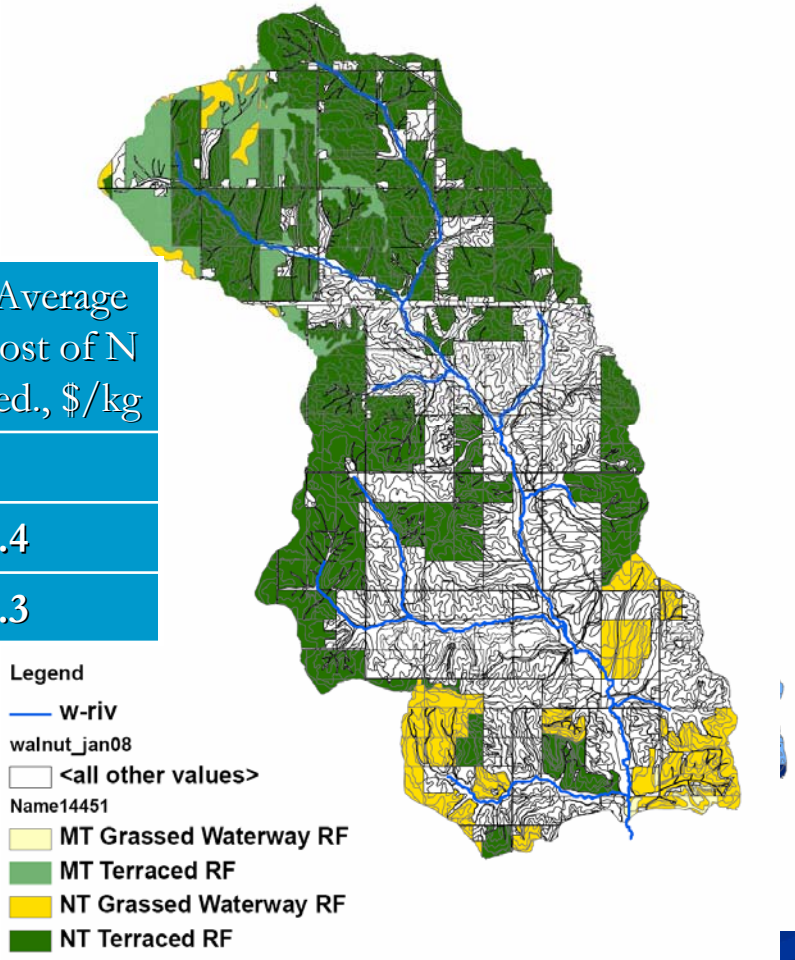


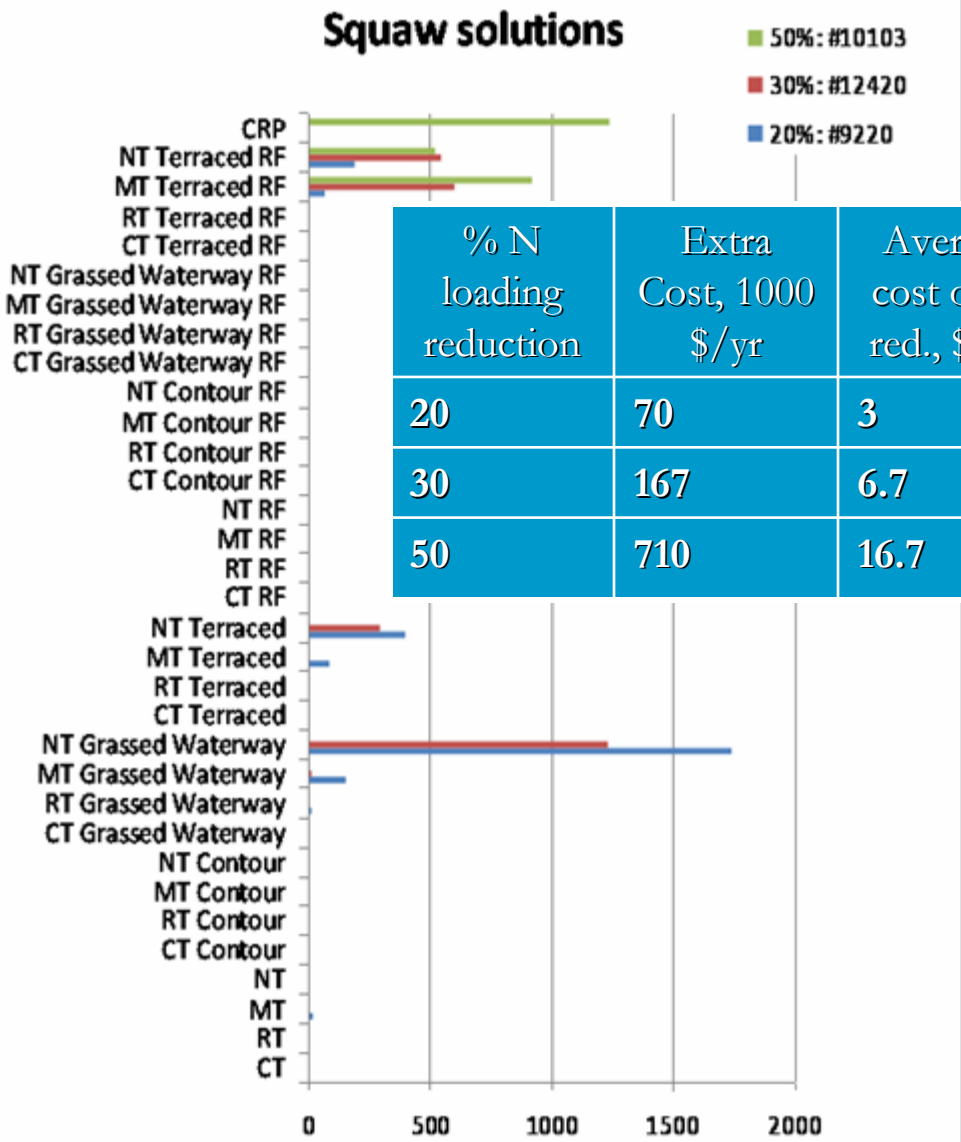
Walnut solutions



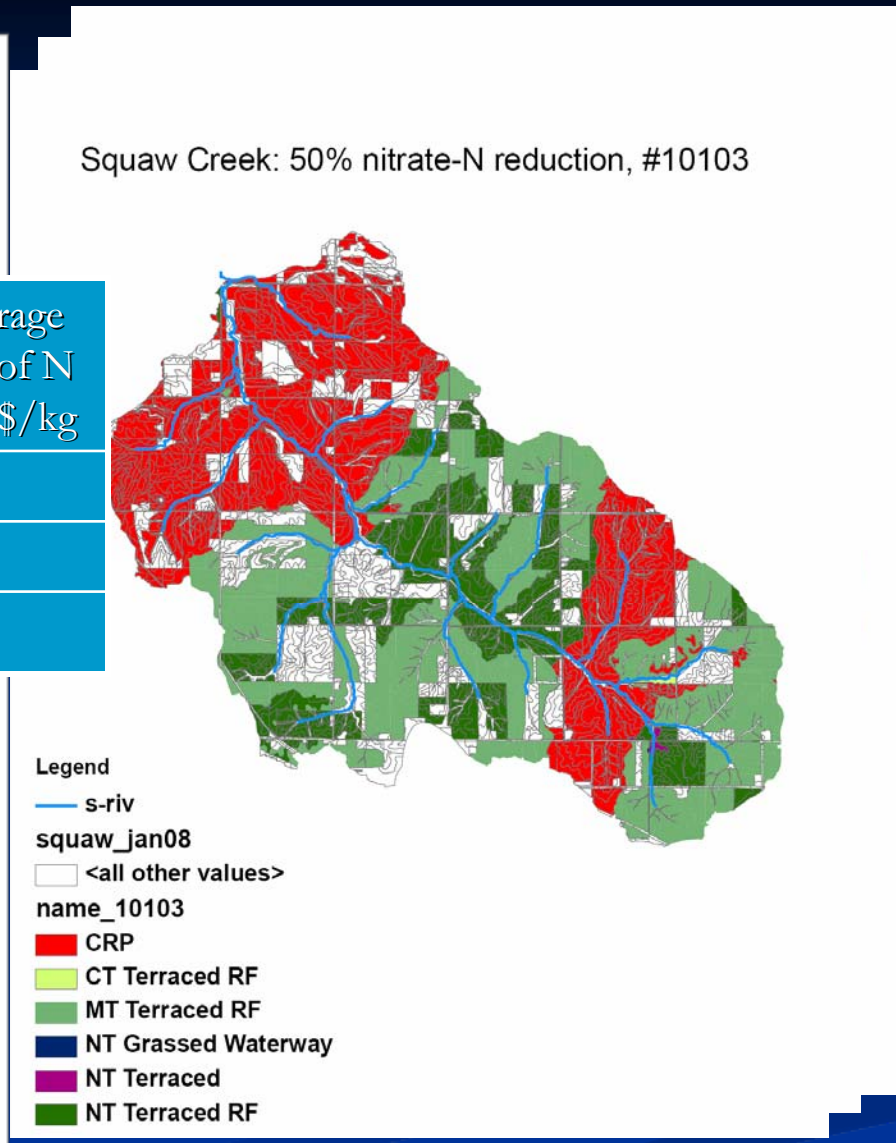
% N loading reduction	Extra Cost, 1000 $/yr	Average cost of N red., $/kg
20	40	3
30	68	3.4
50	270	8.3

Walnut Creek, 50% nitrate-N reduction, #14451





% N loading reduction	Extra Cost, 1000 $/yr	Average cost of N red., $/kg
20	70	3
30	167	6.7
50	710	16.7



Concluding Remarks

- Goal of project: to inform policy makers about the costs of water quality improvement
- Assess costs of alternative landscape configurations and policies to support them
- Recognize importance of heterogeneity; don't expect (and don't find) "one size fits all" solutions
- We only speak of "conservation practices" as modeled within SWAT