Walnut Creek: Monitoring, Modeling, and Optimizing Prairie Restoration

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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.
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
Nitrate Concentrations and Loads

WNT2 range 0.5 to 14 mg/l
SQW2 range 2.1 to 15 mg/l

Exceeded 10 mg/l (MCL) 32.8% in Walnut Creek 51.5% in Squaw Creek

Similar temporal pattern of detection – higher in spring and early summer
Subbasin WNT3
35.7% prairie

Subbasin WNT5
45.9% prairie

Subbasin WNT6
14.3% prairie
Annual Changes in Nitrate
Conclusions from monitoring

- Project results indicate that prairie reconstruction can improve water quality in agricultural watersheds.
- Many years are needed to detect changes in nitrate due to slow groundwater flow velocities in glacial till catchment.
- Much more in Schilling and Wolter’s work.
Questions we would like to address

1. Given the location of prairie restoration, what does water quality modeling tell us about the "prairie effect": the impact of prairie restoration on nutrient loadings?

2. If we wish to achieve nutrient loading reductions at least cost, where should we have put the prairie?
The “Prairie Effect”

- We wish to isolate the effect of prairie restoration
  - Land use has changed in the rest of the watershed, which confounds the impact of the restoration
- Create a “counterfactual” scenario by overlaying 2005 prairie area onto the 1990 land use map of the watershed
- Run the SWAT model for the actual 1990 land use and the counterfactual to isolate the impact of the prairie
The Prairie Effect and Cost-Effectiveness

- For example, suppose prairie restoration is predicted to reduce nitrate loadings from $N_0$ to $N_1$
- Can (could) one do better?
  - Either achieve the same level of nutrient reductions at lower cost or
  - Achieve higher nutrient reductions at the same cost
Why is this important?

1. We are looking for a modeling confirmation of the effectiveness of restoration
2. We are looking to develop the capability to efficiently locate future prairie restoration (or other conservation practices) in the watershed
3. We are looking to inform restoration policies elsewhere
Fundamental Questions

- To select the mix and location of agricultural conservation practices to meet water quality improvement objectives at least cost
  - Here we focus on prairie restoration
- What are the trade-offs between costs and water quality improvements?
- Conceptually, we wish to solve a multiobjective problem:
- min (Cost, Pollutant 1, … , Pollutant K)
  - Subject to
    - Conservation technology and physical constraints
The solution is a set of prescriptions for location of conservation practices which yield Pareto-efficient outcomes in (Cost, Pollutant 1, …, Pollutant K) space.

For convenience, call this frontier of outcomes a “conservation PPF”.
Solution Framework

- We wish to approximate the solution to:
  \[ \text{min } (\text{Cost, Nitrate, Phosphorus}) \]

- Looking for a 3-dimensional conservation PPF

- Of the 3 objectives to be minimized only cost can be readily computed (as cost of land retirement)

- 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
One possible watershed configuration (a candidate solution)

Practice options = (Leave As Is, Convert to Prairie)
Population = set of configurations

13 Fields
2 conservation practices
$2^{13}$ (8192) possible configurations
We end up with over 1300 hundred “fields”
Algorithm progression

Walnut Creek Generation 0030
Population 0050

[Plots showing data points related to phosphorus and nitrogen levels]
Results

“Prairie Effect” is estimated to be:

- 28% reduction in Nitrate-N
- 18% reduction in Total P

Preliminary findings suggest that

- It could be possible to achieve the same nutrient reductions for about 30% cheaper
- It could be possible to obtain up to an additional 14% reduction in N and 10% reduction in P for the cost of existing prairie
Where could the prairie be located to achieve same reductions at lower cost?
Where could the prairie be located to achieve higher reductions at the same cost?
Preliminary Conclusions and Future Work

- Preliminary modeling suggests that restoration is indeed quite effective in reducing nutrient loadings.
- We could do “better” if our only objectives were nutrient reductions (but prairie restoration has other goals!)
- We develop a framework which
  - Can suggest the cost-effective placement of additional prairie or other conservation practices in Walnut Creek
  - Can accompany future restoration efforts