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ABSTRACT

The Environmental Quality Incentives Program and other voluntary Federal conservation programs follow a similar approach for enrollment. Consistent with the legislation, agency personnel identify eligibility criteria, suitable conservation practices, and a process to score, rank, and select applications for funding. Our research outlines a formal multiple criteria decision analysis system that is broadly applicable to current Federal conservation programs to score, rank, and enroll applications, and distribute program funds. Then, we apply the decision system to Indiana's EQIP program using data from 2005. The incorporation of GLEAMS model improved our estimates of water quality impacts by reintroducing the spatial heterogeneity.

Keywords: *Multiple Criteria Decision Analysis, Federal Conservation Programs, Environmental Quality Incentives Program, GLEAMS*

I. INTRODUCTION

Agricultural activities contribute to numerous environmental and potentially harmful health problems. Row crop production and conventional tillage on sloping lands degrade soil resources. One or two crops such as corn and soybeans grown over millions of acres in the Midwest significantly reduce biodiversity. Runoff waters from agricultural fields transport eroded soils, nutrients, and chemicals to nearby streams where these contaminants degrade aquatic habitats, negatively impact

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water supply systems, and reduce recreational activities. Smoke from agricultural burning, dust from tillage, and pesticide drift from spraying pollute the air we breathe, thus affecting our respiratory system (Feenstra 1997).

To mitigate nonpoint source pollution, improve the environment, and reduce potentially adverse health impacts associated with agricultural production, the Federal government offers technical, financial, and educational support to farm and ranch operators through a diverse set of conservation programs. The Conservation Reserve Program (CRP) and the Environmental Quality Incentives Program (EQIP) dominate the other programs in terms of program participation, enrolled acres and funding.

Given such high participation rates for voluntary programs, it is clear the agricultural community monetarily benefits from them. It also appears that society remains committed to these agricultural conservation programs given its continuing support for them in the 2007 farm bill. Long-term societal support for these programs, however, depends on assessing positive changes occurring on the land, in the air, and in the water and deciding if the beneficial changes are worth the large expenditures of Federal funds.

Maps of a conservation program's resource concerns and applications are useful in a preliminarily analysis of a Federal conservation program's performance and identification of potential problems associated with its design. Figure 1 and Figure 2 illustrate the aggregated resource concerns and applications from 2004 and 2005

Indiana's EQIP program. The darkest blue areas refer to areas exhibiting the most resource concerns; the lightest, the fewest resource concerns. Once applications are overlaid on the maps, it becomes apparent that a substantial number of the applications accepted for EQIP funding lie outside of the most environmentally sensitive areas, the darkest blue areas. Stated another way, one would expect approved applications to more likely be found in the highest resource concern areas, especially if conservation practices addressed more than one resource concern.

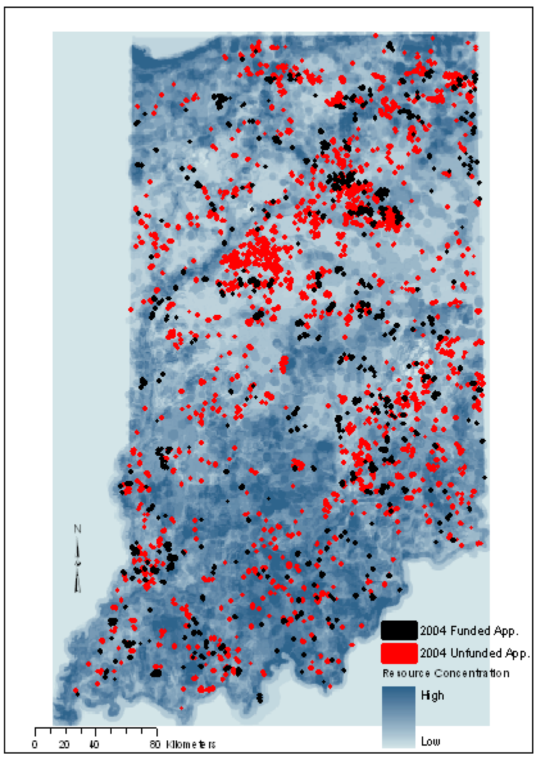


Figure 1: EQIP Applications, 2004

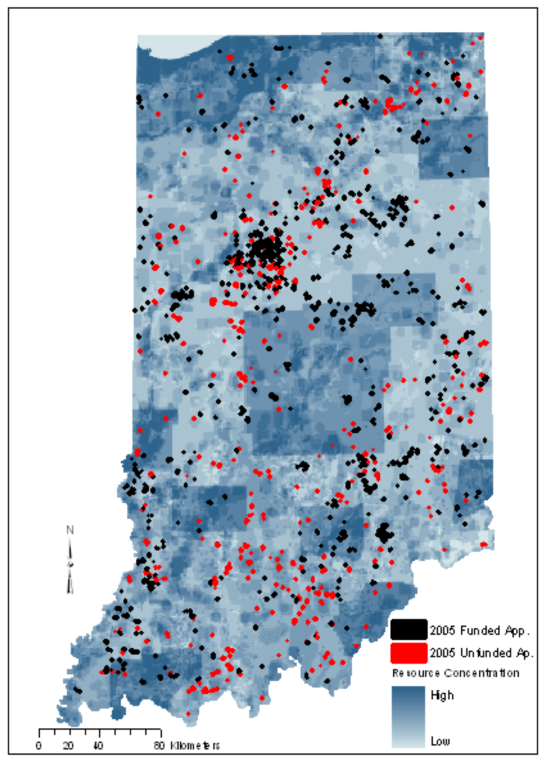


Figure 2: EQIP Applications, 2005

Many reasons have been given for this disconnect between resource concerns and results. First, EQIP is a voluntary, federally-funded program. A portion of the landowners who oppose the use of Federal dollars for these types of activities may also farm the highest resource concern areas. A second related reason focuses on problematic, low productive lands where the required application costs of applying the needed conservation practices outweigh the land's income potential. A third reason, and one discussed in most of the assessment studies of EQIP and other Federal conservation programs, is program design such as not including all the objectives, misspecifying objectives, weighting objectives incorrectly, and selecting inappropriate criteria and scoring methods for ranking applications (Searchinger and Friedman 2003; Friedman and Heimlich 2004; Soil and Water Conservation Society and Environmental Defense 2007). Our paper addresses the program design concern in the context of adoption of multiple criteria decision analysis procedures, methods, and tools to improve the performance of Federal conservation programs.

II. ASSESSMENTS OF FEDERAL CONSERVATION PROGRAM DESIGNS

Many assessment studies have focused on a conservation program's objectives as a means of improving program performance. Federal conservation programs almost always include multiple objectives since a separate program for each objective is not optimal from the perspective of program administration, implementation costs, linkages among the environmental problems and the methods used to address them (Cattaneo, Hellerstein et al. 2006). They are critiqued about not having a specific, documented rationale for the selection of objectives and the weights assigned to them (Bertoni 2006; Hajkowicz and Collins 2007; Shames 2007).

Researchers have also criticized that the environmental indicators, which determine how well an applicant does with respect to each objective, are not clearly defined and appraised (Powell and Wilson 1997). Program managers of the Conservation Reserve Program, for example, developed the Environmental Benefit Index (EBI). The EBI assigns points to land parcels converted from agricultural crops to grasses or trees based on expected environmental improvements in various objectives and the importance of these improvements to the public (Hansen and Hellerstein 2006). Ribaudo et al. (2001) discussed the vagueness of the indicators in CRP's Environmental Benefit Index and what they supposedly represented. The environmental indicators defined for EQIP by States also carry the same ambiguity.

Points granted for applying conservation practices is another possible design problem identified by researchers. Current Federal conservation programs such as CRP, EQIP, and Farm and Ranch Land Protection Program (FRPP) utilize an ordinal scale to assess the effectiveness of an application in achieving program objectives. The Conservation Practice Physical Effects (CPPE) matrix developed by the USDA-NRCS (2006) summarizes each conservation practice's impact on environmental and natural resource problems according to the qualitative scale that ranges from "Significant Increase in the Problem" to "Significant Decrease in the Problem" (Lawrence, Stone et al. 1997; United States Department of Agriculture 2002; Natural Resources Conservation Service 2006). Indiana, Illinois and North Carolina adopted this matrix and converted these qualitative definitions to a quantitative scale in order to assign points and sum them up to compute an overall estimate of potential benefits from applying the conservation practices specified in EQIP applications.

Many authors have criticized the conversion of qualitative rankings to points. Smith et al. (1987) and Wolman (2006) emphasized that such addition is an improper application of ordinal scales since the intervals between the points are meaningless. Several authors in the literature also expressed their concern that equal increases in points might not have equal increases in value/utility. Additionally, Guikema and Milke (1999) discussed the range of points, which is required to be similar among attributes to be used directly.

Each program’s decision rule also influences the selection of applications for funding and impacts cost-effectiveness of the program outcomes (Babcock, Lakshminarayan et al. 1997; Hajkowicz, Higgins et al. 2007; Soil and Water Conservation Society and Environmental Defense 2007). For example, in Babcock et al. (1997) study benefit maximization rule would achieve a much higher proportion of potential environmental benefits for water erosion and groundwater vulnerability, whereas cost minimization should achieve a greater proportion of wind erosion benefits.

In summary, previous conservation program assessments, many of which were discussed above, have focused on specific problems or specific components such as identifying and weighting competing objectives and quantifying program attributes

(Lakshminarayan, Johnson et al. 1995; Lawrence, Stone et al. 1997; Guikema and Milke 1999). They also critiqued that the program implementation methods vary from state to state and year to year (Ponder, Wiggins et al. 2005; Cattaneo, Hellerstein et al. 2006; Johansson and Cattaneo 2006; Soil and Water Conservation Society and Environmental Defense 2007). This large body of research leads us to the conclusion that the next series of assessments need to examine the broader decision system and its associated framework to design a generic multiple criteria decision system which is applicable to the majority of the Federal conservation programs.

III. INDIANA EQIP MULTIPLE CRITERIA DECISION ANALYSIS SYSTEM

Indiana Environmental Quality Incentives Program decision system is developed by following the procedure of multiple criteria decision analysis (MCDA). This system first includes identification of the system components, goals, objectives and attributes; development of a hierarchic structure; and determination of each objective's relative importance; assessments of value functions; and selection of a decision rule. Then, the GLEAMS-NAPRA model is incorporated into the system to improve the estimation of changes in water quality indicators and assign measurable, quantitative points. A weighted-additive value function method is employed to calculate overall scores for the applications. Using the benefit-cost ratios of the applications, we score, rank, select, and distribute available program funds.

In the literature, it is common and well-accepted to organize goals, objectives and attributes in a hierarchical structure (Keeney and Raiffa 1976; Saaty 1980; Zeleny 1982; Clemen 1996; Kirkwood 1997; Malczewski 1999). As specified in the Farm Security and Rural Investment Act of 2002 (Pub. L. No. 107-171 (116 Stat.). 134. 2002), the goals of EQIP are to promote agricultural production and environmental quality as compatible goals. In order to provide directions to State and local levels for implementing EQIP to achieve the goals, USDA Natural Resources Conservation Service (NRCS) has established the first level objectives, National Priorities as NRCS called, as enhancing soil, water and air quality, increasing and protecting wildlife habitat by assisting producers in installing and maintaining conservation practices (U.S. Department of Agriculture Natural Resources Conservation Service 2002).

The EQIP MCDA system captures the goals identified in the Farm Security and Rural Investment Act of 2002 and objectives delineated by NRCS. The objectives hierarchy of the EQIP decision system is shown in Figure 3 below.

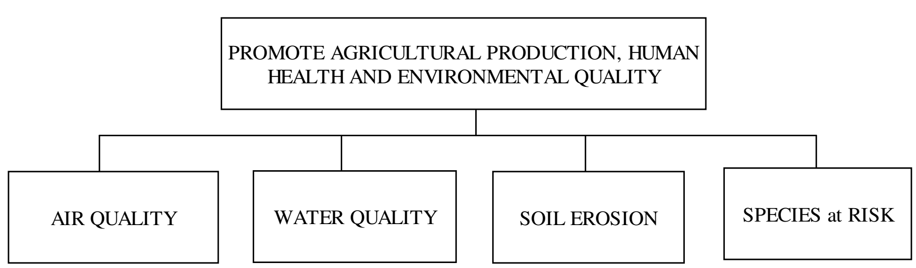


Figure 3: EQIP MCDA System Objective Hierarchy

This analysis focuses on identification and measurement of attributes to serve the water quality objective. In the literature, reductions in the amount of pollutants entering water ways and lakes suggest improvements in water quality. The major surface and ground water pollutants produced by agricultural activities are sediment, nutrients, and pesticides.

Let (*i*) denotes the program objective where $1 \le i \le 4$ since there are four objectives identified in the hierarchy and (*j*) specifies the attributes identified to measure each objective, the decision hierarchy with updated water quality attributes is diagrammed in Figure 4.

The decision system includes a single decision maker – the government, which determines the eligible applications that maximizes the environmental benefits achieved with a given budget for enrollment under certainty. The weighted-additive value function for assessing applications is

$$\text{Application Overall Value} = \sum_{i}^{m} w_i v_i \left[\sum_{j}^{m_i} w_{ij} \left(\sum_{l}^{n} f_j \left(S_{jl} \right) \right) \right]$$

where

$w_i \Rightarrow$ Weight of the i^{th} objective

$v_i \Rightarrow$ Value of the objective i

$m \Rightarrow$ Number of objectives

$w_{ij} \Rightarrow$ Weights of the j^{th} attribute for objective i

$m_i \Rightarrow$ Number of attributes for objective i

$f_j \Rightarrow$ Conversion function of attribute j

$S_{jl} \Rightarrow$ Attribute j outcome for practice l

$n \Rightarrow$ Number of practices proposed

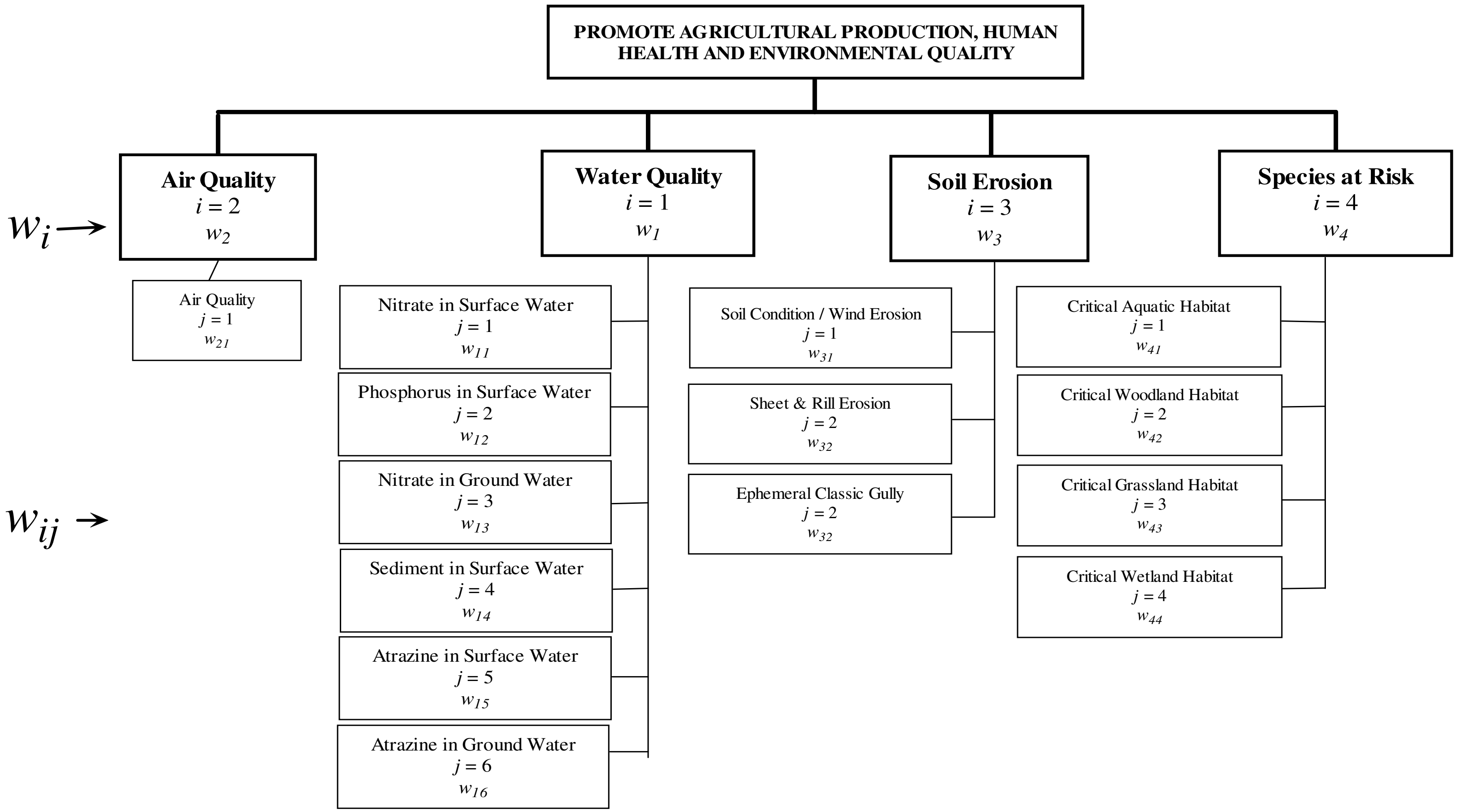


Figure 4: Indiana EQIP Decision System Hierarchy

Simulation models and expert opinions provide outcome scores for attributes when eligible conservation practices are implemented. Those scores are represented by S_{jl} in the overall value calculation formula. Each attribute's conversion function f_j converts its scores into dimensionless quantities. The dimensionless quantities of all attributes for every objective are weighted and linearly summed.

A major criticism of using MCDA is the value that a human attaches to each attribute's points or scales (Smith and Theberge 1987; Feather, Hellerstein et al. 1999; Guikema and Milke 1999; Ribaudo, Hoag et al. 2001). Value functions indicate how satisfaction changes as the levels of an attribute change. In a value function, each impact is defined by a single predicted value. A decision maker's subjective preference about each outcome is integrated into the analysis using v_i. The values of objectives are also weighted and summed to calculate the perceived improvement in overall environmental quality.

Indiana Case Study

For the 2005 Environmental Quality Incentives Program, Indiana's Natural Resources Conservation Service identified 86 eligible conservation practices, also known as best management practices (BMPs). Indiana program managers for 2005 EQIP used the Conservation Practice Physical Effects matrix (USDA Natural Resources Conservation Service 2006) to identify impacts and assign scores S_{jl} in the value calculation formula. This matrix qualitatively evaluates each practice's impact on environmental and natural resource problems. Indiana program managers converted the qualitative assessment to quantitative values to score and rank applications. Scores do not reflect the locations of applications, site characteristics, and other specifications such as soils, slope or precipitation. This means that every applicant who selects the same BMP receives the same score. Additionally, the Conservation Practices Physical Effects (CPPE) matrix ignores interactions among the proposed BMPs. Below in Table 1, you will find the CPPE scores of the four most popular BMPs proposed by non-livestock applicants.

BMPs	Nutrients in Surface Water	Nutrients in Groundwater	Sediment in Surface Water	Pesticides in Surface Water	Pesticides in Groundwater
Residue Management/No till	1	0	4	5	1
Filter Strip	5	3	5	3	1
Nutrient Management	5	5	0	0	0
Pest Management	0	0	2	5	5

Table 1: CPPE matrix scores for EQIP 2005 water quality attributes

The attributes – nutrients, sediment, and pesticides in surface and ground water – to measure changes in water quality are also outputs of Groundwater Loading Effects of Agricultural Management Systems - National Agricultural Pesticide Risk Analysis (GLEAMS-NAPRA) hydrologic simulation model. Therefore, we substituted CPPE scoring with estimates derived from GLEAMS-NAPRA to hopefully improve our estimation of water quality impacts of conservation practices. The integration of GLEAMS-NAPRA into the MCDA system provides the opportunity to replace “categorical-converted-to-quantitative” rankings with continuous measurements that account for heterogeneous physical conditions, management systems, climate, and BMP’s.

The GLEAMS model includes four components – hydrology, erosion, nutrients, and pesticides – and incorporates various hydrological processes such as infiltration, runoff, soil evaporation, plant transpiration, rainfall/irrigation, snow melt and soil water movement within the root zone. GLEAMS simulates the effects of cropping systems on surface and ground water quality – edge-of-field and bottom-of-root zone loadings of water, sediment, pesticides, and plant nutrients – on a daily basis utilizing climate, soil, and management data inputs (Leonard, Knisel et al. 1987).

The National Agricultural Pesticide Risk Analysis (NAPRA) model is utilized with GLEAMS to estimate sediment, nutrient, and pesticide loadings to surface and ground water. GLEAMS-NAPRA model performs regional simulations by dividing regions into “representative” fields (Lim and Engel 2003). GLEAMS model inputs and outputs rely extensively on GIS data and software, but researchers complete all the steps manually (Lim 2001). GLEAMS-NAPRA model adds a GIS interface to parameterize the model based on STATSGO database soil characteristics, National Agricultural Statistics Service 2003 land use, and long-term precipitation data for Indiana (Thomas 2006).

In this analysis, the GLEAMS-NAPRA model is utilized to estimate statewide sediment, nitrate, phosphorus, and pesticides (specifically atrazine) loadings to surface and ground water before and after implementation of best management practices. By definition, scenario 1 is the base condition where no best management practices have been applied. The remaining scenarios include the addition of one or more of the following four BMPs: residue management/no-till, filter strip, nutrient management, and pest management. No-till is defined as a system for planting crops without plowing, using herbicides to control weeds and resulting in reduced soil erosion and the preservation of soil nutrients. Filter strips are land areas of either planted or indigenous vegetation, situated between a potential, pollutant-source area and a surface-water body that receives runoff. No-BMP fertilizer application rates were developed based on 5 years of USDA Cropping Practices Surveys (U.S. Department of Agriculture Economic Research Service 1990-1995). Thomas (2006) provides details on the method used to obtain applications rates of 222 N kg/ha and 125 P_2O_5 kg/ha for Indiana producers. Fertilizer application rates for the nutrient management BMP (NRCS practice code 590) were based on Tri-State fertilizer recommendations associated with potential crop yields (Vitosh, Johnson et al. 1995). Pest management entails use of all suitable methods of pest (insect, weed, rodent, etc) control to keep populations below the economic injury level. Totally, we have identified 16 scenarios that represent realistic options. Details of those scenarios are summarized in Table 2.

Scenario Number	Practices Applied	Tillage (Cultivation)	Fertilizer Rate		Atrazine Rate	Filter Strip
			ANH[e]	T3P[f]		
1	No-BMPs (Base Scenario)	Conventional Tillage	222 kg/ha	125 kg/ha	2.0 lb/ac	No
2	RM[a]	No-Till	222 kg/ha	125 kg/ha	2.0 lb/ac	No
3	NM[b]	Conventional Tillage	tri-state rate	tri-state rate	2.0 lb/ac	No
4	FS[c]	Conventional Tillage	222 kg/ha	125 kg/ha	2.0 lb/ac	Yes
5	PM[d]	Conventional Tillage	222 kg/ha	125 kg/ha	1.5 lb/ac	No
6	RM+NM	No-Till	tri-state rate	tri-state rate	2.0 lb/ac	No
7	RM+FS	No-Till	222 kg/ha	125 kg/ha	2.0 lb/ac	Yes
8	RM+PM	No-Till	222 kg/ha	125 kg/ha	1.5 lb/ac	No
9	NM+FS	Conventional Tillage	tri-state rate	tri-state rate	2.0 lb/ac	Yes
10	NM+PM	Conventional Tillage	tri-state rate	tri-state rate	1.5 lb/ac	No
11	FS+PM	Conventional Tillage	222 kg/ha	125 kg/ha	1.5 lb/ac	Yes
12	RM+NM+FS	No-Till	tri-state rate	tri-state rate	2.0 lb/ac	Yes
13	RM+NM+PM	No-Till	tri-state rate	tri-state rate	1.5 lb/ac	No
14	RM+FS+PM	No-Till	222 kg/ha	125 kg/ha	1.5 lb/ac	Yes
15	NM+FS+PM	Conventional Tillage	tri-state rate	tri-state rate	1.5 lb/ac	Yes
16	ALL	No-Till	tri-state rate	tri-state rate	1.5 lb/ac	Yes

a - RM: Residue Management: No-Till (NRCS Practice Code 329A)
b - NM: Nutrient Management (NRCS Practice Code 590)
c - PM: Pest Management (NRCS Practice Code 595)
d - FS: Filter Strip (NRCS Practice Code 393)
e - ANH: Anhydrous Ammonia, representing nitrogen
f - T3P: Superphosphate, representing phosphorus

Table 2: GLEAMS-NAPRA simulation scenarios

The GLEAMS-NAPRA simulation runs of each of the 16 scenarios produce six important outcomes relevant to this research:

- nitrate loading to surface water,
- phosphorus loading to surface water,
- nitrate loading to ground water,
- sediment loading,
- atrazine loading to surface water and
- atrazine loading to ground water.

Phosphorous loading to groundwater is not included because phosphorous in the soil solution exists as the negatively charged phosphate ion, and phosphate is extremely reactive and binds with elements, which are present in all soils at relatively high levels. This causes the P to form new chemicals in the soil that bind tightly with the soil clay and organic matter (McDonald 2003).

Differences in loadings between the base scenario (scenario 1) and each of the remaining BMP scenarios were used to estimate field-scale water quality benefits.

$$\begin{pmatrix} Pollutant\ Loading \\ Reduction \end{pmatrix} = \begin{pmatrix} Pollutant\ Loading \\ After\ BMP \end{pmatrix} - \begin{pmatrix} Pollutant\ Loading \\ Before\ BMP \\ [Base\ Scenario] \end{pmatrix}$$

For example, consider the comparison between no BMPs (scenario 1) and residue management/no-till (scenario 2) and the resulting changes in pollutant loadings for nitrate, phosphorus, and atrazine loadings in surface water, sediment loading and nitrate and atrazine loadings in ground water. Changes in nitrate and phosphorus loadings are shown in Figure 5.A, Figure 5.B and Figure 5.C. The maps demonstrate that higher nitrate reduction occurs with the application of the residue management/no-till BMP in northern Indiana whereas phosphorus reduction is greater in southern Indiana. Though not readily apparent given the complex interactions among soils, landscape, precipitation and farming practices, soil and topography of the field appear to be the major factors contributing to these results.

Residue management/no-till is highly effective in reducing soil erosion. Residue acts as a protective blanket and slows the flow of runoff, thus reducing sheet and rill erosion. Sediment loadings drop significantly throughout the state as shown in Figure 5D.

The herbicide atrazine is highly soluble in water. Because residue management/no-till traps and slows the flow of runoff, one would expect the changes in atrazine loading shown in Figure 5.E and Figure 5.F. The reduced loading of atrazine to surface water is partially offset by the increased infiltration and loading of Atrazine in groundwater.

The changes in nutrient, sediment, and pesticide loadings to surface and ground waters shown in Figures 5.A to 5.F illustrate the impacts of one BMP, residue management/no-till. Soil characteristics, slope, precipitation, and farming practices contribute to the variation in loadings across the state. GLEAMS-NAPRA model allows us to capture and quantify those impacts.

A) B)

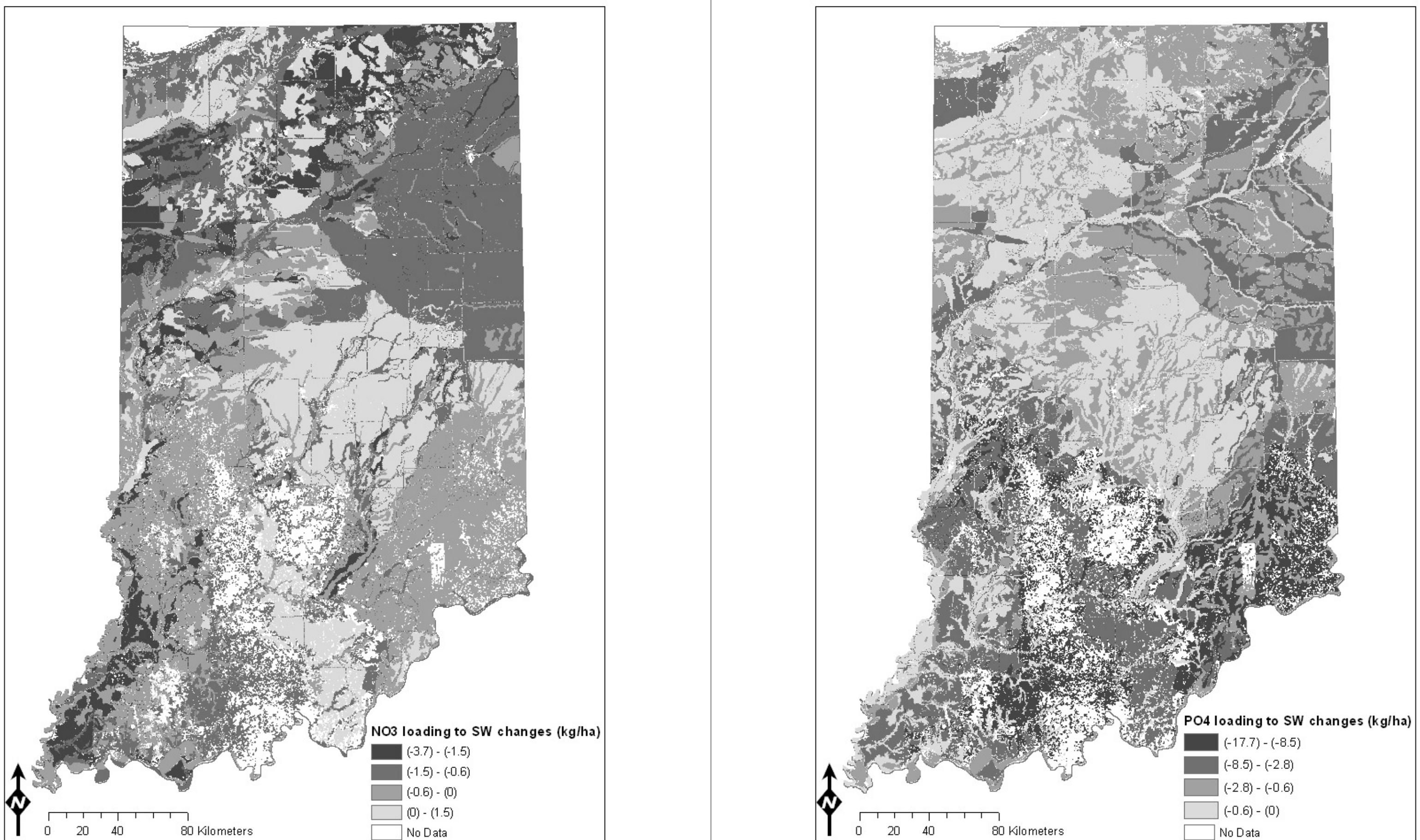
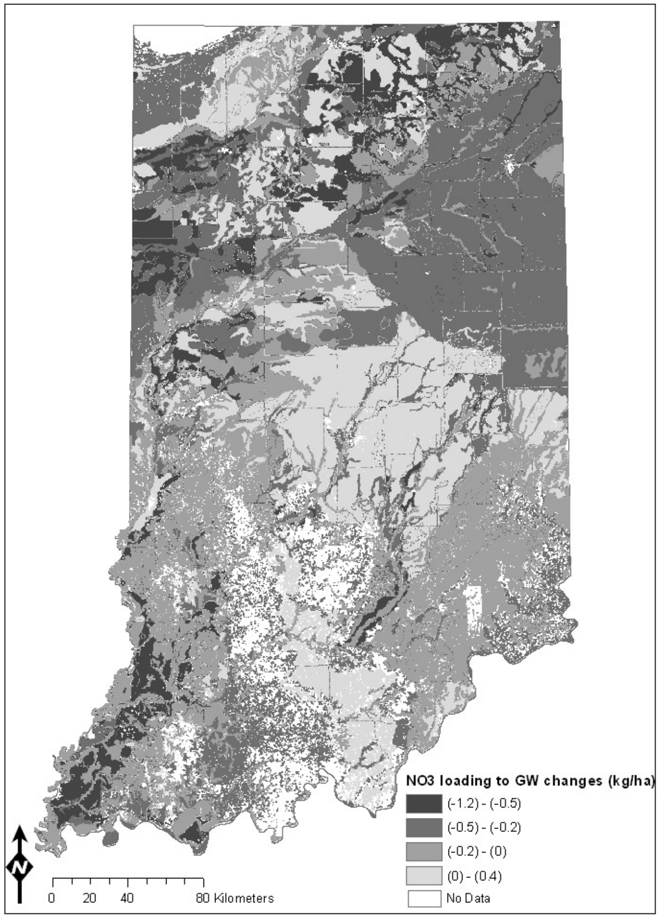


Figure 5:Changes in median annual total pollutant loading between No-Till scenario (Scenario 2) and base condition (Scenario 1) A) NO_3-N loading to surface water kg/ha. B) PO_4 loading to surface water kg/ha.

C) D)



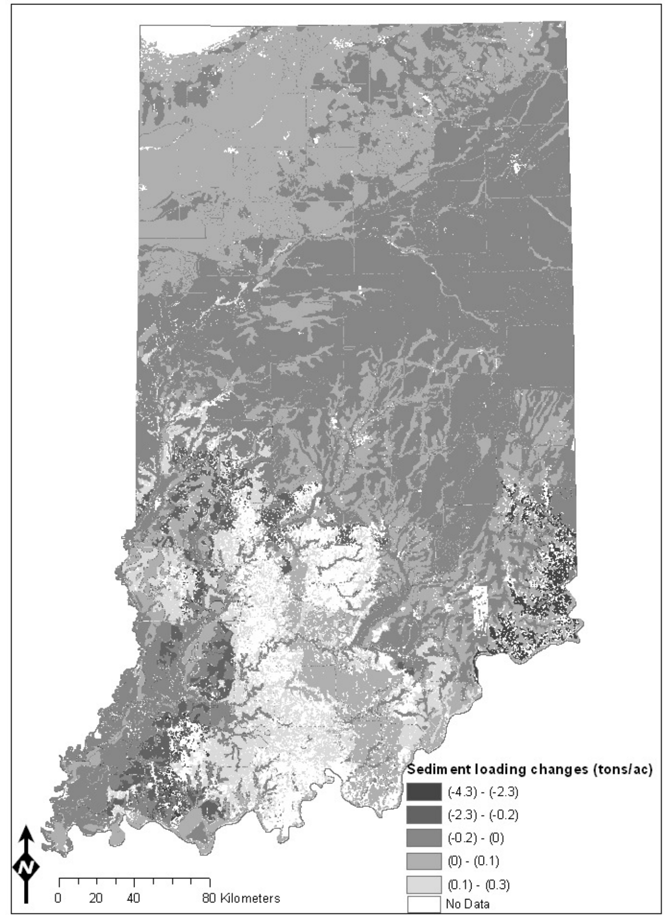


Figure 5: Changes in median annual total pollutant loading between No-Till scenario (Scenario 2) and base condition (Scenario 1) C) NO_3-N loading to ground water kg/ha. D) Sediment loading tons/acre.

E) F)

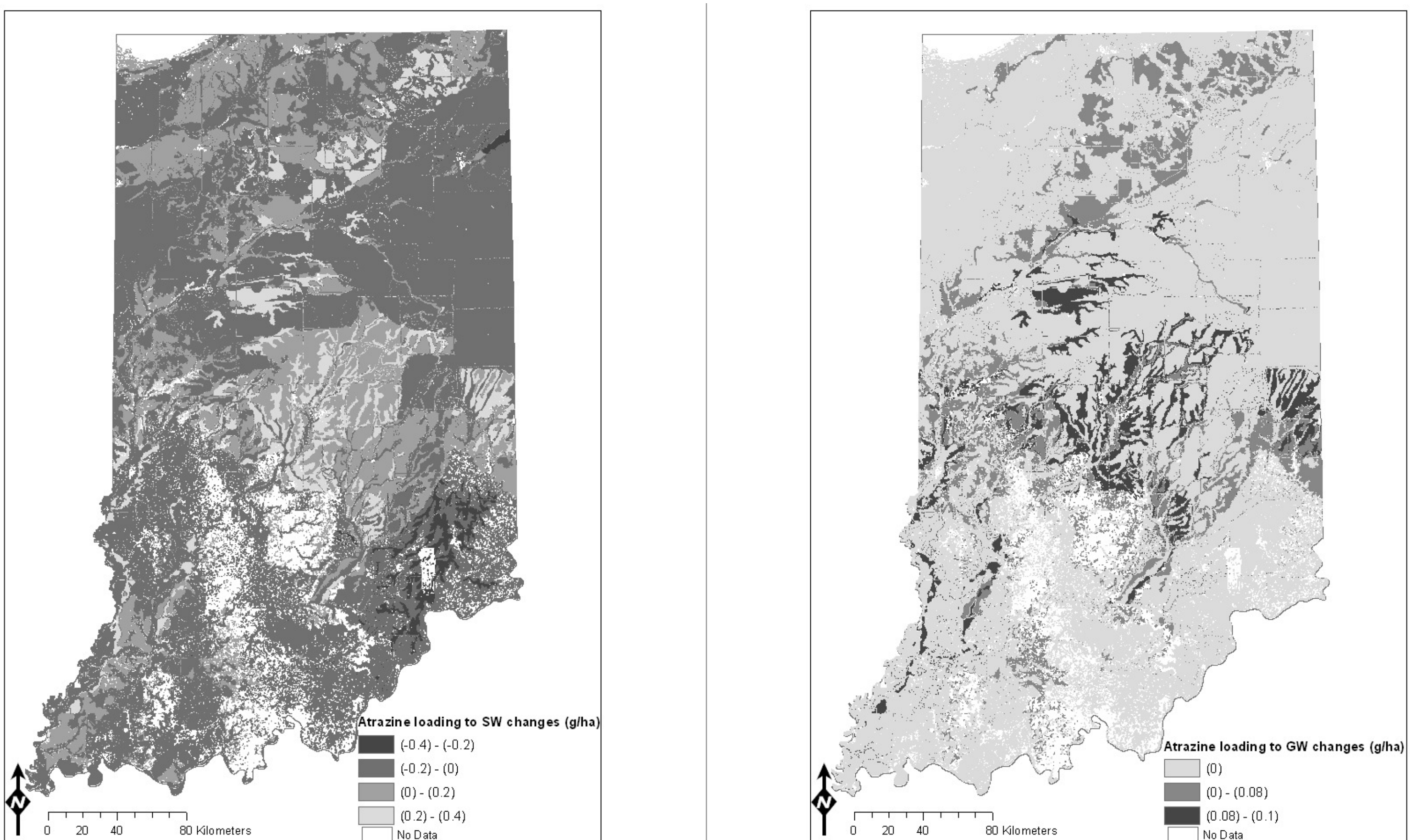


Figure 5 Changes in median annual total pollutant loading between No-Till scenario (Scenario 2) and base condition (Scenario 1) E) Atrazine loading to surface water g/ha. F) Atrazine loading to ground water g/ha.

As we stated before, CPPE matrix assigns the same score regardless of where a BMP such as residue management/no-till is applied in Indiana. The maps shown in Figure 5 clearly show that the effectiveness of this BMP in reducing nutrient, sediment and pesticide loadings depends on soils, landscape, precipitation, and farming practices. The implications of the existing EQIP scoring tool and the MCDA system is shown in Figure 6 where 2005 EQIP funded applications are overlaid on the nitrate loading to surface water map from Figure 5.A. Based on the CPPE matrix, all of these applications received the same score (1 point in Table 1) for applying this BMP. GLEAMS-NAPRA results, on the other hand, show considerable variation in load reduction among applications, especially in the magnified section. The MCDA system incorporates heterogeneity, thus allowing scores to vary according to estimated impacts.

Changes in loadings attributable to BMPs are considered the environmental benefits and should be incorporated to score calculation in EQIP. In the next step of this analysis, those loading reductions will replace the "categorical-converted-to-quantitative" scores S_{jl} in the application overall value calculation formula. Every application's overall value will be calculated using these new, measurable attributes. Applications will be scored and ranked based on the environmental value they provide per public dollar expended, and the highest ranked applications will be funded until program funds are expended. Finally, comparisons will be made between the MCDA system and the actual EQIP 2005 program. We will compare changes in the number and type of applications funded, their locations throughout the

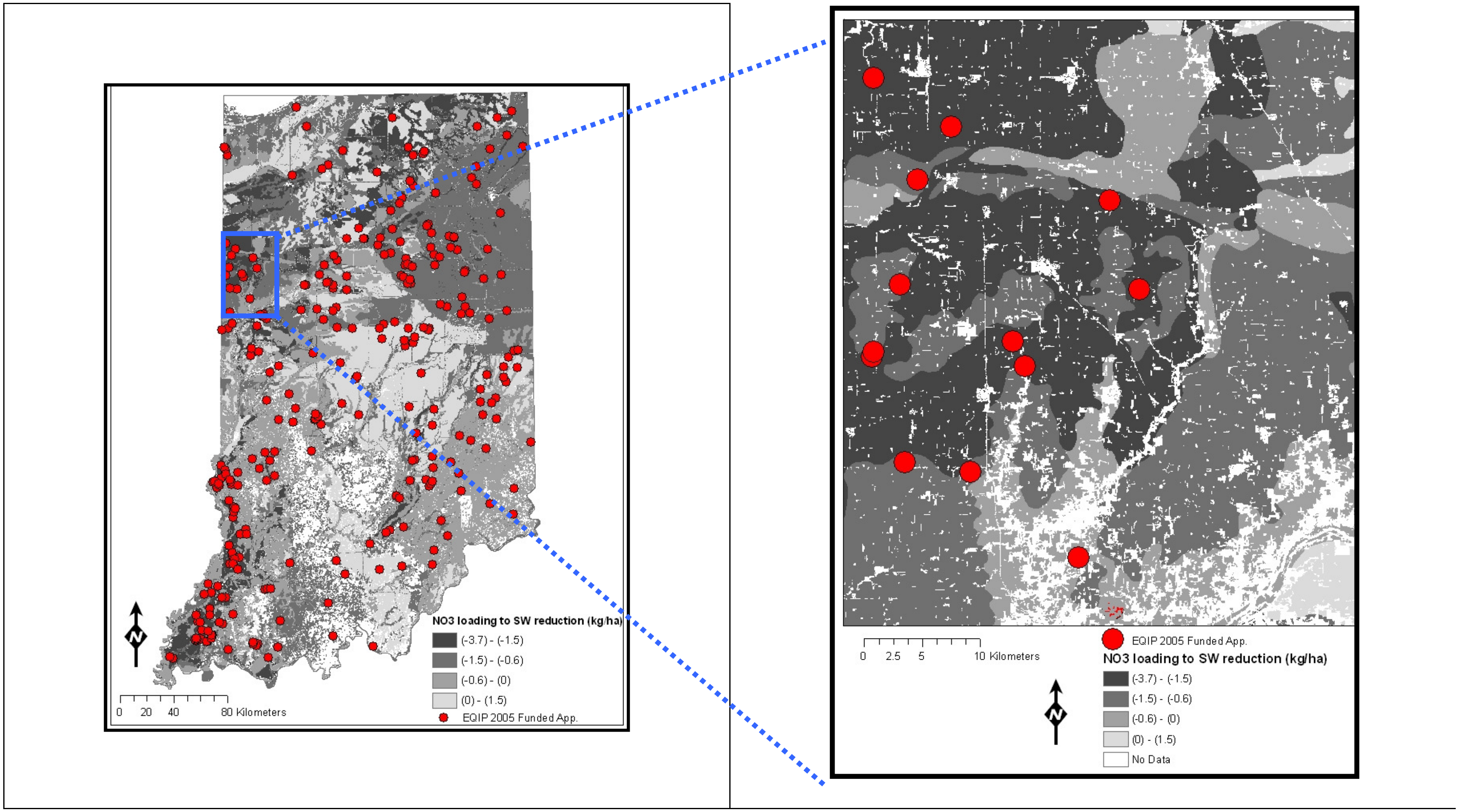


Figure 6: 2005 Indiana EQIP funded applications and nitrate loading to surface water reductions after implementation of No-Till scenario (Scenario 2)

state, and estimated environmental benefits. When this analysis has been completed, we expect applications selected for funding under the MCDA system will be significantly different from the applications actually funded in 2005. We also hypothesize that environmental benefits will likely be much higher than the MCDA system.

IV. CONCLUSION

Design and assessment of Federal conservation programs following multiple criteria decision analysis approach can improve program performance by enrolling more cost efficient applications. Furthermore, common mistakes such as mismatched objectives and criteria, spatial homogeneity, unintentional conversion of qualitative rankings to points, uniform weighting of sub-level objectives can be minimized. Third, an MCDA system facilitates the role and use of simulation models such as the GLEAMS-NAPRA model, which allowed us to reintroduce spatial heterogeneity and quantitative attributes. In addition, the GLEAMS-NAPRA model also provides government agencies the opportunity to identify problematic nonpoint-source areas and possibly change program eligibility requirements or the incentive structure to target these areas and entice producers to submit applications.

In summary, the development and use of formal multiple criteria decision analysis systems for Federal conservation programs will likely improve program effectiveness. It supports a sound and practical framework to assess the conservation programs covering all components of the program design and their impacts on program outcomes. Indiana Environmental Quality Incentives Program decision system provides a transparent scoring and ranking approach that increases objectivity and consistency, and generates results that can be repeatable, reviewable, and easy to understand. As shown in this paper, the key elements – spatial databases, decision modeling processes, and simulation models – are available to move from the existing informal decision processes to the formal multiple criteria decision systems.

V. BIBLIOGRAPHY

Babcock, B. A., P. G. Lakshminarayan, et al. (1997). "Targeting Tools for the Purchase of Environmental Amenities." Land Economics **73**(3): 325-339.

Bertoni, D. (2006). Agricultural Conservation: USDA Should Improve Its Process for Allocating Funds to States for the Environmental Quality Incentives Program. United States Government Accountability Office. **GAO-06-969**.

Cattaneo, A., D. Hellerstein, et al. (2006). Balancing the Multiple Objectives of Conservation Programs. U.S. Department of Agriculture, Economic Research Service. **Economic Research Report No. 19**.

Clemen, R. T. (1996). Making Hard Decisions : An Introduction to Decision Analysis. Boston, PWS-Kent Pub. Co.

Feather, P., D. Hellerstein, et al. (1999). Economic Valuation of Environmental Benefits and the Targeting of Conservation Programs: The Case of the CRP. U.S. Department of Agriculture, Resource Economics Division, Economic Research Service. **Agricultural Economic Report No:778:** 64 pp.

Feenstra, G. (1997). "What is Sustainable Agriculture?" http://www.sarep.ucdavis.edu/concept.htm. Retrieved September 13, 2006.

Friedman, S. and R. Heimlich (2004). Getting a Bigger Bang for the Buck: Assessment of EQIP 2003 Allocation and Ranking Systems and Ideas for further Improvements, Center for Conservation Incentives, Environmental Defense.

Guikema, S. and M. Milke (1999). "Quantitative Decision Tools for Conservation Programme Planning: Practice, Theory and Potential." Environmental Conservation **26**(3): 179-189.

Hajkowicz, S. and K. Collins (2007). "A Review of Multiple Criteria Analysis for Water Resource Planning and Management " Water Resources Management **21**(9): 1553-1566.

Hajkowicz, S., A. Higgins, et al. (2007). "Optimisation and the Selection of Conservation Contracts." The Australian Journal of Agricultural and Resource Economics **51**(1): 39-56.

Hansen, L. and D. Hellerstein (2006). Conservation Program Design: Better Targeting, Better Outcomes. U.S. Department of Agriculture, Economic Research Service. **Economic Brief Number 2**.

Johansson, R. and A. Cattaneo (2006). "Indices for Working Land Conservation: Form Affects Function." Review of Agricultural Economics **28**(4): 567-584.

Keeney, R. L. and H. Raiffa (1976). Decisions with Multiple Objectives: Preferences and Value Tradeoffs. Cambridge, Cambridge University Press.

Kirkwood, C. W. (1997). Strategic Decision Making: Multiobjective Decision Analysis with Spreadsheets. Belmont, CA, Wadsworth Publishing Company.

Lakshminarayan, P. G., S. R. Johnson, et al. (1995). "A Multi-objective Approach to Integrating Agricultural Economic and Environmental Policies." Journal of Environmental Management **45**(4): 365-378

Lawrence, P. A., J. J. Stone, et al. (1997). "Using Measured Data and Expert Opinion in a Multiple Objective Decision Support System for Semiarid Rangelands." Transactions of the ASAE (American Society of Agricultural Engineers) **40**(6): 1589-1597.

Leonard, R. A., W. G. Knisel, et al. (1987). "GLEAMS: Groundwater Loading Effects of Agricultural Management Systems." Transactions of the ASAE **30**(5): 1403-1417.

Lim, K. J. (2001). Enhanced NAPRA WWW Spatial Decision Support System (SDSS) with River Water Qualit Modeling Capability. Agricultural and Biological Engineering Department. West Lafayette, Indiana, Purdue University. **PhD Dissertation**.

Lim, K. J. and B. Engel (2003). "Extension and Enhancement of National Agricultural Pesticide Risk Analysis (NAPRA) WWW Decision Support System to Include Nutrients." Computers and Electronics in Agriculture **38**(3): 227-236.

Malczewski, J. (1999). GIS and Multicriteria Decision Analysis. Canada, John Wiley & Sons, Inc.

McDonald, I. D. (2003). "Phosphorus Leaching?" Retrieved January 19, 2008, from http://www.omafra.gov.on.ca/english/crops/field/news/croptalk/2003/ct_1103a11.htm .

Natural Resources Conservation Service (2006). National Conservation Practice Standards - NHCP.

Ponder, J. S., R. Wiggins, et al. (2005). Using ArcIMS to Prioritize EQIP Applications for USDA NRCS Wyoming ESRI Federal User Conference, Washington, D.C. .

Powell, M. R. and J. D. Wilson (1997). Risk Assessment for National Natural Resource Conservation Programs. Discussion Paper 97-49, Resources for the Future.

Pub. L. No. 107-171 (116 Stat.). 134. (2002). The Farm Security and Rural Investment Act of 2002. **116 Stat.:** 134.

Ribaudo, M. O., D. L. Hoag, et al. (2001). "Environmental Indices and the Politics of the Conservation Reserve Program." Ecological Indicators **1**(1): 11-20.

Saaty, T. L. (1980). The Analytic Hierarchy Process. New York, McGraw-Hill.

Searchinger, T. and S. Friedman (2003). Getting a More Bang for the Buck: Nine Suggestions for Improving State Ranking Criteria: A Discussion Paper Washington, DC: Environmental Defense.

Shames, L. (2007). Agricultural Conservation: USDA Should Improve Its Management of Key Conservation Programs to Ensure Payments Promote Environmental Goals. United States Government Accountability Office. **GAO-07-370T**.

Smith, P. G. R. and J. B. Theberge (1987). "Evaluating Natural Areas Using Multiple Criteria: Theory and Practice." Environmental Management **11**(4): 447-460.

Soil and Water Conservation Society and Environmental Defense (2007). Environmental Quality Incentives Program (EQIP) Program Assessment.

Thomas, M. A. (2006). Evaluation of Nutrient Management Plans Using an Integrated Modeling Approach. Agricultural and Biological Engineering Department. West Lafayette, Indiana, Purdue University. **MS. Thesis**.

U.S. Department of Agriculture Economic Research Service. (1990-1995). "Cropping Practices Survey: Raw data." Retrieved January 13, 2008, from http://www.ers.usda.gov/data/archive/93018/.

U.S. Department of Agriculture Natural Resources Conservation Service. (2002). "Conservation Programs Manual, Part 515 Environmental Quality Incentives Program." Retrieved January 19, 2008, from http://policy.nrcs.usda.gov/viewerFS.aspx?id=3086.

United States Department of Agriculture (2002). Risk Assessment for the EQIP Program. NRCS, USDA.

USDA Natural Resources Conservation Service (2006). Field Office Technical Guide, NRCS.

Vitosh, M. L., J. W. Johnson, et al. (1995). "Tri-State Fertilizer Recommendation for Corn, Soybeans, Wheat and Alfalfa." Retrieved January 13, 2008, from http://www.ces.purdue.edu/extmedia/AY/AY-9-32.pdf.

Wolman, A. G. (2006). "Measurement and Meaningfulness in Conservation Science." Conservation Biology **20**(6): 1626–1634.

Zeleny, M. (1982). Multiple Criteria Decision Making. New York, McGraw-Hill.