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Using Multi-Criteria Decision Models to Assess the Economic and Environmental Impacts of Farming Decisions in an Agricultural Watershed

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This paper reports on the integration of a farm decision model with a watershed biophysical model to evaluate the economic and environmental impacts of farming decisions in an agricultural watershed. A baseline, one uncoordinated and four watershed-level coordinated decision scenarios were evaluated and compared as alternative ways of managing the significant tradeoffs expected when multiple conflict management objectives exist. The four coordinated scenarios outperform the uncoordinated one in terms of economic returns and key environmental impacts. The study's findings contribute to the understanding of biophysical and economic processes in agricultural watersheds.

Water quality degradation from agricultural production is among the top agro-environmental concerns in the United States. Watershed management is generally recognized as the most efficient way to improve water quality and other environmental indicators while maintaining regional economic viability (National Research Council, Born and Genskow). Watershed management integrates information and knowledge across several disciplines and spatial and temporal scales to consider simultaneously biophysical processes, environmental impacts of alternative management systems, and behavioral responses of stakeholders to policy changes (National Research Council).

Most studies of watershed management assume that a social planning authority, such as a watershed council, integrates information, resolves conflicts, makes decisions, and carries out watershed management plans (Prato et al.; Qiu, Prato, and Kaylen). In an impaired agricultural watershed, a council may set goals for watershed management, and evaluate policies and practices for achieving those

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goals. However, the effectiveness of those policies and practices and the success of management plans ultimately rely on farmers' decisions when lands in the watershed are predominately privately owned. The National Research Council has called for research that provides a better understanding of how people and institutions can interact more effectively to accomplish successful watershed management.

Ideally, watershed management has a collaborative problem-solving planning and management orientation. While regulations and penalties can play a role in management schemes, many envision the most successful plans as emphasizing voluntary participation by multiple local and nongovernmental interests (Born and Genskow). In any case, farmers' objectives and their behavioral responses to penalties, incentives, moral persuasion, or other influences on their decision making, need to be incorporated into models of watershed management. A spatial decision support system (SDSS) that integrates geographic information, biophysical simulation modeling, and decision models can be used to facilitate the process. An SDSS is a knowledge-based system that integrates data, information, and models for the purpose of identifying and evaluating solutions to complex problems involving spatially distributed information.

This study integrates a decision model with a watershed biophysical simulation model and financial calculations to evaluate economic and environmental impacts of farming decisions in a Missouri agricultural watershed. Farming management decisions are multi-objective and so should be evaluated with a multi-criteria decision-making (MCDM) model. MCDM is typically employed in complex decision environments involving multiple objectives and/or many participants (Janssen). MCDM has been used to evaluate alternative agricultural systems that aim to reduce agricultural nonpoint source pollution and improve environmental quality when outcomes address multiple and conflicting objectives (Foltz et al.; Prato and Hajkowicz; Dunn, Keller, and Marks).

In general, there are two types of MCDM models that either: (1) determine optimal compromise solutions over continuous solution spaces, usually solved using continuous mathematic programming; or (2) solve problems over a discrete decision space, ranking a few predetermined decision alternatives and selecting the best alternative based on multiple decision criteria. While the two types of models are suitable for different situations, discrete MCDM models have the advantage of simplicity and flexibility for decision analysis in agricultural, natural resource, and environmental management (Prato and Hajkowicz).

In the MCDM application summarized in this article, farmers are represented as facing multiple conflicting economic and environmental objectives. A discrete MCDM method called the weighted sum model (WSM) was used to help farmers select the best farming system from a finite set of alternative farming systems according to how they and/or a watershed-level coordinating body weights objectives. In a parallel exercise, hydrological processes and environmental impacts of farming systems in an agricultural watershed were evaluated using a watershed biophysical simulation model, Soil and Water Assessment Tool (SWAT) (Arnold et al.). This study's results demonstrate how an understanding of farming decisions at the field and/or farm scale can be used for decision making at watershed scale.

The Study Watershed

The 19,132-acre Goodwater Creek watershed in north central Missouri is typical for that region. There are a few dairy farms in the watershed, and crop production is the principal agricultural activity. Corn–soybean, sorghum–soybean, and corn–soybean–wheat are the typical rotations. Other rotations include soybean–soybean–wheat and sorghum–soybean–wheat. Cropland for corn, soybean, sorghum, and wheat accounted for 72% of the total watershed area in 1993. Other land use categories include pasture and hay, residential area, water, forest, roads, tree line, and grass waterway. Goodwater Creek watershed is a representative claypan soil watershed and has typical soil and water quality problems of the claypan soil region that accounts for 10 million acres in the midwestern United States. Comprehensive soil and water quality studies have been conducted in this watershed and the claypan soil region since 1990 through the Missouri Management Systems Evaluation Area (MSEA) and Missouri Agricultural Systems for Environmental Quality projects sponsored by the U.S. Department of Agriculture.

Atrazine and nitrogen runoff have been identified as primary concerns in the watershed and the claypan soil region. Observations in six fields in the claypan soil region of Missouri showed that the edge-of-field losses of atrazine in surface runoff ranged from less than 1% to 19% of the applied amounts. The Missouri MSEA Team reported that atrazine concentration in surface water greatly exceeds the maximum contamination level of 3 parts per billion (ppb) for forty-five to sixty days after application in the spring. Even though Goodwater Creek is not used as a drinking water source, it flows into the Mark Twain reservoir, which is a major source of drinking water in northeast Missouri. Dissolved nitrogen (N) losses have consistently ranged from 10% to 30% of applied N.

Intensive use of nitrogen fertilizer in the Mississippi River basin has been associated with increased hypoxic conditions in the Gulf of Mexico (Council for Agricultural Science and Technology). According to the Missouri MSEA Team, NO_3 concentration in surface runoff in the experimental fields in the watershed exceeds 10 parts per million (ppm)—the maximum concentration level set by the Environmental Protection Agency for NO_3 in drinking water—about six weeks following nitrogen fertilizer application. However, NO_3 concentration in Goodwater Creek rarely exceeds 6 ppm due to extensive riparian buffers and other nonfertilized land uses. Low NO_3 concentrations also have harmful impacts on ecosystems. For example, hypoxic conditions occur even though average NO_3 concentrations in the Mississippi River are substantially below the maximum concentration level for drinking water. While no-till farming systems provide better soil erosion control on claypan soils, they cause higher herbicide losses than minimum tillage systems that incorporate herbicides (Ghidey and Alberts).

Farming Systems and Decision Criteria

Qiu and Prato identified thirty-six farming systems as a complete representation of crop production practices in the watershed. The thirty-six farming systems are combinations of three-crop rotations (corn–soybean, sorghum–soybean, and corn–soybean–wheat), two tillage systems (minimum and no till), three fertilizer applications (high, medium, and low), and two pesticide application rates (high and low). The amounts and methods of fertilizer and pesticide application as well as field operations for each crop in each farming system were determined by consulting with farmers and agrochemical dealers in the watershed and with University of Missouri extension personnel.

Prato and Hajkowicz identified five objectives that act as decision criteria for selecting farming systems in the Goodwater Creek watershed: increasing net returns (NR), reducing economic risk (ER), improving drinking water quality (DW), enhancing aquatic ecosystem health (AE), and reducing soil loss (SL). NR, calculated as the average, annual net returns from a farming system at field-level, reflects a farmer's economic motivation to use a particular system. ER is defined as downside risk and measured by the average deviation of net returns below the average net returns of a farming system. It captures the possible loss from stochastic market and weather conditions across different years. DW is specified as monthly atrazine concentration in runoff, while a proxy for AE is monthly nitrate (NO_3) concentration in runoff. SL is quantified as the annual average sediment leaving an agricultural field. Soil loss not only affects the long-term productivity of agricultural land, but also contributes to several environmental and water quality problems such as water pollution and loss of stream habitat for fish and aquatic organisms.

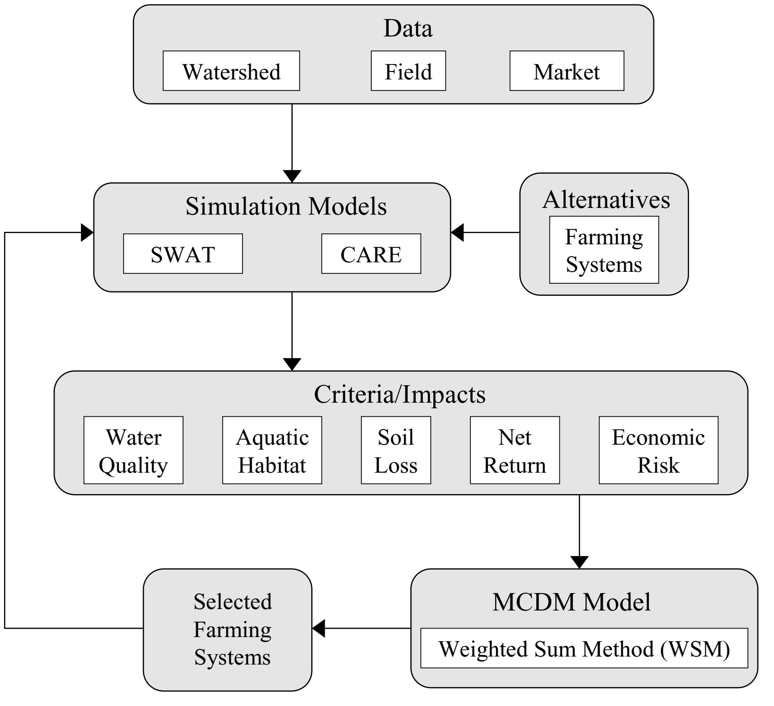
Evaluation Framework and Methods

Figure 1 presents the general framework used to evaluate economic and environmental impacts of farmers' decisions in Goodwater Creek. Watershed, field, and market data, along with data on the field practices describing alternative farming systems, were imported into models to determine values for each of the five decision criteria for each of the thirty-six farming systems for each field in the watershed. A biophysical simulation model (SWAT) was used to determine values of environmental criteria. An enterprise budget generator, the Cost and Return Estimator (CARE) (U.S. Department of Agriculture) was used to calculate the net return of each farming system for each field during 1988–99, which was then used to calculate the values of the two economic criteria. An MCDM model, WSM, was used to apply sets of criterion weights that represent several farming management decision scenarios and to select the farming system for each field. The selected farming systems were imported into SWAT and CARE models to evaluate the economic and the environmental impacts of different farming decision scenarios at the watershed level.

Determining Criterion Values

SWAT predicts the impact of land management practices on water, sediment, and agricultural chemicals in large complicated watersheds with varying soils, land use, and management conditions over long periods of time (Arnold et al.). The Goodwater Creek watershed was divided into thirty-two sub-watersheds for SWAT analysis. Sub-watershed delineation was based on hydrological relationships and required that each field be allocated to one sub-watershed. Within each sub-watershed, there are a number of hydrological response units (HRUs). To capture water quality impacts at the field level, each agricultural field in a sub-watershed was treated as a single HRU. Besides the agricultural fields, there

Figure 1. Framework for evaluating economic and environmental impacts of farmers' behavior in an agricultural watershed



are other areas in a sub-watershed such as grassland, forest, and roads. These areas were lumped into 797 separate HRUs based on their land use types. Among them, 735 HRUs were agricultural fields. The remainder was grassland, forest, roads, and urban areas. Geophysical data for each sub-watershed and HRU were derived from topography, soil, hydrology, and land use in the watershed using GIS. SWAT was run for twelve years for each farming system using the actual weather data from 1988 to 1999. The SWAT output was used to calculate annual average sediment yield, monthly average atrazine and NO_3 in runoff at the edge of agricultural fields. Heidenreich, Zhou, and Prato validated the SWAT model in the study area and concluded that the SWAT generates reasonable estimates on stream flow, sediment yield, NO_3 concentration in surface and ground water, and atrazine concentration in runoff.

Net return and its downside risk for each farming system on a field were calculated for 1988–99. The average annual net return was calculated from SWAT-simulated crop yields of the farming system in the field, crop yield goals and estimated production costs of the farming system in the watershed, and annual nominal crop prices in Missouri during 1988–99. Even though the corn and soybean yields estimated by SWAT matched the average measured yields at the county level well, sorghum and wheat yields appeared to be overestimated (Heidenreich, Zhou, and Prato). Another weakness of the specific version of SWAT is that estimated crop yields were not sensitive to the changes in nitrogen input. To resolve these problems, a composite crop yield is used to calculate the net returns and the downside risks. The composite crop yield is the product of a crop yield goal and a crop yield index. The crop yield goal reflects farmers' expectation of crop yield and captures management factors such as fertilizer and pesticide use and field operations. It is based on field experimental data from the Missouri MSEA project, Missouri average crop yields for the two counties in which the watershed is located, and fertilizer/pesticide use for each farming system. Even though the yield goal is the same, actual crop yield may vary due to natural conditions. The crop yield index captures the impacts of natural (soil, topographic, and hydrologic) conditions in each field. It is the ratio of the simulated crop yield in a field to the average simulated crop yield in the watershed. CARE was used to estimate the production costs of the farming systems, which included the operating costs and excluded land and machinery ownership costs.

The downside risk of a farming system was calculated in three steps. First, the annual negative deviation of net return for a farming system equals the annual net return minus the average net return of the farming system. Second, the average negative deviation of net return is the average value of the resulting negative numbers calculated in the first step. Third, the downside risk is measured by the absolute value of the average negative deviation of net return calculated in the second step.

The values of the five criteria for the thirty-six farming systems vary substantially across the 735 agricultural fields in the watershed. For example, the farming system MHH1 (minimum tillage, high fertilizer and pesticide application rates, and corn–soybean rotation) had the highest average net return of $104.18 per acre, but also the largest standard deviation of net returns of $28.48 per acre. Therefore, MHH1 does not always have the highest net return in all fields. Variation in criterion values can be attributed to spatial variability in natural conditions such as soil, topography, and hydrology in the watershed.

Criteria were measured in different units. In order to apply the weights to the criteria so that comparisons could be made, all criteria were standardized using the following approach:

(1a) $$x_i^* = \frac{x_i - \min(x_i)}{\max(x_i) - \min(x_i)} \text{ for positive criteria where more is better, and}$$

(1b) $$x_i^* = \frac{\max(x_i) - x_i}{\max(x_i) - \min(x_i)} \text{ for negative criteria where less is better}$$

where x_i is the measured criterion value for the ith farming system, min (x_i) and max(x_i) are the minimum and maximum criterion values across all the farming systems, and x_i^* is the standardized value for x_i. Standardized values range between 0 and 1 and have the same indication that more is better. In this study, net returns were standardized using equation (1a) and the other four criterion values were standardized using equation (1b). The standardization procedure is performed for each of 735 fields in the watershed.

Developing Criterion Weights

In order to understand farmers' preferences, Prato and Hajkowicz conducted a survey of farmers in the Goodwater Creek watershed and estimated criterion weights using three different methods—fixed point scoring, paired comparison, and judgment analysis. The fixed point scoring approach asked farmers to directly assign percentage weights to each of the five criteria so that the total percentage equals 100. For the paired comparison method, farmers were asked to rate the importance of one objective relative to each of the others on a scale of 0–9. Thus, for the five criteria, ten comparisons were made. The weights were derived from these importance ratings using the analytic hierarchy process method (Saaty 1980; Saaty 1994). Judgment analysis required farmers to assign unique scores between 1 and 100 to fifteen farming systems with realistic semi-hypothetical values for all five criteria. Regression analysis was used to estimate the regression coefficients between the scores and the objectives. The judgment analysis weights were derived from the standardized regression coefficients (Cooksey).

The survey shows that NR was the most important criterion and represents the primary interest of farming. SL was the second most important, which we might assume reflects recognition of the on-farm as well as off-farm benefits of controlling soil erosion. AE is the least important environmental criterion among farmers. The ranks of DW and ER for judgment analysis were different from their ranks for the other two methods, but the average weights for these criteria were similar. In general, the three methods revealed a relatively consistent preference over five criteria by farmers in the watershed (Prato and Hajkowicz).

Watershed Management Decision Scenarios

The criterion weights developed by Prato and Hajkowicz were used to design six decision scenarios that determine the farming system for each field and to evaluate their economic and environmental impacts in the watershed. These included a baseline, an uncoordinated farming decision, and four coordinated farming decisions.

The baseline is designed to represent the best situation for each farming decision made on each field by manipulating the thirty-six farming systems and the twenty sets of criterion weights obtained using the fixed point scoring method from the farmer survey. If the specific combination of the farming system and criterion weight gives the highest score of the weighted summation of criteria, it would be selected to represent the baseline condition.

A stylized uncoordinated farming decision scenario assumes that farming decisions are based on farmers' current economic and environmental preferences, but that they are uncoordinated at the watershed level. This decision scenario was implemented by randomly selecting one from the twenty sets of weights obtained using the fixed point scoring method in the farmer survey when selecting a farming system for each field. This simplified method was used because the survey had only twenty participants out of seventy-five farmers in the watershed and it did not reveal the physical location of the participants' fields in the watershed for confidential reasons.

Watershed management practices strongly encourage the involvement of stakeholders, partnership, and stewardship with private sectors in watersheds (Turner, National Research Council). Through watershed assessment, survey, meetings, workshops, and one-on-one communications, active participation of farmers in a watershed management process promotes coordinated decisions (Osterman et al., MacKenzie, Ewing). Osterman et al. implemented a three-step watershed planning and management procedure in the Missouri Flat Creek watershed, Washington. The three steps are (1) problem awareness that brings farmers into the process of consensus-building to identify problems and solutions tailored to the natural and social systems of the watershed; (2) awareness of solutions created by conservation plans, treatment guides, and a conference on streamside management; and (3) implementation of solutions through economic incentives, technical assistants, education, and information sharing.

The three-step procedure united farmers in the watershed and built consensus on the goals of watershed management among farmers. The cooperation and coordination within the watershed community were achieved through extensive education and information exchange, consensus-building, and the impact of neighbor-affecting-neighbor. In this application, the coordinated farming decision scenarios assumed that the farmers in Goodwater Creek watershed were able to build consensus on the water quality problems and alternative farming systems for solving the problems through an integrated watershed management and planning process. The established consensus will guide farmers' farming decisions in their fields. These coordinated scenarios were implemented using the same weights over the five economic and environmental criteria to select the preferred farming systems for all the fields in the watershed. The four coordinated farming decision scenarios included an average farmer scenario and three environment-oriented farming decision scenarios. The average farmer scenario used the average of the three sets of criterion weights derived from the farmer survey. Criterion weights for the three environment-oriented farmer behavior scenarios were derived from three different importance rankings of five criteria using the expected value method. This method assumes that each set of criteria weights in the decision space has equal probability and the weight vector is calculated as the expected value of the feasible set (Rietveld). In general, there are J criteria, $\lambda_1, \ldots, \lambda_J$, which are ranked as $1, \ldots, J$. Assuming the uniform distribution of the criterion weights, following Rietveld, the expected values of $\lambda_1, \ldots, \lambda_J$ are

$$
\begin{aligned}
E(\lambda_1) &= \frac{1}{J^2} \\
E(\lambda_2) &= \frac{1}{J^2} + \frac{1}{J(J-1)} \\
&\vdots \\
E(\lambda_{J-1}) &= \frac{1}{J^2} + \frac{1}{J(J-1)} + \cdots + \frac{1}{J \cdot 2} \\
E(\lambda_J) &= \frac{1}{J^2} + \frac{1}{J(J-1)} + \frac{1}{J \cdot 2} + \frac{1}{J \cdot 1}.
\end{aligned} \tag{2}
$$

Based on equation 2, the expected values of criterion weights would be 0.45, 0.26, 0.16, 0.09, and 0.04 from the most to the least important ordered criteria. The

Table 1. Criterion weights for farming decision scenarios used to select the most preferred farming systems in Goodwater Creek watershed, Missouri

Scenarios	Criterion Weights				
	NR	ER	DW	AE	SL
Baseline[a]					
Uncoordinated[b]					
Average farmer[c]	0.339	0.164	0.157	0.079	0.261
Water quality improvement[d]	0.260	0.090	0.450	0.040	0.160
Aquatic ecosystem enhancement[d]	0.260	0.090	0.040	0.450	0.160
Soil loss control[d]	0.260	0.160	0.090	0.040	0.450

[a]Criterion weights for each field are selected from twenty sets of weights obtained from the farmer survey by Prato and Hajkowicz and give the highest score of the weighed summation of criteria for the selected farming system on that field.
[b]Criterion weights for each field are randomly selected from twenty sets of weights obtained from the farmer survey.
[c]Criterion weights for the average farmer scenario are the average values for criterion weights from the farmer survey.
[d]Criterion weights are derived from the ordinal order of criteria for each scenario.

important order for an environment-oriented scenario is the selected environmental criterion followed by the remaining four criteria in the order as revealed in the farmer survey. Specifically, the order is DW, NR, SL, ER, and AE for the water quality improvement scenario, AE, NR, SL, ER, and DW for aquatic ecosystem enhancement, and SL, NR, ER, DW, and AE for the soil loss control scenario. Table 1 presents criterion weights for these scenarios.

Selecting Farming Systems

Selection of a farming system from a set of finite farming systems when facing multiple economic and environmental objectives provides a typical case in a discrete decision space. WSM is the multi-criteria decision-making method used here to select the farming system for a field. WSM selects a farming system for each field based on a weighted summation of criteria. Let S_i be the WSM score for farming system i, then,

$$(3) \qquad S_i = \sum_{j=1}^{n} x_{ij}^{*} w_j, \quad \text{for } i = 1, 2, \ldots, m, \quad \text{with} \quad \sum_{j=1}^{n} w_j = 1$$

where m is the number of alternative farming systems, j is the criterion index, n is the number of criteria, x_{ij}^{*} is the standardized value of the jth criterion for farming system i using equation (1), and w_j is the assigned criterion weight for criterion j as discussed in the previous section. The preferred farming system is the one with the highest S value. WSM is derived from additive utility theory and assumes that the relationship between a criterion and its associated utility is linear and the decision maker is risk neutral. Even though the simplified assumptions violate some common economic concepts, such as the diminishing marginal utility and interactive effects among the attributes, WSM is simple and easy to use and has been widely applied in decision making involving multiple criteria. After measuring the criteria of each farming system described above, GAMS (General Algebraic Modeling System) (Brooke, Kendrick, and Meeraus) was used to program the WSM model and to select the preferred farming system for each field in the watershed.

Results

Table 2 shows the watershed economic and environmental impacts of six farming decision scenarios. At the baseline, total watershed net returns (TWNR) and economic risk are $1.33 million and $0.20 million, respectively, and the environmental impacts are 61.52 ppb for monthly atrazine concentration in runoff, 10.18 ppm for monthly NO_3 concentration in runoff, and 3.08 tons per acre for annual soil loss.

The uncoordinated decision scenario that randomly uses one of the twenty reported criterion weights to determine the farming system for each field in the watershed, resulted in a TWNR of $1.02 million, economic risk of $0.18, monthly atrazine concentration in runoff of 50.70 ppb, monthly NO_3 concentration in runoff of 8.03 ppm, and annual soil loss of 3.59 tons per acre. Compared to the baseline, the uncoordinated scenario had slightly better impacts in atrazine and NO_3 runoff, but resulted in about $0.31 million loss in TWNR and a slight increase in soil loss.

The average farmer-coordinated scenario, which assumes that all farmers in the watershed have the same average values of the measured criterion weights from the farmer survey, and the soil loss control coordinated scenario emphasizing soil loss is the most important shared criterion for making farming decisions, show similar economic and environmental impacts in the watershed. This is expected because controlling soil loss has been a long-term environmental policy in the U.S.

Table 2. Economic and environmental impacts of the selected most preferred farming systems under six farming decision scenarios in Goodwater Creek watershed, Missouri

	Impacts				
Scenarios[a]	TWNR (dollars)	Downside Risk (dollars)	Atrazine Runoff (ppb)	NO_3 Runoff (ppm)	Soil Loss (ton/acre)
Baseline	1,331,434	204,817	61.52	10.18	3.08
Uncoordinated	1,022,663	183,181	50.70	8.03	3.59
Average farmer	1,371,490	198,204	50.28	9.97	3.11
Water quality improvement	1,193,651	191,983	22.85	5.53	4.62
Aquatic ecosystem enhancement	1,171,422	200,599	33.53	4.84	4.70
Soil loss control	1,389,181	203,227	53.33	10.23	3.10

[a] As defined in table 1.

agriculture and the average farmer scenario captures that objective. Compared with the baseline, both of these coordinated scenarios have higher TWNR, lower economic risk, lower atrazine, and NO_3 concentration in runoff and similar soil loss. They clearly have advantages over the baseline in terms of economic and environmental impacts.

Table 2 shows that the water quality improvement and aquatic ecosystem enhancement coordinated decision scenarios result in substantial decreases in atrazine and NO_3 concentration in runoff. The water quality improvement scenario has the lowest value of 22.85 ppb for monthly atrazine concentration in runoff compared to 61.52 ppb in the baseline. The aquatic ecosystem enhancement has the best impact of 4.84 ppm for monthly NO_3 concentration in runoff compared with the baseline level of 10.18 ppm. Results show the significant tradeoffs between economic and environmental impacts. Despite the lower values on atrazine and nitrogen runoff, these two coordinated scenarios have lower TWNRs than the baseline. The TWNRs for the water quality improvement and aquatic ecosystem enhancement scenarios are $0.14 million and $0.16 million less than in the baseline, respectively. There is also a concern of high soil loss with these two scenarios. The annual soil loss rate increases about 50% above the baseline level of 3.08 tons per acre. Also note the conflict between controlling atrazine and NO_3 runoff and soil loss in this claypan soil watershed. For example, no-till farming systems designed to reduce soil loss contribute to higher atrazine and NO_3 runoff. In this specific watershed, research efforts are being directed to develop best management practices such as installing vegetative barriers or strips in crop fields that control runoff and soil loss simultaneously (Los et al.).

Table 3 presents the proportions of fields for which particular farming systems are selected in the watershed for six farming decision scenarios. Recall that the baseline represents the farming system and the criterion weight that give the highest score of the weighted summation of criteria for each field in the watershed. Three farming systems are primarily selected at the baseline: MHL1 (minimum till, high fertilizer and low pesticide application rates, and corn–soybean rotation), MHH2 (minimum till, high fertilizer and high pesticide application rates, and sorghum–soybean rotation), and MHL2 (minimum till, high fertilizer and low pesticide application rates, and sorghum–soybean rotation).

As expected, the uncoordinated decision scenario results in the most diverse selection of farming systems with twenty of the thirty-six farming systems being selected. Under this uncoordinated scenario, the most frequently selected farming systems are MHH1 (minimum till, high fertilizer and low pesticide application rates, and corn–soybean rotation), MHL1, MHL2, MLL2 (minimum till, low fertilizer and pesticide application rates, and sorghum–soybean rotation), NLL2 (no till, low fertilizer and pesticide application rates, and sorghum–soybean rotation), and MHL3 (minimum till, high fertilizer and low pesticide application rates, and corn–soybean–wheat rotation) with the proportions of about 0.10 and above of being selected in fields. For the average farmer-coordinated scenario, MHL2 is selected across 97.5% of all fields. The high net return and low DW and SL with MHL2 fit well with the preferences of an average farmer.

The water quality improvement coordinated scenario results primarily in the selection of MHL3 at a rate of 88.3%. Under the aquatic ecosystem enhancement coordinated scenario, the preferred farming systems are primarily NHH3 (no

Table 3. Proportions of fields for which particular farming systems are selected under six farming decision scenarios for Goodwater Creek watershed, Missouri

Farming System[a]	Baseline	Uncoordinated	Average Farmer	Water Quality Improvement	Aquatic Ecosystem Enhancement	Soil Loss Control
MHH1	0.002	0.097	0.002	0.002	0.002	
MHL1	0.566	0.098	0.016			0.226
MLL1		0.005				
NHH1		0.019			0.002	
NLH1		0.006				
NHL1		0.011				0.019
NLL1		0.003				
MHH2	0.167	0.036	0.003	0.003	0.002	
MLH2		0.002				
MHL2	0.128	0.164	0.975	0.078		0.740
MLL2	0.075	0.106				
NHH2		0.003	0.003	0.003	0.003	0.003
NLH2		0.002				
NHL2		0.014	0.002	0.002		0.013
NLL2	0.061	0.162				
MHH3		0.022			0.215	
MHL3		0.094		0.883	0.066	
MLL3	0.002	0.050				
NHH3		0.005		0.002	0.711	
NLH3		0.016				
NHL3		0.005		0.028		
NLL3		0.083				
Total	1.000	1.000	1.000	1.000	1.000	1.000

[a]The farming systems are defined as follows. The first letter indicates tillage system (Minimum or No till), the second nitrogen application level (High, Medium, or Low), the third atrazine application level (High or Low) and the number the crop rotation (1 for corn–soybean, 2 sorghum–soybean, and 3 corn–soybean–wheat).

till, high fertilizer and pesticide application rates, and corn–soybean–wheat rotation) and MHH3 (minimum till, high fertilizer and pesticide application rates, and corn–soybean–wheat rotation). These were selected because they have much higher net returns among the farming systems with corn–soybean–wheat rotation that have lower values in AE.

Even though the average farmer and soil loss control coordinated scenarios have similar economic and environmental impacts in the watershed, the selected farming systems are quite different. While the average farmer scenario primarily selects MHL2 for almost every field, the soil loss control scenario selects MHL2 at a rate of 74%, with MHL1 as a second common farming system. In general, the water quality improvement and aquatic ecosystem enhancement coordination scenarios favor selection of farming systems with a corn–soybean–wheat rotation rather than a two-crop rotation because wheat uses relatively less nitrogen and no atrazine. The average farmer and soil loss control coordinated scenarios favor farming systems with two-crop rotations, such as corn–soybean or sorghum–soybean, because a three-crop rotation increases potential soil loss.

Summary, Implications, and Conclusions

Watershed management requires collaborative planning, democratic decision making and environmental equity, integration of knowledge, sciences, and policies and successful watershed partnership (National Research Council, Born and Genskow). Consequently, successful watershed management results in coordinated rather than uncoordinated stakeholder decisions. The coordinated decision behavior stems from the shared information, knowledge, experiences, attitudes, and beliefs among the stakeholders (Osterman et al., MacKenzie, Ewing). This kind of ideal coordination is rarely seen in practice because of the difficulties entailed in accomplishing coordination when there are unreconciled preferences for multiple and often conflicting priorities among the parties whose actions affect the watershed. Coordination can be achieved only if varying preferences are altered so that the values of tradeoffs among multiple objectives' are acceptable.

The empirical application of multi-criteria decision making for watershed management summarized in this article shows that coordinated management decisions based on farmers' preferences are superior in environmental and economic terms over uncoordinated, independent actions based on those same preferences. This study also confirms the otherwise demonstrated existence of significant tradeoffs between economic return and environmental impacts of agricultural production (Van Kooten, Weisensel, and Chinthammit; Qiu, Prato, and Kaylen). If the coordinated environmental goals of Goodwater Creek watershed management were to place highest priority on atrazine and nitrogen runoff, significant tradeoffs between economic return and environmental improvement would exist.

In this study, coordinated decisions for watershed management assume shared preferences across economic and environmental outcomes of farming activities, as specified by common sets of criterion weights. But it should be noted that farmers' preferences for economic and environmental impacts of their farming decision can be shifted. Besides the farmers' own ability to handle information, research, extension, public education, media, and peer pressure may play significant roles in changing farmers' preferences and promoting coordinated decision behavior. All scenarios assume that farmers will make rational decisions according to their economic and environmental preferences specified by the criterion weights in selecting farming practices for their fields. However, using the theory of reasoned action (Fishbein and Ajzen) in social psychology, Carr argues that general attitudes, beliefs, and preferences do not lead to specific pro-environmental action or behaviors. According to the theory of planned behavior (Ajzen), which extends the theory of reasoned action, conservational behavior is determined by attitude that reflects personal beliefs and interests, subjective norm that reflects social influences, and perceived behavior control (Beedell and Rehman). Ophuls identifies four basic solution types that lead preferences and beliefs to pro-environmental individual actions or behaviors: (*a*) government laws, regulations, and incentives that encourage pro-environmental behavior; (*b*) education programs that share information and change people's attitude; (*c*) informal social processes that operate in small social groups and communities; and (*d*) pro-environmental moral, religious, and/or ethical appeals.

The MCDM approach linked to bio-economic modeling can be adapted to overcome some of the barriers to successful watershed management, given these behavioral dictates. For example, once a baseline set of preferences is incorporated in multiple criteria weighting (as accomplished in this study), weights can be parametrically altered and environmental and economic outcomes generated for each of a large series of criteria weighting schemes. From the subsequent set of generated outcomes, the watershed coordinating body could choose those criteria weights that minimize the value of tradeoffs necessary to meet minimum watershed-level objectives. Armed with these weights and those collected as part of the baseline situation's description, the coordinating body can determine the extent to which farmers' preferences for various objectives need to be altered to come closer to optimizing watershed management. A final step would be to design, regulatory, penalty, reward, incentive, and/or education programs to affect the degree of preference alteration needed to implement the chosen watershed coordination. The critical key is that bio-economic modeling gives one of the basis for determining the targets for preference alteration.

The process of achieving coordinated decision behavior through changing farmers' preference, belief, and/or attitudes may take too long for some impatient resource managers. An alternative is to develop and encourage the use of best management practices. However, past soil and water conservation programs that have developed a large menu of practices faced the practical necessity of narrowing their targets for technical assistance to a few key farming systems and best management practices that help to achieve the environmental goals of coordinated watershed management. This study shows that targeting could be a practical approach. Resource managers may choose to develop watershed management programs that encourage adoption of those farming systems and practices shown to obtain superior results under ideal preference weighting schemes. The two approaches for achieving coordinated decision behavior are not exclusive. As pointed out by Osterman, the strategy of moving farmers from awareness to action should be integrative.

Another barrier to successful watershed management is the lack of understanding of the social, economic, and biophysical processes leading to particular states of a watershed by the watershed council members charged with coordination. The biophysical, economic, and decision model integration developed in this study could be used for demonstration purposes, educating such council members not only about the individual processes, but how they interact with one another in an SDSS, thus facilitating integrated watershed management process. SDSS helps to convert the watershed management plans that direct land use and management changes from diverse interests into commonly measurable economic and environmental impacts that can be used in scenario comparison and decision making. In this specific example, an SDSS links farmers' field-level management decisions to economic and environmental impacts at the watershed scale. It contributes to successful watershed management by enhancing stakeholders' understanding of biophysical and economic processes, prioritizing environmental problems and identifying desired farming systems, and best management practices in agricultural watersheds.

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