Watershed-Scale Economic and Environmental Tradeoffs Incorporating Risks: A Target MOTAD Approach

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This paper evaluates the economic and environmental tradeoffs at watershed scale by incorporating both economic and environmental risks in agricultural production. The Target MOTAD model is modified by imposing a probability-constrained objective function to capture the yield uncertainty caused by random allocation of farming systems to soil types and by introducing environmental targets to incorporate environmental risk due to random storm events. This framework is used to determine the tradeoff frontier between watershed net return and sediment yield and nitrogen concentration in runoff in Goodwater Creek watershed, Missouri. The frontier is significantly affected by environmental risk preference.

Agriculture is a leading nonpoint source of water pollution in the United States (EPA 1994). Public concern about nonpoint source pollution from agricultural production has generated interest in examining tradeoffs between economic and environmental objectives in selecting farming systems. Knowledge of economic and environmental impacts of alternative farming systems and their tradeoffs would improve farmers' understanding of alternative farming systems and assist decision makers in designing appropriate incentive mechanisms to encourage farming systems that alleviate agricultural externalities such as soil erosion and water pollution. Even though agricultural water pollution can be studied at plot, field, and farm levels, the watershed is the most logical geographical unit for identifying holistic cause-and-effect water quality relationships, linking upstream uses to downstream effects, developing reasonable water cleanup plans, targeting limited resources, and educating and involving the public (Water Environment Federation 1992). Watershed-based approaches have been espoused by the Clean Water Act and several government agencies (Ethridge and Olson 1993).

This study evaluates the economic and environmental tradeoffs in an agricultural watershed in the midwestern United States. It is motivated by the Missouri Management Systems Evaluation Areas (MSEA) program that was established in 1989 by the President's Initiative on Enhancing Water Quality. The uniqueness of the Missouri MSEA project is the claypan soil in the study area. The study site, Goodwater Creek watershed, is located within, and typically represents, the Central Claypan Major Land Resource Area, an area of about ten million acres in the midwestern United States. Claypan soil is poorly drained, resulting in considerable surface runoff (Missouri MSEA Management Team 1995).

Previous Research

Significant tradeoffs have been found between economic and environmental objectives. Economic and environmental tradeoffs have been explored using different approaches. Van Kooten, Weisensel, and Chinthammit (1990) used dynamic optimization and an additive utility function measured as a function of net returns and soil quality to value the tradeoff between net returns and soil stewardship in a watershed. Ma (1993) used the ε-constraint method developed by Haimes and Hall (1974) to evaluate the tradeoffs among net return, soil erosion, and nitrogen available for leaching in a representative farm. Zhu, Taylor, and Sarin (1993) used the dynamic version of the surrogate

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worth tradeoff method to assess the tradeoffs between net revenue, nitrate leaching, and soil loss, and the time paths for using farming systems to achieve expected economic and environmental objectives in a representative farm.

Economic and environmental outcomes of agricultural production are stochastic in nature. For example, stochastic variation in agricultural prices significantly affects farmers' economic returns, and weather variability affects both economic returns and environmental effects of agricultural production. Milon (1987) used chance-constrained programming (Charnes and Cooper 1963) instead of traditional linear programming to capture the stochastic nature of the environmental effects of agricultural production and to identify an efficient watershed management plan. Wu (1994) used a chance-constrained programming model to evaluate the stochastic nature of net returns and environmental impacts and the economic and environmental tradeoffs in an agricultural watershed. In addition, he considered how the spatial arrangement of cropping systems in a watershed affects economic net returns and environmental quality. Zhu, Taylor, and Sarin (1994) and Xu, Prato, and Zhu (1996) argued that distributional assumptions for environmental indicators used in a chance-constrained programming model can have important impacts on the results. Teague, Bernardo, and Mapp (1995) used a modified Target MOTAD model to incorporate environmental risk, evaluate the tradeoffs between net returns and environmental impacts of agricultural practices in the Central High Plains, and identify farm plans that maximize net return while maintaining environmental risk below a critical or target level.

This paper extends the application of the Target MOTAD model by Teague, Bernardo, and Mapp (1995) to incorporate economic risk in an agricultural watershed associated with the crop yield variability. Even though crop yield is affected by many factors such as soil, slope, aspect, and landscape position, for simplicity, it is assumed that crop yield varies by soils. This paper does not consider economic risk associated with variability in agricultural prices. The approach used in this paper is different from the approaches of Xu, Prato, and Zhu (1996) and Wu (1994) because it uses a modified Target MOTAD model instead of a chance-constrained programming model to capture environmental risks and evaluate economic and environmental tradeoffs in selecting farming systems in an agricultural watershed.

Optimization Model

The Target MOTAD was originally proposed for decision makers who maximize expected returns and do not want returns to fall below a critical target level. Tauer (1983) shows that all management plans on the Target MOTAD efficient frontier are efficient in terms of second-degree stochastic dominance. The Target MOTAD model is a two-attribute risk and return model. Economic return is measured by the sum of the expected economic returns per unit of activity multiplied by individual activity levels. Riskiness of returns is measured by the probability weighted average of the negative deviations of the resulting economic returns from a target-return level under different states of nature. A risk-return frontier can be traced out by varying this risk parametrically. Mathematically, the model is as follows:

$$(1) \qquad \max \ E(z) = \sum_{j=1}^{n} c_j x_j$$

subject to

$$(2) \qquad \sum_{j=1}^{n} a_{kj} x_j \leq b_k \qquad k = 1, \ldots, K$$

$$(3) \qquad T - \sum_{j=1}^{n} c_{rj} x_j - y_r \leq 0 \qquad r = 1, \ldots, s$$

$$(4) \qquad \sum_{r=1}^{s} p_r y_r = \lambda \qquad \lambda = M \rightarrow 0$$

for all x_j and $y_r \geq 0$, where $E(z)$ is the expected return of the farm plan; c_j is the expected return of activity j; x_j is the level of activity j; a_{kj} is the amount of resource k used per unit of activity j; b_k is the level of resource k available; T is the target return level; c_{rj} is the net return for activity j in state of nature r; y_r is the net return deviation below T for state of nature r; p_r is the probability of state of nature r; λ is the risk aversion parameter, which is varied from M to 0; K is the number of resource equations or constraints; n is the number of activities; s is the number of states of nature; and M is a large number.

Following Teague, Bernard, and Mapp (1995), equations (3) and (4) are modified as follows to capture environmental risk:

$$(3') \qquad T_e - \sum_{j=1}^{n} v_{rj} x_j + d_r \geq 0 \qquad r = 1, \ldots, s$$

$$(4') \qquad \sum_{r=1}^{s} p_r d_r = \lambda_e \qquad \lambda_e = M \to 0$$

where T_e is the target identified for the environmental indicator, i.e., the environmental objective in watershed management; v_{rj} is the value of the environmental indicator for activity j in state of nature r estimated using a biophysical simulation model; d_r is the deviation above T_e in state of nature r; and λ_e is the expected value of negative deviations above an environmental target, i.e., the environmental risk measure.

Teague, Bernard, and Mapp's modification (1995) incorporates environmental risk but eliminates the economic risk associated with variability in net returns. As stated above, there are many sources of economic risk. There are two ways of incorporating economic risk into the model. If the states of nature, their probabilities, and the impacts on net return can be clearly identified, then economic risk can be considered by keeping the original equations (3) and (4) in the model. Otherwise, the economic risk can be incorporated by imposing a probability-constrained objective. Given a confidence level, α, the probability-constrained objective is to achieve a level of net return π with a probability of α, i.e., $\Pr(\mathbf{c}'\mathbf{x} \geq \pi) \geq \alpha$. Suppose the coefficient vector in the objective function, $\mathbf{c}$, has a normal distribution with mean μ and variance-covariance matrix Σ. Then, the economic objective has a normal distribution, i.e., $\mathbf{c}'\mathbf{x} \sim N(\mu'\mathbf{x}, \mathbf{x}'\Sigma\mathbf{x})$. Normality is assumed for convenience. The equivalent objective function is:

$$(1') \qquad \max \qquad \mu'\mathbf{x} + Z_\alpha(\mathbf{x}'\Sigma\mathbf{x})^{1/2},$$

where Z_α is the standard normal variate and risk weight, and $(\mathbf{x}'\Sigma\mathbf{x})^{1/2}$ is the standard deviation of the economic returns of production activities. Simply assuming the activity returns are independent, then equation (1′) simplifies to:

$$(1'') \qquad \max \sum_{j=1}^{n} \mu_j x_j + Z_\alpha \left(\sum_{j=1}^{n} \sigma_j^2 x_j^2 \right)^{1/2},$$

where σ_j^2 is the variance of c_j.

This objective function incorporates economic risks associated with production activities. When α equals 50%, this objective function is the same as in the original linear objective function since Z_α equals zero. This is called the economic risk-neutral case since the standard deviation of the economic return does not enter into the objective function. The economic risk is imposed by increasing α. Z_α is negative when α is greater than 50%. For example, $Z_\alpha = -1.96$ when α equals 95%. Since the standard deviation of the economic return is negatively weighted in the objective function with α greater than 50%, this is called the economic risk-averse case.

The system of equations (1″), (2), (3′), (4′) with positive x and y incorporates both economic and environmental risks. Equation (1″) is a quadratic function, i.e., the risk-adjusted total watershed net return (TWNR). Equation (2) is a resource constaint. In this application, the only resource constraint imposed is that the sum of proportions of cropland allocated to alternative farming systems must be less than or equal to one, which is essentially a land availability constraint. This application does not consider watershed-scale capital, labor, and material constraints. Equations (3′) and (4′) are environmental constraints. Equation (3′) measures the deviations of the environmental indicator from its target level under different states of nature. Equation (4′) requires the expected value of the deviation to be less than or equal to an environmental risk factor (λ_e) that has the same units of measurement as the environmental indicator. A planner can be a watershed management committee that consists of farmers, landowners, district supervisors, agency representatives, and business leaders. The value of λ_e reflects the planner's environmental risk preference. For an extremely risk-averse planner who does not want environmental pollution to exceed the target level under any state of nature, $\lambda_e = 0$. λ_e increases with respect to the planner's willingness to accept a higher level of environmental risk.

The solution to the modified Target MOTAD model generates an optimal watershed management plan that maximizes the risk-adjusted TWNR subject to achieving a satisfactory level of environmental risk that measures the degree of compliance with the target level for the environmental indicator. Any watershed management plan with $\lambda_e = \lambda_0$ will produce, on the average, λ_0 amount of pollution above the specified target. An economic-environmental tradeoff frontier can be determined by specifying the planner's environmental risk. Varying the environmental risk and environmental target allows a planner to generate different economic-environmental tradeoff curves and watershed management plans.

Study Area and Farming Systems

The above framework is used to evaluate the tradeoffs between TWNR and reductions in agricultural water pollution in Goodwater Creek watershed, Missouri, the site of the Missouri Management Systems Evaluation Area (MSEA) project. Goodwater Creek watershed is located in Boone and Audrain counties in north central Missouri, near the city of Centrailia. Goodwater Creek is a tributary of the Salt River, which is a major tributary of the Mississippi River. The watershed contains approximately 19,110 acres, of which 72% is in cropland and 28% in noncropland. The principal soil types in the watershed are Mexico silt loam, Mexico silt clay loam, and Putnam silt loam, which accounts for 32%, 30%, and 15% of the watershed, respectively. Other soil categories include Belknap silt loam, Armstrong silt loam, Leonard silt loam, Twomile silt loam, Gifford silt loam, Chariton silt loam, Adco silt loam, and Lenzburg gravely clay loam.

The Missouri MSEA project evaluated six farming systems. A farming system consists of a crop rotation, tillage method, and nitrogen and pesticide management plan. These systems are summarized in table 1. CBMHH (corn-soybean rotation with minimum tillage and high fertilizer and pesticide application rates) represents the prevailing farming system in the watershed. SBMMM (sorghum-soybean rotation minimum tillage, medium fertilizer and pesticide application rates), CBWMLL (corn-soybean-wheat rotation with minimum tillage and low fertilizer and pesticide application rates) and CBRMB (corn-soybean rotation with ridge tillage, medium fertilizer application rate, and banded pesticide application) are alternative farming systems for reducing agricultural nonpoint source water pollution. Farming systems CBRMB and CBNMH (corn-soybean rotation with no-till and medium fertilizer and high pesticide application rates) are alternative farming systems for reducing soil erosion. GLCNN is a cool season grass and legume with conventional tillage and no pesticide and fertilizer application. It approximates conditions for cropland enrolled in the Conservation Reserve Program (CRP) and is specifically designed to reduce both soil erosion and water contamination.

Date Development

Estimation of Annual Net Returns

Annual net returns for farming systems are estimated using the following procedure. First, annual net returns for a farming system in different soil types are calculated. Annual net return varies by soil type because crop yield is assumed to vary by soil type. It is estimated by subtracting average variable production costs from the gross return for a farming system. Mathematically, annual net return is:

$$(5)\quad ANR_{js} = \sum_{n=1}^{N}(P_nY_{jsn} - C_{jn}) \Big/ N \qquad \text{for all } j \text{ and } s,$$

where j is the index of farming system, s is the index of soil type, n is the crop index for farming system j, N is the number of crops in the farming system j, P_n is the market price for crop n, C_{jn} is the variable production cost for crop n in farming system j, Y_{jsn} is the yield for crop n with farming system j in soil s, and ANR_{js} is the net return for farming system j in soil s. Five-year (1987–91) average market prices of crops in Boone and Andrain counties in Missouri are used to calculate net returns. They are \$2.48, \$6.08, \$2.08, and \$2.01 per bushel for corn, soybeans, sorghum, and wheat, respectively. Variable production costs for each crop in each rotation of a farming system are estimated using the Cost and Return Estimator (CARE) developed by USDA Soil Conservation Service (1988). These costs include fertilizer, chemicals, seeds, machinery, labor, interest charge, and crop drying costs. Crop yield varies by soil type and farming system. The procedure for estimating crop yields is briefly described.

Using the same notation as above,

Table 1. Summary of Six Farming Systems for Goodwater Creek Watershed, Missouri

Name	Crop Rotation[a]	Tillage Method	Nitrogen Use	Pesticide Use	Goals: Grain Yield	Profit	Water Quality	Erosion Control
CBMHH	C-B	Min-Till	High	High	X	X		
SBMMM	S-B	Min-Till	Medium	Medium		X	X	
CBWMLL	C-B-W	Min-Till	Low	Low		X	X	
CBRMB	C-B	Ridge-Till	Medium	Banded		X	X	X
CBNMH	C-B	No-Till	Medium-high	High		X		X
GLCNN	G-L	Conv-Till	None	None			X	X

[a]C = corn, B = soybean, S = sorghum, W = wheat, L = legume, G = grass.

(6) $$Y_{jsn} = \frac{Y^{MSEA}_{j'mscl'n}}{Y^{NRCS}_{'mscl'n}} Y^{NRCS}_{sn},$$

where $Y^{MSEA}_{j'mscl'n}$ is the average yield of crop n for farming system j in the dominant soil of Mexico silty loam estimated from 1991–93 Missouri MSEA field and experimental plot data, $Y^{NRCS}_{'mscl'n}$ is the NRCS (Natural Resources Conservation Service) yield for crop n in a Mexico silty clay loam soil, and Y^{NRCS}_{sn} is the NRCS yield for crop n in soil s. The NRCS crop yields reflect soil productivity and are the expected crop yields under high levels of management (USDA NRCS 1995). The gross return for farming system GLCNN is specified as $65 per acre per year, which is the annual rental rate for CRP land in Missouri.

The annual field-level net return for a farming system is the weighted average of the annual net return for that farming system by soil type with weights given by the percentages of soil types in the field. There are a total of 139 fields. Since each field has a different combination of soil types, the annual net return of each farming system varies by field. The mean and variance of annual net return for a farming system in the watershed are estimated based on the annual net return for that farming system across all fields in the watershed. As shown in table 2, the mean annual net returns per acre for CBMHH, SBMMM, CBWMLL, CBRMB, CBNMH, and GLCNN are $133.06, $97.77, $88.68, $120.04, $84.17, and $34.78, respectively. The associated standard deviations are $11.31, $8.28, $7.87, $9.82, $9.39, and 0, respectively. The mean values reflect the expected annual net return for each farming system in the watershed, while the variances capture the variation in net return due to variability in soil type.

Estimation of Environmental Indicators

Environmental indicators are estimated using the AGNPS (Agricultural Non-Point-Source) pollution model (Young et al. 1987). AGNPS is a spatially distributed, single-event watershed simulation model that subdivides a complex watershed into grid cells. Model outputs include runoff, upland erosion, channel erosion, sediment yield, and nitrogen, phosphorus, and chemical oxygen demand in runoff and sediment. These outputs can be used to classify nonpoint source pollution problems in an agricultural watershed. In this study, AGNPS is used to simulate the effects of farming systems on water quality in Goodwater Creek watershed.

Since nonpoint source loads are primarily rainfall-driven phenomena that deliver pulses of varying mixtures and concentrations to surface and ground water (Milon 1987), precipitation is considered as the only source of environmental risk in this study. A twenty-four-hour maximum precipitation is the design storm event used in AGNPS to estimate average values of the environmental indicators. The design storm events are based on precipitation data for 1942 to 1991 from Kingdom City, Missouri, near Goodwater Creek watershed. The daily precipitation ranges from 1.20 to 5.76 inches. The 50 design storms were then divided into 16 rainfall intervals. The range of each interval is 0.24 inches. The 16 intervals correspond to 16 states of nature with probabilities determined by dividing the number of observations falling into each interval by 50, the total number of years in the precipitation record. AGNPS is run for each rainfall interval by implementing a single farming system on all cropland in the watershed. The same farming system is used on all cropland in the watershed in order to isolate the impacts of a farming system on water quality at the watershed outlet. Wu (1994) provides a detailed explanation of this procedure and the derivation of other AGNPS input parameters.

Two environmental indicators are evaluated: total soluble nitrogen concentration in runoff (SN) in parts per million (ppm) and total sediment yield

Table 2. Simulated Annual Net Return, Soluble Nitrogen in Runoff and Sediment Yield for Alternative Farming Systems

Farming Systems	Annual Net Return ($ per acre)[a]		Soluble Nitrogen in Runoff (ppm)[b]		Sediment Yield (tons)[b]	
	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation
CBMHH	133.06	11.31	12.69	4.64	1436	1356
SBMMM	97.77	8.28	4.66	1.40	1455	1352
CBWMLL	88.68	7.87	7.81	2.87	1046	972
CBRMB	120.04	9.82	8.33	2.58	1111	1029
CBNMH	84.17	9.39	5.70	2.13	459	403
GLCNN	34.78	0	0.97	0.05	226	185

[a]Wu 1994, p.143.
[b]Wu 1994, p.150.

(SY) in tons at the watershed outlet. Both nitrogen and sediment are important surface water pollutants in the study area. The values of SN and SY for alternative farming systems vary significantly across different states of nature (storm events). As shown in table 2, expected values of SN for farming systems CBMHH, SBMMM, CBWMLL, CBRMB, CBNMH and GLCNN are 12.69, 4.66, 7.81, 8.33, 5.70, and 0.97 ppm, respectively. The expected values of SY are 1436, 1455, 1046, 1111, 459, and 226 tons, respectively.

Results and Analysis

A baseline is established by maximizing expected TWNR (equation [1] subject to a resource constraint (equation [2]). Farming system CBMHH is the baseline farming system without risk restrictions. In the baseline, TWNR is $1.73 million, expected SN is 12.69 ppm, and expected SY is 1436 tons at the watershed outlet.

Tradeoffs between TWNR and environmental indicators are evaluated by varying the target levels of environmental indicators (T_e), the confidence level for TWNR (α), and the environmental risk (λ_e). Target levels for SN and SY are varied between 0 and 50% reduction from their expected levels in the baseline in increments of 5%. This results in target levels of 12.69, 12.05, 11.42, 10.78, 10.15, 9.51, 8.88, 8.25, 7.61, 6.98, and 6.34 ppm for SN, and 1436, 1365, 1293, 1221, 1149, 1077, 1006, 934, 862, 790, and 718 tons for SY at the watershed outlet. Confidence levels (α) of 50% and 95% of achieving economic objectives are used to represent the decision maker's economic risk-neutral and risk-averse preferences, respectively. Three environmental risks are considered. No environmental risk is implemented by setting $\lambda_e = 0$ for both SN and SY. For high environmental risks, $\lambda_e = 1.75$ ppm for SN and $\lambda_e = 500$ tons for SY. The high environmental risk is determined by setting the environmental targets (T_e) at their baseline levels (no reduction) and solving the economic risk-neutral ($\alpha = 0.50$) model for different values of λ_e. Specifically, λ_e is varied in increments of 0.25 ppm for SN starting from zero and 50 tons for SY starting from zero. The high environmental risk is the value of λ_e for which TWNR equals the expected TWNR in the baseline. The low environmental risk is arbitrarily set between zero and the high environmental risk. GAMS (General Algebraic Modeling System) is used to solve all models (Brooke, Kendrick, and Meeraus 1992).

There are four sets of solutions for evaluating the tradeoffs between net returns and surface water quality. The first two solutions relate to the tradeoffs between net returns and SN at three different SN risk levels with and without economic risk aversion. The second two solutions relate to the tradeoffs between net returns and SY at three different SY risk levels with and without economic risk aversion.

Tradeoffs between Net Returns and Soluble Nitrogen in Runoff

Figure 1 depicts the tradeoffs between expected TWNR and the percentage reduction in SN. The negative slopes show that expected TWNR declines as the percentage reduction in SN increases. The tradeoff curves become steeper after certain SN reduction levels. For example, with economic risk neutrality, the tradeoff curve is steeper after 40% reduction in SN with no SN risk and after 30% reduction with low SN risk. The steeper tradeoff curves imply that reductions in SN become more expensive at high percentage SN reduction levels. For a fixed economic risk (50% or 95%), it can be seen that the curves become steeper as the SN risk decreases (from 1.75 to 0.75 to 0) in both cases. It appears that reducing SN risk increases the tradeoffs between expected TWNR and percentage reduction in SN. In other words, the expected TWNR decreases as the willingness to accept nitrogen contamination decreases.

However, as willingness to accept economic risk decreases (from the economic risk-neutral level of 50% to the economic risk-averse level of 95%), the expected TWNR stays the same or shifts downward. Hence, expected TWNR does not necessarily decrease as willingness to accept economic risk decreases. In general, the economic risk has very slight impacts on the tradeoffs between TWNR and SN. The biggest difference in the expected TWNR between economic risk neutrality and aversion is $44,390 with SN risk of 1.75 ppm at zero reduction in SN.

Table 3 presents the watershed management plans at different SN target and risk levels with and without economic risk aversion. As previously stated, CBMHH is the baseline farming system because it is the most profitable farming system with the highest variation in net return. As environmental restrictions increase (i.e., lower environmental target or risk), CBRMB replaces CBMHH, then SBMMM replaces CBRMB, and finally GLCNN replaces SBMMM. This sequence implies that CBRMB maximizes TWNR with the lowest envi-

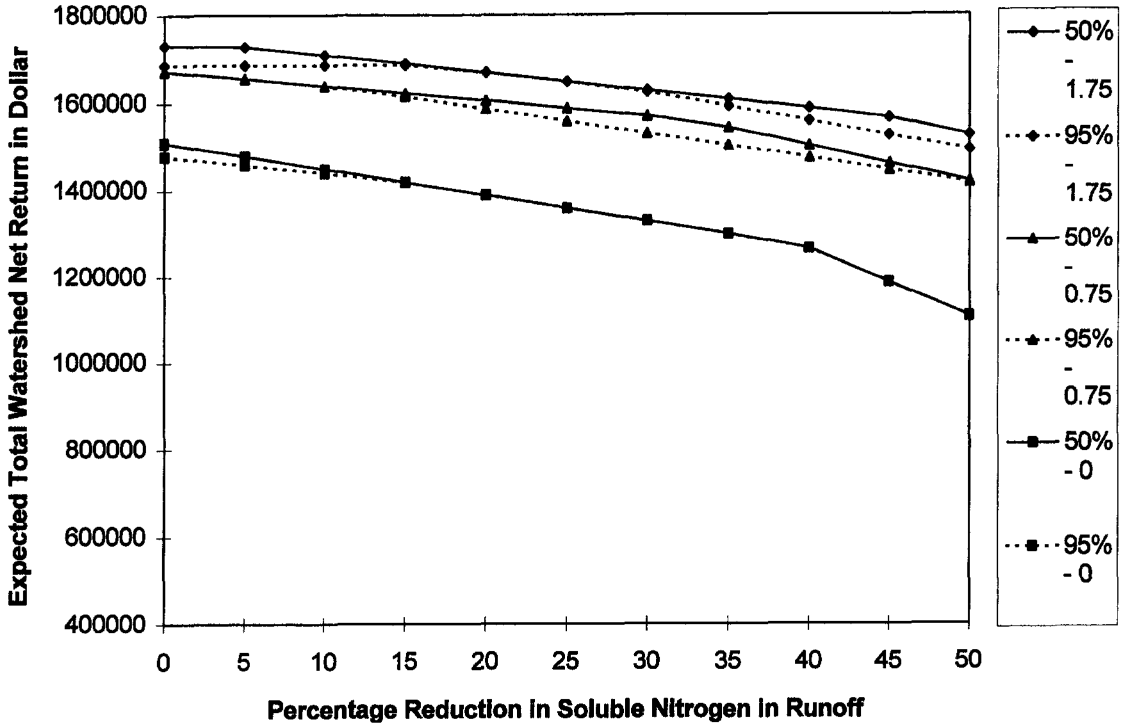

Figure 1. Tradeoffs between Total Watershed Net Returns and Soluble Nitrogen in Runoff for Different Water Quality Risks with Economic Risk Neutrality and Risk Aversion

ronmental restriction. SBMMM is better at reducing SN than CBRMB but is less profitable. GLCNN achieves the greatest reduction in SN but has the lowest net return. The farming systems in the watershed management plans are consistent in their economic and environmental impacts and their associated variations. Their rankings by the average net return and its standard deviation and by the average SN and its standard deviations are the same. As shown in table 2, the relative deviation for SN is much higher than for annual net return. These characteristics of the net return and SN of these farming systems also explain why the SN risks dominate the economic risk in terms of their impacts on the tradeoffs between TWNR and SN.

Tradeoffs between Net Returns and Sediment Yield

Figure 2 displays tradeoff curves between expected TWNR and the percentage reduction in SY. Compared with the tradeoffs between TWNR and SN, there are five major differences for the tradeoffs between TWNR and SY. First, since the tradeoff curves in figure 2 are flatter than the tradeoff curves in figure 1, tradeoffs between TWNR and SY are less than tradeoffs between TWNR and SN. Second, the tradeoffs are almost linear when SY risks are allowed. This implies that the abatement cost for SY is almost the same at different abatement levels with willingness to accept the SY risks. Third, there is a major difference in the tradeoffs between TWNR and reduction in SY with and without SY risk. Suppose the environmental objective is to achieve a 25% reduction in SY with neutral economic risk. TWNR is $1.64 million and $1.40 million with the high (500 tons) and low (250 tons) SY risks, respectively. With no SY risk, TWNR is $0.48 million, which is about one-third of TWNR with high and low SY risks. Fourth, environmental risk has a greater effect on the tradeoffs involving reduction in SY than reductions in SN. For example, going from high to no SY risk reduces TWNR by $1 million relative to the baseline. In contrast, going from high to no SN risk reduces TWNR by $210,000 relative to the baseline. Fifth, the economic risk has weaker impacts on tradeoffs between TWNR and SY than the tradeoffs between TWNR and SN. With no SY risk, the tradeoffs are coincident with risk neutrality and risk aversion. With SY risks, there are very

Table 3. Solutions for Proportions of Cropland in Alternative Farming Systems at Different Target and Risk Levels for Soluble Nitrogen in Runoff

		Percentage Reduction in Soluble Nitrogen in Runoff										
Risk	Farming System	0	5	10	15	20	25	30	35	40	45	50
Economic Risk Neutral (α = 50%)												
1.75	CBMHH	1	0.9821	0.8728	0.7560	0.6369	0.5177	0.3986	0.2762	0.1535	0.0287	0
1.75	SBMMM	0	0	0	0	0	0	0	0	0	0	0.1203
1.75	CBRMB	0	0.0179	0.1272	0.2440	0.3631	0.4823	0.6014	0.7238	0.8465	0.9713	0.8797
0.75	CBMHH	0.6564	0.5597	0.4630	0.3613	0.2589	0.1565	0.0542	0	0	0	0
0.75	SBMMM	0	0	0	0	0	0	0	0.0633	0.2033	0.3439	0.4846
0.75	CBRMB	0.3436	0.4403	0.5370	0.6387	0.7411	0.8435	0.9458	0.9367	0.7967	0.6561	0.5154
0	SBMMM	0.1804	0.2841	0.3877	0.4914	0.5950	0.6986	0.8023	0.9059	0.9911	0.8949	0.7986
0	CBRMB	0.8196	0.7159	0.6123	0.5086	0.4050	0.3014	0.1977	0.0941	0	0	0
0	GLCNN	0	0	0	0	0	0	0	0	0.0089	0.1051	0.2014
Economic Risk Averse (α = 95%)												
1.75	CBMHH	0.7380	0.7380	0.7380	0.7380	0.6369	0.5177	0.4182	0.3619	0.3033	0.2436	0.1796
1.75	SBMMM	0	0	0	0	0	0	0.0246	0.1065	0.1860	0.2646	0.3415
1.75	CBRMB	0.2620	0.2620	0.2620	0.2620	0.3631	0.4823	0.5572	0.5316	0.5107	0.4918	0.4789
0.75	CBMHH	0.6564	0.5597	0.4630	0.3959	0.3464	0.2957	0.2436	0.1901	0.1363	0.0764	0.0148
0.75	SBMMM	0	0	0	0.0454	0.1147	0.1826	0.2487	0.3127	0.3786	0.4422	0.5035
0.75	CBRMB	0.3436	0.4403	0.5370	0.5587	0.5389	0.5217	0.5077	0.4972	0.4850	0.4815	0.4817
0	CBMHH	0.122	0.0800	0.0371	0	0	0	0	0	0	0	0
0	SBMMM	0.3584	0.4008	0.4418	0.4914	0.5950	0.6986	0.8023	0.9059	0.9911	0.8949	0.7986
0	CBRMB	0.5196	0.5193	0.5211	0.5086	0.4050	0.3014	0.1977	0.0941	0	0	0
0	GLCNN	0	0	0	0	0	0	0	0	0.0089	0.1051	0.2014

slight differences between tradeoffs with risk neutrality and risk aversion. The biggest difference in the expected TWNR between economic risk neutrality and aversion is $37,940 with SY risk of 500 tons without reduction in SY.

Table 4 presents the watershed management plans at different SY target levels and risks with and without economic risk aversion. As environmental restrictions increase (i.e., lower environmental target and risk), CBRMB replaces CBMHH, then CBNMH replaces CBRMB, and finally GLCNN replaces CBNMH. As was the case with SN, CBRMB is still the preferred alternative for maximizing net returns while achieving the desired environmental goals. CBNMH, as opposed to SBMMM for SN, is the next farming system to enter the solution as environmental quality is improved. As the environmental goals are tightened even further, GLCNN (CRP option) enters the solution. These farming systems have the same characteristics as discussed in the previous section. It is these characteristics that account for the weak impacts of economic risk on the tradeoffs between TWNR and SY.

Summary and Conclusions

This paper develops an integrated framework to evaluate the tradeoffs between economic and environmental objectives for six farming systems and examines how these tradeoffs are influenced by a decision maker's attitudes toward economic and environmental risks. Constraints in the Target MOTAD model are modified to capture risk in the water quality impacts of storm events. A probability-constrained objective function is used to capture risk in net returns caused by stochastic variation in crop yields due to differences in soil types. This framework is used to evaluate the tradeoffs between TWNR and reductions in SN and between TWNR and reductions in SY for six farming systems being assessed in the Missouri MSEA project in Goodwater Creek watershed in Missouri.

Results show that there are significant tradeoffs between economic and environmental objectives. Tradeoffs are significantly affected by a decision maker's attitudes toward environmental risk. A much lower TWNR is achieved for a given environmental target without environmental risk than with environmental risk. In other words, complete compliance with environmental standards is much more expensive than allowing some violation with these standards in a stochastic environment. This result highlights the consequences of a decision maker's environmental risk attitudes in watershed management. Different decision makers, such as farmers and watershed managers, have different attitudes toward environmental risks that will result in very different watershed management plans

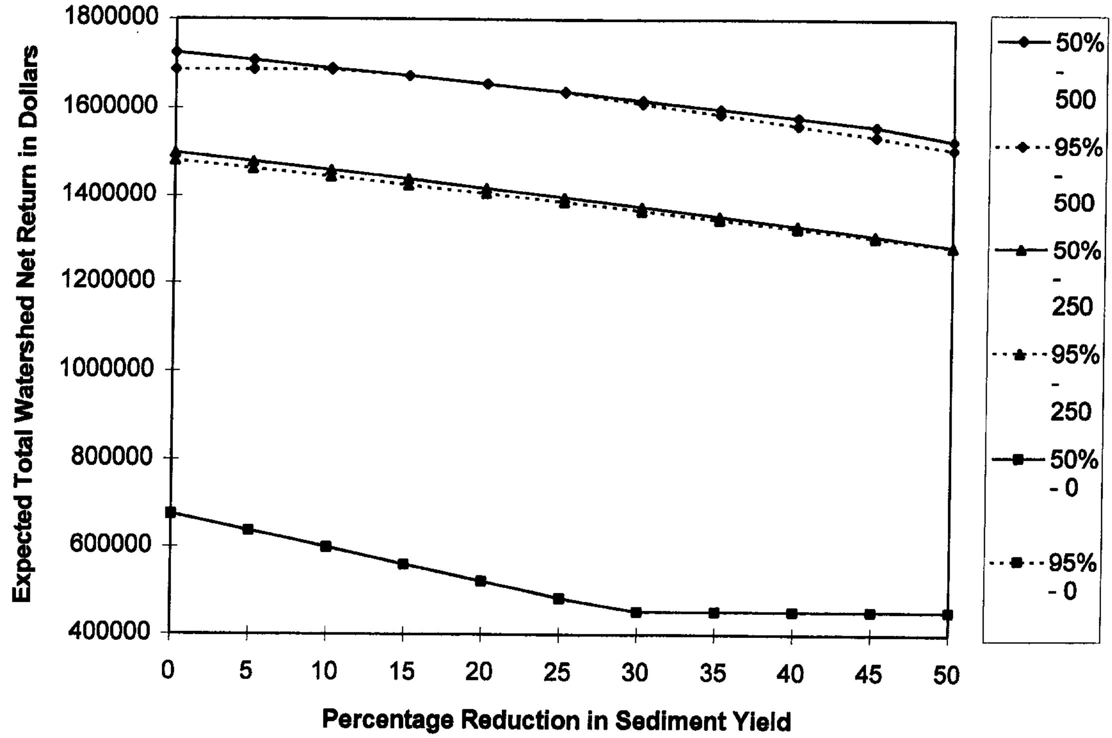

Figure 2. Tradeoffs between Total Watershed Net Returns and Sediment Yield for Different Water Quality Risks with Economic Risk Neutrality and Risk Aversion

even when the same environmental standard is required. Elimination of such differences is crucial for successful watershed management and can be accomplished through education, economic incentives, technical assistance, and compromise. Impacts vary by environmental indicator. The SY risks have more significant impacts on the tradeoffs than the SN risks.

Table 4. Solutions for Proportions of Cropland in Alternative Farming Systems at Different Target and Risk Levels for Sediment Yield

	Farming	Percentage Reduction in Sediment Yield										
Risk	System	0	5	10	15	20	25	30	35	40	45	50
Economic Risk Neutral (α = 50%)												
500	CBMHH	0.9619	0.8589	0.7560	0.6530	0.5500	0.4402	0.3268	0.2133	0.0998	0	0
500	CBRMB	0.0381	0.1411	0.2440	0.3470	0.4500	0.5598	0.6732	0.7867	0.9002	0.9931	0.9245
500	CBNMH	0	0	0	0	0	0	0	0	0	0.0069	0.0755
250	CBRMB	0.8634	0.8207	0.7781	0.7355	0.6908	0.6446	0.5984	0.5522	0.5060	0.4568	0.4053
250	CBNMH	0.1366	0.1793	0.2219	0.2645	0.3092	0.3554	0.4016	0.4478	0.4940	0.5432	0.5947
0	CBNMH	0.3479	0.2879	0.2278	0.1678	0.1078	0.0477	0	0	0	0	0
0	GLCNN	0.6521	0.7121	0.7722	0.8322	0.8922	0.9523	1	1	1	1	1
Economic Risk Averse (α = 95%)												
500	CBMHH	0.738	0.7380	0.7380	0.6530	0.5500	0.4468	0.4201	0.3932	0.3660	0.3385	0.3045
500	CBRMB	0.262	0.2620	0.2620	0.3470	0.4500	0.5499	0.5331	0.5166	0.5005	0.4849	0.4670
500	CBNMH	0	0	0	0	0	0.0033	0.0468	0.0902	0.1335	0.1766	0.2285
250	CBMHH	0.276	0.2546	0.2329	0.2110	0.1873	0.1631	0.1386	0.1139	0.0889	0.0616	0.0332
250	CBRMB	0.4499	0.4393	0.4292	0.4193	0.4100	0.4001	0.3906	0.3815	0.3727	0.3644	0.3554
250	CBNMH	0.2741	0.3061	0.3379	0.3696	0.4027	0.4368	0.4708	0.5047	0.5384	0.5740	0.6114
0	CBNMH	0.3479	0.2879	0.2278	0.1678	0.1078	0.0477	0	0	0	0	0
0	GLCNN	0.6521	0.7121	0.7722	0.8322	0.8922	0.9523	1	1	1	1	1

The results show that economic risk has very limited impacts on tradeoffs between TWNR and environmental objectives in contrast to the dominant impacts of environmental risks. The tradeoffs between TWNR and environmental objectives with economic risk neutrality are just slightly different from those with economic risk aversion. This result can be explained by the fact that variations in the environmental impacts of the farming systems entered into the optimal solution are associated with and overshadow variations in their economic impacts.

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