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ENVIRONMENTAL AND ECONOMIC IMPACTS OF ALTERNATIVE MANAGEMENT SYSTEMS FOR THE MINERAL CREEK WATERSHED

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ABSTRACT

The Maquoketa River drains 1,879 square miles of predominantly agricultural land in northeastern Iowa and is one of 13 tributaries of the Mississippi River that have been identified as contributing some of the highest levels of suspended sediments, nitrogen, and phosphorus to the Mississippi stream system. Initiatives focused on improving water quality have been implemented in several Maquoketa subwatersheds including the Mineral Creek Watershed (MCW), which covers over 12,000 ha in the west central portion of the Maquoketa River Watershed. A key component of the MCW water quality initiative was the application of an environmental and economic modeling system for over 20 different scenarios that include implementation of contouring, terracing, notill, and other practices on part or all of the MCW cropped acreage. Reductions in sediment, total N losses, and total P losses for 15 scenarios reported here were predicted to range from essentially zero to 52%, 0.3 to 26%, and 5 to 63%, respectively, relative to the baseline conditions. Aggregate impacts on producer net returns predicted across the entire watershed for the 15 scenarios as compared to the baseline ranged from an increase of $14/acre to a decline of $19/acre.

KEYWORDS. modeling, watershed, water quality, nutrients, scenarios, environmental, economic.

INTRODUCTION

Significant effort is being expended across the U.S. to address water quality problems at the watershed level. This phenomenon is being driven by the desire to manage different scales of watersheds in a holistic manner in tandem with regulatory pressures such as those required by the Total Maximum Daily Load (TMDL) process. Local stakeholders are becoming increasingly involved in watershed projects, to have a voice in changes that could potentially impact them.

An example of this approach is the Mineral Creek Watershed (MCW), located within the larger Maquoketa River Watershed (MRW) in eastern Iowa (Figure 1). The MRW has been implicated as one of 13 tributaries of the Mississippi River that contribute the highest levels of suspended sediments, nitrogen, and phosphorus to the Mississippi stream system. In response, coordinated action has been initiated across the entire MRW and also in separate projects within specific subwatersheds, in an effort to mitigate nonpoint source pollution emanating from cropland and pastures. A watershed council consisting of local stakeholders was formed as part of the MCW subwatershed project to provide a forum for exchanging ideas and to allow stakeholders to help target the use of best management practices (BMPs). Cost-share funds for BMPs were provided by the U.S. Environmental Protection Agency (USEPA) Section 319 Nonpoint Source Program via the Iowa Department of Natural Resources, and the Water Protection Fund of the Iowa Department of Agriculture and Land Stewardship's Division of Soil Conservation. Further support for the

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MCW Project, in the form of Iowa State University Extension assistance and simulation modeling, was provided by the U.S. Department of Agriculture (USDA) Cooperative State Research, Education and Extension Service Section 406 Water Quality Program.

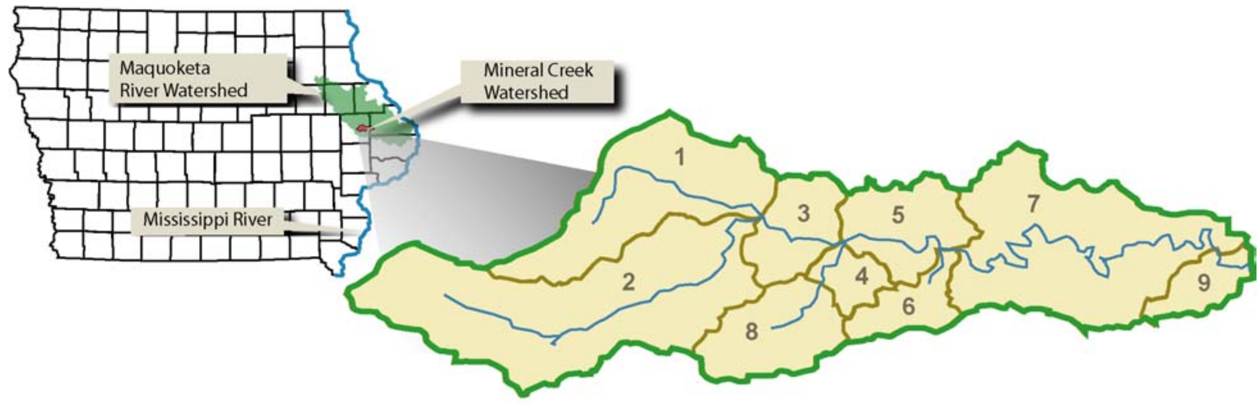

Figure 1. Locations of the Mineral Creek and Maquoketa River Watersheds in eastern Iowa, and the nine subwatersheds that were delineated for the simulation study.

The simulation modeling performed for the MCW was carried out with the Comprehensive Environmental and Economic Optimization Tool – Livestock and Poultry (CEEOT-LP) and was an extension of previous simulation work (Gassman et al. 2002; Keith et al. 2000) conducted for the Upper Maquoketa River Watershed (UMRW), which is another subwatershed located in the headwaters of the Maquoketa River system. The goal of the MCW modeling was to assess both the environmental and economic impacts of alternative management strategies applied to all or part of the watershed. The objectives here are to: (1) briefly describe the watershed and the modeling system, (2) describe the model input development process and the key input assumptions, and (3) present results of selected scenarios that were executed for the MCW.

Watershed Description

The MCW covers slightly over 12,400 ha in Jones and Jackson Counties in the eastern portion of the MRW (Figure 1). The dominant landuse is cropland planted in rotations of corn-soybean, continuous corn, or corn-alfalfa, which together comprise roughly 68% of the watershed land area. The two other key landuse categories are pasture (19%), which includes Conservation Reserve Program (CRP) fields, and woodland (12%). A total of 33 operations were identified as having one or more types of livestock at the time of the study, with the livestock mix consisting primarily of swine, feeder cattle, and beef cows. Subsurface tile drains underlay much of the cropland and are potentially a key conduit of nitrate-nitrogen (NO_3-N) to the Mineral Creek stream system.

Modeling System

Holistic analysis of alternative BMPs or policies for a specific watershed is performed through an interface of economic and environmental components within CEEOT-LP. The Farm-level Economic Model (FEM) is a representative farm model (Osei et al., 2000a) that is used to simulate farm-level economic impacts in response to different policy scenarios. The model operates on an annual time step and can be executed for extended periods of 30 years or more. Economic outputs generated by FEM include total revenue, total cost, net returns, costs of individual production components (labor, etc.), debt payment, and owner's equity.

The environmental component consists of two models, the field-level Agricultural Policy/Environmental eXtender (APEX) model (Williams et al., 1995) and the watershed-level Soil and Water Assessment Tool (SWAT) model (Arnold et al., 1998). The APEX model is a modified version of the Erosion Productivity Impact Calculator (EPIC) model (Williams, 1990) and is used in CEEOT-LP to simulate variations in manure application rates and methods, and other management alternatives, in response to specified policy scenarios. It operates on a daily time step and can be applied for a wide range of soil, landscape, climate, crop rotation, and management practice combinations. Crop yields, edge-of-field nutrient and sediment losses, and other water and nutrient balance variables are among key outputs provided from the model.

SWAT was developed to simulate continuous-time streamflow with a high level of spatial detail by allowing the division of a watershed or river basin into hundreds or thousands of grid cells or sub-watersheds. The model operates on a daily time step and is designed to evaluate management effects on water quality, sediment, and agricultural chemical yield in large, ungauged basins. Outputs generated from SWAT are similar to those provided by APEX. Edge-of-field flows, sediment losses, and nutrient losses simulated in APEX were coupled with losses simulated in SWAT from other land uses and routed in SWAT through the stream system to the MCW outlet. A total of nine subwatersheds were created for the MCW SWAT simulations (Figure 1) using the Arcview SWAT interface (AVSWAT) developed by Di Luzio et al. (2001).

Baseline Simulation Assumptions and Input Data

Different groupings of MCW livestock operations were developed for FEM and APEX, in order to address specific aspects of the economic and environmental analyses. All 33 of the MCW livestock operations were simulated individually in APEX for the study. Generic configurations developed for different types of UMRW livestock operations (Osei et al., 2000a; Gassman et al., 2002) were also used for the MCW simulations, with some minor modifications. Four types of livestock operations were simulated in APEX for the MCW: swine open lot, swine confinement, feeder cattle, and beef cattle. A new set of FEM representative farms were developed for the MCW analysis, based on a clustering procedure performed for the 33 livestock operations. This procedure resulted in a total of eight different types of FEM representative farms: swine open lot, swine confinement, feeder cattle, large feeder cattle, small beef, large beef, beef and feeder, and beef and calf.

A survey of MCW landowners was conducted to obtain information about fertilizer, tillage, and conservation practices, total livestock present and associated manure management systems, and other pertinent practices and/or equipment used on their respective operations. it was determined that the three main cropping systems used in the watershed were continuous corn, corn rotated with soybean (corn-soybean or soybean-corn), and five-year rotations consisting of two years of corn followed by three years of alfalfa (corn-corn-alfalfa-alfalfa-alfalfa or alfalfa-alfalfa-alfalfa-corn-corn), based on survey information and discussions with the watershed council. Distributions of crop rotations by SWAT subwatershed (Figure 2) were determined in part by the survey responses, and further refined by observations across the watershed and additional consultation with members of the watershed council. A similar process was followed in developing analogous livestock distributions by SWAT subwatershed (Figure 3).

The simulated baseline fertilizer rates are based on average rates derived from the surveys and are listed in Table 1 as a function of crop sequence and manured versus nonmanured fields; these rates reflect modest levels of nitrogen crediting due to manure inputs and/or previous crop effects (i.e., soybean and alfalfa). Application rates of 44.8 t/ha (20 t/ac) for solid manure and 46,745 l/ha (5,000 gal/ac) for liquid manure (from swine confinements) were simulated in both FEM and APEX for the baseline, based on typical practice in northeast Iowa (Osei et al., 2000b).

The tillage systems simulated for the baseline reflected in part results obtained from the survey and generally represented mulch tillage practices. A chisel plow pass in late October after harvest and a field cultivator pass in late April before planting were simulated in the corn years of all three crop rotations (an extra chisel plow pass was simulated in April of the first corn year in the corn-alfalfa rotations), while a single field cultivator pass was simulated for soybean prior to planting. A tandem disk pass in late March, spike tooth harrow pass in early April before seeding, and a culti-packer pass after seeding were simulated for the first year of alfalfa; no other tillage passes were simulated in the second or third alfalfa years. The mulch tillage system simulated for the corn-soybean and soybean-corn rotations was actually a greater level of tillage than that suggested by the surveys; i.e., only a single field cultivator pass prior to corn planting with notill being the dominant tillage method in the soybean years. However, it was decided that additional tillage should be included for the rotations of corn and soybean due to the perception that the survey may have captured a “low tillage year” for the corn-soybean rotations and to provide increased sensitivity between the baseline and notill scenarios performed with CEEOT-LP.

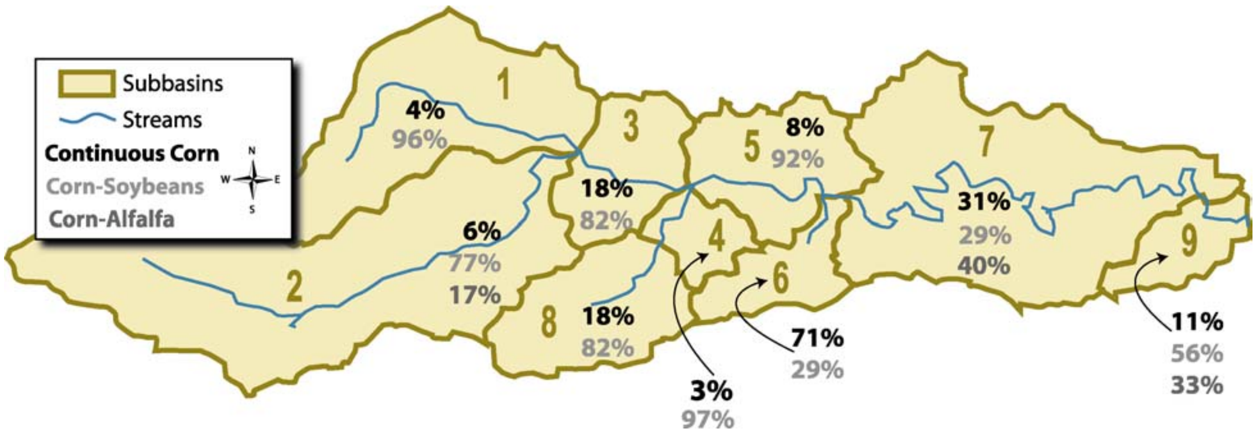

Figure 2. Assumed crop rotation distributions by SWAT subwatershed for the MCW.

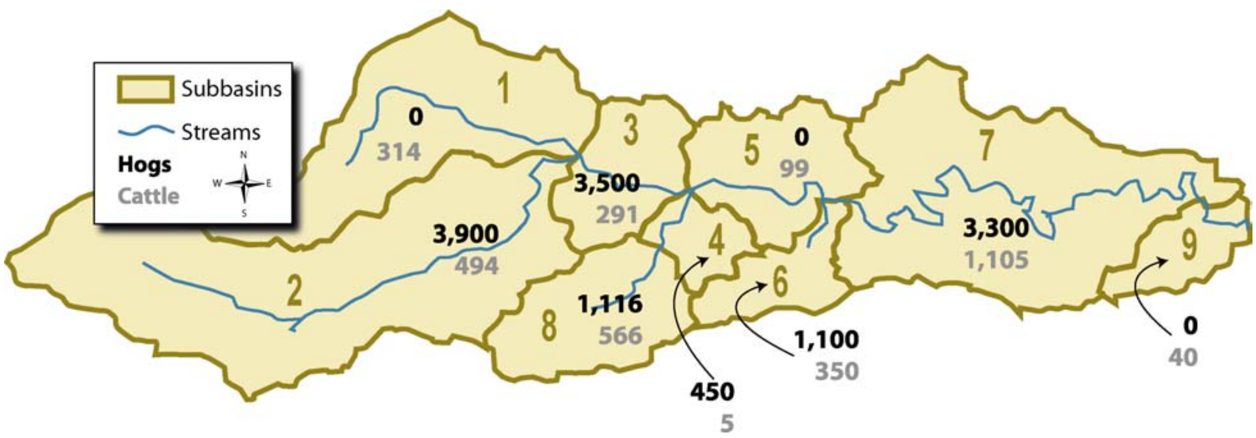

Figure 3. Assumed livestock distributions by SWAT subwatershed for the MCW.

Table 1. Expected yields and fertilizer rates based on MCW survey results.

Crop	Crop sequence	Expected yield (bu/ac)	Manured fields (kg/ha)			Nonmanured fields (kg/ha)		
			Main N rate	Fall crop removal[a]		Main N rate	Fall crop removal[a]	
				N	P_2O_5		N	P_2O_5
corn	after corn	146	129	10	48	146	10	48
corn	after soybean	146	103	0	0	120	0	0
corn	after alfalfa	146	83	10	48	100	10	48
soybean	after corn	51	0	22	105	0	22	105

[a]Applied in the fall after crop harvest as diammonium phosphate (DAP)

Historical daily precipitation, and maximum and minimum temperature data, were obtained for the thirty-year period of 1971-2000 (U.S. Department of Commerce, 1971-2000) for the towns of Anamosa and Maquoketa, Iowa, which are located near the western and eastern ends of the MCW, respectively (both towns are located outside the watershed). These climate data, along with daily solar radiation, windspeed, and relative humidity generated internally in the models, were used to drive APEX and SWAT for the baseline and alternative management scenarios. Soil map and associated layer data, landuse (based on 1992 satellite imagery) and digital elevation (DEM) layers required for the SWAT simulations were obtained from IDNR-GSB (2000). Soil layer data required for the APEX simulations were obtained from Baumer et al. (1994). The percent of the cropped acreage in each subwatershed that was tile drained was based on the expert opinion of members of the watershed council, which resulted in the following levels: 70% in subwatersheds 1 and 2, 100% in subwatersheds 3, 4, 5, 6, and 8, and 30% in subwatersheds 7 and 9.

MODELING METHODOLOGY AND SCENARIOS

To perform the environmental component of the 30-year scenarios, the Anamosa and Maquoketa 30-year daily climate records were distributed to the subwatersheds closest to each town. This resulted in the Anamosa data being input for subwatersheds 1, 2, 3, 4, and 8 and the Maquoketa data being used for subwatersheds 5, 6, 7, and 9. The APEX simulations were initially performed for each livestock operation located in a given watershed. These APEX simulations consisted of simulating manure and fertilizer applications, in combination with other management practices, to fields cropped in continuous corn or corn rotated with soybeans. Following completion of the APEX simulations, the 30-year daily output files generated for each operation within a given subwatershed were then aggregated into a single data file for input into SWAT. The SWAT runs were then performed by simulating the remaining fields of corn rotated with soybeans or alfalfa (about 75% of the total MCW cropped area), and the pasture (including CRP), woodland, and other non-cropped MCW areas. The FEM simulations were performed independently for each scenario for the eight livestock farm categories and a representative corn-soybean farm without livestock. Rotations of corn with alfalfa were included in the FEM beef and feeder cattle simulations (this was not accounted for in APEX due to the reliance on the UMRW simulation structures, which assumed that alfalfa would only be grown on dairy operations).

Table 2 lists the 15 scenarios from the original simulation set that are discussed here. Scenarios 1-5, 12, and 13 depict implementation of specific conservation practices on all or part of the total MCW cropped acreage. The surveys indicated that some producers had already implemented one or more of these conservation practices, although it was difficult to ascertain the extent of land area affected across the whole watershed. It was also desired to simulate the potential full impact of applying these practices, so it was assumed that conservation practices were not used in the baseline. The effect of the conservation practices was mainly accounted for by adjusting the "support practice (P) factor" (Wischmeier and Smith, 1978), used in the erosion calculations, from 1.0 in the baseline to the following values (ranges indicate slope effects): .1 to .16 for terraces, .5 to .8 for contouring, and .4 for contour buffers and grassed waterways. Additional effects of improved vegetation were also simulated in APEX and SWAT for the grassed waterways. Elimination or reduction of the fall crop removal fertilizer rates (Table 1) was simulated in scenarios 6, 7, 14, and 15. Scenarios 14 and 15 represent simplified depictions of using variable rate technology, which was focused on reducing the level of phosphorus fertilizer applications Manure was assumed applied on a P basis for the two VRT scenarios using rates reported in Gassman et al., (2002). Increasing implementation of notill across the total MCW cropped acreage is captured with scenarios 8-10. All tillage passes were eliminated for the land areas affected by the notill scenarios, except for the first year of alfalfa (which requires the previously described tillage treatments). Scenario 11 reflects the effects of notill in combination with contouring.

Table 2. Selected scenarios that were simulated for the MCW with CEEOT-LP.

Scenario	Name	Description
1	CT25	Contouring practiced on 25% of the cropped acreage; limited to slopes ≥ 3.5%
2	CT75	Contour practiced on 75% of the cropped acreage; limited to slopes ≥ 3.5%
3	CB25	Contour buffers implemented on 25% of the cropped acreage
4	CB75	Contour buffers implemented on 75% of the cropped acreage
5	GW100	Grassed waterways with excellent vegetative cover used on 100% of the cropped acreage
6	NF25	No applications of fall crop removal fertilizer on 25% of the cropped acreage
7	NF75	No applications of fall crop removal fertilizer on 75% of the cropped acreage
8	NT25	Notill practiced on 25% of the cropped acreage
9	NT75	Notill practiced on 75% of the cropped acreage
10	NT100	Notill practiced on 100% of the cropped acreage
11	NTCT75	Notill and contouring practiced on 75% of the cropped acreage

12	TR25	Terracing practiced on 25% of the cropped acreage; limited to slopes ≥ 3.5%
13	TR75	Terracing practiced on 75% of the cropped acreage; limited to slopes ≥ 3.5%
14	VRT25	Variable rate tech. (reduced fall crop removal rates) used on 25% of cropped acreage
15	VRT75	Variable rate tech. (reduced fall crop removal rates) used on 75% of cropped acreage

RESULTS AND DISCUSSION

Environmental and economic indicators are given in Table 3 for the 15 scenarios, relative to the baseline. The environmental indicators show the impact of alternative management strategies at the watershed outlet. The net returns are aggregate levels computed for the whole watershed.

Table 4. Environmental and economic impacts of the selected MCW scenarios relative to the baseline.

Scenario	Sediment (%)	Organic N (%)	Nitrate (%)	Total N (%)	Organic P (%)	Soluble P (%)	Total P (%)	Net returns ($/acre)
CT25	-6.2	-11.6	1.9	-4.4	-14.4	-2.7	-12.4	-0.7
CT75	-18.2	-29.7	3.7	-11.9	-29.4	-14.7	-26.8	-2.1
CB25	-8.9	-14.7	1.8	-5.8	-18.6	-2.4	-15.8	-4.7
CB75	-23.4	-38.4	3.9	-15.9	-39.4	-24.3	-36.8	-14.0
GW100	-52.3	-43.3	-1.7	-21.2	-42.1	-21.5	-39.5	-5.4
NF25	-0.1	-0.9	-0.8	-0.8	-8.1	-11.7	-8.7	4.6
NF75	-0.3	-1.1	-5.3	-3.3	-15.5	-43.4	-20.4	13.8
NT25	-4.3	-8.0	1.7	-2.8	-8.1	5.2	-5.8	-0.3
NT75	-9.8	-21.7	2.3	-8.9	-15.1	14.5	-9.9	-0.9
NT100	-9.8	-27.8	5.2	-10.2	-17.8	19.0	-11.3	-1.2
NTCT75	-23.0	-39.5	4.8	-15.9	-35.2	-2.2	-29.4	-2.9
TR25	-18.5	-23.9	4.3	-8.9	-30.8	-5.5	-26.3	-6.4
TR75	-42.6	-65.0	7.7	-26.3	-67.7	-43.7	-63.5	-19.2
VRT25	0.5	2.1	-1.3	0.3	-3.4	-10.8	-4.7	0.4
VRT75	0.5	1.9	-4.9	-1.7	-9.7	-36.4	-14.4	1.1

Sediment reductions were predicted for all the management strategies that are designed to reduce erosion losses (Table 3). Essentially no effect on sediment loss was estimated for the scenarios focused on reductions of the fall crop removal fertilizer applications. Installing grassed waterways on 100% of the cropped landscape resulted in the greatest predicted reduction in sediment loss (52%), followed by terraces (43%), contour buffers (23%), and notill used in tandem with contouring (23%). Increasing use of notill (scenarios 8-10) resulted in relatively small sediment load reductions, with no additional impact predicted by including 100% of the crop fields versus only 75% of the cropped acreage. The impacts predicted for the organic N and P losses generally followed those predicted for the sediment losses for the erosion reduction strategies, except that the TR75 scenario was predicted to have the largest reductions (65 and 68% for organic N and P, respectively). Minor effects on organic N were predicted for the fertilizer reduction strategies; however, organic P reductions ranging from 3.4 to15.5% were predicted for these scenarios. Slight increases were estimated in nitrate losses for nearly all the simulations except the GW100 and fertilizer reduction scenarios. These nitrate increases resulted from greater infiltration and subsequent higher losses to the stream system via subsurface tile lines. Reductions in soluble P losses were predicted to occur for nearly all the scenarios, with the greatest reductions predicted for the TR75 (44%), NF75 (43%), and the VRT75 (36%) scenarios. However, the soluble P and other losses predicted for the NF75 (and NF25) scenarios may not be fully attainable because total elimination of fall crop removal fertilizer applications is probably unrealistic for MCW conditions. Soluble P losses were predicted to increase for the three notill scenarios, which has been reported for some field studies (e.g., http://www.kfb.org/pdf/environmental/Newsltr%20Fall%202001.pdf). Reductions in total N and P losses were predicted for all 15 scenarios; the TR75, GR100, CB75, and NTCT75 scenarios were indicated to be the most effective.

The aggregate net returns reported in Table 3 reflect the effect of each scenario across all of the MCW cropped acreage, regardless of the amount of land directly affected by each scenario. Thus the effects on the portion of producers directly impacted by the changes is much greater; e.g., only 25% of the total cropped acreage was included in the CT25 scenario, so the decline in net returns to the fields that were actually contoured was about $2.80/acre (versus the $0.70 shown in Table 3). In general, most of the scenarios were predicted to result in lower aggregate net returns, ranging between 0.3 and $19/acre. The only exceptions to this trend were the NF25, NF75, VRT25, and VRT75 scenarios, which were predicted to result in higher net returns ranging from 0.4 to $14/acre. The increased net returns for the four fertilizer reduction scenarios reflect the gains obtained from less use of fertilizer after harvest in the fall. However, the effects of the NF25 and NF75 scenarios are again likely overstated, due to the previously stated reason. Government CRP payments equivalent to $110/acre were incorporated into the FEM assessment of contour buffers and grassed waterways. However, cost share funds were not factored into costs of implementing terraces; the impact on net returns would clearly be significantly reduced if cost share funds, currently 75% in the study area, were included for the terrace scenarios.

Figures 4 and 5 show graphical representations of the total P losses and total N losses plotted against the net returns (profit impacts) for the 15 scenarios. These plots reveal that some of the most effective strategies for reducing nutrient losses in the MCW are also some of the most potentially expensive approaches. This fact underscores the need to assess a range of possible management strategies for a watershed, to determine which practices are likely to provide the greatest pollutant reductions at the least cost.

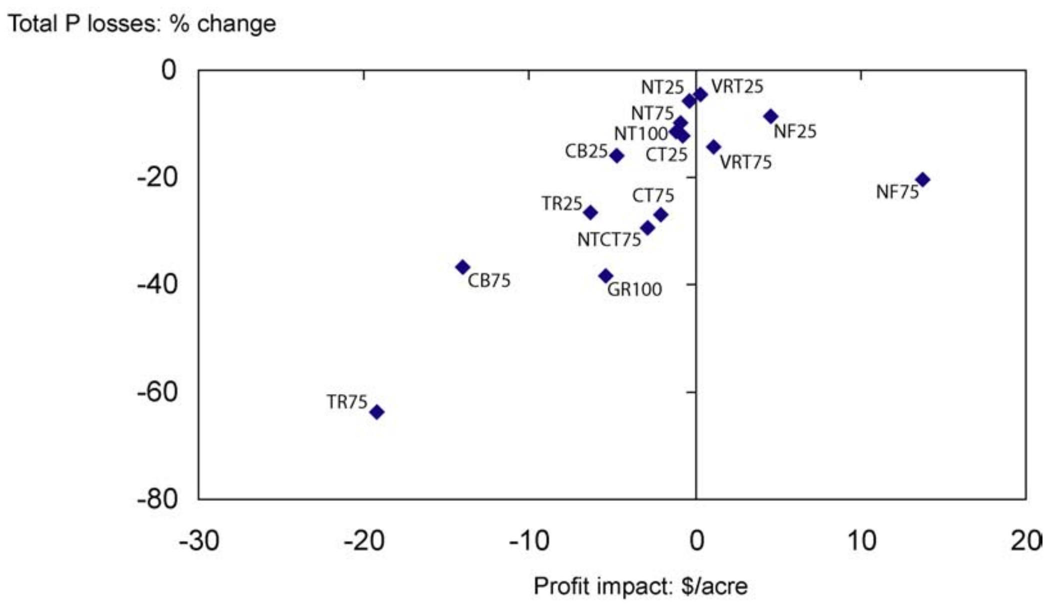

Figure 4. Total P losses versus net returns (profit impacts) for the 15 scenarios listed in Table 2.

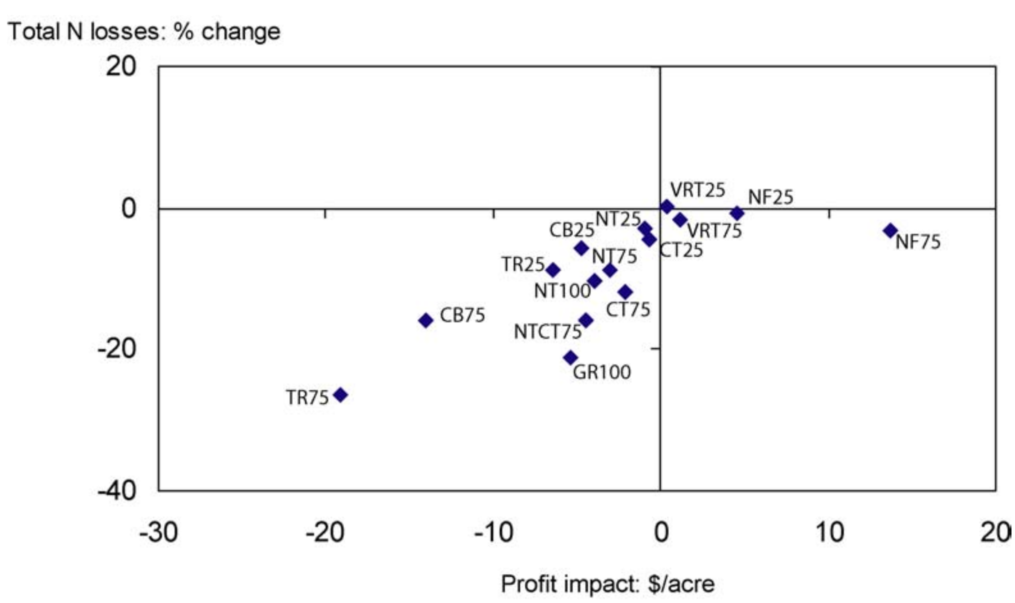

Figure 5. Total N losses versus net returns (profit impacts) for the 15 scenarios listed in Table 2.

CONCLUSIONS

The application of CEEOT-LP to the MCW provided a robust method of evaluating the environmental and economic impacts of adopting a range of alternative management practices to part or all of the cropped acreage in the watershed. The results showed that the four strategies designed to reduce or eliminate the application of fall crop removal fertilizer resulted in reductions of total N and P losses at the watershed outlet and also in improved aggregate net returns. However, the effects of totally eliminating the fall fertilizer rates are likely overstated in the current analysis. Several other scenarios including the implementation of terraces, grassed waterways, and contour buffers were indicated to be effective practices in reducing sediment and nutrient loads, but were also predicted to result in reduced net returns to producers. Further research is needed to evaluate additional variations of these scenarios, including the effect of including cost share for terraces, as well as other possible management practices that could be effective in mitigating pollutant losses to the MCW stream system.

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