Do Conservation Practices and Programs Benefit the Intended Resource Concern?

John V. Westra, Julie K. H. Zimmerman, and Bruce Vondracek

Many conservation programs under the 2002 Farm Act address resource concerns such as water quality and aquatic communities in streams. Analyzing two such programs, simulated changes in agricultural practices decreased field-edge sediment losses by 25–31% in two geophysically distinct Minnesota watersheds. However, while in-stream sediment concentrations and lethal fisheries events decreased significantly in one watershed, there was no discernable improvement for the fisheries in the other, despite potentially spending over $100,000 annually in conservation payments. These results highlight the importance of performance-based conservation payments targeted to genuine resource concerns in watersheds and the value of integrated bioeconomic modeling of conservation programs.

Key Words: Agricultural Drainage and Pesticide Transport (ADAPT), Conservation Reserve Program (CRP), Conservation Security Program (CSP), fisheries, green payments, water quality

Over the last 70 years, the federal government has worked with agricultural producers and land owners to conserve natural resources such as soil, mitigate negative environmental externalities like water pollution, maintain net farm income at some acceptable level, and keep budgetary outlays within some fiscally responsible limit. Programs that encourage producers to use crop residue management (conservation tillage) practices, or programs such as the Conservation Reserve Program (CRP) that promote the retirement of highly erodible lands, have been somewhat successful at reducing soil losses (Conservation Tillage Information Center, 2003; Ribaudo, Osborn, and Konyar, 1994).

Despite such efforts, agricultural production activities remain one of the primary reasons for water quality impairment or nonattainment of designated uses (fishable, swimable, or drinkable) for riverine systems (60%), and to a lesser extent lakes (30%), estuaries (15%), and ocean shoreline areas (15%) in this country (U.S. Environmental Protection Agency, 2000). Given this situation, one might wonder if conservation programs designed to reduce soil loss effectively protect water quality in general, and more specifically, fisheries populations in freshwater environments.

Recently, under the Conservation Title of the 2002 Farm Security and Rural Investment Act (FSRIA) (the 2002 Farm Act), a new conservation initiative for working lands was created. The Conservation Security Program (CSP) is a performance-based program which rewards farmers with "green payments" for conservation practices or structures

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that address environmental or natural resource concerns such as soil loss, water quality, and fisheries and wildlife habitat. The CSP was designed to "reward the best and motivate the rest" (7 CFR Part 1470, p. 7720).

In this study, we examine how well the CSP and the CRP address water quality and freshwater fisheries concerns in two different watersheds in Minnesota, and estimate how such programs affect producer income and how much they cost the government. The timely analysis presented in this research demonstrates that if programs like CSP are to be successful, they may need to be targeted more toward the actual resource concern of interest to the people in a given watershed. For example, if the resource concern is fisheries and the conservation practices being funded by this program do not result in a measurable improvement in this resource, then the program is not very effective or economically efficient. Another contribution of this research is its description and demonstration of the usefulness of tools like integrated bioeconomic models for analyzing complex biophysical processes and the policies designed to influence them.

For an ex ante analysis of how cost-effective conservation programs might be, or to determine how successfully such programs might address the environmental concerns for which they were designed, an integrated bioeconomic model is crucial (Wu et al., 2004). With an integrated approach, a bioeconomic model incorporates the field-level economic information of land use changes and the biophysical or environmental impacts of these alternative land management systems and aggregates them up to a larger scale, such as a watershed or river sub-basin or basin.

This approach to modeling and analyzing agricultural conservation programs is crucial because it captures the heterogeneous nature of the landscape and reflects the level at which many economic and agronomic decisions are made—the field. By modeling the physical process at the field level and aggregating up to the watershed, the spatial variability and nonlinear impacts of farming systems on the environment can be captured. Furthermore, the differing economic impacts of conservation programs on various farming systems can be captured with this integrated bioeconomic analysis.

Review of Literature

The increased sediment from many agricultural practices, primarily row-crop production, adversely influences the structure and function of streams, and often changes fish diversity (size and age structure, and species composition) and temporal variability in fish abundance (Berkman and Rabeni, 1987; Schlosser, 1991; Harding et al., 1998; Schleiger, 2000). Sublethal and lethal effects on fish assemblages from suspended sediment include avoidance behavior, impaired respiration, reduced feeding rates and growth, reduced tolerance to disease or toxicants, increased physiological stress, and mortality (Newcombe and Jensen, 1996).

Protecting and enhancing the fisheries, improving surface water quality, and reducing soil erosion are some of the multiple benefits certain agricultural practices can provide. But are people concerned about these resources? And how much would society pay for such benefits?

In a recent study in Minnesota, where the two watershed study areas are located, survey respondents were asked about their willingness to provide financial incentives to producers to produce such environmental benefits. In that study, Welle (2001) estimated mean annual willingness to pay for a 50% reduction in environmental impacts from agriculture, such as soil loss and damage to fisheries, was $201 per household or $362 million for the state. These contingent values indicate people consider water quality and fisheries or the ability to fish a stream or river to be important resources that can be affected positively or negatively by agriculture.

Despite the difficulty in addressing environmental problems associated with agricultural activities, researchers began combining the physical or biophysical aspects of agricultural systems with economic models of agricultural policy to analyze nonpoint source (NPS) pollution nearly 30 years ago. Primarily due to limitations of the biophysical modeling, initial economic analyses of agricultural nonpoint pollution used estimates of soil erosion rates with fixed delivery ratios, regardless of proximity to water or watershed topography, as proxies for actual effluents (Wade and Heady, 1977; Osteen and Seitz, 1978; Heimlich and Ogg, 1982; Spurlock and Clifton, 1982). Although pioneering, earlier efforts were constrained by limited sets of production alternatives or had severe, unrealistic restrictions on management practices (Taylor and Frohberg, 1977).

More complex analyses followed, utilizing more sophisticated hydrological models with more detailed information about current agricultural practices, a limited set of best management practices (BMPs), and the movement of agricultural nonpoint pollution to the edge of the field or the receiving body

(Park and Shabman, 1982; Crowder and Young, 1987). Vatn et al. (1997) used an integrated framework to analyze reduction of sedimentation and agricultural phosphorus pollution. More recently, integrated biophysical, economic models have been employed to evaluate economic instruments for reducing agricultural phosphorus nonpoint pollution with effluent taxes and conservation tillage subsidies (Westra, Easter, and Olson, 2002) and point-nonpoint pollution permit trading (Johansson, 2002).

Recent advances in field-scale agricultural modeling have allowed scientists to predict sediment and nutrient loadings to streams by incorporating within-field hydrological processes and watershed agricultural practices (Gowda et al., 1999a; Westra, Easter, and Olson, 2002). Zimmerman, Vondracek, and Westra (2003) combined these two advances by relating agricultural practices and sediment and nutrient loading to in-stream fisheries effects.

By extending such integrated analyses, this research contributes to the existing literature by examining how conservation efforts—through programs like CSP or CRP—address particular resource concerns such as sediment loss and in-stream fisheries populations, and estimating how such programs affect net farm income and conservation program payments. The linkages established in such integrated bioeconomic modeling help to determine if any measurable improvement has occurred in the resource concern (fisheries) in a watershed from the conservation practices and accompanying payments.

Braden et al. (1989), and Braden, Larson, and Herricks (1991), described how changes in production activities might affect habitat suitable for fish, but not specifically fish morbidity or mortality. Due to data and model limitations, Braden, Larson, and Herricks (1991) used only four seasonal, median soil loss estimates to evaluate policies for potentially reducing the adverse effects of agriculture on in-stream fisheries habitat. Such a level of abstraction or analysis for fisheries impacts yields inadequate understanding of the potential effect that one or two severe runoff events might have on fish communities.

Although the nonlinear nature of the impact of such biophysical processes has not been adequately addressed by previous empirical, economic analyses of conservation programs (Wu, 2003; Wu et al., 2004), the present study contributes to the literature by demonstrating how a set of these relationships could be modeled in an agricultural watershed. The ability to model acute and cumulative fisheries impacts from changes in agricultural practices has importance as a potential tool for: (*a*) measuring the effectiveness of performance-based conservation practices under programs like CSP; (*b*) establishing an effective total maximum daily load (TMDL) for agricultural watersheds (Vondracek, Zimmerman, and Westra, 2003); (*c*) modeling the effectiveness of conservation practices at addressing TMDLs; and (*d*) estimating the associated economic costs to agriculture in addressing TMDLs.

This study quantifies some of the potential economic costs or inefficiencies in terms of producer payments if performance-based or "green payments" conservation programs do not achieve the intended environmental improvements. We describe some other factors that may mitigate or attenuate the intended beneficial effects of conservation practices and suggest possibilities for addressing these resource concerns more cost-effectively.

An initial hypothesis of this study was that lethal and sublethal effects (as defined by Newcombe and Jensen, 1996) of suspended sediment on fish would decrease as CSP practices were adopted and targeted CRP cropland was enrolled in either of the two watersheds. It was also hypothesized that CSP practice payments, combined with program payments for CRP, would offset any decline in net farm income (NFI) associated with changing agricultural production practices in either watershed.

To evaluate these hypotheses, the following objectives were established:

- Estimate sediment loads from a field-scale biophysical process model, Agricultural Drainage and Pesticide Transport (ADAPT), to estimate watershed-scale effects in two watersheds (a coolwater stream and a warmwater stream);
- Quantify the effects of estimated suspended sediment concentrations and duration of exposure on fish assemblages;
- Estimate potential CSP payments for qualifying conservation practices and program payments for CRP targeted cropland;
- Integrate the geospatially referenced, biophysical information from simulated production activities, combined with production cost and return estimates, and practice and program payments, to create a bioeconomic positive mathematical programming model for analyzing baseline (current conditions) and CSP/CRP (conservation) scenarios;

- Use the bioeconomic model to compare the effects of suspended sediment concentrations on fisheries populations in the baseline with the conservation scenario;
- Use the bioeconomic model to compare the effects on net farm income (NFI) between the baseline and the conservation scenarios; and
- Use the bioeconomic model to estimate the economic program costs associated with the conservation scenario.

In the next section, the methodology is described. Information is presented about the two study areas, the representation of production activities, costs and returns for production activities, CSP and CRP payments, the biophysical process model (ADAPT), and the integrated bioeconomic model (a positive mathematical programming model). Following the methods section, results of the study are presented, with findings from the economic analysis, and biophysical and fisheries results. The paper ends with a discussion of the findings and concluding remarks.

Methodology

Conservation Programs and Payments

Under the provisions of the CSP, if a producer agrees to address one resource of concern on one portion of the farm over a five-year period, then the Tier I payment received would be 5% of the national cropland rental rate for 2001, plus up to 75% of the cost of implementing the practice. However, if a producer wishes to address one resource of concern on the entire agricultural operation over a 10-year period, then the Tier II payment received by the producer would be 10% of the national cropland rental rate for 2001, plus up to 75% of the cost of implementing the practices, plus any bonus payments deemed appropriate by the U.S. Department of Agriculture/Natural Resources Conservation Service (USDA/NRCS). Under Tier III, a producer addressing all resource concerns on the entire agricultural operation would receive payment at 15% of the national cropland rental rate for 2001, plus up to 75% of the implementation costs for these practices, plus any bonus payments USDA/NRCS deemed appropriate.

For this analysis, it was assumed producers would qualify for either Tier II or Tier III CSP payments. For Tier II CSP payments, a producer would address at least one resource concern, over a 10-year period, on the entire farm. If the U.S. nationwide cropland rental rate was used, then the annual Tier II payments would be \$7.10 per acre per year (10% of the 2001 U.S. nationwide annual cropland rental rate of \$71 per acre). A case for producers receiving Tier III CSP payments could be made if one assumes the resource concerns in the watershed were soil conservation, water quality, and the fisheries of the watershed. In this case, annual Tier III CSP payments would be \$10.65 per acre (15% of the 2001 nationwide cropland rental rate).

For calculating potential CSP payments, qualifying practices included the small grain-alfalfa hay rotation with conservation tillage and recommended fertilizer rates. Merely using conservation tillage in a corn-soybean rotation would not qualify for CSP payments. Thus, only land in the small grain-alfalfa hay rotation qualified for CSP payments. Because equipment used for this rotation was within the machinery complement of farmers in both watersheds, and most producers would possess the management skills needed to incorporate small grain and hay crops into their rotation, marginal costs of implementing these practices would be nonpositive or negligible. Therefore, no 75% cost-share payment for establishing the practice is included in this analysis. Results for both Tier II and Tier III CSP payments are presented below.

To complement the CSP working lands program, we examined how a continuous CRP targeted to land along streams would further reduce the amount of sediment lost at the edge of the field from reaching the streams in a watershed. With this in mind, land within 100 yards of stream banks that was cultivated under the baseline was assumed, for the conservation scenario, to be enrolled in the continuous CRP. To calculate the federal costs for land retirement, the 2001 statewide continuous CRP annual rental rate (\$87.24) was used.

Producers owning property within the Minnesota River Basin also may qualify for the Conservation Reserve Enhancement Program (CREP) if they meet certain eligibility criteria. Of the two study areas in this analysis, producers in the Chippewa watershed study area potentially could enroll the continuous CRP land in the CREP. For the federal component, CREP payments for 2001 statewide averaged \$107.68 annually for the life of the contract (at least 10 years). The state component of the CREP payment would increase this amount considerably. However, in this analysis, we use only the CRP rental rates. Therefore, the estimated economic effects under the conservation scenario for the

Chippewa watershed represent a lower bound on the conservation payments producers could potentially receive.

Estimating Production Expenses

Most variable or direct production expenses for all systems were estimated from information provided by producers in our farmer survey. Variable production costs for cropping systems, such as seed, fertilizer, agrichemicals, and machinery costs (fuel, oil, and repairs), and land rent were calculated from input levels obtained from the producer surveys. Using information on the machinery complement producers provided in their survey responses, machinery costs were estimated with procedures and data from Lazarus (2001). Direct or variable production costs for livestock operations included feed, hay, vitamin or mineral supplements, and veterinary expenses, among others. Among other details, livestock producers provided information on pregnancy, culling, calving, weaning, and death loss percentages, and stocking rates for pasture or intensively grazed paddocks.

Additional direct expenses, such as crop insurance, marketing, custom labor, and operating interest, and all fixed expenses or fixed costs such as depreciation, utilities, taxes, and any other economic costs, were estimated from data of comparable operations from the respective Farm Business Management Associations for the pertinent region in which the watershed was located—Southeastern Minnesota (Olson, Westman, and Nordquist, 2001; Farm Business Management, 2001a) and West Central Minnesota (Farm Business Management, 2001b). The data from the Farm Business Management Associations represented a large sample of producers (over 350 for some commodities) from which average overhead and fixed expenses could be calculated for all types of crop and livestock operations.

Any associated changes in costs resulting from changes in tillage and nutrient application rates were incorporated into the estimates of that farming system's production costs. Changes in production costs for conservation tillage practices were determined by adjustments to the machinery costs using machinery complement information from the producers and applying procedures consistent with data from Lazarus (2001). Estimated changes in production costs for adopting conservation tillage practices were comparable to those obtained by Olson and Senjem (1996) in similar regions of Minnesota. Production cost estimates from changes in nutrient application rates or methods were adjusted by the machinery complement used and quantity of fertilizer applied. As all producers surveyed in these two watersheds had the necessary equipment to transition to more small grains or hay in a crop rotation, no additional transition costs for purchase of additional capital equipment were assumed for the conservation scenario.

ADAPT Modeling

Representative farming systems were simulated using the ADAPT model (Desmond and Ward, 1996), a field-scale water table management model which combines GLEAMS (Leonard, Knisel, and Still, 1987) and DRAINMOD (Chung, Ward, and Schalk, 1992), for two reasons. First, ADAPT is able to model crop fields that have artificial drainage—a dominant feature of many fields in both watersheds. Other biophysical process models incapable of modeling artificial drainage would have overestimated the runoff and sediment losses from both watersheds. Second, ADAPT has been calibrated to several years of nutrient loss data from several experimental plots with similar farming systems and some of the same soils as those present in the watersheds and simulated for this research and analysis (Davis et al., 2000).

Both watersheds were disaggregated into their major soil associations to reflect the physical, chemical, and topological characteristics of the predominant soils. To represent differences in delivery ratios of sediments and nutrients, each soil association was divided into areas within 100 yards of water bodies ("close") and areas not within 100 yards of water ("distant") (Sharpley et al., 1999). Approximately 16 producers, representative of typical farming systems in each watershed, provided management information for their operations. With this information, we estimated production costs and returns and created input files for simulating biophysical processes. For each farming system, specific hydrology and erosion input files for ADAPT were created using data for the predominant STATSGO map units from the Map Unit Use File (MUUF) soils database.

Baseline conditions were determined by simulating current farming systems in both watersheds (tables 1 and 2). Alternative systems for the conservation scenario consisted of changes in tillage (conventional to conservation, for producers who currently used conventional tillage), reduction in

Table 1. Baseline Land Use Characteristics in Wells Creek and the Chippewa Watershed Study Areas

Land Use Description	WELLS CREEK (acres)	CHIPPEWA (acres)
Cultivated Land:		
Alfalfa hay conservation tillage	3,386	614
Alfalfa hay conventional tillage	2,153	835
Continuous corn conservation tillage	2,868	—
Continuous corn conventional tillage	825	—
Corn-soybean conservation tillage	7,116	10,168
Corn-soybean conventional tillage	8,185	20,321
Corn-sugar beets conventional tillage	—	4,000
Total Cultivated Land	24,533	35,938
Grassland or Pastureland:		
Pasture–dairy	3,104	666
Intensive grazing–dairy	163	35
Pasture–beef	740	2,623
Intensive grazing–beef	82	291
Total Grassland/Pastureland	4,089	3,615
Forest–Shrub–Grassland	10,430	2,667
Wetlands	52	381
Other	1,067	2,071
Total All Lands	**40,171**	**44,672**

Table 2. Baseline Livestock Characteristics in Wells Creek and the Chippewa Watershed Study Areas

	WELLS CREEK			CHIPPEWA		
Livestock Description	Intensive Grazing Animals	Non-intensive Grazing Animals	Total Animals	Intensive Grazing Animals	Non-intensive Grazing Animals	Total Animals
Cattle and Calves–Dairy:						
Dairy cows	120	2,273	2,393	4	85	89
Dairy heifers	87	1,662	1,750	3	63	67
Dairy steers	64	1,221	1,285	6	110	115
Total Dairy	271	5,156	5,428	13	258	271
Cattle and Calves–Beef:						
Beef cows	60	542	602	19	168	187
Beef heifers	44	396	440	14	126	140
Beef steers	32	291	323	24	218	243
Total Beef	136	1,229	1,365	57	512	570
Hogs:						
Hogs–sows			976			290
Hogs–others			7,650			4,142
Total Hogs			8,626			4,432
Other:						
Sheep			219			133
Lambs			133			165
Poultry			95			17,951

phosphorus and nitrogen fertilizer application rates (from a producer's current rate to University of Minnesota Extension Service recommended rates), and combinations of these. For this study, conservation tillage is defined as mulch-till, ridge-till, no-till, and strip-till farming, as well as reduced-till farming. Because this definition of conservation tillage includes reduced-tillage practices, it is broader than the same term as defined by the Conservation Tillage Information Center (CTIC). Nonetheless, our definition of conservation tillage practices does correspond to the set of crop residue management practices which result in at least 15% residue on cropland after planting (CTIC, 1999). Thus, for this study, conservation tillage systems have at least 15% residue remaining after planting on land following soybeans and at least 30% residue remaining after planting in the spring on land following corn. With conventional tillage, less than 15% residue remains after planting (CTIC, 1999).

Although the yields producers provided in the survey were used in most instances in the analysis, ADAPT was used to estimate how crop yields would change with conservation tillage. Estimated yield reductions (1%) for conservation tillage from ADAPT simulations conformed to observed data from Minnesota (Randall et al., 1996). Net returns for these alternative systems were adjusted to reflect the changes in crop yields.

Actual daily weather data (precipitation and temperature) over a 50-year simulation period (1950–1999) were obtained from weather stations in both watersheds from the Historical Data Retrieval and Climate Summaries online webpage.[1] Land cover, management practices for crops (rotations, nutrients, and tillage) and livestock, and location of the operation (county, township, and section), along with slope and soils data were overlaid with a Geographic Information System (GIS) to create data input files for the ADAPT simulations. The major soil associations in both watersheds were divided into areas roughly equivalent to fields termed "transformed hydrological response units," or THRUs (Gowda et al., 1999b). An ADAPT simulation was performed for each THRU, a hydrograph was developed for each subwatershed, and the hydrographs were combined and then routed to the outlet of each watershed to estimate the sediment delivered to the mouth of both streams. Thus, we could model how changes in farming practices influence edge-of-field soil loss, in-stream sediment concentration, and lethal and sublethal fisheries events.

For the baseline, crop acreage and livestock numbers from the *1997 Census of Agriculture* [USDA/National Agricultural Statistics Service (NASS), 1999a] were combined with the land use data to reflect the predominance and location of various production practices in the watershed. The number of acres for each simulated farming system was "expanded" using an area-weighted representation of that type of farming system in the watershed.

We defined base flow for both streams as the flow that was exceeded 90% of the time from daily stream gauge data (Payne, 2001). Base flow for the Chippewa River was 0.5 m^3/sec., while for Wells Creek it was 1.12 m^3/sec. The proportion of in-stream sediment concentration due to stream bank erosion was assumed to be 20% in Wells Creek (USDA/NRCS, 1998) and 40% in the Chippewa (Magner, 2001; Mulla, 2001). Bank erosion estimates were constant for both the baseline and conservation scenarios to separate the effects of land use on in-stream sediment concentrations from those due to stream bank stabilization. However, stream bank erosion likely would decrease when the area for riparian buffers with permanent cover along streams increased. Therefore, the estimated environmental benefits from the conservation scenario in either watershed most likely are conservative.

In-stream sediment concentrations (mg/L) were calculated based on estimates of daily sediment load, daily runoff, base flow for each stream, and the proportion of in-stream sediment due to stream bank erosion. Using this information, we quantitatively related the biological response of fishes to suspended sediment concentrations and duration of exposure in each stream using lethal and sublethal threshold values from Newcombe and Jensen (1996) and a procedure described by Zimmerman, Vondracek, and Westra (2003). The fish assemblages in the analysis included juvenile and adult salmonids (representing Wells Creek), and adult warmwater non-salmonids (representing the Chippewa).

Integrated Bioeconomic Model

Using information from the biophysical simulation results from ADAPT as technical coefficients of nonpoint "outputs" combined with the cost and returns estimates for the various farming systems (current and alternative), we defined the objective function of the bioeconomic model as maximizing net farm income in the watershed:

[1] Webpage: http://climate.umn.edu/doc/historical.htm.

$$(1)\quad \text{Max}\ \Pi(t, m; f, s, e) = \sum_{e}^{E}\sum_{s}^{S}\sum_{f}^{F}\left(\sum_{c}^{C} q_{cfse}p_c - \sum_{n}^{N} x_{cfse}w_n - FC_{fse} + GP_{fse}\right)a_{fse}$$

subject to:

$$(2)\quad \sum_{f}^{F} a_{fse} \le A_{fse} \times (1.025),\ \ \forall f, s, e,$$

$$(3)\quad \sum_{f}^{F} a_{fse} \ge A_{fse} \times (0.975),\ \ \forall f, s, e,$$

$$(4)\quad \sum_{s}^{S}\sum_{f}^{F} a_{fse} \le \sum_{f}^{F} A_{fse},\ \ \forall f, s, e,$$

$$(5)\quad \sum_{e}^{E}\sum_{s}^{S}\sum_{f}^{F} a_{fse} \ge \sum_{s}^{S}\sum_{f}^{F} A_{fse} \times (0.975),\ \forall e, t = 2,$$

$$(6)\quad a_{fse} \ge 0,\ \ \forall f, s, e,$$

where, for each activity, t is tillage system; m is nutrient (nitrogen and phosphorus) management; f is field within the soil association-water proximity combination; s is soil association; e is proximity to water within the soil association; a_{fse} is acres of production activity; A_{fse} is acres of production activity estimated to be present for the baseline (using data described above); q_{cfse} is quantity of output c from each activity (including sediment, nitrogen, and phosphorus outputs, c_s, c_n, and c_p, respectively); p_c is price of output c; x_{nfse} is variable input n used for each activity; w_n is price of variable input n; FC_{fse} are fixed costs for each activity; and GP_{fse} are government commodity program payments for each activity.

For the alternative farming systems, a_{fse} is equal to zero in the baseline to reflect the fact that these activities for specific producers in specific regions of the watershed are not happening currently. Output prices were average marketing year prices for six years (1992–1997) for Minnesota (USDA/NASS, 1999b). Although the output prices (damage costs) for potential pollutants such as sediment, nitrogen, or phosphorus were assumed to be zero, these physical outputs were included for physical accounting purposes and as an indication of the multi-product production process of many agricultural systems.

To reflect the baseline distribution of cropping activities, the objective function (1) was subject to constraints (2) through (6). In equations (2) and (3), land was constrained at the field level within each soil association-water proximity combination to no more than 102.5% or less than 97.5% of observed levels, respectively. Equation (4) constrained the total cropland used in each region (soil association-water proximity combination) to no more than 100% of the total land estimated to be available for cultivation in each region. With equation (5), current conservation tillage ($t = 2$) acreage was constrained to be no less than 97.5% of observed levels for land close to and distant from water in the watershed. Due to the disparate sources of data used in the analysis, an error margin of 2.5% for equations (2), (3), and (5) allowed for a feasible solution to the baseline model. Equation (6) constrained all activities to nonnegative levels.

After the baseline model results were obtained, the conservation scenario was modeled, again with an objective function of maximizing net farm income in the watershed:

$$(7)\quad \text{Max}\ \Pi(t, m; f, s, e) = \sum_{e}^{E}\sum_{s}^{S}\sum_{f}^{F}\left(\sum_{c}^{C} q_{cfse}p_c - \sum_{n}^{N} x_{cfse}w_n - FC_{fse} + GP_{fse} + CSPII_{fse} + CSPIII_{fse} + CRP_{fse}\right)a_{fse}$$

subject to:

$$(8)\quad \sum_{f}^{F} a_{fse} \le A^{*}_{fse},\ \ \forall f, s, e,$$

$$(9)\quad \sum_{f}^{F} a_{fse} = A^{*}_{fse},\ \ \forall f, s, e, t = 2,$$

$$(10)\quad \sum_{f}^{F} a_{fse} = A^{*}_{fse},\ \ \forall f, s, e, m = 3,$$

$$(11)\quad \sum_{f}^{F} a_{fse} = A^{*}_{fse},\ \ \forall f, s, e = 1,$$

$$(12)\quad a_{fse} \ge 0,\ \ \forall f, s, e,$$

where, in the conservation objective function (7), $CSPII_{fse}$ is the Tier II Conservation Security Program payment for each qualifying system, $CSPIII_{fse}$ is the Tier III Conservation Security Program payment for each qualifying system, and CRP_{fse} is the Conservation Reserve Program payment for each system selected for CRP.

The field acreage levels for current and alternative systems are constrained by equation (8) to the acres estimated to be present for the corresponding baseline system from the baseline model solution,

A^*_{fse}. With constraint (9), each system is restricted to conservation tillage ($t = 2$), except for sugar beet systems, for which there is no conservation tillage alternative. To receive CSP payments, producers would need to use recommended levels of phosphorus and nitrogen [$m = 3$ in equation (10)]. To be eligible for CRP payments [equation (11)], all land within 100 yards of any stream or river within the watershed ($e = 1$) is required to be planted to grass (buffer strips) or trees (riparian buffers). Nonnegative activity levels are required in the conservation scenario [equation (12)].

To analyze the impact of conservation practices on one or more resource concerns to people within a watershed or river basin, an integrated approach is necessary. This approach links the effects of farmer production decisions at the field level, in response to conservation policies and programs, with watershed-scale impacts on sedimentation, water quality, and fisheries communities. The methodological approach we use contributes to the existing literature by capturing ecological threshold effects and creating linkages between managed systems and ecosystems. These linkages are essential in analyzing or designing conservation policies that address critical resource concerns (Wu, 2003).

Study Areas

Of the two study areas, the first is a subwatershed of the Chippewa River drainage, located primarily in Chippewa County, with a small section in Swift County in western Minnesota (figure 1). The Chippewa River is classified as a warmwater river, with a diverse fish assemblage and a temperature range of 23EC to 26EC in August [Minnesota Department of Natural Resources (MNDNR), 1998]. This 44,672-acre watershed is relatively flat (slopes of 1–2%) with moderately to very poorly drained soils and extensive artificial tile drainage systems. This watershed mostly is in row-crop agriculture, with 81% of the land area under cultivation, 8% in grassland or pasture primarily for beef cattle, and 5% forested (tables 1 and 2). Almost all of the cultivated land is under a corn-soybean rotation, with some land in sugar beets, and approximately 1,400 acres in small grains with hay (USDA/NASS, 1999a). Based on data from the Conservation Tillage Information Center (CTIC, 1999), approximately 30% of cropland in Chippewa County is under some form of residue management or conservation tillage system.

The second study area is Wells Creek, which has steeply sloped (6–40% slope), well-drained soils in Goodhue County of southeastern Minnesota (figure 1). The stream has historically supported a coolwater fish assemblage, with low species diversity and naturally reproducing brown trout *Salmo trutta* populations (MNDNR, 1999). This 40,171-acre watershed has a significant agricultural presence with 61% of the total watershed area under cultivation, 10% is in grassland or managed pasture primarily for dairy cattle, and 26% of the watershed is forested, mainly on steep slopes and riparian areas (tables 1 and 2). Data from the *1997 Census of Agriculture* (USDA/NASS, 1999a) for Goodhue County indicate the majority of cultivated land is under a corn-soybean rotation, followed by small grain-hay rotations with some land in corn-small grain-hay rotation. Approximately 55% of cultivated land was under some type of conservation tillage in Goodhue County (CTIC, 1999).

Results

Economic Findings

Under the conservation scenario, we estimated annual total revenue (TR) decreased by $426,643, while annual total costs (TC) declined by $410,417 in Wells Creek (table 3). As a result, annual net farm income (NFI) (without CSP or CRP payments) declined by less than $17,000 (1%) from the baseline when certain CSP-eligible agricultural practices were implemented throughout the watershed. In the Chippewa, total revenue decreased by $302,114, but estimated total costs declined by $274,523. Consequently, annual net farm income declined by less than $28,000 (3%) when certain agricultural practices (conforming to the provisions of the CSP) were implemented throughout the Chippewa study area.

Tier II CSP payments (CSP II) in the Wells Creek watershed were estimated to be $35,457 annually. Including Tier II CSP payments increased NFI in the conservation scenario by 1% over the baseline. If Tier III CSP payments (CSP III) of $53,186 were received by producers in the Wells Creek watershed, annual NFI in the conservation scenario increased by 2% above the baseline.

By contrast, in the Chippewa, potential CSP II payments were only $9,237 annually. Thus, in the conservation scenario, NFI remained 2% below baseline levels in the Chippewa (table 3). Potential CSP III payments in the Chippewa were less than $14,000 annually. Hence, adding Tier III CSP payments to NFI in the conservation scenario still resulted in estimated income which was 2% below baseline levels.

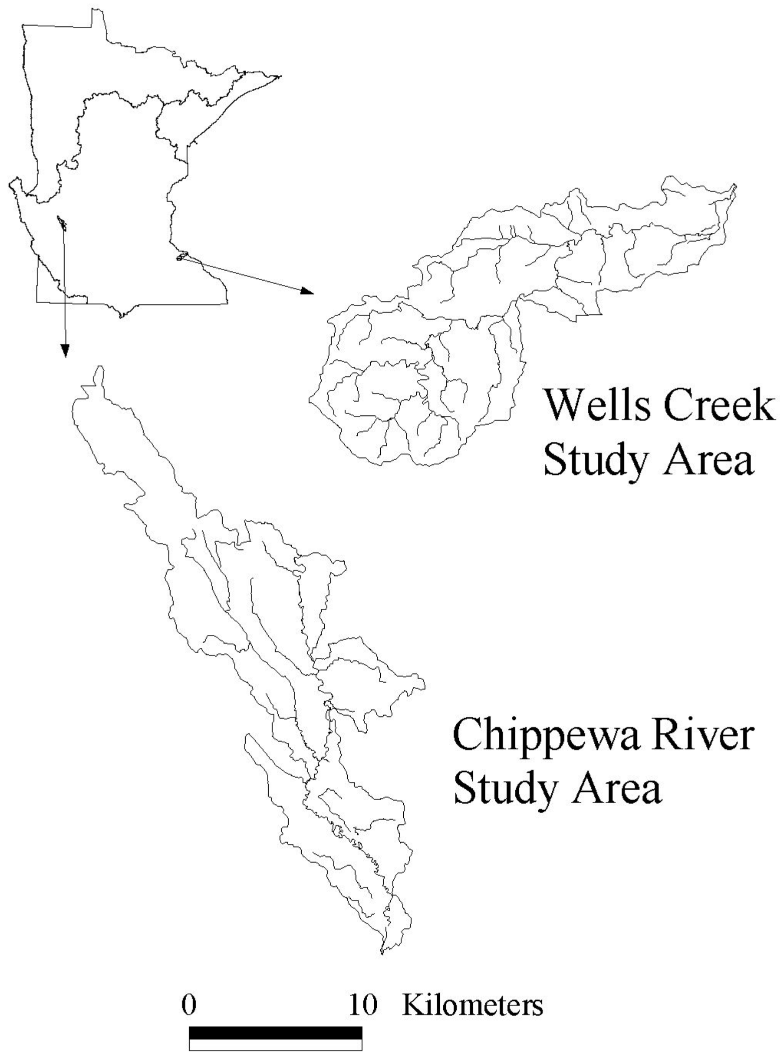

Figure 1. Map showing locations of two Minnesota watershed study areas

Table 3. Economic Results of Baseline and CSP/CRP (Conservation) Scenarios, With and Without Potential CSP and CRP Payments (modeling period = 18,263 days)

	Wells Creek				Chippewa			
			Annual Difference				Annual Difference	
Description	Baseline ($/year)	CSP/CRP ($/year)	Absolute	Percent	Baseline ($/year)	CSP/CRP ($/year)	Absolute	Percent
Total Revenues (TR)	15,568,605	15,141,962	!426,643	!3%	10,081,231	9,779,117	!302,114	!3%
Total Costs (TC)	13,521,781	13,111,364	!410,417	!3%	9,201,615	8,927,092	!274,523	!3%
CSP Payments:								
Tier II (CSP II)		35,457				9,237		
Tier III (CSP III)		53,186				13,856		
CRP Payments (CRP)		119,170				76,684		
Net Farm Income (NFI) = TR − TC	2,046,824	2,030,598	!16,226	!1%	879,616	852,025	!27,591	!3%
NFI + CSP II	2,046,824	2,066,055	19,231	1%	879,616	861,262	!18,354	!2%
NFI + CSP III	2,046,824	2,083,784	36,960	2%	879,616	865,881	!13,735	!2%
NFI + CSP II + CRP	2,046,824	2,185,225	138,401	7%	879,616	937,946	58,330	7%
NFI + CSP III + CRP	2,046,824	2,202,954	156,130	8%	879,616	942,565	62,949	7%

Table 4. Biophysical and Fisheries Results of Baseline and CSP/CRP (Conservation) Scenarios (modeling period = 18,263 days)

	Wells Creek				Chippewa			
			Annual Difference				Annual Difference	
Description	Baseline	CSP/ CRP	Absolute	Percent	Baseline	CSP/ CRP	Absolute	Percent
Sediment (tons/year)	39,615	27,334	!12,281	!31%	2,000	1,500	!500	!25%
Nitrogen (pounds/year)	3,001	1,891	!1,110	!37%	13,966	11,592	!2,374	!17%
Phosphorus (pounds/year)	7,542	3,620	!3,922	!52%	5,108	3,065	!2,043	!40%
Sediment delivered (days/50 years)	1,729	1,632	!97	!6%	2,590	2,404	!186	!7%
Mean in-stream sediment concentration (mg/L)	1,174	872	!302	!26%	380	476	96	25%
Lethal fish events (mean no./year)	5	2	!3	!63%	11	11	—	0%
Sublethal fish events (mean no./year)	30	31	1	3%	41	37	!4	!9%

In the conservation scenario, cropland currently cultivated that was within 100 yards of water bodies was assumed to be eligible for and enrolled in the continuous CRP. Total program payments for CRP were calculated by using the acreage identified in the integrated bioeconomic analysis and the statewide CRP annual rental rates for 2001 enrolled acres (a proxy for CRP contract rates) (table 3). In Wells Creek, by combining CRP payments (approximately $119,000 annually) with the NFI and the CSP Tier II or Tier III payments, producer income increased in the conservation scenario by 7–8% above baseline levels. Similarly, in the Chippewa, when the annual CRP payments of almost $77,000 were added to the NFI and CSP payments, watershed-wide income for producers increased by 7% above baseline levels.

Biophysical Outcomes

Of the total 18,263 days over the modeling period, sediment loading decreased from 2,590 days to 2,404 days in the Chippewa, compared to a decline from 1,729 days to 1,632 days in Wells Creek, for the baseline and conservation scenarios, respectively (table 4). The average duration of runoff events was longer in the Chippewa than Wells Creek, which resulted in longer average exposure times to suspended sediment for fish in the Chippewa watershed. Water runoff in both watersheds decreased slightly under the conservation scenario (a 3% reduction from the baseline in Wells Creek, and a 1% reduction from the baseline in the Chippewa). On days when sediment loading occurred, mean sediment concentration was higher in Wells

Creek than in Chippewa for both the baseline and the conservation scenarios (table 4). The mean in-stream sediment concentration in Wells Creek declined when comparing the baseline to the conservation scenario (1,174 mg/L to 872 mg/L). Counterintuitively, in the Chippewa, mean sediment concentration increased from the baseline to the conservation scenario (380 mg/L to 476 mg/L) (table 4).

In Wells Creek watershed, annual sediment loading decreased by 31% with CSP-eligible agricultural practices from the estimated baseline load of 39,615 tons (table 4). Nitrogen loss decreased by 37% from the baseline load of 3,001 pounds annually, and phosphorus loss declined by 52% from the estimated baseline load of 7,542 pounds annually under the conservation scenario in Wells Creek. In the Chippewa subwatershed, an estimated 2,000 tons of sediment reaches the main stem of the Chippewa River annually. This load decreased under the conservation scenario by 25%. Under the conservation scenario, nitrogen loss declined by 17% (from an estimated 13,966 pounds annually to 11,592 pounds), and phosphorus loss decreased by 40% (from an estimated 5,108 pounds annually to 3,065 pounds).

Fisheries Effects

Mean sediment concentrations for both streams and both scenarios were above the threshold for sublethal effects to fish, but were not lethal if exposure at these concentrations was for one day or less. The mean annual number of days with lethal sediment concentrations to fish was considerably higher in the Chippewa than Wells Creek for both scenarios (baseline and conservation). The mean number of days per year with lethal sediment concentrations to fish remained unchanged in the Chippewa (11 days for both the baseline and the conservation scenarios) (table 4). However, the mean number of days per year with potentially lethal fisheries events declined significantly in Wells Creek (5 days to 2 days for the baseline and the conservation scenarios, respectively) ($p < 0.0001$). In Wells Creek, lethal fish effects were estimated to decline from the baseline by over 60% with the conservation scenario.

The mean annual number of days with sublethal sediment concentrations was somewhat higher in the Chippewa than Wells Creek. Mean sublethal events in the Chippewa decreased slightly from baseline to the conservation scenario (41 to 37 days per year). Counterintuitively, the number of sublethal events in Wells Creek increased with CSP practices (30 to 31 days per year), although this result was not statistically significant (table 4).

Discussion

Conservation programs, such as the Conservation Security Program (CSP) or the Conservation Reserve Program (CRP), are designed to address resource concerns. Although the resource concerns of these two programs might not be identical, they both were designed to address, among other things, sedimentation and water quality. Beyond reducing sedimentation from farming, the CSP is designed to reward producers for using practices that actually improve water quality and fisheries communities, where these are the particular resource concerns. However, little research has examined whether in practice these programs actually achieve the desired results. For example, Braden et al. (1989), and Braden, Larson, and Herricks (1991), evaluated how conservation practices potentially affect fisheries habitat, but not fisheries communities. Most research efforts have not captured the threshold effects or impact that acute episodes of sedimentation may have on aquatic organisms such as coolwater or warmwater fisheries.

To adequately address this question, it is essential to establish the linkages from the conservation policy or program through the producer's management decision-making process to the subsequent biophysical effects on the environment. Modeling the process in this way is critical to assisting policy makers in understanding the impacts of the policy. Furthermore, tools such as these integrated bioeconomic models may assist agency staff (for example, at USDA/NRCS) in determining how effective conservation practices are at improving the targeted resource. As a result of analyses such as these, it is apparent that for performance-based programs to work properly, much modeling or monitoring of production practices and impacts on the eventual, intended resource will need to occur.

The results indicate, at least in certain watersheds, beneficial effects on fish assemblage might be achieved with relatively minimal adverse effects on agricultural production and net farm income. "Green payments" of CSP alone or in combination with CRP might provide producers sufficient compensation (for potential loss of income) to address their local resource concerns.

In Wells Creek, slightly more than 5% of row-crop acreage was converted to grass riparian buffers under the conservation scenario. On the remaining working lands, there was a net increase of almost 1,800 acres of cropland planted to small grain-alfalfa hay rotations with conservation tillage. Changing land management practices, and retiring riparian cropland areas, reduced net farm income by less than 1% per year from baseline levels. Another way to interpret these findings is that producers in Wells Creek would have needed to receive an additional $16,000 annual compensation (under CSP) to be as well off as they are now. Under the conservation scenario, potential producer payments greatly exceeded this amount—$35,000 and $53,000 annually for CSP II and CSP III, respectively. Adding the potential CRP payments of $119,000 annually demonstrates how producers potentially receive sufficient compensation to offset any reductions in current farm income by participating in either the CSP or CRP.

Although the fisheries effects differed from Wells Creek, in the Chippewa study area the economic impacts were similar. When producers used conservation practices (CSP) and riparian cropland was retired (CRP), annual total costs decreased, but total revenues decreased slightly more. Consequently, net farm income was reduced in this subwatershed by 3% annually from baseline levels. For producers to be as well off under this conservation scenario, they would need to receive approximately $28,000 annually for lost income. Results of the analysis demonstrate that CSP payments alone are insufficient to compensate producers for this income loss. However, when producers are compensated for retiring riparian cropland with CRP payments, producer income in the conservation scenario in the Chippewa exceeds the baseline level by $58,000–$63,000 annually, depending on the combination of programs analyzed (table 1).

Unfortunately, in the Chippewa, the anticipated beneficial effects on the fisheries population from conservation programs did not materialize. Although estimated edge-of-field sediment losses were reduced by 25% from the baseline in the conservation scenario, there was no discernable improvement in the fisheries, despite potential program payments exceeding $100,000 annually. Decreases in suspended sediment were less evident in the Chippewa River as land use changed, likely due to other factors controlling runoff patterns, differences in the tolerance of warmwater fish species to suspended sediment compared to salmonids, and the interaction of these factors with land use effects. Another potential factor is that the Chippewa River has a much greater proportion of suspended sediment input from stream bank erosion than Wells Creek (Mulla, 2001). Although stream bank erosion in the Chippewa would likely be reduced with decreased surface runoff, we kept the proportion of sediment from stream bank erosion constant throughout all scenarios for both streams. The geophysical differences between the two study areas and tolerance levels of their respective fish communities account for much of the response of the fish communities under the conservation scenario.

Effects of land use practices on fish assemblages, as well as on patterns of sediment and runoff, depended on (among other things) the physical attributes of the watershed. The mean number of days with lethal and sublethal sediment concentrations was higher in the Chippewa than in Wells Creek. This difference is likely a function of the combined influences of differences among fish assemblages (coolwater versus warmwater), land use practices, topography, and soils between the two watersheds. In general, for exposures exceeding one day, the warmwater fish assemblage in the Chippewa was more sensitive to sediment concentrations than the coolwater assemblage in Wells Creek. Sediment concentrations were often lower in the Chippewa River watershed than those in Wells Creek, but were delivered for a longer duration. Thus, the duration of sedimentation exposure was more critical in the Chippewa.

The concentration of suspended sediment in a stream on any given day is a product of several factors, including land use practice, soil type, vegetative cover, topography, precipitation, and time of year (Wood and Armitage, 1997). Whereas physical differences such as soil type, topography, and precipitation amounts and timing likely contributed to differences in suspended sediment concentrations between watersheds, land use was varied in our analysis to examine how implementing certain CSP-compliant practices would affect suspended sediment concentrations and fish assemblages in watersheds with different physical attributes. The results revealed that although the implementation of conservation practices played an important role in controlling the amount of sediment reaching a stream, interactions between land uses, the complexities and biological attributes of the fish assemblage in a stream, and physical properties of a watershed ultimately determine the degree of change within a watershed that needed to occur to have a measurable effect on the fisheries. Thus, physical and physiological characteristics and processes of the watershed and the biological complexities of aquatic ecosystems may diminish some of the potential environmental benefits when farmers use conservation practices.

In Wells Creek watershed, the steeply sloped, well-drained soils allowed runoff to rapidly reach the stream, resulting in a pattern of peaks of high sediment concentrations that quickly subside. In contrast, the relatively flat, moderately to very poorly drained soils of the Chippewa watershed take more time to drain. Paradoxically, this leads to a greater number of days and more protracted periods with runoff, although sediment concentrations are generally lower. Hence, the relatively flat topography influences runoff patterns in the watershed, which may explain why the Chippewa River watershed with less annual rainfall than Wells Creek had more consecutive days with measured runoff.

In summary, although our modeling exercise did not aim to accurately predict the number of days that exceeded lethal or sublethal thresholds for the fish assemblage in either stream, or absolute differences between the scenarios or between study areas, it did allow us to examine overall trends with respect to land use change in response to performance-based conservation practices. Thus, although we would not expect to observe this exact response of fish populations if these scenarios were to be implemented as a field experiment, the model does suggest a significant positive environmental response in the fish community in Wells Creek under the conservation scenario, whereas such an improvement is not as evident in the Chippewa.

From a policy perspective, these results highlight the importance of identifying the intended resource concerns and targeting conservation practices and payments to address them. In the instance of Wells Creek, conservation measures tailored to increasing residue management and targeting riparian buffers and grassed waterways in steeply sloped areas of the watershed may achieve the most environmental benefits for the conservation dollars spent. On the other hand, in a relatively flat landscape like the Chippewa, conservation efforts and program dollars might be targeted more efficiently at creating grass buffers around tile drain inlets or creating artificial wetlands in appropriate areas to trap or filter sediments before entering streams, as opposed to encouraging and implementing conservation tillage practices on a large scale.

This research can be extended in several ways. By using an integrated bioeconomic model, other conservation programs designed to address various resource concerns can be analyzed. Such programs might include water quality trading systems to address TMDLs or programs like the Environmental Quality Incentives Program (EQIP) designed to address, among other things, concerns about potential nutrient runoff from livestock or confined animal feeding operations (CAFOs).

Another extension of this research would be the development of a dynamic aspect to these integrated bioeconomic models. This would enable researchers to analyze some of the temporal dimensions or long-term consequences of nonpoint pollution. For example, we might someday have a better understanding of how long it takes conservation practices enacted today in Minnesota or Iowa to reduce the hypoxic zone in the Gulf of Mexico, and in turn assess how this affects shrimp populations and shrimp landings.

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