Bulletin No. 687

Controlling Erosion and Nonpoint Source Pollution in Idaho's Tom Beall Watershed

Tony Prato, Hong-Qi Shi, Ron Rhew and Merlyn Brusven

Agricultural Experiment Station

University of Idaho

College of Agriculture

Controlling Erosion and Nonpoint Source Pollution in Idaho's Tom Beall Watershed

Tony Prato, Hong-Qi Shi, Ron Rhew and Merlyn Brusven

Soil erosion and nonpoint source pollution are serious problems for the nation and Idaho. In 1982, sheet, rill and wind erosion on nonfederal rural land claimed 5.4 billion tons of soil. Of this amount, 4.3 billion tons or 80 percent occurred on cropland. About 173 million acres or 41 percent of the nation's 421 million acres of cropland eroded at rates exceeding the soil loss tolerance or T value, and 718 million acres or 28 percent had an EI value greater than or equal to eight.[1] In Idaho in 1982, more than 50 million tons of soil were lost from 6.4 million acres of cropland through sheet, rill and wind erosion. Of this cropland, 3.7 million acres or 58 percent eroded in excess of T and 2.6 million acres or 41 percent had an EI value greater than or equal to eight (USDA 1987).

Agricultural runoff laden with sediment and nutrients is a major source of nonpoint source pollution (NSP). Nationally, about 46 percent of the sediment, 47 percent of the total phosphorus and 52 percent of the total nitrogen discharged into U.S. waterways comes from agricultural sources (Gianessi et al. 1986). Nitrogen and phosphorus in agricultural runoff result from extensive application of fertilizer. About 85 percent of Idaho's water quality problems have been attributed to nonpoint sources (Moore 1987).

Soil erosion has reduced crop productivity by an estimated $1.3 billion per year (Alt and Putman 1987). Nonpoint source pollution from soil erosion impairs beneficial uses of water and increases the costs of municipal water treatment, flood protection and maintenance of navigation channels, irrigation systems and reservoir storage capacity. It also degrades fish spawning and rearing habitat, reducing fish populations and the net economic value of commercial and recreational fisheries. Damages from agricultural NSP have been estimated at between $2 and $6 billion, with a most likely estimate of $3 billion (Ribaudo 1986).

The effectiveness of measures for controlling cropland erosion and NSP varies with cropping pattern, climate, topography and farming methods. In one national study, the offsite economic damages from cropland erosion were found to range between $0.54 per ton of erosion in the Northern Plains to $6.14 per ton in the Northeast (Ribaudo 1987).

The Palouse region of eastern Washington and northern Idaho is one of the most productive dryland wheat-producing regions of the world. Due to steeply sloped landscape and the occurrence of major storm events during periods of low residue cover, soil erosion on Palouse cropland exceeds 11 million tons per year (USDA 1984). For this reason, the Soil Conservation Service (SCS) has targeted the Palouse region as a critical area for controlling erosion and water quality degradation (USDA 1985, Duda 1985).

Objectives

A better understanding of the relationships between resource management systems (RMS), soil erosion and NSP in dryland watersheds would improve the ability of resource managers to control erosion and NSP in the Palouse.[2] The primary objective of this study is to develop and test procedures for determining economically efficient and environmentally acceptable RMSs for controlling soil erosion and NSP in Idaho's Tom Beall Watershed. Specific objectives are:

1. To develop a computer-based system for estimating soil erosion and runoff on individual fields and the associated water quality impacts of alternative RMSs.
2. To estimate erosion and the delivery of sediment and nutrients to receiving waters for current land uses and to identify areas in the watershed that account for high rates of soil erosion.
3. To determine economically efficient RMSs for reducing total erosion and NSP.

---

[1] EI=RKLS/T where RKLS are the site specific erosion factors in the Universal Soil Loss Equation (USLE). An EI greater than or equal to eight defines highly erodible land in the conservation provision of the Food Security Act of 1985.

[2] An RMS is a combination of crop rotation, tillage method and land treatment practice.

Review of Literature

Current research is inadequate for determining the economic impacts of reducing erosion and NSP in the Palouse. First, while national research has demonstrated the importance and extent of cropland erosion and NSP (Pavelis 1985, Ribaudo 1986, Strohbehn 1986), results of such research are of limited value in determining efficient RMSs to control erosion and NSP in particular watersheds.

Second, no previous studies have attempted to determine economically efficient RMSs for controlling soil erosion on individual farms and reducing sediment and nutrient pollution in a dryland watershed in Idaho. One study of agricultural water pollution abatement in Idaho did not explicitly consider the link between the application of RMSs and improvements in water quality (e.g., Idaho Soil Conservation Commission et al. 1987). Rather, it was implicitly assumed application of RMSs that reduce erosion rates to soil loss tolerances would result in acceptable water quality. Several studies have evaluated the cost effectiveness of alternative end-of-field treatments for reducing sediment and/or nutrient pollution of water (Fitzsimmons et al. 1978, Lindeborg et al. 1975, Walker et al. 1986). All three of these studies were conducted in irrigated areas, and none included the on-site productivity benefits of erosion control in the economic evaluation of practices.

Third, previous studies of best management practices (BMP) for northern Idaho's dryland farming region have been confined to representative farms or fields and have ignored the on-site and water-quality benefits of BMPs (Brooks and Michalson 1983, Berglund and Michalson 1980, Harker and Michalson 1978). Thomas et al. (1985) evaluated sediment pollution for alternative land treatments in the Mission Creek Watershed in northern Idaho. Treatment units were very large, sediment delivery rates were assumed to be a fixed proportion of erosion rates and constant for all acreage in a treatment unit, and nitrogen and phosphorus pollution were not considered. Another study used gross sediment delivery ratios for six major land uses in three northern Idaho sub-basins to estimate sediment delivery to Lower Granite Reservoir (USDA 1986).

Integrated assessments of erosion and water quality have been made in other states. Crowder et al. (1984) applied the CREAMS model to determine those conservation practices that maximize net farm income on a Pennsylvania dairy farm. Crowder and Young (1985) applied CREAMS to typical fields in the Conestoga Headwaters RCWP to determine the soil, nutrient and chemical losses associated with various conservation practices. Cost effectiveness of these practices was also evaluated. Neither study was at the watershed level because CREAMS is a field-scale model. Frevert and Crowder (1987) used the Agricultural Nonpoint Source (AGNPS) pollution model to evaluate potential water quality improvements from implementing alternative BMPs on dairy farms located in a Vermont watershed.

Finally, Braden and Johnson (1985) developed the SEDEC model to identify land management practices that minimize the cost of reducing sediment deposition in a small agricultural watershed. Their study accounted for the long term productivity benefits of soil erosion but not NSP.

Resource Problems In Lapwai Drainage

In 1981, the SCS identified the Palouse and Camas regions of northern Idaho and associated streams as having severe erosion and water quality problems (USDA 1981). The lower Clearwater River and its principal tributaries, Potlatch Creek and Lapwai Creek, were included in this problem area. Lapwai Creek is a tributary of the Clearwater River, located about 12 miles upriver from the confluence of the Snake and Clearwater Rivers at Lewiston. Lapwai Creek is a fourth order stream. Mission Creek and Sweetwater Creek are the two primary tributaries of Lapwai Creek (Fig. 1).

The Lapwai drainage lies primarily within the Nez Perce Indian Reservation in Nez Perce County. Portions of the headwaters of Lapwai Creek lie in Lewis County. The watershed is a multiple use drainage of about 200,000 acres. Precipitation in the watershed averages 12.3 inches per year with seasonal maximums occurring in February and March (Kucera et al. 1983). Annual temperatures range from a minimum of 25.7°F in January to a maximum of 89.4°F in July. Principal crops grown in the watershed include winter wheat, barley, peas and forage crops.

The intensive farming methods employed in the Lapwai drainage have caused significant topsoil erosion, runoff and NSP. Approximately two-thirds of the agricultural land in the Lapwai drainage is classified as highly erodible, making it subject to the conservation compliance provision of the Food Security Act of 1985 (Shi 1987). Erosion and runoff from these lands have degraded water quality and reduced beneficial uses of water in the Lapwai drainage. Based on Idaho standards, water quality in Lapwai Creek is marginal with high seasonal turbidity and sediment-nutrient concentrations (Thomas et al. 1985). Poor riparian management has contributed to increased water temperatures from direct solar gain, lack of riparian vegetation which serves as a sediment trap and poor wildlife habitat (Thomas et al. 1985).

Part of the sediment originating in Lapwai drainage is transported to the Clearwater and Snake rivers and deposited in the Port of Lewiston and Lower Granite Reservoir. Although the amount of sediment which Lapwai Creek delivers to these sites is unknown, about 45 percent of the annual sediment load in Lower Granite Reservoir originates in the Clearwater River sub-basin. The Port of Lewiston is trapping much of the sediment that used to pass through to the Columbia River. This has necessitated dredging of the Snake River in the

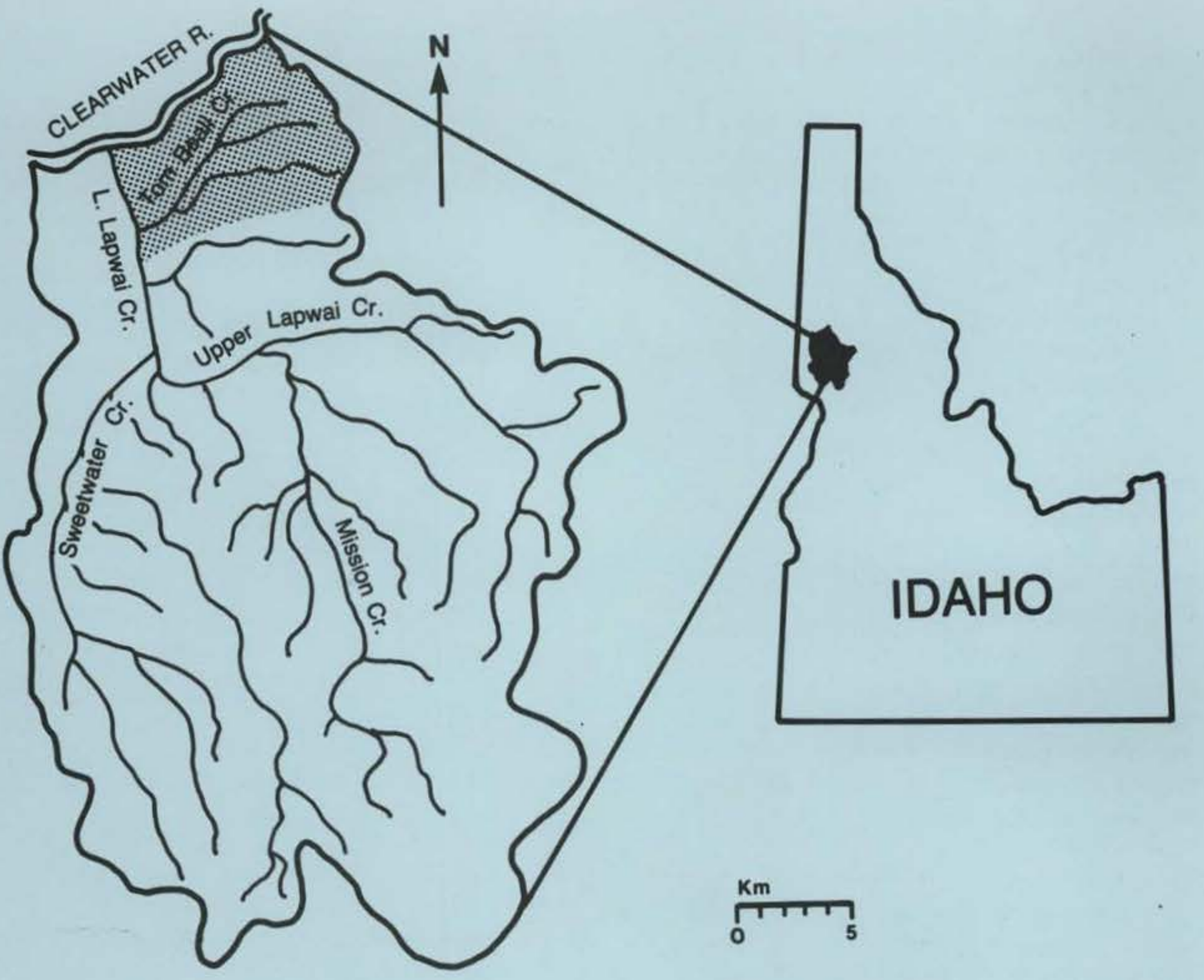

Fig. 1. Tom Beall Creek Watershed in Lapwai drainage.

Lewiston area to maintain the navigation channel and the freeboard needed for flood protection in Lewiston.

In the last 2 years, the U.S. Corps of Engineers has spent in excess of $4.5 million on dredging operations at Lewiston and Clarkston. Sediment deposition in Lower Granite Reservoir, located 25 miles down the Snake River from Lewiston, has reduced water storage capacity for hydroelectric power generation and increased wear and tear on turbine generators. This sediment will eventually have to be removed to avoid losses in hydroelectric generating capacity at Lower Granite Dam.

High sediment loads have also increased the cost of municipal water treatment in Lewiston and Clarkston, and industrial water use by Potlatch Corporation. NSP caused by cropland erosion in the Lapwai drainage is also degrading aquatic ecosystems and fish spawning and rearing habitat which can negatively impact fish populations. The impacts on the anandromous fishery (steelhead trout and chinook salmon) are potentially significant because these species constitute an important economic, recreational and cultural resource for the region.

Study Area

Tom Beall Watershed is located in the Lapwai drainage (Fig. 1). The mainstem of Tom Beall Creek is formed by the confluence of the north and south forks, 1.5 miles east of Tom Beall's confluence with Lapwai Creek. The creek is projected to flow at 2,029 cubic feet per second and has a runoff volume of 0.71 inches during a 25-year, 24-hour storm event. The watershed contains 11,267 acres of cropland and grazing land in the following categories:

Land use	Acres	Percent
Pasture/grass/hay	3,361	29.8
Winter wheat	3,259	28.9
Fallow	2,062	18.3
Spring peas	1,412	12.5
Spring barley	580	5.1
Austrian winter peas	202	1.8
Lentils	149	1.3
Winter barley	106	0.9
Turnips for seed	80	0.7
Grass for seed	56	0.5
Totals	11,267	99.8

About one-third of the land in the watershed is Indian allotment land and two-thirds is privately owned. Most of the arable land in the watershed is owned by the Nez Perce Tribe and is leased to approximately 16 farm operators. The average farm size is about 1,000 acres.

Due to the watershed's steep and undulating topography (Fig. 2), about 75 percent of the cropland in the watershed has an EI value in excess of eight (Fig. 3). Extensive use of conventional tillage leaves little residue on the land after planting. Most of the erosion in the watershed is caused by snow melt runoff and warm winter rains in January and February. Since the soil is usually frozen at this time of year, surface water cannot percolate into the soil. Runoff erodes the topsoil down to the frozen layer and carries large amounts of sediment down to lower lands and finally into Tom Beall Creek. Considerable erosion occurs from high intensity rains during the growing season.

The average annual erosion rate is estimated at 12.4 tons per acre per year (TAY) based on current land use and farming practices. Erosion rates in the watershed vary considerably because of differences in soil, slope and land use (Fig. 4; Table 1). Many of the riparian areas along Tom Beall Creek are heavily grazed or farmed, increasing the amount of runoff reaching the creek and causing large segments of the watershed to become incised. As a result, average water quality in Tom Beall Creek is poor (Brusven and Carpenter 1987, Brusven et al. 1986) and the watershed is contributing large amounts of sediment, nutrients and pesticides to Lapwai Creek.

Methods

Geographic Information System

A computer-based Geographic Information System (GIS) was used to assemble and analyze information on soil type, topography, watercourses, cropping pattern, watershed and field boundaries, conservation practices and the movement of sediment and nutrients through the watershed.[3] The GIS was used to produce maps of these spatial characteristics and to generate the input data needed to run the physical and economic submodels used in the analysis. To optimize resolution and use the GIS to determine watershed boundaries, the GIS data base was set up as an 85 × 100 matrix. This procedure resulted in a cell size of approximately 3.3 acres with 3,145 cells in the watershed. The basic topographic features of the watershed were obtained from the Lapwai and Culdesac North 7.5 minute USGS quadrangles.

Topographic information was entered into the GIS by digitizing all elevation contours (40-foot interval)

Table 1. Current annual erosion rates in the Tom Beall Watershed.

Erosion rate	Acres	Percent
(tons/acre/yr)		(%)
0 to 5	1,480	17.8
6 to 10	2,304	27.7
11 to 15	1,764	21.2
16 to 20	1,294	15.5
21 to 25	847	10.1
26 to 30	381	4.5
31 to 35	199	2.4
> 35	53	0.6
Total	8,321	100.0

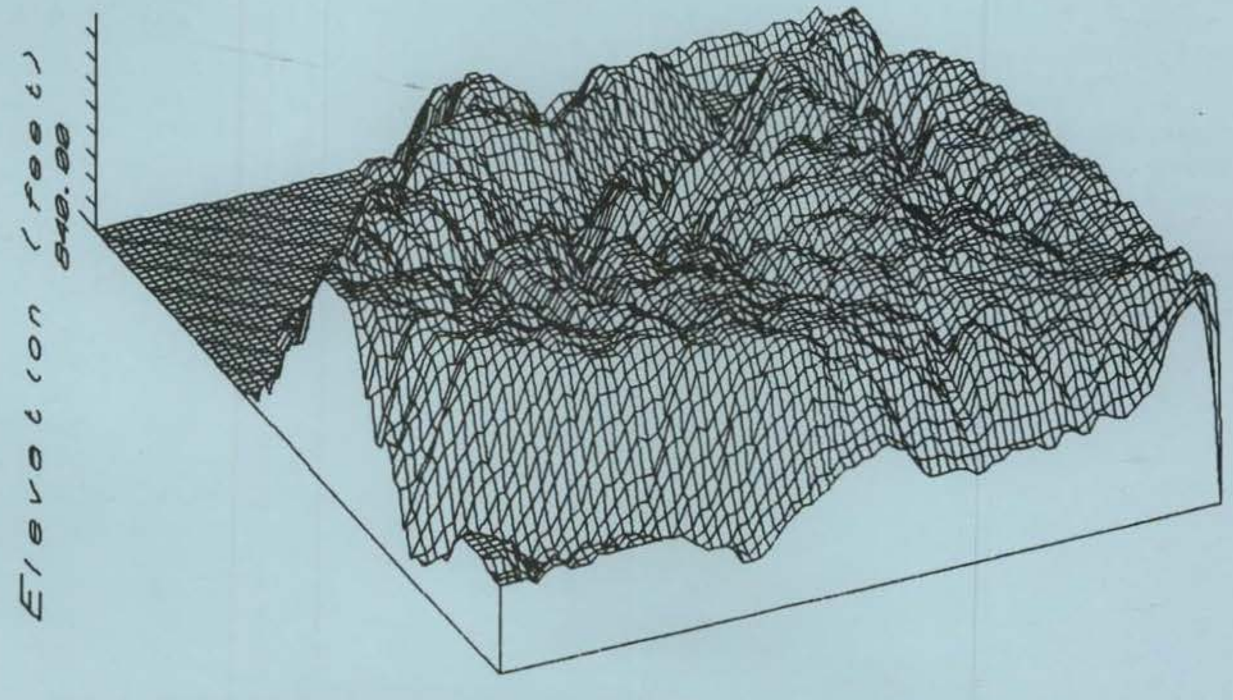

Fig. 2. Topography in Tom Beall Watershed (10° viewing angle).

---

[3] The professional Map Analysis Package, the GIS software system, was used for this study.

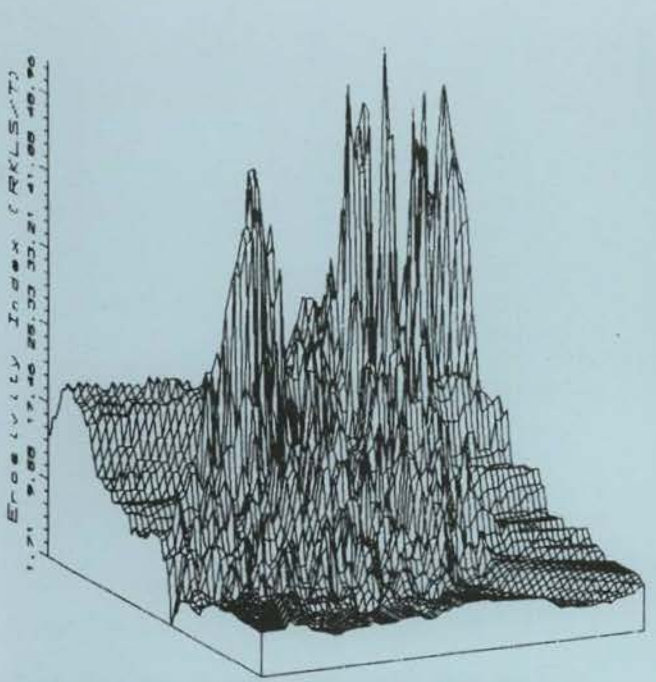

Fig. 3. Erosion potential in Tom Beall Watershed.

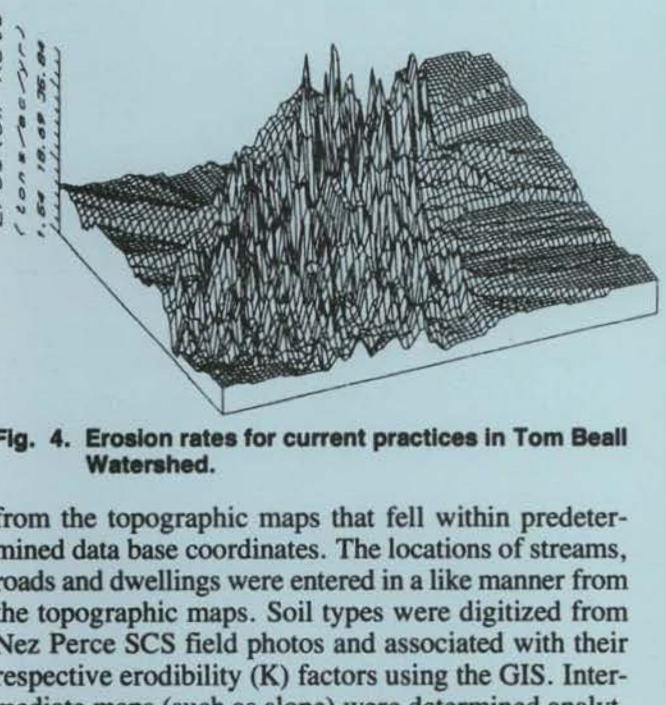

Fig. 4. Erosion rates for current practices in Tom Beall Watershed.

from the topographic maps that fell within predetermined data base coordinates. The locations of streams, roads and dwellings were entered in a like manner from the topographic maps. Soil types were digitized from Nez Perce SCS field photos and associated with their respective erodibility (K) factors using the GIS. Intermediate maps (such as slope) were determined analytically by the GIS. Three-dimensional topographic maps were created from GIS data using Golden Graphics software (Fig. 3). Land use information was obtained from 7.5 minute aerial photographs of the watershed and ASCS crop records. A farm survey was used to verify land use and field boundaries.

Soil Erosion and Water Quality Models

Soil erosion was calculated by inputting the USLE factors for each cell into the Universal Soil Loss Equation (Wischmeier and Smith 1978). Fig. 5 shows how the GIS was used to generate the soil, topographic, meteorologic and conservation practice factors in the USLE. The soil erosion rate for an individual field or farm is a weighted average of the rates for all cells included in the field or farm.

AGNPS was used to determine the effects of RMSs on water quality at the outlet of the watershed for individual storm events (Young et al. 1985). This computer simulation model was developed by the Agricultural Research Service to predict erosion, runoff, eroded and delivered sediment, nitrogen, phosphorus and chemical oxygen demand in runoff for individual storm events and land use practices. Erosion, runoff and sediment-nutrient routing are estimated with respect to a cellular grid pattern specified by the user. Four storm events were simulated: 10, 25, 50 and 100 years, each lasting 24 hours. Fig. 6 shows how the GIS was used to generate the input parameters required for the AGNPS model. Since AGNPS is an event model and the USLE is an annual average model, the erosion losses predicted by each are not comparable. No attempt was made to aggregate the event-based erosion and pollution levels given by AGNPS to annual average amounts.

Economic Models

The Microcomputer Budget Management System (MBMS) was used to estimate variable and fixed costs of production for a wheat-pea rotation on a 1,000-acre representative farm in the watershed. The MBMS is an enhancement of the Oklahoma Budget Generator (McGrann et al. 1986). Separate production costs were estimated for conventional, minimum and no tillage. Production costs included machinery, fuel and lube and repair costs for specified tillage operations, but excluded the cost of land, owner-operator labor and management. Farming equipment was assumed to be new and owned by the farm operator.[4] Each farmer also was assumed to have 100 percent equity in land, and that half the land was considered to be planted to winter wheat, the other half to spring peas. Production costs and average yields were estimated from a survey of farm operators in the watershed. Production costs used in the analysis are given in the Appendix.

Net returns per acre for each RMS were estimated using the Erosion Planning (EROPLAN) model. EROPLAN estimates annualized net return per acre including value of additional yields obtained by reducing erosion. Gross returns per acre equal wheat and pea yields multiplied by corresponding prices. The price of wheat equaled the 1987 target price of $4.38 per bushel, and the pea price equaled the 1987 market level of $0.08 per pound. Prices and costs were assumed to remain constant in real terms throughout the 20-year evaluation period. A 4 percent real discount rate was used.

---

[4] Use of new machinery is a simplifying assumption. Farmers in the watershed have equipment of various ages, but the exact ages were not known.

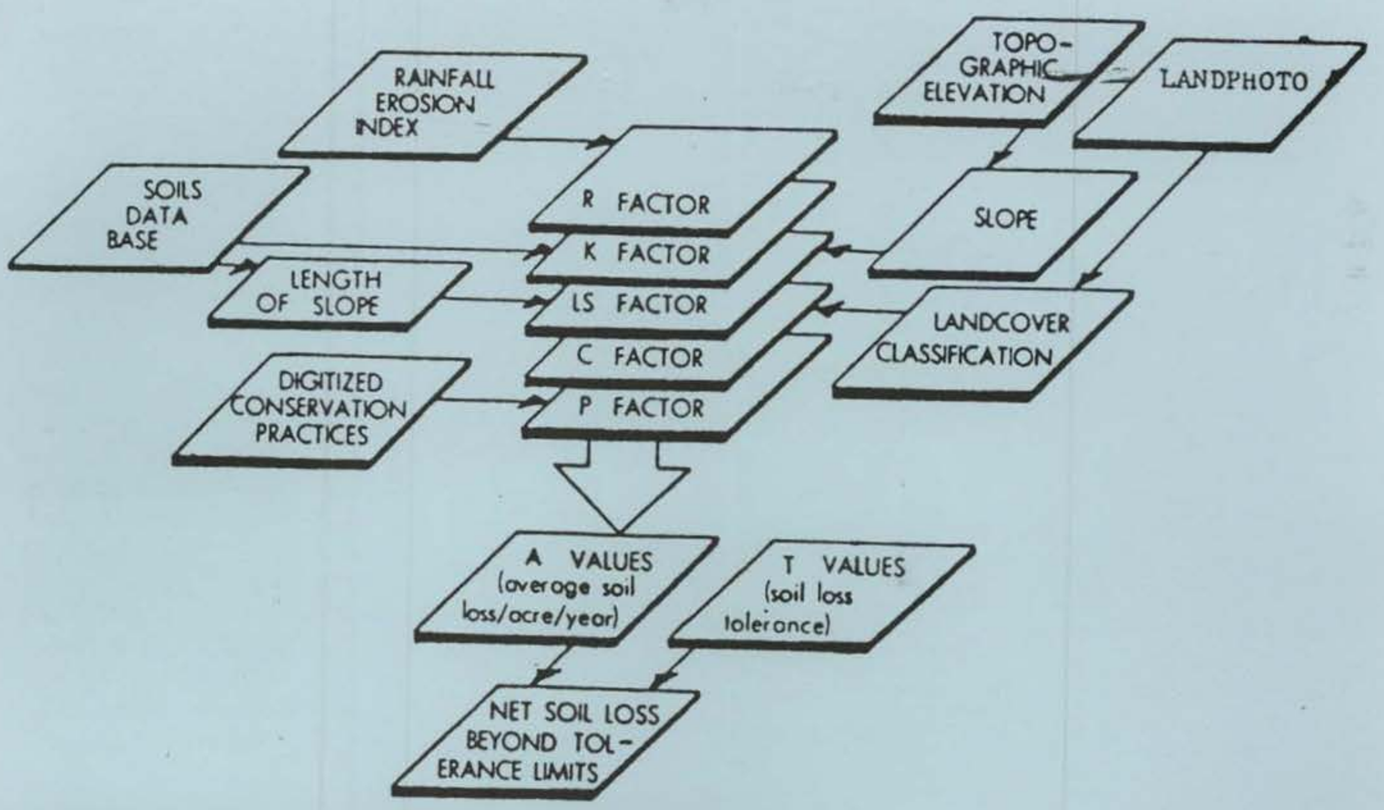

Fig. 5. Integrating GIS and USLE (adapted from Pelletier 1985).

Optimization Model

A linear programming (LP) optimization model was used to determine the RMSs for the 16 farms in the watershed that maximized total net farm income subject to a specified amount of erosion reduction in the watershed. The model is as follows:

$$1.\ \max Z = \sum_{ijkf} \sum_{ijkf} \sum_{ijkf} \sum_{ijkf} \sum_{ijkf} A_{ijkf} * C_{ijkf}$$

subject to:

$$2.\ \sum_{ijk} \sum_{ijk} \sum_{ijk} A_{ijkf} \leq A_f, \text{ for all } f$$

$$3.\ \sum_{f} A_f \leq A$$

$$4.\ \sum_{ijkf} \sum_{ijkf} \sum_{ijkf} \sum_{ijkf} A_{ijkf} * S_{ijkf} \leq S$$

where:

Z = total net farm income in the watershed;

C_{ijkf} = annualized net returns per acre for crop rotation i, tillage system j and land treatment k on farm f;

A_{ijkf} = acres in crop rotation i, tillage system j and land treatment k on farm f;

A_f = acreage in farm f;

S = soil erosion constraint for the watershed;

S_{ijkf} = tons of erosion per acre for crop rotation i, tillage system j and land treatment k on farm f;

i = 1, . . . , I is the designation for crop rotation;

j = 1, . . . , J is the designation for tillage system;

k = 1, . . . , K is the designation for land treatment practice;

f = 1, . . . , F is the designation for farm.

The objective function (1) is total net farm income in the watershed. The first constraint (2) prevents the total acreage in RMSs from exceeding the size of the farm. The second constraint (3) ensures that all acreage in the watershed is treated. The third constraint (4) prevents total erosion in the watershed from exceeding the specified level.

Since a farm can have more than one soil type, C_{ijkf} and S_{ijkf} are weighted averages of the corresponding annualized net returns and soil erosion rates, respectively, for all soil types on that farm. The soil erosion coefficients, S_{ijkf}, are the estimated soil loss rates predicted with the USLE. The erosion constraint level, S, was decreased parametrically to determine the change in total net farm income associated with reduced erosion. These income changes can be interpreted as the net social marginal cost of erosion reduction, that is, private marginal cost plus the long term productivity benefits of erosion reduction.

Since it is more difficult for farmers to change their cropping pattern than their tillage and land treatment-practices (Carlson et al. 1985), only a wheat-pea rotation was permitted. Permanent vegetation was introduced as a non-cropping option to significantly reduce erosion rates on highly erodible soil for low erosion constraint levels. A 2.6 percent yield penalty was assumed for minimum tilled wheat and a 15 percent

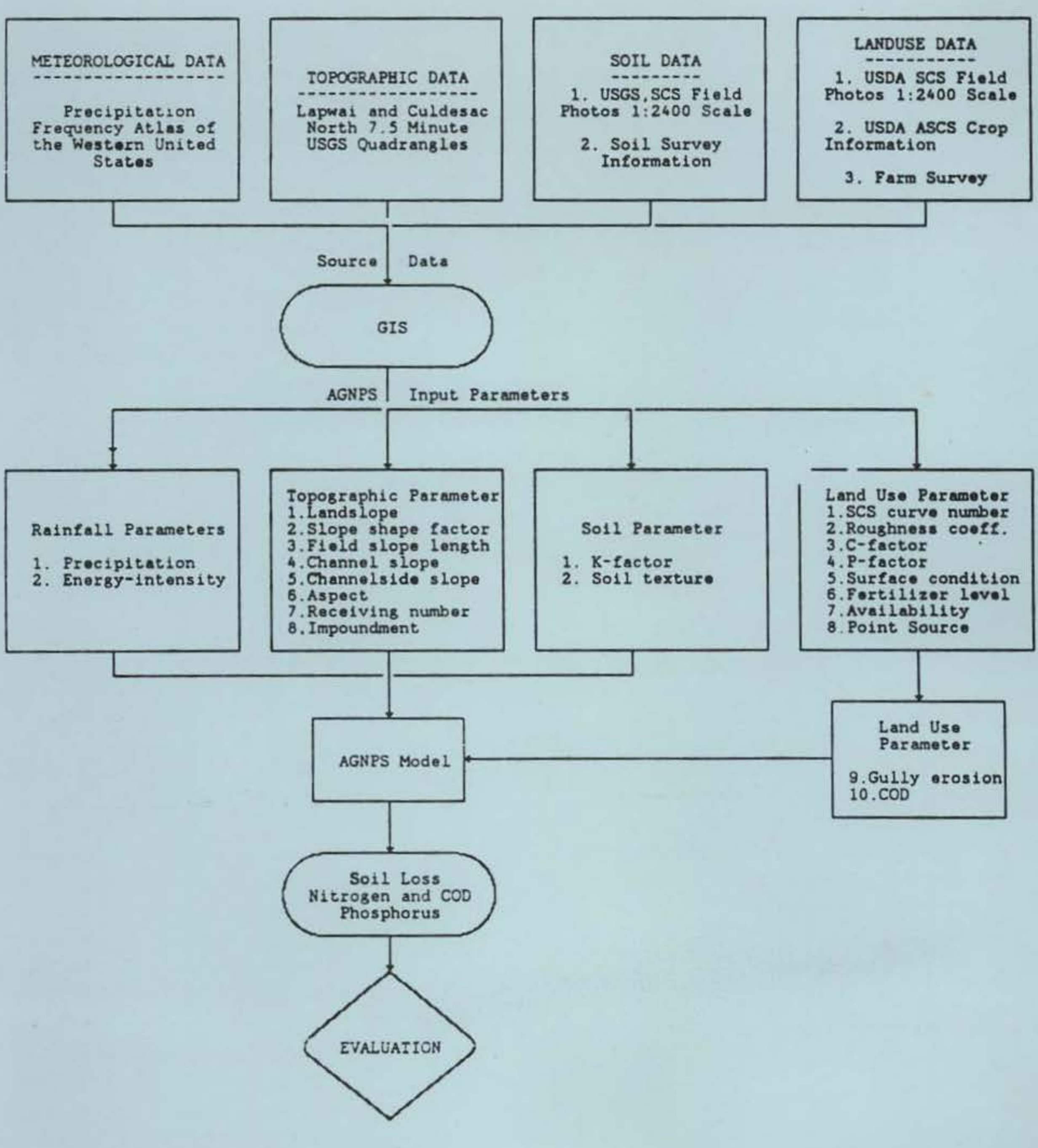

Fig. 6. Integrating GIS and AGNPS.

yield penalty for no tilled wheat.[5] Peas were assumed to be conventionally tilled because minimum tillage and no tillage are generally not used with peas in the Palouse.

The following RMSs were included in the LP model:

CTUD = conventional tillage with up-and-down cultivation
CTCS = conventional tillage with cross-slope farming
CTCF = conventional tillage with contour farming
CTDS = conventional tillage with divided-slope farming
MTCS = minimum tillage with cross-slope farming
MTCF = minimum tillage with contour farming
MTDS = minimum tillage with divided-slope farming
NTCS = no-till with cross-slope farming
NTCF = no-till with contour farming
NTDS = no-till with divided-slope farming
PV = permanent vegetation

Conventional tillage is an inversion tillage system which clears most of the soil surface of any residue and

---

[5] The minimum tillage wheat penalty was estimated from the farm survey and the no tillage wheat penalty is the value used by Taylor and Young (1985).

vegetation. It is the most common tillage practice used in the Tom Beall Watershed. Minimum tillage is a form of non-inversion tillage, and no-till typically involves seeding with a no-till drill. Both minimum and no-till leave at least 30 percent residue cover on the soil surface after planting. Erosion is reduced 50 to 90 percent when minimum tillage or no-till replaces conventional tillage (Poincelot 1987, USDA 1985).

With up-and-down cultivation, plowing and planting are done in the direction of the slope of the fields. All field operations are done perpendicular to the slope with cross-slope farming and on the contour with contour farming. Divided-slope farming uses more than one crop or field condition to divide a field. Permanent vegetation involves planting a cover crop such as alfalfa grass. This practice may be the only way to reduce soil erosion rates to tolerable levels on highly erodible land.

A flow chart of the four submodels used in the analysis is given in Fig. 7.

Results

Results are reported for four analyses. First, the level and economic efficiency of erosion reduction were compared for all RMSs and farms in the watershed. Second, the optimization model was used to determine the optimal RMSs for achieving alternative levels of erosion reduction. Third, a net private marginal cost curve for erosion reduction was derived and used to discuss the socially optimal level of erosion reduction. Fourth, the water quality impacts of alternative erosion control plans were evaluated.

Erosion Reduction and Economic Efficiency

Since farms in the watershed have different topography and soils, erosion rates varied widely, even for the same RMS (Fig. 8). Farms were divided into the following four groups:

Group	Current erosion rate
I	≥ 5 TAY (1T) < 10 TAY (2T)
II	≥ 10 TAY (2T) < 15 TAY (3T)
III	≥ 15 TAY (3T) < 20 TAY (4T)
IV	≥ 20 TAY (4T)

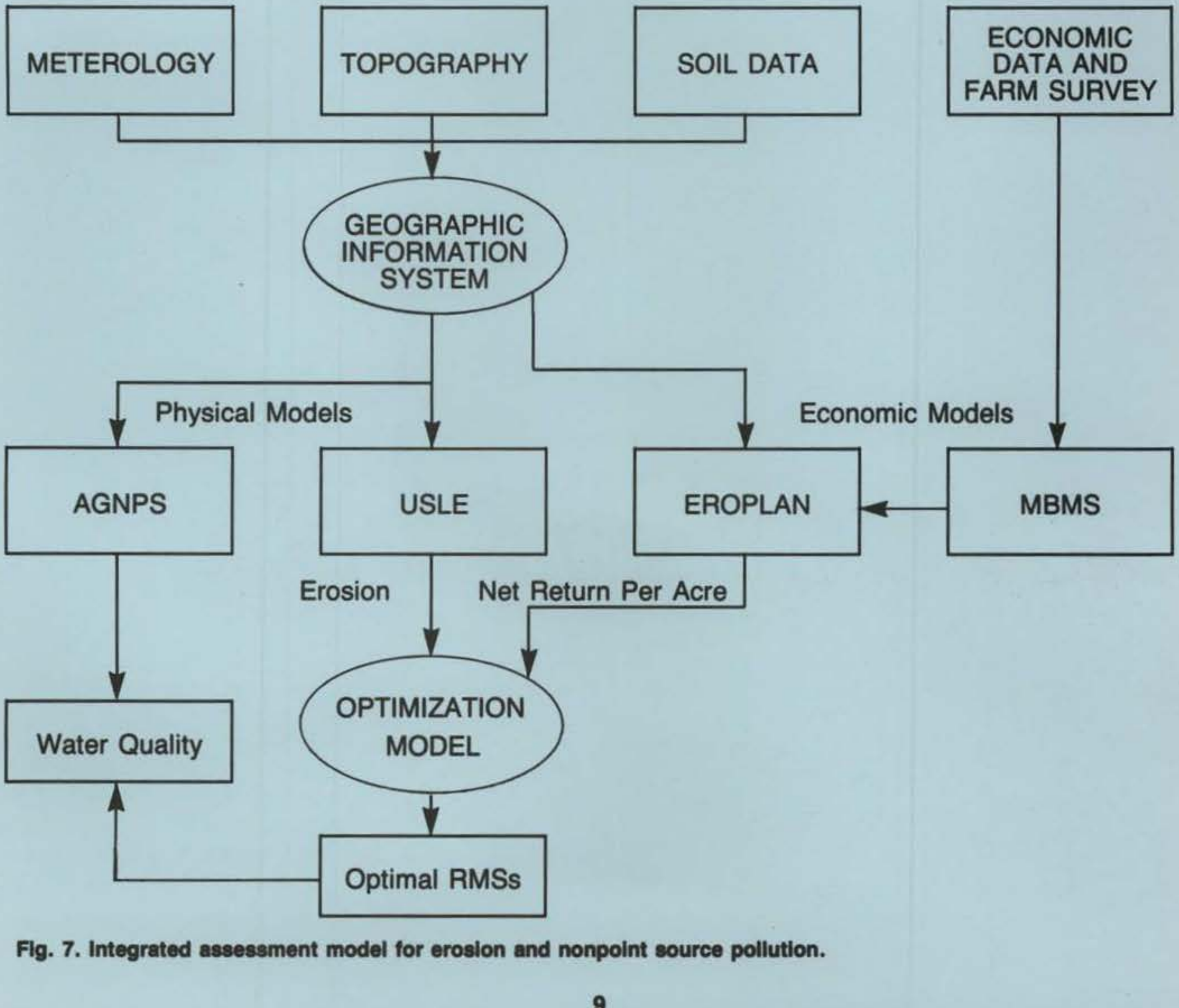

Fig. 7. Integrated assessment model for erosion and nonpoint source pollution.

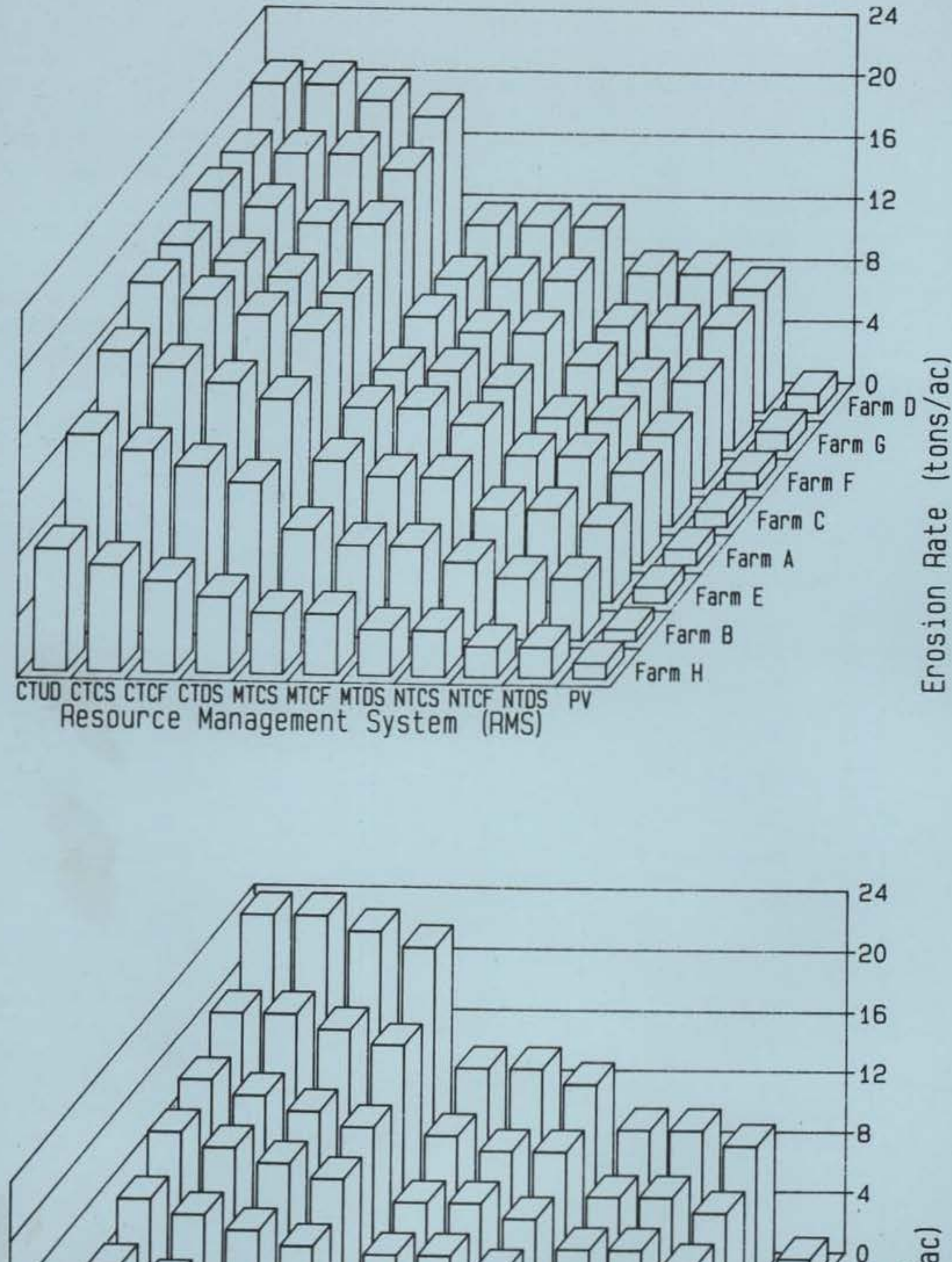

Fig. 8. Erosion rates of RMSs in Tom Beall Watershed.

Erosion rates by farm and RMS and the change in erosion rates for alternative RMSs relative to the base RMS (CTCF) are given in Table 2. Erosion decreased from 2 to 8 TAY for RMSs with minimum tillage, from 3 to 12 TAY for RMSs with no tillage and from 5.5 to 17.8 TAY when permanent vegetation was used.

Erosion rates for all RMSs with conventional tillage exceeded the soil loss tolerance except for CTDS on farm H in group I. For all group I farms, erosion was reduced to the soil loss tolerance level by employing RMSs with minimum tillage and no-till. In the second group, the soil tolerance level was exceeded for all farms using RMSs with minimum tillage except MTDS on farm L, and for all farms using RMSs with no-till except NTDS on farms E and N. Average erosion rates for group III farms exceeded 1T for all RMSs with minimum and no tillage, except NTDS on farm K. The two farms in group IV exceeded the tolerance level for all RMSs except permanent vegetation.

Table 2 also shows the annualized net return per acre for each RMS and farm, the net change in annualized net return per acre relative to the baseline RMS (CTCF) and the average cost per ton of erosion reduction when an alternative RMS replaces the baseline RMS. Average cost per ton of erosion reduction is the change in annualized net return per acre divided by the per acre reduction in erosion.

Relative to CTCF, average net return per acre decreased by \$1.37 with CTDS; increased by \$1.18 with MTCS except for the decreases on farms H and G; increased \$1.32 with MTCF except for the decreases on farms H and G; decreased \$.74 with MTDS except for the increases on farms D and P, both of which are in group IV; and decreased by \$20.93, \$20.71, \$22.76 and \$95.42 on all farms with NTCS, NTCF, NTDS and PV, respectively.

Annualized net return with MTCS and MTCF were generally higher than with conventional tillage because minimum tillage had a lower variable cost and a higher soil productivity benefit. Net returns with MTDS were lower, except on the two highest-eroding farms, because divided-slope farming was more costly than cross-slope and contour farming. Net returns were considerably lower for all RMSs with no-till because no-till had a higher variable cost and a larger yield penalty. Net return decreased substantially with PV because it had a negative net return. Fig. 9 shows the weighted average annualized net returns per acre for the RMSs analyzed here.

For all farms in groups I and II, and all but farm G in group III, average costs relative to CTCF were positive for all RMSs except MTCS and MTCF (Table 2). A positive (negative) average cost implies that annualized net return per acre increases (decreases) when erosion is reduced. Average cost was negative for MTCS and MTCF on these same farms. Average cost was positive for all RMSs on farm G and for minimum tillage on group IV farms.

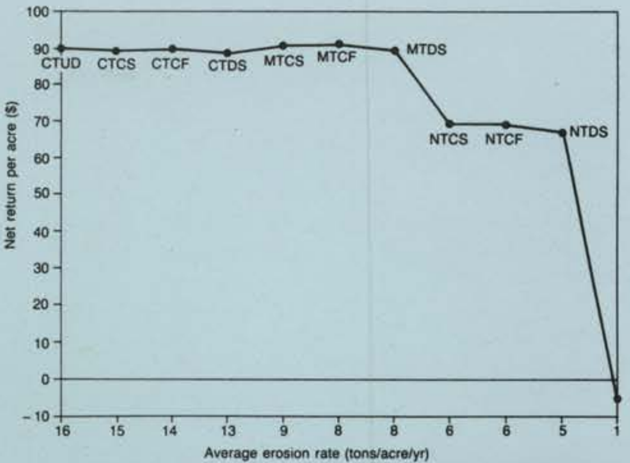

Fig. 9. Weighted average annualized net returns vs. erosion rates for RMSs in the Tom Beall Watershed.

tive for all RMSs on farm G and for minimum tillage on group IV farms.

Net returns and average costs indicate that minimum tillage with cross-slope farming or contour farming is the most economically efficient RMS for reducing erosion. Averaged over the entire watershed, annualized net return per acre increased by \$1.05 and \$1.38, for MTCS and MTCF, respectively. On average, MTCS and MTCF reduced erosion to 8.7 and 8.3 TAY, respectively.

Optimal Resource Management Systems

The LP model determined the RMSs for each farm that maximized net farm income in the watershed subject to alternative soil erosion control levels. Results of the LP analysis are given in Tables 3 (without cost sharing) and 4 (with cost sharing). Erosion reduction is measured relative to the total erosion that occurs when CTCF is used on all farms in the watershed. A 40 percent reduction in erosion corresponds to an average erosion rate of 2T and a 70 percent reduction corresponds to an average erosion rate of 1T.

Without cost sharing, a 40 percent erosion reduction required shifting all but two farms from CTCF to MTCF. Farm G was split between CTCF (52 percent) and MTCF (58 percent), and farm H continued to use CTCF. To achieve a 70 percent erosion reduction, 11 farms and most of another farm had to use no-till and two farms and part of a third had to be planted to permanent vegetation. The remaining two farms used minimum tillage. To reduce erosion by more than 70 percent entailed greater use of permanent vegetation.

Cost sharing provides a maximum of \$12 per acre per year for 2 years when minimum tillage is used, \$18 per acre per year for 2 years when no tillage is used and a one-time payment of \$11.25 per acre for divided-slope farming. Cost sharing lowered the cost of conservation practices and changed the optimal RMSs. Optimal RMSs with cost sharing (Table 4) employed divided-slope instead of contour farming on all but one

Table 2. Net returns, erosion rates and average costs per ton of erosion reduction for alternative RMSs for the Tom Beall Watershed.

Farm unit code	Erosion and net return	Resource Management Systems (RMSs)										
		CTUD	CTCS	CTCF[5]	CTDS	MTCS	MTCF	MTDS	NTCS	NTCF	NTDS	PV
Erosion Group I												
H	Erosion rate[1]	8	7	6	5	4	4	3	3	2	2	0.5
	Net change[2]	—	—	0	-1	-2	-2	-3	-3	-4	-4	-5.5
	Net return per acre ($)	92.99	93.07	93.43	91.70	93.17	93.40	91.33	70.58	70.77	68.23	-5.36
	Net change[3]	—	—	0	-1.73	-0.26	-0.03	-2.1	-22.9	-22.7	-25.2	-98.8
	Average cost[4]	—	—	—	1.73	0.13	0.02	0.7	7.62	5.67	6.3	17.97
M	Erosion rate[1]	9	8	7	6	5	4	3	3	2	2	0.6
	Net change[2]	—	—	0	-1	-2	-3	-4	-4	-5	-5	-6.4
	Net return per acre ($)	89.96	89.50	90.06	88.69	91.05	91.38	89.54	69.12	69.34	67.29	-5.36
	Net change[3]	—	—	0	-1.37	0.99	1.32	-0.52	-20.9	-20.7	-22.8	-95.4
	Average cost[4]	—	—	—	1.37	-0.5	-0.44	0.13	5.24	4.14	4.55	14.91
O	Erosion rate[1]	11	9	8	7	5	5	4	4	3	2	0.6
	Net change[2]	—	—	0	-1	-3	-3	-4	-4	-5	-6	-7.4
	Net return per acre ($)	90.85	90.35	90.86	89.39	91.57	91.87	89.97	69.50	69.70	67.61	-5.36
	Net change[3]	—	—	0	-1.47	0.71	1.01	-0.89	-21.4	-21.2	-23.3	-96.2
	Average cost[4]	—	—	—	1.47	-0.24	-0.34	4.49	5.34	0.24	3.88	13.00
B	Erosion rate[1]	13	12	11	10	7	6	6	5	4	4	0.8
	Net change[2]	—	—	0	-1	-4	-5	-5	-6	-7	-7	-10.2
	Net return per acre ($)	89.84	89.43	89.99	88.62	91.01	91.34	89.50	69.10	69.32	67.27	-5.36
	Net change[3]	—	—	0	-1.37	1.02	1.35	-0.49	-20.9	-20.7	-22.7	-95.4
	Average cost[4]	—	—	—	1.37	-0.26	-0.27	0.10	3.48	2.95	3.25	9.35
E	Erosion rate[1]	16	15	14	13	9	8	8	6	6	5	0.9
	Net change[2]	—	—	0	-1	-5	-6	-6	-8	-8	-9	-13.1
	Net return per acre ($)	90.13	89.66	90.20	88.80	91.16	91.48	89.62	69.22	69.44	67.38	-5.36
	Net change[3]	—	—	0	-1.4	0.96	1.28	-0.58	-21.0	-20.8	-22.8	-95.6
	Average cost[4]	—	—	—	1.4	-0.19	-0.21	0.10	2.62	2.60	2.54	7.29
L	Erosion rate[1]	13	12	10	9	7	6	5	5	4	3	0.8
	Net change[2]	—	—	0	-1	-3	-4	-5	-5	-6	-7	-9.2
	Net return per acre ($)	89.91	89.46	90.02	88.65	91.03	91.36	89.51	69.11	69.33	67.28	-5.36
	Net change[3]	—	—	0	-1.37	1.01	1.34	-0.51	-20.9	-20.7	-22.7	-95.4
	Average cost[4]	—	—	—	1.37	-0.34	-0.34	0.10	4.18	3.45	3.25	10.37
Erosion Group II												
N	Erosion rate[1]	15	14	13	12	8	8	7	6	5	5	0.9
	Net change[2]	—	—	0	-1	-5	-5	-6	-7	-8	-8	-12.1
	Net return per acre ($)	90.01	89.54	90.09	88.72	91.08	91.41	89.56	69.13	69.35	67.31	-5.36
	Net change[3]	—	—	0	-1.37	0.99	1.32	-0.53	-21.0	-20.7	-22.8	-95.5
	Average cost[4]	—	—	—	1.37	-0.20	-0.26	0.09	2.99	2.60	2.85	7.90
K	Erosion rate[1]	17	16	15	14	9	9	8	6	6	5	1.0
	Net change[2]	—	—	0	-1	-6	-6	-7	-9	-9	-10	-14.0
	Net return per acre ($)	89.86	89.41	89.97	88.60	91.00	91.33	89.49	69.09	69.31	67.26	-5.36
	Net change[3]	—	—	0	-1.37	1.03	1.36	-0.48	-20.9	-20.7	-22.7	-95.3
	Average cost[4]	—	—	—	1.37	-0.17	-0.23	0.07	2.32	2.30	2.27	6.81
Erosion Group III												
A	Erosion rate[1]	18	17	16	15	10	10	9	7	7	6	1.1
	Net change[2]	—	—	0	-1	-6	-6	-7	-9	-9	-10	-14.9
	Net return per acre ($)	89.27	88.95	89.53	88.22	90.74	91.08	89.26	68.92	69.15	67.12	-5.36
	Net change[3]	—	—	0	-1.31	1.21	1.55	-0.27	-20.6	-20.4	-22.4	-94.9
	Average cost[4]	—	—	—	1.31	-0.20	-0.26	0.04	2.29	2.26	2.24	6.37

[1] Erosion rate in tons per acre per year.

[2] Change in erosion rate relative to CTCF.

[3] Change in net return per acre relative to CTCF.

[4] Average cost per ton of erosion reduction ($/ton).

[5] Baseline

CTUD = conventional tillage and up-and-down cultivation
CTCS = conventional tillage and cross-slope farming
CTCF = conventional tillage and contour farming
CTDS = conventional tillage and divided-slope farming
MTCS = minimum tillage and cross-slope farming
MTCF = minimum tillage and contour farming
MTDS = minimum tillage and divided-slope farming
NTCS = No-till and cross-slope farming
NTCF = No-till and contour farming
NTDS = No-till and divided-slope farming
PV = permanent vegetation

Table 2. (cont'd.)

Farm unit code	Erosion and net return	Resource Management Systems (RMSs)										
		CTUD	CTCS	CTCF[5]	CTDS	MTCS	MTCF	MTDS	NTCS	NTCF	NTDS	PV
Erosion Group III (cont'd)												
	Erosion rate[1]	18	17	16	15	10	10	9	7	7	6	1.1
	Net change[2]	—	—	0	−1	−6	−6	−7	−9	−9	−10	−14.9
C	Net return per acre ($)	90.15	89.95	90.49	89.07	91.33	91.64	89.77	69.31	69.54	67.38	−5.36
	Net change[3]	—	—	0	−1.42	0.84	1.15	−0.72	−21.2	−21.0	−23.1	−95.9
	Average cost[4]	—	—	—	1.42	−0.14	−0.19	0.10	2.35	2.33	2.31	6.43
	Erosion rate[1]	19	18	17	17	11	10	10	8	7	7	1.1
	Net change[2]	—	—	0	0	−6	−7	−7	−9	−10	−10	−15.9
F	Net return per acre ($)	89.30	89.03	89.60	88.28	90.77	91.12	89.30	68.88	69.11	67.02	−5.36
	Net change[3]	—	—	0	−1.32	1.17	1.52	−0.30	−20.7	−20.5	−22.6	−95.0
	Average cost[4]	—	—	—	1.32	−0.20	0.22	0.04	2.30	2.05	2.26	6.00
	Erosion rate[1]	19	19	19	18	11	11	11	8	8	8	1.2
	Net change[2]	—	—	0	−1	−8	−8	−8	−11	−11	−11	−17.8
G	Net return per acre ($)	92.99	93.07	93.43	91.70	93.17	93.40	91.33	70.58	70.77	68.23	−5.38
	Net change[3]	—	—	0	−1.73	−0.26	−0.03	−2.1	−22.9	−22.7	−25.2	−98.8
	Average cost[4]	—	—	—	1.73	0.03	0.004	0.26	2.08	2.06	2.29	5.55
	Erosion rate[1]	18	17	16	15	10	10	9	7	7	6	1.1
	Net change[2]	—	—	0	−1	−6	−6	−7	−9	−9	−10	−14.9
I	Net return per acre ($)	90.58	90.26	90.77	89.32	91.51	91.81	89.92	69.45	69.66	67.58	−5.36
	Net change[3]	—	—	0	−1.45	0.74	1.04	−0.85	−21.3	−21.1	−23.2	−96.1
	Average cost[4]	—	—	—	1.45	−0.12	−0.17	0.12	2.37	2.35	2.32	6.45
	Erosion rate[1]	20	20	19	18	12	11	11	8	8	7	1.2
	Net change[2]	—	—	0	−1	−7	−8	−8	−11	−11	−12	−17.8
J	Net return per acre ($)	88.67	88.55	89.15	87.88	90.48	90.84	89.07	68.73	68.97	66.98	−5.36
	Net change[3]	—	—	0	−1.27	1.33	1.69	−0.08	−20.4	−20.2	−22.2	−94.5
	Average cost[4]	—	—	—	1.27	−0.19	−0.21	0.01	1.86	1.83	1.85	5.31
Erosion Group IV												
	Erosion rate[1]	21	21	20	19	12	12	12	9	9	8	1.3
	Net change[2]	—	—	0	−1	−8	−8	−8	−11	−11	−12	−18.7
D	Net return per acre ($)	87.74	87.78	88.41	87.20	90.03	90.41	88.68	68.45	68.70	67.38	−5.36
	Net change[3]	—	—	0	−1.21	1.62	2.00	0.27	−20.0	−19.7	−21.0	−93.8
	Average cost[4]	—	—	—	1.21	−0.20	−0.25	−0.03	1.81	1.79	1.75	0.20
	Erosion rate[1]	24	24	23	22	14	14	13	10	10	9	1.5
	Net change[2]	—	—	0	−1	−9	−9	−10	−13	−13	−14	−21.5
P	Net return per acre ($)	83.37	83.91	84.75	83.97	87.73	88.23	86.73	66.84	67.19	65.39	−5.36
	Net change[3]	—	—	0	−0.78	2.98	3.48	1.98	−17.9	−17.6	−19.4	−90.1
	Average cost[4]	—	—	—	0.78	−0.33	−0.39	−0.20	1.38	1.35	1.38	4.19

[1] Erosion rate in tons per acre per year.

[2] Change in erosion rate relative to CTCF.

[3] Change in net return per acre relative to CTCF.

[4] Average cost per ton of erosion reduction ($/ton).

[5] Baseline

CTUD = conventional tillage and up-and-down cultivation
CTCS = conventional tillage and cross-slope farming
CTCF = conventional tillage and contour farming
CTDS = conventional tillage and divided-slope farming
MTCS = minimum tillage and cross-slope farming
MTCF = minimum tillage and contour farming
MTDS = minimum tillage and divided-slope farming
NTCS = No-till and cross-slope farming
NTCF = No-till and contour farming
NTDS = No-till and divided-slope farming
PV = permanent vegetation

farm at the 40 percent erosion reduction level and divided-slope in place of contour farming on the four farms that used no tillage at the 70 percent erosion reduction level.

Acreages for the optimal RMS and the changes in total net farm income for alternative erosion reduction levels are given in Tables 5 (without cost sharing) and 6 (with cost sharing). As erosion reduction increased, more acreage was shifted from conventional tillage to minimum tillage, no tillage and permanent vegetation. Although the first run imposed no erosion constraint, it decreased erosion by 30 percent and increased total net farm income 1.5 percent without cost sharing and 15.8 percent with cost sharing. Net farm income increased by the same amounts when erosion was reduced by 40 percent. For a 70 percent erosion reduction, total net farm income decreased 34.7 percent without cost sharing and 17.7 percent with cost sharing. Total net farm income dropped quickly when erosion reduction exceeded 40 percent without cost sharing and 60 percent with cost sharing (Fig. 10). A reduced cost analysis showed that, in 90 percent of the cases, total net farm income decreased by using RMSs excluded from the LP solutions at the 1T and 2T constraint levels.

Table 3. Optimal resource management systems by erosion reduction levels and land treatment units for Tom Beall Watershed (without cost sharing).

Treatment unit		Optimal RMSs for different erosion reduction levels								
		1	2	3	4	5	6	7	8	9
(Farm)	(Acres)	40% (2T)	50%	60%	70% (1T)	80%	90%	91%	92%	93.11%
A	1,026.1	MTCF	MTDS (67%) NTDS (33%)	NTDS	NTDS	PV	PV	PV	PV	PV
B	1,916.5	MTCF	MTCF	MTCF	NTCF	NTCF	NTCF (20%) PV (80%)	PV	PV	PV
C	830.8	MTCF	MTDS	NTDS	NTDS	PV	PV	PV	PV	PV
D	1,085.7	MTCF	NTDS	NTDS (74%) PV (26%)	PV	PV	PV	PV	PV	PV
E	638.8	MTCF	MTCF	NTDS	NTDS	NTDS	PV	PV	PV	PV
F	225.1	MTCF	NTCF	NTCF	NTCF	PV	PV	PV	PV	PV
G	105.9	CTCF (52%) MTCF (48%)	MTCF	NTCF	NTCF (87%) PV (13%)	PV	PV	PV	PV	PV
H	3.3	CTCF	MTDS	MTDS	MTDS	MTDS	NTCF	NTCF	PV	PV
I	360.8	MTCF	MTDS	NTDS	NTDS	NTDS	PV	PV	PV	PV
J	188.7	MTCF	NTDS	NTDS	NTDS	PV	PV	PV	PV	PV
K	486.6	MTCF	MTDS	NTDS	NTDS	NTDS	PV	PV	PV	PV
L	281.4	MTCF	MTDS	MTDS	NTDS	NTDS	NTDS	NTDS	PV	PV
M	228.4	MTCF	MTDS	MTDS	MTDS	MTDS	NTCF	NTCF	NTCF	PV
N	172.1	MTCF	MTDS	NTCF	NTCF	NTCF	PV	PV	PV	PV
O	1,158.5	MTCF	MTDS	NTCF	NTDS	NTDS	NTDS	NTDS	NTDS (64%) PV (36%)	PV
P	76.1	MTCF	NTDS	PV	PV	PV	PV	PV	PV	PV

The figure in the parentheses is the percent total farm acreage in that RMS.

CTCF = conventional tillage and contour farming
CTDS = conventional tillage and divided-slope farming
MTCF = minimum tillage and contour farming
MTDS = minimum tillage and divided-slope farming
NTCF = No-till and contour farming
NTDS = No-till and divided-slope farming
PV = permanent vegetation

Table 4. Optimal resource management systems by erosion reduction levels and land treatment units for Tom Beall Watershed (with cost sharing).

Treatment unit		Optimal RMSs for different erosion reduction levels								
		1	2	3	4	5	6	7	8	9
(Farm)	(Acres)	40% (2T)	50%	60%	70% (1T)	80%	90%	91%	92%	93.11%
A	1,026.1	MTDS	MTDS (45%) NTDS (55%)	NTDS	NTDS	PV	PV	PV	PV	PV
B	1,916.5	MTDS	MTDS	MTDS (26%) NTDS (74%)	NTDS	NTDS	NTDS (20%) PV (80%)	PV	PV	PV
C	830.8	MTDS	MTDS	NTDS	NTDS	PV	PV	PV	PV	PV
D	1,085.7	MTDS	NTDS	NTDS	PV	PV	PV	PV	PV	PV
E	638.8	MTDS	MTDS	NTDS	NTDS	NTDS	PV	PV	PV	PV
F	225.1	MTDS	MTDS	NTDS	NTDS	PV	PV	PV	PV	PV
G	105.9	MTDS	MTDS	NTDS	NTDS (87%) PV (13%)	PV	PV	PV	PV	PV
H	3.3	MTDS	MTDS	MTDS	MTDS	MTDS	NTDS	NTDS	PV	PV
I	360.8	MTDS	MTDS	NTDS	NTDS	NTDS (99%) PV (1%)	PV	PV	PV	PV
J	188.7	MTCF	NTDS	NTDS	NTDS	PV	PV	PV	PV	PV
K	486.6	MTDS	MTDS	NTDS	NTDS	NTDS	PV	PV	PV	PV
L	281.4	MTDS	MTDS	MTDS	NTDS	NTDS	NTDS	NTDS	PV	PV
M	228.4	MTDS	MTDS	MTDS	MTDS	MTDS	NTDS	NTDS	PV	PV
N	172.1	MTDS	MTDS	MTDS	NTDS	NTDS	PV	PV	PV	PV
O	1,158.5	MTDS	MTDS	MTDS	NTDS	NTDS	NTDS	NTDS	NTDS (84%) PV (16%)	PV
P	76.1	MTDS	NTDS	NTDS	PV	PV	PV	PV	PV	PV

The figure in the parentheses is the percent total farm acreage in that RMS.

CTCF = conventional tillage and contour farming
CTDS = conventional tillage and divided-slope farming
MTCF = minimum tillage and contour farming
MTDS = minimum tillage and divided-slope farming
NTCF = No-till and contour farming
NTDS = No-till and divided-slope farming
PV = permanent vegetation

Table 5. Optimal acreage for RMSs under different erosion reduction levels (without cost sharing) for Tom Beall Watershed.

Percent erosion reduction compared to baseline	Net income ($)		Acreage in Resource Management Systems (RMSs)											
	Amount	Percent	CTCF		MTCF		MTDS		NTCF		NTDS		PV	
Baseline (0)	789,958.9	100.0%	8,769	(100.0%)										
30	802,118.9	101.5%	109	(1.2%)	8,660	(98.8%)								
40	802,117.4	101.5%	283	(3%)	8,485	(97.0%)								
50	749,237.8	94.8%			2,661	(30.0%)	4,209	(48%)	225	(3%)	1,690	(19%)		
60	649,243.8	82.2%			1,916	(22.0%)	1,672	(19%)	503	(6%)	4,331	(49%)	362	(4%)
70	516,187.9	65.3%					232	(3%)	2,406	(27%)	4,972	(57%)	1,176	(13%)
80	343,720.1	43.5%					232	(3%)	2,089	(24%)	2,923	(33%)	3,542	(40%)
90	103,737.3	13.1%							614	(7%)	1,440	(16%)	6,731	(77%)
91	75,349.3	9.5%							234	(3%)	1,440	(16%)	7,111	(81%)
91.5	55,335.2	7.0%							232	(3%)	1,166	(13%)	7,387	(84%)
92.0	23,975.6	3.0%							228	(3%)	740	(8%)	7,816	(89%)
92.5	−7,722.7	−0.1%							228	(3%)	306	(3%)	8,251	(94%)
93.0	−39,638.2	−5.0%							100	(1%)			8,685	(99%)
93.1	−46,131.1	−5.8%							13				8,772	(100%)
93.11	−47,083.6	−6.0%											8,785	(100%)

The figure in the parentheses is the percent of total watershed acreage in that RMS.

CTCF = conventional tillage and contour farming
CTDS = conventional tillage and divided-slope farming
MTCF = minimum tillage and contour farming
MTDS = minimum tillage and divided-slope farming
NTCF = No-till and contour farming
NTDS = No-till and divided-slope farming
PV = permanent vegetation

Table 6. Optimal acreage for RMSs under different erosion reduction levels (with cost sharing) for Tom Beall Watershed.

Percent erosion reduction compared to baseline	Net income ($)		Acreage in Resource Management Systems (RMSs)									
	Amount	Percent	CTCF		MTCF		MTDS		NTDS		PV	
Baseline (0)	789,958.9	100.0%	8,769	(100.0%)								
30	915,010.0	115.8%			189	(2%)	8,596	(98%)				
40	915,010.0	115.8%			189	(2%)	8,596	(98%)				
50	879,006.1	111.3%					8,032	(91%)	753	(9%)		
60	791,709.9	100.2%					2,343	(27%)	6,442	(73%)		
70	650,146.6	82.3%					232	(3%)	7,377	(84%)	1,176	(13%)
80	445,946.5	56.5%					232	(3%)	5,011	(57%)	3,542	(40%)
90	165,951.9	21.0%							2,054	(23%)	6,731	(77%)
91	133,130.1	16.9%							1,674	(19%)	7,111	(81%)
91.5	109,342.8	13.8%							1,398	(16%)	7,387	(84%)
92.0	72,174.1	9.1%							968	(11%)	7,816	(89%)
92.5	34,519.8	4.4%							534	(6%)	8,251	(94%)
93.0	−3,128.5	−0.4%							100	(1%)	8,685	(99%)
93.1	−10,663.0	−1.3%							13		8,772	(100%)
93.11	−11,768.2	−1.5%									8,785	(100%)

The figure in the parentheses is the percent of total watershed acreage in that RMS.

CTCF = conventional tillage and contour farming
CTDS = conventional tillage and divided-slope farming
MTCF = minimum tillage and contour farming
MTDS = minimum tillage and divided-slope farming
NTDS = No-till and divided-slope farming
PV = permanent vegetation.

Marginal Costs

The LP results were used to determine the net marginal cost of erosion reduction. Marginal cost of erosion reduction is the change in total net farm income per ton of erosion reduction. Since the annualized net return per acre for each RMS includes the onsite productivity benefits of erosion control, the LP shadow prices for the erosion constraint without cost sharing measure the net social marginal cost of reducing erosion. Fig. 11 depicts the net marginal cost curve for the watershed.

Net marginal cost was negative for the first 40 percent of erosion reduction but positive after this point. Net marginal cost was about $2 per ton of erosion reduction when erosion decreased from 41 to 44 percent, and increased to $6 per ton when erosion was reduced by 48 percent. Net marginal cost increased rapidly for additional erosion reduction because no tillage and permanent vegetation had to be used to satisfy the erosion constraint. For a social planning horizon of 20 years and a social discount rate of 4 percent, the net marginal cost curve (Fig. 11) is equivalent to the net social marginal cost curve. The socially optimal level of erosion reduction occurs where the net social marginal cost equals the marginal social benefit of erosion control. Since the onsite benefits of erosion reduction are in-

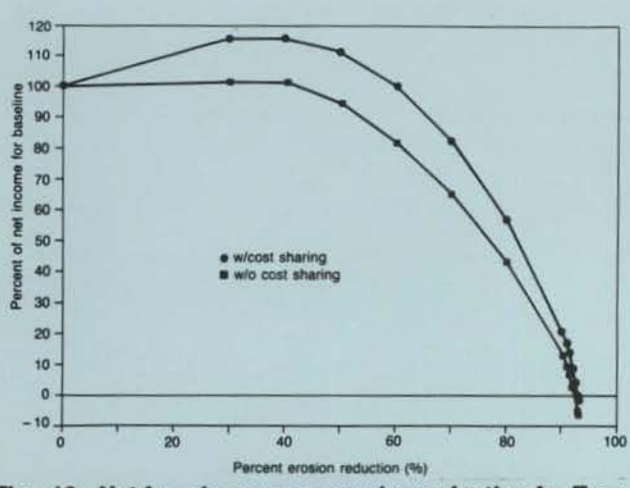

Fig. 10. Net farm income vs. erosion reduction for Tom Beall Watershed (with vs. without cost sharing).

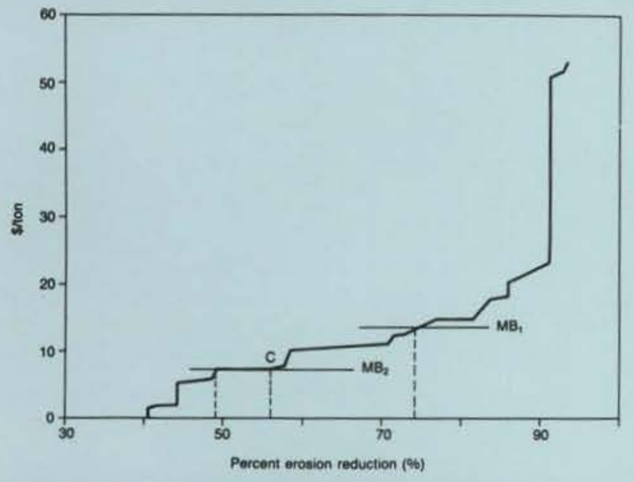

Fig. 11. Net marginal cost of erosion reduction for Tom Beall Watershed (without cost sharing).

corporated in the net marginal cost curve, marginal social benefits include only the marginal offsite benefits of erosion control.

Fig. 11 depicts the socially optimal levels of erosion reduction for two social marginal benefit levels, MB1 and MB2. The marginal benefit curves are assumed to be perfectly elastic because the watershed's contribution to sediment, nutrients and pesticides is small relative to the total amounts of these pollutants in the Clearwater River.

Since farmers cannot capture the offsite benefits of erosion reduction, a subsidy would be required to reduce erosion by more than 40 percent. The optimal subsidy equals the marginal offsite benefit. Unfortunately, the socially optimal level of erosion reduction and the optimal subsidy could not be determined because the offsite benefits of reducing erosion in Tom Beall Watershed are not known. When offsite benefits have been determined, however, the net marginal cost curve estimated in this study can be used to determine the socially optimal level of erosion reduction for the Tom Beall Watershed.

Water Quality Effects Of Erosion Control

The water quality effects of current practices and RMSs that maximized total net farm income for the 1T and 2T erosion control levels were determined with the AGNPS model. The Idaho SCS has established 1T as the desired erosion rate and 1.5T as the maximum erosion rate for fields subject to the conservation compliance provision of the 1985 Food Security Act. For analytical purposes, the upper limit was extended to 2T because this erosion control level provides the highest total net farm income.

The total amount of erosion in the watershed and nonpoint source pollutants[6] at the outlet of Tom Beall Creek were determined for 10, 25, 50 and 100-year storm events (of 24 hours duration) with current practices and the optimal RMS for reducing erosion to 2T and 1T (Table 7). Sediment and nutrient loadings and COD levels decreased as storm intensity increased, but at a decreasing rate. Between current practices and 2T, total erosion fell 10 percent, sediment declined 43 to 49 percent, nitrogen and phosphorus dropped 36 to 41 percent, and soluble COD declined 21 to 30 percent. The lower limit in each percentage range corresponds to a 100-year storm and the upper limit to a 10-year storm.

From 2T to 1T, erosion and sediment declined 50 percent, nitrogen and phosphorus decreased 41 to 47 percent and COD fell 7 percent. Sediment, nutrients and COD decreased from current practices to 2T and from 2T to 1T because cropland erosion and the sediment delivery ratios diminished. Averaged over the four storm events, erosion and losses of sediment, nitrogen, phosphorus and soluble COD decreased by 8, 45, 38, 38 and 24 percent, respectively, with the optimal RMSs for 2T, and by 33, 72, 64, 64 and 29 percent, respectively, with the optimal RMSs for 1T.

Total nitrogen and phosphorus (attached plus dissolved) and soluble COD at the watershed outlet increased at a decreasing rate with storm intensity, and decreased from current practices to 2T and from 2T to 1T (Table 8). Total nitrogen and phosphorus decreased 35 to 37 percent between current practices and 2T, and 40 to 42 percent between 2T and 1T. The decrease in soluble COD is substantially greater between current practices and 2T than between 2T and 1T (25 vs. 7 percent). Reductions in total nitrogen and phosphorous between current practices and 2T and between 2T and 1T, and soluble COD reductions between current practices and 2T declined slightly with respect to storm intensity. Between 2T and 1T, however, the reductions in soluble COD became larger as storm intensity increased. The results indicate that controlling erosion significantly reduces sediment, nutrients and soluble COD at the watershed outlet.

---

[6] Nonpoint source pollutants are sediment, nitrogen and phosphorus attached to sediment, and soluble chemical oxygen demand (COD).

Table 7. Nonpoint source pollutants for alternative erosion control levels in Tom Beall Watershed.

Water pollutant	Storm event year	Erosion control level					
		Current practices		2T		1T	
Erosion[1] (tons)	10	34,559	(37%)[2]	31,238	(21%)	14,841	(20%)
	25	48,465	(41%)	43,795	(25%)	22,209	(24%)
	50	56,456	(43%)	50,956	(26%)	26,464	(26%)
	100	65,278	(44%)	58,947	(28%)	31,030	(27%)
Sediment[3] (tons)	10	12,793		6,560		2,968	
	25	19,871		10,745		5,330	
	50	23,906		13,249		6,881	
	100	28,722		16,293		8,378	
Nitrogen[3] in sediment (lb)	10	39,125		22,935		12,246	
	25	55,419		34,040		19,303	
	50	64,447		40,474		23,454	
	100	74,202		47,427		27,917	
Phosphorus[3] in sediment (lbs)	10	19,511		11,520		6,123	
	25	27,709		17,020		9,652	
	50	32,276		20,237		11,727	
	100	37,049		23,766		14,010	
Soluble[3] chemical oxygen demand (lb)	10	92,676		65,070		60,608	
	25	134,084		100,770		92,713	
	50	163,396		120,489		111,979	
	100	179,539		141,348		131,281	

[1] Total amount of erosion generated on all fields in watershed.

[2] Figure in parentheses is the sediment delivery ratio.

[3] Total amount of sediment, nitrogen, phosphorus and chemical demand (COD) released at watershed outlet.

Conclusions

The economic efficiency of erosion reduction in the Tom Beall Watershed can be increased substantially by targeting erosion control to the most highly erodible land. The cost per ton of erosion reduction on the most erodible farms is about four times lower than on the least erodible farms, three times lower than on the second most erodible farms and two times lower than on the third most erodible farm.

Erosion control directly affected the optimal choice of resource management systems and total net farm income in the watershed. Maximizing total net farm income for a 40 percent reduction in total erosion without cost sharing requires substituting minimum tillage with contour farming for conventional tillage with contour farming. Total net farm income increased 1.5 percent with minimum tillage because it had a higher net return per acre than conventional tillage. For current levels of cost sharing and a 40 percent reduction in erosion, total net farm income increased 16 percent by replacing conventional tillage-contour farming with minimum tillage and divided-slope farming. A 40 percent reduction in erosion corresponds to an average erosion rate for the watershed of 10 tons per acre per year (2T).

Table 8. Total nitrogen, total phosphorus and soluble chemical oxygen demand for alternative erosion control levels in Tom Beall Watershed (lb/acre).

Water pollutant	Storm event	Erosion control level		
		Current practices	2T	1T
Total nitrogen[1]	10	4.06	2.55	1.47
	25	5.71	3.71	2.23
	50	6.62	4.37	2.67
	100	7.60	5.08	3.14
Total phosphorus[1]	10	1.92	1.17	0.64
	25	2.72	1.71	0.99
	50	3.17	2.03	1.20
	100	3.63	2.37	1.42
Soluble chemical oxygen demand[2]	10	8.93	6.27	5.84
	25	12.92	9.71	9.03
	50	15.07	11.61	10.79
	100	17.30	13.62	12.65

[1] In sediment plus dissolved in runoff water.

[2] In runoff.

Resource management systems that maximized total net farm income subject to a 70 percent reduction in erosion without cost sharing were predominantly no-till with contour farming. This alternative resulted in a 35 percent decrease in total net farm income. To achieve a 70 percent reduction in erosion with cost sharing required extensive use of no-till with divided-slope farming and decreased total net farm income 18 percent. Reducing current erosion by 70 percent is equivalent to achieving an average erosion rate for the watershed of 5 tons per acre per year (1T).

The socially optimal level of erosion reduction occurs where the net social marginal cost equals the net marginal (offsite) benefit of erosion reduction. The net social marginal cost curve showed that the socially optimal level of erosion reduction in the watershed is at least 40 percent. To justify greater erosion reduction, the marginal offiste benefit must exceed the net social marginal cost of additional erosion reduction.

Idaho has established a maximum erosion rate of 7.5 tons per acre per year (1.5T) for highly erodible lands in connection with the conservation compliance provision of the Food Security Act of 1985. Results of this study indicate that those resource management systems that decreased the average erosion rate in the watershed to 7.5 tons per acre per year reduced total erosion by 55 percent and increased total net farm income by 6 percent with cost sharing.

Reducing the average erosion rate to 5 tons per acre per year resulted in a 70 percent decline in total erosion and an 18 percent drop in total net farm income with cost sharing.

The optimal resource management systems for reducing erosion to 1T and 2T substantially lowered sediment, nitrogen, phosphorus and chemical oxygen demand at the watershed outlet. Averaged over four storm events (10, 25, 50 and 100 years), the amount of sediment, nitrogen, phosphorus and chemical oxygen demand declined by 45, 38, 38 and 24 percent, respectively, at the 2T level, and by 72, 64, 64 and 29 percent, respectively, at the 1T level.

Literature Cited

Alt, Klaus, and John Putman. 1987. Soil erosion: Dramatic in places but not a severe threat to productivity. Agricultural Outlook. 4:28-30. USDA-ERS.

Berglund, Steve, and E. L. Michalson. 1980. Economics of the five-point program in Latah County. Univ. of Idaho Ag. Exp. Sta. Res. Bull. 113.

Braden, J. B., and G. V. Johnson. 1985. Efficiency of sediment control policies. Univ. of Illinois Dept. Ag. Econ. Staff Paper, Series E.

Brooks, R. O., and E. L. Michalson. 1983. An economic evaluation of best management practices in the Cow Creek Watershed, Latah County, Idaho. Univ. of Idaho Ag. Exp. Sta. Res. Bull. 127.

Brusven, M. A., and G. P. Carpenter. 1987. Nonpoint source pesticide contamination of waters in Idaho Palouse creeks and streams and its possible effects on aquatic organisms. Progress report to Western Regional Pesticide Impact Assessment Program, Davis, CA.

Brusven, M. A., Ron Rhew and Roger Haro. 1986. Baseline monitoring analysis of Lapwai Creek and selected tributaries in relation to nonpoint source agricultural pollution. Research Report submitted to Nez Perce Tribe, Lapwai, Idaho.

Carlson, J. E., D. A. Dillman and W. R. Lassey. 1985. The farmer and erosion: Factors influencing the use of control practices. Univ. of Idaho Ag. Exp. Sta. Res. Bull. 601.

Crowder, B. M., and C. E. Young. 1985. Modeling agricultural nonpoint source pollution for economic evaluation of the Conestoga Headwaters RCWP project. USDA-ERS Staff Rep. AGES850614.

Crowder, B. M., D. J. Epp, H. B. Pionke, C. E. Young, J. G. Beirlein and E. J. Partenheimer. 1984. The effects on farm income of constraining soil and plant nutrient losses: An application of the CREAMS simulation model. Pennsylvania Ag. Exp. Sta. Bull. 850.

Duda, A. M. 1985. Environmental and economic damage caused by sediment and agricultural nonpoint sources. Water Res. Bull. 21:225-232.

Fitzsimmons, D. W., J. R. Busch, R. B. Long, K. H. Lindeborg, G. M. McMaster, C. E. Brockway, L. R. Conklin, G. C. Lewis, C. W. Berg and E. L. Michalson. 1978. Evaluation of measures for controlling sediment and nutrient losses from irrigated areas. U.S. Environmental Protection Agency, EPA-600/2-78-138.

Frevert, Kathleen, and B. M. Crowder. 1987. An analysis of agricultural nonpoint pollution control options in the St. Albans Bay Watershed. USDA-ERS Staff Rep. AGES870423.

Gianessi, L. P., H. M. Peskin, Pierre Crosson and Cyndi Puffer. 1986. Nonpoint source pollution controls: Are cropland controls the answer? Resources for the Future, Inc. special report.

Harker, J. M., and E. L. Michalson. 1978. Soil conservation and farm management planning: A descriptive economic model. Univ. of Idaho Ag. Exp. Sta. Res. Bull. 104.

Idaho Soil Conservation Commission, Idaho Division of Environment and USDA Soil Conservation Service. 1987. Lower Portneuf River: Agricultural water pollution abatement plan, Portneuf Soil and Water Conservation District, Bannock County, Idaho.

Kucera, P. A., J. H. Johnson and M. A. Bear. 1983. A biological and physical inventory of the streams within the Nez Perce Reservation. Bonneville Power Administration.

Lindeborg, K. H., L. R. Conklin, R. B. Long and E. L. Michalson. 1975. Economic analysis of on-farm methods for controlling sediment and nutrient losses. *In* Proceedings, National Conference on Irrigation Return Flow Quality Management. Colorado State Univ., Fort Collins.

McGrann, J. M., K. D. Olson, T. A. Powell and T. R. Nelson. 1986. Microcomputer budget management system user manual. Texas A&M University Dept. Ag. Econ.

Moore, Elbert. 1987. Combating non-point source pollution. Univ. of Idaho, Idaho Agriculture Today No. 171 (radio series transcript).

Pavelis, G. A. 1985. Conservation and erosion control costs in the United States. USDA-ERS Staff Report AGES850423.

Pelletier, R. E. 1985. Evaluating nonpoint source pollution using remotely sensed data in soil erosion models. J. Soil and Water Cons. 40:333-335.

Poincelot, R. P. 1987. Toward a more sustainable agriculture. AVI Publ. Co., Inc. Westport, CT.

Ribaudo, M. O. 1986. Reducing soil erosion: Offsite benefits. USDA-ERS Ag. Econ. Report 561.

Ribaudo, M. O. 1987. Agriculture's impact on water quality. *In* Agricultural resources: Cropland, water and conservation situation and outlook report. USDA-ERS AR-8.

Shi, Hong-Qi. 1987. Integrated assessment of soil erosion and water quality in Idaho's Tom Beall Watershed. M.S. thesis, Univ. of Idaho Dept. Ag. Econ. and Rural Soc.

Strohbehn, Roger (ed.). 1986. An economic analysis of USDA erosion control programs: A new perspective. USDA-ERS Ag. Econ. Report 560.

Taylor, D. B., and D. L. Young. 1985. The influence of technological progress on the long run farm level economics of soil conservation. West. J. Ag. Econ. 10:63-76.

Thomas, Howard, L. D. Logan and William McNamee. 1985. Draft Mission-Lapwai erosion-sedimentation analysis. USDA, U.S. Forest Service and Idaho Dept. of Water Res.

U.S. Department of Agriculture, Soil Conservation Service, Forest Service, Idaho Department of Health and Welfare, Division of Environment, Idaho Soil Conservation Commission and Soil Conservation Districts. 1985. Detailed work outline, Idaho special studies, erosion control and water quality.

U.S. Department of Agriculture, Soil Conservation Service. 1984. Idaho's soil and water: Condition and trends.

U.S. Department of Agriculture, Soil Conservation Service. 1986. Lower Granite sedimentation study (amended). West National Technical Center, Portland, OR.

U.S. Department of Agriculture. 1981. Soil, water and related resources in the United States: Status, condition and trends, 1980 RCA Appraisal, Part I. General Accounting Office, Washington, DC.

U.S. Department of Agriculture. 1987. The second RCA appraisal: Soil, water and related resources on nonfederal land in the United States, analysis of condition and trends. Review draft.

Walker, D. J., P. E. Patterson and J. R. Hamilton. 1986. Costs and benefits of improving irrigation return flow water quality in the Rock Creek, Idaho, rural clean water program. Univ. of Idaho Ag. Exp. Sta. Res. Bull. 139.

Wischmeier, W. H., and D. D. Smith. 1978. Predicting rainfall erosion losses. USDA Ag. Handbook 537.

Young, R. A., C. A. Onstad, D. D. Bosch and W. P. Anderson. 1985. Agricultural nonpoint source pollution model, a guide to model users. North Central Soil Cons. Res. Lab., Morris, MN.

APPENDIX — Crop Budgets

Table A.3. Crop Budget for Winter Wheat with Conventional Tillage

— ECONOMIC COSTS and RETURNS —
Owner Budget
by Stage

WINTER WHEAT
CONVENTIONAL TILLAGE SYSTEM

Date of Printing : 12/16/87

GROSS INCOME Description	Quantity	Unit	$ / Unit	Total
WINTER WHEAT	77.000	BU.	4.3800	337.26
Total GROSS Income				337.26

VARIABLE COST Description	Quantity	Unit	$ / Unit	Total
PREHARVEST				
FERT. SPREADER	1.000	Acre	1.250	1.25
ANHYDROUS AMMON.	110.000	lb.	.160	17.60
SULFUR	12.000	lb.	.180	2.16
WHEAT SEED	70.000	lb.	.100	7.00
CUSTOM SPRAY	1.000	ACRE	4.000	4.00
URAN	5.000	GAL	.890	4.45
DIREX	0.375	qt.	4.860	1.82
BUCKTRIL	0.250	qt.	24.720	6.18
CUSTOM SPRAY	1.000	ACRE	4.000	4.00
HOELON	1.000	QT.	13.500	13.50
Fuel & Lube - Machinery		Acre		6.24
Repairs - Machinery		Acre		4.61
Labor - Machinery	1.122	Hour	6.001	6.73
Total PREHARVEST				79.54
Interest - OC Borrowed	81.249	Dol.	0.100	8.12
HARVEST				
Fuel & Lube - Machinery		Acre		3.26
Repairs - Machinery		Acre		4.63
Labor - Machinery	0.829	Hour	6.000	4.98
Total HARVEST				12.86
Total VARIABLE COST				100.53

Break-Even Price, Total Variable Cost $1.30 per BU. of WINTER WHEAT

GROSS INCOME minus VARIABLE COST 236.73

Table A.3. (cont.)

FIXED COST Description	Unit	Total
Machinery and Equipment	Acre	52.43
Land	Acre	50.00
Total FIXED Cost		102.43

Break-Even Price, Total Cost $2.63 per BU. of WINTER WHEAT

FIXED COST Description	Unit	Total
Total of ALL Cost		202.96
NET PROJECTED RETURNS		134.30

Table A.4. Crop Budget for Winter Wheat with Minimum Tillage

— ECONOMIC COSTS and RETURNS —
Owner Budget
by Stage

WINTER WHEAT AFTER PEAS
MINIMUM TILL

Date of Printing : 12/16/87

GROSS INCOME Description	Quantity	Unit	$ / Unit	Total
WINTER WHEAT	75.000	BU.	4.3800	328.50
Total GROSS Income				328.50

VARIABLE COST Description	Quantity	Unit	$ / Unit	Total
PREHARVEST				
FERT. SPREADER	1.000	Acre	1.250	1.25
NITROGEN	80.000	lb.	.240	19.20
SULFUR	12.000	lb.	.180	2.16
WHEAT SEED	60.000	lb.	.100	6.00
GROUND SPRAY	1.000	Acre	4.250	4.25
BUCKTRIL	0.250	qt.	24.720	6.18
DIREX	0.375	qt.	4.860	1.82
CUSTOM SPRAY	1.000	ACRE	4.000	4.00
HOELON	1.000	QT.	13.500	13.50
Fuel & Lube - Machinery		Acre		4.11
Repairs - Machinery		Acre		3.62
Labor - Machinery	0.913	Hour	5.717	5.22
Total PREHARVEST				71.32
Interest - OC Borrowed	92.495	Dol.	0.100	9.25
HARVEST				
Fuel & Lube - Machinery		Acre		3.26
Repairs - Machinery		Acre		4.63
Labor - Machinery	0.829	Hour	6.000	4.98
Total HARVEST				12.86
Total VARIABLE COST				93.43

Break-Even Price, Total Variable Cost $1.24 per BU. of WINTER WHEAT

GROSS INCOME minus VARIABLE COST 235.07

Table A.4. (cont.)

FIXED COST Description	Unit	Total
Machinery and Equipment	Acre	58.39
Land	Acre	50.00
Total FIXED Cost		108.39

Break-Even Price, Total Cost $2.69 per BU. of WINTER WHEAT

FIXED COST Description	Unit	Total
Total of ALL Cost		201.81
NET PROJECTED RETURNS		126.69

Table A.5. Crop Budget for Winter Wheat with No Tillage

-- ECONOMIC COSTS and RETURNS --
Owner Budget
by Stage

WINTER WHEAT AFTER PEAS
NO TILLAGE

GROSS INCOME Description	Quantity	Unit	$/unit	Total
WINTER WHEAT	65.000	BU.	4.3800	284.7
Total GROSS Income				284.7

VARIABLE COST Description	Quantity	Unit	$/unit	Total
PREHARVEST				
NITROGEN	130.00	LBS.	0.19	$24.70
PHOSPHORUS	20.00	LBS.	0.33	6.60
SULFUR	20.00	LBS.	0.25	5.00
WHEAT SEED	85.00	LBS.	0.12	10.20
CUSTOM HIRE NO-TILL DRILL	1.00	ACRE	29.00	29.00
KARMEX	1.00	LBS.	5.20	5.20
MCPA SODIUM SALT	2.00	QT.	2.40	4.80
BENLATE	1.00	LBS.	13.27	13.27
HOELON	0.67	PT.	6.92	4.62
CUSTOM AERIAL	0.25	ACRE	4.00	1.00
MACHINERY REPAIR	1.00	ACRE	0.38	0.38
MACHINERY FUEL	1.00	ACRE	0.92	0.92
MACHINERY LUBE	1.00	ACRE	0.14	0.14
TRACTOR REPAIR	1.00	ACRE	0.69	0.69
TRACTOR FUEL	1.00	ACRE	0.68	0.68
TRACTOR LUBE	1.00	ACRE	0.10	0.10
LABOR(TRACTOR & MACHINERY)	0.47	HOUR	6.50	3.08
CROP INSURANCE	1.00	ACRE	3.24	3.24
OVERHEAD COST	129.83	DOL.	0.05	6.49
INTEREST ON OP. CAPITAL	73.97	DOL.	0.12	8.88
Total PREHARVEST				$130.09
HARVEST				
MACHINERY REPAIR	1.00	ACRE	2.78	2.78
MACHINERY FUEL	1.00	ACRE	0.75	0.75
MACHINERY LUBE	1.00	ACRE	0.11	0.11
LABOR(TRACTOR & MACHINERY)	0.40	HOUR	6.50	2.60
Total HARVEST				$ 6.24
TOTAL VARIABLE COST				$136.33

Break-Even Price, Total Variable Cost $2.10/bu of WINTER WHEAT

Table A.5. (cont.)

FIXED COST Description	Unit	Total
Machinery and Equipment	Acre	24.96
Land	Acre	58.75
Total FIXED Cost		$ 83.71

Break-Even Price, Total Cost $ 3.38 per BU. of WINTER WHEAT

Total of All Cost	220.04
NET PROJECTED RETURN	64.66

Note: Budget for winter wheat with no tillage system was generated using the same equipment, machinery hours, and input material levels as the budget for winter wheat with no tillage generated by Caplan (1987).

Table A.6. Crop Budget for Peas with Conventional Tillage

— ECONOMIC COSTS and RETURNS —
Owner Budget
by Stage

Dry Peas
Conventional Tillage

Date of Printing : 10/07/87

GROSS INCOME Description	Quantity	Unit	$ / Unit	Total
DRY PEAS	22.000	cwt	8.0000	176.00
Total GROSS Income				176.00

VARIABLE COST Description	Quantity	Unit	$ / Unit	Total
PREHARVEST				
PEA SEED	160.000	cwt.	.140	22.40
PRE-MERGE 3	12.000	qt	3.080	36.96
SPRAYER	1.000	acre	1.250	1.25
AVADEX	1.250	qt.	9.140	11.42
SPRAYER	1.000	acre	1.250	1.25
IMIDAN	2.000	lb.	3.180	6.36
AIR SPRAY	1.000	ACRE	4.250	4.25
Fuel & Lube - Machinery		Acre		5.04
Repairs - Machinery		Acre		3.25
Labor - Machinery	0.974	Hour	6.001	5.84
Total PREHARVEST				98.03
Interest - OC Borrowed	61.791	Dol.	0.100	6.18
HARVEST				
Fuel & Lube - Machinery		Acre		2.59
Repairs - Machinery		Acre		3.83
Labor - Machinery	0.559	Hour	6.001	3.36
Total HARVEST				9.78
Total VARIABLE COST				113.98

Break-Even Price, Total Variable Cost $5.18 per cwt of DRY PEAS

GROSS INCOME minus VARIABLE COST 62.02

Table A.6. (cont.)

FIXED COST Description	Unit	Total
Machinery and Equipment	Acre	41.23
Land	Acre	50.00
Total FIXED Cost		91.23
Break-Even Price, Total Cost $9.32 per cwt of DRY PEAS		
Total of ALL Cost		205.22
NET PROJECTED RETURNS		-29.22

About This Research

This research was supported in part by the Idaho Water Resources Research Institute and the Idaho Soil Conservation Service. Tony Prato and Hong-Qi Shi are professor and former graduate student, respectively, Department of Agricultural Economics and Rural Sociology, and Ron Rhew and Merlyn Brusven are former graduate student and professor, respectively, Division of Entomology, Department of Plant, Soil and Entomological Sciences, University of Idaho, Moscow, Idaho.

Published and distributed by the
Idaho Agricultural Experiment Station
Gary A. Lee, Director
University of Idaho College of Agriculture
· Moscow, Idaho 83843

500, March 1989

$1.50 per copy