694 5/9/86 # 14042

Marginal Analysis of Soil Loss Control on the Mission-Lapwai Watershed, Idaho

Station Bulletin 667
May 1986

Agricultural Experiment Station
Oregon State University, Corvallis

MARGINAL ANALYSIS OF SOIL LOSS CONTROL ON THE MISSION-LAPWAI WATERSHED, IDAHO

William A. McNamee

Howard R. Thomas

Stanley F. Miller

William A. McNamee is a former research assistant and Stanley F. Miller is a professor, Department of Agricultural and Resource Economics, Oregon State University, Corvallis. Howard R. Thomas is an economist with the U.S. Department of Agriculture, Soil Conservation Service, West National Technical Center, Portland, Oregon.

CONTENTS

TABLES

FIGURES

MAPS

MARGINAL ANALYSIS OF SOIL LOSS CONTROL ON THE MISSION-LAPWAI WATERSHED, IDAHO

PREFACE

Use of our nation's waterways for a variety of purposes is often affected by the intrusion of sediment. In its natural state, erosion and sedimentation have a renewing effect on lands and waterways. For instance, natural levels of sedimentation provide building materials for sand bars and river deltas and supply nutrients which support the ecosystem of estuaries and marshes. Excessive erosion caused by human activity, however, accelerates the degradation of source lands and often overburdens waterways with sediment. It is this unnatural acceleration of nature's leveling system that is addressed in this report.

The relationship between the onsite and offsite costs of erosion and the costs and benefits of controlling excessive soil loss is not well defined and difficult to measure. The goal of this report is to examine this important relationship. The area selected for study is the Mission-Lapwai Watershed, a tributary to Idaho's Clearwater River. This watershed is about 10 miles east of the Clearwater River's confluence with the Snake River. The adjacent cities of Lewiston, Idaho, and Clarkston, Washington, are situated at the Clearwater and Snake's confluence. This location was chosen for study because of the important economic consequences of sedimentation in the Lewiston-Clarkston vicinity.

This report will present the analytical design and analysis results of the Mission-Lapwai Watershed study. A comprehensive discussion of the development and formulation of the mathematical models used in the analysis is available in OSU Agricultural Experiment Station Special Report 767. It is intended that the analytical tools used for this study will be useful in other watershed studies which have similar resource conditions.

INTRODUCTION

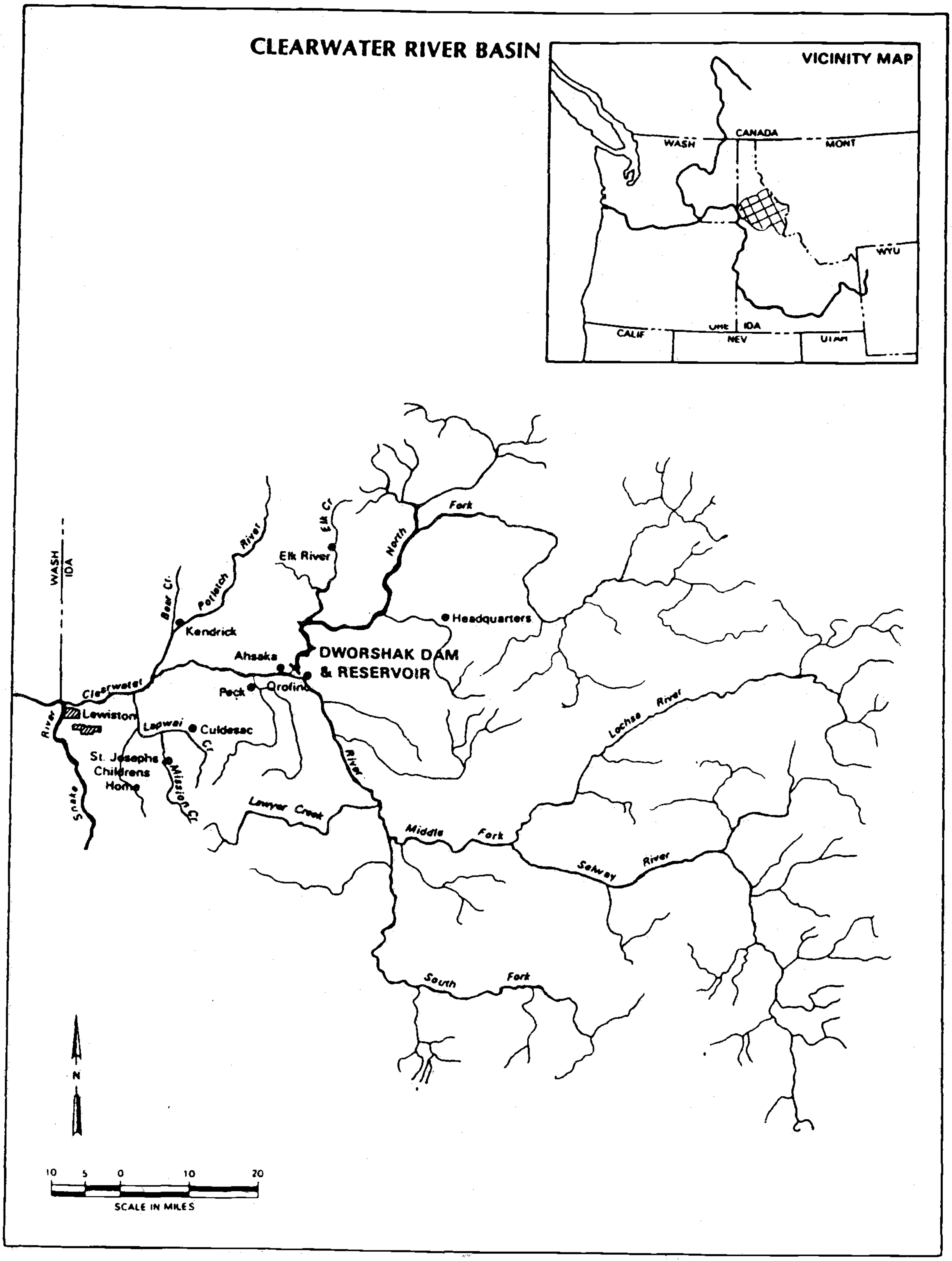
In 1975, the completion of Lower Granite Dam on the Snake River extended slackwater river barge service to the adjacent cities of Clarkston, Washington, and Lewiston, Idaho. Less than 10 years later, this area faces serious navigation channel maintenance problems because of sedimentation of Lower Granite reservoir [Corps, 1984].[1/] Continued sedimentation also threatens the long-term adequacy of the levee system which protects much of downtown Lewiston, Idaho, from the Clearwater River. The Army Corp of Engineers maintains navigation by dredging silt material at an average cost of $2.75 per ton. This cost is expected to increase significantly, however, as future disposal of dredged material may include transporting the tailings several miles to an inland disposal site.[2/]

A potential alternative to the high cost of dredging sediment from Lower Granite reservoir is to reduce the sediment flow in the Clearwater and Snake Rivers by treating the soil loss problem at its source. Any long-term solution to the Lower Granite reservoir sedimentation problem should consider land treatment alternatives. This report addresses this issue by evaluating the physical and economic potential for soil loss control on the Mission-Lapwai Watershed of the Clearwater River Basin (Map 1). Although this watershed contributes less than 5 percent of the total sediment flow to Lower Granite Reservoir, it was chosen for analysis because it

---

1/ Lower Granite Dam is on the Snake River, about 35 miles below the Lewiston-Clarkston vicinity.

2/ The dredged material is placed along the river bank, however, limited space makes future disposal in this manner doubtful.



Map 1. Clearwater River Basin.

encompasses a wide range of land and water resource problems [USDA, 1985].

Soil erosion on the Mission-Lapwai Watershed presents several problems. Excessive topsoil loss threatens the long-term productivity of the watershed's agricultural lands. In addition, the riparian ecosystem bordering Mission and Lapwai Creeks is poorly managed and has lost much of its ability to filter sediment flow. The resulting siltation of stream waters damages fish spawning and rearing habitat. Downstream water users (i.e., municipalities, industry, etc.) face potential costs because of turbidity in their water supply. Finally, suspended sediment flowing from the watershed to the Clearwater River eventually settles to the bottom of the slackwater behind Lower Granite Dam, causing navigation channel maintenance problems and increasing the flood threat to Lewiston, Idaho [USDA, 1985].

The goal of this report is to determine the economic efficiency of controlling soil loss at its land source by evaluating the onsite and offsite costs and benefits of soil loss control on the Mission-Lapwai Watershed. Specific objectives are: (1) to estimate the cost effectiveness of various soil loss control land management practices, (2) to determine the value of onsite and offsite (downstream) benefits of sediment reduction, and (3) to develop an economically efficient strategy for soil loss control based on a marginal analysis of the benefits and costs. The analytical design developed may prove adaptable for use in related erosion control studies.[3/]

3/ A comprehensive discussion of the development and formulation of the mathematical models used in this analysis of the Mission-Lapwai Watershed is available in OSU Agricultural Experiment Station Special Report 767.

Description of Mission-Lapwai Watershed

Mission Creek is a tributary of Lapwai Creek within the Clearwater River Basin. Mission Creek flows into Lapwai Creek roughly 7 miles from Lapwai's confluence with the Clearwater River. The portion of the watershed drained by Lapwai Creek is nearly 200,000 acres and is similar in physical structure and land use to that of Mission Creek, which is 43,520 drained acres (Table 1) [Chase, 1984]. Mission Creek was the focus of this study. It was assumed that Mission Creek results are expandable to the Lapwai Creek portion of the watershed.

Table 1. Land Use in Mission Creek Area (acres)

Agricultural		16,470
Dry Cropland	13,800	
Pasture and Hay	2,670	
Forest and Forested Range		24,870
Rangeland		2,176
Total		43,516

Source: Mission-Lapwai Erosion/Sedimentation Analysis, Idaho Cooperative Irrigation Study, 1985.

Mission Creek runs about 17 miles from its headwaters on the northeast corner of the Camas Prairie to its confluence with Lapwai Creek. The course of the stream cuts through many layers of basalt.[4/] The uplands are rolling and gentle and the stream's intermediate section cuts through very steep canyons. The lower stream segment flows through a valley, which varies in width from a few hundred feet

4/ Rock of volcanic origin.

to one-half mile [USDA, 1985]. The topography divides the Mission Creek area into three distinct treatment units: (1) the rolling hills of the upper region, (2) the intermediate canyons, and (3) the lower bottom lands (Map 2). Elevations range from 4,500 to 1,500 feet. The drop over the stream's 17 mile course is roughly 3,000 feet.

In the Mission Creek area, 38 percent of the land is in agricultural use, 57 percent is forest or forested range, and the remaining 5 percent is rangeland. The main agricultural crops are wheat, barley, peas, hay, and pasture. On forest land, stands of lodgepole pine predominate. Other species include Ponderosa pine, Western larch, and Douglas fir. Commercial timber harvests have converted much timbered land to forested range and cropland.

The climate of the area is influenced by weather systems from the Pacific. Average annual precipitation varies from 20 inches at the confluence of Mission and Lapwai Creeks to 28 inches on the higher elevations. Most precipitation occurs from October to March. Winters are cold with temperatures below freezing. Summers are dry and hot. The crop growing season averages 110 to 130 days.

In the Mission Creek drainage area, landownership is primarily by private individuals. The Nez Perce Indians maintain title to a few hundred acres of reservation land. The Bureau of Land Management (BLM) and the State of Idaho own a few small parcels (Table 2).

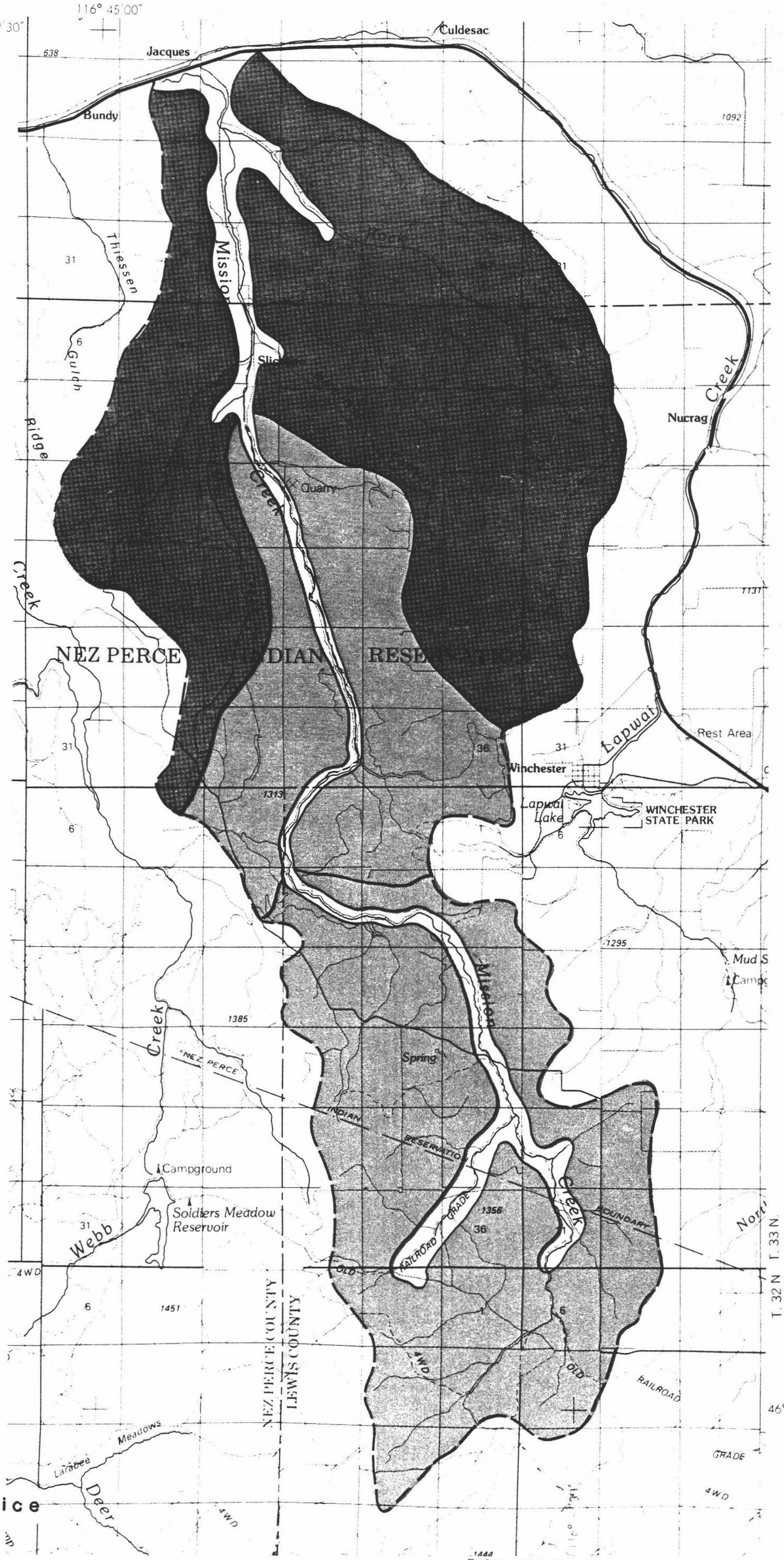
Economic Profile of Local Area

The Lewiston-Clarkston vicinity represents the principal urban area influenced by sediment flow from the Mission-Lapwai Watershed. Lewiston, the Nez Perce County seat, is at the confluence of the

TREATMENT REGIONS

LEGEND

- Riparian
- Bottom
- Canyon
- Upper



MISSION CREEK/ LAPWAI

COOPERATIVE RIVER BASIN STUDY

LEWIS & NEZ PERCE COUNTIES, IDAHO

June 1984 SCS Boise, Idaho

0 1 2 3 4 Miles

0 10000 20000 Feet

Source: USGS 1:100000 Planimetric Series

USDA Soil Conservation Service

USDA-SCS-FORT WORTH, TEXAS 1984

4-R-39030

Table 2. Landownership, Mission Creek Area

Ownership		Acres
Private		40,365
Nez Perce Indians		2,515
BLM		240
Idaho		400
	TOTAL	43,520

Source: Mission-Lapwai Erosion/Sedimentation Analysis, Idaho Cooperative Irrigation Study, 1985.

Clearwater and Snake Rivers. Directly across the Snake River is Clarkston (Asotin County, Washington), which combines with Lewiston to form the primary commercial center for North Central Idaho and portions of eastern Washington.

The 1980 population of the combined counties was 50,043 (Table 3). The area's economy is moderately diverse. The major manufacturing industries are lumber and wood products and paper and allied products. Potlatch Corporation is the major employer in these sectors. Of the nonmanufacturing services, wholesale and retail trade, service businesses, and government are the primary employers (Table 4).

Three port authorities are in the Lewiston-Clarkston Valley -- the Port of Lewiston, the Port of Clarkston, and the Port of Wilma. The ports became operational with completion of Lower Granite Dam on the Snake River in 1975. River barge service is primarily used by grain growers from southeastern Washington, northern Idaho, Montana, the Dakotas, and Wyoming. Grain is shipped by truck to port

Table 3. Population and Density, Nez Perce and Asotin Counties and the cities of Lewiston and Clarkston.

	Population		Square	Density	
	1970	1980	Miles	1970	1980
Nez Perce	30,376	33,220	844	36.0	39.4
Asotin	13,799	16,823	633	21.8	26.5
Lewiston	26,068	27,986			
Clarkston	10,109	10,586			

Source: 1980 Census of Population

Table 4. Nonagricultural wage and salary workers, Nez Perce and Asotin Counties.

	1981	1982	1983	1984
Nonagri. Wage and Salary	17,860	17,010	17,830	18,240
Total Manufacturing	4,480	4,200	4,360	4,170
Food & Kindred Products	560	570	450	590
Lumber & Wood Products	1,690	1,580	1,620	1,470
Paper & Allied Products	1,230	1,210	1,370	1,340
Other Manufacturing	1,000	840	920	770
Total Nonmanufacturing	13,380	12,810	13,470	14,070
Construction	900	790	880	970
Transportation	650	640	630	620
Communication & Utilities	380	380	350	390
Wholesale Trade	950	930	930	1,050
Retail Trade	3,400	3,340	3,510	3,590
Finance, Ins., & Real Est.	970	980	1,040	1,120
Service & Misc. & Mining	3,670	3,510	3,880	3,950
Government, Administration	1,470	1,410	1,360	1,360
Government, Education	990	830	890	1,020

Source: Idaho Department of Employment

terminals, where it is transferred to river barges for water-borne shipment to Lower Columbia River export facilities (Table 5). The ports also handle shipments of pulp and paper products and some containerized shipments of hay cubes, peas, and lentils. Barge service delays from siltation of the navigation channel are very costly to port operations [Rush, 1984].

Table 5. Grain Shipments (tons) from Area Ports

	Port of Lewiston	Port of Clarkston	Port of Wilma	Total
1975	147,527	---	---	147,527
1977	588,939	75,005	---	663,944
1979	884,276	380,045	---	1,264,321
1981	1,024,330	315,587	321,609	1,661,527
1983	807,635	351,475	316,808	1,475,918

Source: Army Corps of Engineers

METHOD OF ANALYSIS

To determine the economic efficiency of soil loss control on the Mission-Lapwai Watershed, three specific values must be determined: (1) the on-site costs of controlling soil loss on erosive lands of the Mission-Lapwai Watershed; (2) the on-site benefit of maintaining the long-term productive potential of the land resource via erosion reduction; and (3) the downstream (off-site) benefits from reduced sediment and turbidity in river water. Potential off-site beneficiaries include fisheries, municipal and industrial water users, and the recipients of navigation and flood control improvements.

In the analysis, soil loss control costs must be balance against control benefits, therefore, a common unit of measurement is needed. Benefits are measured in dollars per ton of reduced sediment flow in the stream's water supply. Thus, soil loss control practices on each land source also will be measured in terms of dollars per ton of sediment reduction. Soil loss control practices will be judged to be economically viable if the aggregate marginal benefit exceeds the marginal cost.

Since some benefits of soil loss control occur downstream, a model was developed to relate soil loss from Mission Creek lands to sediment deposition in the Clearwater River. The "Sediment Transport" model uses estimated sediment levels and probability of sediment movement by storm event to calculate sediment deposition and movement through the stream system. This procedure relates the physical quantity of sediment available for transport through the stream system to the sediment outflow into the Clearwater River. Since the amount of sediment available for transport is a function of soil loss and land management practices to control soil loss, the model provides a means to relate land treatment impacts through the stream system to sediment deposition in the Clearwater River. Through this procedure it is possible to compare the cost effectiveness of land treatments to other means of controlling or removing sediment. The "Sediment Transport" model provides the necessary linkage between on-site soil loss control costs and off-site (downstream) benefits.

Land Source Costs

Erosion and sedimentation in the Mission Creek area arise from three prime sources: farming practices on agricultural lands, forestry activities (i.e., logging, road construction, etc.), and the lack of soil-stabilizing vegetation along the riparian zone bordering Mission Creek. Land use practices which cause soil loss and potential management practices which reduce this loss vary by land source.

Separate models to evaluate the soil loss problem found on each land source were developed. Linear programming (LP) was chosen as the analytical tool. The LP objective function for the agricultural model was the maximization of farm net income subject to resource constraints; the objective function for the forest and riparian LP models was the minimization of soil loss control costs subject to resource constraints. Permissible levels of erosion and sediment were included as resource constraints in each model formulation. LP model coefficients were specified in common units (most units were specified on a per acre basis), thus all model results were readily comparable. Note that a thorough discussion of the formulation of the LP models used in this analysis is given in OSU Agricultural Experiment Station Special Report 767.

The construction of agricultural, forest, and riparian LP models allowed soil loss (measured in tons) from each land source to be constrained below its present (1983) level. As the constraint was reduced, the optimal soil loss control practices were modified. Each change resulted from a new decision variable (i.e., land management practice) entering the optimal solution, which in turn changed the marginal cost (shadow price) of soil loss control on each land source. These marginal cost schedules from each model allowed comparison of soil loss control costs among land sources.

Benefit Values

Land productivity effects and off-site benefits must also be determined. As noted, soil loss can potentially reduce long-term agricultural productivity. A mathematical simulation model developed by Thomas and Lodwick (1981) was used to measure losses in land productivity.[5/] Downstream benefits were analyzed separately and are discussed later.

Summary

To briefly summarize the method of analysis, the marginal cost of controlling soil loss at its land source was predicted by evaluating results of the agricultural, forest, and riparian LP models. These results indicated which land management practices were cost effective

---

5/ See Appendix for a discussion of the Thomas and Lodwick simulation model.

in reducing topsoil erosion. The sediment transport model estimated how much of the sediment entering Mission Creek -- as derived from the LP model results -- was transported downstream to the Clearwater River.[6/] Individual benefit values in terms of dollars per ton of sediment reduction next were estimated. The individual benefit values were summed and compared with the land source marginal cost schedule (Figure 1).

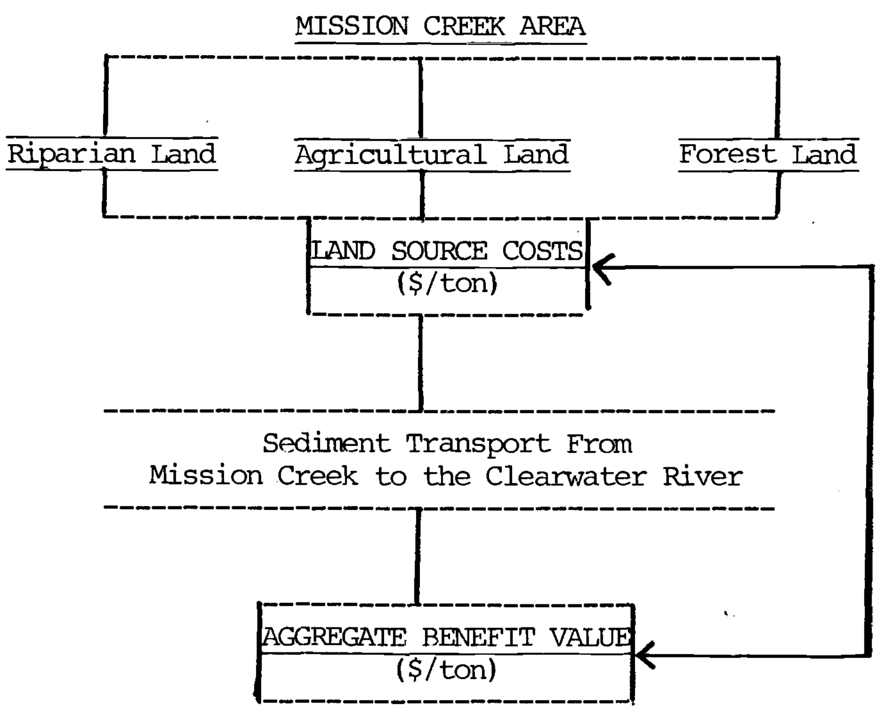


Figure 1. Comparison of the marginal costs and benefits of soil loss control.

6/ This estimate of sediment flow is important for comparing marginal costs and benefits, since one ton of sediment reduction in Mission Creek does not necessarily imply one less ton of sediment flow in the Clearwater River (i.e., some sediment deposition occurs along the stream's course).

LAND SOURCE COSTS OF SOIL LOSS CONTROL, MODEL FORMULATIONS, AND RESULTS

Agricultural Lands: There are 16,470 acres of agricultural land in the Mission Creek drainage. The area was divided into seven land treatment units (Table 6). Four crops can be produced on the seven land units under three alternative tillage methods. In addition, four soil loss control treatments were considered. Alternative crop/tillage/treatment combinations produce different levels of surface erosion and farm net income. Per acre erosion rates were calculated with the Universal Soil Loss Equation (USLE).[7/] Net income was computed with the Oklahoma Crop Budget Generator.[8/] The sediment

Table 6. Agricultural Land Inventory

CROPS	LAND UNIT			TILLAGE	TREATMENT
	Code	Definition	Acres		
Wheat	A1	5-15% slope	700	Conventional	Normal
Peas	A2	16-25% slope	4,000	Minimum	Div Slp
Barley	A3	>25% slope	2,000	No-Till	Strcrp
Pasture	A4	3-7% slope	7,100		Terrace
	A5	Irr. Pasture	770		
	A6	Nonirr. Past.	900		
	A7	25-40% slope	1,000		

7/ The USLE is a formula which can compute soil loss per acre based upon six factors: (1) a rainfall erosion factor, (2) a soil erodability factor, (3) length of slope factor, (4) steepness of slope factor, (5) cover type and management factor, and (6) erosion control practice factor.

8/ This is a computer program that calculates enterprise cost-return budgets based upon factor usage and prices.

delivery rate from the agricultural lands to Mission Creek was assumed to be a fixed percentage of the erosion rate upon each land treatment unit.

Homogenous levels of soil management exist in all treatment units. The primary tillage practice consists of moldboard plowing. As a result, most of the crop residue is turned under, leaving the soil in a highly erosive condition.[9/] No conservation treatments are being used [Chase, 1984].

Erosion and sediment rates, crop yield, and production cost and net return depend on the cropping pattern. Ten crop sequences were determined applicable for the Mission Creek area (Table 7).

Table 7. Crop Sequences for Mission Creek

Code	Definition
WW	Winter wheat after winter wheat
WP	Winter wheat after peas.
PG	Peas after grain.
WF	Winter wheat after fallow.
FG	Fallow after grain.
WG	Winter wheat after barley grain.
BG	Spring barley after grain.
HG	Hay and pasture after grain.
BH	Spring barley after hay and pasture.
HH	Hay and pasture after hay and pasture.

9/ General definitions for tillage alternatives are: (1) Conventional tillage is where 100 percent of the topsoil is mixed by plowing and secondary tillage operations, usually a moldboard plow is used; (2) Minimum tillage involves less soil disturbance with some crop residue left on the soil surface, a chisel plow is often used. Weeds are controlled with more herbicides and less cultivation; (3) No tillage involves only intermediate seed zone preparation and less than 25 percent of the soil surface is worked.

According to Carlson (1981), to control soil loss, farmers are more likely to change production practices than to change the type of crops they crow. This attitude was incorporated into the LP model by allowing changes in tillage and treatment practice, while holding crop acreages constant. Crop yields under minimum and no-tillage were assessed a 5 percent yield penalty, since research [Harder, 1980; STEEP, 1980; Hoag, 1984] has indicated potential reduced yields with conservation tillage practices.

Benchmark estimates of the current levels of erosion, sedimentation, and net income (Table 8) were predicted by initially running the model with crop, tillage, and treatment acreages set to their present (1983) levels. Soil loss rates were not constrained. Interpretation of LP results indicate the present annual sediment flow from agricultural lands to riparian land units is 78,393 tons (Table 8). Soil loss is most severe on agricultural land units A2 (16 to 25% slope), A3 (greater than 25% slope), and A4 (cut-over forest, 3 to 7% slope). These three land units account for 95 percent of total agricultural sediment flow.

The next step in the analysis was to parametrically reduce the permissible level of sediment on each land treatment unit. (The crop acreages were held constant; only tillage and treatment practices were allowed to vary). The resulting optimal solutions provided estimates of the marginal cost of sediment control and predicted which management practices are most cost effective in reducting soil loss.

A line graph of the marginal cost schedule for sediment control on agricultural lands (Figure 2) shows that marginal costs are initially negative, indicating the "best of both worlds" -- sediment

Table 8. Present (1983) Levels of Agricultural Land Erosion, Sediment, and Net Returns for the Mission Creek Area

LAND UNIT	CROP	TILLAGE	TREAT- MENT	ACRES	EROS (tons)	SEDI (tons)	NET RETURNS
A1	WW	CONV	NORMAL	100	1,050	263	$ 3,300
A1	PG	CONV	NORMAL	300	4,050	1,014	1,500
A1	WP	CONV	NORMAL	300	4,800	1,200	34,860
TOTAL	**	*****	*****	700	9,900	2,477	$ 39,660
A2	WG	CONV	NORMAL	1,000	18,600	5,580	$ 33,000
A2	BG	CONV	NORMAL	1,000	17,000	5,100	12,400
A2	PG	CONV	NORMAL	500	8,900	2,670	2,500
A2	WP	CONV	NORMAL	500	15,250	4,575	48,950
A2	WF	CONV	NORMAL	500	23,700	7,110	56,450
A2	FG	CONV	NORMAL	500	8,950	2,685	(20,000)
TOTAL	**	****	*****	4,000	92,400	27,720	$133,300
A3	BG	CONV	NORMAL	600	11,400	3,648	$ 7,440
A3	WG	CONV	NORMAL	600	15,720	5,028	19,800
A3	WF	CONV	NORMAL	400	20,920	6,696	37,840
A3	FG	CONV	NORMAL	400	7,840	2,508	(16,000)
TOTAL	**	****	*****	2,000	55,880	17,880	$ 49,080
A4	BG	CONV	NORMAL	1,350	18,090	3,618	($10,800)
A4	WG	CONV	NORMAL	1,350	18,090	3,618	44,550
A4	PG	CONV	NORMAL	700	8,120	1,624	3,500
A4	WF	CONV	NORMAL	1,500	48,000	9,600	141,900
A4	FG	CONV	NORMAL	1,500	34,950	6,990	(60,000)
A4	WF	CONV	NORMAL	700	21,000	4,200	55,720
TOTAL	**	****	*****	7,100	148,250	29,650	$174,870
A5	HG	CONV	NORMAL	70	203	41	($ 2,800)
A5	BH	CONV	NORMAL	70	63	12	4,074
A5	HH	CONV	NORMAL	630	0	0	50,400
TOTAL	**	****	*****	770	266	53	$ 51,647
A6	HG	CONV	NORMAL	50	725	145	($ 4,000)
A6	BH	CONV	NORMAL	50	290	58	(150)
A6	HH	CONV	NORMAL	800	0	0	8,000
TOTAL	**	****	*****	900	1,015	203	$ 3,850

Table 8 (Cont). Present (1983) Levels of Agricultural Land Erosion, Sediment, and Net Returns for the Mission Creek Area

LAND UNIT	CROP	TILLAGE	TREAT- MENT	ACRES	EROS (tons)	SEDI (tons)	NET RETURNS
A7	HG	CONV	NORMAL	50	560	224	($ 4,000)
A7	BH	CONV	NORMAL	50	465	186	870
A7	HH	CONV	NORMAL	900	0	0	9,000
TOTAL	**	****	*****	1000	1,025	410	$ 5,870
MISSION CREEK TOTAL				16,470	308,736	78,393	$458,304

can be reduced and net returns increased simultaneously. This situation occurs as minimum tillage replaces conventional tillage in the optimal cropping pattern ("Tillage Used" column of Table 9). In general, minimum tillage has lower machinery requirements and thus lower per acre production costs. Even though crop yields under the minimum tillage alternative were assessed a penalty of 5 percent, net returns initially rise as minimum tillage replaces conventional tillage in the LP optimal solution. After roughly 10,000 tons of sediment reduction, marginal costs become positive and net returns begin to decline as further sediment reduction requires use of the more expensive treatments of divided slope farming, no-tillage, and terraces.

Sediment can be reduced by 10,721 tons before marginal costs become positive (see the "Sediment Reduction" column of Table 9). This reduction is achieved by converting 3,400 (i.e., 1,350 + 1,350 + 700) acres on land unit A4 to minimum tillage, and converting 400 (i.e., 100 + 300) acres on land unit A1 to minimum tillage. Land units A2 and A3 have 2,500 (i.e., 1,000 + 1,000 + 500) and 1,200

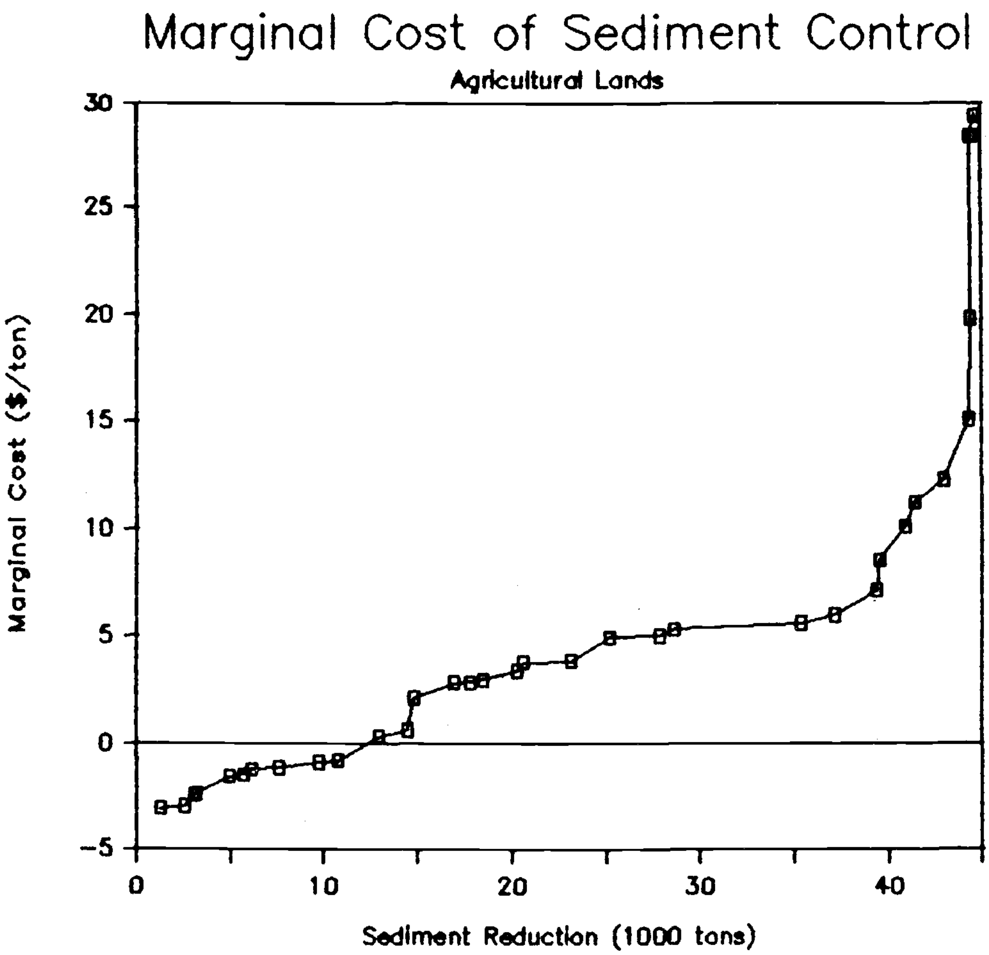


Figure 2. Marginal cost schedule for sediment control upon agricultural lands.

Table 9. Marginal Cost ($/ton) of Sediment Control, Agricultural Land Treatment Units

MARGINAL COST ($/ton)	LAND UNIT	CROP TREATED	TILLAGE USED	TREATMENT USED	ACRES TREATED	SEDIMENT REDUCTION (tons)
($3.08)	A4	BG	MINIMUM	NORMAL	1,350	1,269
($2.97)	A4	WG	MINIMUM	NORMAL	1,350	2,538
($2.42)	A4	PG	MINIMUM	NORMAL	700	3,028
($2.37)	A1	WW	MINIMUM	NORMAL	100	3,146
($1.55)	A2	WG	MINIMUM	NORMAL	1,000	4,946
($1.48)	A3	BG	MINIMUM	NORMAL	600	5,714
($1.23)	A1	PG	MINIMUM	NORMAL	300	6,128
($1.15)	A3	WG	MINIMUM	NORMAL	600	7,586
($0.90)	A2	BG	MINIMUM	NORMAL	1,000	9,686
($0.82)	A2	PG	MINIMUM	NORMAL	500	10,721
$0.32	A4	WP	MINIMUM	NORMAL	700	12,891
$0.61	A2	WP	MINIMUM	NORMAL	500	14,436
$2.12	A1	WP	MINIMUM	NORMAL	300	14,832
$2.85	A4	FG	CONV	DIV SLP	1,500	16,932
$2.87	A2	PG	NO-TILL	NORMAL	500	17,802
$2.98	A2	FG	CONV	DIV SLP	500	18,472
$3.38	A2	WF	CONV	DIV SLP	500	20,242
$3.78	A1	PF	NO-TILL	NORMAL	300	20,638
$3.84	A3	WG	NO-TILL	NORMAL	600	23,134
$4.93	A2	WP	NO-TILL	NORMAL	500	25,159
$5.00	A4	FG	CONV	TERRACES	1,500	27,859
$5.31	A4	PG	NO-TILL	NORMAL	700	28,607
$5.58	A4	WF	CONV	TERRACES	1,500	35,327
$5.98	A3	BG	NO-TILL	NORMAL	600	37,133
$7.11	A2	WG	NO-TILL	NORMAL	1,000	39,383
$8.52	A7	BH	NO-TILL	NORMAL	50	39,495
$10.10	A4	WP	NO-TILL	NORMAL	700	40,881
$11.23	A1	WP	NO-TILL	NORMAL	300	41,415
$12.24	A2	BG	NO-TILL	NORMAL	1,000	42,885
$15.09	A4	WG	NO-TILL	NORMAL	1,350	44,316
$19.80	A6	HG	NO-TILL	TERRACES	50	44,367
$28.39	A6	BG	CONV	TERRACES	50	44,407
$29.41	A2	WP	NO-TILL	DIV SLP	500	44,662

Note: Marginal cost values in parenthesis are negative.

(i.e., 600 + 600) acres switched to minimum tillage, respectively ("Acres Treated" column of Table 9). Once the marginal cost becomes positive, the economics of further sediment reduction depend on a comparison with the value of the estimated marginal benefit (i.e., fisheries, navigation, municipal and industrial use, etc.). Sediment reduction will remain economically viable as long as the marginal benefit of sediment control exceeds the marginal cost.

Forest Lands: In the 24,870 acres of Mission Creek forest land, road construction represents the major source of surface erosion. There is no timber harvesting so only alternative management practices which reduce erosion and sedimentation caused by roaded areas were considered in the forest LP model.

To remain consistent with the agricultural land analysis, forest LP model coefficients were specified on a per acre basis, requiring the conversion of miles of forest roads to acres. Three types of forest roads were analyzed: (1) one-lane dirt roads, (2) one and one-half-lane gravel roads, and (3) two-lane gravel roads. Surface erosion varies by road type and location. To account for location, five separate forest treatment units were determined (Table 10).

Five alternative soil loss control management practices were identified. The first consists of directly seeding grass along the roadway at an estimated cost of $150 per acre.[10/] The next alternative establishes slash windrow filters along dirt roads at a cost of $650 per acre. A slash windrow filter involves placing slash (i.e., limbs, cuttings, etc.) across the road surface to slow water

---

[10/] Includes site preparation, materials, and labor.

Table 10. Forest Land Treatment Units.

Code	Type	Canopy Cover	Slope	Road Acres
F1	Mixed Forest & Range	10 to 60%	<40%	14.4
F2	Streamside & Wetlands	N/A	N/A	20.4
F3	Forest	>60%	>40%	44.1
F4	Forest	>60%	<40%	82.0
F5	Mixed Forest & Range	10 to 60%	>40%	44.0

runoff and trap sediment flow. Planting vegetation (grass and shrubs) and placing water bars along dirt roadways at a cost of $1,750 per acre is the third management practice. The fourth alternative is to place mulch along the roadway, seed grass and fertilize at a cost of $2,350 per acre, and the final alternative expands on the fourth by placing netting to better stabilize the soil and cots an estimated $3,300 per acre.

The objective function of the forest LP model minimized the cost of sediment reduction. Under present (1983) conditions, the 204.9 acres of forest roads produce 919 tons of sediment annually (Table 11). Thus, given the present agricultural sediment flow of 78,393 tons, forest roads produce only a small proportion of the total sediment flow to Mission Creek.

After determining the present soil loss rate, the sediment constraint was parametrically reduced. Results indicated the marginal cost of reducing soil loss from the roaded areas of forest lands and which management treatments were most cost effective.[11/] The marginal cost schedule begins at $1.87 per ton of sediment reduction and

[11/] Marginal cost estimates for forest road soil loss control treatments assume that the investment period is 25 years and the discount rate is 8.375%.

Table 11. Present Levels of Forest Road Erosion and Sediment, Mission Creek

LAND UNIT	ROAD TYPE	ACRES	EROSION (tons)	SEDIMENT (tons)
F1	2 LN GRAVEL	5.0	18.5	5.5
F1	1.5 LN GRAV.	5.8	19.1	5.2
F1	1 LN DIRT	3.6	108.7	16.6
TOTAL	---	14.4	146.4	27.3
F2	2 LN GRAVEL	10.3	58.7	17.5
F2	1.5 LN GRAV.	5.0	25.5	7.0
F2	1 LN DIRT	5.1	238.2	35.7
TOTAL	---	20.4	322.4	60.2
F3	2 LN GRAVEL	20.0	206.0	62.0
F3	1.5 LN GRAV.	13.1	123.1	34.1
F3	1 LN DIRT	11.0	946.0	141.9
TOTAL	---	44.1	1,275.1	238.0
F4	2 LN GRAVEL	41.0	164.0	49.2
F4	1.5 LN GRAV.	20.5	73.8	20.5
F4	1 LN DIRT	20.5	656.0	98.4
TOTAL	---	82.0	893.8	168.1
F5	2 LN GRAVEL	2.0	17.2	5.2
F5	1.5 LN GRAV.	2.0	15.2	4.2
F5	1 LN DIRT	40.0	2,772.0	416.0
TOTAL	---	44.0	2,804.4	425.4
FOREST LAND TOTAL		204.9	5,442.0	919.0

increases quite rapidly (Figure 3). Planting grass on the on-lane dirt roads at an investment cost of $150 per acre is the first treatment to enter the sediment reduction optimal solution (Table 12). Seeding grass on the gravel roads ($150 per acre) and the use of slash windrow filters (i.e., placing limbs, cuttings, etc. across the road surface) on dirt roads, at a cost of $650 per acre, next enter the optimal solution. In comparison to the effect on agricultural lands, potential sediment reduction on forest lands is small and more expensive per unit.

Riparian Lands: Before entering the stream's water supply, sediment flowing from the agricultural and forest lands must pass through the riparian zone bordering Mission Creek. The streambank condition and vegetative cover of the riparian lands greatly influence the water quality of Mission Creek. The riparian LP model was constructed to evaluate management practices designed to improve the streamside's physical condition, thereby reducing sediment inflow to stream waters. the specific objective of the model was to minimize the cost of sediment reduction. The optimal solutions predict which management practices control sediment in a cost effective manner and provide an estimate of the marginal cost of sediment reduction within the riparian zone.

The topography of the Mission Creek Watershed requires that the riparian zone be divided into three segments: (1) the rolling hills of the "Upper Riparian", (2) the intermediate "Canyons", and (3) the lower "Bottomlands." Sedimentation from agricultural and forest lands flows into each of these riparian segments (Table 13). In addition, the land of each riparian zone contributes sediment to stream waters.

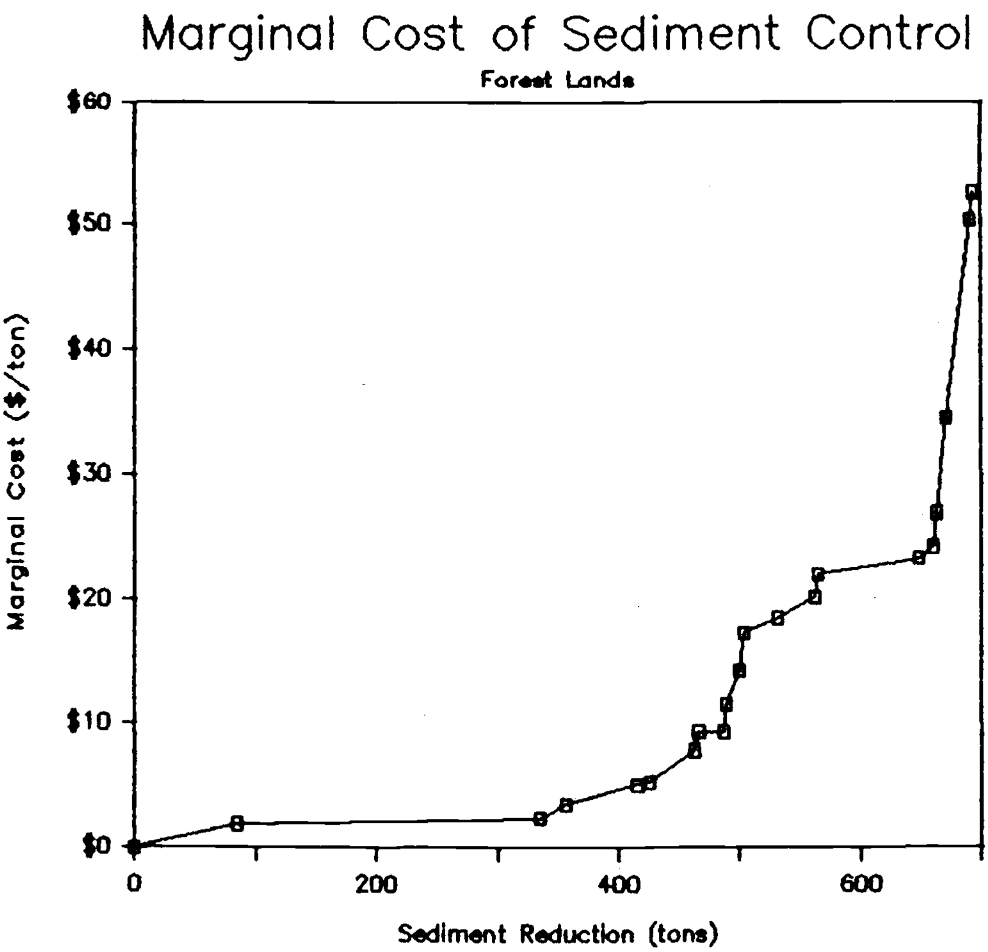


Figure 3. Marginal cost schedule for sediment control upon forest lands.

Table 12. Marginal Cost ($/ton) of Sediment Reduction, Forest Land Treatment Units

MARGINAL COST ($/ton)	LAND UNIT	ROAD TYPE	TREATMENT USED	ACRES	SEDI REDUCT (tons)
$ 1.87	F3	1 LN DIRT	SEED GRASS	11.0	85
$ 2.33	F5	1 LN DIRT	SEED GRASS	40.0	335
$ 3.45	F2	1 LN DIRT	SEED GRASS	5.1	356
$ 5.04	F4	1 LN DIRT	SEED GRASS	20.5	415
$ 5.26	F1	1 LN DIRT	SEED GRASS	3.6	425
$ 7.80	F3	2 LN GRAVEL	SEED GRASS	20.0	462
$ 9.30	F3	1.5 LN GRAV	SEED GRASS	13.1	466
$ 9.30	F5	2 LN GRAVEL	SEED GRASS	2.0	486
$ 11.51	F5	1.5 LN GRAV	SEED GRASS	2.0	488
$ 14.22	F2	2 LN GRAVEL	SEED GRASS	10.3	499
$ 17.27	F2	1.5 LN GRAV	SEED GRASS	5.0	503
$ 18.47	F3	1LN DIRT	SLASH FILT WIND	11.0	532
$ 20.15	F4	2 LN GRAVEL	SEED GRASS	41.0	561
$ 21.98	F1	2 LN GRAVEL	SEED GRASS	5.0	564
$ 23.25	F5	1 LN DIRT	SLASH FILT WIND	40.0	648
$ 24.17	F4	1.5 LN GRAV	SEED GRASS	20.5	660
$ 26.86	F1	1.5 LN GRAV	SEED GRASS	5.8	663
$ 34.53	F2	1 LN DIRT	SLASH FILT WIND	5.1	670
$ 50.31	F4	1 LN DIRT	SLASH FILT WIND	20.5	690
$ 52.55	F1	1 LN DIRT	SLASH FILT WIND	3.6	693
$152.80	F3	1 LN DIRT	GRS, NET, MLCH, FERT	11.0	712
$410.65	F4	1 LN DIRT	GRS, NET, MLCH, FERT	20.5	724

Table 13. Percentage of Total Sediment Flow from Agricultural and Forest Land Units that Enters Each Riparian Land Unit

Agricultural & Forest Land Units	Riparian Land Units Upper	Canyon	Bottom
A1	--	--	100%
A2	100%	--	--
A3	--	30%	70%
A4	100%	--	--
A5	--	100%	--
A6	25%	--	75%
A7	--	--	100%
F1	67%	--	33%
F2	50%	50%	--
F3	100%	--	--
F4	100%	--	--
F5	--	100%	--

Management practices implemented on the riparian treatment units reduce the amount of sediment that enters Mission Creek from the agricultural and forest lands and also reduce soil loss from the riparian area itself. Ten alternative soil loss control management practices were identified for the riparian lands (Table 14). There are 45 acres in the Upper riparian unit, 41 acres in the Canyon unit, and 77.5 acres in the riparian Bottomlands. For each land unit, current sediment delivery caused by riparian land and streamside erosion is estimated to be 90, 70, and 100 tons per acre, respectively.

Table 14. Riparian Land Management Practices

1.) Fencing land to tightly control livestock
2.) Moderate livestock watering and grazing control
3.) Grading and vegetating streambank
4.) Structural stabilization of streambank
5.) Control road crossings
6.) Culvert improvement
7.) Bridge support improvement
8.) Seeding grass
9.) Planting shrubs
10.) Planting grass, shrubs, and trees

LP model results indicate that under present (1983) conditions the largest amount (84%) of sedimentation in Mission Creek comes from agricultural lands and 15 percent comes from the riparian lands, only 1 percent comes from the forest roads (Table 15). Total annual sediment inflow to Mission Creek is estimated to be 93,982 tons (Table 16.

Table 15. Present Level of Sediment Inflow (tons) to Mission Creek, by Land Source

Source	Acres	Sediment Inflow (tons)
Agricultural Land	16,470	78,393
Forest Land (Roads)	205	919
Riparian Land	164	14,670

Table 16. Present Level of Sediment Inflow (tons) to Mission Creek, by Riparian Treatment Unit

	Land Source		
Riparian Treatment Unit	Agricultural & Forest	Riparian	Total
Upper	35,349	4,050	39,399
Canyons	6,467	2,870	9,337
Bottom	37,496	7,750	45,246
Total Inflow	79,312	14,670	93,982

The largest sediment inflow comes from the Bottom (48%) and Upper (42%) treatment units. Only 10 percent of total sediment inflow enters through the Canyons. The marginal costs for controlling sediment inflow to Mission Creek are relatively low (Figure 4). Riparian LP model results indicate that significant sediment reduction can be achieved via the practices of controlling road crossings, seeding grass, and livestock watering control (Table 17). These three practices would reduce sediment inflow by an estimated 20,627 tons (22%) annually. The marginal cost would range between $.01 and $.29 per ton of sediment reduction.

These riparian LP results are of a static nature. The physical ability of the riparian zone to trap and control sediment is limited.

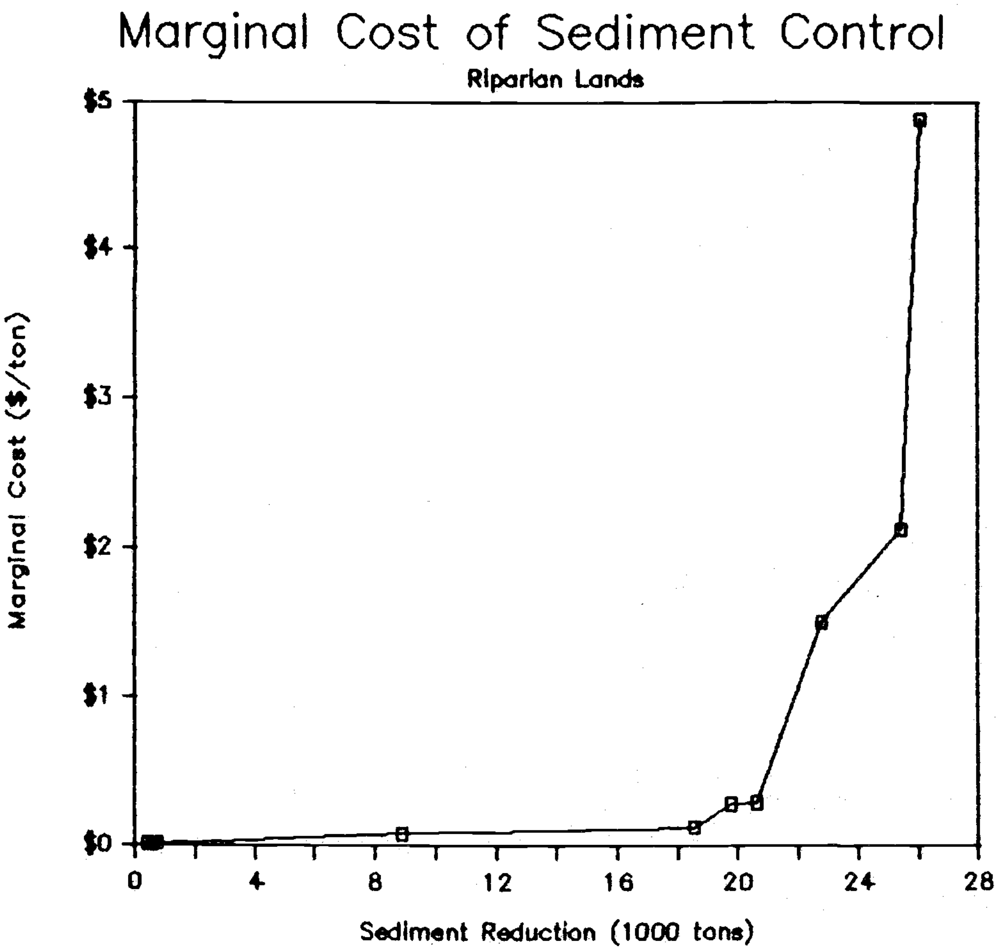


Figure 4. Marginal cost schedule for sediment control upon riparian lands.

Table 17. Marginal Cost ($/ton) of Sediment Control, Riparian Land Treatment Units

MARGINAL COST ($/ton)	RIPARIAN SEGMENT	TREATMENT USED	SEDIMENT REDUCTION (tons)
$0.01	BOTTOM	CONTROL ROAD CROSSINGS	387
$0.01	UPPER	CONTROL ROAD CROSSINGS	587
$0.01	CANYON	CONTROL ROAD CROSSINGS	731
$0.08	UPPER	PLANT SEED GRASS	8,916
$0.12	BOTTOM	PLANT SEED GRASS	18,545
$0.28	CANYON	LIVESTOCK WATERING CONTROL	19,736
$0.29	CANYON	PLANT SEED GRASS	20,627
$1.50	UPPER	PLANT GRASS, SHRUBS, & TREES	22,798
$2.12	BOTTOM	PLANT GRASS, SHRUBS, & TREES	25,448
$4.88	CANYON	PLANT GRASS, SHRUBS, & TREES	26,056

Over time the effectiveness of riparian management practices may change as the sediment flow from agricultural and forest lands varies. The problem of measuring the long-run effectiveness of riparian management practices will be further discussed in the marginal analysis section of this report.

Sediment Transport Model

This model was designed to account for the quantity of sediment that enters Mission Creek from each riparian segment and, via sediment delivery ratios, to provide an estimate of the tons of sedimentation flowing from the Mission-Lapwai Watershed to the Clearwater River. Results of the riparian LP model runs predict the amount of sediment that enters the water flow of each riparian segment of Mission Creek. These results are input to the sediment transport model that calculates, via sediment delivery ratios, an estimate of the tons of sedimentation flowing from Mission Creek to the Clearwater River.

With the determined present (1983) sediment inflow to Mission Creek, the sediment transport model predicts the following results (Table 18).

Under "present" conditions, total annual sediment inflow to Mission Creek is 93,982 tons.[12/] The middle row of Table 18 shows the tons of sediment contributed by each stream segment to the Clearwater River, the bottom row lists the cumulative sediment flow. Total annual sedimentation entering the Clearwater River from Mission creek is estimated to be 61,808 tons.

Table 18. Present Sediment Inflow to Mission Creek and Cumulative Delivery to the Clearwater River.

	Mission Creek		
	Upper	Canyons	Bottom
Sediment Inflow (tons)	39,399	9,337	45,246
Sediment Delivery to Clearwater River (tons) by Segment	23,829	7,538	30,441
Cumulative Delivery to Clearwater River (tons)	23,829	31,367	61,808

As surface erosion control practices applied to the Mission Creek watershed are changed, the sediment transport model provides a means to estimate the resulting change in sediment inflow to the Clearwater River. The sediment delivery ratios used in the model were developed by U.S. Forest Service hydrologists, who used field testing and historical data to make the estimates [Logan, 1984]. The ratios are exogenous to the model.

12/ 39,399 + 9,337 + 45,246.

BENEFITS OF SOIL LOSS CONTROL

Five potential benefits of erosion and sediment control were investigated: (1) fishery enhancement; (2) reduction of municipal and industrial water treatment costs; (3) less dredging of navigation channels; (4) mitigation of flood threat (principally to Lewiston, Idaho); and (5) maintenance of long-term agricultural productivity. Each potential benefit will be discussed individually.

The analysis of each benefit focuses on present conditions in the Mission-Lapwai Watershed and the Lewiston-Clarkston area. The social efficiency of past government or private investments that affected present conditions will not be considered. For example, navigation channel maintenance and the present flood threat to Lewiston are the direct result of the construction of Lower Granite Dam on the Snake River. They are economic externalities that the Army Corp of Engineers, in evaluating the construction of Lower Granite Dam, considered but did not accurately estimate. The completion of Lower Granite Dam, however, essentially creates an irreversible condition. Therefore, the benefit analysis of this section will consider present environmental conditions as given, recognizing that they are partially the result of past social investment decisions.

Fishery Enhancement: The spawning and rearing habitat of Mission Creek is in poor condition and not producing fish to its potential. The two prime limiting factors are: (1) high water temperatures, especially during the summer months, are lethal or near lethal, and (2) fine sediments embedded in spawning gravel. The latter factor reduces spawning capacity and rearing habitat. Mission Creek is functioning between 20 to 40 percent of its full fishery potential [Brouha, 1984].

To upgrade fishery capacity, Brouha recommended a habitat improvement program involving bank stabilization and planting of trees and shrubs. Implementation of the recommended improvement program could potentially increase the number of annually returning summer steelhead spawners by 190 fish. The U.S. Fish and Wildlife Service has estimated that for the Upper Columbia/Snake region the value of a returning summer steelhead spawner is $214 [Brouha, 1984].

Discounting the annual value flow of the enhanced steelhead fishery over a 25-year period yields a present value of $255,860.[13/] A discount rate of 8.375 percent was used.[14/] Riparian LP model results indicate that the fishery enhancement practice of planting shrubs and trees reduces sediment inflow to Mission Creek by 25,000 tons annually (625,000 tons over a 25-year period). In addition, the riparian LP model predicts the marginal cost of sediment reduction via the practice of planting trees and shrubs to range from $1.50 to $4.88 per ton, depending on the riparian section being treated and sediment inflow from the agricultural and forest lands.[15/]

13/ Brouha estimated it would require 9 years from the date of plan implementation to achieve a returning summer steelhead spawner run of 190. Other studies which have valued steelhead fisheries for the Columbia system (i.e., Brown-1976, Smith-1978, and Loomis-1984) suggest that $217 per returning steelhead spawner is an optimistically high value.

14/ The discount rate is that of the Water Resource Council.

15/ See Table 17.

Dividing the estimated present value of fishery enhancement by the predicted 25-year sediment reduction figures yields a benefit value for an enhanced summer steelhead fishery of \$.41 per ton of sediment reduction. (Lowering the discount rate to 4 percent would increase the per ton benefit value to \$.71). Thus, the cost of fishery enhancement exceeds the benefits if the only benefits realized were those of the improved fishery. This conclusion, however, is incomplete -- as the total benefit per ton of sediment reduction is the sum of all individual benefits.

Municipal and Industrial Water Use: The urban and industrial area impacted by sediment in the Clearwater River is Lewiston, Idaho, and the adjacent city of Clarkston, Washington. Clarkston obtains its municipal water supply from ground aquifiers (i.e., wells). Lewiston, however, obtains its municipal water from the Clearwater River and thus the city's water treatment costs are affected by the quality of river waters. Data were collected from Lewiston's water treatment facility regarding the change in chemical treatment procedure as the level of turbidity (measured in parts per million - ppm) in the plant's water supply varied. A linear function was estimated to determine variable water treatment cost as a function of turbidity. The dependent variable was daily chemical treatment cost and the independent variable was water turbidity measured in parts per million (ppm). Results were:

$$\text{Daily Treatment Cost} = \$88.24 + \$.58\ (\text{ppm})$$

$$t \text{ statistics} = (10.83) \quad (8.19)$$

$$R^2 = .90$$

The average flow of the Clearwater River is 30,000 CFS (Cubic Feet per Second). It was calculated that at this flow rate, 100 tons of sediment per day would flow by Lewiston for each unit ppm of turbidity. Therefore, each ton of sediment flowing in the Clearwater River raises Lewiston's municipal water treatment cost by $.0058. Note that fixed costs are not included in this estimate since they do not depend on the water intake turbidity level. Chemical usage does change as the turbidity level varies, but it represents only a small portion of total costs.

Although benefits of sediment reduction to municipal water users are not significant now, this situation could be altered if Lewiston finds it necessary to transport sediment from its water treatment plant to some disposal site outside city boundaries. Trucking costs could run between $1.50 and $2 per ton of sediment. The city recognizes this as a potential future problem, but is hopeful that a new sediment pond will reduce any future disposal problems ([Erickson, 1984].

The major industrial facility using large amounts of Clearwater River water is the Potlatch Corporation, just east of Lewiston. Potlatch Corporation treats water used in its pulp and paper operation. The cost structure for Potlatch's water treatment facility is similar to that of the municipal plant, in that a large proportion of total costs are fixed. Regression analysis was used to estimate daily chemical water treatment cost as a function of the water supply turbidity level. Results were:

$$\text{Daily Treatment Cost} = \$1193.69 + \$21.12(\text{ppm})$$

$$\text{t statistics} = (23.16) \quad (24.04)$$

$$R^2 = .97$$

Dividing the regression coefficient for the turbidity level by 100 indicates that each ton of sediment flowing in the Clearwater River raises Potlatch's water treatment cost by $.21. Potlatch's paper and pulp operation requires that the turbidity level of treated water be kept below 5 ppm [Jones, 1984]. This is a much stricter requirement than for municipal water and adds significantly to the treatment cost. In addition, Potlatch intakes roughly 10 times as much river water as does the Lewiston municipal plant (30 million gallons per day versus 3 million gallons per day).

Maintenance of Navigation Channel: With the completion of Lower Granite Dam on the Snake River in 1975, slackwater river barge navigation was extended to the Lewiston-Clarkston area. The U.S. Army Corps of Engineers was given the responsibility to maintain a 15-foot navigation channel to Lewiston and Clarkston. In recent years, siltation of the navigation channel has been serious. Since 1981, the Corps has dredged more than 330,000 cubic yards of material (one cubic yard equals one ton) at an approximate cost of $2.75 per ton [Corps, 1984]. The dredged material was placed along the river bank. Future disposal of dredging material in this manner is doubtful and may include transporting the material by truck several miles to an inland disposal site. If this occurs, dredging and disposal costs could well reach $4.50 per ton.

The serious nature of the sedimentation problem was exemplified during the 1984 summer. The Port of Clarkston was closed because of channel siltation in front of the port's grain terminal. Channel depth was 6.5 feet. The port was forced to reroute its grain shipments to the Port of Lewiston at a cost of $.10 per bushel. Port operations were restored in mid-August after 12,000 cubic yards of material were dredged at a cost of $40,000. Total cost of the closure to the Port of Clarkston was nearly $115,000 [Rush, 1984].

For this study, the assumption is made that one ton of sediment deposition on the river bottom results in one ton of material that will need to be dredged. Given this assumption, a benefit value for navigation maintenance of $4.50 per ton of sediment reduction will be used in sections of this report.

Flood Control: A levee system along the banks of the Clearwater River protects Lewiston from flooding. Silt deposited on the river's bottom raises the water's height and increases the flood threat. One management option to cope with this threat is to raise the height of the levee system. The Army Corps of Engineers is studying this alternative, but does not yet have adequate sediment data to develop a levee redesign plan [Corps, 1984].

The current solution is to dredge the river bottom so the levee system remains functionally adequate. The cost of dredging would be the same as that for navigation channel maintenance ($4.50 per ton). In the Lewiston-Clarkston vicinity, however, a reduction of one ton of sediment simultaneously benefits navigation and flood control.[16/] Thus, a value of $4.50 per ton of reduced sediment will be allocated to navigation maintenance and flood control.

16/ In other studies, this may not be the case since flood control and navigation benefits may occur at separate locations.

Long-Term Agricultural Productivity: Recognizing topsoil as one input of crop production, it seems reasonable to assume that loss of topsoil from surface erosion eventually will cause crop yields to decline. This assumed productivity loss, however, is not readily apparent when one looks at crop yield trends in Pacific Northwest agriculture. The yield loss is often hidden by technological advances which allow other production inputs (i.e., machinery, fertilizer, varietal improvements, etc.) to substitute for the lost topsoil. An evaluation of the benefits of soil loss control on long-term productivity must isolate the influence of technological change from that of topsoil depletion.

To accomplish this, the model developed by Thomas and Lodwick (1981), which links a technological change coefficient with erosion-induced productivity decline estimates, was used. Model results predict the net present value of productivity loss for each of the land treatment units of the Mission Creek area.[17/] Present value figures were calculated for the current (1983) rate of soil loss and an assumed 25 percent reduction in soil loss (Table 19). Productivity loss values were discounted for a period of 25 years at an interest rate of 8.375 percent.[18/]

Dividing the change in net present value of productivity loss by the aggregate change in sediment level over a 25-year period gives an

---

17/ See Appendix for a summary description of the Thomas and Lodwick model.

18/ The useful life of most land management practices is assumed to be 25 years.

Table 19. Net Present Value of Soil Loss for Agricultural Lands

Land Unit	Present Level		25% Reduction	
	Sediment	Present Value	Sediment	Present Value
A1	2,477	$ 16,946	1,858	$ 12,709
A2	27,720	189,640	20,790	142,230
A3	17,880	146,790	13,410	110,093
A4	29,650	243,419	22,238	182,564
A5	53	290	40	218
A6	203	1,667	152	1,250
A7	410	3,366	308	2,524
TOTAL	78,393	$602,117	58,795	$451,588

estimated benefit of $.31 per ton of sediment reduction. The following section will summarize benefit value estimates.

Summary of Benefit Values: The benefit values per ton of reduced sediment flow in Mission Creek and the Clearwater River were estimated to be:

Fishery	$ .41
Municipal & Industrial	.22
Navigation and Flood	4.50
Long-Term Productivity	.31
Total Benefit	$5.44

The $5.44 benefit value must be compared to the marginal cost values for land source sediment control. The sediment transport model calculated that for each ton of sediment that enters Mission Creek, .65 tons will be delivered to Lapwai Creek's confluence with the Clearwater River.[19/] In addition, the Army Corps of Engineers estimates that Lower Granite Dam is a 75 percent effective sediment trap. This means that for each ton of sediment flowing in the

19/ This figure depends on the transport ratios assumed in the sediment transport model. In this study, for a normal weather year a .40 ratio was used and for a 10, 25, 50, or 100-year storm event a ratio of .60 was used.

Clearwater River, .75 tons will be deposited as silt and .25 tons will flow downriver beyond Lower Granite Dam. Thus, for each ton of sediment which flows into Mission Creek, .65 tons reaches the Clearwater River and .4875 tons (i.e., (.65)(.75)) is deposited as silt.

Multiplying the municipal and industrial benefit by .65 and the navigation and flood benefit by .4875 results in the following total benefits.

Fisheries	$ .41
Municipal & Industrial	.14
Navigation & Flood	2.20
Long-Term Productivity	.31
Total Benefit	$3.06

The long-term productivity benefit applies only to agricultural lands. The low soil loss rates on forest lands do not threaten long-term forest productivity. It was also assumed that riparian zone productivity will not be significantly altered by soil loss control practices. Thus, the benefit value applied to the forest and riparian lands does not include the $.31 long-term productivity benefit. The finalized net benefit per ton of sediment reduction to be compared with the land source marginal cost schedules is:

Agricultural Lands	$3.06
Forest Lands	$2.75
Riparian Lands	$2.75

Because the Mission-Lapwai Watershed contributes a small proportion of the total sediment flow in the Clearwater River, it was assumed that the marginal benefit will not vary with the amount of sediment reduction. Given the determined marginal costs and benefits of soil loss control for the Mission Creek area, the following section will develop alternative soil loss control management plans.

ANALYSIS OF MARGINAL COSTS AND BENEFITS

This section will develop alternative soil loss control management plans. Four management plans will be outlined. The first plan will adhere to the economic criteria that land management practices are viable as long as the marginal benefit of sediment reduction exceeds the marginal cost. It represents the optimal strategy for soil loss control. The strategy, however, is based on strict economic efficiency and does not consider the distributional impacts in terms of which members of society pay the costs and which receive the benefits of soil loss control. Recognizing that the decisions of policymakers are bounded by political constraints, three additional soil loss control management plans will be outlined. Each of these plans will be suboptimal from an economic efficiency viewpoint. Nevertheless, the plans will help to empirically identify the available spectrum of soil loss control strategies.

Before discussing the alternative management plans, recall from the riparian LP discussion that the efficiency of riparian land management practices are assumed to vary over time, depending on sediment inflow from agricultural and forest lands, which in turn depends on the management plan being implemented.[20/] To simulate the dynamics of riparian treatment efficiency, a time dimension of 25 years was added to the riparian LP model. A vector of treatment efficiency coefficients for each of the four soil loss control management plans discussed in this section was developed. These

---

[20/] The effectiveness of agricultural and forest soil loss control management practices is assumed to remain constant over time.

coefficients represent the annual percentage effectiveness of management practices and vary inversely with the amount of sediment inflow during the previous time period (i.e., year). Using the treatment efficiency vector, the riparian LP model can be updated annually and predict the sediment inflow to Mission Creek for each year of the 25-year planning period. These data then can be input to the sediment transport model to calculate each management plan's impact on sediment delivery from Mission Creek to the Clearwater River over the 25-year planning horizon.

Definition of Management Plans

Plan #1. This plan is optimum from an economic efficiency perspective and is based on the criteria that land management practices to control soil loss are economically viable as long as the marginal benefit exceeds the marginal cost. Since the estimated benefit per ton of sediment reduction is $3.06 for agricultural lands and $2.75 for forest and riparian lands, this plan will employ management practices on each of the three land sources of surface erosion which have a marginal cost less than or equal to the benefit value. This plan represents the greatest amount of sediment reduction that is economically feasible given the marginal cost and benefit values determined in this study.

Plan #2. Interpretation of the marginal cost results indicated that riparian land management practices offer the potential for significant sediment reduction at a relatively low cost, and therefore, should be an integral part of a cost effective soil loss control strategy. Thus, Plan #2 involves implementing the riparian practices of controlling road crossings, livestock watering control, and seeding grass. The plan is cost effective, but suboptimal in that many of the economically viable land management practices are not implemented.

Plan #3. On agricultural lands, marginal costs are initially negative, indicating that it is simultaneously possible to reduce soil loss and increase net income. Thus, this plan will employ all agricultural land management practices which have a negative marginal cost. In addition, the riparian land practices of Plan #2 will be employed. Successful implementation of this plan will require the cooperation of area farmers, many uncertain of the yield impact created by minimum tillage, the prime agricultural land management practice employed. This uncertainty may hinder farmer acceptance of minimum tillage practices [Chase, 1984].

Plan #4. This plan deviates from the first three plans in that it assumes that all land treatment practices with marginal costs of less than $6 will be implemented. Thus, this strategy will employ soil loss control practices which are not viable under the economic criteria that the marginal benefit must exceed the marginal cost. The purpose of Plan #4 is to demonstrate the increase in investment costs and reduction in the plan's overall net present value when noneconomic criteria are used to determine the social benefits of soil erosion control.

Summary of Management Plans

The land management practices recommended for agricultural, forest, and riparian lands under Plan #1 are economically optimal under the criterion that the marginal benefit of sediment reduction exceed the marginal cost. Primarily via the practice of minimum tillage, sediment flow from agricultural land to Mission Creek waters could be reduced by 18,472 tons annually (Table 20). Under Plan #1, the net present value of agricultural land productivity benefit, as estimated using the Thomas and Lodwick (1981) model, was $138,595.

Annual net farm income would be $5,039 greater than that of the benchmark (1983) level. The present value of this income change is $52,110 (discounted over a 25-year period @ 8.375 percent). Income is higher than the benchmark estimate because marginal costs are initially negative as minimum tillage replaces conventional tillage in the optimal cropping pattern, thus net income rises. Marginal costs become positive only after sediment flow has been reduced by 10,721 tons (Table 20). The marginal cost increase is the result of minimum tillage being employed on wheat after pea acreages of land units A1, A2, and A4 (Table 6 for definition of land units) and no-tillage being practiced on 500 acres in pea after grain production on land unit A2. In addition, the fallow after grain acreages on land units A2 and A4 are switched to divided slope farming.

On the forest lands, sediment can be reduced 335 tons (Table 21). This is accomplished by seeding grass on the one lane dirt surface roads of land units F3 and F5 (Table 10 for definition of forest land units), at a total cost of $7,650. Thus, only a comparatively small amount of sediment reduction is economically justified on the forest roads.

On riparian lands, the optimal strategy of Plan #1 involves controlling road crossings and planting seed grass on all riparian

Table 20. Plan #1, Agricultural Land Treatments

MARGINAL COST ($/ton	LAND UNIT	CROP TREATED	TILLAGE USED	TREATMENT USED	ACRES TREATED	SEDI REDUCT (tons)
($3.08)	A4	BG	MINIMUM	NORMAL	1350	1,269
($2.97)	A4	WG	MINIMUM	NORMAL	1350	2,538
($2.42)	A4	PG	MINIMUM	NORMAL	700	3,028
($2.37)	A1	WW	MINIMUM	NORMAL	100	3,146
($1.55)	A2	WG	MINIMUM	NORMAL	1000	4,946
($1.48)	A3	BG	MINIMUM	NORMAL	600	5,714
($1.23)	A1	PG	MINIMUM	NORMAL	300	6,128
($1.15)	A3	WG	MINIMUM	NORMAL	600	7,586
($0.90)	A2	BG	MINIMUM	NORMAL	1000	9,686
($0.82)	A2	PG	MINIMUM	NORMAL	500	10,721
$0.32	A4	WP	MINIMUM	NORMAL	700	12,891
$0.61	A2	WP	MINIMUM	NORMAL	500	14,436
$2.12	A1	WP	MINIMUM	NORMAL	300	14,832
$2.85	A4	FG	CONV	DIV SLP	1500	16,932
$2.87	A2	PG	NO-TILL	NORMAL	500	17,802
$2.98	A2	FG	CONV	DIV SLP	500	18,472

Note: Marginal cost values in parenthesis are negative.

Table 21. Plan #1, Forest Land Treatments

MARGINAL COST ($/ton)	LAND UNIT	ROAD TYPE	TREATMENT USED	ACRES	SEDIMENT REDUCTION (tons)
$1.87	F3	1 LN DIRT	SEED GRASS	11.0	85
$2.33	F5	1 LN DIRT	SEED GRASS	40.0	335

segments. In addition, controlling livestock watering is recommended for the Canyon segment (Table 22). The practices of planting grass, shrubs, and trees on the Upper and Bottom riparian land units are also economically viable with a benefit value of $2.75 per ton of sediment reduction. These riparian treatments have investment costs of $113,743 and reduce sediment inflow to Mission Creek by 25,448 tons annually.

Table 22. Plan #1, Riparian Land Treatments

MARGINAL COST ($/ton	RIPARIAN SEGMENT	TREATMENT USED	SEDIMENT REDUCTION (tons)
$0.01	BOTTOM	CONTROL ROAD CROSSINGS	387
$0.01	UPPER	CONTROL ROAD CROSSINGS	587
$0.01	CANYON	CONTROL ROAD CROSSINGS	731
$0.08	UPPER	PLANT SEED GRASS	8,916
$0.12	BOTTOM	PLANT SEED GRASS	18,545
$0.28	CANYON	LIVESTOCK WATERING CONTROL	19,736
$0.29	CANYON	PLANT SEED GRASS	20,627
$1.50	UPPER	PLANT GRASS, SHRUBS, & TREES	22,798
$2.12	BOTTOM	PLANT GRASS, SHRUBS, & TREES	25,448

Through the combined agricultural, forest, and riparian land treatments of Plan #1, the sediment transport model indicates that sediment inflow to the Clearwater River over the 25-year planning period can be reduced by 789,680 tons. In the benefit analysis section, downstream benefits per ton of sediment reduction in the Clearwater River are estimated to be $5.13 (i.e., fisheries = $.41, municipal and industrial = $.22, navigation and flood = $4.50). therefore, the reduced sediment flow in the Clearwater River for the 25-year period should be valued at $5.13 per ton. Discounting the 25-year benefit stream of Plan #1 by 8.375 percent yields a net present value of $1,618,100. The total cost of the optimal soil loss control strategy is $121,393. Thus, the net present value of Plan #1 is $1,687,412 (i.e., $(1,618,100 + 138,595 + 52,110 - 121,393)).

Plan #2 assumes that soil loss control investment funds are in short supply and thus emphasizes the riparian land management practices which have low marginal costs per ton of sediment reduction. The recommended practices include controlling road crossings and planting seed grass on all riparian segments. In addition, controlling livestock watering is recommended for the Canyon segment. The marginal cost of these practices ranges from $.01 to $.29 per ton of sediment reduction (Table 22). The investment cost for these practices is $28,018. Over a 25-year period sediment flow from Mission Creek to the Clearwater River would be reduced by 467,240 tons. Discounting the 25-year benefit stream by 8.375 percent yields a present value of $996,940. Thus, the net present value of Plan #2 is $968,922 (i.e., $996,940 - $28018).

Plan #3 recommends the same riparian treatments as Plan #2, plus recommending the implementation of agricultural land management practices which have a negative marginal cost. This essentially involves switching to minimum tillage for several crops grown on land units A1, A2, A3, and A4 (Table 20). Sediment flow from agricultural land to Mission Creek could be reduced by 10,721 tons annually. The present value of the productivity benefit for the 25-year analysis period is $80,440.

Under Plan #3, annual farm net income could be increased by $17,994. Discounting this annual income at 8.375 percent over a 25-year period yields a net present value of $186,085. Riparian costs remain at $28,018. Sediment inflow to the Clearwater River over a 25-year period would be reduced by 607,050 tons, which implies an aggregate present benefit @ $5.13/ton) value of $1,253,480. Total net present value of Plan #3 is $1,491,987.

Plan #4 assumes that agricultural, forest, and riparian land management practices with marginal sediment control costs of less than $6 will be implemented. Assuming that the predicted marginal benefit values remain unchanged, Plan #4 represents a suboptimal strategy.

Nevertheless, the scenario is useful in illustrating the impact on treatment investment cost and the overall net present value of sediment reduction beyond the optimal level of Plan #1. The additional agricultural and forest land management practices employed under Plan #4 are listed in Tables 23 and 24.

Table 23. Additional Agricultural Land Treatments Under Plan #4

MARGINAL COST ($/ton)	LAND UNIT	CROP TREATED	TILLAGE USED	TREATMENT USED	ACRES TREATED	SEDI REDUCT (tons)
$3.38	A2	WF	CONV	DIV SLP	500	20,242
$3.78	A1	PG	NO-TILL	NORMAL	300	20,638
$3.84	A3	WG	NO-TILL	NORMAL	600	23,134
$4.93	A2	WP	NO-TILL	NORMAL	500	25,159
$5.00	A4	FG	CONV	TERRACES	1500	27,859
$5.31	A4	PG	NO-TILL	NORMAL	700	28,607
$5.58	A4	WF	CONV	TERRACES	1500	35,327
$5.98	A3	BG	NO-TILL	NORMAL	600	37,133

Table 24. Additional Forest Land Treatments Under Plan #4

MARGINAL COST ($/ton)	LAND UNIT	ROAD TYPE	TREATMENT USED	ACRES	SEDIMENT REDUCTION (tons)
$3.45	F2	1 LN DIRT	SEED GRASS	5.1	356
$5.04	F4	1 LN DIRT	SEED GRASS	20.5	415
$5.26	F1	1 LN DIRT	SEED GRASS	3.6	425

Agricultural land sediment can be reduced by 37,133 tons annually. Net farm income, however, is reduced $89,212 from the present (1983) benchmark level. This is nearly a 50 percent reduction in sediment and a 20 percent decline in net income from present situation levels. The present value of the long-term productivity benefit is $278,610 and the 25-year net income stream loss is $922,588.

Additional agricultural land management practices employed include using no-tillage on pea after grain acreage on land units A1 and A4. Terraces are constructed for the 3,000 acres of wheat after fallow and fallow after grain production on land unit A4. In addition, 1,200 acres of no-tillage are suggested for the wheat after grain and barley after grain acreages of land unit A3. Finally, divided slope farming is practiced on the 500 acres of wheat after fallow production on land unit A2 (Table 23).

Forest land sediment can be reduced an additional 90 tons (to 425 tons) by seeding of grass on the one-lane dirt surface roads of all five land treatment units (80.2 acres). The investment cost of seeding grass would be $12,030.

Under Plan #4, grass, shrubs, and trees are planted on all three riparian land treatment units of Mission Creek. This raises riparian treatment costs to $150,643. Plan #4 will reduce the 25-year sediment inflow from Mission Creek to the Clearwater River by 947,260 tons. Valuing downstream benefits at $5.13 per ton of reduced sediment flow implies a present value for sediment reduction in the Clearwater River of $1,967,820. Total costs of Plan #4 are estimated to be $1,085,261.

Thus, the net present value of Plan #4 is $1,161,169 (i.e., $(279,610 + 1,967,820 - 1,085,261)). This is substantially below the value of the optimal strategy of Plan #1 (i.e., $1,687,412). In addition, Plan #4's investment cost is nearly $1 million greater than that of Plan #1.

Present value cost and benefit estimates for soil loss control Plans #1 through #4 are summarized in Table 25. Estimates of the net present value of each plan assume that the downstream benefits are valued at $5.13 per ton of sediment reduction in the Clearwater River. A graphical presentation of each plan's impact on sediment delivery from Mission Creek to the Clearwater River over the assumed 25-year planning horizon is shown in Figure 5.

Table 25. Summary of Soil Loss Control Management Plans

	Present Value of Costs ($)			
Land Source	Plan #1	Plan #2	Plan #3	Plan #4
Agricultural	(52,110)	0	(186,085)	922,588
Forest	7,650	0	0	12,030
Riparian	113,743	28,018	28,018	150,643
Total	69,283	28,018	(158,067)	1,085,261
	Present value of Benefits ($)			
Benefit	Plan #1	Plan #2	Plan #3	Plan #4
Ag Productivity	138,595	0	80,440	278,610
Downstream	1,618,100	996,940	1,253,480	1,967,820
Total	1,756,695	996,940	1,333,920	2,246,430
Net Present Value of Plan	1,687,412	968,922	1,491,987	1,161,169

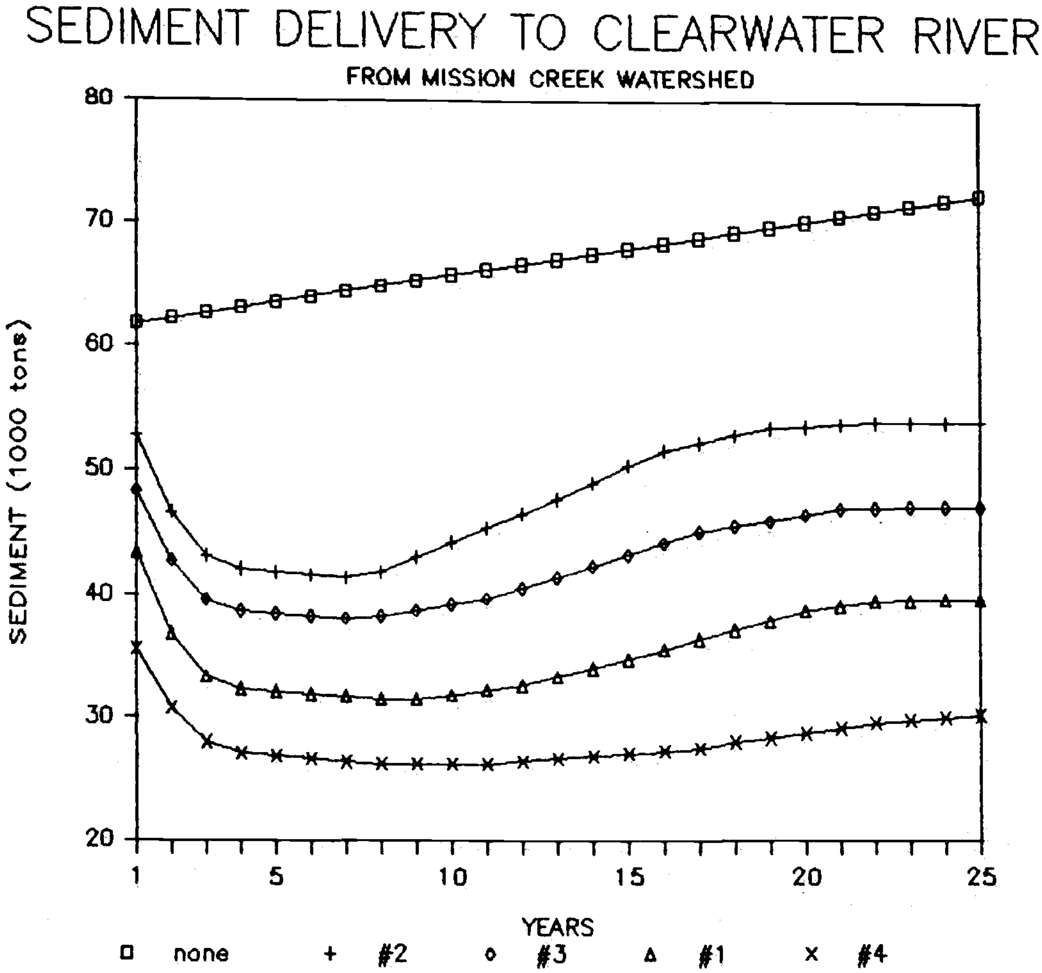


Figure 5. Impact of soil loss control management plans on sediment delivery from Mission Creek to the Clearwater River over 25-year planning horizon.

With no control.......... ▫
Plan #1 .... ▲
Plan #2 .... +
Plan #3 .... ◆
Plan #4 x

SUMMARY

In dealing with the Lower Granite Dam sedimentation problem, the results of this analysis of the Mission-Lapwai Watershed indicate that it is economically efficient to treat the soil loss problem at its land source. Although these results are specific to the Mission Creek area, they do indicate that similar cost effective erosion reduction opportunities may exist for other areas of the Clearwater and Snake River drainages. The four soil loss control plans discussed in the previous section should provide policymakers with a concept of the range of soil loss control opportunities which are economically viable from a social welfare standpoint.

The economic criteria that soil loss control practices are economically viable as long as the marginal benefit exceeds the marginal cost indicates that Plan #1 represents the optimal strategy. The distributional impacts of this plan, however, are such that the investment costs would be borne by the landowners, primarily farmers, and the majority of the benefits would accrue to society in general. Applying the Kaldor-Hicks compensation principle would allow all individuals to potentially be made better off by Plan #1. Unless landowners were actually compensated for land management investment costs, however, their private interest would not coincide with that of society.

The mentioned graph (Figure 5) shows that a significant amount of sediment reduction can be achieved by Plans #2 and #3. These two strategies are suboptimal. Nevertheless, they require investment costs which are substantially less than that of the optimal Plan #1.

Therefore, if government funds for compensation payments are limited, either of these plans offers a potential alternative strategy for achieving soil loss control on the Mission-Lapwai Watershed. Plan #2 employs only riparian land treatments and has investment costs of $28,018; Plan #3 includes the same riparian practices and adds the use of minimum tillage on some agricultural lands. It was concluded from LP model results that switching to minimum tillage should increase farm net income, so the private and social interest should coincide. Local farming tradition and uncertainty regarding the yield impacts of switching to minimum tillage, however, may hinder farmer acceptance of Plan #3 recommendations.[21/]

Soil loss reduction beyond that achieved by the optimal strategy is possible, but only through use of increasingly expensive practices that will lower the net present value of the management plan. Plan #4, for example, has a much higher cost and lower net present value than does Plan #1. Thus, if policymakers decide to target surface erosion control to levels beyond those of Plan #1, the costs imposed upon landowners will increase rapidly. Landowner participation probably would require very high compensation payments (i.e., more than $1 million for Plan $4).

21/ The estimated current (1983) annual net farm income for the Mission Creek area is $458,000. Analysis results suggest that Plan #3's minimum tillage recommendations would increase annual net income by $18,000, which is a 4 percent increase. Farmer attitudes towards risk, however, were not considered in the analysis. This is an area which needs further study.

REFERENCES

Brouha, Paul and Rick Stowell. 1984. "A Physical and Biological Inventory of the Aquatic Resources of Mission Creek, Idaho." Paper presented at the USDA Offsite Impacts Conference, Walla Walla, Washington.

Brown, William G., Douglas M. Larson, Richard S. Johnston, and Roy J. Wahle. 1976. Improved Economic Evaluation of Commercially and Sport-Caught Salmon and Steelhead of the Columbia River. Oregon State University Agricultural Experiment Station Special Report 463.

Carlson, John E., Don A. Dillman and William R. Lassey. 1981. The Farmer and Erosion: Factors Influencing the Use of Control Practices. University of Idaho Agricultural Experiment Bulletin No. 601.

Chase, Bryon, 1984. Soil Conservation Service, Lewiston, Idaho. Personal communication.

Corps. 1984. Lower Granite Project, Snake River, Washington and Idaho: Sedimentation Study - Interim Report. U.S. Army Corps of Engineers, Walla Walla District.

Erickson, Alan. 1984. Manager of Lewiston's Water Treatment Plant. Personal communication.

Harder, R. W., C. L. Peterson, and E. A. Dowding. 1980. "Influence of Erosion on Soil Nutrient Availability, Physical and Chemical Properties, and Winter Wheat Yield in Northern Idaho." Paper presented at the Tillage Symposium, Bismark, ND.

Hoag, Dana, Herbert Himna, and Duane Erickson. 1984. 1984 Costs of Alternative Tillage Systems in the Winter Wheat-Dry Pea Area of the Palouse Region of Washington and Idaho. Washington State University Extension Service Bulletin 0943.

Jones, Ken. 1984. Superintendent, Potlatch Power and Recovery Department. Lewiston, Idaho. Personal communication.

Logan, Leon. 1984. Hydrologist, U.S. Forest Service, Missoula, Montana. Personal communication.

Loomis, John B. and William G. Brown. 1984. "The use of Regional Travel Cost Models to Estimate the Net Economic Value of Recreational Fishing at New and Existing Sites." Paper presented at the National Marine Fisheries Service Workshop, July 24-26, Seattle, Washington.

McNamme, William A. 1985. Economics of Soil Loss Control on the Mission-Lapwai Watershed, Idaho. Ph.D. dissertation, Department of Agricultural and Resource Economics, Oregon State University.

Rush, Ben. 1984. Manager, Clarkston Grain Terminal. Clarkston, Washington. Personal communication.

STEEP Project. 1980. "A Survey on Crop Production in the Palouse." Washington State University and University of Idaho, Departments of Agricultural Economics and Rural Sociology.

Thomas, Howard R. and Weldon Lodwick. 1981. "Practical Estimation of Erosion Costs." Unpublished paper, USDA-ERS, Oregon State University.

USDA. 1985. Mission-Lapwai Erosion/Sedimentation Study. USDA Soil Conservation Service and Forest Service, and Idaho Department of Water Resources. Boise, Idaho.

APPENDIX

Summary of the Thomas and Lodwick Simulation Model: Long-Term Productivity Loss From Soil Erosion

This appendix reviews the variables and equations used in the Thomas and Lodwick model. The purpose of the model is to identify the productivity benefits associated with controlling soil loss from agricultural lands. The model calculates the difference between crop yield over time when no soil loss occurs versus when soil loss does occur (Figure A-1). For simplicity, only wheat production will be considered.

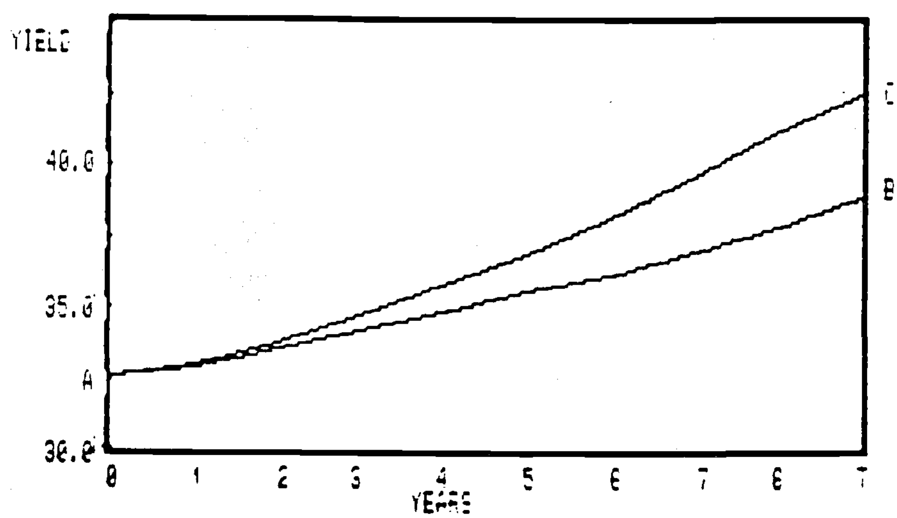


Figure A-1. Wheat yield over time; with and without soil loss.

The area ABC in Figure A-1 represents the potential per acre wheat yield loss from erosion for years 1 to T. Line segment AC represents the potential increase in yield when no erosion occurs and line segment AB represents the yield change when soil loss exists.

The area ABC is calculated by the following equation:

$$\text{Area ABC} = \sum_{t=1}^{n} [Ye^{at} - (Y - bt)e^{at}]$$

$$= \sum_{t=1}^{n} bte^{at}$$

Where: Y = Crop yield in the initial time period.
e = Exponential function.
b = The rate of decline in productivity from soil loss.
a = The rate of technological change.
t = Time in annual increments.

The coefficient for determining the net present value of the productivity loss from erosion is obtained by discounting each annual increment of the area ABC. Therefore, the equation is:

$$\text{NPV Coef.} = \sum_{t=1}^{n} [(bte^{at})/(1 + i)^{t}]$$

To complete, the analysis estimates of factors "a" and "b" must be obtained. Based on regression analysis of Snake River Basin wheat yields from 1938 to 1980, the technological factor "a" was estimated to be .01449 bushels per year. The estimate of "b" is based on the loss of productivity per acre inch of topsoil loss. For example, if the assumed yield loss per acre inch of topsoil loss was 3 bushels and the assumed weight of one acre inch of soil was 154 tons, then the "b" factor would be .0194 (i.e., (3/154) = .0194), which implies that for each ton of soil loss .0194 bushels of wheat production is lost.

Assuming a wheat price of $1 per bushel and an erosion rate of 1 ton per acre, the NPV coefficient represents the per acre level of investment that could be allocated to reduce erosion. The net present value of future production which will not be realized because of erosion is calculated by multiplying the NPV coefficient by the estimated per acre soil loss rate and the assumed wheat price per bushel.

For the Mission Creek agricultural land units the following data were used for input to the Thomas and Lodwick model:

Technological Coefficient "a"	= .01449
Weight of one acre inch of topsoil	= 154 tons
Wheat Yield Loss per inch of soil loss:	
Land Treatment Unit A1	= 2.5 bushels
Land Treatment Unit A2	= 2.5 bushels
Land Treatment Unit A3	= 3.0 bushels
Land Treatment Unit A4	= 3.0 bushels
Land Treatment Unit A5	= 2.0 bushels
Land Treatment Unit A6	= 3.0 bushels
Land Treatment Unit A7	= 3.0 bushels
Assumed wheat price per bushel	= $3.66