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Loss of topsoil from agricultural and forest lands is of increasing national concern. Soil erosion can rob the land of productive potential, create environmental damage, and negatively impact commerce and trade. This study analyzed the physical and economic potential for control of erosion and sedimentation problems on the Mission-Lapwai Watershed of the Clearwater River Basin, Idaho. The economic objective of analysis design was to develop a "preferred" plan for surface erosion control based upon comparison of the marginal costs and benefits of sediment reduction.

An inventory of the Watershed's land resource identified agricultural lands, forest roads, and the riparian ecosystem bordering Mission Creek as the prime

sources of soil loss. Alternative land management practices to reduce surface erosion from each land source were defined and their investment cost and impact on the soil loss rate estimated. A linear programming (LP) framework was used to predict which of the alternative land management practices were most cost effective in reducing soil loss. The shadow price of the LP model's sediment constraint provided an estimate of the marginal cost of soil loss reduction.

Benefits of soil loss control were identified and the marginal value of sediment reduction for each benefit estimated by descriptive analysis and appropriate mathematical techniques. Five benefits 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; and (5) Maintenance of long term agricultural productivity. Individual benefit values were summed to determine the total net benefit per ton of sediment reduction to be compared with the land source marginal cost schedule.

Interpretation of marginal analysis results indicated that the implementation of several soil loss control management practices were economically feasible. Riparian management practices of controlling road crossings, livestock watering control, and the seeding of grass, together with the use of conservation (minimum) tillage on agricultural lands and the seeding of grass along forest one lane dirt roads could reduce erosion and sedimentation significantly. The success of soil loss control efforts, however, would require the cooperation of area landowners, particularly farmers.

Economics Of Soil Loss Control on the Mission-Lapwai Watershed, Idaho

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

I. INTRODUCTION

Erosion of agricultural and forest land and the associated sedimentation of streams and reservoirs is a serious problem in several areas of the Lower Snake River Basin. The problem is particularily acute in the Mission-Lapwai Watershed, which is located in the Clearwater River drainage of northern Idaho. This thesis will investigate the physical and economic potential for soil loss control upon the Mission-Lapwai Watershed.

Why is soil loss a problem?

In the United States, loss of topsoil from forest and agricultural lands is of increasing concern. This concern has past justification, as history is replete with examples of civilizations which have succumbed to environmental and economic stress primarily caused by depletion of their soil resource [Carter, 1981]. The Tigris and Euphrates river basin, North Africa, the Eastern Mediterranean area, and the lowlands of Central America are examples of regions which once supported progressive and dynamic civilizations, but are today constrained by the land's limited productivity [Brown,1982].

A strong natural resource base enables society to create surplus production of the basic survival goods of food, shelter, and clothing.[1/] Surplus production of these primary consumption goods allows society to allocate energy and materials to the development of knowledge and production techniques which contribute to the progress of civilization. If deforestation and the pressure of cropland expansion lead to the loss of topsoil, then the land's productivity may gradually decline. If this occurs, the quality of civilization within society may also decline.

The basic concern is that soil loss threatens society by robbing the land of productive capacity. In addition, through siltation of streams, reservoirs, canals, and harbors soil erosion creates environmental damage and negatively impacts commerce and trade. This environmental and economic damage limits society's prosperity and advancement.

Soil Conservation in the United States

In the United States, major public awareness of the threats of soil erosion were vividly awakened in the 1930's by the Dust Bowl of the drought-stricken Great Plains states. During this time Hugh Hammond Bennett, a USDA soil

{1} Surplus production is that production which exceeds the effective demand of the primary producers.

scientist, authored the government circular, "Soil Erosion, A National Menace", which helped draw public attention to problems caused by soil erosion. Bennett was instrumental in Congressional passage of the Soil Conservation Act of 1935 (Public Law 74-46). This law created the Soil Conservation Service (SCS) as a permanent agency within the USDA and remains the basis of the nation's soil conservation policy [Sampson, 1981].

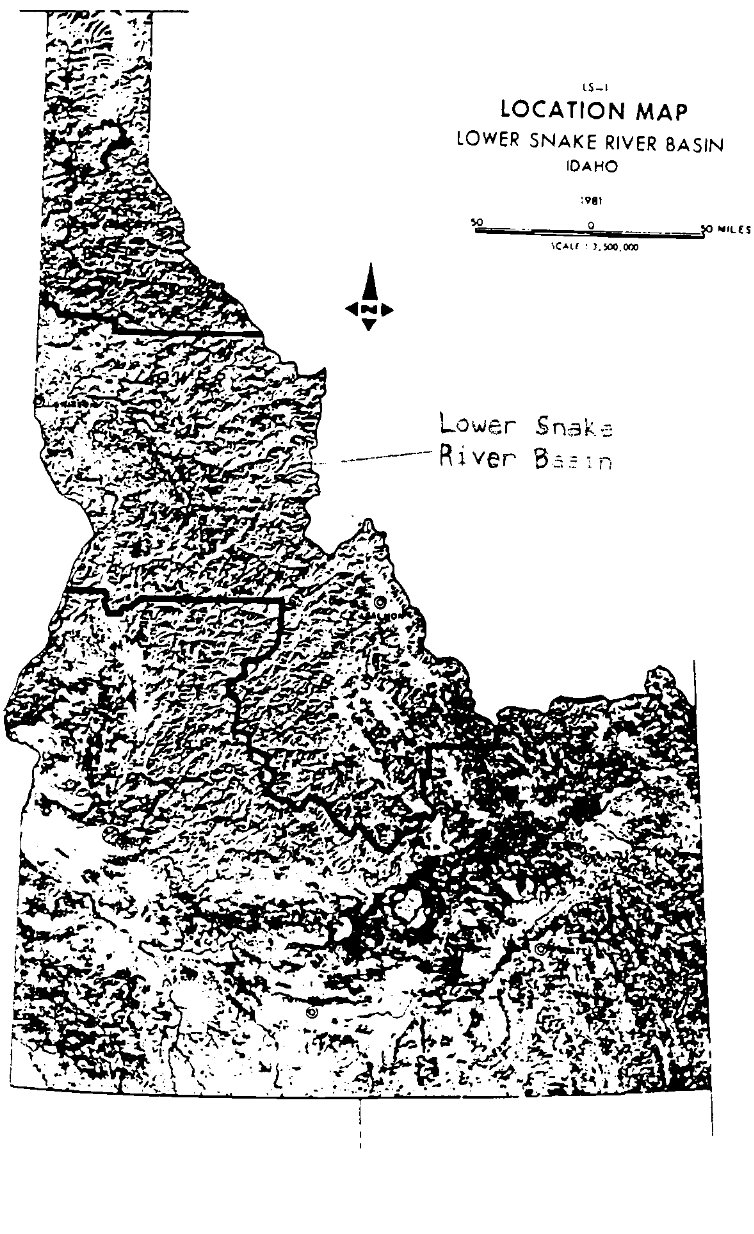
With passage of P.L. 74-46 and under congressional and USDA guidance, local soil conservation districts were established throughout the country. Through conservation districts, SCS personnel offer technical assistance to area farmers. If a farmer decides to accept SCS soil conservation recommendations and implement a conservation plan, he may apply for federal cost-sharing support to help finance the expense of land conservation practices. Via this method of encouraging voluntary participation by private property owners, the SCS has evolved nationally into a leading resource conservation agency.

Under the Watershed Protection and Flood Prevention Act (Public Law 566) of 1954, the SCS was given additional authority to develop a national program of technical and financial assistance to communities for watershed protection and flood prevention on watersheds of 250,000 acres or less. The act also authorized the USDA to cooperate with other federal and state agencies in river basin planning, surveys, and investigations [Rasmussen, 1982]. The authority for this study of the Mission-Lapwai Watershed of the Clearwater River Basin is derived from P.L. 566.

Lower Snake River Basin

In July of 1982 the Soil Conservation Service, Economic Research Service, and Forest Service of the U.S. Department of Agriculture, in cooperation with the Idaho Department of Water Resources, completed a study of water and related land resource problems in the Lower Snake River Basin of Idaho (Map 1) [USDA, 1982]. This study identified areas of significant and serious soil erosion of agricultural and forest lands and sedimentation of streams and reservoirs. The study concluded that soil erosion exceeds the tolerable soil loss limit "T" on 580,000 acres (49 percent) of the Basin's cropland.[2/] In addition, 950 miles of abandoned forest roads, which are the prime source of soil loss on forest lands, are in need of rehabilitation. The study estimated that a large amount of soil is being transported

(2) "T" is defined as the maximum gross erosion rate in tons per acre that will sustain productivity of the soil resource.



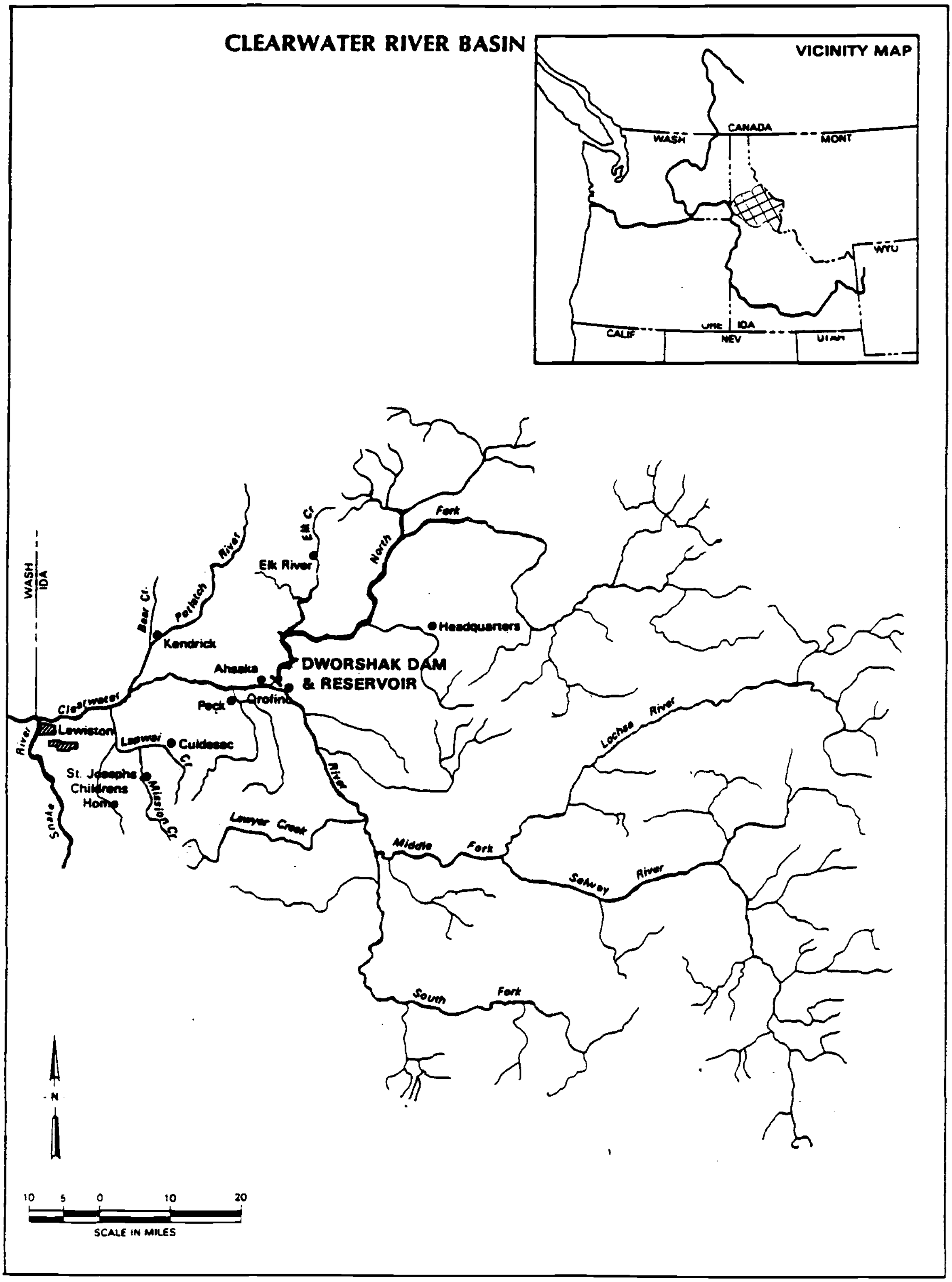
Map 1. Lower Snake River Basin.

from the Basin each year to reservoirs on the Lower Snake River.[3/]

These results indicated a need for detailed planning to correct soil loss damage in the Lower Snake River Basin. The cooperating government agencies agreed to identify specific areas for thorough investigation of the costs and benefits of alternative soil loss control plans. The Mission-Lapwai Watershed of the Clearwater River Drainage was selected as one of the areas for site-specific analysis (Map 2).

The Mission Creek area was chosen for analysis because it encompasses a wide range of land and water resource problems. Excessive soil loss threatens productivity on both agricultural and forest lands. Much of the riparian zone bordering Mission Creek is poorly managed. These conditions contribute to siltation of Mission Creek waters, with resulting damage to fish and wildlife habitat. In addition, downstream users of stream water (i.e. municipalities, industry, navigation, etc.) face potential costs due to turbidity in their water supply. The suspended sediment is transported downstream and eventually settles to the bottom of the slackwater behind Lower Granite Dam, thus causing navigation channel maintainance

{3} Annual average sediment in the Clearwater River at Spaulding (a few miles east of Lewiston) is estimated to be 833,000 tons.



Map 2. Clearwater River Basin.

problems and increasing the flood threat to the city of Lewiston, Idaho.[4/]

Goals and Objectives of Thesis

The goal of this thesis is to identify, evaluate, and present potential solutions to erosion and sedimentation problems in the Mission-Lapwai Watershed. Specific economic objectives are: (1) to estimate the cost effectiveness of various soil loss control management practices, (2) to determine the onsite and offsite (downstream) benefits of sediment reduction, and (3) to develop a "preferred" plan for soil loss control based upon a comparison of the benefits and costs.

Description of Mission-Lapwai Watershed

Mission Creek is a tribubutary of Lapwai Creek within the Clearwater River Drainage. 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 in size and is similiar in physical structure and land use to that of Mission Creek. Therefore, the data analysis of this study concentrated on the Mission Creek area of the watershed,

(4) Lower Granite Dam is located on the Snake River about 35 miles below Lewiston, Idaho.

with the assumption that results are expandable to the Lapwai Creek portion.

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.[5/] The uplands are rolling and gentle, while the stream's intermediate section cuts through very steep canyons. The lower stream segment flows through a valley, which varys in width from a few hundred feet to one-half mile. The topography divides the riparian zone into three distinct treatment units: (1) the rolling hills of the Upper region, (2) the intermediate Canyons, and (3) the lower Bottom lands (Map 3). Elevations range from 4500 to 1500 feet. The drop over the stream's 17 mile course is roughly 3000 feet.

The Mission Creek area is 43,520 acres in size (Table 1), roughly 38 percent of which is in agricultural use, 57 percent is forest or forested range, and the remaining 5 percent is rangeland (Map 4). The main agricultural crops are wheat, barley, peas, hay, and pasture. On forest land, stands of lodgepole pine predominate. Other species found include ponderosa pine, western larch, and douglas fir. Past commercial timber harvests have converted much land to

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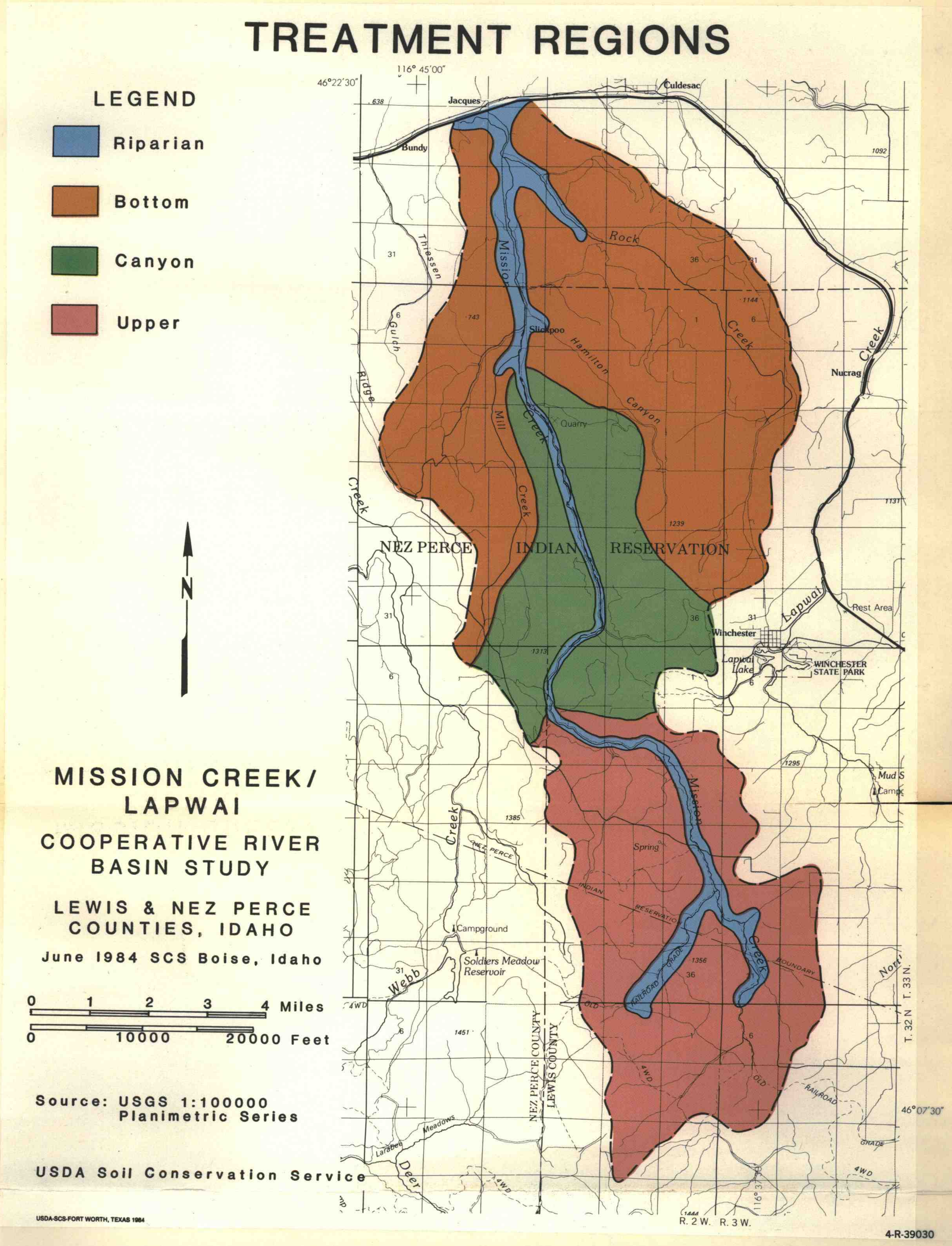
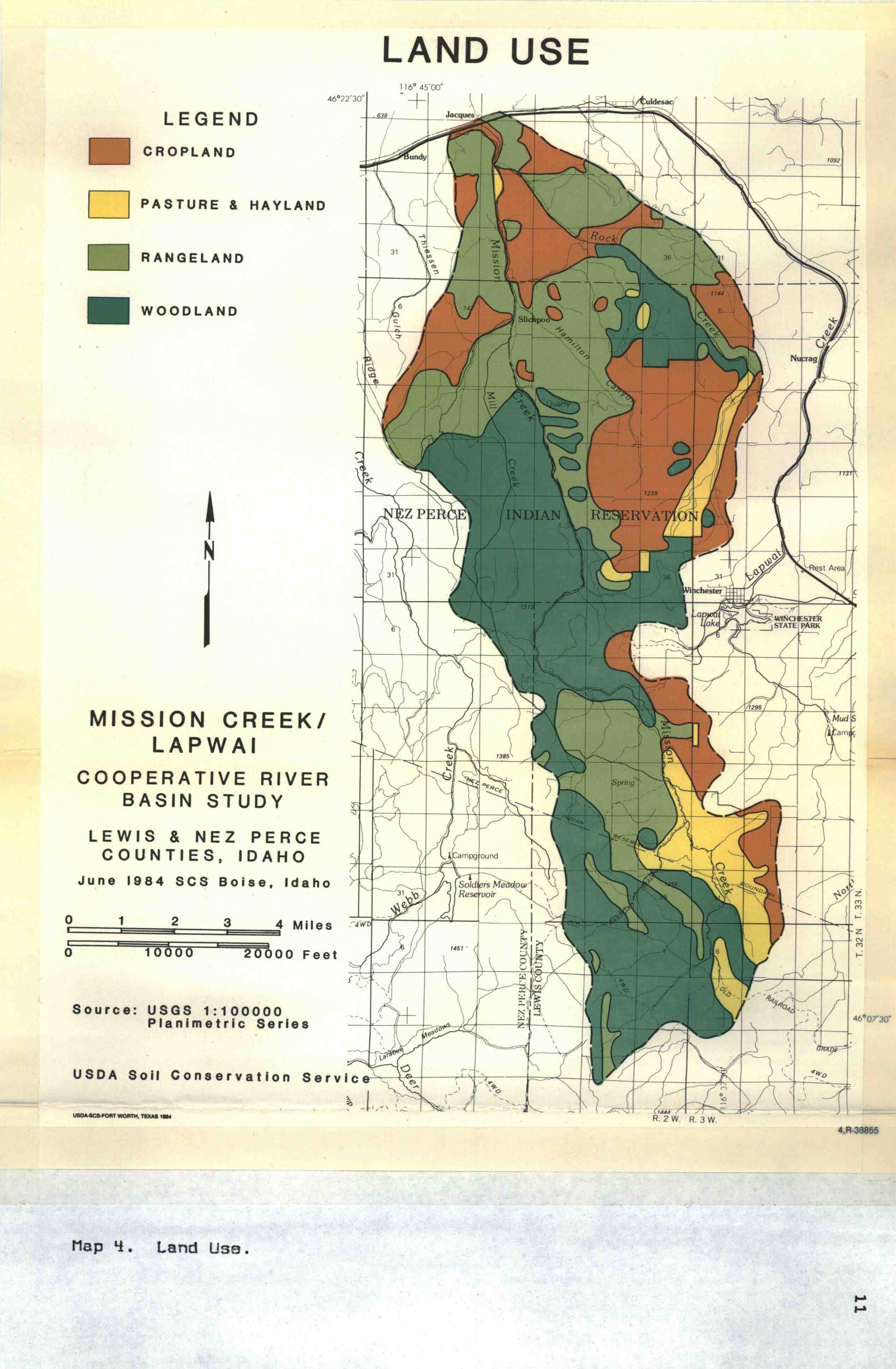
(5) Rock of volcanic origin.



Map 3. Treatment Regions.



Map 4. Land Use.

forested range.

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

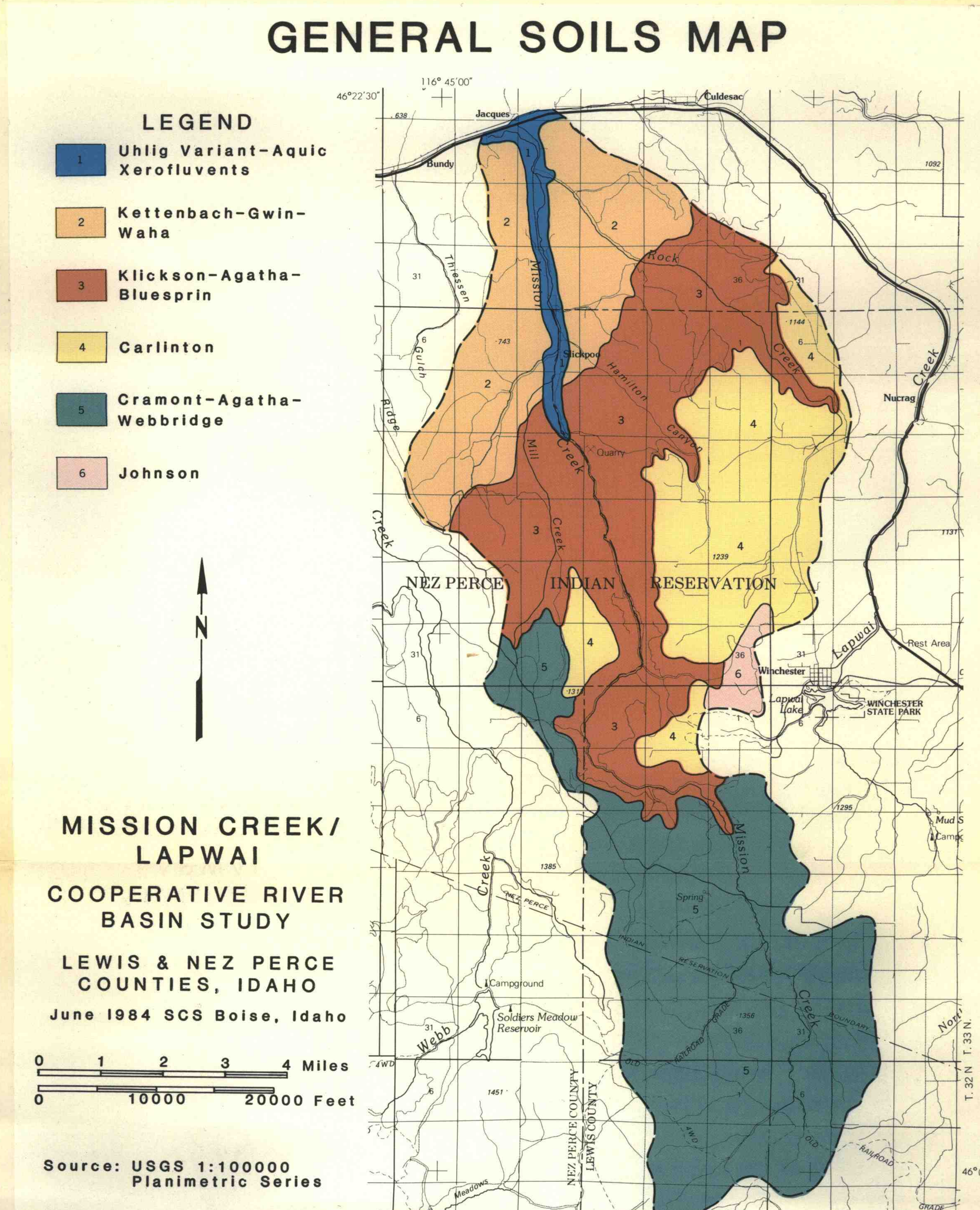
Agricultural		16,470
Dry Cropland	13,800	
Pasture & Hay	2,670	
Forest & Forested Range		24,870
Rangeland		2,176
Total		43,520

Source: Mission-Lapwai Watershed, USDA River Basin Report, 1985.

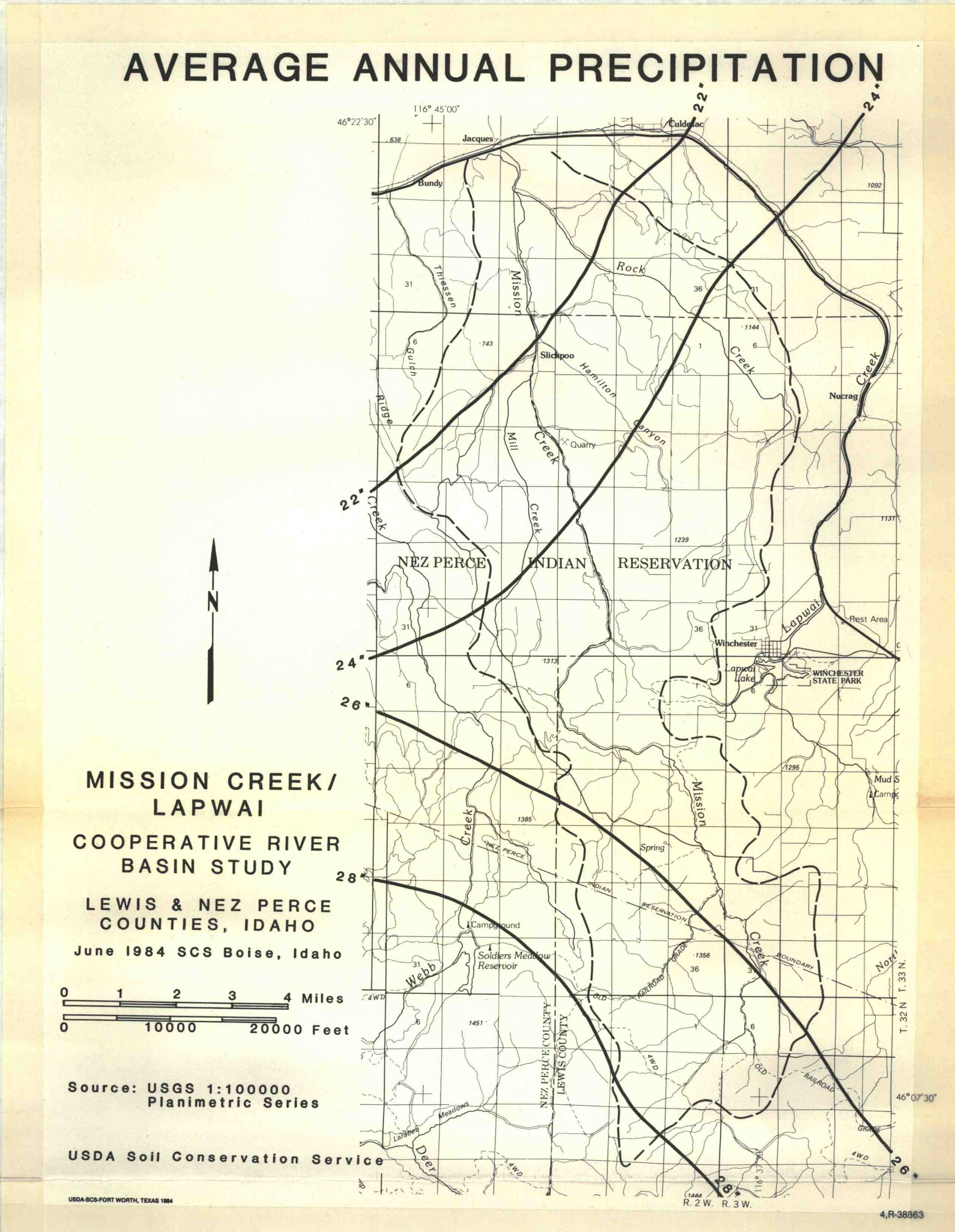
In the Upper riparian region the soils have formed in deep loess deposits under both forest and prairie conditions.[6/] Soils on the steep hillsides and canyons developed from colluvial material derived dominantly from basalt. Textures are loam, clay loam, or clay with varying amounts of rock fragments. These soils are well drained and shallow to moderately deep. Bottom riparian region soils include silt loam surface horizons and silty clay loam or silty clay subsoils at depths of 14 to 24 inches. These soils have areas with seasonally high water tables (Map 5).

The climate of the area is normally influenced by weather systems from the Pacific. Average annual

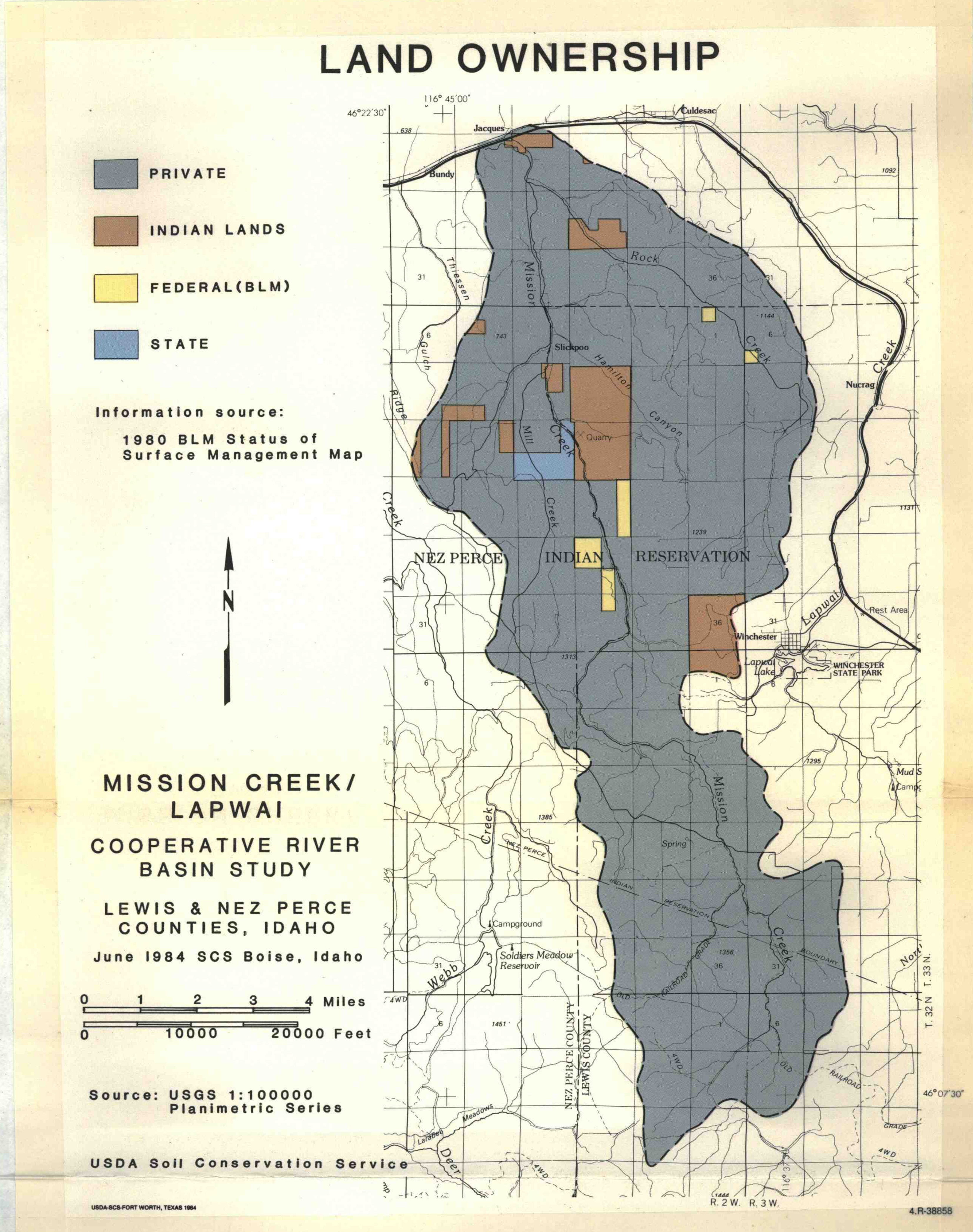
{6} The prairie soils have a higher organic matter content and are less erosive than the forest soils.



Map 5. General Soils Map.



Map 6. Annual Average Percipitation.



Map 7. Land Ownership.

precipitation varys from 20 inches at the confluence of Mission and Lapwai Creeks to 28 inches on the higher elevations of the Upper riparian region (Map 6). Most precipitation occurs during the months of October to March. Winters are cold with temperatures below freezing, while the 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 (Map 7). The Nez Perce Indians have managed to maintain title to a few hundred acres of their reservation land. While the Bureau of Land Management (BLM) and the State of Idaho own a few small parcels (Table 2).

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 Watershed, USDA River Basin Report, 1985.

Economic Profile of Local Area

The cities of Lewiston, Idaho and Clarkston, Washington represent the principle urban areas influenced by the water quality of the Clearwater River. Lewiston, the Nez Perce County Seat, is located at the confluence of the 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). Population growth from 1970 to 1980 was 5901 (12 percent). Nearly 80 percent of the area's residents live in the Lewiston-Clarkston vicinity.

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

	Population		Square Miles	Density	
	1970	1980		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 & 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, Adminstration	1,470	1,410	1,360	1,360
Government, Education	990	830	890	1,020

Source: Idaho Department of Employment

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).

Unemployment levels in the Lewiston-Clarkston vicinity remained in the 5 to 6 percent range throughout the 1970's (Table 5). Since 1980, however, the severe decline in wood product's demand has had a significant impact. The area's diversified economy has allowed it to weather the slowdown in economic activity better than some more timber dependent communities. Nevertheless, layoffs at Potlatch Corporation and the associated impacts on the service and retail sectors caused the unemployment rate to rise from 1980 through 1982. The unemployment rate decline in 1983 and 1984 is the result of not only a somewhat better economic climate, but also the result of outmigration, as people have left the area to seek work elsewhere.

Table 5. Unemployment Rate (percent), Nez Perce and Asotin Counties.

1970	1975	1980	1981	1982	1983	1984
5.5	6.5	7.0	7.0	7.7	5.5	5.2

Source: Idaho Department of Unemployment

There are three port authorities located in the Lewiston-Clarkston Valley -- the port of Lewiston, the Port of Clarkston, and the Port of Wilma. All three port districts were created in 1958 when funding was approved by area voters. The ports did not, however, become operational untill the completion of Lower Granite Dam on the Snake River in 1975. The dam extended slackwater river barge navigation to the Lewiston-Clarkston area. The 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 terminals, where it is transferred to river barges for water-borne shipment to Lower Columbia River export facilities (Table 6). The ports also handle

Table 6. 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	1,661,526
1983	807,635	351,475	316,808	1,475,918

Source: Army Corps of Engineers

shipments of pulp and paper products and some containerized shipments of hay cubes, peas, and lentils. Approximately 100 people are employed by businesses located at the ports. There have been no significant changes in the area's labor force due specifically to the advent of the three ports [Nichols, 1981].

Organization of Thesis

Chapter I has provided an introduction to the nature of the soil erosion problem and presented a general description of the Mission Creek study area. A review of literature dealing with the economics of soil loss control will be the subject of Chapter II. Selected studies which have investigated the costs and benefits of erosion control will be summarized. These studies will be used to help form the methodology used to evaluate the potential for soil loss control on the Mission Creek drainage.

Chapter III will discuss the analysis design used in this study. Model formulations for determining the costs and benefits of soil loss control will presented. Interpretation of model results will be the subject of Chapter IV. These results will be used to evaluate the relative economic efficiency of alternative plans of soil erosion control. A summary of final results will be given in Chapter V.

II. LITERATURE REVIEW OF STUDIES CONCERNING THE ECONOMICS OF SOIL LOSS CONTROL

This literature review will assess recent studies which have evaluated the economic effects of erosion and sedimentation. The main focus is to identify analytical techniques which may be applied in the methodology of this thesis. The last section will outline the analysis design considered most appropriate for evaluating soil loss control on the Mission Creek study area.

The generalizations, procedures, and findings of erosion control studies tend to vary by geographic location and scale. Differences in soil types, topography, climate, cropping patterns, methods of production, and other factors contribute to the problem of adapting a study's procedure and results from one area to another. Therefore, this review will primarily emphasize studies which have been done in the Pacific Northwest.

Economic studies of erosion may be classified into three general categories: (1) Cost-return budgets; (2) Mathematical simulation; and (3) Linear programming . Each of these analytical techniques represents a method to empirically measure the value of soil conservation practices and projects. The general procedure, assumptions, and limits of each technique will be discussed in the following section.

Classification of Analytical Techniques

Cost-return budgets: The main purpose of budgeting is to compare the profitability of different kinds of organization [Castle, 1972]. In agriculture, the farm budget is a physical and financial plan of operation for the farm over a specified period of time. The expected costs are summarized according to some classification scheme (i.e. fixed and variable costs, cash and non-cash costs, etc.). An estimate of crop yields and price provides a total revenue projection. The expected net revenue from alternative production plans can then be compared. A partial farm budget considers the profitability of one specific farm enterprise, while assuming input and output factors for all other farm enterprises remain constant.

There are basically three sources of data used for cost-return budgets: (1) A survey of a random sample of farms; (2) A consensus from a committee of producers and/or farm management specialists; and (3) An engineering approach based on a synthesized model of the productivity process [Nelson, 1977]. The date of the data as well as the source are important. This should be noted as technology and cost changes require continual updating of past budgets.

It is necessary to make a variety of assumptions about the enterprise upon which the cost-return budget is based. The assumed size of the production unit will influence the distribution of fixed costs and the ability to take advantage of any economies of scale. The researcher must assume the level of management employed. Management efficiency will influence the use of production inputs and crop yields. Assumptions must also be made about the exact set of technology or production practices that are used.

Studies which use cost-return budgets to evaluate the value of soil conservation practices generally do so by estimating the profitabilty of alternative types of tillage practices. Conventional tillage practices tend to leave the soil bare and unprotected during the heavy precipitation months, often resulting in excessive erosion. Conservation tillage practices, including both minimum and no tillage, can limit soil loss by leaving larger clods and more crop residue on the soil surface [Holst, 1979].[7/] Thus, a cost-return budget can be estimated for each

{7}. 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.

alternative tillage practice and the onfarm tradeoffs between profits and soil loss predicted.

Conservation tillage uses fewer machinery operations than does conventional tillage and, therefore, creates less soil disturbance. Weed control is largely accomplished through use of chemicals. Thus, the budgeting of conservation tillage alternatives represents an attempt to measure the change in cost due to fewer machinery operations and more chemical use. How conservation tillage affects crop yields is also of prime importance. Research in northern Idaho has indicated that a switch from conventional to conservation tillage can decrease yields in some areas [Harder, 1980]. Yield decreases were attributed to greater weed, disease, and germination problems under the "trashy seedbed" conditions of conservation tillage. In a study supported by the USDA STEEP (Solutions to Environmental and Economic Problems) research project, a survey of farmers in the Palouse region of eastern Washington revealed that farmers expected slight decreases in wheat, pea, and lentil yields when using conservation tillage [STEEP, 1980]. Currently, however, the empirical evidence on comparative yield between alternative tillage systems is inclusive [Hoag, 1984].

A partial budgeting approach was used by Bauer (1983) to compare the cost of producing one acre of winter wheat and one acre of annual ryegrass under alternative tillage methods. The study area was Oregon's Willamette Valley. The results indicated a short run benefit in switching from conventional to conservation (minimum) tillage. Net returns with conservation tillage increased and less topsoil was lost. Reduced variable machine costs were the main reason for the higher returns with conservation tillage. This result assumed crop yields remain constant.

In another budgeting study, Hoag (1984) compared the cost of alternative tillage systems in the winter wheat-dry pea area of eastern Washington and northwestern Idaho. Three tillage alternatives were considered; conventional, minimum, and no-till. With no-till the crop is planted by a special drill and is seeded directly into the untilled soil, thus limiting disturbance of the topsoil. For a two year wheat-pea rotation, Hoag found the per acre cost of minimum tillage to be $8.50 less than the cost of conventional tillage. No-till costs, however, were $11.20 greater than the conventional tillage cost, primarily because of the high per acre ownership cost of the no-till drill.

In a cost-return budget study of the profitability of conservation tillage in the eastern Palouse, Young (1984) calculated similiar tillage cost differentials for a wheat-pea rotation. Profit changes were predicted depending upon whether the farmer had an optimistic, average, or pessimistic expectation of yield performance after switching to conservation tillage. Results revealed that perceived profit reductions were much lower for minimum tillage than for no-tillage and that "optimistic" farmers view minimum tillage as exceeding the profitability of conventional tillage. Under none of the expectations was no-tillage considered more profitable than conventional tillage.

Cost-return budgeting studies which evaluate the economics of soil conservation are limited by their partial and static nature. Budgets estimate changes in farm net returns, but their cost structure does not consider possible offsite impacts of soil erosion such as reduced water quality, damage to fish and wildlife habitat, and other environmental concerns. In addition, budgeting studies consider a specified period of time (usually one production period). Loss of topsoil, however, threatens the land's long-term productive potential. This is a cost which should be considered in the evaluation of the economics of soil loss control.

Mathematical simulation: Computer simulation models facilitate the evaluation of long range scenarios because they can accept forecasts and assumptions about a firm's environment and growth capabilities, can rapidly process the necessary data, and can reveal dynamic interactions over the specified time horizon [Meier, 1969]. Several studies have evaluated productivity effects of cropland erosion with the use of simulation models. Simulation provides a method to pretest the impacts of topsoil loss by using mathematical functions to relate topsoil depth to crop yield. The model can assess the long term profitability of various soil conserving production practices by calculating the present value of each alternative practice's net return stream.

The key soil characteristics are texture, structure, organic matter content, and depth of rooting zone [Crosson, 1983]. These characteristics provide plant roots with nutrients, air, water, and growing space -- the essentials for healthy plant growth. Technology, specifically chemical fertilizers, can restore nutrients lost to erosion. However, where erosion reduces the depth of the rooting zone and thus constrains air, water, and space availability, technology cannot compensate for the adverse yield effect [Young, 1980]. Thus, technological advances can allow production inputs (i.e. machinery, fertilizers, etc.) to substitute for lost topsoil, but only to a certain extent. Continued soil loss will eventually reduce crop yields. A simulation model of the long-term impacts of erosion must isolate the influence of technological change from that of topsoil depletion.

An early attempt to quantify the long-term onsite costs of soil erosion was made in 1961 by Pawson [Bauer, 1983]. A curvilinear function relating topsoil depth to yield was estimated using field trial data from the Palouse region of eastern Washington. The premise behind the curved function is that the greater the depth of topsoil, the less effect an inch of erosion will have on crop yield. Young (1981) expanded upon Pawson's work by proposing a multi-period computer simulation model to estimate the future benefits, in terms of higher yields and net incomes, which are generated by implementing soil conservation practices. The model attempted to link the physical, biological, economic, and social components of the farming system through time.

Taylor (1982) developed the simulation model proposed by Young. The model evaluates various soil conserving practices through the use of a nonlinear topsoil depth-yield response function which includes a multiplicative coefficient to account for the rate of technological change. The simulation model calculates the topsoil loss, crop yields, and discounted net farm income for an individual farmer using a specific tillage practice for each year of simulation up to 100 years.

In the Taylor model, net income is calculated as gross income minus variable and fixed costs. As erosion occurs over time, the model predicts yield change but assumes that fixed and variable costs remain constant. Bauer (1983) argued that production costs, in real dollars, have historically increased over time, and thus the Taylor model overestimates future farm net income. The simulation model was modified by Bauer to include an annual growth rate for fixed and variable costs. The revised model was used to analyze a representative farm on the Camas Prairie of northern Idaho. The farm size was 1122 acres, with one-half the land in winter wheat, one-third in spring barley, one-sixth in dry peas, and the remaining land fallow. According to Bauer's analysis, if an individual farmer has a long planning horizon (75 years) and a low personal discount rate (5 percent) conservation (minimum) tillage could be the most profitable system. If, however, the farmer has a short planning horizon and a high personal discount rate, conventional (heavy) tillage is the most profitable system.

In a U.S. Department of Agriculture study, Thomas and Lodwick (1981) developed a simulation model to isolate the yield impact of soil loss from technological changes which improve productivity. The length of planning horizon and social discount rate are exogenous inputs to the model.

Model results predict the net present value of future productivity lost because of soil erosion. The present value figure indicates the level of investment that could be allocated to reduce erosion. This model is well suited to small area analysis such as this study of the Mission-Lapwai Watershed.

Mathematical simulation models which evaluate the long range impacts of soil erosion require a great deal of agronomic information. Data regarding the relation between topsoil depth and crop yield require years of test trials and are difficult to obtain for specific areas. Thus, data availability and time constraints limit the use of simulation models. In addition, the estimation of the future rate of technological change is subject to considerable uncertainity. Simulation results are heavily dependent upon the assumed technological change coefficient. Simulation models of the type discussed in this section consider only the onsite costs and benefits of erosion and thus, can provide only a partial picture of the true economic costs of soil loss. Note that this study of the Mission-Lapwai Watershed has the objective of measuring onsite and offsite benefits of soil loss control.

Linear Programming: The function of a linear programming (LP) model is to find an "optimal solution" within the bounds of a set of linear equations and inequalities [McCarl, 1976]. Within the model an objective function is either maximized or minimized subject to a series of linear constraints (for example, farm net income can be maximized subject to limits on the availabilty of land, labor, and capital). Varying resource contraints within the LP model allows the testing of a wide range of alternative resource combinations [Beneke, 1973].

The LP model may be used to predict the consequences of different alterations in the environment. This predictive ability makes LP a useful tool in evaluating the economic impact of alternative soil loss control practices. In a 1983 review of literature dealing with the economics of erosion and sedimentation, Dickason and Piper indicate the popularity of LP by stating that 28 of the 54 studies reviewed used LP as the primary analytical tool. By its very nature LP modeling requires a thorough understanding of the problem environment. Defining the decision variables of the objective function, resource constraints, linkages between decision variables and constraints, and identifying the resulting data requirements forces the researcher to carefully view the problem. The knowledge gained from model formulation provides valuable insight which enhances study findings.

Large scale cost-minimizing LP models were developed as part of an ongoing Iowa State University effort to perform both regional and national agricultural analysis. In 1977 and 1978, Wade and Heady analyzed five sediment control alternatives for 18 major river basin regions in the mainland United States. Each region was divided into several land classes. Cropping alternatives were set to produce crops historically grown in each region. The study concluded that "the minimum sediment alternative requires extreme changes in the production system that increase total production cost greatly." Large scale models such as this tend to be informative about the overall cost effectiveness of soil loss control programs, but only from a national perspective. Results simply aren't detailed enough to be useful for site specific application.

In a 1979 soil conservation study of the Palouse River Basin, a USDA study team used an LP model to identify combinations of land management practices which control soil loss in a cost effective manner. The basic model formulation was to maximize farm net income subject to constraints on crop production, land availability, and permissable levels of erosion. A wide choice of land management and tillage practices which control soil loss were specified as activities in the model. The model's soil loss estimates were based on the Universal Soil Loss

Equation (USLE).[8/] As the permissable level of erosion was reduced, the model predicted which practices were most cost effective in reducing erosion. Changes in crop production costs and returns for each level of erosion were calculated by the LP model. In this manner the study was able to estimate the costs of reducing soil loss in the Palouse and suggest which land conservation practices are economically efficient.

A similiar approach was used by a USDA study team to investigate the economics of soil conservation on the Snake River Basin of Idaho (1982). The LP model for agricultural land analysis was designed in the same manner as that for the Palouse study. A second major LP model was developed for forested areas. Sources of erosion from forest lands include roads, streambanks, fire trails, power corridors, burned areas, and timber harvest related conditions such as clear cuts, selective cuts, and skid trails. Alternative treatment practices for each of these conditions were identified, and their establishment costs and impact on erosion estimated. The objective of the forest LP model was to minimize the cost of reducing erosion to specified levels. Model results predicted the most cost effective erosion control practices.

{8}. The USLE was developed over several years by a number of people. Credit for much of the work goes to W.H. Wischmeier (1978), a scientist with the USDA's Agricultural Research Service.

Another USDA study (1981) evaluated erosion and sediment control alternatives for the Lolo Creek Watershed, Idaho. LP models for both agricultural and forested lands were developed. Instead of simply looking at the change in farm net income or forest practice cost at various erosion reduction levels, this study parameterized the soil loss constraint downward and used the constraint's shadow price to identify an erosion control marginal cost schedule. Due to time and funding limits the onsite and offsite benefits of reducing soil loss were not considered. If a marginal benefit schedule could be estimated, however, it would allow the equating of marginal cost with marginal benefit and thus provide an optimal strategy for soil loss control. This idea will provide the basis for the analysis of soil conservation on the Mission-Lapwai Watershed.

Linear programming models are set in a comparative static framework. Coefficient values are specified exogenously and remain constant in the model. Thus, the prices, yields, erosion and sediment rates, etc. of the soil conservation LP's discussed in this section are determined outside the model. This limits LP use in modeling the dynamic process of soil loss, particularly the topsoil depth-yield relation. Research methods such as dynamic programming could better evaluate the process of technological change and economic adjustments, however, the data requirements for such an analysis are extreme and beyond the scope of this thesis.

LP model optimal solutions represent the best choice among the soil conserving practices specified within the model. Thus, the model's accuracy and thoroughness in evaluating a situation is dependent upon proper and complete specification of coefficients and alternative soil conserving activities. A further limit of LP modeling is that the offsite (downstream) effects of erosion are not explicitly considered. For public investment decisions, a comprehensive cost-benefit analysis of soil loss control needs to include both onsite and offsite effects.

Scope and Methodological Considerations

In the Mission-Lapwai Watershed, soil erosion and resulting sedimentation have created concern for the area's land and water resources. The purpose of this thesis is to identify, evaluate, and present potential solutions to the watershed's soil loss problem. The economic objective is to to develop a method of analysis which will compare the marginal cost with the marginal benefit of soil loss control.

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 stabelizing vegetation along the riparian zone bordering Mission Creek. Land use practices which cause soil loss and potential management practices to mitigate this loss vary by land source. Thus, this study needs to develop a methodology to evaluate the potential for erosion and sediment reduction upon each of the three land sources. It will be necessary to identify management practices which, from both a physical and economic viewpoint, offer the best opportunity for erosion and sedimentation reduction for the entire watershed. The literature review of the previous section indicates that linear programming will provide a method of choosing between alternative soil loss control management practices so as to reduce erosion and sedimentation in a cost effective manner.

Given the separability of the surface erosion problem between the agricultural, forest, and riparian lands; a separate LP model to evaluate the soil loss problem found on each land source will be developed. For each model, the first task will be to inventory the land resource and identify the relationship between land management practices and the resulting erosion and sedimentation. Next, treatment practices to help control erosion will be identified, their effectiveness determined, and their costs estimated.

The LP models will be constructed so that soil loss (measured in tons) from each land source can be constrained below its present (1983) estimated level. As the constraint is made more restrictive, model results will provide estimates of the marginal cost ($/ton) of erosion and sediment reduction, and predict which land management practices can be used to reduce soil loss. The marginal cost schedule developed from each model will allow comparison of soil loss control costs among land sources.

Land productivity effects and offsite benefits must also be determined. As noted, soil loss can potentially impact agricultural and forest productivity. The mathematical simulation model developed by Thomas and Lodwick will be used to measure any productivity effects. In terms of downstream impacts, fish and wildlife habitat and downstream users of stream water (i.e. municipalities, industry, navigation, etc.) face potential damage and costs due to sedimentation of the water supply. Improvement in water quality due to erosion control practices implemented upon the lands of the Mission Creek drainage may be valued as a potential benefit to these downstream water users. No specific model will be used to determine downstream benefits, rather each impact will be analyzed separately using a descriptive approach.

Since the analysis will eventually need to balance soil loss control costs with benefits, a common unit of measurement is needed. Benefits are most conveniently measured in $/ton of reduced sediment flow in the stream's water supply. Thus, the analysis of of soil loss control strategies for each land source will also measure control costs in terms of $/ton of sediment reduction. The benefit/cost analysis will then be based on the criterion that soil loss control practices are economically viable if the marginal benefit exceeds the marginal cost.

The methodology needs to provide a means to link the cost of soil loss control upon each land source with the offsite (downstream) benefits. A model which keeps track of the amount of sediment entering Mission Creek from each land source and provides an estimate of sediment flow to Lapwai Creek and its confluence with the Clearwater River will be developed. This "Sediment Transport" model will provide the necessary linkage between onsite soil loss control costs and offsite (downstream) benefits (Figure 1).

Model design for each of the three land sources of erosion and sedimentation will be presented in the following chapter. In addition, the development and use of the sediment transport model will be given. A discussion of the type of descriptive analysis to be used for each offsite benefit will complete the chapter.

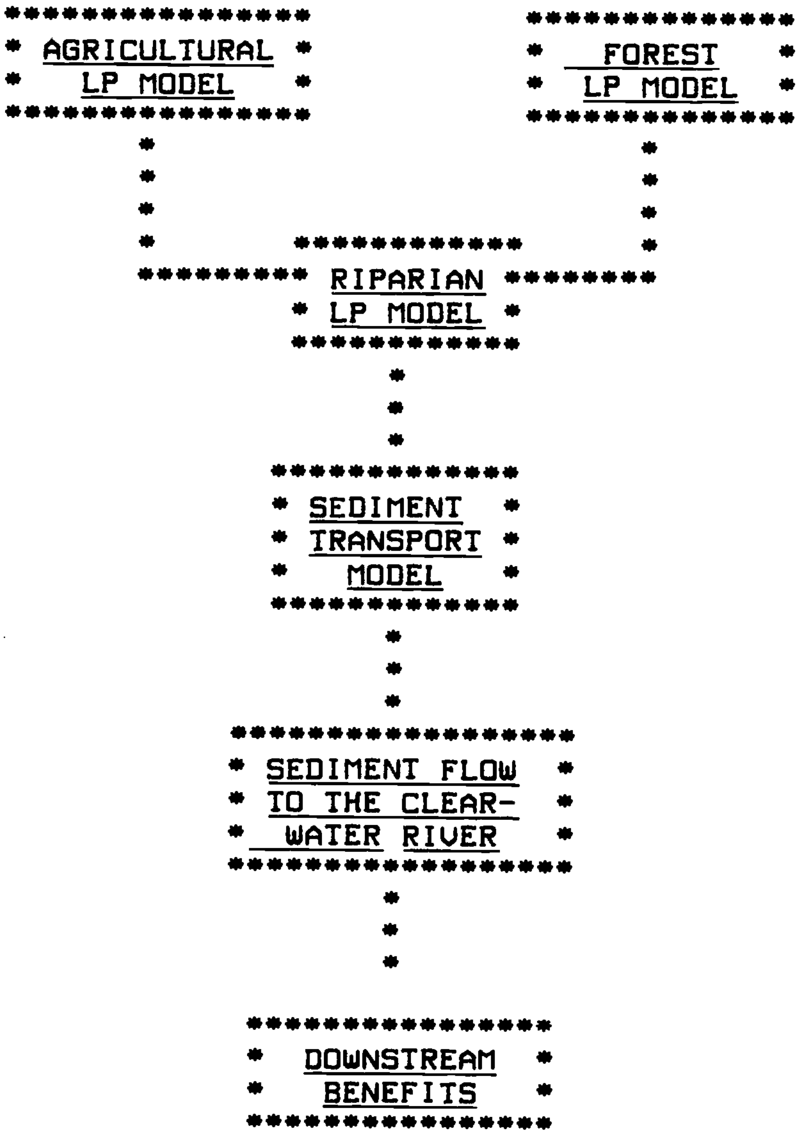


Figure 1. Model Linkage for Comparison of the Marginal Costs and Benefits of Soil Loss Control.

III. ANALYTICAL DESIGN

This chapter presents the analytical design that will be used to determine the marginal costs and benefits of soil loss control upon the Mission-Lapwai Watershed. The first section discusses physical and economic data needs. Next, the linear program model formulations for the agricultural, forest, and riparian lands will be given. The third section will present the design of the sediment transport model. A discussion of potential downstream benefits of soil loss control will complete the chapter.

Physical and Economic Data Needs

As mentioned, soil loss on the Mission Creek drainage originates from three distinct land sources: (1) Agricultural lands, (2) Forest lands, and (3) the Riparian land bordering Mission Creek.[9/] Separate LP models will be developed for each land source.[10/] The first step in developing the LP model is to make a complete inventory of the land resource. This inventory should include the acreages of present land uses, current land management practices, and an estimate of the relation between land

{9}. Soil loss on the 2176 acres of rangeland is less than one ton per acre and not considered a serious problem.
{10}. It is feasible to develop one large LP model which would include all three land sources, however, the model would be expensive and cumbersome to run. Separate LP models have the advantage of being easier to manipulate and may be run on microcomputers, such as the IBM PC.

management practices and resulting erosion and sedimentation. It's useful to divide each prime land use into subcategories; for instance the agricultural land may be classified into separate units based on slope, soil type, cropping pattern, location, and other distinctive features. Classifying land source acreages into separate treatment units improves the thoroughness of LP model results, since the model can predict which erosion control practices are most cost effective upon each separate treatment unit.

Once the land resource has been inventoried, it is necessary to identify technically feasible land treatment practices which, if implemented, will help control soil loss. The nature of these treatment practices will vary by land source. On agricultural land, for example, changes in crop production practices, such as minimum or no tillage, will mitigate soil loss. Planting of seed grass along abandoned timber harvest roads or skid trails on forest lands, or better livestock control along the riparian lands are other alternative practices to control soil loss. After identifying potential land treatment practices, their establishment and maintenance cost must be estimated. Development of alternative treatment practice data requires the assistance, experience, and knowledge of professionals such as USDA soil scientists and foresters.

The next step in physical data development is to estimate the soil loss rates for present land management practices and the alternative land treatment practices. This can be done through measurement of strategically located test plots, which is time consuming and expensive. A more expedient method of predicting erosion rates is to use the Universal Soil Loss Equation (USLE). The USLE is a mathematical equation which calculates water caused sheet and rill erosion.[11/] The formula can compute average annual soil loss per acre for a given area based on 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 [Sampson, 1981]. The USLE is primarily used for agricultural lands, however a version for forest and rangeland has been developed. If test plot data are available, they can be valuable in verifying the accuracy of USLE estimates of soil loss. Professional judgement and experience must also be considered.[12/]

After inventoring the land resource, identifying present management practices and alternative erosion

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{11}. The equation does not compute soil loss due to gullying or wind.
{12}. USLE predictions of soil loss are subject to error, having someone knowledgable of the study area look over USLE estimates is a good check that helps lesson the degree of error.

control practices, and estimating the rate of soil loss by land treatment unit and management practice, the next data acquisition step is to develop the economic information. For the agricultural lands LP model the objective will be to maximize farm net returns subject to permissable levels of soil loss. Thus, a cost-return budget for present and potential crop enterprises upon each land treatment unit is needed. To develop the enterprise budgets the physical production data on factor inputs and outputs must be collected. In this Mission-Lapwai study the physical production data were input to the Oklahoma Crop Budget Generator [Kletke, 1975], which is a computer program that calculates enterprise cost-return budgets. The crop enterprise budgets calculated for the Mission-Lapwai Watershed express net income in dollars per acre return to land and management.

The objective of both the forest and riparian LP models will be to minimize the cost of erosion control as the soil loss constraint is parameterized downward. Thus, the per acre cost of each soil loss control management practice needs to be specified in the model. These costs are difficult to estimate. One approach is to review past studies that used similiar models, such as those of the Snake River Basin [USDA, 1982] or Lolo Creek Watershed [USDA, 1981]. An engineering approach can be used to further refine cost estimates. Forest Service research specialists can provide much of the technical data requirements.

LP optimal solutions for each of the three land sources of erosion will provide the following results: (1) the value of the objective function (i.e. maximum farm net income or minimum treatment cost), (2) which decision variables (i.e. soil loss control treatments) are nonzero and enter the optimal solution, (3) the reduced costs of decision variables, (4) which constraints are binding and which are slack, and (5) the shadow price of resource constraints [McNamee, 1984]. The meaning of each of these results will now be discussed.

The value of the objective function for the agricultural land LP model indicates the maximum farm net returns obtainable given the specified activities and resource constraints, including the constraint on the permissable level of soil loss. For the forest and riparian LP models, the value of the objective function indicates the minimum aggregate cost of treatments necessary to limit erosion and sedimentation to levels specified in the resource constraints. Nonzero decision variables represent those soil loss control treatments that enter the optimal solution. All nonzero decision variables make up what is called the solution basis. The reduced costs of decision variables represent the marginal opportunity cost of placing a decision variable into the solution and making the necessary substitutions (i.e. if a nonbasis variable is forced into the solution, then one or more basis variables must be removed from the solution).

A resource constraint becomes binding when its limited availability confines the value of the objective function. Any constraint which is binding has what is called a shadow price. The shadow price is a measure of how much the objective function value will change per unit change in the resource constraint. This concept will be used to develop a marginal cost schedule of soil loss control for each land source of the Mission Creek area. As the soil loss constraint is made more restrictive, model results will predict the constraint's shadow price (i.e. marginal cost). Thus, by making the constraint on the permissable level of sediment increasingly more restrictive, the model will predict the constraint's shadow price and provide the marginal cost of soil loss control in terms of dollars per ton of sediment reduction.

A resource constraint is slack when its availability does not confine the value of the objective function. The shadow price of a slack resource constraint is zero, since a unit change in its supply will not influence the objective function value. Model formulation for the agricultural, forest, and riparian lands will now be presented.

Linear Program Model Formulation

Agricultural Lands: There are 16,470 acres of agricultural land in the Mission Creek drainage. For data gathering and analysis purposes the area was divided into seven land treatment units. The land resource inventory indicated that four crops can be produced on the seven land units under three alternative tillage methods. In addition, four soil loss control treatments are considered (Table 7). Alternative crop/tillage/treatment combinations will produce different levels of surface erosion and farm net income. As noted, per acre erosion rates were calculated with the Universal Soil Loss Equation (USLE) and net income was computed with the Oklahoma Crop Budget Generator. The sediment delivery rate from the agricultural lands to the Mission Creek water supply was calculated as a percentage of the erosion rate upon each land treatment unit.

Present levels of management in all treatment units are relatively the same. Conventional tillage is primarily used, thus moldboard plowing turns under most of the crop residue and leaves the soil in a highly erosive condition.

No conservation treatments are presently being used. A description of each treatment unit follows.

Table 7. Agricultural Land Inventory.

CROPS	LAND UNIT Code	Definition	Acres	TILLAGE	TREATMENT
Wheat	A1	5-15% slope	700	Conventional	Normal
Peas	A2	16-25% slope	4000	Minimum	Div Slp
Barley	A3	>25% slope	2000	No-Till	Strcrp
Pasture	A4	3-7% slope	7100		Terrace
	A5	Irr. Pasture	770		
	A6	Nonirr. Past.	900		
	A7	25-40% slope	1000		

Treatment unit A1 consists of 700 acres of dry cropland on 5-15 percent slopes. A winter wheat-spring pea rotation is the common cropping sequence. Average annual per acre erosion is estimated to exceed 10 tons. Unit A2 includes 4000 acres on slopes of 16-25 percent. The area is cropped with winter wheat, spring barley, peas, and summer fallow. Soil loss is serious, with estimated annual erosion rates exceeding 20 tons per acre.

On treatment unit A3 winter wheat, spring barley, and summer fallow make up the cropping pattern on 2000 acres of land with slopes greater than 25 percent. The steep slopes create a severe erosion hazard, with average annual per acre soil loss exceeding 27 tons. Unit A4 consists of 7100 acres of cut-over forestland which is now in crop production. Winter wheat, spring barley, peas, and summer fallow are cultivated on slopes of 3-7 percent. The low organic matter of the forest soils makes erosion a major problem. In addition, this unit is located at high elevation where rain on spring thaw is a serious erosion hazard. Estimated soil loss rates average 20 tons per acre.

Irrigated pasture accounts for the majority of the 770 acres of alluvial lands along Mission Creek in treatment unit A5. Irrigation water is applied in a supplemental manner which is dependent upon the availability of stream water. The pasture is highly productive, supporting up to 10 AUM's (Animal unit months). Erosion averages less than 1 ton per acre. Treatment unit A6 consists of 900 acres of nonirrigated pasture located in the higher elevations of the Upper riparian region. The land can support at most 3 AUM's and has an annual average erosion rate of just over 1 ton. Treatment unit A7 consists of 1000 acres of steep and shallow cropland which has been planted to improved grasses and legumes. Pasture production is about 3 AUM's and soil loss is roughly 1 ton per acre.

The LP model designed for the agricultural land in the Mission Creek area has the objective of maximizing net farm income, subject to constraints on crop, tillage, and treatment acreages and permissable levels of erosion and sedimentation. The model is initially run with crop, tillage, and treatment acreages set to their present (1983) levels. The soil loss constraints are left unbounded. The optimal solution of this run provides a benchmark estimate of the "present" levels of erosion, sedimentation, and net income. Next, permissable levels of sediment are parametrically reduced. The solution provides an estimate of the marginal cost of sediment control and predicts which management practices are the most cost effective in reducing soil loss.

In order to reduce LP model size and complexity, it was decided to set up a separate model for each agricultural land treatment unit.[13/] Model results are readily comparable since the model formulation and coefficient units remain consistent. The marginal cost schedule for sediment control will provide the main basis for comparison between treatment units.

The mathematical formulation of the agricultural land linear program model is:

Maximize: $Z = CX$

Subject to: 1.) $AX = B1$

{13}. This was done in an attempt to limit the computational requirements of all LP models to the capacity of microcomputers, such as the IBM PC.

2.) $YX \geq 0$

3.) $PX \geq 0$

4.) $MX = B2$

5.) $TX \leq B3$

6.) $RX \leq B4$

7.) $EX \leq ERO$

8.) $SX \leq SED$

9.) $LX \geq 0$

10.) $X \geq 0$

This formulation is in matrix notation where:

C is a 1 x n vector of objective function coefficients, in this case net revenue estimates for each crop/tillage/treatment combination.

X is a n x 1 vector of decision variables, in this case the crop/tillage/treatment combination.

A is a 1 x n vector of 1's, which keeps account of the total land area that enters the optimal solution.

B1 is the total land area constraint.

Y is a 1 x n vector of the per acre gross income for each decision variable.

P is a 1 x n vector of the per acre production cost for each decision variable.

M is a m x n matrix, which keeps account of the number of acres of each of the m crops that enter the optimal solution.

B2 is the m x 1 crop acreage constraint.

T is a t x n matrix, which keeps account of the acreage of each of the t tillage practices that enter the optimal solution.

B3 is the t x 1 tillage practice constraint.

R is a r x n matrix, which keeps account of the acreage of each of the r treatment practices that enter the optimal solution.

B4 is the r x 1 treatment practice constraint.

E is a 1 x n vector of the per acre erosion rate for each decision variable.

ERO is the permissable level of erosion constraint.

S is a 1 x n vector of the per acre sediment rate for each decision variable.

SED is the permissable level of sediment constraint.

L is a n x n singular diagonal matrix to keep account of the number of acres for each crop/tillage/treatment combination that enters the optimal solution.

Constraint #10 is for non-negativity of the decision variables.

An example of the LP matrix tableau which considers two crops (wheat & barley), two tillage practices (conventional & minimum), and four alternative land treatments (normal, divided slope, stripcropping, and terraces) is shown in Table 8. This tableau helps to illustrate LP model design. The first constraint specifies the number of acres in the agricultural land treatment unit. The second and third constraints act as accounting rows for gross income and total production cost. The acreage of each crop is set by the fourth constraint. Tillage and treatment acreages can

Table 8. Summary Tableau for the Agricultural Linear Program Model.

ACTIVITIES.......	X11	X12	X13	X14	X21	X22	X23	X24	X31	X32	X33	X34	X41	X42	X43	X44	
OBJ FUNCT COEF...	C11	C12	C13	C14	C21	C22	C23	C24	C31	C32	C33	C34	C41	C42	C43	C44	
CONSTRAINT #1....	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	= B1
CONSTRAINT #2....	Y11	Y12	Y13	Y14	Y21	Y22	Y23	Y24	Y31	Y32	Y33	Y34	Y41	Y42	Y43	Y44	>= 0
CONSTRAINT #3....	P11	P12	P13	P14	P21	P22	P23	P24	P31	P32	P33	P34	P41	P42	P43	P44	>= 0
CONSTRAINT #4....	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0									= B2
CONSTRAINT #4....									1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	= B2
CONSTRAINT #5....	1.0	1.0	1.0	1.0					1.0	1.0	1.0	1.0					<= B3
CONSTRAINT #5....					1.0	1.0	1.0	1.0					1.0	1.0	1.0	1.0	<= B3
CONSTRAINT #6....	1.0				1.0				1.0				1.0				<= B4
CONSTRAINT #6....		1.0				1.0				1.0				1.0			<= B4
CONSTRAINT #6....			1.0				1.0				1.0				1.0		<= B4
CONSTRAINT #6....				1.0				1.0				1.0				1.0	<= B4
CONSTRAINT #7....	E11	E12	E13	E14	E21	E22	E23	E24	E31	E32	E33	E34	E41	E42	E43	E44	<= ERO
CONSTRAINT #8....	S11	S12	S13	S14	S21	S22	S23	S24	S31	S32	S33	S34	S41	S42	S43	S44	<= SED
CONSTRAINT #9....	1.0																>= 0
CONSTRAINT #9....		1.0															>= 0
CONSTRAINT #9....			1.0														>= 0
CONSTRAINT #9....				1.0													>= 0
CONSTRAINT #9....					1.0												>= 0
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CONSTRAINT #9....															1.0		>= 0
CONSTRAINT #9....																1.0	>= 0

be limited by constraints five and six, respectfully. If no limits are desired, these rows are left unbounded. The seventh constraint limits the permissable level of erosion, while the eighth constraint limits sediment. The ninth constraint accounts for the acreage of each decision variable that enters the optimal solution, although specific decision variable acreage can be constrained if desired.

LP model coefficients were specified on a per acre basis. The erosion and sediment rates, crop yield, and production cost and net return depend on the cropping pattern. Therefore, the following crop sequences were determined applicable for the Mission Creek area (Table 9).

Table 9. 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 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.

Research at the University of Idaho [Carlson, 1981] has indicated that to control soil loss farmers are more likely to change production practices than to change the type of crops they grow. Hence, LP model resource contraints were set to allow changes in tillage and treatment practices, however acreages in each crop were held constant. In addition, research [Harder,1980; STEEP, 1980; Hoag, 1984] has indicated potential reduced yields with conservation tillage practices. Therefore, crop yields under minimum and no-tillage will be assessed a 5 percent yield penalty. A listing of estimated coefficients for crop sequences on each land treatment unit is given in Appendix A.

Forest Lands: The land resource inventory indicated that on the 24,870 acres of forest land in the Mission Creek area, road construction represents the major source of surface erosion. Timber harvesting is not prevalent at the present time. Hence, only alternative management practices which can reduce erosion and sedimentation caused by roaded areas are considered in the forest LP model.

To remain consistent with the agricultural land analysis, forest LP model coefficients need to be specified on a per acre basis, thus it was necessary to convert miles of forest roads into acres. Three types of forest roads were identified: (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).

The first forest treatment unit (F1) consists of mixed forest and range with 10 to 60 percent canopy cover on slopes less than 40 percent. This unit includes a total of 14.4 acres of roads. The second treatment unit (F2) includes land adjacent and in close proximity to streams, including wetlands, and has 20.4 acres of roads. Lands with 60 percent or more canopy cover on slopes greater than 40 percent make up the next treatment unit (F3). There are 44.1 acres of roads on this unit. The fourth treatment unit (F4) includes lands with 60 percent or more canopy cover on slopes less than 40 percent and has 82.0 roaded acres. Mixed forest and range with 10 to 60 percent canopy cover and slopes greater 40 percent make up the last treatment unit (F5). This unit has 44.0 acres of roads.

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

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. 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 so as to slow water runoff and trap sediment flow. Planting vegetation (grass and shrubs) and placing water bars along dirt roadways at a cost of $1750 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 $2350 per acre, and the final alternative expands on the fourth by placing down netting to better stabelize the soil and costs an estimated $3300 per acre. A listing of alternative management practices for each treatment unit and the associated erosion and sediment rates is given in Appendix B.

The objective function of the forest LP model minimizes the cost of erosion and sedimentation reduction. As with the agricultural lands, a separate LP model was set up for each of the five land treatment units. Model results indicate which management practices are most cost effective in controlling soil loss as the sediment constraint is parametrically reduced. The sediment constraint's shadow price provides an estimate of the marginal cost of soil loss reduction. The forest LP formulation is:

Minimize:		Z = CX
Subject to:	1.)	AX = B1
	2.)	RX <= B2
	3.)	EX <= ERO
	4.)	SX <= SED
	5.)	TX >= 0
	6.)	X >= 0

This formulation is in matrix notation where:

C is a 1 x n vector of objective function coefficients, in this case the per acre cost of forest management treatment practices.

X is a n x 1 vector of decision variables, in this case management treatment by road type.

A is an m x n matrix to keep account of the number of acres in each road type. There are m road types.

B1 is an m x 1 constraint for the number of acres in each of the m road types.

R is an r x n matrix, which keeps track of the acreage of each of the r management treatment practices that enter the optimal solution.

B2 is the r x n management treatment practice constraint.

E is an 1 x n vector of the per acre erosion rate for each decision variable.

ERO is the permissable level of erosion constraint.

S is an 1 x n vector of the per acre sediment rate for each decision variable.

SED is the permissable level of sediment constraint.

I is a n x n singular diagonal matrix to keep account of the number of acres in each management treatment by road type (i.e. decision variable) that enters the optimal solution.

Constraint #6 is for non-negativity of the decision variables.

An example tableau of the forest LP model matrix helps to illustrate model formulation (Table 11). The first constraint specifies the number of acres in each of the three road types. The acreage in each management treatment practice can be limited by the second constraint, if no limit is desired the row is left unbounded. The third constraint limits the permissable level of erosion, while the fourth constraint limits sediment. The fifth constraint basically acts as an accounting row to keep track of the number of acres of each management practice by road type that enter the optimal solution, although the constraint may be used to force certain decision variables into or out of the solution.

Riparian Lands: Before entering the stream's water supply, sediment flowing from the agricultural and forest

Table 11. Summary Tableau for the Forest Linear Program Model.

ACTIVITIES.......	X11	X12	X13	X14	X15	X21	X22	X23	X24	X25	X31	X32	X33	X34	X35	
OBJ FUNCT COEF...	C11	C12	C13	C14	C15	C21	C22	C23	C24	C25	C31	C32	C33	C34	C35	
CONSTRAINT #1....	1.0	1.0	1.0	1.0	1.0											= B1
CONSTRAINT #1....						1.0	1.0	1.0	1.0	1.0						= B1
CONSTRAINT #1....											1.0	1.0	1.0	1.0	1.0	= B1
CONSTRAINT #2....	1.0					1.0					1.0					<= B2
CONSTRAINT #2....		1.0					1.0					1.0				<= B2
CONSTRAINT #2....			1.0					1.0					1.0			<= B2
CONSTRAINT #2....				1.0					1.0					1.0		<= B2
CONSTRAINT #2....					1.0					1.0					1.0	<= B2
CONSTRAINT #3....	E11	E12	E13	E14	E15	E21	E22	E23	E24	E25	E31	E32	E33	E34	E35	<= ERO
CONSTRAINT #4....	S11	S12	S13	S14	S15	S21	S22	S23	S24	S25	S31	S32	S33	S34	S35	<= SED
CONSTRAINT #5....	1.0															>= 0
CONSTRAINT #5....		1.0														>= 0
CONSTRAINT #5....			1.0													>= 0
CONSTRAINT #5....				1.0												>= 0
CONSTRAINT #5....					1.0											>= 0
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CONSTRAINT #5....														1.0		>= 0
CONSTRAINT #5....															1.0	>= 0

lands must pass through the riparian zone bordering Mission Creek. The streambank condition and vegetative cover of the riparian lands greatly influences the water quality of Mission Creek. The riparian LP model is 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 is 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 12). In addition, the land of each riparian zone contributes sediment to stream waters.

Management practices implemented upon the riparian treatment units will reduce the amount of sediment that enters Mission Creek from the agricultural and forest lands and will also reduce soil loss from the the riparian area itself. Ten alternative soil loss control management practices were identified for the riparian lands (Table 13). 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 present sediment delivery caused by riparian land and streamside erosion is estimated to be 90, 70, and 100 tons per acre, respectively. A listing of each management practice's efficiency in reducing sediment delivery to Mission Creek is presented in Appendix C.

Table 12. 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%	--

Table 13. Riparian Land Management Practices.

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

As with the agricultural and forest lands, a separate LP model was built for each riparian land treatment unit. Model formulation is:

Minimize: $Z = CX$

Subject to:

1.) $LX = B1$

2.) $RX \le SED1$

3.) $MX \le SED2$

4.) $TX \le SED3$

5.) $X \ge 0$

This formulation is in matrix notation where:

$\underline{C}$ is a 1 x n vector of objective function coefficients, in this case the per acre cost of riparian management practices.

$\underline{X}$ is a n x 1 vector of decision variables, in this case riparian management treatments.

$\underline{L}$ is a 1 x n vector of 1's to account the acreage in the land treatment unit.

B1 is the land acreage constraint.

R is a 1 x n vector of the per acre sediment delivery from the riparian land and streamside to Mission Creek under each management practice.

SED1 is the riparian land sediment constraint.

M is a 1 x n vector of the amount of sediment (per acre) inflow to Mission Creek from the agricultural and forest lands under each management practice.

SED2 is the constraint on sediment inflow from the agricultural and forest lands.

I is a 1 x n vector of the total sediment inflow (per acre) to Mission Creek under each management practice.

SED3 is the total sediment inflow constraint.

Constraint 5 is for non-negativity of the decision variables.

The acreage of the riparian land treatment unit is set by the first constraint. Sediment inflow to Mission Creek from the riparian land and the combined inflow from agricultural and forest lands are limited by constraints two and three, respectively. The fourth constraint limits total sediment inflow to Mission Creek. A summary tableau of the riparian LP matrix helps to illustrate model design (Table 14).

The physical ability of the riparian land to trap and control sediment inflow is limited. Over time the effectiveness of riparian management practices may change as the sediment flow from agricultural and forest lands varies. The basic assumption is that the greater the sediment inflow to the riparian lands, the less efficient soil loss control practices will be over-time. A change in sediment control practice efficiency would influence the coefficients in the R, M, and T vectors of the riparian LP model formulation.

Table 14. Summary Tableau for the Riparian Linear Program Model.

ACTIVITIES.......	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11	
OBJ FUNCT COEF...	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	
CONSTRAINT #1....	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	= B1
CONSTRAINT #2....	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	<= SED1
CONSTRAINT #3....	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	<= SED2
CONSTRAINT #4....	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	<= SED3

To simulate the dynamics of riparian treatment efficiency, a time dimension of 25 years will be added to the analysis. The assumption will be made that over time the efficiency of soil loss control practices on agricultural and forest lands remains constant. Riparian treatment efficiency over-time, however, will change depending upon sediment inflow from the agricultural and forest lands. The next chapter will discuss what management practices are economically viable upon the forest and agricultural land treatment units. This information will provide the basis for developing a set of alternative land management plans. Each plan will give a predicted sediment inflow from agricultural and forest lands to the riparian treatment units. Based on this information, a vector of riparian treatment efficiency coefficients will be developed for each soil loss management plan. These coefficients will represent the average effectiveness (percent) of management practices for each year of the 25 year time horizon and will vary inversely with the amount of sediment inflow from the previous year. With this procedure the riparian LP model coefficients can be updated annually and the model will predict sediment inflow to Mission Creek for each year of the 25 year time period. The riparian treatment efficiency vector will be developed in the following chapter.

Sediment Transport Model

This model is designed to keep track of the amount of sediment which 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. Estimates of tonnage of sediment flowing into Mission Creek are derived from the riparian LP model. As the type of surface soil loss control practices applied upon the Mission Creek land area are changed, the inflow tonnages to the sediment transport model can be adjusted and the model will calculate the resulting change in stream sediment flow to the Clearwater River. Thus, the model acts as a link between the marginal cost of land source sediment control and the offsite (downstream) benefits.

The sediment transport model consists of a series of equations which are set up on a Lotus 1-2-3 spreadsheet.[14/] The amount of sediment transported depends upon how much enters the stream from each riparian segment, the amount of stream channel erosion in each segment, and upon the the amount of silt deposition along stream segments. Basically the model multiplies sediment inflow to each stream segment by the estimated percent of

{14}. Lotus 1-2-3 is a microcomputer software package created by Lotus Development Corporation.

total sediment inflow that will be transported downstream to the Clearwater River. The model accumlates the sediment flow as it moves downstream; for example, sediment delivery through the Canyons segment is the sediment inflow figure derived from the riparian LP model multiplied by the delivery percentage, plus the flow which the sediment transport model calculates moves downstream from the Upper riparian segment. The Lotus spreadsheet was developed so that input data regarding stream channel acreage, streambank soil loss, sediment inflow from each riparian segment, and delivery ratios through stream segments can be readily changed. An example of the spreadsheet format is presented in Appendix D.

Benefits of Soil Loss Control

Soil loss, through its influence on water quality, represents a potential cost to fisheriers and other downstream water users (i.e. municipalities and industry, navigation, flood control, etc.). Reducing sediment inflow to Mission Creek may, therefore, be viewed as a potential benefit to downstream water users. In addition, erosion control produces the onsite benefit of helping to maintain the land's long term productivity.

In this study of the Mission-Lapwai Watershed, five potential benefits of erosion and sediment control were identified: (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 the city of Lewiston, Idaho); and (5) maintenance of long-term agricultural productivity. Each potential benefit will be investigated individually using a descriptive approach and appropriate mathematical analysis.

The objective of the offsite benefit analysis is to estimate the value per ton of reduced sediment flow in the water supply of each downstream user. Data for fishery enhancement analysis will be obtained from U.S. Forest Service fishery biologists, who in 1983 conducted a survey of the existing spawning and rearing habitat of Mission Creek [Brouha, 1984]. Previous studies which have analyzed the value of freshwater fisheries in the Pacific Northwest will be used to supplement economic value estimates. Water treatment procedures and costs will be collected from the City of Lewiston and Potlatch Corporation.[15/] Regression analysis will be used to estimate the change in water

{15}. Clarkston draws its water suppy from ground aquifers. Potlatch is the only major industrial water user in the Lewiston-Clarkston area.

treatment cost as the turbidity level of the water supply changes.

The Army Corps of Engineers is responsible for maintaining the slackwater navigation channel to the Lewistion-Clarkston area and is also involved in studying the flood threat to Lewiston, which is being aggravated by silt deposition in the Clearwater River. Corps' data on navigation channel maintenance and flood control will be used to estimate the value of reduced sediment flow. For long term agricultural productivity, the mathematical simulation model developed by Thomas and Lodwick (1981) will provide the method to estimate the marginal value of this benefit. A descriptive analysis of each potential benefit will be presented in the following chapter.

Summary of Analytical Design

To summarize analytical design, the combination of the agricultural, forest, riparian, and sediment transport models furnishes a method to estimate the amount of sedimentation flowing from the Mission-Lapwai Watershed to the Clearwater River under various soil loss control strategies. The agricultural and forest LP models are divided into seven and five land treatment units, respectively. Sediment flowing from each land unit enters a specific riparian segment. By comparing the marginal costs of sediment control predicted for each land source, it is possible to develop a cost effective management strategy for soil loss control. Once sediment enters Mission Creek, it is transported downstream towards Lapwai Creek and the Clearwater River. The sediment transport model calculates an estimate of the amount of sediment that would enter the Clearwater River from the Mission-Lapwai Watershed. This model provides the necessary linkage between on-site soil loss control costs and downstream (off-site) benefits. Estimates of the potential benefits of sediment reduction to downstream water users can then be balanced against control costs to develop an "preferred" erosion and sediment reduction strategy.

Results from the agricultural, forest, and riparian LP model runs will be interpreted in the following chapter. Next, a descriptive analysis to determine the marginal value per ton of reduced sediment flow for each potential benefit will be presented. Based on comparison of marginal costs and benefits, alternative soil loss control management plans will be developed. Finally, the sediment transport model will be used to predict sediment flow from the Mission-Lapwai Watershed to the Clearwater River under each management plan.

IV. INTERPRETATION OF RESULTS

This chapter will consist of three main sections. First, the linear program model results for the agricultural, forest, and riparian lands will be evaluated. LP results predict the marginal cost of sediment control for each land source and treatment unit of the Mission Creek area. Each potential benefit of soil loss control is described in the second section. Individual benefit values will be summed to estimate the total benefit per ton of sediment reduction. In the last section, by comparison of the marginal costs and benefits of sediment reduction, alternative soil loss control management plans will be developed. Estimates of sediment flow to the Clearwater River under each management plan will be calculated by the sediment transport model.

Interpretation of Model Results

Agricultural Lands: The objective of the agricultural land LP model is to maximize farm net returns. The first step in the analysis is to predict the present (1983) levels of erosion, sediment, and crop enterprise net returns for each land treatment unit. This was accomplished by running the LP model with crop, tillage, and treatment practice constraints fixed at their present acreages. These constraints were determined in the land resource inventory. The results of the LP analysis (Table 15) were checked by SCS personnel to verify the accuracy of the predictions.

Table 15. 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	1000	18,600	5,580	$33,000
A2	BG	CONV	NORMAL	1000	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	**	****	******	4000	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	**	****	******	2000	55,880	17,880	$49,080
A4	BG	CONV	NORMAL	1350	18,090	3,618	($10,800)
A4	WG	CONV	NORMAL	1350	18,090	3,618	$44,550
A4	PG	CONV	NORMAL	700	8,120	1,624	$3,500
A4	WF	CONV	NORMAL	1500	48,000	9,600	$141,900
A4	FG	CONV	NORMAL	1500	34,950	6,990	($60,000)
A4	WP	CONV	NORMAL	700	21,000	4,200	$55,720
TOTAL	**	****	******	7100	148,250	29,650	$174,870

Table 15 (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
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
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

The results in Table 15 provide benchmark estimates of present levels of erosion, sediment, and net returns for each agricultural land treatment unit. The present annual sediment flow from agricultural lands to riparian land units is 78,393 tons. Soil loss is most severe on agicultural land units A2 (16-25% slope), A3 (greater than 25% slope), and A4 (cut-over forest, 3-7% 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 permissable level of sediment upon each land treatment unit.[16/] Note that crop acreages were held constant, only tillage and treatment practices were allowed to vary. Optimal solutions of these runs provide an estimate of the marginal cost of sediment control and predict which management practices are most cost effective in reducing soil loss.

A line graph of the marginal cost schedule for sediment control upon agricultural lands (Figure 2) shows that marginal costs initially decrease, indicating the "best of both worlds" -- sediment can be reduced and net returns increased simultaneously. This situation occurs as minimum tillage replaces conventional tillage in the optimal cropping pattern (see "Tillage Used " column of Table 16). In general, minimum tillage has lower machinery requirements and thus lower per acre production costs.[17/] Crop yields under the minimum tillage alternative were assessed a penalty of 5 percent, nevertheless net returns initially rise as miminum tillage replaces conventional tillage in the LP optimal solution. Marginal costs

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{16}. In parametrically reducing the sediment constraint, the LP algorithm indicates each change in the optimal basis. The results predict which decision variables (i.e. management practices) enter the optimal solution and the resulting change in the sediment constraint's level and shadow price.
{17}. See Appendix A.

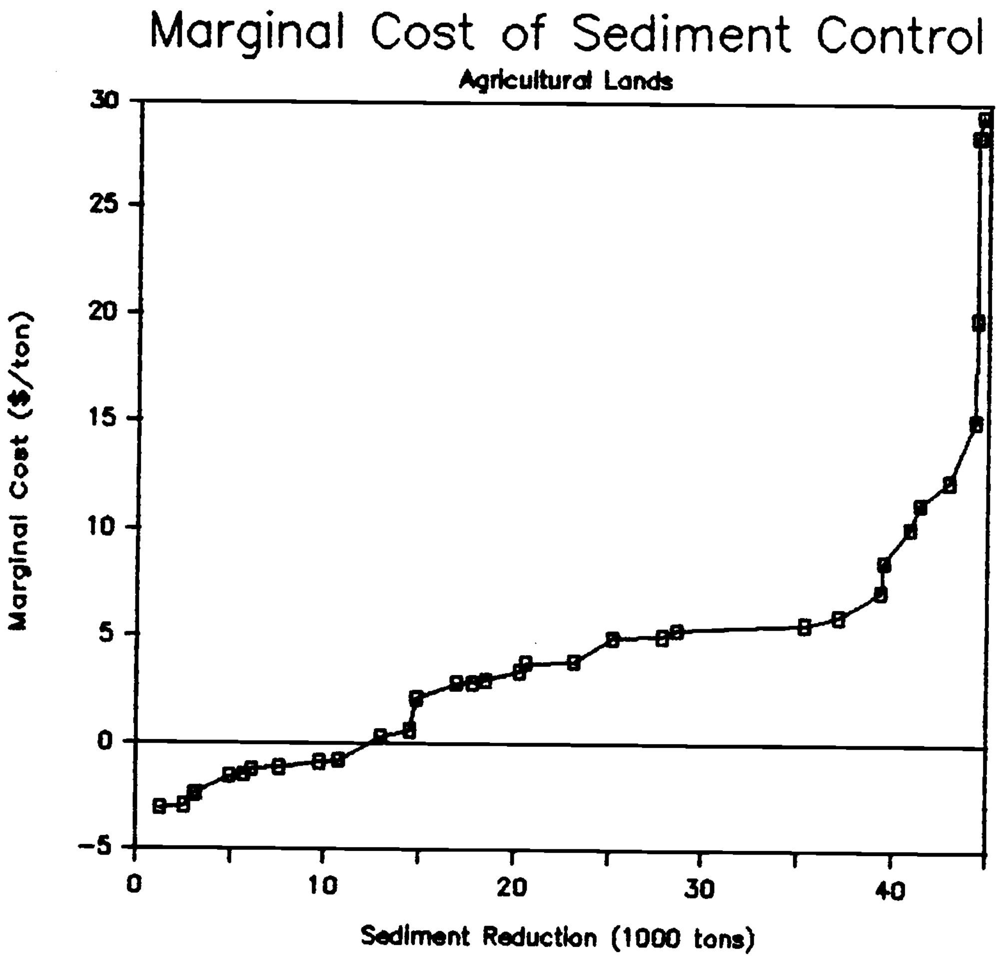

Figure 2. Marginal cost schedule for sediment control upon agricultural lands.

Table 16. 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	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
$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
$7.11	A2	WG	NO-TILL	NORMAL	1000	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	1000	42,885
$15.09	A4	WG	NO-TILL	NORMAL	1350	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.

eventually increase and net returns decline as further sediment reduction requires use of the more expensive treatments of divided slope farming, no-tillage, and terraces.

Results predict that sediment can be reduced by 10,721 tons before marginal costs begin to increase (see the "Sediment Reduction" column of Table 16). This reduction is achieved by converting 2400 (i.e. 1350 + 1350 + 700) acres on land unit A4 to minimum tillage, 400 (i.e. 100 + 300) acres are converted to minimum tillage on land unit A1, while land units A2 and A3 have 2500 (i.e. 1000 + 1000 + 500) and 1200 (i.e. 600 + 600) acres switched to minimum tillage, respectively (see "Acres Treated" column of Table 16). The economics of further sediment reduction depend upon the value of the estimated marginal benefit, which will be determined later in this chapter. Sediment reduction remains economically viable as long as the marginal benefit of sediment control exceeds the marginal cost. A complete listing of marginal cost estimates and associated treatment alternatives by land unit is given in Appendix E.

<u>Forest Lands:</u> The objective function of the forest LP model minimizes the cost of sediment reduction. To determine the present (1983) level of sediment flow the

model is run with the soil loss constraint unbounded. Results indicate that the 204.9 acres of forest roads produce 919 tons of sediment annually (Table 17). 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 indicate the marginal cost of reducing soil loss from the roaded areas of forest lands and which management treatments are most cost effective.[18/] The marginal cost schedule begins at $1.87 per ton of sediment reduction and increases quite rapidly (Figure 3). Planting grass on the one lane dirt roads at a investment cost of $150 per acre is the first treatment to enter the sediment reduction optimal solution (Table 18). 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 agricultural lands, sediment reduction on forest lands is slight and expensive. A detailed listing by land unit of

{18}. 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%.

marginal costs and associated management practices required to obtain sediment reduction is given in Appendix F.

Table 17. 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

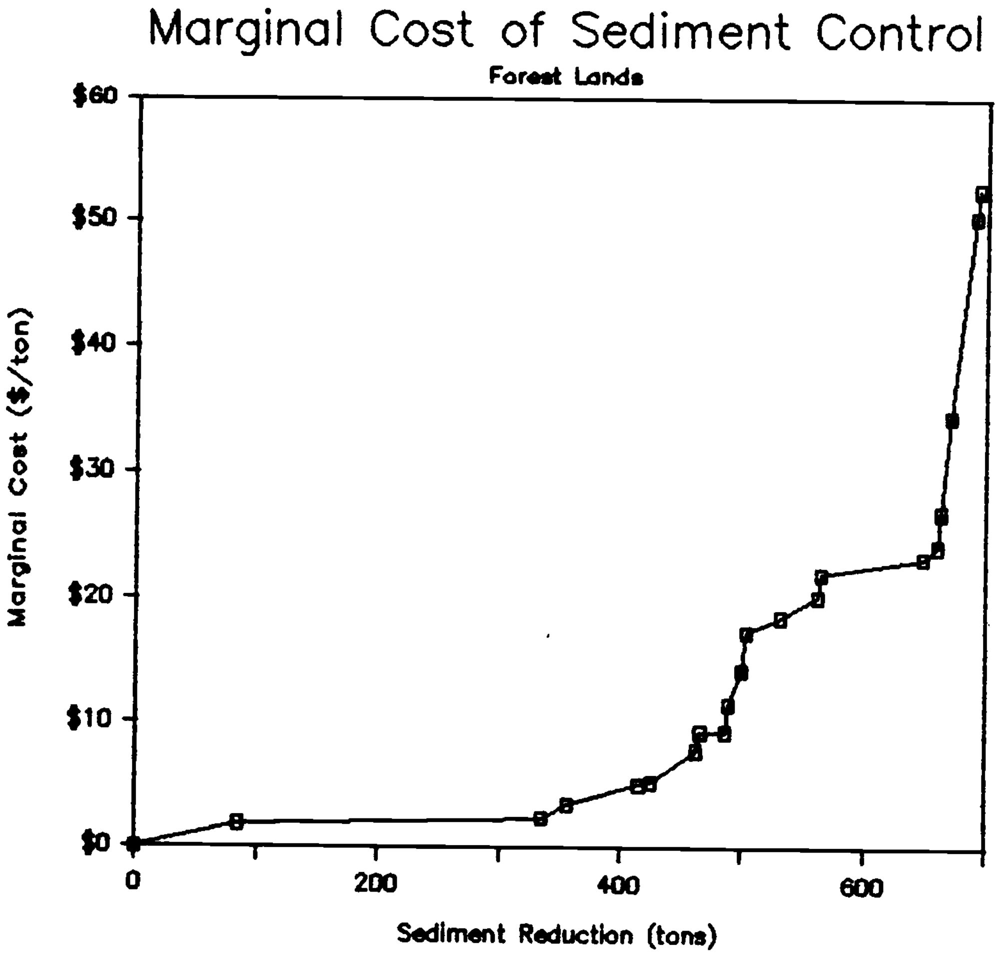

Figure 3. Marginal cost schedule for sediment control upon forest lands.

Table 18. 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	1 LN 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

Riparian Lands: The riparian LP model evaluates the cost effectiveness of management practices designed to reduce sediment inflow to Mission Creek. As mentioned in the previous chapter, the physical ability of the riparian land to trap and control sediment is limited. Over time the effectiveness of riparian management practices may change as the sediment inflow from the agricultural and forest lands varies. A change in treatment effectiveness will alter riparian LP model coefficients and thus, the marginal cost and sediment reduction estimates. Appendix C lists the optimal (i.e. 100%) effectiveness of each riparian land management practice in reducing sediment inflow to Mission Creek.

As discussed in the Linear Program Model Formulation section of chapter III, agricultural, forest, and riparian lands contribute sediment to stream waters. LP model results predict that under present (1983) conditions the largest amount (84%) of sedimentation in Mission Creek comes from agricultural lands, while 15 percent comes from the riparian lands, and only 1 percent from the forest roads (Table 19).

Table 19. 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

The riparian lands were divided into three separate treatment units: (1) Upper, (2) Canyons, and (3) Bottom.

Sedimentation from agricultural and forest land units flows into specific riparian treatment units.[19/] In addition, the riparian land contributes sediment to Mission Creek waters (Table 20).[20/] Under present conditions, total sediment inflow to Mission Creek is estimated to be 93,982 tons annually.

Table 20. 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%) riparian treatment units. About 10 percent of total sediment inflow enters through the Canyons. The potential for cost effective control of sedimentation entering Mission Creek appears quite favorable (Figure 4).

{19}. See Table 12, Chapter III for a percentage breakdown of sediment flow from agricultural and forest land units to riparian land units.
{20}. Soil loss by riparian land unit is: Upper -- 45 acres @ 90 tons per acre; Canyons -- 41 acres @ 70 tons per acre; and Bottom -- 77.5 acres @ 100 tons per acre.

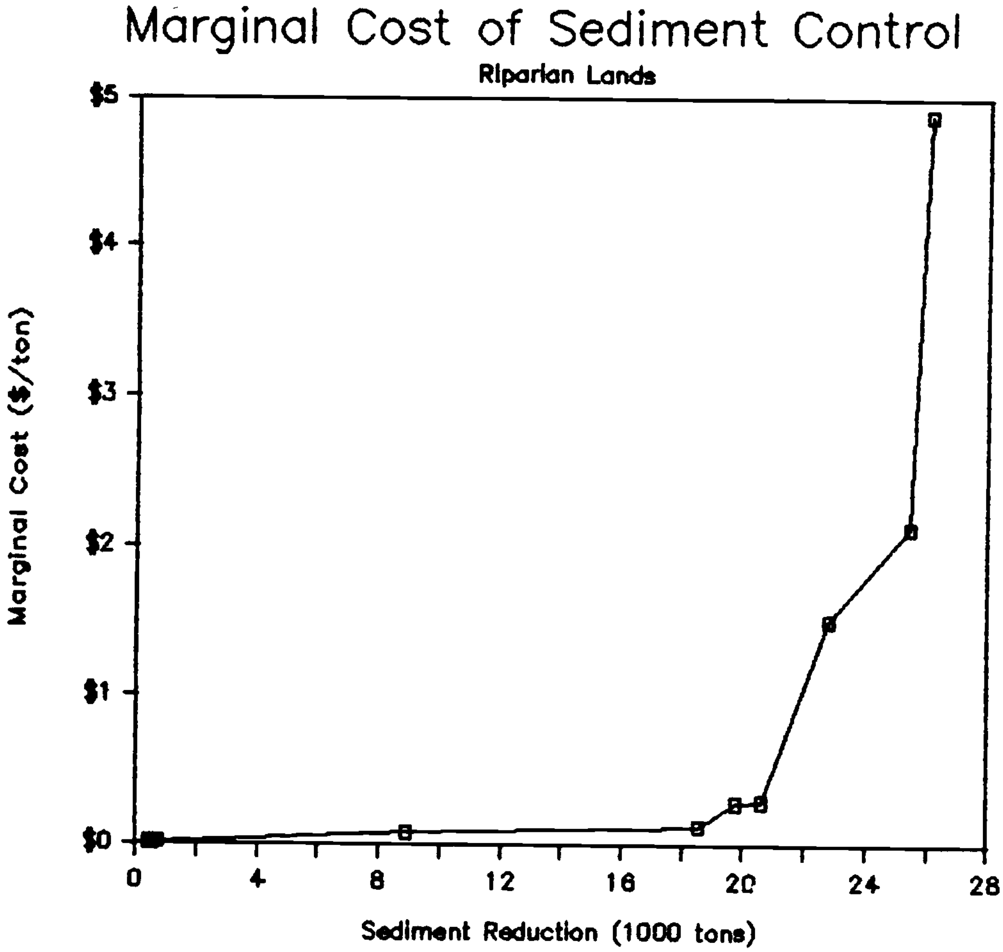

Figure 4. Marginal cost schedule for sediment control upon riparian lands.

Assuming a 50 percent management practice efficiency, 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 21).[21/] These three practices

Table 21. 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

Note: Marginal cost estimates assume a treatment operating efficiency of 50 percent.

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. Even if treatment efficiency is only 25 percent of maximum, however, the

{21}. Given the high sediment inflow to the riparian lands, it was considered unlikely that riparian management practices could operate at optimum efficiency.

riparian lands still offer substantial potential for cost effective sediment reduction (Appendix G).

Sediment Transport: As mentioned, results of the riparian LP model runs predict the amount of sediment which enters the water flow of each riparian segment of Mission Creek. These results are input to the sediment transport model which calculates, via sediment delivery ratios, an estimate of the tons of sedimentation flowing from the Mission-Lapwai Watershed to the Clearwater River. With the determined present (1983) sediment inflow to Mission Creek, the sediment transport model predicts the following results (Table 22).

Under "present" conditions, total annual sediment inflow to Mission Creek is 93,982 tons.[22/] The Lapwai Creek watershed is 200,000 acres in size and contributes an estimated 322,500 tons of sediment to the stream's waters.[23/] The middle row of table 22 shows the tons of sediment contributed by each stream segment to the Clearwater River, while the bottom row lists the cumulative sediment flow. Total annual sedimentation entering the

{22}. 39,399 + 9,337 + 45,246.
{23}. The average per acre soil loss on the Lapwai Creek drainage area is assumed to be 75 percent of that on the Mission Creek lands. This implies an average per acre sediment delivery to Lapwai Creek of 1.6125 tons.

Clearwater River from Mission and Lapwai Creeks is estimated to be 237,203 tons.

As surface erosion control practices applied to the Mission Creek watershed are changed, the stream transport model provides a means to estimate the resulting change in sediment inflow to the Clearwater River. The model provides the link to compare the cost of surface erosion control with the offsite (downstream) benefits.

Table 22. Present Sediment Inflow to Mission and Lapwai Creeks and Cumulative Delivery to the Clearwater River.

	Mission Creek			Lapwai
	Upper	Canyons	Bottom	Drainage
Sediment Inflow (tons)	39,399	9,337	45,246	322,500
Sediment Delivery to Clearwater River (tons) by Segment	23,829	7,538	30,441	176,396
Cumulative Delivery to Clearwater River (tons)	23,829	31,367	61,808	237,203

<u>Benefits of Soil Loss Control</u>

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 the city of Lewiston, Idaho); and (5) maintenance of long-term agricultural productivity. Each potential benefit will be discussed individually.

The analysis of each benefit will focus on the present conditions existing in the Mission-Lapwai Watershed and the Lewiston-Clarkston area. The social efficiency of past government or private investments which have impacted the present conditions will not be considered. For example, navigation channel maintenance and the present flood threat to the city of Lewiston are the direct result of the construction of Lower Granite Dam on the Snake River. They are economic externalities which the Army Corp of Engineers, in evaluating the social welfare of Lower Granite Dam, considered but did not accurately estimate. The completion of Lower Granite Dam, however, essentially creates an irreversable shift in society's social welfare function and reevaluation of the decision to construct Lower Granite Dam will not alter the present circumstances. 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 which may or may not have been socially optimal.

<u>Fishery Enhancement:</u> The existing 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) lethal or near lethal water temperatures, especially during the summer months, and (2) fine sediments embedded in spawning gravel. The latter factor reduces spawning capacity and rearing habitat. Mission Creek is presently 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 stabelization 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 $217 [Brouha, 1984].

Discounting the annual value flow of the enhanced steelhead fishery over a 25 year period yields a present value of $255,860.[24] A discount rate of 8.375 percent was used. Riparian LP model results indicate planting of 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 upon the riparian section being treated and sediment inflow from the agricultural and forest lands.[25]

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, in terms of sediment control the cost of fishery enhancement exceeds the benefits if the only benefits realized are those of the improved fishery. This conclusion, however, is partial -- as the total benefit per ton of sediment reduction is the sum of all individual benefits.

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(24). Brouha estimated it would require 9 years from the date of plan implementation to achieve a returning summer stealhead spawner run of 190.
(25). See Table 21.

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 aquifers (i.e. wells). Lewiston, however, does take its municipal water from the Clearwater River and thus the city's water treatment costs are impacted 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 regression was run to determine 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 impacts Lewiston's municipal water treatment cost by $.0058. This relatively small figure occurs because most of the costs of water treatment are fixed (i.e. plant and facilities). Chemical usage does change as the turbidity level varies, but it represents only a small portion of total costs.

It appears, therefore, that benefits of sediment reduction to municipal water users are not significant at the present time. This situation could be altered in the future if the city of Lewiston finds it necessary to transport sediment from its water treatment plant to some disposal site located outside city boundaries. Trucking costs could run between $1.50 and $2.00 per ton of sediment. The city recognizes this as a potential future problem, but is hopeful that a newly constructed 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, located 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 similiar 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 impacts 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. As mentioned in Chapter I, the 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 one of three port terminals -- Lewiston, Clarkston, or Wilma -- where it is transferred to river barges for water-borne shipment to Lower Columbia River export facilities. The ports also handle shipments of pulp and paper products and some containerized shipments of hay cubes, peas, and lentils.

The U.S. Army Corps of Engineers was given 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 over 330,000 cubic yards of material (1 cubic yard equals one ton) at a 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 shut down due to 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 applied in latter sections of this thesis.

Flood Control: A levee system along the banks of the Clearwater River protects the city of Lewiston from flood. 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. Currently, 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].

An immediate (and temporary) solution is to dredge the river bottom so that the existing levee system remains functionally adequate. The cost of dredging would be the same as that for navigation channel maintenance ($4.50 per ton). However, a reduction of one ton of sediment simultaneously benefits navigation and flood control. Thus, a value of $4.50 per ton of reduced sediment will be allocated to navigation maintenance and flood control.

Long Term Agricultural Productivity: Recognizing topsoil as one input of crop production, it seems reasonable to assume that loss of topsoil due to surface erosion will eventually cause crop yields to decline. This assumed productivity loss, however, is not readily apparent when one looks at crop yield trends in American agriculture. The yield loss is often hidden by technological advances which allow other production inputs (i.e. machinery, pesticides, fertilizer, etc.) to substitute for the lost topsoil. An evaluation of the benefits of soil loss control upon 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.[26/] Present value figures

(26). See Appendix I for a summary description of the Thomas and Lodwick model.

were calculated for the present rate of soil loss and an assumed 25 percent reduction in soil loss (Table 23). Productivity loss values were discounted for a period of 25 years at an interest rate of 8.375 percent.

Table 23. Net Present Value of Soil Loss for Agricultural Lands.

Land Unit	Present Level Sediment	Present Level Present Value	25% Reduction Sediment	25% Reduction 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

Dividing the change in net present value of productivity loss by the aggregate change in sediment level over a 25 year period gives an 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 indicates that for each ton of sediment that enters Mission Creek, .65 tons will be delivered to Lapwai Creek's confluence with the Clearwater River.[27/] 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 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.

{27}. This figure depends upon 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.

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 the agricultural lands. The low soil loss rates on forest lands does not presently 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

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 of Soil Loss Control

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. This plan represents the optimal strategy for soil loss control. The strategy, however, is based upon 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 chapter III that the effectiveness of agricultural and forest soil loss control management practices are assumed constant over-time. The efficiency of riparian land management practices, however, varies over-time, depending upon sediment inflow from the agricultural and forest lands, which in turn depends upon the management plan being implemented. 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 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) (Appendix H). 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. This data then can be input to the sediment transport model to calulate 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 stance and is based upon the criteria that land management practices to control soil loss are economically viable so 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. This plan assumes limited availabilty of soil loss control investment funds. 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 the 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 of whom are uncertain of the yield impact created by minimum tillage, which is the prime agricultural land management practice employed. This uncertainity 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 the land treatment practices with marginal costs of less than $6.00 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 economically unsound treatment practices are used.

Summary of Management Plans

The land management practices recommended for the agricultural, forest, and riparian lands under Plan #1 are economically optimal under the criteria that the marginal benefit of sediment reduction exceed the marginal cost. Primarily via the practice of minimum tillage, sediment flow from the agricultural land to Mission Creek waters could be reduced by 18,472 tons annually (Table 24). Under

Table 24. 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.

Plan #1, the net present value of the agricultural land productivity benefit, as estimated using the Thomas and Lodwick (1981) model, was $138,595. Annual net farm income would be $5039 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 initially decrease as minimum tillage replaces conventional tillage in the optimal cropping pattern, thus net income rises. Marginal costs begin to increase only after sediment flow has been reduced by 10,721 tons (see Table 24). The marginal cost increase is the result of minimum tillage being employed on wheat after pea acreages of land units A1, A2, and A4 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 25). This is accomplished by seeding grass on the one lane dirt surface roads of land units F3 and F5, at a total cost of $7650. 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 segments. In addition, controlling livestock watering is recommended for the Canyon segment (Table 26). 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 25. 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

Table 26. 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 were 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 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 (see Table 26). 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% 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 recommends the implementation of the agricultural land management practices which have a negative marginal cost. This essentially involves switching to minimum tillage for several of the crops grown on land units A1, A2, A3, and A4 (see Table 24). 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 $6.00 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 27 and 28.

Table 27. 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 28. 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 3000 acres of wheat after fallow and fallow after grain production on land unit A4. In addition, 1200 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 (see Table 27).

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. $(278,610 + 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.

Final Comments: Present value cost and benefit estimates for soil loss control Plans #1 through #4 are summarized in Table 29. 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 and plan influence on sediment inflow to each riparian segment is provided in Figures 6 to 8.

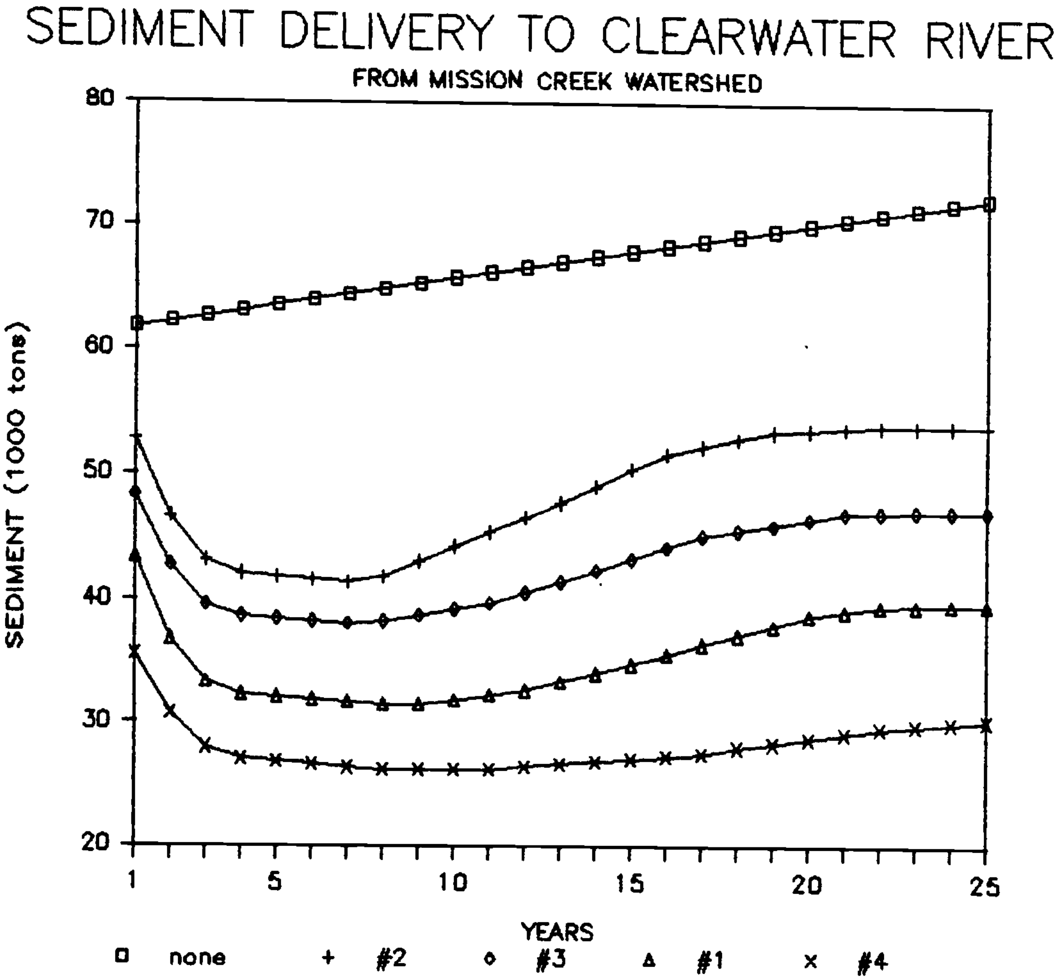

Figure 5. Impact of soil loss control management plans on sediment delivery from Mission Creek to the Clearwater River over 25 year planning horizon.

With no control.......... [ ]
Plan #1 .... /\
Plan #2 .... +
Plan #3 .... <>
Plan #4 X

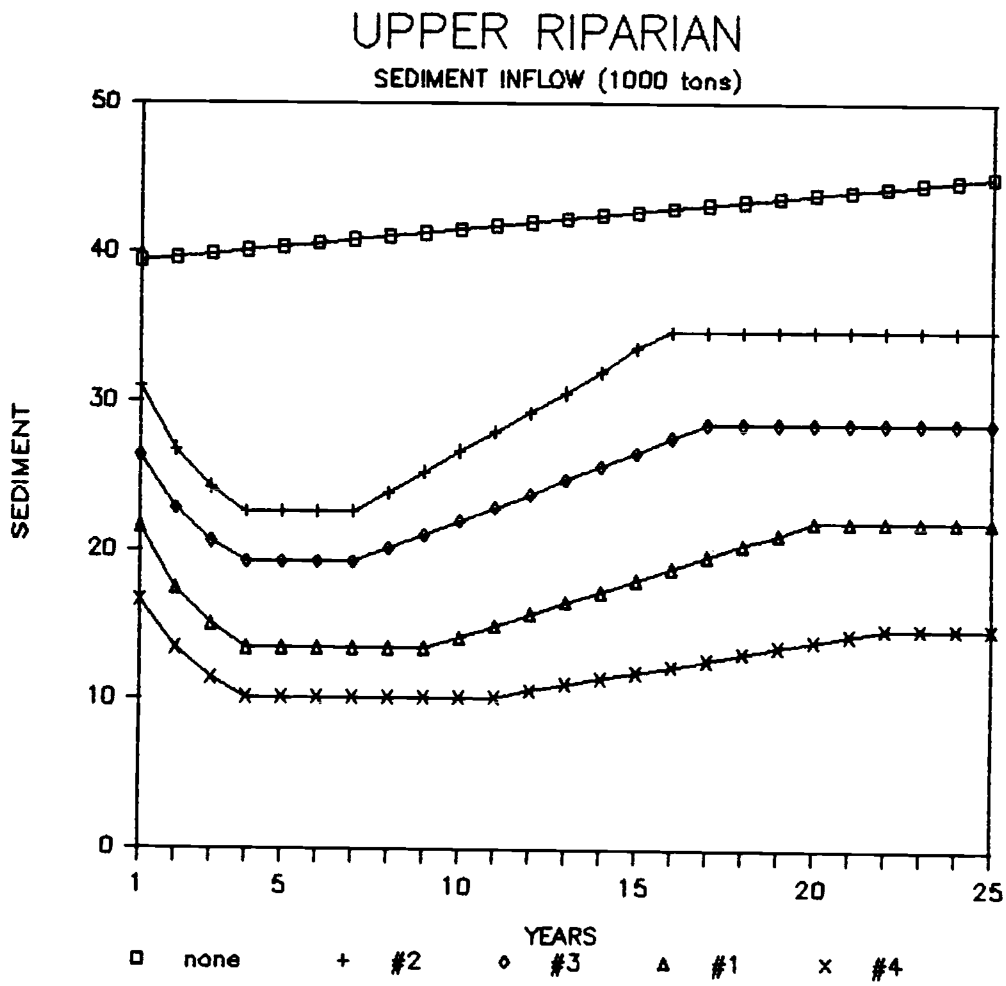

Figure 6. Impact of soil loss control management plans on sediment inflow to Upper stream segment.

With no control.......... []
Plan #1 .... /\
Plan #2 .... +
Plan #3 .... <>
Plan #4 X

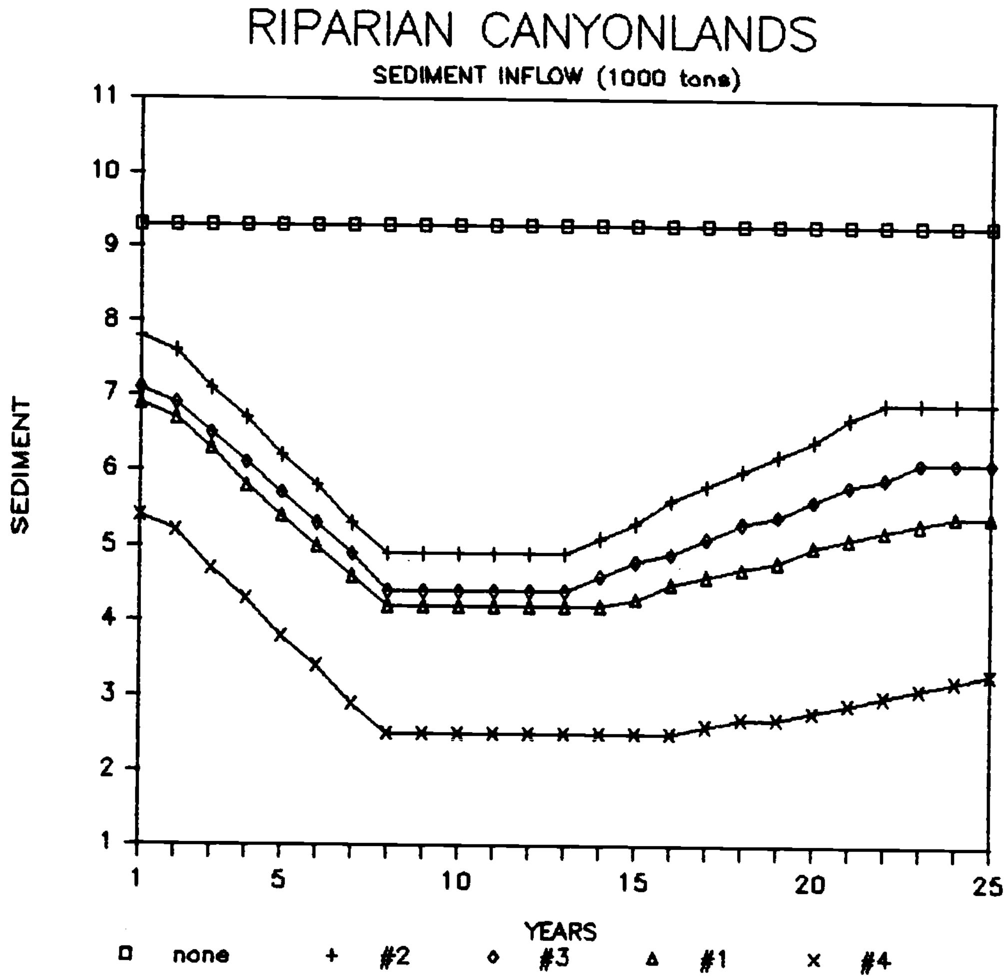

Figure 7. Impact of soil loss control management plans on sediment inflow to Canyon stream segment.

With no control.......... []
Plan #1 .... /\
Plan #2 .... +
Plan #3 .... <>
Plan #4 X

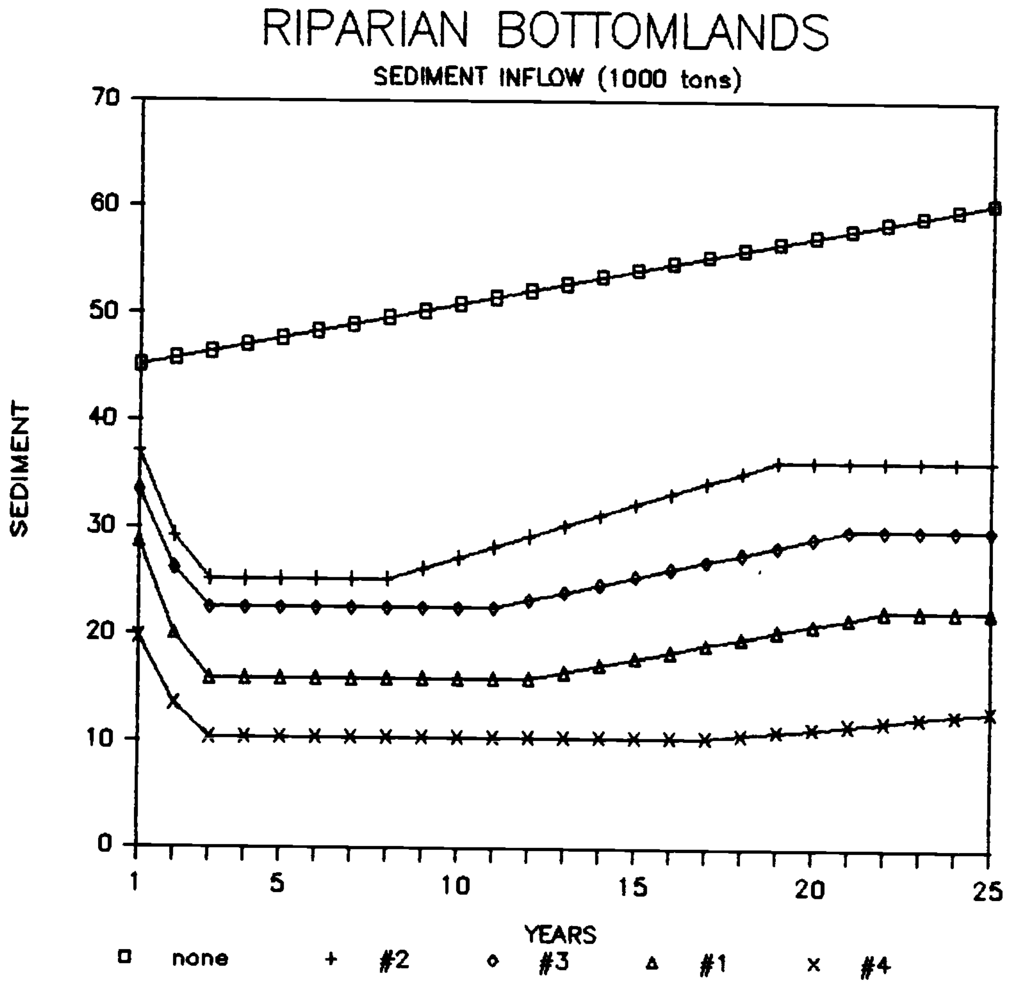

Figure 8. Impact of soil loss control management plans on sediment inflow to Bottom stream segment.

With no control.......... [ ]
Plan #1 .... /\
Plan #2 .... +
Plan #3 .... <>
Plan #4 X

Table 29. 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

The economic criteria that soil loss control practices are economically viable so 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, while 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 graphs (Figures 5 to 8) show 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 upon the Mission-Lapwai Watershed. Plan #2 employs only riparian land treatments and has investment costs of $28,018, while Plan #3 includes the same riparian practices and adds the use of minimum tillage upon some agricultural lands. It was concluded from LP model results that switching to minimum tillage should increase farm net income, thus in this case the private and social interest should coincide. Local farming tradition and uncertainity regarding the yield impacts of switching to minimum tillage, however, may hinder farmer acceptance of Plan #3 recommendations.

Soil loss reduction beyond that achieved by the optimal strategy is possible, but only through use of increasingly expensive practices which 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 would probably require very high compensation payments (i.e. over $1 million for the case of Plan #4).

V. SUMMARY AND CONCLUSIONS

The purpose of this thesis was to identify, evaluate, and present potential solutions to erosion and sedimentation problems on the Mission-Lapwai Watershed of the Clearwater River Basin, Idaho. The study area encompassses a wide range of land and water resource problems. One concern is that excessive topsoil loss threatens the long term productivity of agricultural lands. Another problem area is the riparian ecosystem bordering Mission and Lapwai Creeks, which is poorly managed and has lost much of its ability to filter sediment flow. The resulting siltation of stream waters degrade fish and wildlife habitat. In addition, downstream users of stream water (i.e. municipalities, industry, navigation, etc.) face potential costs due to turbidity in their water supply. The 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 the city of Lewiston, Idaho.

The economic objective of the analysis design was to develop a "preferred" plan for surface erosion control upon the Mission-Lapwai Watershed through comparison of the marginal costs and benefits of soil loss reduction. Data analysis concentrated on the Mission Creek area of the watershed, with the assumption that results can be expanded to the Lapwai Creek portion. Three land categories were identified as the prime sources of surface erosion: (1) Cropping activities on agricultural lands; (2) Timber harvest roads on forest lands; and (3) The deteriorated riparian zone bordering Mission Creek.

Land management practices which control erosion were evaluated under the economic criteria that the marginal benefit of soil loss reduction must exceed the marginal cost. A common unit of measurement was needed to compare marginal benefits and costs. Downstream benefits are most conveniently measurement in $/ton of reduced sediment flow in the stream's water supply, thus the marginal benefit and cost values were both measured in dollars per ton of sediment reduction.

Land management practices to reduce soil loss from each land source were defined and their effectiveness and per acre establishment costs estimated. The literature review of Chapter II revealed that linear programming offered a method to determine the cost effectiveness of alternative land management practices which control soil loss. In addition, the shadow price of the LP model sediment constraint provides an estimate of the marginal cost of sediment reduction. As presented in Chapter III, separate LP models were developed for each of the three land sources of erosion. LP model results, interpreted in Chapter IV, were used to conclude which land management practices were most cost effective in reducing soil loss and predict a marginal cost schedule for sediment reduction upon each of the three land sources of surface erosion.

Linear program model results predicted that marginal costs of sediment reduction on agricultural lands initially decrease, indicating that it is possible to simultaneously reduce soil loss and increase farm net income. This occurs as minimum tillage replaces conventional tillage in the optimum cropping pattern. Marginal costs eventually increase, however, as the more expensive practices of no tillage and terraces enter the LP model optimal solution. On forest lands the estimated marginal cost of sediment reduction is relatively high. Only the seeding of grass on one lane dirt roads appears economically viable. Note, however, that forest roads contribute only 1 percent of the total annual sediment inflow to Mission Creek. The potential for cost effective reduction of sediment inflow to Mission Creek via improvement of the riparian ecosystem appeared quite favorable. Controlling road crossings, livestock watering control, and seeding of grass along the riparian zone could decrease annual sediment inflow to

Mission Creek by 20 percent, with marginal costs ranging between \$.01 and \$.29 per ton of sediment reduction.

A sediment transport model which, via sediment transport ratios, calculates how much of the sediment inflow to Mission Creek (as derived from the agricultural, forest, and riparian LP models) is moved downstream to the Clearwater River was developed in Chapter III. This model provided the necessary linkage for comparison of onsite soil loss control costs and the offsite (downstream) benefits. In addition, the sediment transport model calculated the impact of alternative soil loss control management plans (Chapter IV) upon sediment flow from the Mission-Lapwai Watershed to the Clearwater River.

Five potential benefits of soil loss control were investigated in Chapter IV: (1) Fishery enhancement; (2) Reduction of municipal and industrial water treatment costs; (3) Less dredging of navigation channels; (4) Mitigation of flood threat; and (5) Maintenance of long term agricultural productivity. Each benefit was investigated individually using a descriptive approach, together with appropriate mathematical analysis. The finalized total net benefit per ton of sediment reduction to be compared with the agricultural, forest, and riparian land source marginal cost schedules was estimated to be:

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

Four alternative soil loss control management plans were defined and evaluated in Chapter IV. The first plan employed management practices on each land source which have a marginal cost less than or equal to the estimated benefit value. Thus, Plan #1 represented the economically optimum soil loss control strategy. The optimum strategy involved implementing the riparian treatment practices of seeding grass, livestock watering control, and controlling road crossings. On agricultural lands conservation tillage, mostly minimum tillage, was recommended for several of the crops and land units. Seeding grass on some of the forest one lane dirt roads was viable under the optimum strategy.

Three suboptimal strategies were also discussed. These alternative plans helped to demonstate the range of decisions available to policymakers. Plan #2 involved implementing land management practices exclusively upon the riparian treatment units, while Plan #3 expanded on this strategy by employing all agricultural land management practices which have a negative marginal cost. Treatment practices with marginal costs of less than $6.00 were implemented in Plan #4. This violates the economic criteria that the marginal benefit must exceed the marginal cost. The fourth plan demonstrates the rapid increase in investment costs necessary to achieve soil loss control beyond the optimum levels of Plan #1.

The implementation of soil loss control management practices could potentially be hindered by landowner resistance. Several of the recommended agricultural practices would negatively impact farm net returns. The social benefits outweigh the costs, however much of the cost is paid by the farmer. Therefore, the private interests of the farmer do not necessarily coincide with the optimal social strategy. For farmers to cooperate with the land management recommendations would probably require compensation payments from society (i.e. USDA cost share payments).

Limits of Analysis Design

The physical data requirements of this study were extensive. Inventoring the land resource, determining soil loss rates, identifying land management practices to control surface erosion and their impact on the soil loss rates, and estimating the sediment flow from the Mission-Lapwai Watershed to the Clearwater River required the time, efforts, and, often, best judgement of numerous USDA foresters, hydrologists, and soil scientists. The reliability of study results and conclusions depend upon the accuracy of these physical input data.

Linear program models are set in a comparative static framework. Crop prices, yields, erosion and sediment rates, and land practice costs are specified exogenously and remain constant in the LP model. Therefore, linear programming is limited in modeling the dynamic process of soil erosion. The risk and uncertainity of future crop yields, prices, storm events, etc. are not considered in the LP formulation. Nevertheless, the LP model is a useful tool in comparing the relative cost effectiveness of alternative soil loss control management practices.

The sediment transport model represents an effort to model a very complex physical process for which there exists a paucity of data. The mathematical equations used in the model incorporate the existence of storm events, sediment delivery ratios, and stream channel erosion. Better data availabilty on these items would allow more mathematical sophistication and flexibilty to be included in the model design.

The benefit values estimated in this study are subject to errors of omission and comission. The prime benefit of sediment reduction was determined to be navigation maintenance and flood control. The estimation of this benefit value was developed directly from physical and cost data obtained from the Army Corps of Engineers and therefore should be quite accurate. All benefit value estimates are specific to the Mission-Lapwai Watershed and the Lewiston-Clarkson area of the Clearwater River. To apply the benefit values used in this study to other areas would not be valid. The general procedure used to estimate each benefit, however, may be useful for other studies of the economics of soil loss control.

Suggestions for Future Research

The general analysis design and procedure used in this thesis is applicable to future watershed studies which investigate the economic costs and benefits of surface erosion control. As mentioned, model design which better considers the dynamics of the soil erosion process over time would be desirable. The farmer's decision regarding whether or not to adopt conservation tillage practices is influenced by his perception of the risk and uncertainity involved. Hence, a model formulation which incorporates a measure of risk and uncertainity into the agricultural lands analysis would provide additional insights.

As an ending caveat, the results of the agricultural lands analysis of this thesis recommended the adoption of conservation tillage practices, primarily minimum tillage. For weed control, minimum tillage substitutes chemical herbicides for machinery cultivation. Surface runoff from farmland picks up chemical residues and carries them into streams and low lying places, where they perculate down into the underground water. Hence, minimum tillage may increase the chemical pollution of surface and ground waters. This is an environmental concern which future studies should address.

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APPENDICES

APPENDIX A

Mission-Lapwai Agricultural Lands L.P. Model Input Data.

This data was used to develop the LP model coefficients for net income, erosion, and sediment. Data is presented for each of the seven agricultural land treatment units.

Crop yields for wheat and barley are in bushels per acre. Pea yields are in hundredweight (cwt.) per acre. Hay (pasture) yields are in animal unit months (AUM). The following 1983 crop price assumptions were used to determine net income:

CROP PRICE ASSUMPTIONS:

WHEAT	$3.66 per bushel
BARLEY	$2.45 per bushel
PEAS	$11.00 per cwt.
PASTURE	$10.00 per AUM

Table A1. Agricultural LP Model Input Data.

LAND UNIT A1, 5-15% SLOPE

CROP	YIELD	EROS	SEDI	COST	INCOME
Conventional Tillage & Normal Treatment					
WW	50.0	10.5	2.6	$150	$33.00
WP	70.0	16.0	4.0	$140	$116.20
WG	55.0	10.5	2.6	$150	$51.30
PG	15.0	13.5	3.4	$160	$5.00
HH	4.0	0.0	0.0	$20	$20.00
Minimum Tillage & Normal Treatment					
WW	48.0	5.8	1.5	$140	$35.80
WP	66.5	10.7	2.7	$130	$113.40
WG	52.2	5.8	1.5	$140	$51.20
PG	14.3	8.0	2.0	$150	$6.70
No-Tillage & Normal Treatment					
WW	48.0	2.7	0.7	$156	$19.80
WP	66.5	3.6	0.9	$150	$93.40
WG	52.2	2.7	0.7	$156	$35.20
PG	14.3	2.7	0.7	$155	$1.70
Conventional Tillage & Divided Slope					
WW	50.0	8.4	2.1	$165	$18.00
WP	70.0	12.8	3.2	$154	$102.20
WG	55.0	8.4	2.1	$165	$36.30
PG	15.0	10.8	2.7	$176	($11.00)
Minimum Tillage & Divided Slope					
WW	48.0	4.6	1.2	$154	$21.80
WP	66.5	8.6	2.2	$143	$100.40
WG	52.2	4.6	1.2	$154	$37.20
PG	14.3	6.4	1.6	$165	($8.30)

Table A1. Agricultural LP Model Input Data.

LAND UNIT A1, 5-15% SLOPE

CROP	YIELD	EROS	SEDI	COST	INCOME
No-Tillage & Divided Slope					
WW	48.0	2.2	0.6	$171	$4.80
WP	66.5	2.9	0.7	$165	$78.40
WG	52.2	2.2	0.6	$171	$20.20
PG	14.3	2.2	0.6	$170	($13.30)
Conventional Tillage & Terraces					
WW	50.0	6.8	1.4	$179	$4.00
WP	70.0	10.4	2.1	$168	$88.20
WG	55.0	6.8	1.4	$179	$22.30
PG	15.0	8.7	1.7	$190	($25.00)
Minimum Tillage & Terraces					
WW	48.0	3.8	0.8	$168	$7.80
WP	66.5	6.9	1.4	$156	$87.40
WG	52.2	3.7	0.7	$168	$23.20
PG	14.3	5.2	1.0	$179	($22.30)
No-Tillage & Terraces					
WW	48.0	1.8	0.4	$185	($9.20)
WP	66.5	2.4	0.5	$179	$64.40
WG	52.2	1.8	0.4	$185	$6.20
PG	14.3	1.0	0.2	$184	($27.30)

Table A1. Agricultural LP Model Input Data.

LAND UNIT A2, 15-25% SLOPE

CROP	YIELD	EROS	SEDI	COST	INCOME
Conventional Tillage & Normal Treatment					
WW	50.0	18.6	5.6	$150	$33.00
WF	65.0	47.4	14.2	$125	$112.90
FG	0.0	17.9	5.4	$40	($40.00)
WP	65.0	30.5	9.2	$140	$97.90
PG	15.0	17.8	5.4	$160	$5.00
WG	50.0	18.6	5.6	$150	$33.00
BG	50.0	17.0	5.1	$110	$12.40
Minimum Tillage & Normal Treatment					
WW	48.0	12.6	3.8	$140	$35.80
WP	61.7	20.2	6.1	$130	$96.00
PG	14.3	10.9	3.3	$150	$6.70
WG	48.0	12.6	3.8	$140	$35.80
BG	47.5	10.0	3.0	$102	$14.30
No-Tillage & Normal Treatment					
WW	48.0	5.1	1.5	$156	$19.80
WP	61.7	6.7	2.0	$150	$76.00
PG	14.3	5.1	1.5	$155	$1.70
WG	48.0	5.1	1.5	$156	$19.80
BG	47.5	5.1	1.5	$120	($3.70)
Conventional Tillage & Divided Slope					
WW	50.0	16.7	4.2	$165	$18.00
WF	65.0	42.7	10.7	$137	$100.90
FG	0.0	16.1	4.0	$44	($44.00)
WP	65.0	27.5	6.9	$154	$83.90
PG	15.0	16.0	4.0	$176	($11.00)
WG	50.0	16.7	4.2	$165	$18.00
BG	50.0	15.3	3.8	$121	$1.40

Table A1. Agricultural LP Model Input Data.

LAND UNIT A2, 15-25% SLOPE

CROP	YIELD	EROS	SEDI	COST	INCOME
Minimum Tillage & Divided Slope					
WW	48.0	11.3	2.8	$154	$21.80
WP	61.7	18.2	4.6	$143	$83.00
PG	14.3	9.8	2.5	$165	($8.30)
WG	48.0	11.3	2.8	$154	$21.80
BG	47.5	9.0	2.3	$112	$4.30
No-Tillage & Divided Slope					
WW	48.0	4.6	1.2	$171	$4.80
WP	61.7	6.0	1.5	$165	$61.00
PG	14.3	4.6	1.2	$170	($13.30)
WG	48.0	4.6	1.2	$171	$4.80
BG	47.5	4.6	1.2	$132	($15.70)
Conventional Tillage & Stripcropping					
WW	50.0	14.8	4.4	$172	$11.00
WF	65.0	37.9	11.4	$143	$94.90
FG	0.0	14.3	4.3	$46	($46.00)
WP	65.0	24.4	7.3	$161	$76.90
PG	15.0	14.2	4.3	$184	($19.00)
WG	50.0	14.8	4.4	$172	$11.00
BG	50.0	13.6	4.1	$126	($3.60)
Minimum Tillage & Stripcropping					
WW	48.0	10.0	3.0	$161	$14.80
WP	61.7	16.1	4.8	$149	$77.00
PG	14.3	8.7	2.6	$171	($14.30)
WG	48.0	10.1	3.0	$161	$14.80
BG	47.5	8.0	2.4	$117	($0.70)
No-Tillage & Divided Slope					
WW	48.0	4.1	1.2	$179	($3.20)
WP	61.7	5.4	1.6	$172	$54.00
PG	14.3	4.1	1.2	$178	($21.30)
WG	48.0	4.1	1.2	$179	($3.20)
BG	47.5	4.1	1.2	$138	($21.70)

Table A1. Agricultural LP Model Input Data.

LAND UNIT A3, OVER 25% SLOPE

CROP	YIELD	EROS	SEDI	COST	INCOME
Conventional Tillage & Normal Treatment					
WW	45.0	26.2	8.4	$150	$14.70
WF	60.0	52.3	16.7	$125	$94.60
FG	0.0	19.6	6.3	$40	($40.00)
WG	50.0	26.2	8.4	$150	$33.00
BG	50.0	19.0	6.1	$110	$12.40
Mimimum Tillage & Normal Treatment					
WW	42.8	18.6	6.0	$140	$16.50
WG	48.0	18.6	6.0	$140	$35.80
BG	47.5	15.0	4.8	$102	$14.30
No-Tillage & Normal Treatment					
WW	42.8	5.6	1.8	$156	$0.50
WG	48.0	5.6	1.8	$156	$19.80
BG	47.5	5.6	1.8	$120	($3.70)

LAND UNIT A4, CUT-OVER FOREST

CROP	YIELD	EROS	SEDI	COST	INCOME
Conventional Tillage & Normal Treatment					
WF	60.0	32.0	6.4	$125	$94.60
FG	0.0	23.3	4.7	$40	($40.00)
WG	50.0	13.4	2.7	$150	$33.00
BG	42.0	13.4	2.7	$110	($8.00)
PG	15.0	11.6	2.3	$160	$5.00
WP	60.0	30.0	6.0	$140	$79.60

Table A1. Agricultural LP Model Input Data.

LAND UNIT A4, CUT OVER FOREST

CROP	YIELD	EROS	SEDI	COST	INCOME
Mimimum Tillage & Normal Treatment					
WG	48.0	8.7	1.7	$140	$35.80
BG	40.0	8.7	1.7	$102	($5.10)
PG	14.3	8.1	1.6	$150	$6.70
WP	57.0	14.5	2.9	$130	$78.60
No-Tillage & Normal Treatment					
WG	48.0	3.4	0.7	$156	$19.80
BG	40.0	3.4	0.7	$120	($23.10)
PG	14.3	3.4	0.7	$155	$1.70
WP	57.0	4.6	0.9	$150	$58.60
Conventional Tillage & Divided Slope					
WF	60.0	22.4	4.5	$137	$82.60
FG	0.0	16.3	3.3	$44	($44.00)
WG	50.0	9.4	1.9	$165	$18.00
BG	42.0	9.4	1.9	$121	($19.00)
PG	15.0	8.1	1.6	$176	($11.00)
WP	60.0	21.0	4.2	$154	$65.60
Mimimum Tillage & Divided Slope					
WG	48.0	6.1	1.2	$154	$21.80
BG	40.0	6.1	1.2	$112	($15.10)
PG	14.3	5.7	1.1	$165	($8.30)
WP	57.0	10.3	2.0	$143	$65.60
No-Tillage & Divided Slope					
WG	48.0	2.4	0.5	$171	$4.80
BG	40.0	2.4	0.5	$132	($35.10)
PG	14.3	2.4	0.5	$170	($13.30)
WP	57.0	3.2	0.6	$165	$43.60

Table A1. Agricultural LP Model Input Data.

LAND UNIT A4, CUT OVER FOREST

CROP	YIELD	EROS	SEDI	COST	INCOME
Conventional Tillage & Stripcropping					
WF	60.0	19.2	3.8	$143	$76.60
FG	0.0	14.0	2.8	$46	($46.00)
WG	50.0	8.0	1.6	$172	$11.00
BG	42.0	8.0	1.6	$126	($24.00)
PG	15.0	7.0	1.4	$184	($19.00)
WP	60.0	18.0	3.6	$161	$58.60
Mimimum Tillage & Stripcropping					
WG	48.0	5.2	1.0	$161	$14.80
BG	40.0	5.2	1.0	$117	($20.10)
PG	14.3	4.9	1.0	$172	($15.30)
WP	57.0	8.7	1.7	$149	$59.60
No-Tillage & Stripcropping					
WG	48.0	2.0	0.4	$179	($3.20)
BG	40.0	2.0	0.4	$138	($41.10)
PG	14.3	2.0	0.4	$178	($21.30)
WP	57.0	2.8	0.6	$172	$36.60
Conventional Tillage & Terraces					
WF	60.0	19.2	1.9	$150	$69.60
FG	0.0	14.0	1.4	$53	($53.00)
WG	50.0	8.0	0.8	$179	$4.00
BG	42.0	8.0	0.8	$133	($31.00)
PG	15.0	6.9	0.7	$190	($25.00)
WP	60.0	18.0	1.8	$168	$51.60
Mimimum Tillage & Terraces					
WG	48.0	5.2	0.5	$168	$7.80
BG	40.0	5.2	0.5	$124	($27.10)
PG	14.3	4.9	0.5	$179	($22.30)
WP	57.0	8.7	0.9	$156	$52.60

Table A1. Agricultural LP Model Input Data.

LAND UNIT A4, CUT OVER FOREST

CROP	YIELD	EROS	SEDI	COST	INCOME
No-Tillage & Terraces					
WG	48.0	2.0	0.2	$185	($9.20)
BG	40.0	2.0	0.2	$146	($49.10)
PG	14.3	2.0	0.2	$184	($27.30)
WP	57.0	2.8	0.3	$179	$29.60

LAND UNIT A5, 0-5% SLOPE

CROP	YIELD	EROS	SEDI	COST	INCOME
Conventional Tillage & Normal Treatment					
WW	80.0	7.0	1.4	$150	$142.80
WG	90.0	7.0	1.4	$150	$179.40
BH	66.5	0.9	0.2	$105	$58.20
HG	5.0	2.9	0.6	$90	($40.00)
HH	10.0	0.0	0.0	$20	$80.00
Minimum Tillage & Normal Treatment					
WW	76.0	4.5	0.9	$140	$138.20
WG	85.5	4.5	0.9	$140	$172.90
HG	4.7	2.0	0.4	$87	($40.00)
No-Tillage & Normal Treatment					
WW	76.0	1.2	0.2	$156	$122.20
WG	85.5	1.2	0.2	$156	$156.90
BH	63.3	0.8	0.1	$118	$37.10
HG	4.7	1.6	0.3	$84	($37.00)

Table A1. Agricultural LP Model Input Data.

LAND UNIT A6, PASTURELAND

CROP	YIELD	EROS	SEDI	COST	INCOME
Conventional Tillage & Normal Treatment					
BH	42.0	5.8	1.2	$105	($3.00)
HG	1.0	14.5	2.9	$90	($80.00)
HH	3.0	0.0	0.0	$20	$10.00
No-Tillage & Normal Treatment					
BH	40.0	2.9	0.6	$118	($21.10)
HG	1.0	7.2	1.4	$84	($74.00)
Conventional Tillage & Divided Slope					
BH	42.0	4.0	0.8	$116	($14.00)
HG	1.0	10.1	2.0	$99	($89.00)
No-Tillage & Divided Slope					
BH	40.0	2.0	0.4	$130	($33.10)
HG	1.0	5.0	1.0	$94	($84.00)
Conventional Tillage & Stripcropping					
BH	42.0	3.5	0.7	$120	($18.00)
HG	1.0	8.7	1.7	$103	($93.00)
No-Tillage & Stripcropping					
BH	40.0	1.7	0.3	$135	($38.10)
HG	1.0	4.3	0.9	$97	($87.00)
Conventional Tillage & Terraces					
BH	42.0	3.5	0.4	$128	($26.00)
HG	1.0	8.7	0.9	$111	($101.00)
No-Tillage & Terraces					
BH	40.0	1.7	0.2	$143	($46.10)
HG	1.0	4.3	0.4	$104	($94.00)

Table A1. Agricultural LP Model Input Data.

LAND UNIT A7, 26-40% SLOPE

CROP	YIELD	EROS	SEDI	COST	INCOME
Conventional Tillage & Normal Treatment					
WW	45.0	21.0	8.4	$150	$14.70
BH	50.0	9.3	3.7	$105	$17.40
HG	1.0	11.2	4.5	$90	($80.00)
HH	3.0	0.0	0.0	$20	$10.00
Minimum Tillage & Normal Treatment					
WW	42.7	11.7	4.7	$140	$16.50
BG	47.5	11.7	4.7	$102	$14.30
WG	38.0	11.7	4.7	$140	($0.90)
No-Tillage & Normal Treatment					
WW	42.7	5.6	2.2	$156	$0.50
WG	38.0	5.6	2.2	$156	($16.90)
BG	47.5	5.6	2.2	$120	($3.70)
BH	47.5	3.7	1.5	$118	($1.70)
HG	1.0	7.5	3.0	$84	($74.00)

Appendix B

__Erosion and Sediment Rates (tons per acre) for Alternative Management Practices on Forest Treatment Units.__

Table 31. Alternative Management Practices For Forest Treatment Units, Erosion Rate (tons per acre) and Acres in Each Unit.

Land Unit & Road Type	Present Erosion Rate	Seed Grass	Slash Windrow Filter	Vegetate Water Bar	Grass Mulch Fertilize	Grass Mulch Fertilize Net	Acres in each road type
Land Unit F1:							
2 lane gravel	3.7	1.5	---		0.9	0.3	5.0 acres
1.5 lane gravel	3.3	1.3	---		0.8	0.2	5.8 acres
1 lane dirt	30.2	12.1	6.0	7.6	7.6	2.1	3.6 acres
Land Unit F2:							
2 lane gravel	5.7	2.3	---	---	1.3	0.4	10.3 acres
1.5 lane gravel	5.1	2.2	---	---	1.3	0.4	5.0 acres
1 lane dirt	46.7	18.7	9.3	12.0	12.0	3.3	5.1 acres
Land Unit F3:							
2 lane gravel	10.3	4.0	---	---	2.6	0.7	20.0 acres
1.5 lane gravel	9.4	3.6	---	---	2.3	0.7	13.1 acres
1 lane dirt	86.0	34.7	17.3	21.3	21.3	6.0	11.0 acres
Land Unit F4:							
2 lane gravel	4.0	1.7	---	---	1.0	0.3	41.0 acres
1.5 lane gravel	3.6	1.5	---	---	0.9	0.3	20.5 acres
1 lane dirt	32.0	12.7	6.7	8.0	8.0	2.3	20.5 acres
Land Unit F5:							
2 lane gravel	8.6	3.3	---	---	2.2	0.6	2.0 acres
1.5 lane gravel	7.6	2.9	---	---	1.9	0.5	2.0 acres
1 lane dirt	69.3	28.0	14.0	17.3	17.3	4.9	40.0 acres
Installation Cost: ($/acre)	$0	$150	$650	$1750	$2350	$3300	---

Table B2. Alternative Management Practices for Forest Treatment Units, Sediment Rates (tons per acre) and Acres in Each Unit.

Land Unit & Road Type	Present Sediment Rate	Seed Grass	Slash Windrow Filter	Vegetate Water Bar	Grass Mulch Fertilize	Grass Mulch Fertilize Net	Acres in each road type
Land Unit F1:							
2 lane gravel	1.1	0.44	---		0.27	0.08	5.0 acres
1.5 lane gravel	0.9	0.36	---		0.23	0.06	5.8 acres
1 lane dirt	4.6	1.84	0.92	1.15	1.15	0.32	3.6 acres
Land Unit F2:							
2 lane gravel	1.7	0.70	---	---	0.40	0.12	10.3 acres
1.5 lane gravel	1.4	0.60	---	---	0.35	0.10	5.0 acres
1 lane dirt	7.0	2.80	1.40	1.80	1.80	0.49	5.1 acres
Land Unit F3:							
2 lane gravel	3.1	1.20	---	---	0.78	0.22	20.0 acres
1.5 lane gravel	2.6	1.00	---	---	0.64	0.18	13.1 acres
1 lane dirt	12.9	5.20	2.60	3.20	3.20	0.90	11.0 acres
Land Unit F4:							
2 lane gravel	1.2	0.50	---	---	0.30	0.08	41.0 acres
1.5 lane gravel	1.0	0.40	---	---	0.25	0.07	20.5 acres
1 lane dirt	4.8	1.90	1.10	1.20	1.20	0.34	20.5 acres
Land Unit F5:							
2 lane gravel	2.6	1.00	---	---	0.65	0.16	2.0 acres
1.5 lane gravel	2.1	0.80	---	---	0.52	0.15	2.0 acres
1 lane dirt	10.4	4.20	2.10	2.60	2.60	0.73	40.0 acres
Installation Cost: ($/acre)	$0	$150	$650	$1750	$2350	$3300	---

Appendix C

Riparian Land Management Efficiency in Reducing Sediment Inflow to Mission Creek, Percentage Reduction from Present (1983) Level.*

* Percentage reduction figures represent full potential of management practice to control soil loss.

Table C1. Riparian Land Management Efficiency in Reducing Sediment Delivery to Mission Creek, Percentage Reduction by Source.

	Management Practice	Riparian Land	Ag & Forest Inflow	Installation Cost
1.)	Fencing land to heavily control livestock	85%	13%	$160/acre
2.)	Moderate livestock watering and grazing control	75%	8%	$85/acre
3.)	Grading and vegetating streambank	95%	---	$1300/acre
4.)	Structural stabelization of streambank	95%	4%	$12,000/acre
5.)	Control road crossings	10%	---	$.10/acre
6.)	Culvert improvement	10%	---	$1000/culvert
7.)	Bridge support improvement	10%	---	$5000/support
8.)	Seeding grass	65%	40%	$150/acre
9.)	Planting shrubs	80%	30%	$800/acre
10.)	Planting grass, shrubs, and trees	85%	50%	$900/acre

APPENDIX D

Sediment Transport Model

Lotus 1-2-3 Spreadsheet Format

THIS IS THE "SEDIMENT TRANSFER MODEL" FOR MISSION-LAPWAI
##
(Instruction: Move down spreadsheet, inputing data where requested.
First hit Alt C, cursor will move automatically.)

FIRST INPUT THE STREAM CHANNEL ACREAGE FOR EACH RIPARIAN SEGMENT.

1.) UPPER RIPARIAN ACREAGE	45.0 ACRES
2.) RIPARIAN CANYONLANDS ACREAGE	41.0 ACRES
3.) RIPARIAN BOTTOMLANDS ACREAGE	77.5 ACRES
4.) LAPWAI CREEK RIPARIAN ACREAGE	150.0 ACRES

WHAT IS STREAMBANK EROSION (tons/acre) FOR EACH RIPARIAN SEGMENT UNDER A NORMAL WEATHER YEAR, A 10 YEAR STORM EVENT, A 25 YEAR STORM EVENT, A 50 YEAR STORM EVENT, AND A 100 YEAR STORM EVENT?

	NORMAL	10 YEAR	25 YEAR	50 YEAR	100 YEAR
5.) UPPER RIPARIAN	66.00	100.00	125.00	200.00	500.00
6.) CANYONLANDS	46.00	100.00	125.00	200.00	500.00
7.) BOTTOMLANDS	76.00	100.00	125.00	200.00	500.00
8.) LAPWAI CREEK	66.00	100.00	125.00	200.00	500.00
9.) WHAT PROPORTION OF SEDIMENT INFLOW IS DELIVERED TO THE CLEARWATER RIVER?	0.40	0.60	0.60	0.60	0.60

WHAT IS THE SEDIMENT INFLOW TO EACH RIPARIAN SEGMENT?
(i.e. Combined sediment inflow from the agricultural, forest, and riparian lands as given by the riparian LP model.)

10.) UPPER RIPARIAN	39.40 thousand tons
11.) CANYONLANDS	9.30 thousand tons
12.) BOTTOMLANDS	45.20 thousand tons
13.) LAPWAI CREEK	322.50 thousand tons

THIS COMPLETES DATA INPUT. THE SEDIMENT TRANSFER MODEL RESULTS FOLLOW.

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************************************************************
                  RESULTS
                 ---------
GIVEN THE INPUT DATA, CUMULATIVE SEDIMENT FLOW THROUGH
EACH RIPARIAN SEGMENT IS AS FOLLOWS:
-----------------------------------------------------------

UPPER RIPARIAN TO CANYONLAND          23.829 thousand tons
CANYONLAND TO BOTTOMLAND              31.367 thousand tons
BOTTOMLAND TO LAPWAI CREEK            61.808 thousand tons
LAPWAI CREEK TO CLEARWATER           237.203 thousand tons

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APPENDIX E

<u>Agricultural Land Marginal Cost Estimates and Associated Land Management Practices, by Land Treatment Unit.</u>*

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* Note that the cropping pattern listed above the $0.00 marginal cost figure indicates the present (1983) conditions.

LAND UNIT	MARGINAL COST	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	$0.00	**	****	******	700	9,900	2,477	$39,660
A1	($2.37)	WW	MIN	NORMAL	100	9,436	2,359	$39,940
A1	($1.23)	PG	MIN	NORMAL	300	7,780	1,945	$40,450
A1	$2.12	WP	MIN	NORMAL	300	6,196	1,549	$39,610
A1	$3.78	PG	NO TILL	NORMAL	300	4,612	1,153	$38,110
A1	$11.23	WP	NO TILL	NORMAL	300	2,476	619	$32,110
A2	--	WG	CONV	NORMAL	1000	18,600	5,580	$33,000
A2	--	BG	CONV	NORMAL	1000	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	$0.00	**	****	******	4000	92,400	27,720	$133,300
A2	($1.55)	WG	MIN	NORMAL	1000	86,391	25,920	$136,100
A2	($0.90)	BG	MIN	NORMAL	1000	79,392	23,820	$138,000
A2	($0.82)	PG	MIN	NORMAL	500	75,942	22,785	$138,850
A2	$0.61	WP	MIN	NORMAL	500	70,793	21,240	$137,900
A2	$2.87	PG	NO TILL	NORMAL	500	67,893	20,370	$135,400
A2	$2.98	FG	CONV	DIV SLP	500	65,660	19,700	$133,400
A2	$3.38	WF	CONV	DIV SLP	500	59,761	17,930	$127,400
A2	$4.93	WP	NO TILL	NORMAL	500	53,011	15,905	$117,400
A2	$7.11	WG	NO TILL	NORMAL	1000	45,512	13,655	$101,400
A2	$12.24	BG	NO TILL	NORMAL	1000	40,613	12,185	$83,400
A2	$29.41	WP	NO TILL	DIV SLP	500	39,763	11,930	$75,900
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	$0.00	**	****	******	2000	55,880	17,880	$49,080
A3	($1.48)	BG	MIN	NORMAL	600	53,475	17,112	$50,220
A3	($1.15)	WG	MIN	NORMAL	600	48,919	15,654	$51,900
A3	$3.84	WG	NO TILL	NORMAL	600	41,119	13,158	$42,300
A3	$5.98	BG	NO TILL	NORMAL	600	35,475	11,352	$31,500

LAND UNIT	MARGINAL COST	CROP	TILLAGE	TREAT-MENT	ACRES	EROS (tons)	SEDI (tons)	NET RETURNS
----	-------	----	-------	------	-----	------	-----	-------
A4	--	BG	CONV	NORMAL	1350	18,090	3,618	($10,800)
A4	--	WG	CONV	NORMAL	1350	18,090	3,618	$44,550
A4	--	PG	CONV	NORMAL	700	8,120	1,624	$3,500
A4	--	WF	CONV	NORMAL	1500	48,000	9,600	$141,900
A4	--	FG	CONV	NORMAL	1500	34,950	6,990	($60,000)
A4	--	WP	CONV	NORMAL	700	21,000	4,200	$55,720
TOTAL	$0.00	**	****	******	7,100	148,250	29,650	$174,870
----	-------	----	-------	------	-----	------	-----	-------
A4	($3.08)	BG	MIN	NORMAL	1350	141,905	28,381	$178,785
A4	($2.97)	WG	MIN	NORMAL	1350	135,560	27,112	$182,565
A4	($2.42)	PG	MIN	NORMAL	700	133,110	26,622	$183,755
A4	$0.32	WP	MIN	NORMAL	700	122,260	24,452	$183,055
A4	$2.85	FG	CONV	DIV SLP	1500	111,760	22,352	$177,055
A4	$4.34	FG	CONV	STR CROP	1500	108,310	21,662	$174,055
A4	$5.00	FG	CONV	TERRACES	1500	98,260	19,652	$163,555
A4	$5.31	PG	NO TILL	NORMAL	700	94,520	18,904	$160,055
A4	$5.58	WF	CONV	TERRACES	1500	60,920	12,184	$122,555
A4	$10.10	WP	NO TILL	NORMAL	700	53,990	10,798	$108,555
A4	$15.09	WG	NO TILL	NORMAL	1350	46,835	9,367	$86,955
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	$0.00	**	****	******	770	266	53	$51,647
----	-------	----	-------	------	-----	------	-----	-------
A5	($11.53)	HG	NO TILL	NORMAL	70	175.7	35	$51,884
A5	$1,055	BH	NO TILL	NORMAL	70	168.672	33.6	$50,407

LAND UNIT	MARGINAL COST	CROP	TILLAGE	TREAT- MENT	ACRES	EROS (tons)	SEDI (tons)	NET RETURNS
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	$0.00	**	****	******	900	1,015	203	$3,850
A6	($4.10)	HG	NO TILL	NORMAL	50	650	130	$4,150
A6	$19.80	HG	NO TILL	TERRACES	50	397.5	79.5	$3,150
A6	$28.39	BG	CONV	TERRACES	50	195	39	$2,000
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	$0.00	**	****	******	1000	1,025	410	$5,870
A7	($4.05)	HG	NO TILL	NORMAL	50	840	336	$6,170
A7	$8.52	BH	NO TILL	NORMAL	50	560	224	$5,215

APPENDIX F

Forest Land Marginal Cost Estimates and Associated Land Management Practices, by Land Treatment Unit.*

* Note that the road types listed above the $0.00 marginal cost figure indicates the present (1983) conditions.

LAND UNIT	MARGINAL COST	ROAD TYPE	TREATMENT	ACRES	EROSION (tons)	SEDIMENT (tons)	TOTAL COST
----	----	-----------	------------	-----	-------	-------	-----
F1	--	2 LN GRAVEL	----	5.0	18.5	5.5	----
F1	--	1.5 LN GRAV.	----	5.8	19.1	5.2	----
F1	--	1 LN NATIVE	----	3.6	108.7	16.6	----
TOTAL	$0.00	---	----	14.4	146.4	27.3	$0
----	----	-----------	------------	-----	-------	-------	-----
F1	$5.26	1 LN NATIVE	SEED GRASS	3.6	92.7	17.3	$540
F1	$21.98	2 LN GRAVEL	SEED GRASS	5.0	75.3	14.0	$1,290
F1	$26.86	1.5 LN GRAV.	SEED GRASS	5.8	58.5	10.9	$2,160
F1	$52.55	1 LN NATIVE	SLH FILT WIND	3.6	40.7	7.6	$3,960
----	----	-----------	------------	-----	-------	-------	-----
F2	--	2 LN GRAVEL	----	10.3	58.7	17.5	----
F2	--	1.5 LN GRAV.	----	5.0	25.5	7.0	----
F2	--	1 LN NATIVE	----	5.1	238.2	35.7	----
TOTAL	$0.00	---	----	20.4	322.4	60.2	$0
----	----	-----------	------------	-----	-------	-------	-----
F2	$3.45	1 LN NATIVE	SEED GRASS	5.1	207.7	38.8	$765
F2	$14.22	2 LN GRAVEL	SEED GRASS	10.3	151.4	28.3	$2,310
F2	$17.27	1.5 LN GRAV.	SEED GRASS	5.0	129.0	24.1	$3,060
F2	$34.53	1 LN NATIVE	SLH FILT WIND	5.1	90.7	16.9	$5,610
----	----	-----------	------------	-----	-------	-------	-----
F3	--	2 LN GRAVEL	----	20.0	206.0	62.0	----
F3	--	1.5 LN GRAV.	----	13.1	123.1	34.1	----
F3	--	1 LN NATIVE	----	11.0	946.0	141.9	----
TOTAL	$0.00	---	----	44.1	1,275.1	238.0	$0
----	----	-----------	------------	-----	-------	-------	-----
F3	$1.87	1 LN NATIVE	SEED GRASS	11.0	818.7	152.8	$1,650
F3	$7.80	2 LN GRAVEL	SEED GRASS	20.0	619.4	115.6	$4,650
F3	$9.30	1.5 LN GRAV.	SEED GRASS	13.1	509.9	95.2	$6,615
F3	$18.47	1 LN NATIVE	SLH FILT WIND	11.0	357.9	66.8	$12,115
F3	$152.80	1 LN NATIVE	GRS,NET,MUL,FER	11.0	259.0	48.4	$41,265
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LAND UNIT	MARGINAL COST	ROAD TYPE	TREATMENT	ACRES	EROSION (tons)	SEDIMENT (tons)	TOTAL COST
F4	--	2 LN GRAVEL	----	41.0	164.0	49.2	----
F4	--	1.5 LN GRAV.	----	20.5	73.8	20.5	----
F4	--	1 LN NATIVE	----	20.5	656.0	98.4	----
TOTAL	$0.00	---	----	82.0	893.8	168.1	$0
F4	$5.04	1 LN NATIVE	SEED GRASS	20.5	579.9	109.1	$3,075
F4	$20.15	2 LN GRAVEL	SEED GRASS	41.0	422.9	79.5	$9,225
F4	$24.17	1.5 LN GRAV.	SEED GRASS	20.5	357.5	67.2	$12,300
F4	$50.31	1 LN NATIVE	SLH FILT WIND	20.5	252.9	47.6	$22,550
F4	$410.65	1 LN NATIVE	GRS,NET,MUL,FER	20.5	184.9	34.8	$76,875
F5	--	2 LN GRAVEL	----	2.0	17.2	5.2	----
F5	--	1.5 LN GRAV.	----	2.0	15.2	4.2	----
F5	--	1 LN NATIVE	----	40.0	2,772.0	416.0	----
TOTAL	$0.00	---	----	44.0	2,804.4	425.4	$0
F5	$2.33	1 LN NATIVE	SEED GRASS	40.0	1,158.9	175.8	$6,000
F5	$9.30	2 LN GRAVEL	SEED GRASS	2.0	1,138.4	172.7	$6,300
F5	$11.51	1.5 LN GRAV.	SEED GRASS	2.0	1,121.8	170.2	$6,600
F5	$23.25	1 LN NATIVE	SLH FILT WIND	40.0	573.3	87.0	$26,600

APPENDIX G

Riparian Land Marginal Cost Estimates and Associated Land Management Practices under Alternative Practice Efficiency Levels.

UPPER RIPARIAN

TREATMENT APPLIED	SEDIMENT INFLOW	TONS OF REDUCTION	MARGINAL COST	TOTAL COST
NONE	39397.50	0.00	0.000	0.00
CTRL ROAD CROSSING	38997.00	400.50	0.006	2.25
SEED GRASS	22626.00	16371.00	0.040	6750.00
GRASS, SHRUBS, TREES	18283.50	4342.50	0.751	40500.00

EFFICIENCY........... 1.00

NONE	39397.50	0.00	0.000	0.00
CTRL ROAD CROSSING	39097.13	300.38	0.007	2.25
SEED GRASS	26818.88	12278.25	0.053	6750.00
GRASS, SHRUBS, TREES	23562.00	3256.88	1.001	40500.00

EFFICIENCY........... 0.75

NONE	39397.50	0.00	0.000	0.00
CTRL ROAD CROSSING	39197.25	200.25	0.011	2.25
SEED GRASS	31011.75	8185.50	0.080	6750.00
GRASS, SHRUBS, TREES	28840.50	2171.25	1.502	40500.00

EFFICIENCY........... 0.50

NONE	39397.50	0.00	0.000	0.00
CTRL ROAD CROSSING	39297.38	100.13	0.022	2.25
SEED GRASS	35204.63	4092.75	0.160	6750.00
GRASS, SHRUBS, TREES	34119.00	1085.63	3.004	40500.00

EFFICIENCY........... 0.25

CANYON RIPARIAN
****

TREATMENT APPLIED	SEDIMENT INFLOW	TONS OF REDUCTION	MARGINAL COST	TOTAL COST
NONE	9337.00	0.00	0.000	0.00
CTRL ROAD CROSSING	9048.70	288.30	0.007	2.05
LVSTK WATER CTRL	6666.60	2382.10	0.141	3485.00
SEED GRASS	4883.11	1783.49	0.145	6150.00
GRASS, SHRUBS, TREES	3665.41	1217.70	2.442	36900.00

EFFICIENCY........... 1.000
****

NONE	9337.00	0.00	0.000	0.00
CTRL ROAD CROSSING	9120.78	216.22	0.009	2.05
LVSTK WATER CTRL	7334.20	1786.58	0.188	3485.00
SEED GRASS	5996.58	1337.62	0.193	6150.00
GRASS, SHRUBS, TREES	5083.31	913.28	3.256	36900.00

EFFICIENCY........... 0.750
****

NONE	9337.00	0.00	0.000	0.00
CTRL ROAD CROSSING	9192.85	144.15	0.014	2.05
LVSTK WATER CTRL	8001.80	1191.05	0.282	3485.00
SEED GRASS	7110.06	891.75	0.290	6150.00
GRASS, SHRUBS, TREES	6501.21	608.85	4.884	36900.00

EFFICIENCY........... 0.500
****

NONE	9337.00	0.00	0.000	0.00
CTRL ROAD CROSSING	9264.93	72.07	0.028	2.05
LVSTK WATER CTRL	8669.40	595.53	0.564	3485.00
SEED GRASS	8223.53	445.87	0.580	6150.00
GRASS, SHRUBS, TREES	7919.10	304.42	9.768	36900.00

EFFICIENCY........... 0.250
****

BOTTOM RIPARIAN

TREATMENT APPLIED	SEDIMENT INFLOW	TONS OF REDUCTION	MARGINAL COST	TOTAL COST
NONE	45246.00	0.00	0.000	0.00
CTRL ROAD CROSSING	44469.50	776.50	0.005	3.88
SEED GRASS	25210.70	19258.80	0.058	11625.00
GRASS, SHRUBS, TREES	19909.80	5300.90	1.060	69750.00

EFFICIENCY........... 1.00

NONE	45246.00	0.00	0.000	0.00
CTRL ROAD CROSSING	44663.63	582.38	0.007	3.88
SEED GRASS	30219.53	14444.10	0.077	11625.00
GRASS, SHRUBS, TREES	26243.85	3975.68	1.413	69750.00

EFFICIENCY........... 0.75

NONE	45246.00	0.00	0.000	0.00
CTRL ROAD CROSSING	44857.75	388.25	0.010	3.88
SEED GRASS	35228.35	9629.40	0.116	11625.00
GRASS, SHRUBS, TREES	32577.90	2650.45	2.120	69750.00

EFFICIENCY........... 0.50

NONE	45246.00	0.00	0.000	0.00
CTRL ROAD CROSSING	45051.88	194.13	0.020	3.88
SEED GRASS	40237.18	4814.70	0.232	11625.00
GRASS, SHRUBS, TREES	38911.95	1325.23	4.240	69750.00

EFFICIENCY........... 0.25

APPENDIX H

Vector of 25 Year Planning Period Treatment Efficiency Coefficients for Riparian Land Units and Soil Loss Control Management Plans # 1 to 4.

Percent Effectiveness of Riparian Treatments
For Upper Land Unit

YEAR	PLAN #1	PLAN #2	PLAN #3	PLAN #4
1	50.0%	50.0%	50.0%	50.0%
2	75.0%	75.0%	75.0%	75.0%
3	90.0%	90.0%	90.0%	90.0%
4	100.0%	100.0%	100.0%	100.0%
5	100.0%	100.0%	100.0%	100.0%
6	100.0%	100.0%	100.0%	100.0%
7	100.0%	100.0%	100.0%	100.0%
8	100.0%	92.0%	93.6%	100.0%
9	100.0%	84.0%	87.2%	100.0%
10	95.2%	76.0%	80.8%	100.0%
11	90.4%	68.0%	74.4%	100.0%
12	85.6%	60.0%	68.0%	96.8%
13	80.8%	52.0%	61.6%	93.6%
14	76.0%	44.0%	55.2%	90.4%
15	71.2%	36.0%	48.8%	87.2%
16	66.4%	28.0%	42.4%	84.0%
17	61.6%	28.0%	36.0%	80.8%
18	56.8%	28.0%	36.0%	77.6%
19	52.0%	28.0%	36.0%	74.4%
20	47.2%	28.0%	36.0%	71.2%
21	47.2%	28.0%	36.0%	68.0%
22	47.2%	28.0%	36.0%	64.8%
23	47.2%	28.0%	36.0%	64.8%
24	47.2%	28.0%	36.0%	64.8%
25	47.2%	28.0%	36.0%	64.8%

Percent Effectiveness of Riparian Treatments
For Canyon Land Unit

YEAR	PLAN #1	PLAN #2	PLAN #3	PLAN #4
1	35.0%	35.0%	35.0%	35.0%
2	40.0%	40.0%	40.0%	40.0%
3	50.0%	50.0%	50.0%	50.0%
4	60.0%	60.0%	60.0%	60.0%
5	70.0%	70.0%	70.0%	70.0%
6	80.0%	80.0%	80.0%	80.0%
7	90.0%	90.0%	90.0%	90.0%
8	100.0%	100.0%	100.0%	100.0%
9	100.0%	100.0%	100.0%	100.0%
10	100.0%	100.0%	100.0%	100.0%
11	100.0%	100.0%	100.0%	100.0%
12	100.0%	100.0%	100.0%	100.0%
13	100.0%	100.0%	100.0%	100.0%
14	100.0%	95.0%	96.0%	100.0%
15	97.0%	90.0%	92.0%	100.0%
16	94.0%	85.0%	88.0%	100.0%
17	91.0%	80.0%	84.0%	98.0%
18	88.0%	75.0%	80.0%	96.0%
19	85.0%	70.0%	76.0%	94.0%
20	82.0%	65.0%	72.0%	92.0%
21	79.0%	60.0%	68.0%	90.0%
22	76.0%	55.0%	64.0%	88.0%
23	73.0%	55.0%	60.0%	86.0%
24	70.0%	55.0%	60.0%	84.0%
25	70.0%	55.0%	60.0%	82.0%

Percent Effectiveness of Riparian Treatments
For Bottom Land Unit

YEAR	PLAN #1	PLAN #2	PLAN #3	PLAN #4
1	40.0%	40.0%	40.0%	40.0%
2	80.0%	80.0%	80.0%	80.0%
3	100.0%	100.0%	100.0%	100.0%
4	100.0%	100.0%	100.0%	100.0%
5	100.0%	100.0%	100.0%	100.0%
6	100.0%	100.0%	100.0%	100.0%
7	100.0%	100.0%	100.0%	100.0%
8	100.0%	100.0%	100.0%	100.0%
9	100.0%	95.0%	100.0%	100.0%
10	100.0%	90.0%	100.0%	100.0%
11	100.0%	85.0%	100.0%	100.0%
12	100.0%	80.0%	96.0%	100.0%
13	97.0%	75.0%	92.0%	100.0%
14	94.0%	70.0%	88.0%	100.0%
15	91.0%	65.0%	84.0%	100.0%
16	88.0%	60.0%	80.0%	100.0%
17	85.0%	55.0%	76.0%	100.0%
18	82.0%	50.0%	72.0%	98.0%
19	79.0%	45.0%	68.0%	96.0%
20	76.0%	45.0%	64.0%	94.0%
21	73.0%	45.0%	60.0%	92.0%
22	70.0%	45.0%	60.0%	90.0%
23	70.0%	45.0%	60.0%	88.0%
24	70.0%	45.0%	60.0%	86.0%
25	70.0%	45.0%	60.0%	84.0%

APPENDIX I

Summary of the Thomas and Lodwick Simulation Model: Long Term Productivity Loss Due to Soil Loss

This appendix will present a summary of the variables and equations used in the Thomas and Lodwick model. Conceptually, the purpose of the model is to identify the productivity benefits associated with controlling soil loss from agricultural lands. Essentially, the model calculates the difference between crop yield over time when no soil loss occurs versus when soil loss does occur (Figure 9). For simplicity, only wheat production will be considered.

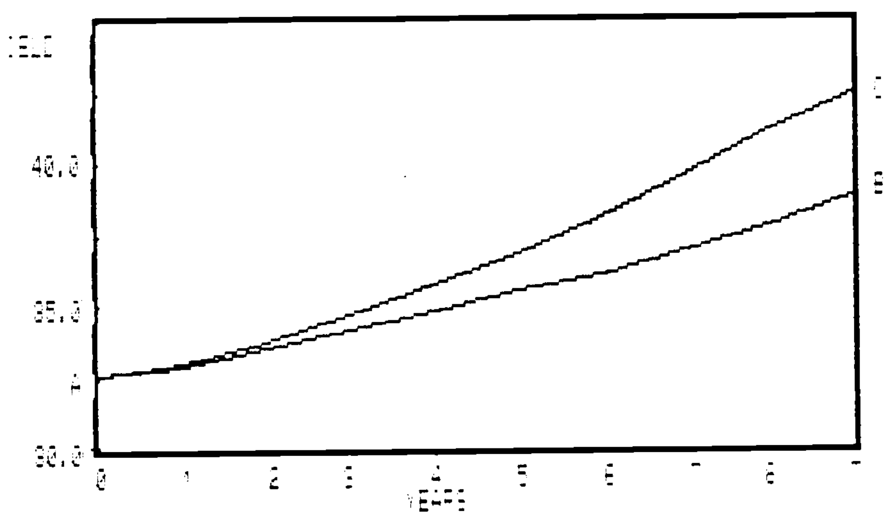

Figure 9. Wheat yield over time; with and without soil loss.

The area ABC in Figure 9 represents the potential per acre wheat yield loss due to 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:

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

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

Where: Y = Crop yield in the initial time period.
e = Exponential function.
b = The rate of decline in productivity due to 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 due to erosion is obtained by discounting each annual increment of the area ABC. Therefore, the equation is:

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

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 $1.00 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