AN ABSTRACT OF THE THESIS OF

Walter B. Moore for the degree of Master of Science in Agricultural and Resource Economics presented on April 18, 1985. Title: OFF-SITE COSTS OF SOIL EROSION IN THE WILLAMETTE VALLEY OF OREGON

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Soil erosion is a major source of pollution in the United States. Erosion can cause both on-site and off-site damages. It has been argued that off-site damages are a significant component of soil conservation benefits and are currently not well known.

Off-site effects of soil erosion are uncompensated externalities. Given significant external costs from erosion, there may be potential for net gains in social welfare from increased soil conservation.

The major objective of this study was to examine, and where possible estimate, the off-site costs of soil erosion in the Willamette Valley. The value of erosion was measured in terms of increased production costs. These costs are incurred by economic agents in offsetting the effects of erosion.

Six types of publicly owned enterprises were studied to determine erosion damages and related costs. These were

municipal water supply, county and state road agencies, navigation supply, water storage reservoirs, and hydroelectric power plants. Of these enterprises, only water storage reservoirs and hydroelectric power plants did not incur substantial costs to offset the effects of erosion.

Municipal water treatment costs were found to be significantly affected by erosion. A sediment damage function for the water treatment process was estimated using econometric modeling. The estimated coefficients relating suspended sediment and treatment costs indicated that the latter increased with an increase in river borne sediment. A 50 percent reduction in river turbidity experienced by the treatment plant studied would decrease chemical water treatment costs and sediment disposal costs by $4750 per year or approximately $4.55 per million gallons of water treated. A 50 percent reduction in sediment loads for the entire Willamette Valley would reduce municipal water treatment chemical costs by an estimated $231,000.

An average cost analysis was also performed. This analysis indicated water treatment costs were $21.00 per million gallons of water treated. Inference to total municipal surface water supply in the Willamette Valley yielded an annual average erosion cost estimate, from natural and man made sources, of $1,052,000.

County and state road maintainence departments must frequently clean drainage structures in response to sediment deposition from erosion. Benton county road maintainence costs, for sediment removal, were estimated to be approximately $222,000 per year in 1984 dollars. An inference to all county road departments in the Willamette Valley, yielded a total erosion cost estimate of $3,743,000 per year. State highway maintainence costs in the Valley due to sediment from erosion were estimated to be $503,000 per year in current dollars.

Sediment removal involved with maintainence of a navigation channel on the lower reach of the Willamette river costs an average of $270,000 per year, expressed in 1984 dollars.

Aggregate erosion costs for all these activities were estimated to be $4,758,000 per year in current dollars. This figure is equal to approximately $0.67 per acre and $432 per square mile for the Willamette Valley. These findings suggest that there exists potential for off-site benefits from increasing soil conservation activities in the Valley. However the economic feasibility of soil conservation projects in the Willamette Valley depends on their implementation costs as well as the on-site and off-site benefits. Cost studies of other activities impacted by erosion are needed to estimate the total off-site costs of erosion in the Willamette Valley.

OFF-SITE COSTS OF SOIL EROSION IN THE WILLAMETTE VALLEY OF OREGON

by

Walter B. Moore

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I. INTRODUCTION

Problem Statement

Soil erosion, and its associated runoff, are widely recognized as major land use problems. Sediment runoff due to erosion, is the largest pollutant by volume of United States waterways and riparian lands (Crosson, Larson et. al). It is estimated that soil eroded from U.S. agricultural lands contributes more than three billion tons of sediment annually to waterways, lakes, and reservoirs (Pinmentel et. al). Similarly another one billion tons of soil per year erodes off-site from forest, urban, and roadside lands (Beasley).

Over the next few decades the erosion problem is expected to become worse. The use of more capital intensive food and fiber production techniques and the utilization of marginal lands to meet growing food demands may increase erosion occurrence (Heady). One recent estimate predicts that the absolute level of soil eroded from U.S. croplands will double by the year 2010 (Crosson).

Social recognition of this problem manifested itself as early as the 1930's in the form of U.S. agricultural conservation programs. More recently, the concerns over water quality and preservation of natural resources have increased public outlays and research into erosion causes and control (Ogg and Crosswhite). In the state of Oregon alone, approximately nine million dollars annually are allocated to soil conservation efforts through the regional offices of the Soil Conservation Service and Agricultural Stabilization and Conservation Service[1]. Still more public monies go into conservation efforts via the U.S. Forest Service, Bureau of Land Management, Environmental Protection Agency, and the Oregon State Department of Environmental Quality. Academic commitment to promote soil conservation technology and policies is also strong (Castle).

Consequences of Erosion

The process of erosion occurs when surface soil particles are displaced and transported to other locations by wind and water. The areas impacted by soil movements can be on-site or off-site depending on whether the displaced soil particles remain in the specific land use area or not.

1) Information supplied by John Vancalcar of the Agricultural Stabilization and Conservation Service and Marcel Tingee of the Soil Conservation Service.

On-Site Effects

The on-site effects of erosion can pose direct costs to the land user. Soil is an indespensible input into many production processes. Soil also serves as a reservoir for nutrients and water. As topsoil is reduced or redistributed by erosion it can alter the productivity of an area. Erosion can affect soil fertility, water storage potential, soil contour, and, as a consequence reduce soil productivity (Beasley).

These on-site effects can ultimately be transferred to non land users in the form of economic costs. As output from a given land area is reduced by erosion, income and thereby profits are constrained. Rising input expenditures (substituting for lost soil and greater tillage requirements) can also affect profitability and/or output price.

Recently a large amount of research has been addressed to the on-site problems created by soil erosion (Crosson and Brubaker, Ogg and Crosswhite). The problems and policy tradeoffs in this area are now much better understood (Larson et. al).

Off-Site Effects

Off-site delivery of eroded soil decreases environmental quality and imposes economic costs on non land users. These off-site effects are known as externalities. The land user's actions impacts others' well being but the user does not account for the external costs or disultilities he causes. The issue of externalities will be raised in more detail in chapter two.

The physical impacts of off-site erosion can be grouped into two general areas, sedimentation and turbidity effects. Sedimentation occurs when eroded soil accumulates in a receptive area. Sediment is deposited in river channels, roadway ditches, adjacent land use areas, estuaries, lakes, and reservoirs (Beasley). Sedimentation can reduce the productivity and/or lifespan of these resources resulting in opportunities foregone. Users of the affected areas may also incur costs in trying to offset the impacts of unwanted sediment. Turbidity is the reduction of clarity and quality of water because of the presence of suspended soil materials such as soil particles. Turbidity can reduce the oxygen and light available in streams and lakes, thus impacting aquatic life. Turbid water can also affect municipal, industrial, and agricultural water users who must employ resources to clean water to acceptable use standards and/or to dispose of sediment residues. Table 1 presents an outline of activities which may be impacted by erosion and its related effects.

Soil erosion may also have positive off-site benefits. Sedimentation from river flooding of croplands can increase soil fertility and depth. Rivers carry a certain amount of suspended sediment to regulate their velocity. Sediment, in this case, may reduce other damages caused by rivers such as scouring and streambank cutting (U.S. Army Corps of Engineers, 1980).

Need for Area Specific Off-site Cost Data

To evaluate the costs imposed by off-site erosion estimates of the values of resources used and/or opportunities foregone due to sediment and turbidity must be obtained (Gum). Externalities have received considerable theoretical treatment but comparatively little actual measurement by economists (Hufschmidt et. al). Similarly, few studies have quantified the off-site costs of soil erosion. At present there is an absence of both nationally and regionally specific estimates of off-site erosion costs (Crosson).

It is known that off-site erosion costs are far from negligible. Pinmentel et. al estimated the 1965 dollar costs of dredging navigation channels, roadway maintainence, and reduced lifespan of reservoirs at $500 million annually.

Table 1 - Potential Off-Site Erosion Impacts

Activity: Municipal Water Supply
Items Affected: Use levels of treatment inputs; rate of cleaning of filters and sediment residual ponds; long run change in capital requirements.

Activity: Municipal Drainage Systems
Items Affected: Catch drains; storm drains; open drainage ways and related check dams.

Activity: Road Systems
Items Affected: Ditches; culverts; road surface; use rates.

Activity: Municipal/County Flood Control
Items Affected: Dikes; runoff ditches.

Activity: Hydroelectric Power Generation
Items Affected: Rate of cleaning of filters and turbines; output potential.

Activity: Water Storage
Items Affected: Reservoir storage capacity; useful lifespan.

Activity: Navigation
Items Affected: Channel depth; use rates.

Activity: Farming
Items Affected: Rate of cleaning of irrigation equipment; productivity of irrigation; crop yield potential.

Activity: Fish and Wildlife Habitat
Items Affected: Availible habitat area; productivity of habitat.

Activity: Recreation
Items Affected: Use levels of river/reservoir; success rates of hunting/fishing.

This figure would likely be over one billion dollars at current price levels. Some area and activity specific erosion costs have been documented. Off-site erosion costs for the lower Potomac River, including dredging, flood damages, commercial fishery, and recreation costs were estimated at nearly seven dollars per ton of eroded soil (Brandt et. al). Navigation channel maintainence costs can range from fifty cents to almost four dollars per ton (Roehl). Many of the activities listed in table 1 have not yet been assessed for economic impacts from erosion.

The few available figures offer little assistance to policy makers and field agents in ascertaining the total social benefits from conservation programs. It has been documented that conservation projects may not be cost effective when only short run on-site benefits are weighed against project costs (Heady). However when off-site costs (potential external benefits from conservation) are also considered these projects may yield much greater net returns. One conservation agent stated that off-site erosion damage estimates were needed " ...to help form a complete picture of the conservation problem."[2].

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2) Conversation with John Vancalcar of the Agricultural Stabilization and Conservation Service, 2/20/'84.

Research Objectives

The principal objective of this research project is to study the economic costs of off-site soil erosion. The purpose is to provide useful information to soil conservation agents in ascertaining the social desirability of soil conservation projects. Specifically the research objectives are:

1) To examine off-site costs of soil erosion;
2) To estimate costs incurred by certain activities in the study area due to soil erosion, and;
3) Where appropriate, use these costs to infer the total costs for the entire study area.

No attempt will be made to attribute any erosion costs or damages to the specific sources either quantitatively or qualitatively. Also, no distinction between naturally occurring erosion and man-made erosion will be drawn. Instead the current level of erosion damages and/or costs will be measured without reference to sources. These cost estimates will then provide some idea of the potential for off-site benefits from soil conservation in the study area.

To calculate actual off-site benefits from a soil conservation project one must be able to attribute eroded soil to its ultimate destination. This involves calculating sediment delivery ratios and destination of sediment eroded from a given land use area. In turn, estimated reductions in erosion can be used in conjunction with information on delivery rates and off-site costs to ascertain project specific off-site benefits.

Study Area

The Willamette Valley of western Oregon was chosen as a geographically specific area in which to measure the off-site costs of erosion. Its proximity to the researcher made this area an appealing choice. Secondly, the Valley contains many of the activities that are known to be impacted by erosion. A third reason for choosing this area was the recent documentation of severe erosion problems in certain areas and under certain climactic conditions (Young et. al). A fourth compelling reason was the targeting of the lower two-thirds of the Valley for increased conservation funding. Knowledge of the off-site costs or erosion in the Willamette Valley could help this effort in development of complete benefit evaluation.

Geography

The Willamette Valley encompasses a land area of approximately 11,500 square miles (figure 1). The Valley lies between the crest of the Coast Range mountains to the west and the peaks of the Cascade Range to the east. The

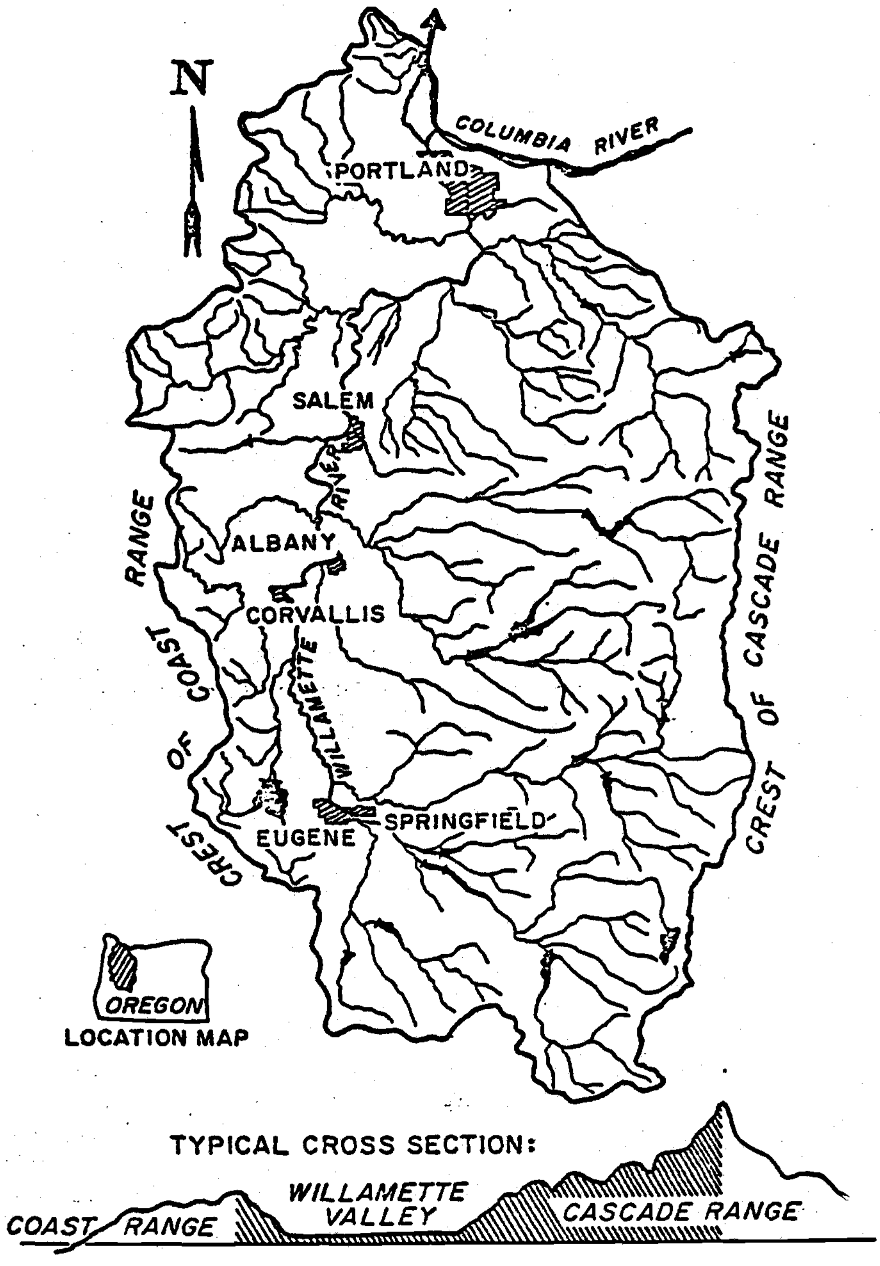

Figure 1. Willamette River Basin

From Stoevener et. al

Middle and South forks of the Willamette river in the Calapooia mountains form the southern boundary of the Willamette watershed. The confluence of the Willamette and Columbia Rivers near Portland defines the northern boundary for the Valley.

The terrain of the Willamette Valley ranges from a broad alluvial plain along the main stem of the river to steep mountains to the west, east, and south. Major tributaries that form adjacent upland valleys are the McKenzie, Santiam, Clackamas, Yamhill, Rickall, Long Tom, and Mary's rivers. The main trunk of the Willamette has an average runoff of 30 billion cubic meters per year making it the 12th largest river system in the U.S. (Stoevener et. al).

Climate

The climate of the Willamette Valley is characterized by warm, dry summers and mild, wet winters. Weather patterns are dominated by the mild marine weather systems of the nearby Pacific Ocean.

Average annual rainfall for the Valley is 63 inches. Seventy percent of this precipitation occurs between November and March. Willamette Valley rains tend to be occur in mild, steady quantities. However, more intense rainfall episodes, rainfall of more than one inch per 24 hours, occur several times per year causing severe runoff episodes (Willamette Basin Task Force). Rainfall occurring after snow or frost can also create significant water and soil runoff potential. Streamflows and river sediment loads vary positively with rainfall patterns in the Valley (Willamette Basin Task Force).

Land Use

The fertile valleys and forested hills brought much of the early prosperity and population to the Willamette region. Current land use is determined by topography, soil capabilities, and population pressures.

Approximately 11,000 of the Valley's 11,500 square miles are suitable for intensive land use. Of that area 64 percent is in forest lands, 29 percent in intensive agriculture, and the remainder in urban areas, park lands and other uses (table 2). Nearly one-half of the Valley's land area is in public ownership (federal, state, county, and municipal). The division of land use between forestry and agriculture is largely determined by the terrain and accessibility of the area.

Table 2 - Population and Land Use:
Willamette Valley, Oregon

County	1980[a] Population	Land Area[b] Square Miles	1972 Land Use in % Forest	Farm	Other
Benton	68,211	668	58	39	3
Clackamas	166,088	1,893	70	21	8
Lane	206,420[c]	2,978[d]	80	16	4
Linn	89,495	2,297	65	31	4
Marion	204,692	1,175	51	45	4
Multnomah	421,980[c]	305[d]	45	16	39
Polk	45,203	740	44	54	2
Washington	245,401	730	42	48	10
Yamhill	55,332	714	45	51	3
Totals	1,502,822	11,500	64%	29%	7%

a) Source: 1980 Census of Population and Housing, U.S. Department of Commerce.
b) Source: 1972 Resource Atlas, Oregon State University Coperative Extension Service.
c) The population figures for Lane and Multnomah counties represent the residents who live in the Valley proper, which is about 75 percent of the total population for each county.
d) These figures represent the aproximatly 67 percent of Lane and Multnomah counties' land area which is within the Willamette Valley.

Erosion Problems

Several recent studies have documented serious erosion problems occurring within the Willamette Valley (Dallas Soil and Water Conservation District, Young et. al). Typical erosion rates of 5 to 20 tons per acre per year, with some sites experiencing soil losses of 100 tons per acre per year have been reported. Massive land slides in clear cut forest areas and from roadway cuts were also cited as significant sources of off-site erosion.

While persistent mild rains and inconspicuous sheet type erosion have led some observers to believe there are few serious erosion problems in the Willamette Valley, these recent field studies suggest differently. Much of the severe erosion events occurs in short term episodes. For example field saturation from persistent mild rains followed by hard rainfall creates significant erosion potential and occurrence.

These findings indicate that off-site erosion costs in the Willamette Valley may be significant. One study estimated that from 30 to 50 percent of eroded soil from study plots were delivered to adjacent creeks and roadways (Dallas Soil and Water Conservation District). Field samples taken on the lower Willamette found that, on the average, the river carried 2000 tons of suspended sediment per day (U.S. Army Corps of Engineers).

Thesis Organization

The remainder of the thesis will present a theoretical discussion and an empirical attempt to measure selected externality costs. Chapter two will develop the relationship between externalities and welfare as well as some operational approaches to measure external costs. Chapter three will detail the methods and results of measuring erosion costs on the municipal water treatment process. Chapter four will detail the impacts and estimated costs of erosion on county and state road maintainence activity. Chapter five will document the impacts and costs of erosion on navigation channel maintainence. Chapter six will examine the impacts and costs of erosion on water storage reservoirs and hydroelectric power generation. Chapter seven will aggregate findings on erosion costs as well as infer certain costs to the entire study area based on sample observations. Chapter eight will provide conclusions regarding the research as well as stress the limitations of the results and offer recommendations for further study.

II. THEORETICAL AND CASE STUDY BACKGROUND

Externalities

Soil erosion can cause a number of off-site damages which are external to the production process. These damages, and resultant effects on social welfare, are known as externalities. An externality occurs when one individual's production or consumption activities alters the well being of others and when the affected party is not compensated by the causing party (Baumol and Oates). This situation arises because there is no mechanism, such as market price, with which the external costs can be internalized. Externalities are often transmitted through public goods such as water or air (Freeman). The outcome is that the externality tends to be over produced by market forces.

In the case of soil erosion, a land manager's production decisions can affect others by imposing the negative externality of eroded soil. The land manager does not account for the cost of off-site erosion to other parties in regard to the degree of conservation he practices. Thus, the land manager cannot capture the external benefits from preventing off-site erosion. He will consider only the on-site benefits of conservation related actions.

Off-site erosion costs are borne by other consumers and producers. These parties may be adversely affected by changes in environmental quality or by the effects of sediment and/or turbidity on production activities. These changes in the consumption or production possibilities are known as technological diseconomies. This type of external effect can result in losses in economic welfare. Off-site erosion can also cause pecuinary diseconomies. These occur when erosion imposes costs on production which are then transmitted on to buyers of the good or service in the form of higher prices.

In general, environmental externalities will not be resolved by private actions when there are large numbers of emitters and/or recipients involved. The individual costs of the externality may be small leaving little incentive for affected individuals to participate in negotiated settlement. Further when a non-point source of pollution such as soil erosion is involved, transaction costs can be quite high posing another barrier to negotiated settlement.

These difficulties to private resolution may prevent society from achieving welfare gains by reducing the externality. Whether or not government intervention to alter private land use decisions is justified on economic efficiency grounds depends on the net benefits (on-site plus off-site benefits minus conservation costs) from the action. If the off-site costs of erosion exceed the costs of conservation then there is potential for net welfare improvement by public sector intervention (subsidies, taxes, regulations etc.). The next section addresses the theoretical basis for measuring effects on welfare from an externality such as erosion.

Welfare Measurement

Economic welfare analysis is a tool for examining the well-being of a society derived from the composition of goods and services available to members of that society. It provides a framework within which to make estimates regarding the changes in well-being from changes in the quality, quantity, or prices of goods or services.

The principal assumption of welfare analysis is that individuals derive utility or satisfaction from available goods and services subject to a budget constraint. This value is most often measured in terms of the prices paid for consumer goods or income received from production. Soil erosion can alter welfare by changing consumption and production possibilities, e.g. through altering the price of related goods and/or services.

Several techniques have been developed to measure the monetary value of changes in welfare of individuals. This study will use ordinary consumers' and producers' surplus as the conceptual background for erosion cost estimation.

However, other measures are more appropriate when large changes in welfare (from a price or quantity change of a good or service) are being measured. Two of these measures are compensating and equivalent variation. Both of these techniques attempt to establish willingness to pay in order to avoid (or conversely encourage) welfare changes from alterations in such things as ambient soil erosion levels. For a more thorough discussion of these measurement tools see Freeman. For the purpose of this paper, which principally developes point estimates of off-site erosion costs, ordinary surplus measures will suffice as a conceptual background for examination of welfare impacts.

Consumers' Surplus

Consumers' surplus is a concept which serves as a guide to estimate the well-being of individuals. The basis for this concept is that utility is derived from a given set of consumption possibilities. Assume an individual gains utility from consumption of goods, X1 ...Xn, bought in the market and from ambient environmental quality, Xe. His/her utility function would look like:

$$U = u(X1,..,Xn;Xe) \quad ; \quad \partial U/\partial Xe > 0 \qquad (1)$$

with the individuals utility level varying positively with perceived changes in the quality of the environment. If one could measure the relation between changes in U with respect to changes in erosion levels a marginal utility schedule based on equation 1 could be derived . This relationship, assuming erosion levels are inversely related to ambient environmental quality, is depicted in figure 2.

However, utility cannot usually be expressed in cardinal terms. Thus, any quantitative information about welfare as related to environmental quality must come from proxy estimates of utility. These implicit economic valuations are derived from estimating consumers' willingness to pay for a given quantity of the good. If marginal consumer valuations could be derived with respect to changes in quantities of erosion, a demand schedule for decreased levels of erosion could result. The actual consumers' surplus could be then estimated. This would be the difference between the maximum amount a consumer would be willing to pay in order to avoid a given quantity of soil erosion and the actual price (cost or disutility) paid. This surplus value (CS) is portrayed in figure 3 as the area under the willingness to pay (demand) curve and above the 'price' line, P*. Changes in the quantity of soil erosion (Q), and thus the implicit price paid for erosion, will vary the size of the consumers' surplus and consequently, the well-being of the individual.

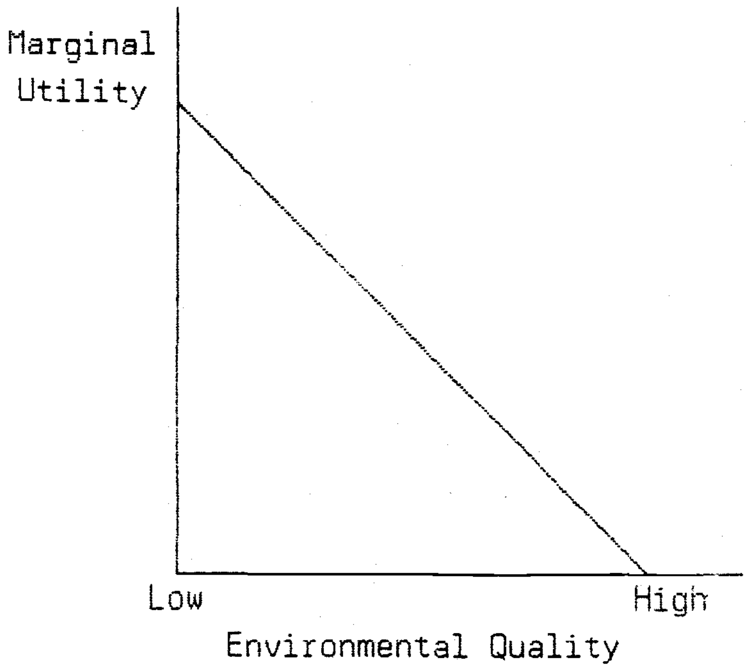

Figure 2 - Consumer Utility Schedule

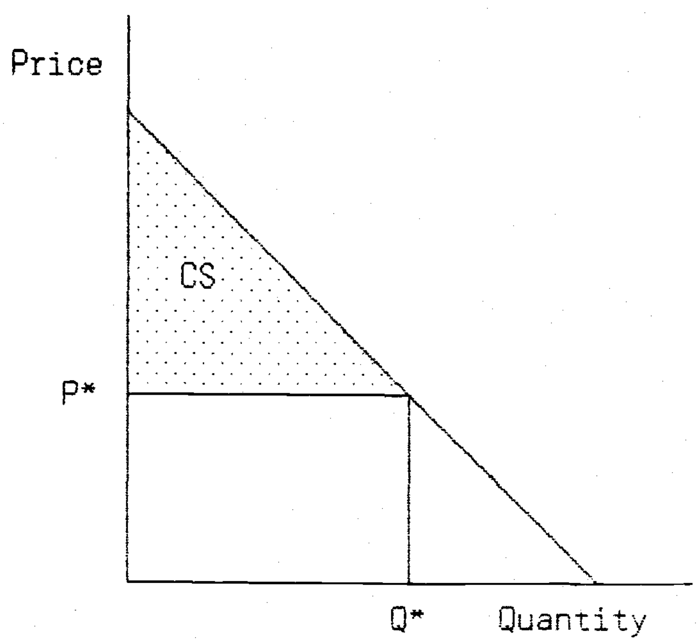

Figure 3 - Point Estimate of Consumer's Surplus

Producers' Surplus

Producers' surplus is the measure of utility gained from engaging in production activity. It is usually measured in terms of economic profits or returns to production. Producers' surplus is equal to the difference between total revenue (price times quantity sold) and supply costs. Figure 4 depicts producers' surplus (PS) for a given supply schedule, S, and price-quantity levels, P* and Q* respectively.

Producers' surplus can be affected by the impacts of soil erosion on the production process. For some firms, the ambient quality of the environment can be a factor that enters the production process. Assume a firm produces a given output, Q*, with as set of nonenvironmental inputs, X1...Xn, and also with a given quality of the environment, Xe. Its production function would appear something like:

$$Q^* = q(X1,\ldots,Xn\ ;\ Xe)\ ;\quad \partial Q/\partial Xe > 0 \qquad (2)$$

with production potential varying positively with the quality of the environment. A decrease in Xe (from increased soil erosion) could force this firm either to employ more resources to maintain Q*, thus increasing production costs, or to curtail output. In each case, given a fixed supply price, the firm would suffer a loss in surplus due to erosion. The change in producers' surplus from an increase in production cost is depicted in figure 5.

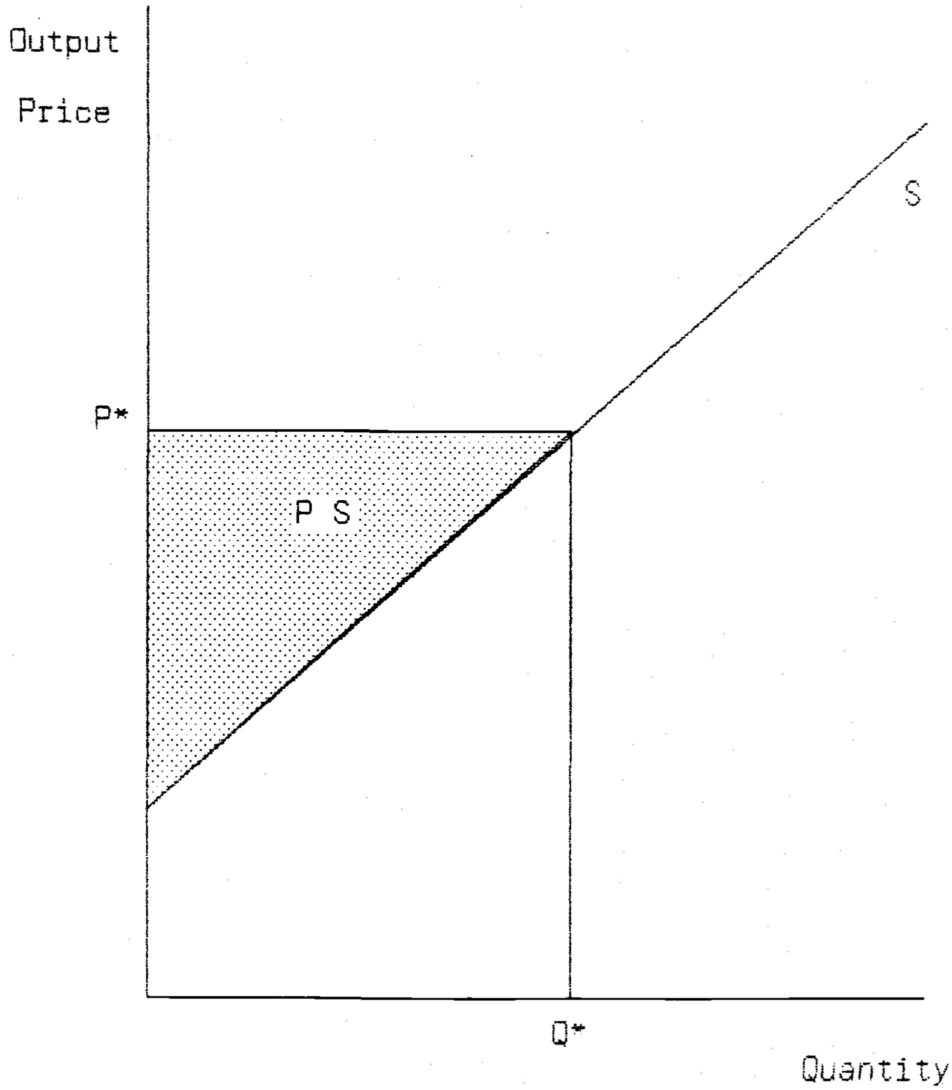

Figure 4 - Point Estimate of Producer's Surplus

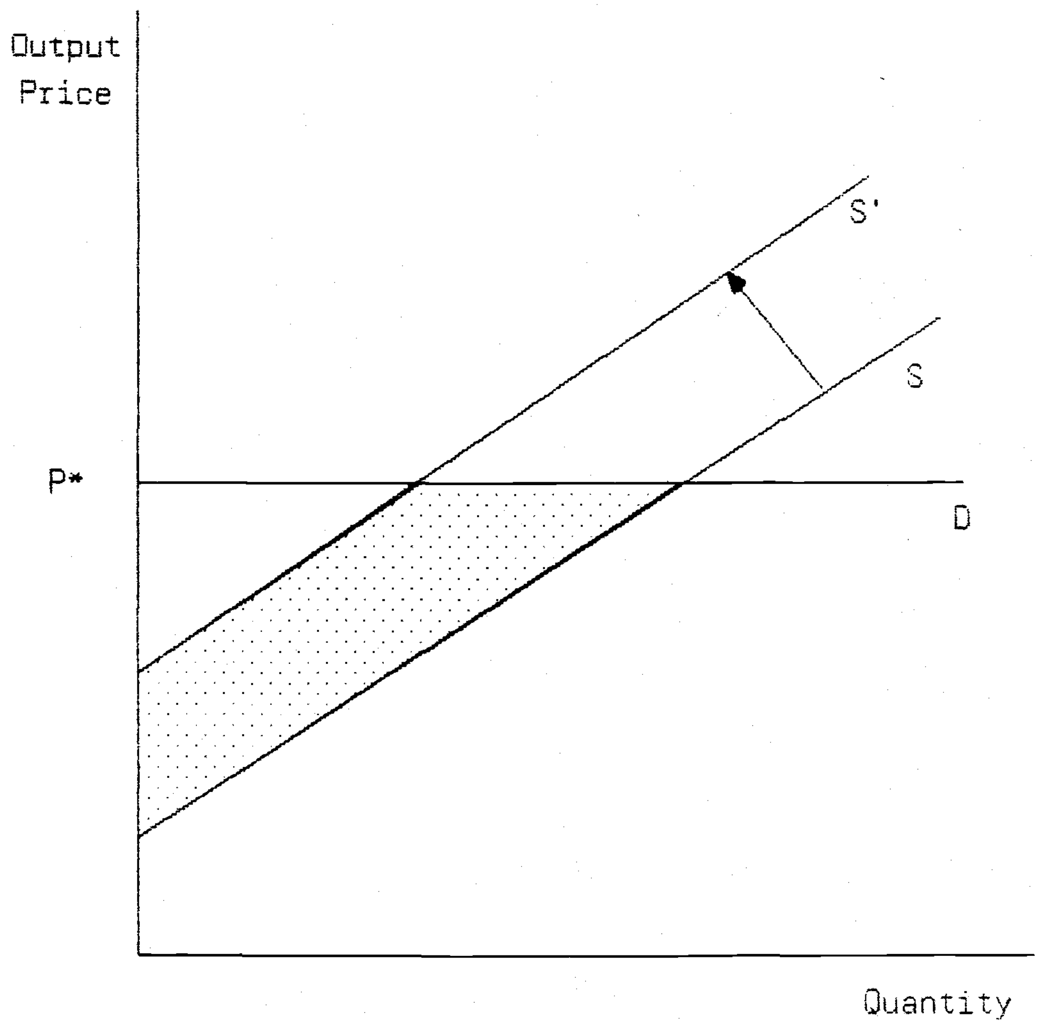

Figure 5 - Welfare Change from an Increase in Production Cost

Total Social Welfare Measurement

The supply and price effects of erosion will typically impact consumer and producer welfare jointly. A shift in the supply function, due to an increase in production costs from soil erosion, will decrease both consumers' and producers' surplus, given some degree of elasticity in both market demand and supply curves. Figure 6 portrays such an upward shift in the supply curve, due to off-site erosion costs, from S to S'. Given market demand, D, for the commodity, output price would rise from P to P', while quantity demanded would fall from Q to Q'. Total welfare, the sum of consumers' and producers' surplus, at initial price and quantity is equal to the area ABC. Given the shift in the supply schedule total social welfare decreases to the area EBG. Of this welfare loss, area 1 represents a transfer of consumers' to producers' surplus. Area 2 is an additional decrease in consumers' surplus and area 3 is the gross decrease in producers' surplus. The actual distribution of welfare losses (between consumers and producers), from a change in production costs, depends on the slope of the demand and supply functions.

There are at least three operational methods for estimating demand curves, and thus consumers' and producers' surplus, for a nonmarket good. One is by means or direct surveys where a willingness to pay function could be

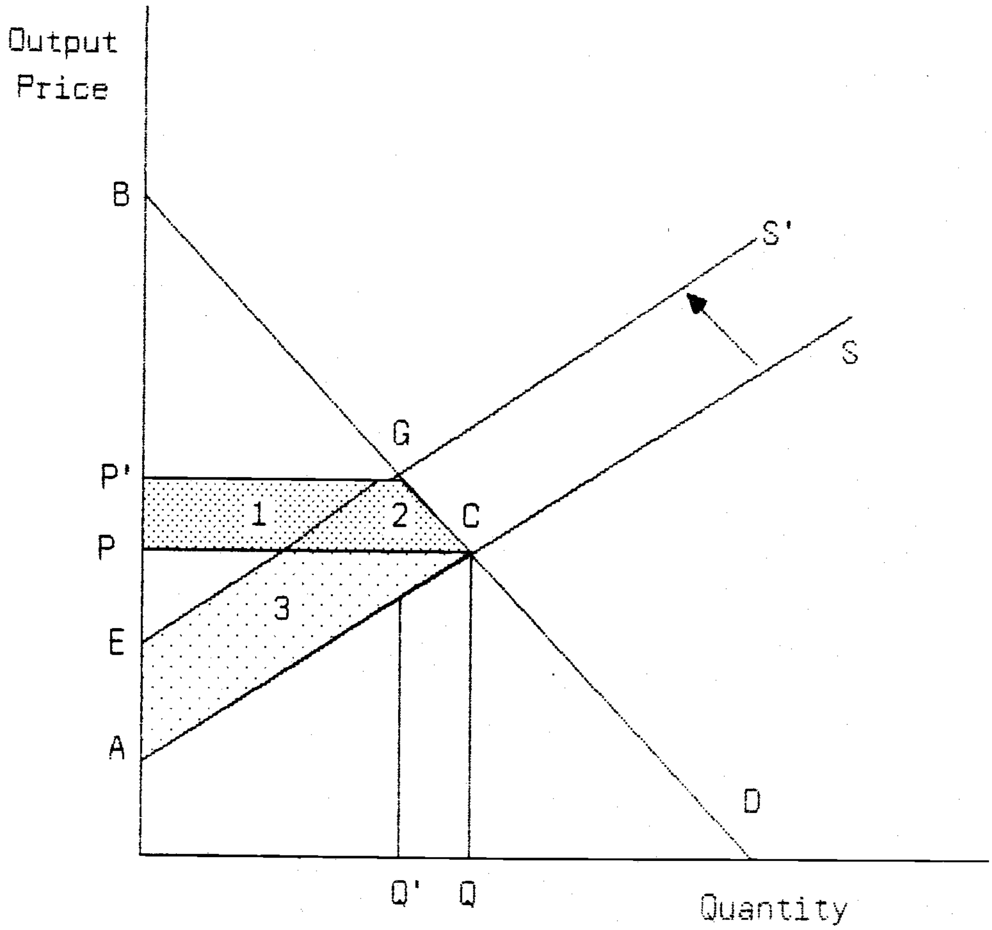

Figure 6 - Total Social Welfare Loss From a Change in Production Cost

solicited. A second method is through referendum in which alternative levels of soil conservation are offered for voter approval. A third method relies upon analysis of market transactions in related goods and services (Freeman).

In this study the third method, the related goods technique, will be implicit in the erosion cost estimation procedures. Inference concerning consumers' surplus will be achieved by examining changes in production costs of public (consumer owned) enterprises due to soil erosion. Both consumers' and producers' surplus will thus be measured simultaneously.

Estimation Procedures

Measurement of the losses of producer and consumer welfare from soil erosion is the objective of this research. These losses will be measured as resource costs incurred at current levels of erosion. Two approaches are discussed below which can provide measurements of the economic costs of erosion on these activities; analysis of production cost, and quantification of the economic losses due to reduced output supply.

Production Cost Approach

Soil erosion can affect production costs by altering the amount of resources (inputs) a firm utilizes to achieve a given output. Erosion can cause firms to incur maintainence, mitigation, replacement, and/or prevention costs (McCarl).

Maintainence costs are borne when soil erosion increases the costs of servicing production equipment. Erosion can clog drainage ditches, irrigation pumps, etc. reducing their productivity. Firms may then have to maintain affected equipment, thus bearing costs attributable to erosion.

Mitigation costs are incurred when firms must overcome effects of soil erosion in order to produce a desired output. Sediment deposition or river turbidity may prevent a desired output from being achieved without corrective expenditures being undertaken. Mitigation can entail, for example, additional costs borne in purifying drinking water or in dredging a navigation channel.

Replacement costs are experienced when capital assets or output must be replaced or relocated due to damages caused by erosion. Substituting thermal for hydroelectric power, or ground for surface water are examples of possible replacement costs due to soil erosion.

Prevention costs are borne when a firm invests in resources to avoid damages to other production inputs by erosion. Flood control dikes and sediment settling ponds (for water treatment) are examples or this type of cost.

These various types of production costs can be measured in terms of a marginal cost curve or through a more general partial budget analysis.

The marginal cost analysis involves estimating the change in production cost with respect to a change in sediment or turbidity levels. A functional relationship between ambient erosion levels and quantities of inputs employed must be established. The parameters estimating this marginal cost function could then be used to predict the effects on production costs from a change in erosion levels experienced by the firm.

Budget analysis examines the amount of resources employed at a given time to offset the effects of erosion. Certain inputs are identified which are used to offset erosion effects on the production process. The cost of these resources attributable to erosion is then estimated. Generally, there is no formal damage function involved in this type of cost estimation.

Output Supply Effects

Soil erosion may constrain the ability of firms to produce a desired output. Firms may not be able to replace or offset the effects of erosion and consequently suffer a decline in output. Examples of potential erosion impacts on output supply are reservoir storage capacity, hydroelectric power production, and wildlife habitat.

Measurement of the effects of output supply reductions on economic welfare can be performed in several ways. One is a formal estimation of the firm's supply function. The shift in this function due to erosion can be estimated to measure the losses in revenues due to erosion. Another method is to compare the firm's average cost of production with and without constrained supply. A third approach is to measure the replacement cost of lost output and impute the economic costs of erosion in terms of a shadow project approach.

Identification and Aggregation Problems

Estimation of cause and effect relationships between erosion and affected economic activities offers many problems in terms of accurate measurement. Proper firm level identification of impacted activities (inputs) may be biased by the firm's budget constraints (insufficient resources to treat erosion problems), and perceptions of the seriousness of the externality problem. Thus, erosion costs identified and/or quantified by firms may or may not equate to actual impacts. Actual resource allocation by the enterprise to offset erosion may not reflect the real costs of erosion to the firm. Some production costs relate only in part to sediment generated by erosion. Dividing or attributing a production cost to erosion can be difficult and/or arbitrary. This separability problem may lead to biased estimates of erosion costs. Production costs which had separability problems were not accounted for in this study. Some real erosion costs may thus be ignored.

Another cost identification problem relates to the variable rates of erosion over time. A cross sectional study such as this may not capture the true long run "average" affects of erosion. Similarly differences between long run perceptions of erosion problems and actual firm level short run responses may also be missed by a point-in-time analysis.

To provide a consistent common denominator, all research findings will be aggregated to encompass the entire study area. This will involve some inference from firm level data to all similar enterprises in the study area. The assumption for this inference is that erosion related costs are uniform across all such enterprises (e.g. municipal water treatment plants and county road maintainence districts). This uniformity assumption may or may not be accurate. If it is not, resultant estimates of aggregate costs may be biased.

Public Enterprises and Efficiency Analysis

All of the economic entities to be studied concerning off-site erosion costs are publically owned. Authors have questioned whether these enterprises use economic resources efficiently, equating production costs with demand at the margin (Musgrave and Musgrave, Wolf). Of relevance to this study is whether these enterprises allocate costs (budget appropriations) to erosion related impacts in accord with public preferences. Since there is no explicit revealed preference as to how much public enterprises should spend to "clean up" off-site erosion it is possible that social costs and producer costs of erosion do not equate. The result of this difference is that estimates of erosion costs based solely on production data may not accurately reflect the true social costs of erosion on the production activity. Producer costs outlined in this paper may not equal the social costs of erosion. Whether public enterprises under or over allocate resources to offset erosion effects, relative to social demand, is not a question to be resolved here. The issue is raised for the qualifications it places on interpreting the erosion cost estimates in this study.

Case Study Selection

Research constraints of time and money limited selection of activities to be studied for erosion impacts Choices of case studies were made based on availibility, access to, and relative ease of data collection. All six of the production activities chosen for study had been widely recognized in the soil conservation literature as being potentially impacted by erosion. Production data for these enterprises are of public record and were available for the study area.

Other activities were omitted from this study because of lack of relevant data and/or much greater difficulty in access to pertinent information. No systematic studies of the effects of sediment on fish and wildlife populations have been performed to date in the study area. Very little inference could be made because of this information constraint. A substantial portion of industrial water use is supplied by municipal water systems, which is included in this study. Self-supplied industrial water is primarily used for cooling purposes. It was perceived that direct data for erosion costs on this type of surface water use would be difficult to obtain. No existing data was found for the study area regarding erosion impacts on irrigation systems and recreation activity. Direct, and extensive, surveys of these potential impacts would be needed to quantify erosion costs. Funding and time constraints prevented such surveys from being undertaken.

III. MUNICIPAL WATER TREATMENT COSTS

Overview

The H.D. Taylor water treatment plant, owned by the city of Corvallis, was chosen as a case study for examining the costs of off-site erosion on municipal water supply. The plant supplies approximately 40 percent of Corvallis's annual water needs. It operates, on the average, 275 days per year, producing a mean daily output of 3.2 million gallons. The Taylor plant draws its source water entirely from the Willamette River.

The production objective of the plant is to provide output water that meets both safety and visual standards[3]. To achieve this objective the plant must eliminate water borne contaminants such as bacteria, algae, sediment, and other harmful or asthetically unpleasant residues. The removal of sediment is an important production activity for the plant, both to achieve visual clarity and to remove harmful contaminants that are bonded to soil particles.

A simplified flow chart of the water treatment process is shown in figure 7. The raw (untreated) input water is pumped from the river into the plant. Treatment engineers measure the water for contaminant levels, temperature,

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3) Information about the plant was patiently provided by Michael Donovan and Ray Lanz, engineer and supervisor respectively for the Taylor treatment plant.

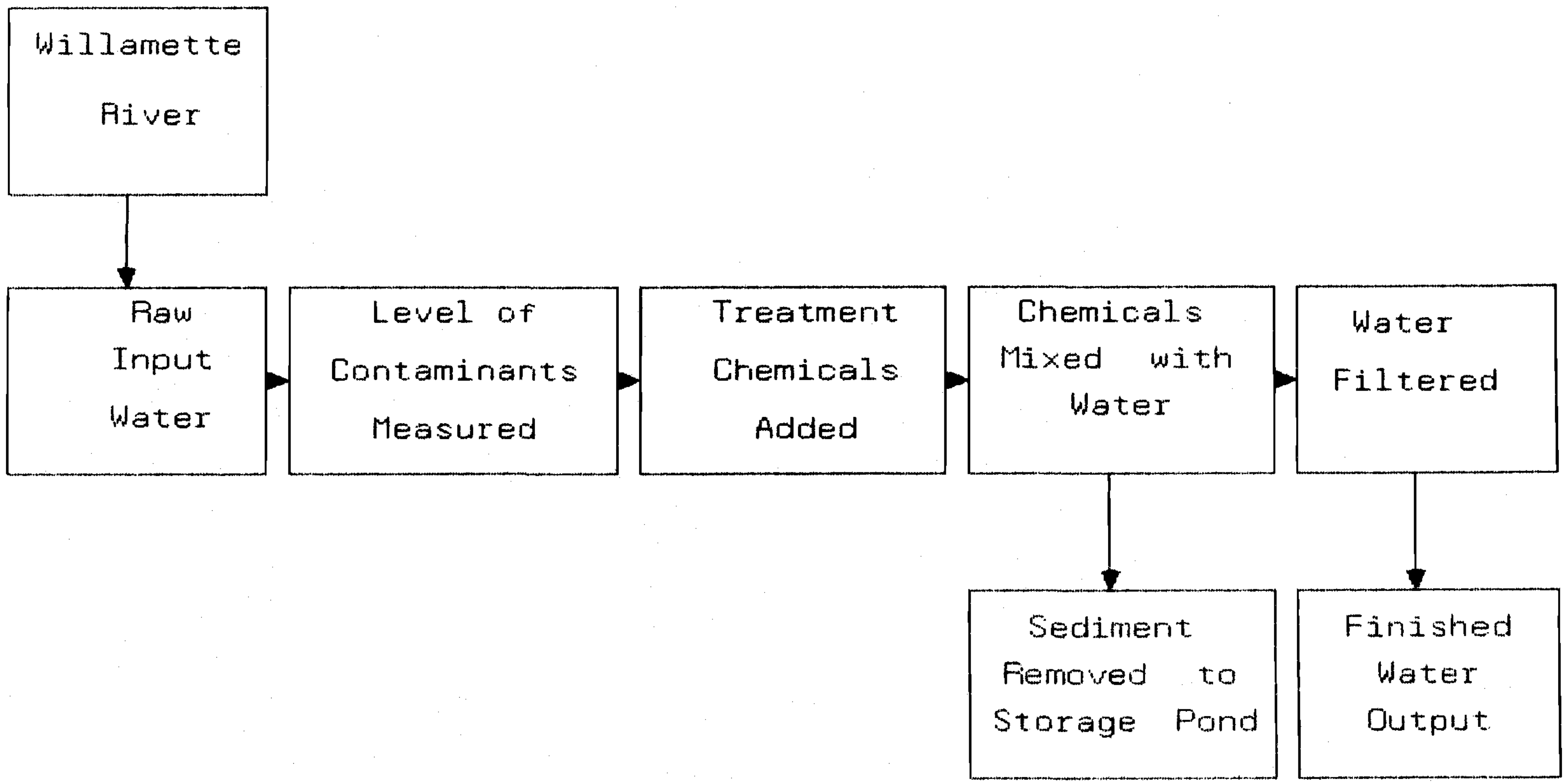

Figure 7 - Schematic Diagram of Water Treatment Process

alkalinity, etc. Based on the ambient levels of these environmental variables, and on a desired output quantity, the engineers mix in chemicals to purify the water. As the water mixes with these chemicals, it passes through a series of ponds which allow the chemicals adequate mixing (floculation) time in order to achieve specified purity objectives. Sediment is removed by bonding soil particles with the chemical agent aluminum sulfate (alum). The bonding process causes the sediment particles to settle out of the water while in the ponds. After sufficient mixing time, the water is passed through filters to screen out algae and remaining fine sediment. The treated water is now largely ready for consumption by residential, business, and industrial customers.

Production Inputs Affected by Erosion

Both fixed and variable costs of the water treatment process can be affected by soil erosion.

Fixed water treatment costs that are related to erosion include presettling ponds, number of filters, size of chemical mixing/storage tanks, and sediment disposal ponds. These inputs are usually incorporated into the initial design of the plant to accommodate an expected range of sediment loads and related mitigation activity. If actual sediment loads change significantly and permanently, (possibly due to a major increase in erosion rates), additional fixed capital investment may be required, raising fixed and thus total treatment costs as related to sediment.

Possible increases in fixed water treatment costs were studied by contacting a water system design engineer. It was indicated by the engineer that turbidity levels play a relatively minor role in the selection of plant size and equipment. The principal design concerns are related to output demand and the elimination of contaminants such as bacteria, solid waste and other acutely dangerous pollutants[4].

For the Taylor treatment plant, only the sediment disposal pond, and chemical mixing/storage tanks are fixed costs directly attributable to erosion. The only `fixed' cost to be quantified here is the annual budget appropriation for cleaning sediment from the disposal ponds[5]. This annual disposal cost of $3500 per year will be included in the average and marginal cost accounting developed below. The annual depreciation values or capital costs of the sediment pond and chemical storage tanks were not considered significant enough to justify estimation.

Variable water treatment inputs directly affected by erosion include use levels of chemical treatment agents, and

4) Conservation with C.Y. Scheh of CH2M-Hill's Inc., Corvallis office.
5) This removal cost is in a pure sense a variable cost. Since appropriations for cleaning the pond were a fixed annual sum for the entire study period it is considered a fixed cost .

the rate of cleaning (backflushing) of filters. These input quantities vary directly with the quality and quantity of sediment experienced at the plant. Only the use levels of chemical inputs were measured in this study. The filter cleaning activity was ignored because of problems of cost separability. The relative impacts of sediment and other solids such as algae on filter cleaning could not be differentiated. Further, the plant's engineers felt that sediment loads played an insignificant role in determining how often they clean filters. While filter cleaning is recognized as a possible erosion cost, it is not estimated in this study.

Sediment Damage Specification

With the assistance of the treatment plant engineers, a functional relationship between input water attributes and required use of chemical mitigation agents was specified.

Alum is the chemical agent used to eliminate sediment from water under treatment. Use levels of alum vary directly with the level of sediment concentration (turbidity) experienced in the raw input water (water). Thus for a given change in river turbidity, all other variables held constant, the quantity of alum required to treat water varies positively with turbidity (turb):

$$\partial \text{alum} / \partial \text{turb} > 0 \qquad (3)$$

Several factors occurring in conjunction with turbidity will also influence use levels of alum.

As water output is increased the amount of sediment that must be treated also increases .Thus the quantity used of alum at the plant will vary positively with the amount of water being treated for a given day:

$$\partial alum/\partial water > 0 \tag{4}$$

Input water temperature (temp) will affect how well alum will bond to sediment. As water temperature drops, the amount of alum used is increased to ensure adequate elimination of sediment. Thus alum use is inversely related to ambient water temperature:

$$\partial alum/\partial temp < 0 \tag{5}$$

Alum is an acidic compound. When it is applied to water, the ph of the water drops substantially below the desired neutral output level. To compensate for this effect lime is added to raise the ph of the treated water to neutral. Thus, there is a positive relationship between use of alum and use of lime:

$$\partial alum/\partial lime > 0 \tag{6}$$

The use of lime is also conditional on the prevailing ph of the input water. As the ph value of water increases, for a given use level of alum, the quantity of lime required to neutralize the water is reduced. Thus lime use is inversely related to ph:

$$\partial lime/\partial ph < 0 \tag{7}$$

The use of these two variables can be expressed in two functional equations:

$$\text{Alum} = f\ (\text{turb, water, temp}); \text{ and} \qquad (8)$$

$$\text{Lime} = f\ (\text{alum, ph}) \qquad (9)$$

A given level of turbidity can influence the amount of alum and lime used to obtain a desired volume of clean water output.

Average Cost Estimation

To estimate the cost relationship between chemical usage and sediment in the water treatment process, data were gathered for all the variables in equations 8 and 9. These data were collected from daily water production records kept at the Taylor plant. Records were obtained for a period starting January 1, 1981 and ending June 20, 1984, a total of 964 production days. The quantities of alum and lime are expressed in pounds per day[6]. The observed levels of input water are in million gallons per day. Ph is expressed in units of acidity, and temperature in degrees fahrenheit. Turbidity is measured on a scale from 0 to 100 with zero representing perfectly clear water and 100 being maximum dirtyness.

6) Lime was not recorded on a daily basis. Therefore estimated daily usage (in pounds) was obtained by interpolating lime use based on alum usage for the period between observations.

Once the daily use quantities of alum and lime were established, average treatment costs were then readily derived. This was accomplished by multiplying daily observations for each chemical by their purchase price; 6.7 cents per pound for alum and 5.1 cents per pound for lime[7]. The daily cost for each input was summed and averaged on a daily and yearly basis.

Table 3 gives the average cost figures for alum and lime separately and totaled. The average variable cost for these inputs were $66 per day and $18,126 per year. Alum comprises roughly 75 percent of average variable chemical cost. These cost figures are also expressed in unit costs per million gallons of water treated . Average unit variable costs for the study period were slightly more than $17.

Estimated average `fixed' water treatment costs are shown in the fourth column of table 3. The annual cost of cleaning sediment from the plant's disposal disposal pond was $3500. This represents an average daily cost of nearly $13 and a unit cost of $3 per day. When fixed costs are added to average unit variable costs, unit treatment costs were approximately $21 per day for the study period. Average annual total costs were $21,626 for the same period.

The average total treatment cost per ton was also calculated from the water treatment plant data . This cost

7) These input costs were constant for the entire study period.

Table 3 - Average Water Treatment Costs

	Alum	Lime	Total Variable	Fixed	Total
Daily Average	$50.14	$15.67	$65.81	$12.73	$78.54
Yearly Average	13,810.00	$4,316.00	$18,126.00	$3500.00	$21,626.00
Unit Average (per million gallons)	$13.24	$4.14	$17.38	$3.36	$20.74

amounted to approximately 1.2 cents per ton of sediment experienced at the plant[8].

While sediment (erosion) costs on the water treatment process are far from insignificant in aggregate terms, the treatment cost per ton of eroded soil is slight. Further, average erosion cost estimates assumes that river water could have zero sediment loads. This is clearly not a realistic assumption as all rivers carry some sediment irrespective of the degree of soil conservation and/or watershed protection(Corps of Engineers, 1980). Therefore, a marginal estimate of water treatment costs due to erosion will be used for inference of Taylor plant costs to municipal water supply systems for the entire Willamette Valley.

Marginal Cost Estimation

The next stage of cost assessment involved estimating a marginal relationship between turbidity and chemical treatment cost. This analysis will allow predictions to be made regarding the effects of changes in erosion rates on chemical treatment costs. The analysis was performed in two steps. First, regression estimates of equations 8 and 9 were obtained. Second, a sensitivity analysis, relating changes

8) The per ton cost was derived by converting turbidity units into a density measure (milligrams per liter). The density measure was readily converted into tons of sediment per million gallons.

in variable treatment cost to changes in turbidity levels, was calculated using parameters derived from the regression equations. Annual sediment disposal costs are then added to the marginal cost estimates.

To estimate the relationships between the variables in equations 8 and 9, these variables were specified in two formal equations. Alum and lime are dependent variables whose use levels are determined by values of ambient environmental conditions and by the quantity of input water. The two treatment inputs were formally expressed as:

$$alum = a1 + b1(turb) + b2(water) + b3(temp) + e1 \qquad (10)$$

$$lime = a2 + b4(ph) + b5(alum) + e2 \qquad (11)$$

where e1 and e2 are stochastic error terms with expected mean equal to zero and with an assumed normal distribution.

Regression models 10 and 11 were estimated using ordinary least squares. All 964 of the daily water treatment observations were used for the regression runs. Several functional forms were attempted in explaining the use of alum and lime in terms of variables b1 through b5.

In estimating the daily use levels of alum (equation 10), a log-linear model proved to have the greatest explanatory power of all forms tried. This model is a linear form of a Cobb-Douglas type production function:

$$\log(Alum) = \log(a1) + b1*\log(turb) + b2*\log(water) + b3*\log(temp) + \log(e1) \qquad (12)$$

The estimated coefficients, standard errors, and related tests of goodness of fit for model 12 are shown in table 4. The log-linear model explained approximately 82 percent of the variation in observed alum use at the Taylor plant. The ratio of explained variation to unexplained variation (F ratio) is significantly greater than zero at the 99 percent confidence level. All coefficients are significant at the 99 percent confidence level. Thus all independent variables are significantly correlated with use levels of alum. The Durbin-Watson test of serial correlation showed positive autocorrelation between observations that was significantly greater than zero at the 99 percent level. The presence of positive serial correlation meant that the standard errors of at least one of the independent variables is biased downwards. The presence of serial correlation is not surprising due to the similarity of variables from day to day and the strong seasonal covariance of the environmental factors that influence alum use.

The coefficients for turbidity, water, and temperature in table 4 are partial elasticities. They can be interpreted as the rate of change in alum with respect to a change in one of the independent variables, all other variables held constant. For a given change in volume of water treated, alum usage increases at a slightly greater than proportionate rate. If the amount of water being treated doubled, use of alum would slightly more than double. Alum

Table 4 - Regression Results

Independant Variable	Dependant Variable: Alum	Dependant Variable: Lime
Constant	8.977 (0.335)[a]	200.526 (84.983)
Water	1.024 (0.017)	
Turb	0.331 (0.012)	
Temp	-1.098 (0.081)	
PH		-21.783[b] (11.682)
Alum		0.346 (0.011)
N	964	964
Rsqr	.819	.521
F	1445	522
Durbin-Watson	0.64	0.56

a) Standard error in parenthesis

b) Significantly different from zero at 90% confidence level.

use has a partial elasticity with respect to changes in temperature that is negative and slightly greater than unity. Thus, if input water temperature were to decrease by one percent alum use would increase by approximately one-point-one percent. The value of .33 for the turbidity variable suggests than use levels of alum have a positive but declining relationship with respect to changes in river water sediment concentration. Alum use increases with higher turbidity levels but at a proportionately decreasing rate. Thus, alum use was estimated to be somewhat insensitive to changes in sediment loads experienced at the Taylor plant.

The regression model that best explained the observed variations in the use of lime was an ordinary linear least squares model specified in equation 11. The Cobb-Douglas model made the ph variable statistically insignificant, therefore this functional form was not used[9].

Results from the equation explaining lime use are presented in the right hand column of table 4. Equation 11 explained 52 percent of the variation in lime usage. The F ratio was significantly different from zero at a 99 percent confidence level. Both regression coefficients were significant at the 90 percent confidence level or greater. Positive serial correlation was again significant at the 99 percent level. This indicates that one or more of the

9) The primary reason for this is that the variations in ph were quite small. When the natural log of this variable was taken this variation was forced to be insignificant with respect to the variation in lime use.

standard errors of the coefficients in model 11 were biased downward.

The ph and alum coefficients in model 11 are in absolute quantity terms as opposed to relative rates of change in model 12. A one unit drop in ph, all other factors held constant, would increase lime use by nearly 22 pounds. A one pound decrease in alum use would increase lime use by slightly more than one-third of a pound. Changes in lime use appear to be somewhat insensitive to changes in alum use. Thus, lime use will also be inelastic to changes in turbidity levels.

These two regression equations, models 11 and 12, were then used to predict daily quantities used and thus costs of alum and lime. These predictions were made by running all observed values of turbidity, temperature, water and ph through the two explanatory models using the coefficients in table 4. Unit costs for alum and lime were then multiplied by predicted use values to obtained estimated costs.

Average daily estimated cost for alum was approximately \$49. For lime this predicted cost was \$15 per day for the study period. These figures were approximately two percent lower than actual observed costs (see table 3). Thus the regression models, on the average, provide reasonably accurate predictions of chemical treatment costs.

Models 11 and 12 were then employed to perform a sensitivity analysis assessing the changes in variable water treatment costs due to a given change in turbidity. The marginal relationship between turbidity and chemical treatment costs was estimated by changing all observed turbidity values by a uniform percentage rate:

Adj.turbidity=turb *(1.0 +/- (%change/100)) (13)

Each adjusted value of turbidity can be then applied to the alum model (equation 12) to obtain an estimate of the change in alum use rate (alum') in response to the change in turbidity:

alum' = f(adj.turb, water, temp) (14)

The change in alum will then alter the use of lime (lime') as expressed in equation 11:

lime' = f(ph, alum') (15)

The sensitivity analysis was examined for adjusted turbidity values that ranged from 50 percent less than observed values to 50 percent more. As in previous cost estimates the predicted values of alum and lime were multiplied by current costs to obtain point estimates of average costs for a given change in turbidity.

The results of the sensitivity analysis are presented in table 5 and figure 8. For a one percent change in turbidity the cost of alum and lime each changed by approximately three-tenths of one percent. For a 50 percent reduction in daily turbidity levels, average daily chemical

Table 5 - Marginal Cost Estimates

Turbidity: % of Normal	Average Daily Cost Alum	Lime	Total	Unit	Average Annual Cost Alum	Lime	Total
50	$38.92	$12.69	$51.61	$13.37	$10,720	$3,495	$14,215
55	$40.17	$13.02	$53.19	$13.78	$11,063	$3,587	$14,650
60	$41.34	$13.34	$54.68	$14.17	$11,386	$3,674	$15,060
65	$42.45	$13.64	$56.09	$14.53	$11,692	$3,756	$15,448
70	$43.50	$13.92	$57.42	$14.88	$11,982	$3,833	$15,816
75	$44.51	$14.19	$58.70	$15.21	$12,259	$3,908	$16,166
80	$45.47	$14.45	$59.91	$15.52	$12,523	$3,979	$16,502
82	$45.84	$14.55	$60.39	$15.64	$12,626	$4,006	$16,632
84	$46.21	$14.64	$60.85	$15.76	$12,727	$4,033	$16,760
86	$46.57	$14.74	$61.31	$15.88	$12,826	$4,060	$16,886
88	$46.92	$14.84	$61.76	$16.00	$12,924	$4,086	$17,011
90	$47.27	$14.93	$62.20	$16.12	$13,021	$4,112	$17,133
91	$47.45	$14.98	$62.42	$16.17	$13,068	$4,125	$17,193
92	$47.62	$15.02	$62.64	$16.23	$13,116	$4,138	$17,253
93	$47.79	$15.07	$62.86	$16.28	$13,163	$4,150	$17,313
94	$47.96	$15.11	$63.07	$16.34	$13,209	$4,163	$17,372
95	$48.13	$15.16	$63.29	$16.40	$13,256	$4,175	$17,431
96	$48.29	$15.20	$63.50	$16.45	$13,302	$4,188	$17,489
97	$48.46	$15.25	$63.71	$16.50	$13,347	$4,200	$17,547
98	$48.62	$15.29	$63.92	$16.56	$13,393	$4,212	$17,605
99	$48.79	$15.34	$64.12	$16.61	$13,438	$4,224	$17,662
100	$48.95	$15.38	$64.33	$16.67	$13,482	$4,236	$17,719
101	$49.11	$15.42	$64.54	$16.72	$13,527	$4,248	$17,775
102	$49.27	$15.47	$64.74	$16.77	$13,571	$4,260	$17,831
103	$49.43	$15.51	$64.94	$16.82	$13,615	$4,272	$17,887
104	$49.59	$15.55	$65.14	$16.88	$13,658	$4,283	$17,942
105	$49.75	$15.59	$65.34	$16.93	$13,702	$4,295	$17,997
106	$49.90	$15.64	$65.54	$16.98	$13,745	$4,307	$18,051
107	$50.06	$15.68	$65.74	$17.03	$13,788	$4,318	$18,106
108	$50.21	$15.72	$65.93	$17.08	$13,830	$4,329	$18,159
109	$50.37	$15.76	$66.13	$17.13	$13,872	$4,341	$18,213
110	$50.52	$15.80	$66.32	$17.18	$13,914	$4,352	$18,266
112	$50.82	$15.88	$66.70	$17.28	$13,997	$4,374	$18,372
114	$51.12	$15.96	$67.08	$17.38	$14,080	$4,396	$18,476
116	$51.41	$16.04	$67.45	$17.48	$14,161	$4,418	$18,579
118	$51.71	$16.12	$67.82	$17.57	$14,241	$4,440	$18,681
120	$51.99	$16.20	$68.19	$17.67	$14,320	$4,461	$18,782
125	$52.70	$16.39	$69.09	$17.90	$14,515	$4,513	$19,028
130	$53.39	$16.57	$69.96	$18.12	$14,705	$4,564	$19,269
135	$54.06	$16.75	$70.81	$18.34	$14,889	$4,614	$19,503
140	$54.71	$16.93	$71.64	$18.56	$15,070	$4,662	$19,732
145	$55.35	$17.10	$72.45	$18.77	$15,245	$4,709	$19,955
150	$55.98	$17.27	$73.24	$18.97	$15,417	$4,755	$20,173

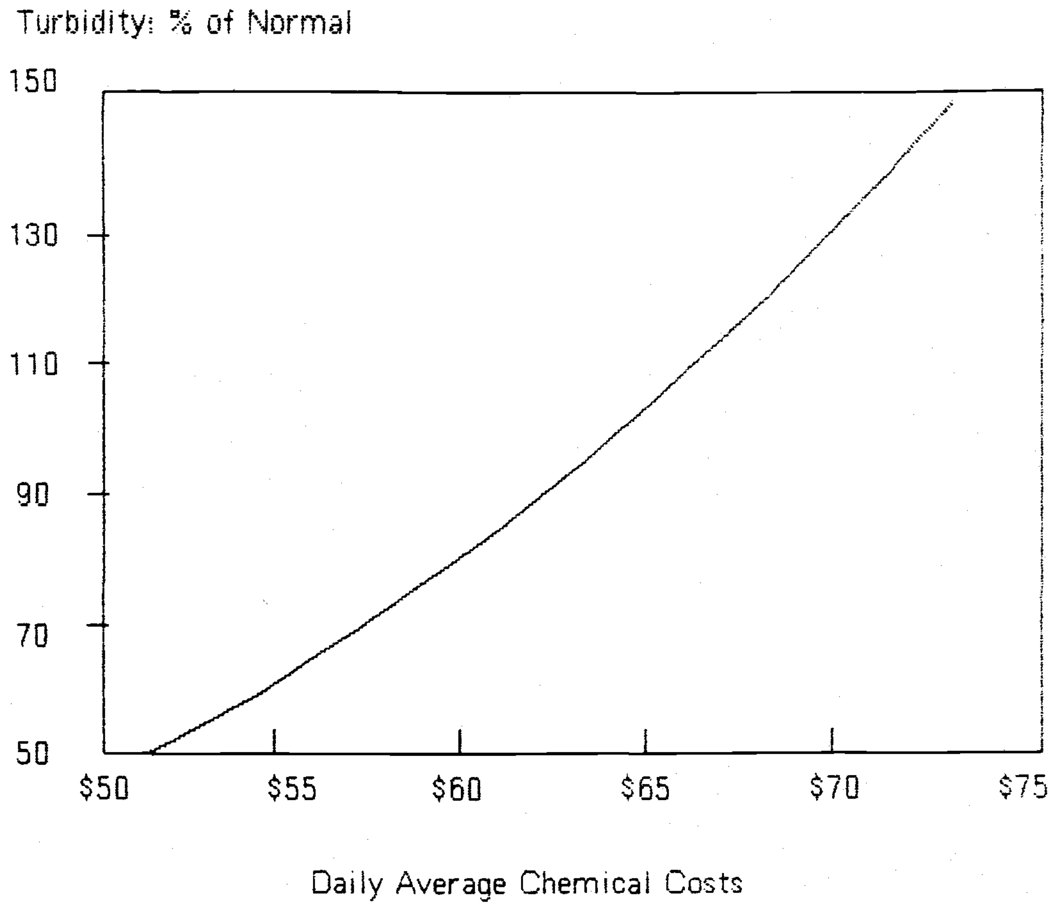

Figure 8 - Marginal Effects of Turbidity on Water Treatment Costs

cost would decrease by approximately $13 dollars or nearly $4 dollars per million gallons treated. Yearly average chemical costs would decline by approximately $3500 dollars. Figure 8 represents a schedule of the marginal increments in average chemical treatment costs as turbidity increases.

A fifty percent reduction in sediment disposal costs would reduce this cost to the plant by $1,750 per year or $0.55 per million gallons of water treated. Thus, a fifty percent reduction in turbidity at the plant may decrease treatment costs by $4.55 per million gallons or $4,750 per year.

The sensitivity analysis suggests that the marginal effects of changes in river borne erosion on chemical treatment costs are slight. While the erosion related costs incurred by the water treatment plant are substantial ($21,626 per year) in aggregate terms, the relative impact of changes in erosion rates on the Taylor plant's production costs are not large.

While the costs of erosion on this one plant are somewhat small, there may still be substantial economic costs borne in the study area when all municipal surface water treatment plants are considered. The water treatment costs for the entire Willamette Valley will be estimated in chapter 7.

IV. COUNTY AND STATE ROAD MAINTAINENCE COSTS

Overview

Off-site soil erosion can reduce the quality of existing road systems. Some eroded soil accumulates in drainage devices which are an integral part of roadway infrastructure. Sediment accumulation from erosion reduces the effectiveness of these structures. As drainage systems become clogged with sediment, both water and soil particles are washed onto roadway surfaces creating driving hazards.

To preserve the function of drainage systems road maintainence crews must periodically clean out accumulated sediment. The use of resources for these operations are costs that relate principally to soil erosion. The frequency of this maintainence activity varies with the severity of erosion and resource constraints of the road agency.

The two road maintainence activities relating principally to erosion are the cleaning of ditches and culverts[10].

Drainage ditches are found adjacent to many roads. Sediment is removed by machinery such as graders, backhoes,

10) A maintainence activity that is partially related to off-site erosion is called repairing erosion. This involves mostly preventing erosion from occurring along roadway cuts, some repair work relating to non-highway caused erosion does fall under this classification. It is not accounted for in this study because of separability problems.

loaders and sweepers. The sediment is then loaded into trucks and hauled to a suitable disposal site. From three to six laborers are needed for this type of operation.

Culverts also need periodic cleaning to maintain effective drainage systems. Typically a backhoe, loader, and dump truck are needed for this operation. A work crew of three or four persons are required for this type of job.

Both of these activities involve the use of human and capital resources. Considerable amounts of labor, machinery, and administrative time go into organizing and implementing these maintainence jobs. The use of these resources represents both real and opportunity costs of erosion to the road agency, and ultimately the taxpayer.

County Road Maintainence Costs

The Benton county road maintainence department was chosen as a case study to examine erosion costs. This maintainence department has responsibility for approximately 524 miles of roadway within Benton county[11].

Within this road department's jurisdiction there are approximately 920 ditch-miles and 10,000 culverts. Ditches are cleaned at a maximum interval of five years (184 ditch-miles per year). Culverts are cleaned once every three

11) Information about Benton county's maintainence activities was provided by Harold Marx, administrative officer.

years. Some areas experiencing critical erosion problems receive more frequent treatment.

Cost data for these two maintainence activities were gathered from county budget records for three fiscal years 1981-1982, 1982-1983, and 1983-1984. The cost figures for both ditch and culvert cleaning include variable, capital, and administrative costs. Variable costs include labor, gasoline, oil, etc.. Capital costs are the depreciation value or rental price of machinery. Administrative costs include scheduling, accounting, and equipment repairs.

The annual ditch and culvert cleaning costs for the three study years are presented in table 6. These costs are expressed in 1984 dollars using the GNP implicit price index. Annual ditch cleaning costs ranged from $197,400 to $219,200. The average ditch cleaning cost for the three years was $209,300 or $1,140 per mile of ditch cleaned. Annual culvert cleaning costs ranged from $8,700 to $13,700. Average costs for cleaning culverts for the three years was $10,700 or $2.92 per culvert cleaned. Average annual total costs for these two maintainence activities were $222,600.

These cost figures represent approximately 8 percent of Benton county's annual operations and maintainence budget. According to Harold Marx, Benton county road department administrator, the actual road maintainence budget for the county is "..less than adequate." to meet maintainence needs. Mr. Marx felt that the county should employ greater

Table 6 - Benton County Maintainence Costs

1984 Dollars

Activity	Fiscal Year 1981-1982	1982-1983	1983-1984	Average
Ditch Cleaning	$219,252	$197,411	$210,555	$209,303
Culvert Cleaning	$13,735	$8,702	$9,687	$10,708
Totals	$232,987	$214,815	$220,242	$222,681

quantities of resources to sediment removal and other maintainence activities if sufficient appropriations allowed. Thus, this maintainence officer felt the figure of $222,600 per year was less than the actual cost of erosion to the county road system due to under-maintainence.

Estimation of county road maintainence costs for the entire Willamette Valley will be made in chapter 7.

State Highway Maintainence Costs

The Oregon state highway department has jurisdiction over approximately 1800 miles of roadway within the Willamette Valley. Area-specific maintainence responsibilities are broken into 16 districts[12].

Each of these districts performs annual maintainence activity on ditches and culverts. These cleaning tasks are performed with essentially the same equipment as at the county level.

Cost data for these maintainence districts were gathered from budget records for same three fiscal years as the Benton county data. State road maintainence costs are inclusive of variable, capital, and administrative components.

12) Information about Oregon state road maintainence activities was provided by Dennis Stevens, State highway accountant.

The annual maintainence costs for the Willamette Valley road districts are presented in aggregate in table 7. Costs are all expressed in 1984 dollars using the GNP implicit price index. Annual ditch cleaning costs ranged from $367,200 to $428,300. Average annual ditch cleaning costs for the entire Valley were $388,600. Annual culvert cleaning costs ranged from $99,800 to $127,800. Average total culvert maintainence costs for state road districts were $114,900. No information about unit (ditch-miles or number of culverts) costs was available from the individual maintainence districts.

Average annual state highway maintainence costs, in the Willamette Valley, from erosion are estimated to be $503,500. This figure represents the sum of culvert and ditch cleaning costs as gathered from the State's budget records. However, the cost data in table 7 may not reflect the true current cost of erosion to state road systems. Some maintainence costs due to erosion may be reported in other work activity classifications by crew foremen and consequently not identified in table 7. Some ditch cleaning costs may be solely related to sediment. Budget constraints may cause some districts to under-maintain ditches and culverts relative to the need for such activity. Thus, road department sediment removal costs identified here may over or under-value actual erosion costs in the Willamette Valley.

Table 7 - State Highway Maintainence Costs

1984 Dollars

Activity	1981-1982	Fiscal Year 1982-1983	1983-1984	Average
Ditch Cleaning	$428,369	$370,247	$367,247	$388,590
Culvert Cleaning	$117,075	$127,846	$99,862	$114,928
Totals	$545,444	$497,999	$467,112	$503,518

V. NAVIGATION CHANNEL MAINTAINENCE COSTS

Overview

Soil erosion can effect the supply of river navigation services. Sediment deposits on river bottoms, and if left unchecked, can reduce the depth of the river channel. This will prohibit deep draft vessels from using the transportation facility.

To mitigate the effects of erosion on navigation activity periodic dredging may be required. Dredging allows for a supply of a consistent quantity (depth) of navigation service. However dredging involves a substantial use of resources, including both labor and capital inputs.

Willamette River Dredging Costs

The U.S. Army Corps of Engineers, working in conjunction with the Port of Portland, has responsibility to maintain a navigation channel on the lower Willamette River. The Corps provides a navigation channel for the Port of at least 14 feet in depth for the lower 12 miles of the Willamette River[13].

13) This channel allows deep draft vessels to enter the shipyards and terminals found in Portland Harbor. No significant river traffic occurs above the Broadway bridge in Portland.

Channel maintainence is a capital intensive process[14]. River bottom sediment is removed by dredges. The removed sediment is loaded onto barges. When the barges are filled they must find a suitable disposal location. Considerable equipment costs are involved in these operations. Capital costs comprise approximately 90 percent of total dredging operation costs.

Dredging cost data for the lower Willamette were gathered for a period from 1970 through 1984. The Corps does not usually dredge the Willamette every year. Therefore a large number of yearly observations were gathered to obtain a more accurate estimate of average annual costs.

Table 8 shows annual dredging costs and quantity of sediment removed. All cost figures are expressed in 1984 dollars using the GNP implicit price deflator. An annual average of 318,700 tons of sediment were removed per year from the Willamette. The average total cost of removal was $270,100 or 85 cents per ton. The unit cost of dredging, for the most recent two river channel dredging operations, was considerably higher than earlier costs shown in table 8. This increase is due in part to the change by the Corps' from using its own dredges on the Willamette to using a private dredging company.

Willamette borne sediment may also add to the sediment load and thus increase dredging costs in the Columbia River.

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14) Information provided by Elane Cooper of the Corps of Engineers' Portland district office.

Table 8 - Willamette River Dredging Costs

1984 Dollars

Year	Tons Removed	Dredging Cost	Administration Cost	Total Cost	Unit Cost
1971	748,963	$321,034	$12,675	$333,709	$0.45
1972	122,458	$115,590	$4,012	$119,602	$0.98
1973	1,615,682	$1,119,737	$77,182	$1,196,919	$0.74
1974	1,017,980	$515,635	$29,911	$545,546	$0.54
1976	126,943	$116,280	$17,537	$133,817	$1.05
1977	214,001	$143,858	$10,400	$154,258	$0.72
1978[a]	63,047	$160,556	$23,095	$183,651	$2.91
1981[b]	16,882	$73,581	$7,649	$81,230	$4.81
1984	536,126	$1,008,121	$24,890	$1,033,011	$1.93
14 Year Average	318,720	$255,314	$14,811	$270,125	$0.85

a) This is the first year the Corps used a privately contracted dredging service.
b) The dredging work in 1981 was done surrounding moorings and boatyards.

However, there is no hydrological evidence of sediment buildup immediately below the confluence of these two rivers. Therefore the marginal contribution of Willamette River sediment to the Columbia, if any, is not quantifiable.

VI. RESERVOIR AND HYDROELECTRIC POWER IMPACTS

Overview

Erosion runoff can effect both reservoir storage capacity and hydroelectric power generation potential. Both production activities use water as a primary input. They can both be impacted by water borne sediment.

Reservoirs hold water in storage for a variety of end uses. Suspended sediment in the stored water tends to deposit on the reservoir bottom. Sediment deposition, over time, can significantly reduce storage capacity. Thus, erosion can result in a reduced output supply potential or in increased maintainence costs if the reservoir is dredged to maintain storage volume.

Hydroelectric power generation uses water to turn turbines and produce electricity. Soil particles in the input water can affect output potential and/or operating costs. Suspended sediment can clog water intakes, turbines, or cooling lines, reducing their efficiency. Power production may be halted in order to protect equipment from serious damage, if input water is too laden with sediment. Water filters may be used to prevent equipment damage. These activities involve increases in capital, maintainence, and/or opportunity costs due to erosion.

Findings

The U.S. Army Corps of Engineers operates 13 water storage reservoirs located on several major tributaries of the Willamette River[14]. These reservoirs provide flood control for the Willamette Valley watershed as well as stream flow augmentation during low flow periods.

No measurable reduction in reservoir storage capacity, due to sedimentation from upstream erosion, has been observed by the Corps. Sediment ranges, designed to measure sediment accumulation, were placed in most of the Willamette reservoirs when they were constructed. Based on observation of these ranges by Corps personnel, during the annual reservoir draw down period, no significant levels of observed sedimentation has been reported. Given the lack of quantifiable sediment effects on these reservoirs, no erosion costs were estimated.

A principal reason for the lack of sediment accumulation is the design features incorporated into the construction of Willamette Valley reservoirs. The reservoirs have outlet gates positioned at the bottom of their retainer walls. As water is released from these penstocks turbulence is created at the bottom of the reservoir, stirring up

14) Useful information regarding sediment impacts on the Willamette system reservoirs was provided by Gordon Green of the Corps of Engineers' Willamette Reservoir Control Center.

sediment. Thus, most accumulated sediment from up stream erosion is passed to receptors below the reservoir.

The Army Corps of Engineers operates hydroelectric power plants at eight of the Willamette system reservoirs[15]. Operators at two of these plants, Foster and Lowell, were surveyed to determine erosion related impacts on hydro power production.

The only indicated impacts that sediment has on these plants is the cleaning of water strainers and filters. Some periodic cleaning of these devices is undertaken by the engineers at the two dams. Cost for this cleaning activity is approximately $100 per year at Foster Dam and $500 per year at Lowell. The rate of cleaning of these filters does not vary significantly throughout the year. A cost attribution problem exists with this maintainence activity because these filters also trap considerable amounts of algae and other solid debris. Not all of the above mentioned costs are related to erosion. Impacts by erosion on these two dams, according to the personnel who run them, is slight. Thus the cost of erosion on these dams will not be included in the cost accounting done in the next chapter.

Based on information supplied by Corps personnel, both reservoirs and hydroelectric power plants in the Valley have experienced little or no measurable impact from erosion.

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15) Information about sediment impacts on hydropower production was supplied by Paul Peters and Wade Stampe engineers for the Middle and Upper Willamette projects respectively.

VII. AGGREGATION OF EROSION COST ESTIMATES

This chapter develops aggregate erosion cost estimates for county road maintainence and municipal water treatment. This will provide a consistent basis for expression of erosion cost estimates for the Willamette Valley. Identified erosion costs for all case studies will then be summarized aggregate form.

Water Treatment Costs

To infer municipal surface water supply costs, due to sediment, to total water supply cost in the study area, several assumptions must be made. First, it is assumed that all municipal treatment plants face the same average level of sediment as measured at the Taylor plant. Second, it is assumed that all municipal treatment face the same unit costs of water treatment in regards to a given level of river borne sediment (turbidity).

These assumptions will be realistic if sediment treatment costs at the Taylor plant reflect a median values vis a vis other municipal water treatment plants in the Willamette Valley. It is plausible that the Taylor plant may have a median, or an average annual treatment cost. One reason why this might be true is that the output of the Taylor plant is greater than some municipal supply systems

(Sweet Home, Newburg) and less than others (Portland, Eugene) in the study area. A second reason for the Taylor plant having a median annual treatment cost is that some municipal surface water sources have higher wintertime turbidity ranges and sediment loads, while some have lower, than the Willamette River which is the Taylor plant's water source. Municipal water treatment plants having greater output demand and/or sediment loads experience higher annual treatment costs than estimated for the Taylor plant. The opposite relationship might be true for plants with lower average output requirements and/or cleaner water sources.

The water production data used for treatment cost inference was obtained from the United States Geological Survey's 1980 national water use survey (Sulley et. al). Since water consumption in this study is expressed on a statewide basis, the Willamette Valley's share of municipal surface water withdrawals had to be factored from state totals.

The population served by Willamette Valley municipal water plants is assumed to be only those living in incorporated areas. Based on 1980 census data there were approximately 1,042,464 persons living in incorporated cities in the Valley.

Roughly 71 percent of Oregon's municipal water withdrawals were from surface waters. A similar ratio of surface to ground water reliance was assumed for the

Willamette Valley. Given this assumption, approximately 739,315 persons in the Willamette Valley are served by municipal supply of surface water. This population is equal to 86 percent of the state's total population served by municipally supplied surface water.

Statewide surface water withdrawals by municipal treatment plants averaged 160 million gallons per day in 1980. Therefore the estimated daily withdrawals in the Willamette Valley are estimated to be 139 million gallons (86 percent of 160 million gallons).

In chapter three the unit marginal costs of water production due to sediment were estimated to be $4.55. Given estimated consumption of 139 million gallons per day in the Valley, daily water treatment costs due to erosion are $663. Annual average municipal water treatment costs are estimated to be $231,276(daily cost times 365.25). Based on this chain of inference slightly more than one-quater of one million dollars per year are estimated to be allocated to eliminating sediment from municipal water supplies in the study area.

County Road Maintainence Costs

Several assumptions must also be made before inferring Benton county road maintainence costs to the other eight county road departments in the Willamette Valley. First, a uniform distribution of erosion is assumed to exist throughout the Valley's roadways. Second, rates of cleaning of ditches and culverts are assumed to be equal for all county road departments. Third, maintainence costs are assumed to be similar on a unit by unit basis. Given these three assumptions, county road maintainence costs are simply a function of the miles of roadway each county has to maintain.

These assumptions will be valid if the Benton county road department incurs sediment removal costs that reflect a median value for all county road departments in the study area. There is little indirect evidence with which to confirm or nullify the relationship of unit sediment removal cost for Benton county vis a vis other road departments in the Valley. If sediment delivery to roadways is a function of land use activity Benton county would qualify for a median status. The allocation of Benton county land use closely approximates the average for the entire Willamette Valley (see table 2). Budget appropriations will also likely influence road maintainence activity levels. According to Harold Marx, Benton county administrator, the county's road maintainence budget is a median budget for the Willamette Valley. Several counties have larger budget sizes while some have smaller maintainence budgets than does Benton county. Based on this minimal evidence, it is plausible that Benton county may have median sediment removal costs for all counties in the Valley.

Each county's road maintainence costs were inferred by a simple multiplier. The multiplier is the quotient of the miles of each county's roads divided by the miles of road maintained by Benton county. These multipliers are given in table 9. The estimated annual maintainence costs for each county, due to eroded sediment, are derived from the product of the multiplier and the average annual maintainence costs estimated for Benton county in chapter four. Based on this formula, average annual county road maintainence costs for the study area, due to soil erosion, are estimated to be $3,743,267 using 1984 dollars. This represents a substantial opportunity cost of resource use to road departments.

Aggregate Cost Accounting

With the addition of estimates of total county road and municipal water treatment costs, an aggregate cost estimate can be obtained for the study area. Table 10 shows estimated average annual costs for the four activities in which significant erosion related costs were found. Total annual costs are estimated at $4,748,186. Assuming uniform distribution of erosion throughout the study area, this figure represents an annual erosion cost of $432 per square mile or $0.67 per acre of land in the Willamette Valley. If

Table 9 - Estimated County Road Maintainence Costs

1984 Dollars

County	Miles of Road Maintained[a]	Multiplier	Estimated Annual Cost
Benton	524	1.00	$222,681
Clackamas	1,581	3.02	$672,497
Lane[b]	1,081	2.06	$458,722
Linn	1,120	2.14	$476,537
Marion	1,246	2.38	$529,981
Multnomah[b]	595	1.14	$253,856
Polk	587	1.12	$249,403
Washington	1,231	2.35	$523,300
Yamhill	841	1.60	$356,290
Totals	8,806		$3,743,267

a) Data from 1972 Resource Atlases published for each county by the Cooperative Extension Service, Oregon State University.
b) Road miles reported for Lane and Multnomah represent only the area of each county estimated to be within the Willamette Valley.

Table 10- Aggregate Estimated Annual Erosion Costs for Certain Activities in the Willamette Valley of Oregon

1984 Dollars

Activity	Estimated Cost	Percent of Total
Navigation Channel Maintainence	$270,125	5.7
Municipal Water Treatment	$231,276	4.9
County Road Maintainence	$3,743,267	78.8
State Highway Maintainence	$503,518	10.6
Total	$4,748,186	100

off-site erosion were assumed to come from only farm land these figures would be $1488 per square mile and $3.95 per acre. County and State road maintainence costs comprise over ninety percent of this total cost given in table 10. Annual water treatment costs are 5 percent of total estimated erosion costs. Navigation channel maintainence, on the average, incurs nearly six percent of estimated erosion costs estimated for the study area.

This aggregate cost estimate by no means is a reflection of the total costs of off-site erosion in the Willamette Valley. Several activities which may be significantly affected by sediment from erosion have been omitted from this study. Both industrial and agricultural enterprises withdraw large quantities of surface water from the Willamette Valley watershed, and thus may be affected by deteriorations in water quality from off-site erosion. The Valley supports abundant and valuable fish and wildlife populations which are dependent on water quality directly and/or indirectly for survival. Recreation activity levels may be directly affected by erosion as asthetic, hunting, and fishing enjoyment are reduced by excessive sediment concentrations. The impact of off-site erosion on these activities, and others not discussed here, should be investigated before attempting a total cost estimate for the Willamette Valley.

VIII. CONCLUSIONS

The objective of this study was to study the impacts of erosion on certain activities, and if possible estimate the economic costs imposed by erosion. These costs represent losses of consumer and producer welfare. The findings of this study indicate that the costs of off-site erosion, and resultant welfare impacts, are not insignificant.

Six production activities in the Willamette Valley were studied to determine impacts of off-site erosion. Municipal water supply, county and state road maintainence departments, and navigation channel maintainence all employed significant amounts of resources to offset the effects of erosion. Water storage reservoirs and hydroelectric power generators in the Willamette Valley did not have quantifiable impacts from erosion.

The H.D. Taylor water treatment plant in Corvallis allocates, on the average, $21,625 per year to eliminate sediment from input water and to dispose of sediment residues. An econometric estimation of a sediment damage function for this water treatment plant indicated that increases in river born erosion increased water treatment costs, but at a rate well below unity. Water treatment costs for the entire Valley, based on the marginal cost analysis, were estimated to be $231,276 per year.

County and state road maintainence costs for cleaning sediment from ditches and culverts were found to be significant. Average annual maintainence costs for the Benton road department were estimated at $222,000. County road maintainence costs for the entire study area, based on the Benton county case study, were estimated to be $3,743,000 per year in 1984 dollars. State highway maintainence costs due to erosion were estimated to be, on the average, $503,000 per year.

Periodic dredging of sediment from the lower Willamette River was also found to be a significant cost of erosion. Annual costs, expressed in 1984 dollars, of maintaining a navigable channel in Portland harbor averaged $270,000 for the past 14 years.

Total annual average costs for these four activities combined were estimated at $4,475,000. This figure represents an erosion cost of $432 per square mile or $0.67 per acre per year in the Willamette Valley. Based on these estimates, there appears to be substantial off-site costs of erosion in the Willamette Valley. There also appears to be potential for economic benefits, in reducing off-site erosion alone, from increased soil conservation activity in the study area.

Data Limitations

There are several important qualifications that must be placed on the cost estimates developed in this study. These qualifications are based on research limitations with respect to aggregation of data, identification of impacts, and scope of analysis.

In chapter seven, water treatment and county road maintainence costs were inferred from a case study level to the entire study area. Several simplifying assumptions were made, namely uniform costs, treatment rates, and production technology to enable an aggregate cost figure to be derived. To the degree that any of these assumptions do not hold, the resultant aggregate cost estimates will not reflect the actual costs incurred by the sum of individual county road departments or water treatment plants in the study area. Thus, inferred county road and water treatment costs may be lower or higher than actual costs incurred for the study area. Only a case by case study could resolve this uncertainty.

In five of the six case studies examining erosion costs, problems with proper identification of impacts arose. Some production costs, both fixed and variable, were in part affected by factors other than erosion. This study chose to take a conservative approach and not include suspected erosion costs which had divisibility conflicts. Another possible identification problem was that the enterprises studied may not understand the full effects, both short and long run, of erosion on their production process. Given these shortcomings, it is possible that some erosion costs were underidenified.

Research constraints of time, money, and information limited the scope of investigation of this study. Numerous possible erosion impacts were not addressed. To the extent that any of these other costs are significant in the Willamette Valley, actual erosion costs may be higher than estimated in this study.

Recommendations

One very clear notion that comes from this research is the need to develop more damage estimation techniques to aid in cost analysis. These would involve developing standardized tools for estimating average, and marginal, costs of erosion on certain activities. These tools could be employed by conservation agents with limited amount of cost/damage infomation.

Exploration of other erosion damages, are also needed both for general and specific knowledge. Erosion impacts on irrigation systems, industrial water use, flood control, fish and wildlife populations, and recreation choices are currently undocumented, but may be significant. Research examining willingness to pay, or social demand for erosion control, would also help in developing estimates of the total social benefits from soil conservation.

For the study area, a much better understanding of the distribution of erosion occurrences and damages is needed to help accurately project total benefits from conservation projects. Better reporting of physical damages by producers, would also greatly help in projection of specific off-site benefits from soil conservation projects.

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