Off-Site Costs of Soil Erosion: A Case Study in the Willamette Valley

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This study attempts to provide relative magnitudes of average and marginal costs of off-site sediment-related costs in Oregon's Willamette Valley. Water treatment; road, river channel, and dam maintenance; and hydroelectric generation are examined. Road maintenance and water treatment are nonnegligible average cost items. These costs should not be interpreted as justification for erosion control as marginal cost estimates for water treatment indicate that controls on the margin would yield roughly one-third the average cost.

Key words: externalities, off-site costs, soil erosion.

Erosion can cause both on- and off-site damages. It has been argued that off-site damages impose significant costs upon society (Crosson). Alterations in off-site costs potentially could increase the social benefits of soil conservation activities; however, few studies have quantified the off-site economic costs of erosion and the magnitude of the various possible components of off-site cost (as discussed in Crosson and Brubaker). The major objective of this research is to execute a pilot case study examining a number of off-site items through which soil erosion may impose costs on society, constructing preliminary estimates on the relative magnitude of these costs. The case study region is the Willamette Valley of Oregon. The major objective of the study is to develop an estimate of the total cost arising through a number of items and to quantify the relative magnitude of these items, identifying those which deserve further and detailed investigation.

Soil erosion and resulting sedimentation can lead to clogged drainage-ways and suspended sediment in rivers. Erosion, sedimentation and/or deposition directly or indirectly increase costs to society in terms of facility maintenance (e.g., ditch cleaning), facility replacement (e.g., building new dams), erosion mitigation (e.g., increased water purification), and/or effect prevention (e.g., sediment settling ponds). In addition, soil erosion processes may influence income by altering production or input requirements. For example, farmers whose lands are inundated by sediment-laden rivers may find an increase in passive fertilization and/or crop acreage damaged by deposition.

The study approach involves the estimation of maintenance and mitigation costs. Data are developed on the change in public expenditures required to maintain existing facilities and to remove silt from water. Such estimates of changes in total cost will be accurate measures of social welfare when one assumes that society's demand curve for the services examined is perfectly inelastic over the range of price changes induced by the increased cost of avoiding damages caused by silt. This assumption, therefore, is made in this study. Such a procedure places an upper bound on social costs. The use of public expenditures also rais-

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es the possibility of divergence between societal expenditures and the actual welfare effect. Often expenditures in any year are influenced by short-run fiscal and political considerations. Partially to avoid this influence, data from several years are used and averages constructed. Clearly, average expenditures may not equal the welfare loss; however, such expenditures are a manifestation of society's willingness to pay for erosion effects mitigation. (Hufschmidt et al. discuss this point extensively.)

An Aside: Total Cost As a Welfare Measure

This study uses change in total cost to measure welfare change induced by changes in sediment loads. Total cost change is a valid welfare measure only when one (*a*) adopts consumers' and producers' surplus as a welfare measure and (*b*) assumes that the demand curve for the item examined is perfectly inelastic over the price range studied. This is demonstrated in figure 1. Suppose *D* and *S'* are demand and supply curves for a good (say purified water) before water quality is altered by a change in sediment load. Suppose *S* is the supply curve after the change. Welfare before the change is shown by area *a* (assuming *a* is the area between the price axis and the demand curve which falls above *S'*. Total cost in this case equals the area (*b* + *c*), which is the area under the supply curve up to the quantity consumed. After the supply shifts, welfare equals *a* + *b* and cost equals *c*. The additional welfare then is given by area *b*, which exactly equals the change in cost.

Study Area

The Willamette Valley is a major watershed in northwestern Oregon, encompassing 11,500 square miles. It is a broad alluvial plain surrounded on three sides by mountain ranges. The area drains into the Columbia River. Major tributaries have formed smaller fertile upland valleys suited for intensive agriculture. Approximately 2,000 square miles of the Willamette Valley are currently utilized for intensive agriculture (principally nuts, fruit, wheat, grass seed, and Christmas trees). In addition, 7,200 square miles are utilized for intensive forestry, with the remainder of the land in urban, park, and other land uses.

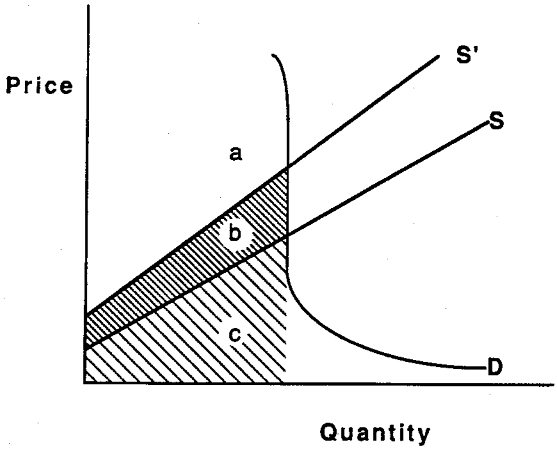

Figure 1. Change in total cost as a welfare measure

Average annual erosion rates for the entire state of Oregon have been estimated at 2 to 4 tons per acre for agricultural lands and .2 to .8 tons per acre for forest lands [U.S. Department of Agriculture (USDA)]. This is probably an overestimate of erosion on Willamette Valley soils but is given for perspective. Topography, climate, and cropping patterns serve to limit erosion potential in the Willamette Valley relative to the rest of Oregon. Much of the valley's farmland is on slopes of 5% or less (Willamette Valley Task Force). Rainfall averages 63 inches per year, with most of it occurring between October and June. Roughly 15% of the agricultural lands in Oregon exhibit erosion rates that annually exceed the natural *T* factor, i.e., the rate at which erosion can occur without decreasing long-term soil productivity. The Willamette Valley is not generally considered to be a high-erosion area. However, hillside areas within seven counties have been targeted as critical soil erosion areas. The targeted area contains roughly 6,350 square miles, of which roughly 1,300 square miles are in cropland. Of this land, 85% is estimated to be eroding at a rate greater than *T* with 26% exceeding 2*T* (SCS 1986). In targeting this area, millions of dollars in off-site dredging and ditch-cleaning costs were cited as justification for erosion control (SCS 1983).

Methods and Cases

Numerous off-site economic entities in the Willamette Valley could be affected by soil erosion and resulting sedimentation. These include those entities whose economic welfare is affected by costs or revenues from (*a*) Columbia and lower Willamette River navigation, (*b*) salmon and steelhead runs, (*c*) drinking water purification, (*d*) flood incidence, (*e*) sewage disposal, (*f*) hydroelectric power generation, (*g*) drainage system operation, (*h*) agricultural production and recreation. Because of data limitations and preliminary discussions with potentially affected parties, this study considers the effect of sediment on municipal water treatment, road drainage system maintenance, navigation channel maintenance, reservoir capacity deterioration, and hydroelectric power plant costs. This does not imply that other factors were not affected; however, data on the other entities' economic costs were not readily available (in the case of fish runs and agricultural production) or were judged not to be worth developing (in the case of sewage disposal, floods, and Columbia River navigation).[1] Moore provides details on these judgments.

The basic approach in this study involved interviewing personnel from potentially affected entities and collecting records on the cost of mitigating sediment effects and/or sediment-related public facility maintenance costs. As the study was exploratory, data was not collected on all such entities in the Willamette Valley but rather on assumed representative entities in each category. Such data were gathered and extrapolations made as to the total cost of each item. This yielded information on the relative magnitude of costs; but it could bias the results if there are important economy-of-scale differences, technology changes, and/or different sediment incidence characteristics across plants. However, given that we wished only to discover the relative magnitude of cost sources and given our limited budget, this procedure was utilized. See Moore for additional details.

Sediment Damage Estimates

Municipal Water Treatments

A considerable volume of Willamette Valley drinking water is drawn from surface waters. Drinking usage requires sediment removal. Sediment is removed mainly by the introduction of chemicals (aluminum sulfate—alum—and lime) and filtration, often using sediment settling and holding areas. Alum is used to bond with the sediment and cause it to settle out of the water; alum use also lowers the water pH. The lime is used to adjust for the water's natural pH level as well as the influence of alum. Subsequently, the sediment is flushed to a holding area which is, in turn, periodically dredged. Filtration also is a minor cost item, but it removes sediment, bacteria, algae, and other residues. Filtration costs were not included because some level of bacteria, algae, and other residues would likely require filtration regardless of the sediment level. (Also, experts indicated that filtration cost was unrelated to sediment load.) Consequently, the cost required to mitigate sediment damage was investigated by examining the alum, lime, and sediment disposal costs. Consideration was also given to possible facility (capital) costs; however, discussion with engineers indicated that sediment load was a minor factor in water treatment facility design.

Daily water treatment records from 1 January 1981 to 20 June 1984—964 production days—were obtained from the H. D. Taylor water treatment plant in Corvallis, Oregon. These records included observed levels of water treated, pH, water temperature, turbidity (a proxy for sediment load), and alum and lime usage. These data were used to estimate predictive equations for daily total alum and lime usage. Linear and log-linear equations were fit, and the best in terms of R^2 were chosen (Moore provides details). These equations, after correction for first-order serial correlation (Cochrane and Orcutt), appear in table 1. The parameter signs correspond with a priori knowledge of the expected impact of each variable. For example, alum use rises with volume of water treated and turbidity (sediment load) and falls with temperature (temperature affects how well alum bonds with sediment; lower temperatures require more alum; thus the negative sign). Similarly, the alum and pH signs for the lime equation were as expected. Discussion of the equation with plant officials and an examination of its simulation properties indicated it was suitable for further experimentation.

The predictive equations were used to develop a cost function involving turbidity. This

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[1] The salmon and steelhead runs have been enhanced in the last 20 years by river chemical pollution cleanup efforts. Relevant fish sediment interaction data were not available. Agricultural production effects were not examined.

was done by first multiplying the daily chemical use equations by the chemical costs, then adding them to give an equation estimating the total cost of withdrawing water given the levels of the exogenous variables. In turn, three-year treatment costs were simulated given the data on levels of water withdrawn, pH, temperature, and turbidity.[2] This simulation yielded an average lime cost of $14.89 per operating day and an average alum cost of $48.23 per operating day. These were between 4% and 5% lower than actual observed chemical costs and were judged to be close enough for our purposes. Summing daily alum and lime costs yielded a daily average cost of $63.11. The cost estimates were increased by adding the average sediment pond cleaning and sludge disposal cost. This amounted to an additional $12.73 per day. Thus, the average daily cost of sediment was $75.84, or $20.00 per million gallons of water treated. Subsequently, the simulation was used to construct marginal cost estimates with respect to sediment load (turbidity). The marginal cost estimate was done by adjusting the historical data such that turbidity was a given percentage lower on each and every day of the historical time period. This permitted development of a cost relationship between percentage of turbidity reduction and cost. The resultant data are given in tables 2A and 2B. The elasticities in the last column of 2B show that a 1% change in turbidity, and thereby sediment, would reduce the cost by roughly ⅓% for sediment load changes between ±50%.

Table 1. Regression Results for Water Treatment Equations

Independent Variable	Dependent Variable Total Daily Alum Use[a] (Pounds)	Total Daily Lime Use[b] (Pounds)
Constant	6.4153 (.4674)[c]	91.4184 (52.0005)
Water withdrawn from river (million gallons)	.4986 (.0126)	
Turbidity of water withdrawn (no. turbidity units)	.2193 (.0152)	
Temperature of water withdrawn (fahrenheit)	−.3851 (.1160)	
pH of water withdrawn		−9.1815 (6.9642)
Alum used in treating water (pounds)		.3673 (.0102)
ρ[d]	.8337 (.0190)	.7236 (.0223)
Sample size	963	963
R-squared	.913	.771
F-statistic	2,525	1,074
Durbin-Watson	2.61	1.94

[a] These parameters are from a double log functional form.
[b] These parameters are from a linear functional form.
[c] Standard error in parentheses.
[d] This is the Cochrane-Orcutt autocorrelation correction factor.

The Taylor plant average cost estimates are relatively small (no more than $22,000). However, an overall perspective on these costs is attained only by constructing an estimate that depicts the simultaneous costs across all the valley water treatment facilities. A crude estimate on a valley-wide basis was constructed under the assumption that the Taylor plant was typical of all valley surface water treatment plants and that they all face the same average level of sediment. (A phone survey of plants in the major cities on the Willamette showed the treatment cost of $20 per million gallons to be approximately equal to the average cost of the other plants. Thus, the assumption was felt to be appropriate.) Inference to the valley level was based on the 1980 total Oregon municipal surface water withdrawal data developed by the U.S. Geological Survey (Sulley). The USGS total surface water withdrawal figure was assumed proportional to population. Because 86% of the total Oregon population lives in the Willamette Valley, 86% of the state's 160 million gallons per day (139 million gallons) was assumed to be used in the Willamette Valley. This works out to an annual average municipal cost of $1,015,472, or, based on the marginal cost relationship, a marginal cost of $201,186 if half the sediment were removed (about $3,385 per 1% reduction in turbidity.

Road Maintenance Costs

Road maintenance costs were also estimated. Here the data only supported an average cost approach. Benton County and State of Oregon officials were interviewed. From their responses, estimates were constructed of sediment-related ditch and culvert cleaning and

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[2] Taking the first-order serial correlation correction into account yielded a cost function which involved the observations on two adjacent days.

Table 2A. Water Treatment Costs

Cost Basis		Average Cost Estimates, Taylor Plant				Willamette Valley Total Cost
		Alum	Lime	Sediment Removal	Total	
		($)				
Annual	Observed	13,810	4,316	3,500	21,626	1,052,964
	Model	13,262	4,094	3,500	20,856	1,015,472
Operating day	Observed	50.22	15.70	12.73	78.65	
	Model	48.22	14.89	12.73	75.84	
Million gallons	Observed	13.24	4.14	3.36	20.74	
	Model	12.71	3.93	3.36	20.00	

other road maintenance costs. Benton County data were obtained from the road maintenance department, which is responsible for about 920 miles of ditches and 10,000 culverts. Ditches and culverts are cleaned at least once every three years. Cost data were obtained for these maintenance activities for the fiscal years 1981–82, 1982–83, and 1983–84. Variable costs for labor, gasoline, oil, and miscellaneous other costs were included, as were capital depreciation and machinery rental prices. Administrative costs involving scheduling, accounting, and equipment were also included. In 1984 dollars, annual costs ranged from $206,000 to $233,000, averaging $219,780, or $1,140 per mile of ditch cleaned and $2.92 per culvert cleaned. Discussion with county employees indicated this to be a lower bound on cost because, in their judgment, the cleaning effort was insufficient due to budget constraints.

A similar procedure was followed with the Oregon State Highway Department. The state maintains over 1,800 miles of roadways as well as numerous ditches and culverts. Cost data were gathered for the 1981, 1982, and 1983 fiscal years. Actual ditch cleaning costs ranged from $367,200 to $428,300, with an average cost of $388,590. Culvert cleaning averaged $114,928. Thus, the total average state cost was $503,518.

These cost estimates were inferred to the Willamette Valley level to develop an overall perspective on their magnitude. The state portion of the cost estimates was already applicable at a valley level, but the county cost estimates needed extrapolation. Inference to the rest of the valley was done assuming that (*a*) road cleaning costs are proportional to the road mileage and (*b*) costs per road mile are constant throughout the valley. The resultant es-

Table 2B. Marginal Cost Estimates

Percentage Change in Historical Sediment Load	Alum Plus Lime Cost	Disposal Cost	Total Cost	Plant Level Change in Cost	Willamette Valley Level Change in Cost	Percent Change in Cost	Elasticity[a]
	($)						
−100	382	0	382	−20,474	−996,873	−98.2	.98
−50	14,974	1,750	16,724	−4,132	−201,186	−19.8	.40
−25	16,323	2,625	18,948	−1,908	−92,900	−9.1	.37
−10	16,970	3,150	20,120	−736	−35,836	−3.5	.35
−5	17,167	3,325	20,492	−364	−17,723	−1.7	.35
−1	17,319	3,465	20,784	−72	−3,506	−.3	.35
0	17,356	3,500	20,856	0	0	.0	
+1	17,393	3,535	20,928	72	3,506	.3	.35
+5	17,537	3,675	21,212	356	17,364	1.7	.34
+10	17,712	3,850	21,562	706	34,375	3.4	.34
+25	18,203	4,375	22,578	1,722	83,844	8.3	.33
+50	18,926	5,250	24,176	3,320	161,650	15.9	.32

[a] Percent change in cost/percent change in sediment load.

Table 3. Willamette River Dredging Costs

Year	Tons Removed	Dredging Cost	Administration Cost	Total Cost	Unit Cost
			($ 1984)		
1971	748,963	321,034	12,675	333,709	.45
1972	122,458	115,590	4,012	119,602	.98
1973	1,616,682	1,119,737	77,182	1,196,919	.74
1974	1,017,980	515,635	29,911	545,546	.54
1976	126,943	116,280	17,537	133,817	1.05
1977	214,001	143,858	10,400	154,258	.72
1978	63,047	160,566	23,095	183,651	2.91
1981	16,882	73,581	7,649	81,230	4.81
1984	536,126	1,008,121	24,675	1,033,011	1.93
14-year average	318,720	255,314	14,811	270,125	.85

timate amounts to $3.71 million a year. In addition, the state spends another half-million dollars. Thus, a total average of $4.22 million a year is estimated to be spent on sediment-related road maintenance.

River Channel Maintenance

The Port of Portland is a major shipping port. Maintaining navigability requires the dredging of sediment deposits on the lower Willamette and Columbia Rivers. Thus, the cost of dredging the Port of Portland is a component of the social cost of soil erosion and sedimentation. Dredging costs were estimated by contacting the U.S. Army Corps of Engineers and gathering dredging cost data. Data were obtained for dredging in the years it was done between 1971 and 1984. These data, expressed in 1984 dollars, are given in table 3. In turn, a fourteen-year average was used as the annual cost under the assumption that the lack of dredging in some years (e.g., 1982 and 1983) was made up for by dredging costs in other years. This yields an average annual cost of $270,125, or $.85 per ton of sediment removed. These figures are directly applicable at the Willamette Valley level.

Table 4. Estimated Annual Average Erosion Costs for Certain Activities in the Willamette Valley of Oregon

Activity	Estimated Cost
Navigation channel maintenance	$ 270,000
Municipal water treatment	1,015,472
County road maintenance	3,743,267
State highway maintenance	503,518
Total	$5,532,257

An attempt was also made to assess Willamette sediment costs in the Columbia system. However, experts said the marginal costs of Columbia dredging because of Willamette Valley sediment were minimal, and so this cost item was neglected.

Reservoirs and Hydroelectric Power Plants

Sedimentation can affect both reservoir storage capacity and hydroelectric power generation potential as well as operating costs. Reservoir and hydroelectric power generation costs were studied by contacting the U.S. Army Corps of Engineers. However, the information obtained indicated that no measurable reduction in Willamette Valley reservoir storage capacity has occurred.[3] Army Corps of Engineers personnel also indicated that the hydroelectric impact was minor involving the cleaning of water strainers and filters. This cleaning cost was approximately $600/year and was partially caused by algae and other foreign matter. Thus, this cost was neglected.

Summary Cost Accounting

The component costs were summed to develop a total cost estimate (table 4). This yields a

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[3] This lack of siltation effects seems inconsistent with the navigation dredging results; however, for the most part the reservoirs are located high in the system above the largest sources of sediment.

$5.5 million annual total estimated cost of sedimentation. This number should be regarded as an upper bound on the sediment-related costs for several reasons. First, all the cost estimates underlying it give the average total cost of sediment, not how much cost would be reduced if sediment were marginally reduced. The water analysis shows that, for example, reducing sediment by 50% results in a $200,000 savings rather than the $500,000 implied by the average cost estimate. Second, while it might be tempting to interpret this result in terms of the value of halting erosion, one must wonder how much of the erosion is haltable and whether the mitigation would be needed under "pristine" conditions (water treatment might be needed under zero erosion conditions). Thus, these numbers are upper bounds.

Attribution of this upper bound total cost estimate back to parcels of land is not possible given our data. However, broad per-acre averages contribute to one's perspective. Using a $5 million figure, this amounts to roughly $.71 per acre of land in the Willamette Valley under a uniform erosion assumption. However, if one assumes that the agricultural land has roughly a six times greater runoff than does the forest land (as implied by the data in the USDA report) and that the urban lands have the same runoff rate as the forest lands, then roughly two-thirds of the total cost is allocatable to agricultural land, with one-third allocated to forest and urban land. Given the relative distribution of these land uses, an approximate average cost per acre is $2.63 for agricultural land and $.28 for nonagricultural land. Furthermore, one would expect the more erosive lands to cause a larger share of this cost; thus, lands eroding above the T-value would be causing in excess of these values.

Concluding Comments

The data developed above show that the allegations arising from the targeting process that millions of dollars are being spent each year on soil erosion related off-site effects in the Willamette Valley are not inconsistent with the data. However, this is an average cost; and, for example, the data show that in the case of water purification, only one-third of a percent of the average cost is mitigated by a one-percent marginal change in the sediment load. Consequently, one must regard the estimate developed above to be an overstatement of the social value of erosion mitigation. Attempts to conserve soil will result in marginal changes in soil erosion. Furthermore, natural processes will likely never permit total elimination of sediment. Nor, probably, would water treatment be reduced to zero activity under "pristine" conditions. Nevertheless, the estimate is informative, particularly since the valley is regarded as an area which is not subject to extensive erosion.

The study indicates some types of cost effects which are relevant to consider and subject to additional study. Namely, the largest erosion effect in the study arose out of the road maintenance account. It would appear important to study road maintenance in more detail by developing primary data on the quantity and composition of material removed as well as the spatial diversity of cleaning costs and its relationship to the characteristics of adjacent land, for example. It appears that sample size for water purification costs should also be increased so as to address questions involving economies of size, technology, and spatial diversity of water sediment load.

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