The Impacts of Soil Erosion on the Mississippi River Dredging Costs

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December 1986

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Introduction

Intolerable soil losses from soil erosion were undoubtedly recognized for centuries, but expressions of concern in the United States were infrequent until the late 1920 and early 1930 era. Bennett and Lowdermilk(1938) stated that soil loss from soil erosion was perhaps "the most potent single factor contributing to the deterioration of productive land". However, after almost 50 years of research and administrative efforts, the core of the erosion problem has not been explored yet. The major problems concerning man-induced accelerated soil erosion found in the literature are summarized as following:

First, almost all the previous researches focus primarily on estimating the productivity losses from erosion. These results show that the effects of erosion on soil productivity in the U.S. and on the costs of producing crops have generally been small and will continue to be small particularly in times when the major concern is with surpluses(Crosson and Stout, 1983).

Second, there is evidence indicating that most soil

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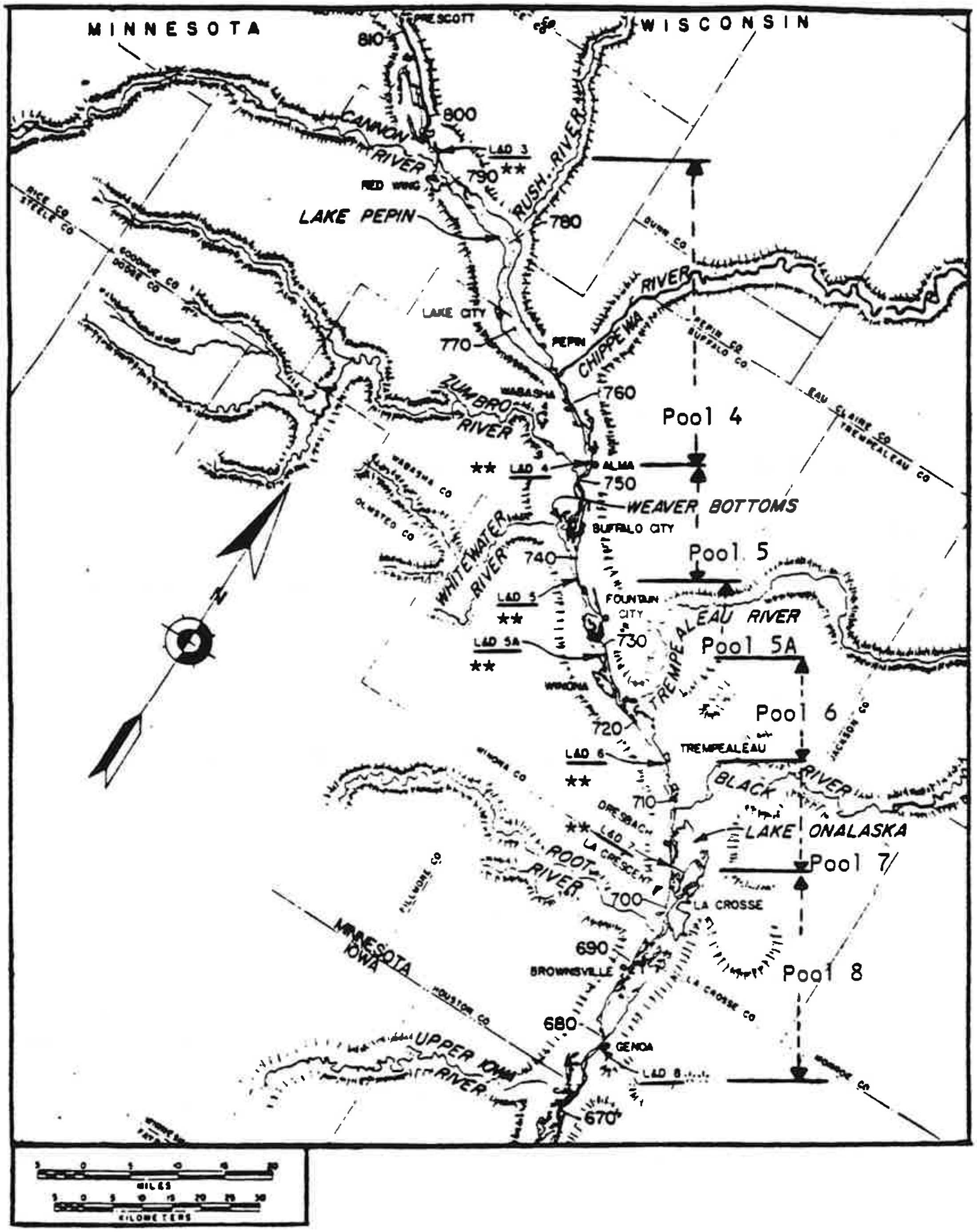
conservation practices are economically justified if all damage costs, on-site and off-site are taken into account. Yet, there has been few if any reliable estimates of the magnitude of off-site damages. A complete list and a systematic procedure for estimating the complete range of off-farm damages are still lacking. [1]

Finally, the difficulties involved in estimating off-site damage costs are threefold. First, there are no well documented biological and technological data which describing how eroded soil affect the relationships between the ecosystem and the products or services it provides. Second, the product-user interface affected by erosion are usually non-market or public goods which are difficult to value. Finally, even if there are accurate estimates for all the off-site damages, one still needs a sediment budget model to estimate the relative importance of different sediment sources, attribute downstream damages to their origins, or effectively target soil conservation programs.

This paper provides a comprehensive list of benefits and costs from deposition of eroded soil particles in the sediment routing process. Dredging costs and demand for dredged material on the Lower-upper Mississippi River main channel are empirically estimated. The estimates are limited to segments of six pools(4, 5, 5A, 6, 7, and 8) in southeast Minnesota(Figure 1). The area was chosen because of its high soil erosion rate, its geological topography

Figure 1
Study Area Map:
Lower-upper Mississippi River Lock & Dam 3-8



LEGEND

** Location of Lock & Dam
670, 680,..., 810, Indicate River Miles North to Mouth of Ohio River

and sediment routing process, and most important, its inevitable spill-over effects on the Mississippi River. The major tributary rivers along the Lower-upper Mississippi River include the Cannon, Zumbro, Whitewater, and Root Rivers on Minnesota side and the Rush, Chippewa, Buffalo, Trempealeau, Black and La Cross Rivers from Wisconsin side.

Sediment Damage Distribution

Eroded soil from upland sources travels through the river basin, ending up at some final basin outlet. In the process it affects outputs and services provided by the river basin ecosystem in each place it is deposited or it passes over in the form of sediment load. Increased sediment levels can cause on-site productivity impacts and a variety downstream impacts on water quality and other uses. Figure 2 provides a comprehensive list of impacts from eroded soil along its sediment routing process. Some of the impacts may be positive, but most of them are negative. Some result from soil erosion itself(increased turbidity), while others are caused by sedimentation in the river basin. Although some of these impacts have been documented by empirical evidence, most of them have not. Furthermore, it is difficult to estimate the extent to which these impacts are caused by cropland erosion. Table 1 lists the gross erosion rates, total sediment basin

Figure 2
The Schematic Diagram
of Soil Erosion---Sediment Routing Process
---Deposition and Non-point Sources Pollution Damages

Classification of Water Related Soil Erosion by Source		
RURAL LAND	URBAN LAND	STREAM
Construction Site	Construction site	Stream Bank
Highway Deicing	Highway Deicing	Stream Bed
Roadside Erosion	Roadside Erosion	-------NA-------
Mining	-------NA-------	-------NA-------
Open Land	-------NA-------	-------NA-------
Range Land	-------NA-------	-------NA-------
Forest Land	-------NA-------	-------NA-------
Crop Land	-------NA-------	-------NA-------

Eroded Soil Particles: First Stage Movement

Deposit at the end of farm field, adjacent farm roads, ditches, ponds, or other fields

Eroded Soil Particles: Second Stage Movement

Leaves local area and deposited on county road, small reservoir, or seeps into the ground water through sink holes

Eroded Soil Particles: Third Stage Movement

Sediment will either be deposited on the bottom of the river channel as a bed load or be moved by the river as a wash load

Eroded Soil Particles: Fourth Stage Movement

Sediment as a wash load in the river and withdrawn for municipal use, irrigation, industrial, or some other beneficial uses

-----FURTHER DOWNSTREAM MOVEMENT

Erosion Damages/Benefits On Farm and/or Off-site

- Productivity loss
- Increased on farm or off-site drainage ditch maintenance cost
- Possible productivity gains from accumulating eroded soil in adjacent farm fields

Erosion Damages/Benefits Off-site, Off-stream

- Pollute ground water
- Increased flood damage, or maintenance and dredging cost of reservoirs
- Dredged material may have some beneficial uses
- Increased costs on county ditch cleaning

Erosion Damages/Benefits Off-site, In-stream

- Increased dredging cost on main river channel
- Increased flood frequency, and related clean up cost of sedimentation
- Sedimentation will reduce the river's surface water area and adversely affect various aquatic organisms, and reduce recreational value of the river
- Dredged material might have beneficial uses
- Cost of river turbidity

Erosion Damages/Benefits Off-site, Off-stream

- Increased water treatment costs for both drinking and cooling purposes
- Increased cost of pumping water from its source
- Costs of removing sediment from irrigation channels
- Highly turbid irrigation water has adverse impacts on both demand for water and irrigated crops
- Suspended sediments may accelerate the rate at which pumps and other equipment wear out, and also cause damages to the cooling system
- Suspended sediment reduce water temperature, increase cooling water efficiency and lower the reservoir's evaporation rate
- Turbidity may affect plant growth in reservoirs

yields, and the delivery ratios for the ten sub-river basins in southeast Minnesota. The soil erosion from cropland sources range from 41%(townships bordering upon Pool No. 7) to 92%(Whitewater River Basin) of the total erosion, while the delivery ratios range from 1.79% in townships connected with Pool No. 8 to 17.82% in the Root River basin.

The sediment from cropland that does reach waterways usually contains a higher percentage of fine soil particles(clay and silt)[2] than other sources. As a result, sediment from agricultural sources is more likely to remain in suspension than that from other sources. This would imply that the contributions of agricultural sources to stream turbidity and backwater sedimentation are high. In contrast, their contributions to main channel sedimentation are perhaps somewhat lower than a straight comparison of total sediment load would suggest.

Similarly, sediments entering a river at its headwaters will have opportunities to generate impacts along its whole length, while sediments entering the river at its mouth can only cause impacts in the estuary. For example, as shown in Figure 1, eroded soil particles from the Cannon River Basin have potential water quality effects on all the pools along the Lower-upper Mississippi River while sediments from the Root River only affect Pool No. 8.[3]

Table 1
Sediment Sources by
Ten Southeast Minnesota Sub-river Basins

Sediment Statistics	Whitewater River Basin	Cannon River Basin	Root River Basin	Zumbro River Basin	Mississippi River Direct
			(t/yr)		
(A)Total erosion	506880	2509056	4356864	3825944	2082816
(B)Erosion (cropland)	463657	2230848	3323727	3340546	1393136
(C)Erosion (Other land)	43223	278208	1033137	486398	689680
(D)Basin yield (Total)	17510	54386	776218	128333	49695
(E)Basin yield (Cropland)	16074	48260	541329	109162	36153
			(%)		
(F)Basin yield (Cropland)	91.79	88.74	69.74	85.05	72.75
(G)Delivery ratio	3.45	2.17	17.82	3.35	2.39

Source: Reproduced from Frank Hao Wen, Determinants of the Optimal Soil Loss Tolerance(T-value) from a Societal View Point-the Study of Minnesota Lower-upper Mississippi River Basin, Ph. D. Thesis, November 1986, Department of Agricultural and Applied Economics, University of Minnesota, Table (VII-5), pp. 311-312.

Table 1
Sediment Sources by
Ten Southeast Minnesota Sub-river Basins
(continued)

Sediment statistics	Mississippi River Direct Basin Pool 4	Pool 5	Pool 5A	Pool 6	Pool 7	Pool 8
	(t/yr)					
(A)Eerosion (Total)	635904	437760	331776	216576	71424	389376
(B)Erosion (Cropland)	487181	304266	242404	205171	28984	206094
(C)Erosion (Other land)	148723	133494	89372	11405	42440	183282
(D)Basin yield (Total)	17635	12578	7122	4064	1327	6972
(E)Basin yield (Cropland)	13714	10021	5648	2361	539	3871
	(%)					
(F)Basin Yield (Cropland)	77.77	79.68	79.35	58.08	40.62	55.51
(G)Delivery ratio	2.77	2.87	2.15	1.88	1.86	1.79

Source: Reproduced from Frank Hao Wen, Determinants of the Optimal Soil Loss Tolerance(T-value) from a Societal View Point-the Study of Minnesota Lower-upper Mississippi River Basin, Ph. D. Thesis, November 1986, Department of Agricultural and Applied Economics, University of Minnesota, Table (VII-5), pp. 311-312.

External Damage Costs

The 9-foot navigation channel for commercial navigation on the Upper Mississippi River was established by creating a series of pools behind dams with locks. From the Twin Cities(Minneapolis-St. Paul) to Cairo, Illinois, the Corps of Engineers built and maintains 29 locks and dams which make this reach of the Upper Mississippi River navigable. Ironically, the lock and dam system which created many of the backwater areas and makes the river navigable also has contributed to the sedimentation process. The impoundment of the river has reduced its ability to transport sediment through the natural "flushing" process which occurs during floods and high flows. Therefore, annual maintenance dredging of the Upper Mississippi River main channel is necessary if the river is to remain navigable for commercial traffic.

Averting Behavior Measure of Damages

For almost every kind of environmental damage, there are averting expenditures people can make to reduce, and sometimes completely remove, the damage. Economists have long been aware that averting behavior is both possible and practiced, and often suggest that expenditures on such behavior can be used as a measure of the damage costs imposed by pollution. In the case of erosion damages, one common practice is use the cost of removing sediments from river channels, drainage ditches, and reservoirs as a measure of damages. The valuation method used to estimate this category of erosion damage costs is called the "engineering approach with averting behavior".

The literature on averting expenditures is difficult to characterize, but to the extent that a consensus has been reached, it is that averting expenditures provide a lower bound estimate of the total costs imposed by sedimentation. The divergence between averting expenditures and the total costs of sedimentation arises from the fact that some consequences of sedimentation cannot be averted. However, Courant and Porter(1981) in their study of the relationship between the willingness to pay for environmental quality and averting expenditures concluded that:(a). averting expenditures are not in general a good measure of willingness to pay; (b). averting expenditures are not always even a lower bound on willingness to pay; and (c). even when averting expenditures are a lower bound, the difference between the level of such expenditures and willingness to pay cannot be attributed to the unavertible aesthetic consequences of pollution(sedimentation). Nevertheless, using procedures similar to that of Courant and Porter(1981), it will be shown that the averting expenditure is a good measure of willingness to pay. In addition, the averting expenditure is an upper bound(a lower bound) estimate of the consumer's equivalent(compensating) variation measure of welfare change from an increase in sedimentation rate, depending on how consumer welfare changes are defined.

Assume that the main channel river depth(MCRD) in the Mississippi River is affected by a sedimentation rate(SD) and dredging volume(DV). To meet the minimum requirement for a navigable river channel(NRC), the MCRD should be at least maintained at MCRD*. The production function of (NRC) is determined by (Eq 1) and the associated constraints shown by (Eq 2) and (Eq 3).

(Eq 1) (NRC) = f(MCRD, SD, DV).

(Eq 2) d(NRC)/d(MCRD) > 0, for MCRD < (MCRD*); and

d(NRC)/d(MCRD) = 0, for MCRD = > (MCRD*).

(Eq 3) d(NRC)/d(SD) < 0, for SD > 0; d(NRC)/d(DV) > 0

The decision maker knows the sedimentation rate and minimum river channel depth requirement for navigation, and must choose averting expenditures so that sedimentation rates(SD) equal dredging volume(DV). Assume that the price(average dredging cost) per unit of dredging volume is P(DV), and the unit of the composite consumption good (X) is chosen so that (X) has price of unity.[4] Thus, the decision maker's problem is to allocate personal income (Y) between the averting expenditures on dredging volume and a composite consumption good (X). However, in this model, sedimentation rate(SD) affects utility only through its effect on the cost for maintaining the channel navigable, i.e. the dredging cost. In addition, both sedimentation rate and main channel river depth(MCRD) do not enter into the utility function directly. The utility function is given by (Eq 4) and the problem is to maximize (Eq 4) subject to the budget constraint of (Eq 5).

(Eq 4) $U = U(NRC, X)$

(Eq 5) $X + P(DV) \times (DV) = Y$

The willingness to pay for marginal increase in the main channel river depth($dMCRD > 0$) when $MCRD < MCRD*$ is defined as the decline in income (dY) that would leave utility constant. Since the decision maker is maximizing utility subject to a budget constraint and parametric prices, the maximization problem can be analyzed by looking at the indirect utility function of (Eq 6)(Varin, 1978).

(Eq 6) $V = V(Y, P(SD))$

Consider the effect of a marginal change in main channel river depth on the decision maker. The definition of willingness to pay requires that (Eq 7) be satisfied.[5]

(Eq 7) $$d(V)/d(SD) = [d(V)/d(Y) \times d(Y)/d(SD)] + [d(V)/dP(SD) \times dP(SD)/d(SD)] = 0$$

This can be rewritten as (Eq 8).

(Eq 8) $$d(Y)/d(SD) = -\{[d(V)/dP(SD)]/[d(V)/d(Y)]\} \times [dP(SD)/d(SD)]$$

From a property of the indirect utility function, the Roy's Identity, we know that (Eq 9) is true.

(Eq 9) $$-[d(V)/dP(SD)]/[d(V)/d(Y)] = P(SD) = (SD*)$$

Where P(SD):The supply function of dredging volume(DV).[6]

Thus (Eq 8) can be written as (Eq 10).

(Eq 10) $d(Y)/d(SD) = [P(SD)] \times [dP(SD)/d(SD)]$

$= (SD*) \times [dP(SD)/d(SD)]$

In words, (Eq 10) can be interpreted as the increase in sedimentation rate(SD) which raises per unit dredging costs (averting expenditures) above the previous level under the lower sedimentation rate. This cost is increased by the amount, $(SD*) \times [dP(SD)/d(SD)]$, the right hand side of (Eq 10). Thus, the loss in benefits resulting from the increase in sedimentation is correctly measured by the increase in averting expenditure required to achieve the desired level of river channel depth, MCRD, which is the equivalent variation measure of consumer welfare change.

However, the observed change in expenditures on averting behavior is not the same thing, since it is a consumer surplus measure of welfare change. The averting expenditure (AE) equals $P(SD) \times (SD*)$, and its change in response to a change in sedimentation rate increase is defined by (Eq 11).

(Eq 11) $d(AE)/d(SD*) = (SD*) \times [dP(SD)/d(SD)] +$

$P(SD) \times [d(SD)/d(SD)]$

$= (SD*) \times [dP(SD)/d(SD)] + P(SD)$

There are two terms on the right hand side of (Eq 11). The first is equal to the equivalent variation measure of consumer's willingness to accept the increase in sedimentation rate. Therefore, the change in averting expenditure(-d(AE)/d(SD*) is larger than the equivalent variation measure of willingness to accept [d(Y)/d(SD) in (Eq 10)] since P(SD) is always greater than zero. Thus, if sedimentation increases, the consumer surplus measure of welfare change, is an upper bound for the equivalent variation measure of willingness to accept. The averting expenditure will be a lower bound if the willingness to accept follows the compensating variation definition.

Average Annual Dredging Cost

Dredges are defined as earth moving machines specialized to drag up or clear earth from a channel, making it deeper or wider. Nearly all existing dredges may generally be divided into two basic categories; namely, mechanical and hydraulic. Mechanical dredges lift the dredged materials by means of buckets while hydraulic dredges lift with pump. Mechanical dredges normally lift material and deposit it on a conveyance for transportation and disposal. They therefore, perform only a part of the total functions which are performed by hydraulic dredges. Channel maintenance in the Lower-upper Mississippi River is normally accomplished with the dredge William A. Thompson, a 20-inch hydraulic cutterhead hydraulic dredge, and the Derrickbarge Hauser, a 4-cubic yard barge mounted clamshell mechanical dredge. During the GREAT I study, two major additions were made to the St. Paul District Channel maintenance floating fleet. The first was a 20-inch booster dredge, the Mullen, which has been added to the dredge William A. Thompson to increase the production rate when the transportation distance of the dredged material is over 6,500 feet. The second was the 12-inch hydraulic dredge Dubuque, which was acquired for use on the smaller channel maintenance sites. In addition, a 16-inch hydraulic cutterhead dredge(the Robers), the barge mounted backhoe dredge, and the bucket chain dredge are included as alternatives. Since there are two different horse-power ratings in each mechanical dredge category, there are a total of nine different dredge plants considered:(1). A 20-inch hydraulic cutterhead dredge(the Thompson). (2). A 16-inch hydraulic cutterhead dredge(the Robers). (3). A 12-inch hydraulic cutterhead dredge(the Dubuque). (4). A barge mounted backhoe dredge, 250 H.P. (5). A barge mounted backhoe dredge, 800 H.P. (6). A barge mounted clamshell dredge(Hauser), 250 H.P. (7). A barge mounted clamshell dredge(Hauser), 800 H.P. (8). A bucket chain dredge, 250 H.P. (9). A bucket chain dredge, 800 H.P.

The appropriate method for dredging depends on the placement site, whether it is on shore or in open water, and the distance from the dredging cut to the site. The placement site is all important in dredging. If the dredging is to be done, the placement site must be acceptable to everyone. Once a placement site is selected, one can talk about dredging technology and dredging method (Kreh 1980).

The primary recommended placement site for each dredging cut in each pool, and the distance between the site and dredging cut are presented in Table 2. Once the dredged material placement site is selected for a specific dredging cut, the lowest costs dredging method is determined. The dredging costs for various hydraulic and mechanical dredges are plotted against different transportation distance to placement site and presented in Figure 3.[7] Comparing the average dredging costs among the three hydraulic and six mechanical dredges, one can conclude the following principles for selecting the most cost effective dredging method:

(a). When the transportation distance to the dredged material placement site is less than 7,200 feet, hydraulic dredges cost less than mechanical dredges. In addition, the 20-inch William A. Thompson dominates all hydraulic dredges.

(b). The most cost effective dredging method when transportation distance to placement site is over 7,200 feet but less than 16,500 feet is the 800 H.P. barge mounted backhoe dredge.[8]

(c). If the transportation distance to the placement site is in between 16,500 feet and 29,577 feet, the most effective dredging method is the 250 H.P. bucket chain dredge.

When the selected dredging method is a hydraulic one, then there may be additional costs related to the placement site. These extra costs include diking, berming, and riprapping costs. In addition, if the placement site is not public owned, the land acquisition cost should also be counted as a part of total dredging costs. Other cost include seasonal removal costs if the capacity of the placement site is not large enough, or is only temporary, and some special construction cost if the site needs to be prepared for retention of dredged materials. Table 2 shows the cost of berming, diking, riprapping, special construction, seasonal removal and land acquisition for each of the placement site.

The estimated average annual dredging costs for each dredging cut shows that dredging cut No. 5 within the lower Pool No. 4 has the largest average annual dredging volume and cost($179,470).[9, 10] In terms of the total annual dredging costs for the entire pool, the lower Pool No. 4($748,469.87) has the highest annual channel maintenance cost while Pool No. 5A has the lowest costs($296,610).

<u>External Damage Cost Functions</u>

External damage functions are determined from the average annual dredging volumes and the average annual dredging costs in each pool. The following six equations

Table 2
Estimated Average Annual Dredging Costs

Pool	Dredge Cut	Placement Site	DTPS* (ft)	Selected Dredging Plant	Average Cu Yd Cost	Volume Per Dredge	Total Dredging Cost	Berming Cost
Pool No. 4, Lower								
4	1	4.02	1,320	20-inch	$3.82	14,700	$56,154	$4,383
4	2	4.02	11,880	800 H.P. Backhoe	6.22	37,300	232,006	-----
4	3	4.02	19,800	800 H.P. Bucket C.	6.65	32,400	215,460	-----
4	4	4.25	11,616	800 H.P. Backhoe	6.22	28,600	177,892	-----
4	5	4.24	9,504	800 H.P. Backhoe	6.22	87,100	541,762	-----
Pool No. 4, Upper								
4	6	4.37	3,168	20-inch	4.63	68,500	317,155	22,981
4	7	4.49	528	20-inch	3.82	39,600	151,272	8,766
4	8	4.57	5,280	20-inch	5.40	21,400	115,560	-----
4	9	4.57	3,960	20-inch	4.63	53,400	247,242	10,227
4	10	4.63	1,584	20-inch	3.82	44,800	171,136	10,227
4	11	4.57	20,856	800 H.P. Backhoe	6.65	23,400	155,610	-----
Pool No. 5								
5	1	5.30	17,424	800 H.P. Bucket C.	6.65	22,800	151,620	-----
5	2	5.30	7,656	800 H.P. Backhoe	6.22	27,700	172,294	-----
5	3	5.30	1,848	20-inch	3.82	21,700	82,894	5,844
5	4	5.30	3,696	20-inch	4.63	25,800	119,454	10,227
5	5	5.26T	25,344	250 H.P. Bucket C.	7.95	14,700	116,865	-----
5	6	5.26T	18,484	800 H.P. Bucket C.	6.65	39,800	264,670	-----
5	7	5.26T	11,088	800 H.P. Backhoe	6.22	35,800	222,676	-----
5	8	5.26T	7,920	800 H.P. Backhoe	6.22	8,800	54,736	2,922
Pool No. 5A								
5A	1	5A.32	15,840	800 H.P. Backhoe	6.22	45,200	281,144	11,688
5A	2	5A.32	8,448	800 H.P. Backhoe	6.22	21,600	134,352	-----
5A	3	5A.32	0	20-inch	3.82	32,900	125,678	8,766
5A	4	5A.25	8,712	800 H.P. Backhoe	6.22	34,000	211,480	-----
5A	5	5A.23	15,312	800 H.P. Backhoe	6.22	36,200	225,164	-----
5A	6	5A.23	2,112	20-inch	4.17	24,800	103,416	5,844

Table 2
Estimated Average Annual Dredging Costs
(Continued)

Pool	Dredge Cut	Placement Site	DTPS* (ft)	Selected Dredging Plant	Average Cu Yd Cost	Volume Per Dredge	Total Dredging Cost	Berming Cost
<u>Pool</u>	<u>No.</u> <u>6</u>							
6	1	6.17	15,840	800 H.P. Backhoe	$6.22	22,700	$141,194	$7,305
6	2	6.17	7,392	800 H.P. Backhoe	6.22	13,300	82,726	13,150
6	3	6.17	1,848	20-inch	3.82	36,200	138,284	11,688
6	4	6.19	2,376	20-inch	4.17	21,400	89,238	4,383
6	5	6.27	1,320	20-inch Backhoe	3.82	8,100	30,942	21,911
6	6	6.27	10,032	800 H.P. Backhoe	6.22	8,100	50,382	-----
<u>Pool</u>	<u>No.</u> <u>7</u>							
7	1	7.20T	5,280	20-inch	5.40	35,400	191,160	5,844
7	2	7.20T	10,824	800 H.P. Backhoe	6.22	35,800	222,676	-----
7	3	7.06	41,184	800 H.P. Clamshell	8.29	20,800	172,432	-----
7	4	7.06	30,888	800 H.P. Clamshell	8.29	29,200	242,068	-----
7	5	7.06	19,536	800 H.P. Bucket C.	6.65	21,400	142,310	-----
7	6	7.05	7,128	800 H.P. Backhoe	6.22	46,600	289,852	-----
7	7	7.06	264	20-inch	3.82	23,400	89,388	2,922
<u>Pool</u>	<u>No.</u> <u>8</u>							
8	1	8.22	9,768	800 H.P. Backhoe	6.22	20,800	129,376	-----
8	2	8.22	2,904	20-inch	4.17	22,800	95,076	-----
8	3	8.30T	7,656	800 H.P. Backhoe	6.22	39,000	242,580	-----
8	4	8.30T	2,376	20-inch	4.17	50,000	208,500	14,611
8	5	8.30T	2,904	20-inch	5.40	29,800	160,920	7,305
8	6	8.06	29,832	250 H.P. Bucket C.	7.95	37,700	299,715	-----
8	7	8.06	23,232	250 H.P. Bucket C.	7.95	35,200	279,840	-----
8	8	8.06	17,160	800 H.P. Bucket C.	6.65	28,400	188,860	-----
8	9	8.06	7,128	800 H.P. Backhoe	6.22	21,400	133,108	-----
8	10	8.28	0	20-inch	3.82	28,000	106,960	5,844

Table 2
Estimated Average Annual Dredging Costs
(Continued)

Pool	Dredge Cut	Diking Cost	Rip-rapping Cost	Special Const. Cost	Land Acqu. Cost	Job+ Longevity (years)	Average Annual Dredging Volume	Average Annual Dredging Cost
Pool No. 4, Lower								
4	1	$11,688	-----	-----	-----	2.5	5,880	$28,890
4	2	-----	-----	-----	-----	2.9	13,056	81,206
4	3	-----	-----	-----	-----	1.3	24,306	161,635
4	4	-----	-----	-----	-----	1.4	20,014	124,487
4	5	-----	-----	-----	-----	1.5	56,632	352,251
Total(Lower Pool No. 4)							119,888	748,469
Pool No. 4, Upper								
4	6	11,491	-----	-----	$10,227	10.0	6,850	36,185
4	7	11,688	$203,087	-----	-----	4.0	9,900	93,704
4	8	-----	62,826	$10,227	-----	10.0	2,140	18,861
4	9	13,150	62,826	17,533	-----	5.0	10,680	70,195
4	10	11,688	200,165	-----	8,766	10.0	4,480	40,198
4	11	-----	62,826	11,688	-----	10.0	2,340	23,012
Total(Upper Pool No. 4)							36,390	282,155
Total Pool No. 4							156,278	1,030,624
Pool No. 5								
5	1	-----	-----	-----	-----	6.7	3,418	22,732
5	2	-----	-----	-----	-----	3.3	8,318	51,740
5	3	10,277	-----	-----	-----	1.7	12,994	59,261
5	4	10,277	-----	-----	-----	1.5	16,775	90,968
5	5	-----	-----	7,305	14,611	1.5	9,558	90,235
5	6	-----	-----	26,299	14,611	2.9	13,931	106,958
5	7	-----	-----	14,611	14,611	4.0	8,950	62,974
5	8	-----	-----	-----	14,611	3.3	2,643	21,702
Total Pool No. 5							76,587	506,570
Pool No. 5A								
5A	1	-----	-----	-----	-----	4.0	11,300	$73,208
5A	2	-----	-----	$8,766	-----	2.9	7,560	50,093
5A	3	$11,688	-----	-----	-----	2.9	11,516	51,149
5A	4	-----	$11,688	-----	$7,350	3.3	10,210	100,802
5A	5	-----	40,910	-----	-----	2.0	18,100	133,036
5A	6	10,227	40,910	-----	-----	20.0	1,240	8,020
Total Pool No. 5A							59,926	416,308

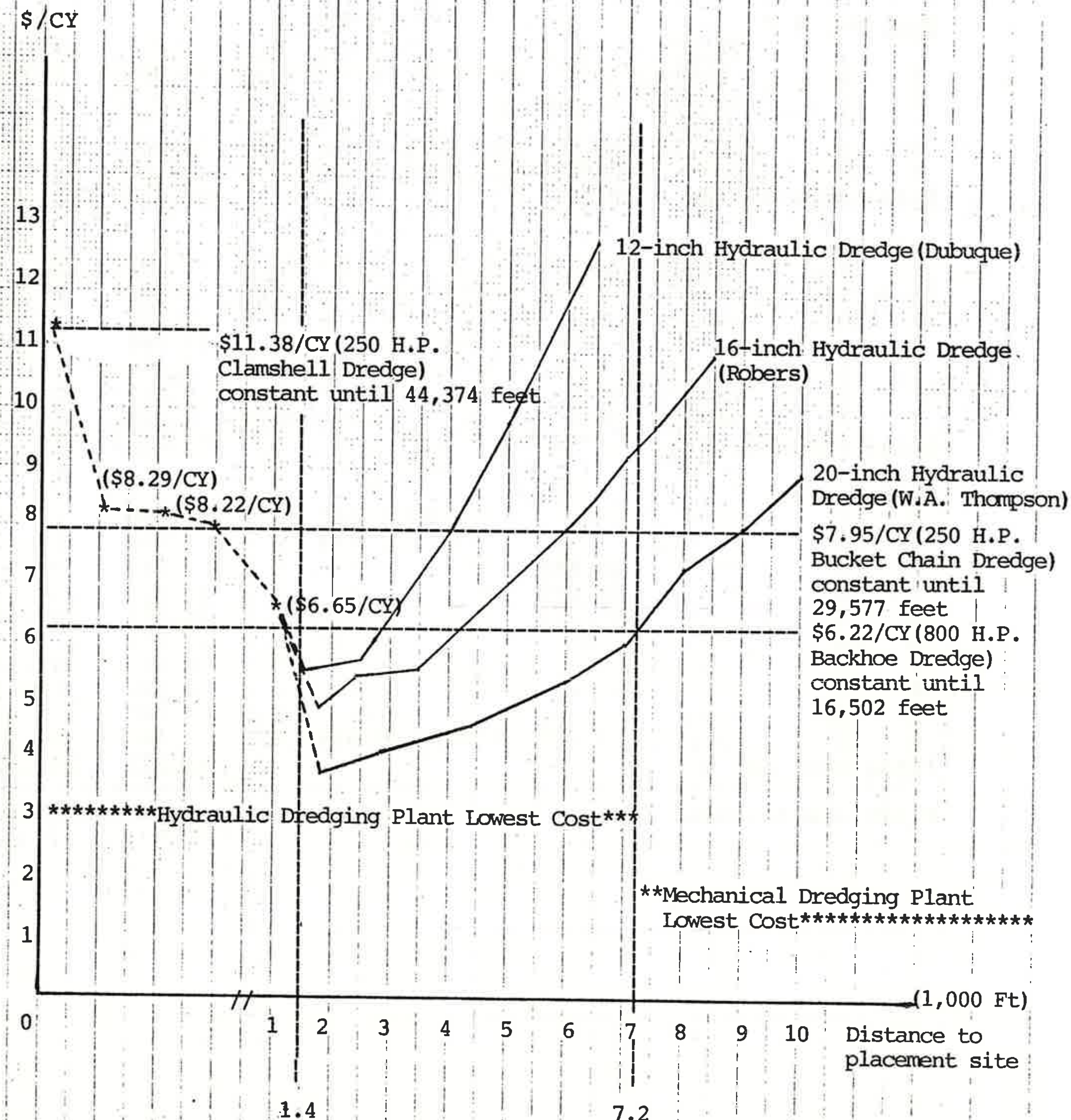
+Job longevity is defined as the number of years which additional dredging for a specific dredging cut is necessary.

Table 2
Estimated Average Annual Dredging Costs
(Continued)

Pool	Dredge Cut	Diking Cost	Rip-rapping Cost	Special Const. Cost	Land Acqu. Cost	Job Longevity (years)	Average Annual Dredging Volume	Average Annual Dredging Cost
Pool No. 6								
6	1	$7,305	-----	-----	-----	3.3	6,817	$47,213
6	2	5,844	-----	-----	-----	6.7	1,994	15,250
6	3	11,688	-----	-----	-----	3.3	10,871	47,231
6	4	10,227	-----	-----	-----	5.0	4,280	20,770
6	5	21,916	$40,910	$27,760*	-----	3.3	2,432	37,372
6	6	-----	40,910	27,760*	-----	2.5	3,240	47,621
Total Pool No. 6							29,634	215,457
Pool No. 7								
7	1	11,688	-----	-----	-----	10.0	3,540	20,869
7	2	-----	-----	-----	-----	4.0	8,950	55,669
7	3	-----	-----	-----	-----	2.2	9,369	77,672
7	4	-----	-----	-----	-----	2.5	11,680	96,827
7	5	-----	-----	-----	-----	10.0	2,140	14,231
7	6	-----	-----	-----	-----	2.9	16,311	101,453
7	7	10,277	-----	-----	-----	10.0	2,340	10,254
Total Pool No. 7							54,330	376,975
Pool No. 8								
8	1	-----	-----	-----	$111,041	20.0	1,040	12,021
8	2	-----	-----	-----	111,041	20.0	1,140	10,306
8	3	-----	56,981	-----	-----	6.7	5,847	44,912
8	4	-----	56,981	-----	-----	2.0	25,000	146,621
8	5	-----	56,981	-----	-----	1.8	16,374	130,162
8	6	-----	-----	-----	-----	1.7	22,575	179,470
8	7	-----	-----	-----	-----	6.7	5,277	41,955
8	8	-----	-----	-----	-----	10.0	2,840	18,886
8	9	-----	-----	-----	-----	5.0	4,280	26,622
8	10	10,227	374,032	7,305	18,994	4.0	7,000	130,841
Total Pool No. 8							91,373	741,796

*Indicate seasonal removal costs, not special construction cost.

Figure 3
Cubic Yard Dredging Cost Comparison
among Various Mechanical and Hydraulic Dredges



were estimated for Pools 4 through 8.

(Eq 12) $(DC) = 25579.716+2.6502678(VDM)+0.0000686(VDM^{2})$

(Eq 13) $(DC) = 19295.709 \times \mathrm{Exp}(0.0001093971\ VDM)$

(Eq 14) $(DC) = 8305.4078+2.8758795(VDM)+0.000249(VDM^{2})$

(Eq 15) $LN(DC) = 12706.755 \times \mathrm{Exp}(0.00013769\ VDM + 0.8094478\ DV)$ [11]

(Eq 16) $(DC) = 7562.9234+2.881462(VDM)+0.00027445(VDM^{2})$

(Eq 17) $(DC) = 17597.349+3.283956(VDM)+0.00015321(VDM^{2})$

Where DC_i : Dredging cost for the ith pool.
VDM : Volume of the dredged material(cu yds).
i : Pool 4, 5, 5A, 6, 7, and 8.

The estimated annual total dredging cost functions can be interpreated as the total external or social cost curves. However, when applying these dredging cost relationships, the following limitations should be considered. First, because the sediment from any specific upland source are seldom fully trapped within one pool, the sediment dredging costs for each pool should be combined together to estimate the full external damage costs from soil erosion. For example, an upland crop production area (A) contributes totally (B) cu yds of sediments to Pool No. 4, but some will be carried to the downstream pools. Assume that the portion of the trapped sediments within each pool requiring dredging activity is (C%), and the transportation capabilities of sediment from one pool to the next are the same for each pool and is (D%). The average annual total external damage costs imposed on the Mississippi River by upland area (A) is the following:

```
(Eq 18) (DC)  =  [(1-(D%))x(C%)x(B)] of (Eq 12) +
                 [(1-(D%))x(D%)x(C%)x(B)] of (Eq 13) +
                 [(1-(D%))x(D%)**2x(C%)x(B)] of (Eq 14) +
                 [(1-(D%))x(D%)**3x(C%)x(B)] of (Eq 15) +
                 [(1-(D%))x(D%)**4x(C%)x(B)] of (Eq 16) +
                 [(1-(D%))x(D%)**5x(C%)x(B)] of (Eq 17)
```

If the portion of the sediment that enters Pool 9 is relatively small, (Eq 18) provides a good measure of the external damage costs from a specific upland crop production area. However, empirical application of the equation is impossible without a sediment budget model.

Second, economic values from beneficial uses of dredged materials represent an offset to the external damage costs from soil erosion. Therefore, the net external (social) effects from erosion in terms of the dredging costs should be adjusted by the benefits from demand for dredged materials.

External Benefits from Dredged Materials

In general, dredged material is a valuable resource which can be economically used for land fill, highway ice control, and blending sand in asphalt. After proper cleaning and modification of the dredged material placement site, it can be used as bare sand along the Mississippi River that is attractive to recreational boaters for camping and picnicking. If all demands for dredged material were satisfied, it is probable that all dredged material would be used beneficially(U.S. Corps of

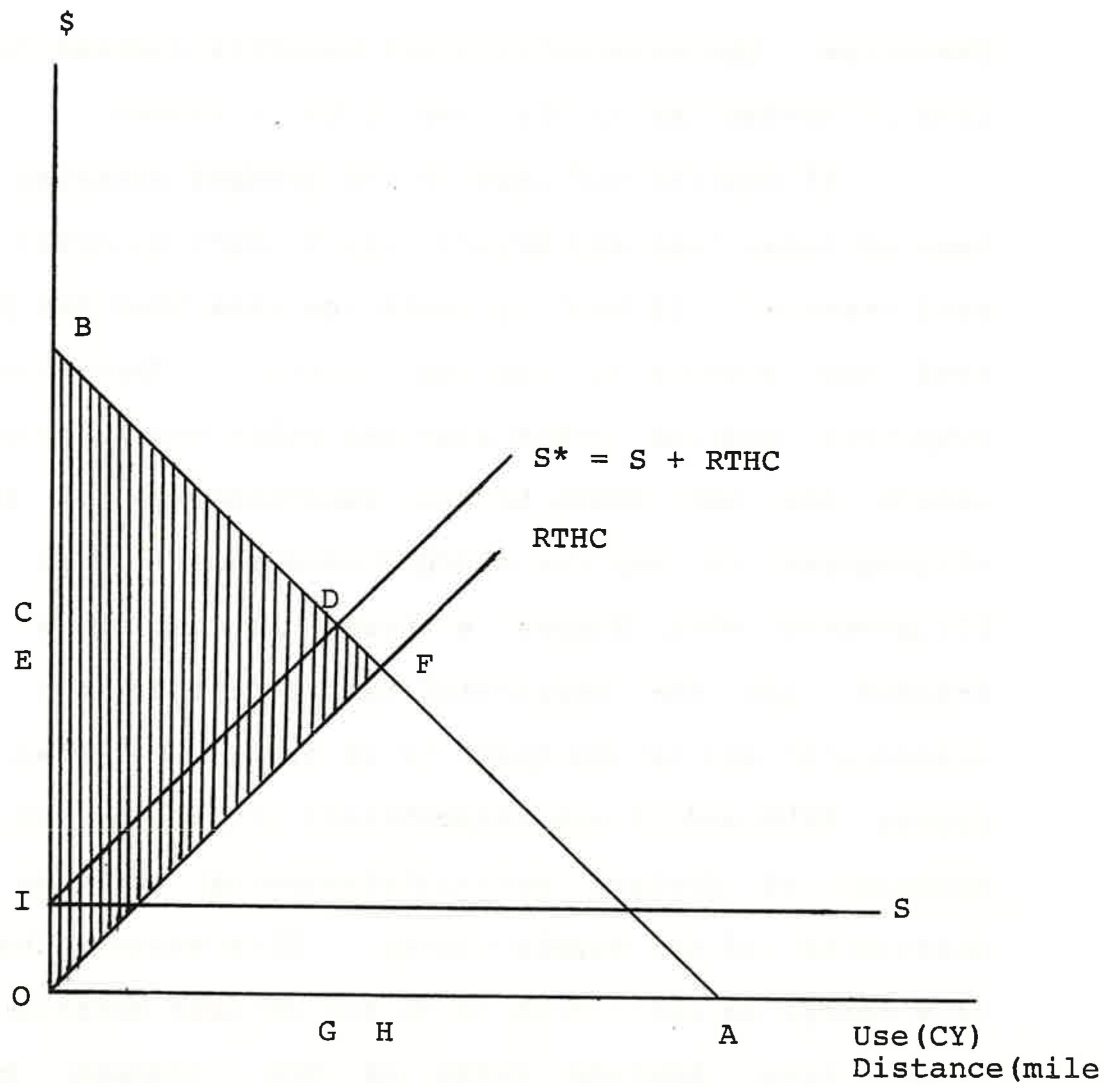
Engineers, 1980).

The dredged materials are presently provided by the Corps of Engineers free of charge to users along the river. However, the value of these dredged materials is not known. Therefore, the external(social) benefits derived from the uses of dredged materials have to be estimated.

if quality and uses of the dredged material are the same as other sand and gravel, the dredged material will be used(demanded) if hauling costs are less than the price of sand and associated hauling costs. Therefore, the roundtrip hauling costs plus any other costs incurred to obtain the sand shall be good approximation of people's willingness to pay for dredged materials. This can be illustrated with Figure 4 where vertical axis is the price($) and the horizontal axis is either the hauling distance(miles) or the quantity of dredged material(cu yd). Curves AFDB and IS are respectively the demand and supply schdules of dredged materials(assuming infinite price elasticity of the supply curve). This assumes that there is a charge or extra cost of OI for dredged material. The round trip hauling costs of the dredged material represented by curve RTHC, are a function of distance(mile) when hauling volume is below a certain limit(in this case 5,000 cu yd).[12] Thus the supply curve including the round trip hauling costs is represented by S*.

Since the dredged materials are free of charge and

Figure 4
Hauling Cost as an Approximation
of Willingness to Pay for Dredged Materials



the users of the dredged sand are both "consumers" and "producers"(hauling the sand themselves), the total social surplus from the free disposal of the dredged material is represented by shaded area of OFB. Limited by available data, we only observe one point, F, on the demand and the RTHC curve, the rectangle area of OHFE is used to approximate the total social surplus(OFB) of the dredged material. The OHFE is the average round trip hauling cost(HF or OE) of the dredged material multiplied by total demand(OH).

Before using hauling costs as a measure for the value of dredged materials, one has to validate the conditions within the Upper Mississippi River against the proposed assumptions. Thus, the following three questions must be addressed:

(1). Is there a quality or use difference between dredged materials and sand sold by gravel companies.

(2). Can the Corps of Engineers be held liable if private sand and gravel suppliers suffer adverse effects resulting from the free deposition of dredged materials?

(3). How does the Corps of Engineers currently handle the dredged materials?

Previous studies suggest that dredged sand is a good substitute for most sand sold by gravel companies. The answer to the second question is somewhat less clear (Stewart, 1978). Yet it appears unlikely that the Corps would be liable if the dredged materials were sold by bid. Private sand producers could then bid on the material and would use it as long as the cost was lower than their other sources of supply.

Currently, the Corps of Engineers is only responsible for the dredging activity and placement site maintenance. However, the State Governments of Minnesota, Wisconsin, and Iowa all charge the user a royalty for sand and gravel removed by private enterprise. If the Corps sold the material to a profit making body within Wisconsin or Minnesota, the user may be required to pay a royalty. The reason for the charge is that the river bottom is the property of the state. Iowa does not charge the royalty when the dredged material is removed by the Corps, regardless of the use to which the Corps puts it(Stewart, 1978). Most of the current surveyed potential users of dredged materials are public agencies and there is no royalty charge(Marx and Kennedy, 1980). Thus the roundtrip hauling cost of the dredged materials appears to be a good measure of the value of external benefits from sediment.

<u>Valuing Dredged Material by Hauling Costs</u>

The maximum distance users would be willing to travel to pick up dredged materials ranges from 2 to 20 miles(Table 3). Data concerning the costs for trucking dredged material indicates that the relationship between hauling distance and average hauling cost is almost linear

Table 3
Price of Sand and Distance Traveled for Dredged Material

Pool	Range of market prices for sand	Average Price of sand	Distance willing to travel to obtain dredged material
	($/CY in 1985 price)		(miles)
4-Upper	1.50 - 2.91	2.21	3 - 20
4-Lower	0.79 - 2.76	1.78	3 - 20
4-Total	0.79 - 2.91	1.85	3 - 20
5	0.79 - 1.97	1.38	2 - 20
5A	0.79 - 1.97	1.38	2 - 20
6	0.24 - 3.15	1.70	2 - 20
7	1.57 - 2.76	2.17	3 - 20
8	0.47 - 5.90	3.19	3 - 20

Source: Recalculated from GREAT I, Study of the Upper Mississippi River, Technical Appendixes, Volume 2, (B)Dredged Material Uses, Table 5, Page 22.

(Wen 1986). The results from a regression analysis of average hauling cost on round trip trucking distance are shown in (Eq 19). At the average trucking distance of 12.20 miles, the average hauling cost(willingness to pay) for dredged material is $3.87 per cu yd in the 1985 prices. [13]

(Eq 19) (TC) = 3.000169 + 0.07098545 (RTD)
(248.02) (76.42)
df = 29, (R**2) = 0.9951

$$(TC) = 3.000169 + 0.07098545\,(RTD)$$

Where (TC) : Average cu yd trucking cost in 1985 prices.
(RTD) : Round trip distance for hauling the dredged material in miles.

Combining the dredging cost data with the average willingness to pay for the dredged materials($3.87/CY), the average annual net off-site damage costs can be estimated (Table 4). As indicated in Table 4, the dredging costs caused by sedimentation in the Mississippi River main channel are large relative to the value of the dredged materials except in the Pool No. 6. However, omitting external benefits would overstate the off-site negative impact from erosion especially in the Pools No. 4, 6, and 8. Only in the Pool No. 7 are the benefits relatively insiginificant.

Conclusions

Two conclusions can be reached from the empirical estimates of off-site erosion impacts on the Lower-upper Mississippi River. (1). Both off-site damage costs

Table 4
The Average Annual Off-site Damage Costs
and Benefits on the Lower-upper Mississippi River

Pool	Dredging Volume	Dredging Cost	Total* Demand	Total** Value	Net Off-site Damage Cost
	CY	$	CY	$	$
4	156,278.00	1,030,624.00	39,675	153,542.00	877,082.00
5	76,587.00	506,570.00	14,575	56,405.00	450,165.00
5A	59,926.00	416,308.00	14,120	54,644.00	361,664.00
6	29,634.00	215,457.00	37,650	145,706.00	69,751.00
7	54,330.00	376,975.00	3,093	11,968.00	365,007.00
8	91,373.00	741,796.00	70,525	272,932.00	468,864.00

Note: *Data on beneficial demand for dredged material are calculated from the <u>GREAT I, Study of the Upper Mississippi River, Technical Appendixes, Vol. 2, (B) Dredged Material Uses, Attachement 5</u>. Prepared by Terry W. Marx and David M. Kennedy, 1980, Wisconsin Department of Natural Resources, La Cross, Wisconsin.
**$3.87 per cubic yard.
Other data are from Table 2.

and benefits are significant within the study area. The existence of huge demand for the dredged materials suggest that substantial external benefits are potentially associated with off-site averting behaviors related to dredging activities. Examples are sedimentation removal from reservoirs, draniage ditches, navigation channels, road sides, water ponds, and floodplains. (2). The demand situations and the associated downstream impacts are not the same across all places where eroded soil is deposited. Therefore, different upstream cropland areas with the same soil erosion rates can result in quite different off-site damage costs and benefits.

Two major policy issues can be raised concerning the recently revised USDA erosion control programs which require conservation efforts to be targeted on highly erodible cropland(USDA, ERS 1986). First, serious off-site damage costs do not necessarily resulted from highly erosive cropland. Similarly, owing to high delivery ratios, and valuable downstream services and products provided by the affected river basin, relatively high off-site damage costs might accrue from less erosive cropland. Thus, major erosion problems will still exist even if conservation efferts are solely targeted on highly erodible cropland. Second, if soil conservation efforts are to be targeted on cropland with significant external impacts, results from a lump sum type off-site damage cost study cannot precisely identify those upland areas where conservation efforts are the most needed. For example, sediment sources in the Lower-upper Mississippi River study area include cropland areas from both southeast Minnesota and western Wisconsin, upstream areas beyond the lock and dam system, stream bank erosion, and erosion from other land uses(pasture, forest, and open land).

Research concerning the complete sediment routing process including the erosion rates, delivery ratio, sedimentation rates, and transportation capabilities of the river is nonexistent. In addition, the few available estimates of the external costs of erosion(e.g. USDA, ERS, 1986, Clark II et al., 1985, and Taylor et al., 1979) are highly imperfect with respect to the results they presented and the underlined economic theory. In addition, a bridge is needed between off-site damage cost estimations and the sources of sediment. One such bridge is the sediment budget model. Only when a sediment budget model, which describes quantatively origins, destinations, and rates of sediment movement, is available can one reliably estimate the relative importance of different sediment sources, identify critical erosion areas, attribute downstream damage costs to origins, and effectively target soil conservation programs. Finally, more research should focus on valuation methods and attempts made to estimate the other external impacts illustrated in Figure 2.

Footnote

[1]. A detail discussion of various off-farm impacts from soil erosion can be found in Clark II, Edwin H., Jennefer A. Haverkamp, and William Chapman, 1985, Eroding Soils:The Off-farm Impacts, The Conservation Fundation/Washington, D.C.

[2]. The particles in a mass of soil can be divided into three different size group:(1). 0.062 millimeters(mm) to 2.0 mm in diameter(sand), (2). 0.002 mm to o.o62 mm(silt), and (3). less than 0.002 mm(clay).

[3]. Assume that all the sediments are fully trapped in the Pool No. 8, or equivalently, the transportation capability of Pool No. 8 is zero.

[4]. P(DV) the average dredging cost function measured in $/CY, is an increasing function associated with dredging volume. i.e. $d[P(DV)]/d(DV) > 0$. In this case, as the MCRD < MCRD*, P(DV) is both the demand and supply functions of the dredging volume requirements.

[5]. This is equivalent to hold the utility constant at the level it was before the increase in sedimentation rate.

[6]. Same as Footnote [4], P(SD) = P(DV).

[7]. The average dredging costs for the mechanical dredges include three cost items:(a). dredging plant operating cost, (b). costs for 1-1,000 H.P towboat and 4-175 cu yd barges per tow, and (3). the unloading dredging plant which is a 800 H.P. backhoe dredge.

[8]. The distance to the dredged material placement site is held constant for each mechanical dredge, and determined based on the following assumptions concerning the dredged material transportation procedures:(for detail discussion, see Wen, 1986, Chapter VI).

(a). Two sets of 4-175 cubic yard dump scow barges. One set is anchored at dredging cut place, and the other set is anchored at the placement site.

(b). 1000 H.P. towboat with 4-175 cubic yard barges per tow. The speed of the 1000 H.P. towboat with 4-175 cubic yard barges per tow is 400 feet per minute which is the same as the speed of towboat without towing any barge.

(c). For the 800 H.P. barge mounted backhoe dredge with hourly production rate of 509 CY, it takes about 82.5 minutes (4x(175)/509=1.375 hours=82.5 minutes) to load the 4-175 cubic yard barges.

(d). The farthest placement site the towboat can reach within 82.5 minutes round trip time(time takes to load next 4-175 cubic yard barges) is 16,500 feet[400 x (82.5/2) = 16,500 feet].

[9]. For detail calculation procedures, see Wen, 1986, Chapter VI.

[10]. Pool No. 4, the longest pool along the lower portion of the Upper Mississippi River lock & dam system, starts at river mile 752.7(Lock & Dam No. 4) and ends at river mile 796.9(Lock & Dam No. 3). From RM 765 to RM 796.9 is Lake

Pepin usually called lower Pool No. 4, and the water area between RM 752.7 and RM 765 is called the upper Pool No. 4.

[11]. Because of the extremely high riprapping costs on cuts 5 and 6 in Pool No. 6, we add the dummy variable(DV) to the regression, i.e. DV = 0 for cuts 1, 2, 3, and 4, and DV = 1 for cuts 5, 6.

[12]. See Wen, 1986, Table (VI-11) in Chapter VI.

[13]. See Wen, 1986, Chapter VI.

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