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ECONOMIC CONSIDERATIONS OF A CONTINENTAL SEDIMENT-MONITORING PROGRAM

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ABSTRACT

Coordinated sediment monitoring for North America is proposed to identify continental-scale sediment yields, fluxes of sorbed contaminants, and trends in the fluxes of sediment and sorbed loads. The program is designed to monitor storage of nonpoint-source pollutants in bottomlands. Canada, the United States, and Mexico presently conduct limited-scope sediment monitoring, but because their programs emphasize specific, local problems, are not coordinated, and lack network design and objectives, they are inadequate to identify and address damage due to large-scale sediment discharges. The program advocated here incorporates continental-scale integrated objectives and management strategies for effective data collection and analysis. Physical, chemical, and biological sediment damage in North America may exceed $\$16 \times 10^9$ annually. In comparison, the annual cost of the proposed monitoring is estimated to be $\$4 \times 10^6$. If information derived from a monitoring program leads to efforts for abatement using multiobjective decision-support technology, results may be reductions in nonpoint-source pollution and overall social costs. A 1% reduction in sediment-related damage would exceed the cost of the proposed monitoring program by as much as 40 times.

Key Words: *Nonpoint-source pollution*, *Economics*, *Sediment monitoring*, *Sediment damages*

1 INTRODUCTION

The accelerated release of sediment from soil and rock surfaces and its movement to, through, and from streams is the most pervasive and costly form of water pollution in North America. Altered erosion of the land surface, especially by man-induced disturbance, is a highly diffuse form of nonpoint-source pollution that is poorly recognized by the public, arduous to measure and document, and linked to environmental degradation and economic loss in ways that are difficult to evaluate. Although costs to society of accelerated nonpoint – source pollution are high, lack of monitoring data that allow evaluation of control actions has diminished the effectiveness of meaningful control policies (U. S. General Accounting Office, 1990). At continental and decadal scales, economic impacts of fluvial sediment due to possible global climate change are receiving cursory attention, in part because short-period time-series contaminant-transport data are insufficient to distinguish large-scale and especially long – term changes. Thus, governmental reaction to sediment movement and attempts to diminish its costs to society have been limited compared to other forms of pollution more easily recognized and treated. Despite the uncertainties, loads of

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water-borne sediment and associated contaminants can be evaluated using appropriate strategies for data collection and analysis. Such strategies, summarized in "A sediment monitoring program for North America", were proposed by Osterkamp and others (1992). The program was designed to define the physical characteristics and transport rates of fluvial sediment, and to assess hazards to humans and other biota by sediment and sorbed contaminants. The purpose of this paper is to demonstrate that the potential monetary benefits of a North American sediment-monitoring program far exceed the costs of establishing and maintaining the program.

The sediment-monitoring program proposed for North America includes a primary set of sampling stations at 145 previously-established sites for hydrometric and water-quality data collection, supplementary sediment monitoring at an undetermined number of stations having specific or unique objectives, and the use of existing data to enhance the sediment-monitoring efforts (Osterkamp and others, 1992). Program objectives are to identify (1) continental-scale sediment yields, (2) fluxes of sorbed contaminants, and (3) trends in sediment and sorbed-contaminant loads, discharges, and magnitudes of bottomland storage due to induced and natural changes in representative watersheds. The proposal includes (1) a monitoring design consistent with the needs and resources of the various countries, (2) data-collection technologies yielding high-quality, low-cost information, (3) integrated continental-scale planning and assessment to assure that data are adequate to meet program needs, (4) compatible standards among nations for equipment, equipment use, and procedures for sampling, analysis, and data reduction, and (5) a systematic management approach among the various countries (Osterkamp and others, 1992).

Meade and others (1990) estimate the average annual discharge of sediment to the North American coasts to be 600×10^6 (metric) tons. A compilation for average-annual sediment discharge from the United States (Curtis and others, 1973) provided a similar estimate. An estimated average of 600×10^7 tons of sediment, however, is released annually as erosion products from North America; thus, approximately 90 percent of the fluvial sediment mobilized each year is deposited on hillslopes, in bottomlands, and in lakes and reservoirs (Meade and Parker, 1985).

Economic loss owing to the alteration of erosion rates and accelerated movement of sediment is difficult to evaluate and is subject to interpretation, but this difficulty does not diminish accelerated erosion as a problem of continental scale. The movement of fluvial sediment from erosion sites to the continental shelf represents a problem with high societal costs. Among these costs are soil loss and reduced productivity in agricultural areas, the need for treating municipal and industrial water supplies, siltation in irrigation systems and navigation lanes, reduced aesthetic value of streams, and adverse effects on biota. The detrimental effects of the much larger component of erosion products that is redeposited, however, may be vast. Many toxic materials that enter stream systems are tightly bound to clay, silt, and organic matter. When sediment is stored, the sorbed toxins, including some nutrients, agricultural chemicals, industrial wastes, metals from mine spoils and other sources, and radionuclides, are also stored and become available for assimilation.

Suspended-sediment samples are collected from numerous stream-gage sites in North America. Generally, the purpose of sediment sampling is to develop continuous-load data or sediment-transport curves from which sediment yields can be calculated. In the United States, about 120 stream sites are sampled daily by the U.S. Geological Survey to give a continuous record of suspended-sediment discharge. Most sediment sampling, however, whether daily or periodic (less frequently than daily, such as weekly or monthly), yields estimates of sediment discharge but not of sorbed-chemical loads. Sampling sites are operated for a variety of purposes, and thus do not collectively have network structure or design. Federal funding for measurement of bedload, which may account for one-half or more of the total sediment load in some streams (W. W. Emmett, U. S. Geological Survey, personal commun., 1990), is not available for United States sampling sites.

Most sediment-data collection in Canada is not within a network framework, but generally is conducted for specific engineering purposes or trend analysis. Environment Canada operates about 250 sampling sites and retains records from about 600 discontinued sites (Day, 1991). Few bedload data are available for Canadian streams.

Numerous streamflow gages are operated in Mexico, many of which are sampling sites for water quality and sediment. Most of the sediment stations provide data pertinent to population centers and engineering projects.

2 ESTIMATES OF MEAN SEDIMENT DISCHARGE, NORTH AMERICA

Erosion and sediment discharge vary complexly with climate, vegetation, topography, geology and soils, and land and water use. To illustrate the complexity and to emphasize the need for systematic data collection if nonpoint-source pollution is to be quantified, Table 1 summarizes erosion data, as suspended-sediment discharges (in metric tons per year) to the oceans, and as sediment yields, the sediment discharges per unit area passing a point on the stream (in metric tons per square kilometer per year), for various parts or watersheds of North America. Most sediment-discharge estimates in Table 1 reflect only movement from North America, about a tenth of the sediment released as erosion products; water-entrained sediment expressed as a yield at a point, however, may be redeposited downslope or downchannel as part of the estimated 90 percent of erosion products that does not reach the oceans. Except as indicated, the data of Table 1 largely reflect conditions after 1960.

Table 1 Estimates of mean sediment discharges and yields for selected drainage basins and areas of North America

Basin or Area	Area (10^6 km^2)	Sediment discharge (10^6/t/yr)	Sediment yield (t/km^2/yr)
U. S. streams to Atlantic Ocean[a]	0.744	12.9	17.3
U. S. streams to Gulf of Mexico[a]	4.50	343	76.2
U. S. streams to Pacific Ocean[a]	1.64	89.9	54.8
Forested watersheds, eastern U. S.[b]	--	--	11
Forested watersheds, western U. S.[c]	--	--	16
Average cropland soil loss, U. S. (1977)[d]	1.7	1900	1100
Mississippi River Basin (ca. 1700)[e]	3.27	400	122
Mississippi River Basin (ca. 1980)[e]	3.27	210	64.2
MacKenzie River Basin[e]	1.81	100	55.2
Colorado River Basin (ca. 1700)[e]	.64	100	160
Colorado River Basin (ca. 1980)[e]	.64	0.1	0.16
Yukon River Basin[e]	.93	60	65
St. Lawrence River Basin[e]	1.3	1.5	1.2

a Modified from Curtis, Culbertson, and Chase (1973)
b Patric (1976)
c J. H. Patric, U. S. Department of Agriculture, written commun., 1983
d Modified from U. S. Soil Conservation Service (1980)
e Modified from Meade and others (1990)

Sediment discharges and yields from the United States are generally least to the Atlantic Ocean, presumably because of the moist climate that favors a stabilizing vegetation cover (Patric, 1976). Owing to agricultural and other land-use disturbances, sediment discharges and yields are highest from the Mississippi River Basin and other watersheds draining to the Gulf of Mexico (table 1). If sediment discharges estimated for pre-European settlement (circa 1700) are considered, corresponding yields in the Gulf and Pacific watersheds were higher than at present (Meade and others, 1990), having approached 120 t/km^2/yr (tons per square kilometer per year)(not listed). A principle cause of the post-1700 reduced sediment yields of streams draining to the Pacific Ocean may be natural storage of sediment as bottomland deposits, reduced sediment transport due to depletion of streamflow, and the storage in reservoirs of the Colorado River Basin of sediment that formerly moved freely to the Gulf of California. Increased erosion owing to agriculture and other land-use practices in basins emptying to the Gulf of Mexico also have been more than offset in recent decades by sediment storage on hillslopes, in bottomlands, and in reservoirs, particularly in western parts of the Mississippi River watershed (Meade and Parker, 1985)(table 1). Sparse vegetation, making soils susceptible to erosion, commonly is considered a cause of high sediment yields in the western United States. Similarly, clearing land of trees and conversion to agriculture is in large part responsible for the nearly 100 – fold difference in mean sediment yields between forested watersheds and croplands of the United States (table 1). Sediment yields for the MacKenzie and Yukon River Basins (table 1) though inaccurately known, are high relative to most other large basins of North America due to erosion by alpine glaciation (Meade and Parker, 1985). The mean sediment yield of the St. Lawrence River Basin is quite low (table 1) owing to erosion-resistant rocks and soils, generally gentle, well-vegetated landscapes, limited land-use disturbance, and substantial storage of sediment in the Great Lakes and other smaller lakes of glacial origin (Meade and others, 1990).

Most discharge estimates in Table 1 are of sediment reaching the oceans, roughly 10 percent of the sediment mobilized each year from upland areas in North America. An exception is the estimate of 1900 x 10^6 t/yr for cropland soil loss in the United States. This estimate accounts for nearly a third of the annual erosion products (and damages) in North America, most of which are redeposited and do not reach the oceans.

Reservoir construction has reduced mean-annual sediment discharge to the oceans by possibly a third, but much of this storage represents sediment released by post-settlement land-use practices. Of the estimated 600×10^7 tons of sediment eroded annually in North America, however, only a small part is stored in reservoirs (Meade and Parker, 1985). At present, the magnitude and distribution of this storage in reservoirs and elsewhere are inaccurately known, but the costs to society are potentially extreme. Among these costs are the effects on agriculture, industry, and municipalities of sediment deposited along rivers, and of sorbed toxic substances stored in bottomlands. Increased knowledge of storage sites and of quantities of the stored erosion products is a principal goal of the North American monitoring proposal. A detailed discussion of terrestrial sediment storage is presented by Walling (1983), and Smith and others (1979) provide evidence that reducing sediment delivery has greater cost effectiveness than does equivalent reduction in soil erosion.

3 COSTS RELATED TO SEDIMENT MOVEMENT AND STORAGE

Damages caused by sediment-related nonpoint-source pollution can be expressed in several categories: (1) direct and indirect costs, (2) agricultural and non – agricultural effects of soil erosion, (3) on-site and off-site effects of erosion, (4) physical, chemical, and biological degradation, and (5) detrimental effects of sediment movement and stored sediment. Direct costs are those resulting directly from an action or process, whereas indirect costs, such as fish poisonings due to herbicide application upstream in a watershed, have a secondary or tertiary relation with the action or process. The terms on-site effect (of erosion) refers to sediment movement at a site of disturbance, such as a cultivated field or a construction site; an off-site effect of erosion occurs at any distance removed from the disturbance. Despite overlap, the five approaches have application depending on the objectives of a study or the perspective of an investigator. To provide social and economic justification for a continental sediment-monitoring program, emphasis is placed on the fourth and fifth categories listed above. Previous analyses of damage due to nonpoint pollution often centered on agricultural/non-agricultural and on-site/off-site effects of erosion. They and the other previously-published damage estimates are summarized in Table 2.

Table 2 lists estimated average-annual costs from physical, chemical, and biological damage due to the movement and storage (deposition) of fluvial sediment, expressed in billions of 1992 United States dollars. The damage estimates are from a range of publications addressing environmental and economic damages by fluvial erosion, sediment transport, and redeposition of the sediment and sorbed contaminants. Most of the estimates are for the United States. Additions to the estimates of 0.092 (9.2 percent) for Canada and 0.051 (5.1 percent) for Mexico, to provide figures for North America, are based on ratios in gross national products and exchange rates between the United States and Canada and Mexico. Adjustments to a common base of 1992 U. S. dollars were made by applying inflators based on the annual consumer-price index to those damages identified as costs to society, and on the annual producer-price index to those damages identified as abatement costs.

Table 2 Cost estimates of sediment – related damages, North America[a]

	Cost estimate ($ × 10^9)
Physical Damages	
Sediment Movement	
Water-conveyance facilities	
Drainage ditches	0.17
Irrigation canals	0.16
Pumping costs	0.01
Water-treatment facilities	
Municipal	1.16
Industrial	0.66
Other instream uses	
Commercial fisheries	0.70
Preservation values	0.88
Sediment Stored	
Recreation	
Freshwater and saltwater fishing	1.58
Boating	1.20
Swimming and camping	1.02
Waterfowl hunting	0.09
Water-storage facilities	
Sediment pools (construction)	0.69
Dredging and excavation	0.07
Replacement capacity	1.12
Water-quality treatment	0.07
Flood damage, agriculture	1.71
Navigation	
Water-traffic damages	0.11
Dredging and disposal	0.91
Chemical Damages	
Sediment Movement	
Eroded nutrients	1.61
Eroded pesticides	0.05
Sediment Stored	
Deposited nutrients	0.95
Deposited pesticides	0.25
Deposited heavy metals	0.02
Biological Damages	
Sediment Movement	
Fish and shellfish	0.70
Ecosystem poisonings	0.12
Sediment Stored	0.04
Total Annual Damages from Sediment, North America	16.05

[a] Costs are expressed as annual averages in billions of U.S. dollars adjusted to a 1992 base.

The estimates of Table 2 indicate the magnitude of economic loss related to soil erosion. Most of the estimates are conservative, and many damages are not included owing to a lack of information permitting even an estimate of monetary losses. Thus, annual losses may average much more than the $\$16.05 \times 10^9$ suggested by Table 2.

3.1 Fluvial Sediment as a Physical Contaminant

Based on investigations by Clark and others (1985) for the Conservation Foundation and by Forster and Abrahim (1985), damages due to the movement of sediment into water-conveyance facilities, especially as reduced storage capacity in reservoirs of the central United States (Crowder, 1987), approach $\$2 \times 10^9$ per year (table 2). The costs from damage to drainage ditches may be substantially in error because estimates are available only for six counties in Ohio. Damage costs to municipal water-treatment facilities of $\$1.16 \times 10^9$ were derived from studies by Ribaudo (1989) for the United States, by Forster and others (1987) in parts of Ohio, and by Holmes (1988) for large parts of the United States. A damage estimate to industrial water-treatment facilities of $\$0.66 \times 10^9$ is also based on the study of Forster and others. Other instream uses also show physical damage by fluvial sediment, but except for the effects on commercial fisheries and preservation values of real estate (Clark and others, 1985), reliable cost information is not available.

The storage of sediment in stream channels, reservoirs, and bottomlands reduces the recreational value of these areas and their utility for water storage, for crop production, and as transport lanes. The costs of these damages (table 2) are derived from Clark and others (1985), Crowder (1987), and Ribaudo (1989). The annual cost to recreation by physical storage of sediment, $\$3.89 \times 10^9$, is based on 1980 estimates, and may be quite conservative because expenditures for recreation in North America since 1980 have generally increased faster than the rate of inflation.

Costs of highway-erosion abatement are disregarded as expenses unrelated to erosion damage, but may approximate $\$0.3 \times 10^9$ (Rutledge and Leonard, 1992). Estimates of costs to agriculture due to scour and deposition (Clark and others, 1985), and to navigation, resulting mainly from sedimentation, (Clark and others, 1985; G. E. Greener, U. S. Army Corps of Engineers, written commun., 1994), have been increased to reflect the flooding of 1993 along the Missouri and Mississippi Rivers. The estimate of flood damage to agriculture assumes that (1) 20 percent of damage is sediment related (Clark and others, 1985, p. 164), and (2) damage by 1993 flooding of $\$10 \times 10^9$ (Goolsby and others, 1993) will be amortized through a 10-year period.

3.2 Fluvial Sediment as a Chemical Contaminant

Studies by Pimentel and others (1980) and Larson and others (1983) provide cost estimates of sediment-related damages from the movement and storage of chemicals (table 2). Consideration is restricted to those chemicals for which costs are available or can be roughly estimated: nutrients, mostly agricultural fertilizers; pesticides, mostly organic compounds applied to croplands; and heavy metals, often related to surface-mining activities. An estimate of $\$1.61 \times 10^9$ for nutrient loss on eroded sediment assumes that fertilizer applications to croplands of North America have remained constant since 1983. The estimate for pesticide loss by soil erosion is based on assumptions that the annual cost of chemicals applied to U. S. croplands, $\$2.8 \times 10^9$ (Pimentel and others, 1980), is unchanged since 1980, and that an average of 1.0 percent of the applied pesticides is moved on sediment from croplands annually. Estimates for damage due to chemicals stored with sediment are restricted to governmental costs for pesticide control (Pimentel and others, 1980, p. 135), and to ratios based on assumed values of pesticides applied annually to those of nutrients or heavy metals available for transport.

The costs indicated in Table 2 for chemical movement and deposition may grossly underestimate actual costs owing to the difficulty in evaluating the damage. Effects on biota, including human health, and costs associated with these effects, are poorly understood, largely because the redistribution of poorly-soluble manufactured chemicals and their metabolites following application, incorporation into soil, and removal by erosion, is poorly understood. Agrichemicals and petrochemicals, released routinely from point sources along streams or infrequently during floods, as occurred in the central United States in summer, 1993, are in part restored as channel and floodplain deposits. The long-term damages to biologic health and the food network by release of chemicals into riverine, estuarine, and terrestrial environments is unknown.

3.3 Biological Damages by Sediment Movement and Deposition

Biological costs incurred by sediment are, like chemical costs, poorly defined and probably underestimated; assignment of some damages as either biological or chemical is arbitrary. Because most sediment damage to biota has not been evaluated monetarily, the costs in Table 2 may be quite inaccurate and conservative. A non-quantitative comparative risk study by the U. S. Environmental Protection Agency (EPA) found nonpoint pollution to be a greater threat to natural ecosystems than that of point sources (U. S. General Accounting Office, 1990). An example, for which the costs presently cannot be assessed meaningfully, is the destruction of coral reefs, Great Barrier Reef, Australia, due to toxic effects of nutrients discharged with water and sediment from agricultural and urban sources (Burke, 1994).

Damages to commercial fisheries by fluvial sediment is among the best-documented impacts to biota. Damage estimates to shellfish in estuarine and brackish-water environments, such as Chesapeake Bay and the Mississippi River delta, are unavailable, but the associated costs may be significant relative to the $\$0.70 \times 10^9$ damage (Clark and others, 1985) listed for fish and shellfish in Table 2. Costs related to ecosystem poisonings are modified from Pimentel and others (1980), and represent documented costs of toxicity by pesticides. The biologic damage for sediment stored, $\$0.04 \times 10^9$ (table 2), is restricted to the effect on crops by saline sediment deposited by irrigation water in western North America (Clark and others, 1985).

3.4 Discussion of Costs

Estimates of costs due to the physical damage of increased sediment movement from croplands are not separated from cost estimates of total erosion in North America (table 2). Clark and others (1985) suggest, however, that agriculture accounts for slightly more than a third of the damage. Thus, croplands may be sources of about $\$5.3 \times 10^9$ in off-site damages, a societal externality (externally-imposed cost) representing 12 percent of the 1992 net farm income ($\$45 \times 10^9$) (U. S. Department of Agriculture, 1992).

Based on their estimate of an average annual erosion rate of 1 250 t/km^2 from croplands, Heady and Vocke (1978) calculated that soil-loss reduction of nearly 50 percent may be accomplished with only minor increase in production costs. If this reduction is distributed among the various damage costs of physical damage from movement and storage of sediment, the annual cost reduction to agriculture is about $\$2.1 \times 10^9$. An analysis by Forster and others (1987) indicated that a 10-percent reduction in gross annual soil erosion in Ohio resulted in only a 4-percent decrease in water-treatment costs, presumably because fixed treatment costs were unaffected.

The costs due to erosion and redeposition of sediment (table 2) are probably underestimates in most cases. Furthermore, the costs of most biological damage, especially by chemicals sorbed on sediment, are omitted because information regarding these costs is not available. A noteworthy example is food-network damage resulting from release of chemicals sorbed on sediment and stored for periods of years to decades. Thus, the estimate of total annual cost due to sediment transport and storage, $\$16 \times 10^9$, is probably substantially low. If through increased knowledge of sources and pathways of sediment and sorbed contaminants leads to meaningful reduction of sediment discharges in North America, the potential savings to government, agriculture, and industry may be billions of dollars annually.

4 PROGRAM COSTS

The present focus for collecting sediment-discharge information in North America is local, with an emphasis on basin-scale data sets that largely precludes a systematic, coordinated management approach. Data collection lacks coordination among countries and among institutions or bureaus within countries. Thus, a continental-scale sediment-monitoring design consistent to the needs of the North American countries has not been achieved, and integrated techniques for planning, sampling procedures, assessment, and interpretation of data do not exist. Results are inadequate, and sometimes duplicate data sets collected at substantial expense for specific, often local, purposes.

Table 3 provides estimates of recent (1992) costs and of anticipated expenditures for the sediment-sampling program proposed here. Part A gives estimates of current sediment activities; because different bureaus within each country typically collect data independently, the number of sampling sites and the associated operation costs may be inaccurate, however, because different bureaus within each country typically collect data independently. Part B lists estimates of additional sediment-sampling activities, with costs, that would be required to expand current activities into a systematic program for North America. Thus, the estimates of Part B are for new sampling——that part of the program not covered by current sampling activities. Part C summarizes sampling and related costs for the North American program advocated by Osterkamp and others (1992), assuming that all costs, whether for new or existing sampling sites, will be borne by this program. As an estimate, therefore, it is assumed that of the 90 daily sampling sites (part C), 75 will be new (part B) and 15 will be selected from the 120 sites currently being operated (part A).

Table 3 Estimated present and projected annual program costs, North American sediment monitoring

Country/Frequency[a]/Activity	Number of Sites	Cost per Site ($\$ \times 10^3$)	Cost ($\$ \times 10^3$)
A. Present program (1992)[b]			
United States, daily sediment	120	25	3 000
United States, periodic sed.	2 000	3	6 000
Canada, periodic/seasonal sed.	250	15	3 750
Mexico, periodic sed.	200	5	1 000
Total, present program cost			13 750
B. Proposed data-program expansion, North America			
Daily sediment	75	25	1 875
Periodic sediment	150	3	450
Periodic chemical analyses	25	25	625
Total cost, data-program expansion			2 950
C. Costs, combined projected program[c]			
Daily sediment	90	25	2 250
Periodic sediment	150	3	450
Periodic chemical analyses[d]	25	25	625
Annualized startup[e]	25	20	500
Interpretation[f]	– –	– –	200
Total cost, proposed North American program[g]			4 025

[a] Daily is sample collection once per day or more often during floods; periodic is less frequent than daily (weekly, etc.)

[b] Estimated numbers of suspended-sediment sampling sites in North America, 1992.

[c] Combined projected program includes some sites of the present program (1992), new sampling sites for the proposed program, and startup and data-interpretation activities. Of the 240 sediment sites, 145 are "primary" and 95 are "supplementary" (Osterkamp and others, 1992); the distribution of daily and periodic sampling among the primary and supplementary would be specified during program-design activities.

[d] Chemical analyses for contaminants sorbed on sediment. All sediment samples collected for chemical analyses are to be from "primary" sites.

[e] Based on startup costs for new sampling sites annualized for 10-year period.

[f] Interpretation includes compilation, reduction, and interpretive studies of data, as well as costs of communicating results of the interpretive studies.

[g] Total cost of the proposed program, regardless of whether a sampling site is new or had formerly been funded from other sources.

The estimates for sediment programs currently operated in North America (table 3, part A) summarize activities conducted by governmental units with explicit responsibility for these activities. If other organizations, public or private, collect sediment information, the estimates may understate the effort and costs. It is likely, therefore, that the total estimated annual cost, $ 4 025 000 (table 3, part C), is less than 30 percent of the cost of present sediment programs. If funding sources of present data programs continue, the cost of data-program expansion (table 3, part B) applies, and the cost for the proposed program may be as little as 25 percent of current expenditures.

Regardless of the specific cost, the program advocated here approximates an annual cost of $ 4 $\times 10^6$, about 0.025 percent of the estimated average annual cost for sediment-related damage in North America. If the operation of the program proposed here, therefore, facilitates selection and implementation of control strategies that reduce damage costs by as little as 1.0 percent, the savings may approach 40 times the program cost (fig. 1). Reduction in damages are expected by using more efficient measures to (1) prevent the mobilization of sediment and sorbed pollutants, and (2) avoid the deposition of sediment already in transport at sites where it may be detrimental.

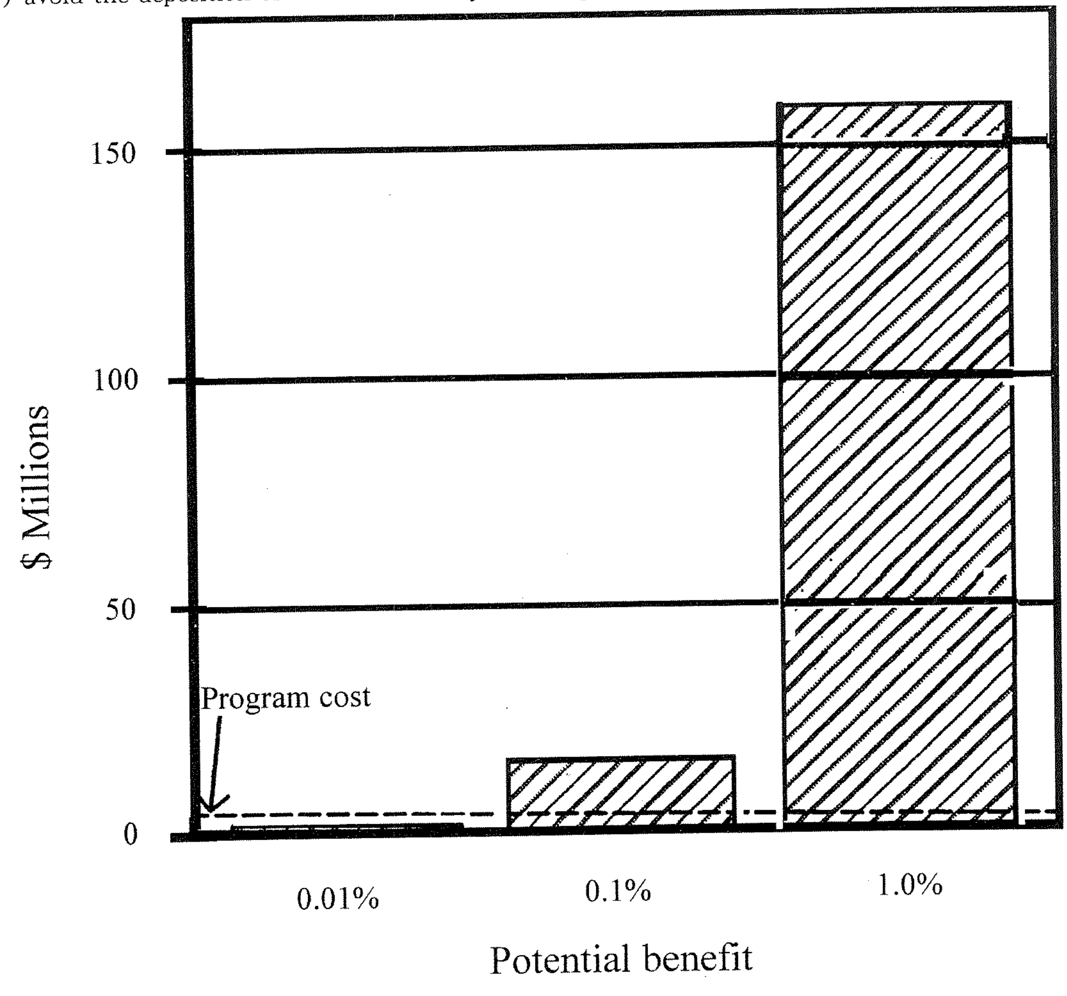

Fig. 1 Graph comparing proposed annual program cost with a range of estimated annual benefits, in 1992 U.S. dollars, for sediment damage reductions in North America of 0.01, 0.1, and 1.0 percent

Locations of the daily and periodic sampling sites and sites for sampling sorbed chemicals are presently unspecified, but secondary sampling sites especially should be concentrated where sediment damages are suspected to be greatest, not where cropland soil losses are already generally known (Crosson, 1988). Cost estimates for the sediment monitoring are founded on traditional techniques of sampling and analysis, but an emphasized component of the program is the development, validation, and inclusion of new measurement technologies. Thus, standard but evolving techniques will be employed, possibly with increasing automation and decreasing costs. If the program costs are shared proportionately to the sampling and analyses conducted in each country, approximately 10, 35, and 55 percent of the total program costs will be contributed by Mexico, Canada, and the United States, respectively. Corresponding annual costs are about $\$0.4 \times 10^6$, $\$1.4 \times 10^6$, and $\$2.2 \times 10^6$. If costs are proportioned according to potential benefits to each country, the United States may pay a larger amount.

5 SOCIAL AND ECONOMIC BENEFITS

As indicated by the estimates of sediment discharge and yield in Table 1, much is presently known about sediment movement in North America. The question arises, therefore, why collect additional information? A fundamental answer is that with increased knowledge of erosion and sediment movement, the potential for efficient remediation and damage reduction is increased.

Increased knowledge of sediment movement and storage is also vital for success of complementary programs requiring abundant data. Recognition of possible global climate change, for example, is limited by insufficient time-series data, a deficiency that could be corrected through long-term monitoring. Large-scale studies to discern ecological and related changes in landscape characteristics, such as those of the Environmental Monitoring and Assessment Program (Kepner and Fox, 1991), commonly are hampered by a lack of baseline data from which trends can be identified. Also, regional- to continental-scale monitoring may be an imperative for the success of these programs. Similarly, long-term monitoring is essential to identify delayed releases of sorbed chemicals, such as nutrients that may be stored for decades (Onstad and Blake, 1980). If short-term, extremely high rates of sediment and sorbed-contaminant discharge are anticipated, as may occur following decommissioning and razing of possibly 50 dams and reservoirs in the United States in the near future (W.L. Graf, Arizona State Univ., personal commun., 1994), the effects of the razings and of future razings can be understood only if a flexible data-collection program is in place.

5.1 Distinguishing Damages and their Magnitudes

Sediment is generally a nonpoint-source pollutant, and whether availability is "induced naturally or artificially, the sources are difficult to identify, predict, and control" (Meade and Parker, 1985, p. 1). Remote sensing and land-use inventories can aid in the identification of sediment sources, but sampling remains the primary means for estimating sediment discharge at drainage-basin scales.

A systematic strategy of sediment sampling is essential for distinguishing loads of nutrients, agricultural and industrial chemicals, and toxic wastes that are transported and deposited as sorbed contaminants on sediment. Long-term sediment sampling is essential to distinguish trends or rate changes in the movement of sediment and its sorbed loads, particularly if a large change occurs quickly owing to landscape disturbance. Presently-available data are inadequate and commonly too imprecise to identify where and to what degree eroded sediment will be redeposited before reaching an ocean. This aspect of the sediment-delivery/ sediment-storage problem is of extreme importance to solute and organic-carbon transport, toxicity and related health considerations to wildlife and humans, and other widely-ranging environmental factors impacted by sediment deposition.

A sediment-monitoring program, therefore, potentially has social benefits beyond the economic benefit. The identification of waterways in which the highest loads of toxic or otherwise deleterious contaminants are carried on sediment permits corrective actions to reduce health risks and environmental impairment. Among these actions are the elimination of the source, selective application of chemicals, and use of sediment-retention structures and vegetation filters to increase on-site or near-site storage capacity. The social damages that occur from these risks are real, but largely indeterminant. The benefits, economic and social, are quantifiable as reductions in damage costs that are possible to estimate only when and where the source and magnitude of a problem is known.

5.2 Remediation

Extrapolating estimates of Fulton and Braestrup (1981), as much as \$ 100×10^9 has been spent in North America since World War II for soil and water conservation. Most of the money was used to develop and apply erosion-control technology on agricultural lands; relatively little has been expended to control damage by sediment from non-agricultural areas. A continental-scale monitoring program would identify nonpoint pollution without prior supposition of source. An emphasis, therefore, would likely be placed on the recognition of environmental and health-related damage due to sediment and sorbed loads, without reducing attention given to the physical damage caused by fluvial sediment. Problem areas from which sediment damages are most costly, would become targeted for coordinated efforts of erosion control (Committee on Long-Range Soil and Water Conservation, 1993).

Remediation of infrastructure damage due to sediment movement generally is delayed if the cause is not clearly identified, a difficulty that can be reduced through well designed monitoring activities. Remediation efforts also can be enhanced by documenting where practices such as conservation tillage, surface-mine reclamation, and resodding of disturbed suburban watersheds have resulted in recent sediment-discharge reductions. The documentation must include knowledge of sediment storage sites.

5.3 Application of Systems Technology

Program cost estimates (table 3, part C) assume the operation of 90 daily sediment-sampling sites and 150 periodic sampling sites; from Osterkamp and others (1992), 145 of the 240 are intended as primary monitoring sites, the remainder as supplementary sites. The primary sites were selected to provide areal distribution and a range, in some cases nested, of watershed sizes. The number of primary sites may be inadequate to yield network characteristics, but selections reflect network objectives. The selection of 95 supplementary sampling sites, using systems technology to provide objectivity, may assure that the proposed monitoring program has network characteristics.

The ability to meet demand for food, fiber, and minerals from North American croplands and rangelands is complicated by (1) accelerated soil-losses that typically are caused by land disturbance, (2) economic costs to society, both on-site and off-site (table 2), that result from accelerated soil loss, (3) economic loss to producers invoking erosion-control practices, (4) public concern of future reduction in productivity due to soil loss, and (5) institutional responses as reflected by pressure for environmental reforms and governmental regulation (Timmons and Amos, 1982). For effective program design and development, these complicating and conflicting factors must be considered and balanced using "best management practices" that are based on adequate ambient monitoring data (U. S. General Accounting Office, 1990). Similar opinions expressed by Ribaudo and Young (1989) reflect their observation that models linking behavior and economics to nonpoint-source pollution are needed to design and use data-collection programs properly. Without a coordinated sediment-monitoring program, national/continental policy analysis of nonpoint-source pollution will continue to be founded on inadequate technical information, and without clear knowledge of national needs, it will be difficult to design an optimal monitoring program.

A possible means for objective evaluation of sampling-site selection (program design) and the use of program results to initiate soil-loss reduction procedures is decision-support technology (Lane and others, 1991; Yakowitz and others, 1993). Decision-support systems incorporate procedures permitting practical solutions to multiobjective problems. A range of applications are currently under development including the selection of optimal farming practices to minimize various forms of nonpoint-source pollution. Combined with selected validated soil-loss models such as RUSLE (Renard and others, 1991) and sediment/chemical routing models such as CREAMS (Knisel, 1980) or WEPP (Lane and Nearing, 1989), multiple-objective decision-support technology can be used to select land-management systems or regional policies to improve stream quality, as well as to modify sampling design as program needs change. A goal of decision-support technology is to bring estimates of sediment yield and sorbed chemicals into consideration when selecting farm-management systems.

6 PROPOSAL SUMMARY

During a 1993 interview, William Reilly, former Administrator, EPA, stated that over half of stream pollution in the United States is from nonpoint sources. A compilation by Rutledge and Leonard (1992), however, suggests that in 1990 abatement expenditures in the United States for nonpoint-source pollution were $\$1.6 \times 10^9$, less than 5 percent of the $\$33.4 \times 10^9$ spent for point-source abatement and about 10 percent of the estimated annual damage costs. The proposal presented here advocates comparatively modest expenditures, but could lead to a distribution of abatement expenditures commensurate with Mr. Reilly's observation. Furthermore, information compiled by a task force on monitoring water quality reported that in the United States less than 0.2 percent of the annual expenditures for abatement is spent on ambient monitoring (Intergovernmental Task Force on Monitoring Water Quality, 1992). If authorized, the proposal could become a part of the recommendation by nearly half of U. S. states "that EPA actively pursue development of a nationwide inplace pollutant program designed to provide both technical guidance and dedicated Federal financial support for expansion of sediment monitoring programs and remediation efforts" (Environmental Protection Agency, 1992, p. 173).

The monitoring program proposed here consists of 240 sediment-sampling sites, 25 of which include sampling for sediment chemistry (table 3, part C). The sites are intended to provide information on sediment and sorbed-pollutant discharges throughout North America, both areally and at varying basin scales. Sites are selected to emphasize significant contributors of erosion products and watersheds in which deposition of sediment and sorbed chemicals may cause extensive damage. In both cases, the purpose of the monitoring is to identify problem watersheds where corrective actions may lead to significant reductions of on-site and off-site damages.

The estimated annual cost of the proposed program is $\$4 \times 10^6$, compared with over $\$16 \times 10^9$ for damages due to erosion and deposition each year. If even minor reductions in nonpoint-source pollution and its damage costs follow from the sampling, it is apparent that the cost of the North American sampling program will be justified. Much less apparent in monetary terms but of possibly greater importance is that the monitoring can aid in controlling the mobilization and deposition of toxic substances that threaten the health of many riverine and estuarine ecosystems and humans.

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