# Increased reservoir benefits:
# The contribution of soil conservation programs

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## Abstract

The objective of this research is to value soil conservation's impact on reservoirs. Using a model based on replacement cost, we estimate the benefits gained by marginal decreases in soil erosion for more than 75,000 reservoirs across the contiguous States. We aggregate benefits across the reservoirs within each of the 2,111 U.S watersheds in order to produce regional benefit estimates. Results show that a one-ton reduction in soil erosion provides benefits ranging from zero to $1.67. Our estimated model can be used to assess conservation benefits. For example, the lower level of soil erosion in 1997, relative to the 1982 level, preserved $139 million in reservoir benefits.

## Introduction

Soil erosion on US cropland in 1997 was nearly 40% lower than cropland erosion in 1982. (Claassen et al., 2001). Most of this reduction in soil erosion is due to new agri-environmental programs and an expanded use of soil conservation practices. However, soil conservation, as with any resource-conserving action, usually comes at a price.

Therefore, it is interesting to consider how soil losses from agricultural lands increase suspended sediment loadings in lakes and streams. Because of increases in sediment loadings, shipping channels and harbors require more frequent dredging; the health of freshwater and ocean ecosystems is reduced; municipal water treatment costs rise; and maintenance costs of hydroelectric and water-cooled power generating facilities increase (Hansen and Claassen, 2001).

In order to value soil conservation's impact on the environmental benefits of reservoirs, we extend the replacement cost theory to cases where benefits are restored for multiple years. More importantly, our theoretical framework provides a means of valuing marginal changes in the amenities due to marginal changes in soil conservation. Our application assumes that dredging is the replacement cost. A reservoir benefit function, based on the replacement cost of the benefits, is estimated and applied in our empirical analysis.

We estimate the marginal benefit of a reduction in soil erosion for more than 75,000 reservoirs that are included in the US Geological Survey's Nation Inventory of Dams (NID). We aggregate impacts across reservoirs within watersheds. Thus we are able to estimate the marginal benefit of a one ton reduction in soil erosion for each of the 2,111 watersheds of the contiguous States.

Results show variations in benefits across watersheds. A marginal reduction in soil erosion provides benefits ranging from zero to $1.67 per ton. Some watersheds have no reservoirs and thus no soil erosion benefits. Others have reservoirs with high dredging benefits or have a great number of reservoirs—both of which increases the benefit of a marginal reduction in erosion. We estimate that the median per-ton benefit of a one-ton reduction in soil erosion is $0.0652.

The following section reviews past research that has attempted to value soil erosion's impact on reservoirs. After a brief discussion of the theory and the data, the models are estimated and used to assess the benefits of recent soil conservation actions.

## Prior Research

Prior research has estimated the economic impact of soil erosion changes for a single reservoir, for the whole US, and for multi-State regions. Although objectives of earlier studies differ from ours, they have similarities and provide a comparison for the approach we propose.

Clark and others (1986) estimated damages to U.S. reservoirs due to erosion from all sources and from agriculture alone. They estimate that $535 million is spent to build additional sediment storage capacity, $77 million is spent on dredging, and $450 million (discounted present value) will be spent in 10 to 20 years to dredge the current year's sediment. Thus total damages of erosion are estimated at over $1 billion and, based on agriculture's share of total erosion, damages from agricultural total $340 million.

Crowder (1987) estimates the per-ton cost of agricultural erosion for each of the 10 U. S Department of Agriculture's (USDA) Farm Production Regions (FPR) of the contiguous States. To do this, Crowder first allocates the total annual cost of reservoir sedimentation—the estimate of Clark and others (1986)—across FPR based on regional sedimentation rates. Regional sedimentation rates are a sum of the sedimentation rate for all reservoirs within a region. The sedimentation rates were estimated by Dendy and Champion (1978). Finally, Crowder estimates a per-ton cost of erosion by dividing FPR total reservoir sedimentation cost by the total erosion within the region. Crowder's estimates ranged from $0.10 to $0.60 per ton of erosion. These estimates have proven useful in assessing USDA soil conservation programs (Ribaudo, 1989).

## Theory

Reservoirs are assets that provide services across many years. All reservoirs are subject to sedimentation. Sedimentation reduces storage capacity and, thus, environmental services. A reduction in sedimentation will marginally reduce the rate of loss of reservoir services. For example, if sediment inflow were to be halted for one year, then sediment levels in subsequent years would be less than expected. With less reservoir sediment, reservoir services would be greater. The marginal value of a one-year halt in sediment inflow is the present value of the gain in reservoir services.

Direct estimation of the value of reservoir services requires one to estimate the demand for each reservoir service. To overcome associated data limitations, we use an indirect method of benefit estimation—the replacement cost approach.[1]

The replacement cost theory is built on the assumption that the value of lost amenities, or environmental services, is greater than or equal to the "replacement cost", or the dollar amount that would be required to recover the lost amenities (Lew et al., 2001). This indirect method of benefit estimation is used in assessing damages from oil spills and other environmental incidents where many environmental amenities are affected.

Our goal is to assess the marginal benefits of a change in soil conservation policy. Therefore, we develop a marginal benefit model that incorporates the relationship between reservoir benefits

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[1] Indirect methods are commonly applied in situations where a variety of environmental amenities might be affected (Winpenny, 1991; McNeely, 1988).

and soil erosion. The benefit model relates the effect of soil erosion to future levels of reservoir services. That is, the marginal benefit function is dependent on the level of soil conservation (erosion) and the remaining life of the reservoir. In our application, the marginal benefit function represents the change in the level of future reservoir benefits given a one-year change in erosion. The economic parameters of the marginal benefit function are derived from the relationship between reservoir benefits and dredging costs, following the replacement cost approach. With an empirical application of these models, we are able to assess the marginal benefits of a change in soil conservation policy.[2]

**Benefits, Costs and Optimal Dredging**

Commonly, reservoirs are dredged before losing 40 percent of their capacity (Lohnes and Austin, 1984; Hanson and Stefan, 1984). We assume that a reservoir is dredged to maximize welfare—at a time D*. Essentially, we assume that when dredging occurs the marginal benefits of waiting an additional year are equated to the marginal costs of delaying the dredging.

We model both benefits and costs as a function of the quantity of sediment dredged. Total benefits restored by dredging equals the quantity of benefits that have been lost. Because benefits are lost as dredging is delayed, the benefit restored by dredging increases as dredging is delayed. The marginal benefit of delaying dredging is the change in total benefits restored when dredging is delayed one year.

Costs also increase with delays in dredging. Total cost is a function of per-unit costs (PUC) and the total quantity dredged. The PUC for a single reservoir is a function of $SED_D$, the quantity of sediment dredged, when there are economies or diseconomies of scale. PUCs are likely to vary across reservoirs due to differences in reservoir characteristics.

Given a linear specification to specify the relationship between reservoir benefits and the extent of sedimentation the annual benefit, we find that the marginal benefit of a one-unit reduction in sediment in a reservoir that has n years of sediment ($SED_n$) (Hansen and Hellerstein, 2004).

$$MB_n = \frac{PUC + \dfrac{\partial PUC}{\partial SED_{D*}} SED_{D*}}{(1 - e^{-r(T-D*)})} \left(1 - e^{-r(T-n)}\right). \tag{1}$$

The marginal benefit function in equation 1 includes the benefits of less sediment in future years resulting from a reduction in sedimentation in the current year,

## Application

We use a variety of data sources to estimate the marginal cost of dredging as a function of the quantity of sediment dredged and reservoir characteristics. We also estimate sedimentation rates as a function of the erosion rate and the size of the reservoir's drainage area. With these functions and appropriate values of T, D, and n, we estimate $MB_n$, the marginal benefits of a reduction in erosion.

[2] A detailed discussion of this replacement cost model for valuing reservoir services is presented in a separate paper.

**PUC**

Various factors are thought to be driving the per-unit costs of dredging. For example, Peterson (1979) argues that per-unit costs decrease with respect to the quantity of sediment dredged and increase with greater dredging depth, sediment-hauling distances, and toxicity of dredged materials. Sediment at greater depths requires more costly dredging techniques. Hauling distances vary. Off-shore deposition and deposition on surrounding lands lower hauling distances. Sediment tainted with heavy metals or toxic chemicals must be appropriately contained, thus increasing disposal costs (Peterson, 1979).

However, our dredging-cost data are relatively thin. We remedy this missing-variable problem by using reservoir capacity as a proxy. We expect increases in reservoir capacity to indicate increases in reservoir depth and surface area.

Based on the available data, PUC are:

$$PUC = C(SED_D, RECAP)\,. \qquad (2)$$

$SED_D$ is the quantity of sediment dredged and RECAP is the reservoir capacity. We expect the coefficient on $SED_D$ to be positive but the marginal effects of SED to be decreasing because prior work indicates that there are economies of scale with respect to the quantity of sediment dredged ($\partial PUC/\partial SED_D > 0$ and $\partial^2 PUC/\partial SED_D^2 < 0$). Prior research has also found that, as reservoir depth and area increase, dredging costs increase so that we expect $\partial PUC/\partial RECAP > 0$ (Peterson, 1982; Peterson, 1979).

**Sedimentation rate**

The largest factor affecting annual sedimentation is the quantity of sediment that flows to the reservoir (USDA, SCS, 1975; Dendy, 1968). The quantity of sediment that flows to a reservoir depends on the number of upstream acres (e.g., the reservoir's drainage area), the rate of erosion on these lands, and the sediment delivery ratio.

Given the available data, the annual quantity of sediment settling in a reservoir or the sedimentation rate (SED/YR) is modeled as:

$$SED/YR = SR(RECAP, SOIL)\,. \qquad (3)$$

where RECAP is the reservoir capacity and SOIL is the rate of soil erosion. Here, we use RECAP as a proxy for the size of the reservoir's watershed—that is, we assume that larger reservoirs will tend to be fed by larger watersheds. Each variable is expected to have a positive effect on sedimentation. Furthermore, the marginal effect of each variable is expected be dependent on size of the other variable. The marginal effect of soil erosion is likely to increase because a high erosion rate will not only increase the quantity of sediment delivered, but also increase the density and size of soil particulate—both of which can increase the rate of sedimentation (Strand and Pemberton, 1982; Brune, 1953).

**The parameters T and D**

Comprehensive data on environmental investments would include the values of the economic life of a reservoir (T) and the dredging times (D*). The available data have no information on T. To overcome this shortcoming, we assume that a reservoir's effective capacity is equal to the reservoir's total storage capacity (RECAP) so that T equals RECAP/(SED/YR). This assumption will maximize T and thus, based on equation 13, provide a more conservative benefit estimate. We test the robustness of this assumption in our empirical application.

The available data have no information on D*. However, D* is a function of the quantity of sediment dredged and the sedimentation rate. The data used to estimate dredging costs indicate that 90 percent of all reservoirs are dredged before sediment accumulation exceeds 25 percent of the reservoir capacity. Furthermore, past research found values of $SED_D$ ranging from 15 to 40 percent of capacity (Lohnes and Austin, 1984; Hanson and Stefan, 1984). In order to derive an estimate of D* for all reservoirs in our data, we assume that the optimal time to dredge is when the reservoir has lost 30 percent of its capacity so that D*=(0.3*RECAP)/(SED/YR). We test the robustness of this assumption in our empirical application.

## Data

The PUC function is estimated from public and private dredging cost data and Census data. The cost data includes total dredging cost, the quantity of sediment dredged, reservoir capacity, and the reservoir's latitude and longitude. Observations were obtained from dredging contractors and State and local governments. We were able to obtain 50 useable observations on dredging costs.

The sedimentation-rate function is estimated from the Reservoir Sedimentation Survey Information System (RESIS) data and from USDA data on land use. The RESIS data include a measure of the size of the reservoir (RECAP), the watershed where the reservoir is located, and periodic measures of reservoir sediment. We were able to measure sedimentation rates for 1,578 reservoirs.[3]

Soil erosion rates (SOIL) are based, primarily, on the 1982 Natural Resources Inventories (NRI) (SCS, USDA, 1984).[4] The Universal Soil Loss Equation (USLE) and measures of land use, slope, soil type, etc., from the NRI, are used to estimates soil erosion rates on private agricultural lands.

In order to apply the marginal benefit function in policy analyses, we must have an adequate sample of reservoirs. The National Inventory of Dams (NID) has attempted to include all reservoirs with holding capacities of 10 acre-feet or more (U.S. Army Corps of Engineers, 2000).[5] With over 77,000 reservoirs, it is thought to be a fairly complete inventory of U.S. dams. After removing large reservoirs—reservoirs that are likely to capture water from more than one watershed— 75,085 NID observations are used in this analysis.

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[3] Although the RESIS data were collected over time and by multiple agencies, it was relatively easy to analyze thanks to efforts of the Natural Resource Conservation Service of the U.S. Department of Agriculture and the Texas Agriculture Experiment Station. RESIS data have been used in other analyses (Stallard et al., 2001; Steffen, 1996).

[4] The U.S. Department of Agriculture's Natural Resources Conservation Service (NRCS), in cooperation with the Iowa State University Statistical Laboratory, have developed this statistical-based sample survey following guidelines set by the Rural Development Act of 1972. This Act, along with the Soil and Water Resources Conservation Act of 1977 and other supporting Acts, mandated that the NRI be conducted at 5-year intervals or less.

[5] The NID is the result of the cooperation of multiple State and 17 Federal agencies. The National Dam Inspection Act of 1972 (P.L. 92-367) authorized the USACE to inventory U.S. dams. Subsequent acts—the Water Resources Development Act of 1986 and the Water Resources Development Act of 1996—authorized the periodic updating and publishing of data. Data can be downloaded directly from the USACE's web site (U.S. Army Corps of Engineers, 2000).

## Results

Various specifications of the PUC function were tested based on the expected relationships between the dependant and independent variables. To best specify economies of scale with respect to SED, quadratic, logarithmic, and inverse specifications have been applied. We tried both linear and quadratic specifications of RECAP. We found PUC is best specified as:

$$PUC = 2.55 + 115{,}000(1/SED_D) + 0.0000249RECAP \quad (4)$$

(3.67) (7.51) (3.10)

$R^2$ adj. = 0.76
N=50

Each coefficient is significant based on a two-tailed t-test where N=50 and $\alpha$=0.99. Marginal effects of both independent variables are positive.

Results are consistent with prior expectations in that, first, there are economies of scale in dredging operations and that the economies of scale fall off as operations increase in size. That is, the marginal effect of $SED_D$ is negative and decreasing. And second, the positive coefficient on RECAP indicates that increases in reservoir depth and surface area, as proxied by RECAP, increase PUC. However, the results do allow us to separate the effects of depth and capacity.

Results indicate that the most appropriate specification of the sedimentation function is:

$$\ln(SED/YR) = -4.12 + 0.775\ln(RECAP) + 0.140SOIL. \quad (5)$$

(41.5) (59.2) (7.74)

$R^2$adj=0.78
N=1236

Each coefficient is significant at the 99% level based on a two-tailed t-test and each has its expected sign. The $R^2$ indicates the model accounts for a large amount of the variation in ln(SED/YR).

The selected specification is consistent with our prior expectation. The product of RECAP and SOIL, which is assumed to represent the quantity of sediment reaching the reservoir, increases the sedimentation rate. Thus, for a given sized reservoir (RECAP), the soil erosion rate has a positive and increasing marginal effect on the sedimentation rate thus is consistent with prior research which suggests that higher erosion rates bring heavier sediment to reservoirs. Also, for a given erosion rate (SOIL), larger watersheds deliver more sediment and thus allow greater sedimentation.

After transforming equation 5, the sedimentation rate can be specified as:

$$SED/YR_{est} = 0.0162RECAP^{0.775}e^{0.140SOIL}. \quad (6)$$

After adjusting for non-linear biases in prediction (Peterson and Stynes, 1986), we find:

$$SED/YR^{*} = 0.0128RECAP^{0.748}e^{0.122SOIL} \quad (7)$$

$R^2$adj=0.26

SED/YR* is an unbiased estimate of SED/YR. The $R^2$ of equation 8 is 0.26 and represents the predictive capability of the sedimentation model.

**Comparisons of observed and estimated values**

For a perspective on the reliability of model predictions, we compare predicted values of PUC and SED/YR*, which are based on equations 4 and 7 and the NID data, to values based on the cost data and RESIS (sedimentation) data.[6] We expect some consistency in the ranges of the predicted values because the ranges of independent variables are comparable. However, we do not expect an exact match in the means of the dependent variables because the distributions of the independent variables in the sample data and the NID data differ.

We also compare the range in the predicted values of PUC and SED/YR*, based on the NID data, with findings of previous research. The differences and their implications are discussed.

The estimated range of PUCs based on the NID data is consistent with the range based on the cost data (table 1). The maximum PUC estimate of the NID data is slightly larger but less than the maximum PUC in the cost data. The median PUC estimate, based on the NID data, is slightly larger than the median estimate from cost data. Since $SED_D$ tends to be smaller in the NID data and that PUCs increase as $SED_D$ decreases, this result is not unexpected.

The range of PUC estimates tends to be more conservative than those suggested in earlier research. Estimates by Peterson (1979), Miltz and White (1987) and Sohngen and Rausch (1998) range from $2.68 to $41.86 per-ton.[7] Peterson (1979) and Miltz and White (1987) felt $7.18 was a conservative estimate. The range suggested in past work is quite wide, relative to the range of the estimated costs. Although we cannot be certain of the true range in PUCs, the consistency between past and current estimates provides some support for our PUC estimates.

Using equation 7, we predict values of SED/YR for observations in the NID data. The minimum predicted value of SED/YR from the NID data is consistent with the RESIS estimate. Although the maximum of SED/YR based on the NID data is nearly twice the estimate based on the RESIS data, the 969,000-tons/year estimate is an outlier. The second highest estimate of SED/YR from the NID data is 528,000 tons/year, which is consistent with the RESIS estimate. Second, the median value of SED/YR, based on the NID data, is approximately 36 percent of the RESIS data estimate. However, because the median value of RECAP is smaller in the NID data and given the relationships in equation 8, estimates of SED/YR based on the NID data should be lower than estimates based on RESIS data..

## Soil Conservation Benefits

Equation 1 is estimated for each reservoir by applying the NID data to our estimates of equations 4 and 7 and our assumptions on T and D*. Results are summed across reservoirs in order to generate both regional (HUC) and national marginal benefit estimates. The marginal benefit estimates are present-value estimates of a one-time marginal reduction in soil erosion.

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[6] Estimates of PUC and SED/YR* based on the sample data have no random error thus provide a better means of comparing predicted values from the NID data to those based on the sample data. These estimates are consistent with the sample data (tables 1 and 2).

[7] All values are expressed in 2000 dollars.

**HUC-level benefits**

*Marginal benefits* Our results show that, across HUCs, there is a large variation in the value of a one-ton reduction in soil erosion. A marginal reduction in soil erosion provides no reservoir-related benefits in 163 HUCs. These watersheds have no reservoirs, based on the NID data. In the remaining watersheds, per-ton benefits peak at $1.67 (table 3).[8] Marginal benefits in eleven watersheds exceed $1.00 per ton. The distribution of the per-ton benefits is skewed toward the lower values—the median per-ton benefit of reduced soil erosion, $0.0652, is less than five percent of the peak benefit estimate. Per-ton benefit estimates are relatively constant around its median value. For example, by dropping the 163 watersheds that have no reservoirs, the median per-ton benefit estimate is $0.0679.

The large variation in marginal benefits offers some insight into the advantage of geospecific environmental benefit measures and the targeting of conservation actions. Not only do marginal benefits vary widely across the country, marginal benefits can vary between neighboring HUCs (figure 1). Variations in marginal values are driven by variations in the number of reservoirs and reservoir characteristics.

The marginal benefits of soil conservation tend to be higher in watersheds east of the Mississippi River (figure 1). The highest marginal benefits tend to be concentrated in watersheds along the northeastern coast and in Ohio, eastern Pennsylvania, northwestern Missouri, northeastern Texas, and central Oklahoma. These areas tend have a large number of reservoirs, relative to the size of the watershed, and thus capture a greater portion of the eroded soils.

Watersheds having no reservoirs tend to be more common in the Rocky Mountain range of northern Idaho—where demands for reservoir services are relatively small—and in Arizona, New Mexico, southwestern Texas, and southeastern California—where water supplies are limited. However, across the southwestern States, the marginal values of soil erosion are relatively large in many watersheds (figure 1).

*Conservation benefits* Annual soil erosion levels have fallen by approximately 40 percent since 1982 and have had impacts on reservoir services. Within some HUCs, annual sheet and rill erosion in 1997 was nearly 11 million tons less than in 1982. However, erosion did not decrease in all HUCs. In 330 HUCs, sheet and rill erosion increased. Although most erosion increases were small, within one HUC, annual sheet and rill erosion was nearly 0.8 million tons more than in 1982.

Within one HUC, the decreased erosion level in 1997 conserved as much as $10 million in reservoir services, relative to the erosion level in 1982. Conversely, one HUC saw losses in reservoir services in 1997 that were $0.28 million greater than losses would have been had erosion remained at its 1982 levels. Across HUCs, the median-level impact of the soil erosion level in 1997, relative to the 1982 level, was a gain in conservation benefits of approximately $2,580 (table 3).

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[8] Unless otherwise noted, estimates are based on a 30-pecent capacity loss before dredging.

Some of the largest gains in reservoir services occur across many of the watersheds in the Corn Belt (figure 2). Although the marginal benefit of reduced erosion in some watersheds in the Corn Belt are not high (figure 1), large decreases in soil erosion boost total conservation benefits within these watersheds above benefits in other watersheds. Conversely, in areas such as the New England States where marginal benefits are high, there is little difference between agricultural erosion levels in 1997 and 1982 so that changes in benefits are relatively small.

Most areas where soil erosion costs increase are west of the Mississippi River. Erosion increases in these areas, in most cases, are due to the conversion of rangeland and grasslands to cropland.

Our benefit estimates are not sensitive to our assumption on D* or, implicitly, the quantity of sediment dredged, $SED_{D*}$ (table 3). All HUC-level mean and median estimates of total and marginal benefits show small increases as D* increases (e.g. $SED_{D*}$ increases from 10 to 40 percent of total capacity). Benefit estimates increase because, the greater the capacity loss before dredging, the longer will be the effect of a conservation measure. However, benefit increases are small because the additional benefits occur in future periods and thus are discounted.

In two earlier studies, the discounted present value (DPV) of sediment's future dredging cost is used as a measure of the cost of sedimentation (Lee and Guntermann, 1976; Clark et al., 1986). In our analysis, we argue that the DPV of future dredging costs is not a cost of sedimentation because if, in the future, sediment is dredged, then the costs will be justified by the subsequent benefits. As a result, the net effect of sedimentation's impact on future dredging cost (e.g., the benefits from future dredging minus the cost of future dredging) will equal zero. In order to illustrate the economic implications of focussing on future dredging costs, we apply the discounted-cost approach and compare these results with our environmental benefit estimates.

HUC-level median-values of the discounted costs of dredging are approximately 10 percent of our benefit estimates (table 3). The discounted-cost approach produces smaller estimates because costs occur well into the future while benefits are affected immediately. As D* (and thus $SED_{D*}$) increases, dredging costs are moved farther into the future. As a result, the median values of discounted costs differ by a factor of 10. Thus, unlike the benefit estimates, discounted cost estimates are very sensitive to assumptions on $SED_D$.

**National benefits**

Nation-wide, total sheet and rill erosion on agricultural lands in 1997 is estimated to be 640 million tons less than in 1982 (Claassen, et al, 2001). This reduction in soil erosion is estimated to have preserved $139 million in reservoir benefits relative to erosion damages in 1982 (table 4). Results show little sensitivity to our assumption on effective capacity (T). They also illustrate that, by assuming that effective capacity equals total storage capacity, benefit estimates tend to be more conservative. Should effective capacity be as low as 60 percent of the reservoirs total capacity, our conservation benefit estimate would increase by less than 7 percent.

Our benefit estimate is not inconsistent with benefit estimates in prior research. The same 640 million-ton reduction in soil erosion would provide $210 million in benefits based on estimates of Ribaudo, and $120 million based estimates of Clark and others.[9] There is no means of determining which, if any, of these measures reflect the true economic impact of the change in erosion. However, one might argue that, despite the differences in approaches, their relative consistency adds to the credibility of each.

At $139 million, the annual gain in reservoir benefits is not negligible. However, it is small relative to the costs of soil conservation programs. But soil erosion has many off-site impacts so that benefits due to reduced reservoir sedimentation should be viewed as one piece of a much larger picture (Hansen and Claassen, 2001).

## Summary

The objective of this research is to value soil conservation impacts on reservoir services. We first estimate the marginal benefit of a reduction in soil erosion. Then, based on the change in total erosion and the marginal benefit estimates, we estimate the benefits of the conservation practices used in 1997, relative to practices used in 1982.

Using a model based on replacement cost theory, the benefit of a marginal change in soil erosion is estimated for over 75,000 reservoirs across the U.S. The marginal soil-conservation benefit for a watershed is the sum of the benefits of all reservoirs within the watershed. Across watersheds, the marginal benefit estimates vary considerably, which suggests that the economic advantage of targeting soil conservation efforts may be quite large. A marginal reduction in soil erosion provides benefits ranging from zero to $1.67 per ton. Some watersheds have no reservoirs and thus no soil conservation benefits. Others have a great number of reservoirs, relative to the size of the watershed, which increases the benefit of a marginal reduction in erosion. The median benefit of a one-ton reduction in soil erosion is $0.0652. Because the median is much less than the maximum, we know that the distribution of marginal benefits is skewed toward lower values.

In the majority of watersheds, sheet and rill erosion in 1997 was lower than their 1982 levels. For example, in one watershed, the 1997 level of soil erosion was 11 million tons less than its 1982 level. However, in 330 watersheds, sheet and rill erosion increased. Though most increases were small, the 1997 level of erosion in one watershed was nearly 0.8 million tons greater the 1982 level.

The economic impacts of erosion levels in 1997, relative to levels in 1982, vary across watersheds because both the differences in erosion levels and the marginal benefit of erosion reductions vary. In watersheds where erosion was lower in 1997, benefits are positive—in one watershed, the lower level of erosion in 1997 preserved $10 million in reservoir services. In watersheds where erosion was higher in 1997, benefits were negative—in one watershed, the higher level of erosion in 1997 increased losses in reservoir services by nearly $0.28 million. The median watershed-level benefit of reduced erosion in 1997, relative to erosion in 1982, was $2,580.

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[9] These benefit estimates are rough approximations. Each is the product of an average benefit estimate and the total change in erosion. Ribaudo (1986) estimated that 5.1 billion tons of erosion was causing $1.7 billion/year in damages to reservoirs. Thus, in this case, damages average $0.33 per ton. Clark and others (1985) estimate damages due to agricultural sediment at $0.36 billion and annual cropland erosion at 1.9 billion tons. In this case, damages average $0.19 per ton.

Nation-wide, total sheet and rill erosion on agricultural lands in 1997 is estimated to be 640 million tons less than in 1982. The lower soil erosion in 1997 is estimated to have preserved $139 million in reservoir services. Based on measures developed in two prior studies, the conservation benefits of the same reduction in erosion are $210 million and $120 million. There is no means of determining which benefit measure best reflects the true economic gain. However, one might argue that, despite the differences in approaches, their relative consistency adds to the credibility of each.

Soil conservation has additional offsite impacts. Recreation, water treatment, industrial water use, etc., are also affected by sediment. Additional research would be needed in order to account for other offsite impacts.

The available data produced statistically significant results that are consistent with expectations. However, better data and additional observations on dredging costs will increase the reliability of the PUC model. Data on reservoir dredging costs, along with details on reservoir characteristics, proved to be difficult to collect. Better data could improve our statistical analysis and reduce the number of assumptions required and thus provide more reliability benefit estimates.

Our analysis relies on a number of assumptions. First, we assume that dredging is efficient when a reservoir has lost 30 percent of its capacity. The available, but limited, data indicate that, across reservoirs, dredging occurs with 10-45 percent capacity loss. We tested the sensitivity of our results to capacity losses of 10 and 40 percent and found no statistically significant change in results. Benefits are not sensitive to capacity loss because increasing capacity losses increases future benefits (e.g., the number of years benefits accrue after dredging) which, after discounting, tend to be relatively small.

Second, we have assumed that the net benefits of a reservoir remain positive until the reservoir is filled with sediment (e.g., the economic life of the reservoir). A sensitivity analysis, based on zero net benefits occurring after 60 and 80 percent capacity loss, found economic impacts to be relatively small. Furthermore, benefit estimates that are based on the 100-percent capacity loss assumption were found to be more conservative.

Third, we have assumed that the NID is a census of reservoirs. If a large portion of reservoirs is not included, then our national benefit estimate is understated. Also, if the NID data do not include all reservoirs within a region, then benefit estimate for that region will be understated.

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**Table 1. Observed and Estimated Variables of the Dredging Costs Model**

| | $SED_D$ (tons) | RECAP (ac-ft) | PUC* ($/ton) | PUC** ($/ton) |
|---|---|---|---|---|
| **COST DATA** | | | | |
| • Maximum | $5.06*10^6$ | 454,000 | 34.47 | 21.60 |
| • Minimum | 6,075 | 8 | 0.32 | 2.62 |
| • Median | 135,000 | 2,540 | 3.81 | 3.76 |
| **NID DATA** | | | | |
| • Maximum | $1.85*10^8$ | 379,000 | | 25.40 |
| • Minimum | 5017 | 10.2 | | 2.70 |
| • Median | 71,500 | 146 | | 4.23 |

*observed
**predicted
***assumes dredging after 30% capacity loss

**Table 2. Observed and Estimated Variables of the Sedimentation Rate Model**

| | RECAP (ac-ft) | SOIL (tons/acre/yr) | SED/YR* (tons/yr) | SED/YR** (tons/yr) |
|---|---|---|---|---|
| **RESIS DATA** | | | | |
| • Maximum | 346,000 | 8.8 | $5.3 * 10^6$ | 516,000 |
| • Minimum | 10.1 | 0.00097 | 19.6 | 101 |
| • Median | 387 | 0.99 | 2,500 | 2,250 |
| **NID DATA** | | | | |
| • Maximum | 379,000 | 10.5 | | 969,000 |
| • Minimum | 10.2 | 0 | | 104 |
| • Median | 144 | 0.91 | | 818 |

*observed
**predicted

**Table 3. Regional Benefits of Soil Conservation in 1997***

| Benefits Across HUCs** | Capacity loss before dredging | | | | | |
|---|---|---|---|---|---|---|
| | 10% | | 30% | | 40% | |
| | Median | Max | Median | Max | Median | Max |
| **Marginal benefits** | | | | | | |
| MB ($/ton) | 0.0650 | 1.66 | 0.0652 | 1.67 | 0.0653 | 1.68 |
| DPV of MC ($/ton) | 0.0322 | 0.945 | 0.00623 | 0.721 | 0.00303 | 0.683 |
| **Total benefits** | | | | | | |
| Benefits ($/year) | 2,590 | $9.89*10^6$ | 2,580 | $9.96*10^6$ | 2,590 | $10.0*10^6$ |
| DPV of cost ($/year) | 1,130 | $7.45*10^6$ | 281 | $2.37*10^6$ | 136 | $1.89*10^6$ |

*Benefits lost due to erosion levels in 1982 minus the benefits lost due to erosion levels in 1997.
**Prior research defined the benefit of reduced erosion as the discounted present value (DPV) of the reduction in dredging costs (Lee and Guntermann, 1976). The DPV of cost is provided in order to compare results.

**Table 4. Nation Benefit of Soil Conservation in 1997**

| National Benefit of Soil Conservation* | Capacity loss before net benefits equal zero | | |
|---|---|---|---|
| | 60% | 80% | 100% |
| Total benefit | 148 | 141 | 139 |

* Million $/year

## Figure 1. Marginal Benefits of Reduced Erosion

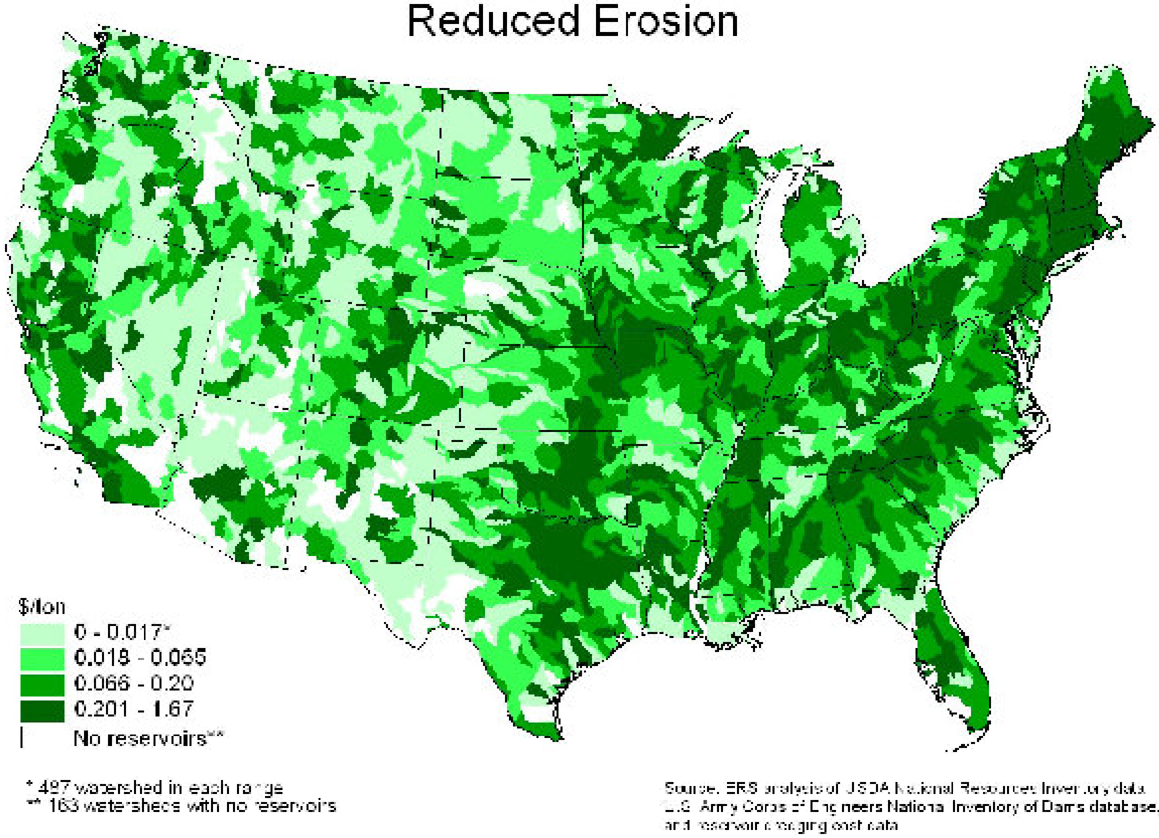

Figure 2. Total Benefits of Soil Conservation in 1997