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Economic Measures of Soil Conservation Benefits

Regional Values for Policy Assessment

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Abstract

This report describes data and methodologies that the Economic Research Service has used to apply monetary values to changes in soil erosion. Values and methodology are clearly described so that analysts can apply the data to specific soil conservation projects. ERS has used the values to estimate soil conservation benefits of changes in farm programs and practices, but no analyses of farm programs or practices are provided here. The benefit values are regional dollar-per-ton measures of 14 different categories of soil conservation benefits. There are other soil conservation benefit categories beyond those reported here, so a full accounting of benefits is not possible. As a result, monetary values derived from applications of these data are likely to be lower-bound estimates of the benefits or costs of changes in soil erosion. The data are thought to be detailed enough for national and regional estimates, but lack precision for smaller scale estimates.

Keywords: Soil conservation, benefit analysis, soil conservation benefits, nonmarket value, soil erosion, water quality benefits, air quality benefits, soil productivity

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Contents

Summary

Annual conservation program expenditures have doubled to more than $5 billion per year over the last decade. A major focus of these programs is on reducing soil erosion. This report describes the per-ton values of 14 types of soil conservation benefits. The values are derived from models that capture the cause-and-effect relationships between agricultural erosion and environmental benefits. Values and methodology are described so that analysts can apply the data to calculate regional and national benefits of specific soil conservation projects. Analysts can also use the per-ton benefit estimates to determine where a 1-ton reduction in soil erosion might be most beneficial.

What Is the Issue?

Conservation programs best serve the public when their funding, design, and implementation maximize benefits relative to costs. Unlike the cost of soil conservation efforts, environmental benefits of decreasing soil erosion are not easy to measure. Information on the values of soil conservation benefits can aid in designing more cost-effective programs and evaluating accomplishments of programs, policies, and practices.

What Does the Report Do?

Past research has generated per-ton soil conservation benefit estimates for 14 types of environmental benefits that are suitable for use in national analyses. The benefit types can be placed in three general categories:

- Twelve benefit types reflect soil conservation impacts on water quality and the subsequent impacts on industries, municipalities, and households.
- One benefit type captures the effect of wind erosion reductions on household cleaning costs.
- One benefit type has values of soil productivity preserved through reductions in wind and water erosion.

The report describes the development of each estimate, and provides some insight into regional variations in soil conservation benefits. The values can be viewed as prices that people, businesses, and government agencies would be willing to pay for a 1-ton reduction in soil erosion. For example, the reduction in municipal water-treatment costs due to a 1-ton reduction in erosion represents municipalities' willingness to pay for that much reduced erosion.

The per-ton benefit values are available on the ERS web site (www.ers.usda.gov) in two databases. One provides per-ton benefits of soil erosion reduction for the 3,074 counties within the 48 contiguous States. The other provides per-ton benefits for the 2,111 8-digit Hydrologic Unit Code (HUC) watersheds within the contiguous States. While the benefit categories in these data encompass many of the benefits of soil conservation, the categories do not measure every benefit. For example, some people may value knowing that water quality is improved—even though they do not use the water—or that endangered species have an improved habitat, but estimates of these benefits are not available. As a result, applications of the available data will provide lower-bound estimates of total soil conservation benefits.

How Was the Study Conducted?

The per-ton benefit estimates are derived from models developed since the 1980s by ERS. The estimates are believed to be the best available for national analyses of soil conservation benefits, and the ERS data are updated as improved models become available. Four of the models generate marginal dollar-per-ton benefit estimates; the others generate average per-ton estimates. Descriptions of the economic frameworks, data sources, and models supporting estimates within each of the 14 benefit categories were synthesized from USDA published reports and peer-reviewed journal articles. All of the reported values were adjusted for inflation by the Consumer Price Index, so that all values are in year 2000 dollars. The values can be directly applied to observed and potential changes in soil erosion. They can also be applied to nonagricultural changes in soil erosion, as long as the changes are appropriately calibrated. Although the data have county- and HUC-level values, the benefit values are credible only when reported at national and multi-State levels. The model descriptions provide insights on how the benefit values can best be applied and results interpreted. Values are reported by category, so users can choose those they feel are appropriate to their own applications.

Introduction

This report describes data and methodologies the Economic Research Service has used to assign monetary values to changes in soil erosion, and then explains how the results are best interpreted. The report presents estimates of per-ton values of 14 types of soil conservation benefits. The values are derived from models that capture the cause-and-effect relationships between erosion and the public's willingness to pay to reduce erosion's environmental impacts. There is one model for each type of benefit.

The data can be used to determine the value of soil conservation benefits of specific practices and programs. They can be applied directly to changes in field erosion and, with appropriate modification, to off-farm measures of soil erosion.

The benefit categories in the data sets, while not comprehensive, are the most complete set of benefit measures currently available for national assessments of soil conservation programs and practices. Many of these categories have been used to value soil conservation impacts of the Conservation Reserve Program (Hansen, 2007; Sullivan et al., 2004; Claassen et al., 2001, Ribaudo et al., 1989), the Environmental Quality Incentive Program (USDA, NRCS, 2003), and the Conservation Security Program (USDA, NRCS, 2004). The values are also built into the Regional Environmental and Agriculture Programming Model (Johansson et al., 2007).

The data are located on the ERS web site (www.ers.usda.gov/publications/tb1922/tb1922App1.xls and www.ers.usda.gov/publications/tb1922/tb1922App2.xls), so a user can easily access and apply the values and adjust them, as appropriate. Though the data do not have a comprehensive set of benefit categories, they still offer a probable lower-bound estimate of the public's willingness to pay for reductions in soil erosion and the subsequent impacts on environmental quality. However, estimates in each benefit category have weaknesses due to limits on the precision of the economic models and the underlying biological, physical, and ecological process models available at the time the benefits were estimated.

The first section of this report discusses each of the soil conservation benefit categories, concepts behind their applications, and interpretation of results. The second section provides the technical background on how the per-ton benefit estimates were derived. The economic reasoning, analytic approach, and primary data supporting each value are discussed.

Benefit Types and Values and Their Applications

Fundamentals of Per-Ton Benefit Estimates

The ERS per-ton benefit values can be found in HUC_MB (app. table 1, online only: www.ers.usda.gov/publications/tb1922/tb1922App1.xls). HUC_MB has 2,111 observations—one for each of the U.S. Geological Survey's (USGS's) 8-digit Hydrologic Unit Code (HUC) watersheds. Per-ton benefit values can also be found in COUNTY_MB (app. table 2, online only: www.ers.usda.gov/publications/tb1922/tb1922App2.xls). County_MB has 3,074 observations—one for each county of the contiguous States. Both datasets have the 14 benefit categories (see box "Soil Conservation Benefit Categories," p. 4, for names and definitions). HUC_MB has the variable *HUC*, which has the 8-digit USGS code for each observation. COUNTY_MB has the variable *county*, which has the 5-digit State-county FIPS code. COUNTY_MB also has the location variables *County_name, State_name*, and *State_abrv*, which contain county names, State names, and abbreviated State names, respectively. Both HUC_MB and COUNTY_MB have the weight variables *Water_weight*, *Soil_productivity_weight*, and *wind_erosion_weight*. Under special circumstances, these data may improve benefit calculations.

Twelve of the benefit categories are applicable to changes in water (sheet and rill) erosion only. One benefit category, *dust cleaning*, is applicable only to changes in wind erosion. The benefit category *soil productivity* is applicable to changes in both wind and water erosion. All benefit estimates have been adjusted for inflation, based on the Department of Labor's Consumer Price Index for all urban consumers (CPI-U), to year 2000 dollars.

The per-ton benefit values are conceptually similar to prices of market goods and services. Therefore, just as total revenue is equal to price times quantity (summed across all goods), total benefits are equal to the benefit values times the changes in erosion. For example, suppose there is a 5-ton reduction in water erosion and a 2-ton reduction in wind erosion within a specific HUC (or county). Then, to estimate the value of the 5-ton reduction in water erosion, we would multiply each of the 12 water-related benefit categories and *soil productivity* of that HUC (county) by 5 tons and sum all 13 values. To estimate the wind erosion benefits, we would multiply *dust cleaning* and *soil productivity* of that HUC (county) by 2 tons and sum the two values. The total benefit of these erosion reductions is equal to the sum of the water and wind erosion benefits within the specific HUC (county). The benefit categories are independent, so benefits are not double-counted.

In more general terms, the total benefit ($Total\_benefits_i$) of a change in water and wind erosion in HUC or county i can be expressed as:

$$
\begin{aligned}
Total\_benefit_i = & \sum_{j=1}^{12} (water\_erosion\_value_{i,j} * \Delta Water\_erosion\_tons_i) \\
& + soil\_productity_i * (\Delta Water\_erosion\_tons_i + \Delta Wind\_erosion\_tons_i) \qquad (1) \\
& + dust\_cleaning_i * \Delta Wind\_erosion\_tons_i .
\end{aligned}
$$

The water-related benefit categories—$water\_erosion\_value_{i,j}$, designated by the j subscripts—are the first 12 of the 14 benefit categories. (See box, “The Soil Conservation Benefit Categories,” p. 4). The values of $\Delta Water\_erosion\_tons_i$ and $\Delta Wind\_erosion\_tons_i$ are the change in water and wind erosion that an analyst wishes to value. The i subscript indicates the relevant HUC or county. Keep in mind that $Total\_benefits_i$ is not a total of all soil conservation benefits. It is a total of what can be estimated from the available data.

Equation 1 can be estimated for all HUCs or counties, when erosion estimates are available. To provide reliable estimates, the HUC-level values of equation 1 must then be aggregated to larger watersheds, such as the U.S. Geological Survey’s 12 2-digit hydrologic drainage basins. And the county-level values must be aggregated to multicounty regions that are larger than States, such as the U.S. Department of Agriculture’s 10 Farm Production Regions (FPRs) and the Economic Research Service’s 9 Farm Resource Regions (FRRs). In general, benefits estimated for smaller geographic regions will be less reliable, given that 11 of the benefit values are multi-State—specifically, FPR-level—averages. Note that three benefit values are estimated by HUC and, as a result, are likely to provide reliable estimates for HUCs and larger regions.

Equation 1 is relevant when HUC- or county-level estimates of erosion are available. But when erosion changes are reported on a larger geographic scale, mean-value estimates of $water\_erosion\_value_i$, *soil_productivity* and *dust_cleaning* suited to the geographic scale will need to be calculated. That is, suppose the analyst has access to FRR-level estimates of changes in soil erosion. Then, in order to estimate the value of the changes in erosion, the analyst needs FRR-level values of $water\_erosion\_value_i$, *soil_productivity*, and *dust_cleaning*. A linear average of the per-ton values is not likely to be appropriate because erosion levels are higher in some counties and HUCs, and it is reasonable to assume that erosion changes are more likely to occur where erosion is greater. To facilitate calculations based on this assumption, $Water\_weight_i$ is set equal to the total water erosion in the county or HUC $_i$. The weighted mean value of water-erosion benefit j for region k, $weighted\_mean\_water\_erosion\_value_{k,j}$ is:

$$weighted\_mean\_water\_erosion\_value_{k,j} = \frac{\sum_{i=1}^{N} water\_erosion\_value_{i,j} * Water\_weight_i}{\sum_{i=1}^{N} Water\_weight_i} \quad (2)$$

The counties i=1 through N lie in region k. And weighted mean values of *soil_productivity* and *dust_cleaning* ($weighted\_mean\_soil\_productivity_k$ and $weighted\_mean\_dust\_cleaning_k$, respectively) are similarly calculated, but using the weights $Soil\_productivity\_weight_i$ and $Dust\_cleaning\_weight_i$, respectively, instead of $Water\_weight_i$.

Then total benefit (inasmuch as the data allow) for region k ($Total\_benefits_k$) of a change in water and wind erosion in region k is expressed as:

The Soil Conservation Benefit Categories

Categories	Consumer/producer surplus gain due to	Level of aggregation	Range of values ($/ton)	Year estimated
Reservoir services	Less sediment in reservoirs	HUC	0 to $1.38	2007
Navigation	Shipping industry avoidance of damages from groundings	HUC	0 to $5.00	2002
Water-based recreation	Cleaner fresh water for recreation	HUC	0 to $8.81	1997
Irrigation ditches and channels	Reduced cost of removing sediment and aquatic plants from irrigation channels	FPR	$0.01 to $1.02	2007
Road drainage ditches	Less damage to and flooding of roads	FPR	$0.20	1986
Municipal water treatment	Lower sediment removal costs for water-treatment plants	FPR	$0.04 to $1.45	1989
Flood damages	Reduced flooding and damage from flooding	FPR	$0.10 to $0.77	1986
Marine fisheries	Improved catch rates for marine commercial fisheries	FPR	0 to $0.93	1986
Freshwater fisheries	Improved catch rates for freshwater commercial fisheries	FPR	0 to $0.12	1986
Marine recreational fishing	Increased catch rates for marine recreational fishing	FPR	0 to $1.57	1986
Municipal & industrial water use	Reduced damages from salts and minerals dissolved from sediment	FPR	$0.07 to $1.47	1986
Steam powerplants	Reduced plant growth on heat exchangers	FPR	$0.04 to $1.05	1986
Soil productivity	Reduced losses in soil productivity	FPR	$0.37 to $1.21	1990
Dust cleaning	Decrease in cleaning due to reduced wind-borne particulates	FPR	0 to $1.14	1990

HUCs are watersheds defined by USGS's 8-digit hydrologic unit codes; FPRs are USDA's multi-state Farm Production Regions.

All dollar values are adjusted to year 2000.

$$Total\_benefit_i = \sum_{j=1}^{12} (weighted\_mean\_water\_erosion\_value_{k,j} * \Delta Water\_erosion\_tons_i)$$
$$+ weighted\_mean\_soil\_productivity_k * (\Delta Water\_erosion\_tons_k + \Delta Wind\_erosion\_tons_k) \quad (3)$$
$$+ weighted\_mean\_dust\_cleaning_k * (\Delta Water\_erosion\_tons_k)$$

Water_weight$_i$, *Soil_productivity_weight*$_i$, and *Dust_cleaning_weight*$_i$ are based on the USDA's 1997 National Resources Inventory (NRI), the most recent data that provide a means of generating county- and HUC-level erosion estimates (USDA, NRCS, 2000). While erosion is likely to have changed since 1997, we know that if erosion changes were proportionately equal across counties and HUCs, the weights would not change. But if changes are not proportional, as is likely the case, then the reliability of the weights may be decreased. Note that 11 of the 14 variables are FPR-level averages, so that when a region *k* is an FPR, weights will not affect benefit estimates. The weights in these data are updated as better erosion estimates become available.

Data Shortcomings

While the data and equations 1, 2, and 3 make it relatively easy to value 14 soil conservation benefits, interpretation of results requires an understanding of the data's shortcomings. The four most important are:

1. **The values in each soil conservation benefit category are average regional values, which do not capture intraregional variations in values**. Values in 11 of the benefit categories of the ERS data have been generated by models that provide values for each of the 10 FPRs (fig. 1). As a result, the per-ton benefit values do not vary across counties or HUCs within the same FPR. The actual value of a 1-ton reduction in erosion is likely to vary across HUCs and counties within each region. Because this variation is not captured, the estimated HUC and county values might be equal to, greater than, or less than the actual values. However, as we aggregate HUC- and county-level estimates, the standard error around benefit estimates is likely to fall.

   In contrast, three of the soil conservation benefit categories—*reservoir*, *shipping*, and *recreation*—have values that are taken from studies that generate HUC-level values. The county-level estimates are based on the HUC/county overlaps and are expected to provide fairly reasonable estimates. But neither the HUC- nor county-level estimates capture the variation in values within HUCs or counties. In other words, these per-ton benefit estimates do not capture field-to-field variations in soil conservation benefits.

   The actual value of a 1-ton reduction in erosion depends both on physical factors—the quantity of sediment that reaches a stream or lake and the subsequent ecological impact—and economic factors, the willingness of firms and individuals to pay to prevent or eliminate the ecological impacts.[1] The per-ton benefit values embody these relationships, or more precisely, the average value of these relationships. When evaluating changes in farm programs and practices, consideration of field-to-field variation is important when erosion changes occur on acreage with greater, or less than, average physical or economic impacts. For example,

[1]To the extent that nutrient and sediment effects on benefits are correlated, the reported dollar-per-ton benefit estimates will include effects of nutrients.

Figure 1
USDA's Farm Production Regions

analyses of programs that target land with specific characteristics, such as riparian buffers, could produce biased results. A 1-ton reduction in erosion by riparian buffers is likely to have greater water quality impacts than a 1-ton reduction elsewhere in the region (HUC, county, etc.) (Khanna et al., 2003). Consequently, a program that reduces relatively more erosion on riparian lands will likely have greater-than-average water quality impacts per ton of erosion. The benefit values are still useful, but conclusions drawn from such analyses must include the caveat that the estimated benefits might be biased downward.

2. **Not all soil conservation benefits are included.** A further shortcoming of the benefit estimates derived from the 14 soil conservation benefit categories is that the estimates do not include all soil conservation benefits. The impacts on wetlands, endangered species, and most coastal recreational activities, as well as people's willingness to pay simply to know that water quality is improved, are examples of conservation benefits that have not been modeled. Finally, to a smaller degree, benefit estimates are likely to be biased downward because 13 of the models are built on theoretical frameworks (the replacement cost, damage function, and averting-behavior frameworks) that cannot capture full willingness to pay (Ribaudo and Hellerstein, 1992).

3. **Benefit values are designed to be applied to farmland erosion**. The per-ton values are applicable to changes in erosion on agricultural lands. However, the benefit values can also be applied to nonagricultural erosion, if properly calibrated. The calibration must be based on an equivalence of the environmental quality impacts of agricultural erosion

and erosion from the nonagricultural source. For example, if, in a given region, a 1-ton reduction in agricultural erosion has the same water quality impact as a 2-ton reduction in erosion at construction sites (measured by the quantity of sediment reaching a stream), then the water quality benefit of a 1-ton reduction in erosion at construction sites is half the value of a 1-ton reduction in agricultural erosion.

4. **Values have been adjusted for inflation, but other time-related factors may be relevant.** Ten of the 14 benefit values were estimated more than 20 years ago, 1 was estimated in the late 1990s, and the remaining 3 were estimated within the last 6 years. Over time, the benefit values might have changed, but the size and direction of change in any one of the benefit values are unknown. For example, municipal water treatment costs are likely to increase with increases in the population served, but advances in water treatment technology are likely to lower treatment cost. Increases in populations might tend to increase the total willingness to pay for improvements in environmental quality, but increases in the availability of substitute activities and goods that come with increases in populations might decrease willingness to pay. Increases in incomes can raise the value of surrounding amenities, but improved transportation can make alternative sites comparable substitutes. These and other factors might affect some or all of the benefit values discussed here. At this point, there appears to be no means of capturing the net effect of these factors. Lacking evidence to suggest otherwise, we assume, after adjusting for inflation, that the benefit values have not changed over time. We do know that, over time, inflation decreases the real purchasing power of the dollar. We therefore have adjusted all benefit values for inflation, based on the Department of Labor’s Consumer Price Index for all urban consumers (CPI-U), to year 2000 dollars.

The Benefit Models: Economic Theory and Empirical Methodologies

Four theoretical frameworks—travel cost, damage function, replacement cost, and averting expenditures—underlie the 14 soil conservation benefit models. (For a detailed discussion of these and other methods, see Lew et al., 2001.) All are indirect means of estimating environmental benefits.

Travel Cost

This method uses expenditure and trip data to estimate the demand for a recreation activity where environmental quality is one of the determinants of demand. Changes in consumer surplus associated with changes in environmental quality can be derived from the estimated demand function. The approach requires data on respondents' recreational activities and travel costs (including the cost of time) and the environmental quality of recreation sites the person visited, as well as potential substitute sites.

Damage Function

This approach applies to businesses that use an environmental input, such as water. It is based on the assumption that the loss in welfare due to a decrease in environmental quality is approximately equal to the value of the loss in revenue or increase in costs. The approach is thought to provide conservative benefit estimates, first, because it implicitly assumes that no remedial actions are taken and, second, because market effects are not considered (Freeman, 1993). However, in the case of a single-product firm, the damage function approach will not underestimate the change in welfare, as long as the change in environmental quality does not change the quality or quantity of the firm's output (Ribaudo and Hellerstein, 1992).

Replacement Cost

This method assumes that the loss in welfare due to a change in environmental quality is approximately equal to the expenditures made to replace, repair, or restore goods and capital assets. Like the damage function approach, the replacement cost approach is believed to provide a conservative benefit estimate because, first, if there are no expenditures, the approach sets the value of the damages equal to zero. Second, as with the damage function approach, the replacement cost method assumes that no remedial action is taken. And third, the approach ignores the cost of reduced performance before the good is replaced.

Averting Expenditures

This approach assumes that the loss in welfare due to a change in environmental quality is approximately equal to the change in expenditures made to counteract the change in quality of the environmental asset. The approach assumes that marginal changes in defensive expenditures leave the quality of the environmental good(s) unchanged (changes in expenditures are a perfect substitute for changes in environmental quality). However, because it is commonly accepted that this assumption does not hold, the averting-expenditures approach is believed to provide conservative benefit estimates

(Freeman, 1993; Ribaudo, 1989). In practice, it can be difficult to isolate the portion of expenditures that is attributable to averting activities (Winpenny, 1991).

Averting expenditures occur before losses are incurred. For example, suppose forest lands are cleared in order to create or expand downhill ski slopes. Without the tree canopy and the ecology of a forest floor, runoff from summer rains swells streams and increases downstream flood frequency and levels. In response, individuals living in the flood plain raise the foundations of their houses. The cost of raising foundations is an averting expenditure and represents part of what people would be willing to pay, in advance, to have prevented the environmental impacts of the ski slopes. Others might move away, or stay and deal with the additional losses; all would be willing to pay to prevent impacts, but their willingness to pay is not captured by the averting-expenditures approach.

Model and Data Descriptions

All of the benefit models are reduced-form models in that the per-ton benefit estimates embody a complex set of physical processes, linking changes in erosion on agricultural lands to environmental quality and the economic values that individuals, firms, and the public sector place on changes in environmental quality. For example, the per-ton estimates related to water quality capture water's effect on soils and nutrients in fields and on their movements to waterways, the subsequent changes in water quality and ecology, the effects that these changes have on water users (individuals, firms, and the public sector), and the values individuals place on changes in these effects (fig. 2).

Of the 14 models described in this report, three models, estimated since 1997, generate dollar-per-ton benefit values for each of the 2,111 8-digit hydrologic unit code (HUC) watersheds of the contiguous States. Each of these models estimates the value of reductions in water erosion. The sum of the per-ton values, by HUC, ranges from zero to $14.38. The other 11 models, most of them estimated in the 1980s, generate benefit values by the multi-state Farm Production Regions (FPRs) (fig. 1). One benefit category—soil productivity benefits—accounts for changes in both water and wind erosion. Ten are applicable only to water erosion. The remaining benefit category is applicable to changes in wind erosion. The sums of the per-ton water erosion and soil productivity benefits by FPR range from $1.46 to $7.12 per ton. The sums of the wind erosion and productivity benefit values within the FPR range from $0.41 to $1.54 per ton (table 1).

Watershed Benefit Models

The three watershed studies apply very different approaches. However, they are similar in that each begins by estimating values of soil conservation impacts at sites and then aggregates across sites to generate HUC-level estimates.

Table 1

Benefit estimates ($/ton) produced by models that generate estimates for Farm Production Regions[1]

Farm Production Region[2]	Irrigation ditches and canals	Road drainage ditches	Municipal water treatment	Flood damages	Marine fisheries	Freshwater fisheries
Appalachia	0.01	0.2	0.05	0.26	0.01	0.02
Corn Belt	0.01	0.2	0.18	0.10	0.00	0.01
Delta States	0.12	0.2	0.04	0.71	0.02	0.12
Lake States	0.03	0.2	0.32	0.50	0.00	0.12
Mountain	0.54	0.2	1.06	0.21	0.00	0.00
N. Plains	0.12	0.2	0.22	0.13	0.00	0.00
Northeast	0.01	0.2	0.27	0.77	0.93	0.00
Pacific	1.02	0.2	0.47	0.33	0.42	0.00
S. Plains	0.22	0.2	1.45	0.27	0.14	0.03
Southeast	0.16	0.2	0.31	0.53	0.00	0.00

—continued

[1]Values reflect a 1-year reduction in erosion.
[2]See figure 1 for the location of each FPR.

Reservoir Services

As sediment accumulates in reservoirs, the quantity and quality of reservoir services are reduced. For example, reservoir sediment can reduce the quality of beaches, shoreline boating, water reserves for power generation, capacity for holding flood waters, and the quality of spawning grounds. An increase in erosion can increase the rate that sediment settles in a reservoir and, as a result, leave the sediment level higher and service lower in subsequent years. Conversely, reducing erosion will reduce the rate that sediment settles in a reservoir and leave future reservoir service levels higher (Hansen and Hellerstein, 2007). Dredging a reservoir restores services, so dredging expenditures can be assumed to represent a restoration (replacement) cost.

The parameters of the benefits model are estimated by applying the replacement cost method and assuming that reservoir owners/managers dredge reservoirs at the optimal time, when marginal benefits equal marginal costs. Dredging costs are assumed to be a function of reservoir characteristics and the quantity of sediment dredged. The reservoir benefits model by Hansen and Hellerstein (2007) is estimated using public and private reports of dredging costs. They also estimate a sedimentation model, linking changes in erosion to changes in reservoir sedimentation, and couple it with the benefit model so benefits can be linked to changes in erosion. Given the historical nature of the dredging data, Hansen and Hellerstein assume the decisions to dredge were based on erosion rates similar to those observed in the 1982 National Resources Inventory (NRI). The NRI contains 800,000 statistically based sample points on U.S. non-Federal range, crop, pasture, and forest lands (USDA, SCS, 1984).

The reservoir benefits model and sedimentation model are used to generate reservoir-level marginal benefit estimates. The model estimates account for the multiyear impacts that a one-time reduction in soil erosion will have. With the marginal benefit estimates, we can value the increase in present and

Table 1

Benefit estimates ($/ton) produced by models that generate estimates for Farm Production Regions[1]—continued

Farm Production Region[2]	Marine recreational fishing	Municipal and industrial use	Steam power-plants	Soil productivity	Dust cleaning	Total water-related	Total wind-related
Appalachia	0.01	0.43	0.92	0.57	0.00	2.47	0.57
Corn Belt	0.00	0.21	1.05	1.01	0.00	2.77	1.01
Delta States	0.02	0.68	0.44	0.43	0.00	2.76	0.43
Lake States	0.00	1.36	0.94	1.21	0.00	4.68	1.21
Mountain	0.00	0.21	0.29	0.26	0.60	3.37	0.86
N. Plains	0.00	0.07	0.33	0.41	0.64	1.46	1.05
Northeast	1.57	1.45	0.66	1.27	0.00	7.12	1.27
Pacific	0.49	0.17	0.04	0.40	1.14	3.54	1.54
S. Plains	0.41	0.28	0.24	0.37	0.38	3.61	0.75
Southeast	0.00	0.48	0.42	0.41	0.00	2.51	0.41

[1]Values reflect a 1-year reduction in erosion.
[2]See figure 1 for the location of each FPR.

Figure 2
Reduced-form models implicity capture the links between changes in erosion and benefit values

Changes in Erosion Are Estimated

Estimates of erosion changes are based on:
1) rainfall erosivity
2) soil erodibility
3) slope characteristics
4) crop management
5) conservation practices

Movement of Soil to Waterway Are Implicitly Captured

Factors that affect the amount of eroded soil that reaches a waterway:
1) distance to waterway
2) slope of the land to the waterway
3) cover on the land

Sediment's Impacts on Physical and Biological Resources Are Implicitly Captured

Sediment's impacts on physical and biological resources:
1) water looks 'dirty'
2) beaches become muddy
3) sediment settles in reservoirs and shipping lanes
4) sediment in flood waters increases flood damages
5) sediment decreases the quality of fish habitat

Physical and Biological Effects on Environmental Amenities Are Implicitly Captured

Environmental amenities that are affected
1) swimming, boating, and recreational fishing
2) commercial fishing
3) navigation
4) water storage

Benefit Values Are Measured

Benefit values are measures of changes in:
1) consumer surplus
2) producer surplus
3) government costs

future reservoir services resulting from a marginal reduction in agricultural erosion.

The HUC-level marginal benefit values for reservoir services are derived from the reservoir-level marginal benefit estimates. Values are calculated in four steps. First, the marginal benefit of a 1-percent reduction in the erosion rate is calculated for each of the more than 70,000 reservoirs in the United States. Second, the marginal benefits are summed across the reservoirs within each HUC. Third, the change in erosion (number of tons) associated with a 1-percent change in the erosion rate on agricultural lands is calculated for each HUC. Finally, each HUC-level marginal benefit estimate is converted to a per-ton estimate by dividing the benefit estimate by the number of tons represented by a 1-percent change in the erosion rate.

The estimates of marginal reservoir benefits vary widely across HUCs. In 163 HUCs, marginal benefits equal zero. These HUCs appear to have no reservoirs affected by agriculture. In the remaining watersheds, per-ton soil conservation benefits are as high as $1.38.

Navigation Industry

Sediment buildup in shipping channels and harbors delays water traffic and damages ships and barges that run aground. To avert these delays and damages, the navigation industry, through the Army Corps of Engineers, dredges harbors and shipping channels. Because the dredging is done to avoid future damages, the costs represent averting expenditures.

The navigation industry model provides HUC-level estimates of the expected reduction in averting expenditures resulting from a 1-ton reduction in erosion. The model is estimated in two steps. First, an average dollar-per-ton cost of erosion is estimated for each site dredged by dividing total site-level dredging costs—where sites are harbors and segments of shipping channels—by total upstream erosion. Data on erosion and a hydrologic model are used to estimate the total tons of erosion upstream of each site. Second, HUC-level per-ton benefits are estimated by summing the dollar-per-ton estimates across all relevant downstream sites (Hansen et al., 2002).

The hydrologic data are from the River Reach File of the U.S. Environmental Protection Agency (EPA), which interconnects 3.2 million miles of streams. Estimates of agricultural erosion by HUC are based on data from the 1997 NRI (USDA, NRCS, 2003). Dredging-cost data are from the U.S. Army Corps of Engineers (1999a; 1999b). Results show that, across HUCs, a 1-ton reduction in soil erosion can reduce dredging costs by from $0.0 to $5.00.

Water-Based Recreation

Suspended sediment in lakes, rivers, and streams harms aquatic wildlife and decreases the water's aesthetic appeal, which lowers the quality of fishing, swimming, and other water-contact activities. To calculate sediment's impact on consumer surplus, a multisite travel-cost demand model for water-based recreation is estimated, where demand is a function of—among other things—

travel costs to each site and its water quality (Feather and Hellerstein, 1997; Feather et al., 1999).

The travel cost model is estimated in a two-step process. First, the site selection process is characterized by a random utility model (RUM). The RUM is estimated using data on individual and site characteristics. The estimated model is then applied to each observation to predict the probability that an individual will select a given recreation site. The second step begins by using the RUM probability estimates. Based on these estimates, an expected price (travel cost) and expected level of environmental quality (where erosion levels and the size and type of water body serve as proxies) are calculated for each individual. The estimates of expected price and site quality are probability-weighted averages of the prices and qualities of the relevant sites.

In the second step, the demand for water-based recreation is estimated by regressing the number of trips taken against expected price, expected environmental quality, and other demand determinants. The marginal change in consumer surplus associated with a change in soil erosion within a HUC is calculated for each affected individual. The HUC-level marginal benefit estimate is the sum of individuals' consumer surplus changes.

The model is estimated using behavioral data from the 1994-95 National Survey of Recreation and the Environment (2005) and environmental data from the 1997 NRI.

Estimates from the water-based recreation model indicate that a 1-ton reduction in soil erosion can increase societal benefits of water-based recreation by from \$0.0 to \$8.81 across the 2,111 U.S. watersheds.

Farm Production Region Benefit Models

The remaining 11 models deliver benefit estimates at the FPR level. Six were originally derived from State or sub-State models, but the model estimates were aggregated and subsequently reported by FPR. The others were derived from national-level data on costs that were then apportioned to FPRs.

Marine Recreational Fishing

Soil erosion can harm marine fisheries by damaging estuaries. Estuaries provide year-round habitat and are the principal spawning grounds for shellfish and a wide variety of fin fish. Sediment and nutrients can impair estuarine habitats, adversely affect fish populations, and decrease the quality of marine recreational fishing.

Clark et al. (1985) generated a national estimate of erosion's impact on marine sport fisheries, based upon analyses by Freeman (1982). Ribaudo (1986) allocated this national estimate to FPRs based upon which estuaries were impaired and the number of saltwater angling days affected. Ribaudo used water quality monitoring data from the National Stream Water Quality Accounting Network (NASQUAN) of the U.S. Geological Survey (USGS) monitoring system to determine which watersheds (USGS's Aggregated Sub-Areas) were impaired by sediment. He assumed that estuaries adjacent to sediment-impaired Aggregated Sub-Areas were also impaired. Data on the location of 180 major estuaries were obtained from the National Oceanic and Atmospheric Administration.

The total number of saltwater angling days within each FPR was obtained from the U.S. Fish and Wildlife Service's Hunting and Fishing Survey (U.S. Dept. of the Interior, 1997). The number of impaired fishing days is estimated by multiplying the percentage of estuaries affected by erosion within an FPR by the total angling days. Affected angling days then become weights for allocating total damages. Damages in each FPR were divided by total erosion in each FPR to arrive at an average damage per ton of erosion. A unit reduction in erosion would produce approximately the same level of benefits. Soil conservation benefits, based on the marine recreational fishing model, range from $0.0 in the five inland FPRs to $1.57 per ton.

Marine Commercial Fisheries

Sediment in estuaries also affects commercial fisheries. As with modeling of impacts on recreational fishing, Ribaudo (1986) used the damage function approach. His analysis begins with a national estimate of total damages to marine commercial fisheries.

Bell and Canterberry (1975) provide an estimate of total annual damages to marine fisheries from all water pollution. Ribaudo assumes that erosion's share of damages to commercial fisheries is the same as erosion's share of damages to marine recreational fishing, as assumed by Clark et al. (1985). His erosion damage model allocates soil erosion damages equally across all impaired estuaries. Impaired estuaries are assumed to be all those that are part of USGS Aggregated Sub-Areas that have been designated as having water quality problems due to erosion. The model then links the damaged estuaries to the FPRs. Those estuaries that lie along the coast of an FPR are linked to that FPR. Total FPR-level damages are estimated by summing across estuaries within each FPR. Finally, per-ton damage estimates are derived by dividing each FPR-level damage estimate by total erosion in the region.

Soil conservation benefits, based on the marine commercial fisheries model, range from $0.0 in the five inland FPRs to $0.94 per ton.

Freshwater Commercial Fisheries

Water pollutants associated with sediment inhibit fish populations and decrease revenues of the freshwater fisheries industry. To derive soil conservation benefits to freshwater fisheries, a model, based on the damage function approach, is estimated from data on sediment's cost to the fisheries.

The national costs of sediment's impact on the commercial freshwater fisheries industry reported by Clark et al. (1985) are allocated across FPRs, based on the FPR's share of the total river-miles with concentrations of suspended sediment, nitrate-nitrite, and total phosphorus above thresholds considered relevant for water-based recreation (Ribaudo, 1986). Estimates of national and regional water quality-impaired river miles are based on USGS NASQAN data, National Water Discharge Inventories data from Resources for the Future, and the EPA River Reach File (Ribaudo, 1986). Recreation-based water quality thresholds were obtained from EPA (Zison, Haven, and Mills, 1977). Damage estimates are divided by total sheet and rill erosion in the FPR from the 1982 NRI to arrive at an average cost per ton of erosion. A unit reduction in erosion would produce a like-level of benefits.

Soil conservation benefits across FPRs range from $0.0 to $0.12 per ton.

Steam-Electric Powerplants

Sediment and algae caused by soil erosion can affect the operation of steam-electric powerplants—most powerplants are steam-electric—and other facilities that use large amounts of water. Suspended sediment and algae can clog condensers, reducing the efficient operation of cooling systems. Periodic removal of algae from condensers restores water inflow rates. The benefits of reducing these costs are estimated by using the replacement cost approach.

Clark et al. (1985) generated a national estimate of annual restoration costs, based on a study of the cost of removing algae from water cooling systems. Ribaudo (1986) allocated these costs across the 10 FPRs, based on the amount of sediment withdrawn in water used for thermoelectric power generation. A proxy for sediment withdrawn is the product of gallons withdrawn and sediment concentration. Data on gallons of water withdrawn within each FPR were obtained from USGS. Average suspended sediment concentrations in each FPR are calculated using NASQUAN monitoring data. The FPR restoration cost estimates are then divided by total sheet and rill erosion in the FPR, based on the 1982 NRI, to arrive at an average cost per ton of erosion.

Soil conservation benefits range from $0.04 to $1.05 per ton.

Municipal and Industrial Water Use

Treated water can still contain minerals, salts, and other materials that damage water-use equipment. The model of erosion's impact on municipal and industrial water use is therefore based on the damage function approach.

Clark et al. (1985) used EPA estimates of the costs of achieving Clean Water Act goals to estimate the annual removal and damage costs of dissolved materials associated with soil erosion. Ribaudo (1986) allocates these damages among the 10 FPRs, based on the amount of water withdrawn for municipal and industrial uses. Ribaudo used the same procedure as for steam cooling, the only difference being that gallons of water withdrawn by industry and households were used to create the weights. FPR-level damage estimates were divided by total sheet and rill erosion from the 1982 NRI to arrive at an average damage per ton of erosion. A unit reduction in erosion would produce a like-level of benefits.

Soil conservation benefits range from $0.07 to $1.44 per ton.

Flood Damages

Suspended sediment in stream waters increases the frequency and severity of flooding. Reservoirs and flood plains have helped reduce flood damages, yet damages still occur. Erosion plays a dual role in flood damages. First, it increases suspended sediment in stream flow, which then adds to the volume of the flow. The greater volume increases flood frequencies and the height of flood waters. Second, with greater concentrations of suspended sediment, floodwaters deposit more sediment, which increases damages to roads, farm fields, homes, and other flooded sites. With available data, the benefits of soil conservation's impacts on flood damages are estimated using the damage function approach.

The total cost of agricultural sediment-related flood damages was obtained from Clark et al. (1985). The national damage estimate was allocated to FPRs based on the distribution of total (sediment and nonsediment) flood damages reported by the U.S. Water Resources Council (1978). The FPR-level flood damage estimates were then divided by total agricultural erosion within the regions to generate dollar-per-ton benefit estimates.

Soil conservation benefits of reduced flood damages range from $0.10 to $0.77 per ton.

Irrigation Ditches and Canals

Nutrients and sediment originating on fields can cause excessive sediment buildup and weed growth in irrigation canals, impeding water flow in irrigation systems. Removing the sediment and weeds can restore the irrigation system to its original condition. With data on sediment and weed removal costs, soil conservation benefits are calculated using the replacement cost approach.

Clark and others (1985) estimated that approximately 15 to 35 percent of the operation and maintenance costs for irrigation systems is for weed control and ditch clearing. Ribaudo (1989) used the midpoint of this range, along with data on maintenance costs from the 1978 Census of Agriculture's *Ranch and Irrigation Survey* (U.S. Bureau of the Census, 1982) to estimate annual weed control and ditch-clearing costs associated with erosion for each State, which he then aggregated to the FPR level. Dividing this value by total sheet and rill erosion provides an estimate of the cost per ton of erosion.

We have used Ribaudo's approach and assumptions, erosion estimates from NRCS (2007), and weed control and ditch maintenance costs from the *2001 Census of Agriculture* to generate a more up-to-date estimate of soil erosion's impact on irrigation ditches and canals.

Soil conservation benefits range from $0.01 to $1.02 per ton.

Soil Productivity

Erosion carries topsoil off fields, which reduces the land's productivity. Some, but not all, yield loss can be offset by increasing nutrient use. Because soil loss decreases output and increases costs, the damage function approach is appropriate for modeling erosion's impact on soil productivity.

The Erosion Productivity Impact Calculator (EPIC) model (Williams et al., 1985) was used to estimate soil and yield losses and increases in input use across 12,000 combinations of geographic regions, soil groups, crops, tillage, and conservation practices (Ribaudo et al., 1990). (The analysis assumes that farmers, in order to maximize profits, increase nutrient use to offset some of the productivity impacts of soil loss). These estimates were aggregated to generate FPR-level estimates of soil loss and the value of its productivity impact (Ribaudo et al., 1990). Per-ton estimates were derived by dividing total productivity impacts by total erosion (water and wind).

Values of *soil productivity* are based on the assumption that the land is in production. Benefits will not accrue while the land is fallow. Calculations for valuing the productivity effects of retired lands must discount benefits from the time when the land returns to production.

Soil conservation benefits, based on the soil productivity model, range from $0.26 to $1.27 per ton.

Road Drainage Ditches

Sediment carried off farms can fill roadside ditches, reducing the capacity of ditches to store and move floodwaters. Floodwaters can damage roads and impede traffic flows. Appropriate maintenance prevents or reduces these costs. With data on road maintenance costs, a model, based on the averting-expenditures approach, was developed to estimate the value of this benefit of soil conservation.

Ribaudo (1989) estimated a model where the annual cost of road maintenance was specified as a function of gross sheet and rill erosion, rural road mileage, and the cost of removing a cubic yard of sediment. Data on ditch maintenance costs were obtained from 33 State highway departments.

Results indicate that each ton of gross erosion reduction translates into an average reduction in ditch maintenance costs of $0.20.

Municipal Water Treatment

Sediment in surface waters can increase municipal water treatment costs. Sediment, in effect, damages or degrades the quality of water. A model that captures municipalities' willingness to pay to improve water quality can be estimated using the damage function approach.

A model of the effect of sediment on water treatment costs was estimated, using a water treatment cost model developed by Holmes (1988). The model expresses operation and maintenance costs of a treatment plant per million gallons of water withdrawn, as a function of the amount of water treated, the water's turbidity, labor cost, and electricity cost. This water treatment cost model was estimated with data from 294 treatment systems around the country.

To apply the treatment cost model to changes in erosion, Ribaudo (1989) estimates a water turbidity model, where turbidity is a log-linear function of soil erosion, streamflow, and water storage capacity. He uses the turbidity model to estimate the change in water turbidity within a USGS Aggregated Sub-Area due to a change in erosion. He then uses the treatment cost model to calculate the marginal benefits of reductions in turbidity for each Aggregated Sub-Area. The per-unit costs were multiplied by estimated changes in turbidity given a marginal change in erosion. To develop FPR estimates of marginal per-ton benefits, estimates within each FPR were summed and weighted by the quantity of surface water the municipalities withdraw.

Soil conservation benefits, based on the municipal water treatment model, range from $0.05 to $1.16 per ton.

Dust Cleaning

Wind-borne particulates pass through cracks and openings in homes and settle on floors and furniture. Cleaning is necessary to get rid of the dust. Available cleaning-cost data and a replacement cost model are used to estimate the benefits of reduced wind erosion.

Huszar and Piper (1986) estimated a household-cleaning-cost model (which was subsequently improved by Huszar, 1989), where costs are a nonlinear function of household characteristics and wind erosion within the household's resident county. Their cost model is estimated with data from a survey of households in New Mexico. Ribaudo et al. (1990) used the model, along with data from 1980 Household Census and data on wind-erosion from the 1982 NRI, to estimate household cleaning costs and changes in costs due to changes in erosion by State for all States in the Northern and Southern Plains, Mountain, and Pacific FPRs. Marginal, per-ton benefit values were derived by dividing the changes in cleaning costs by the associated changes in wind erosion (Ribaudo et al., 1990).

Soil conservation benefits, based on the dust cleaning model, range from $0.0 in the six eastern FPRs to $1.14 per ton.

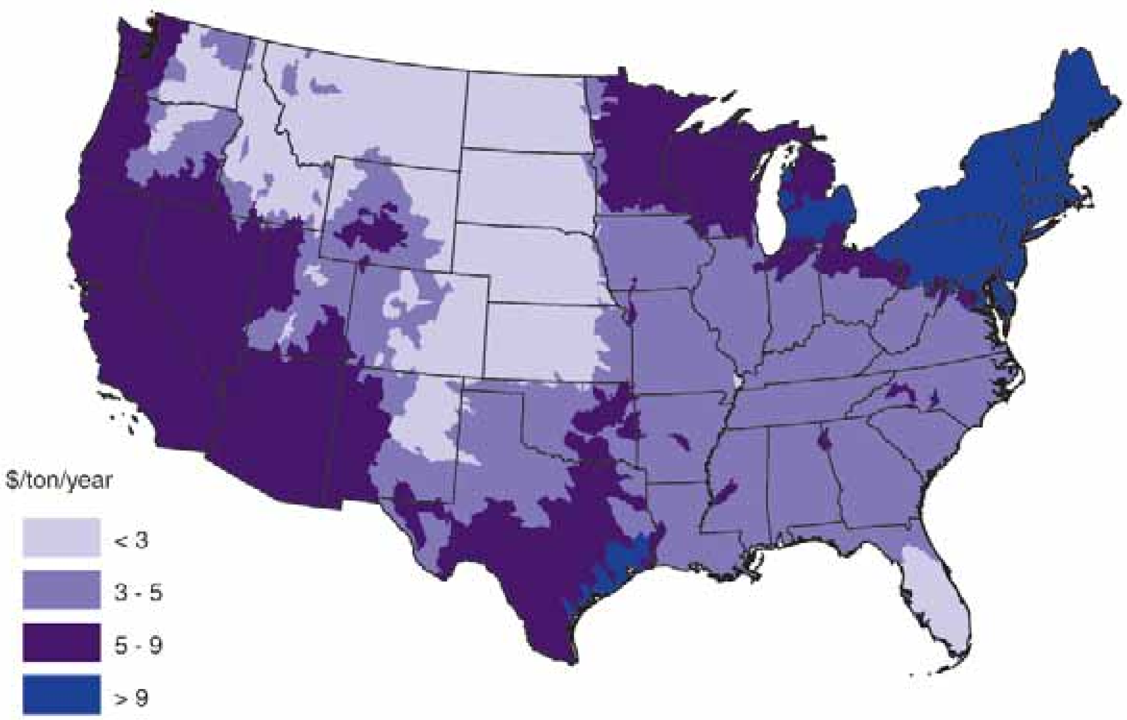
Most of the per-ton benefit estimates of the 11 FPR models are less than $0.50 (table 1). Though per-ton values are not high, each provides insight into the benefits of soil conservation programs and practices. Furthermore, the values provide a rough perspective on where the value of a reduction in erosion might be greatest.

Soil Conservation Benefits: HUC- and County-Level Values

The HUC-level water quality benefit categories (*reservoir services, navigation, and water-based recreation*) vary across H.JCs. For those water quality benefit categories based on FPR-level estimates, values are broken down to HUC-level estimates based on the location of the HUC. Most HUCs lie in a single FPR. In these cases, the HUC-level values are set equal to the FPR-level values. Where HUCs lie in more than one FPR, the HUC-level values are erosion-weighted average values of the appropriate FPRs. The HUC-level sums of all categories of water-erosion benefits range from $1.11 to $17.55 per ton (fig. 3).

Values of wind-erosion impacts are estimated at the FPR level. The same approach as that used for HUC-level water quality benefits is used to generate HUC-level estimates of wind-erosion values. Wind-erosion benefit values, for the most part, follow FPR boundaries (fig. 4). Values vary along the borders of FPRs, where HUC-level estimates are weighted averages of he

Figure 3
Range and distribution of all water-erosion benefit values, by HUC



HUC-level[1] water-erosion benefit categories are: *reservoir services, navigation, water-based recreation, marine fisheries, freshwater fisheries, municipal industrial, steam electric, irrigation ditches, flood damages, soil productivity, road ditches*, and *municipal water treatment*. Only *reservoir services, navigation*, and *water-based recreation* are estimated at the HUC level. Other values are based on FPR-level[2] estimates.

[1]HUCs are watersheds defined by the U.S. Geological Survey's 8-digit hydrologic unit codes.
[2]FPRs are USDA's multi-state Farm Production Regions.

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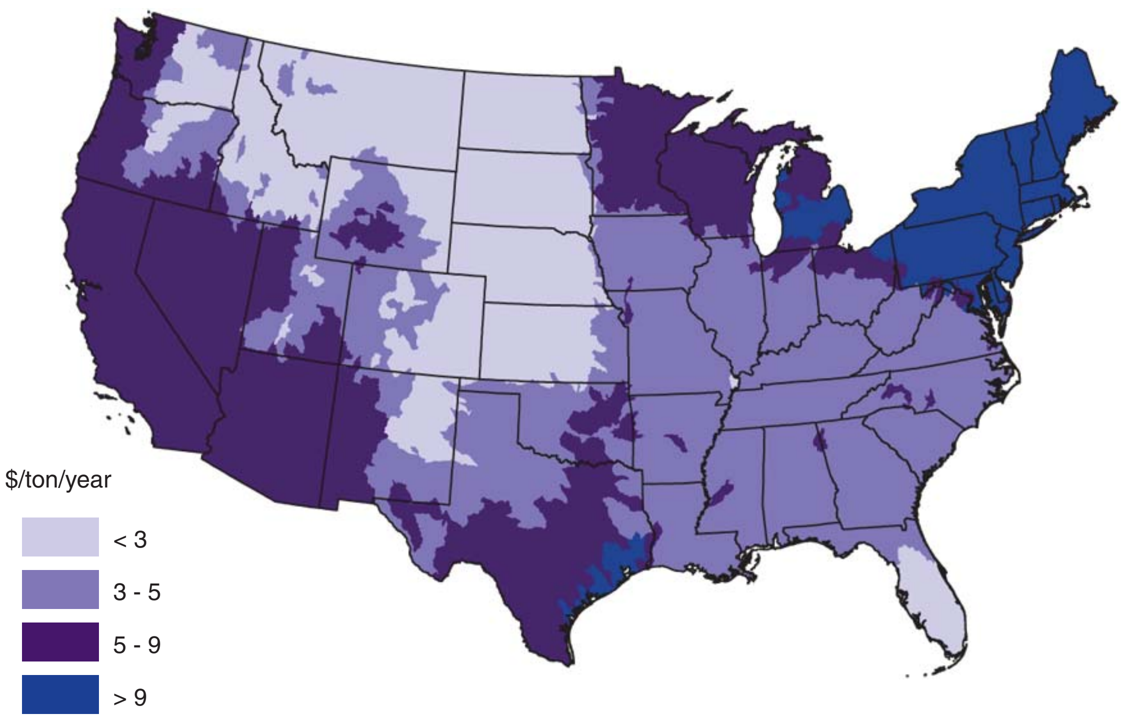
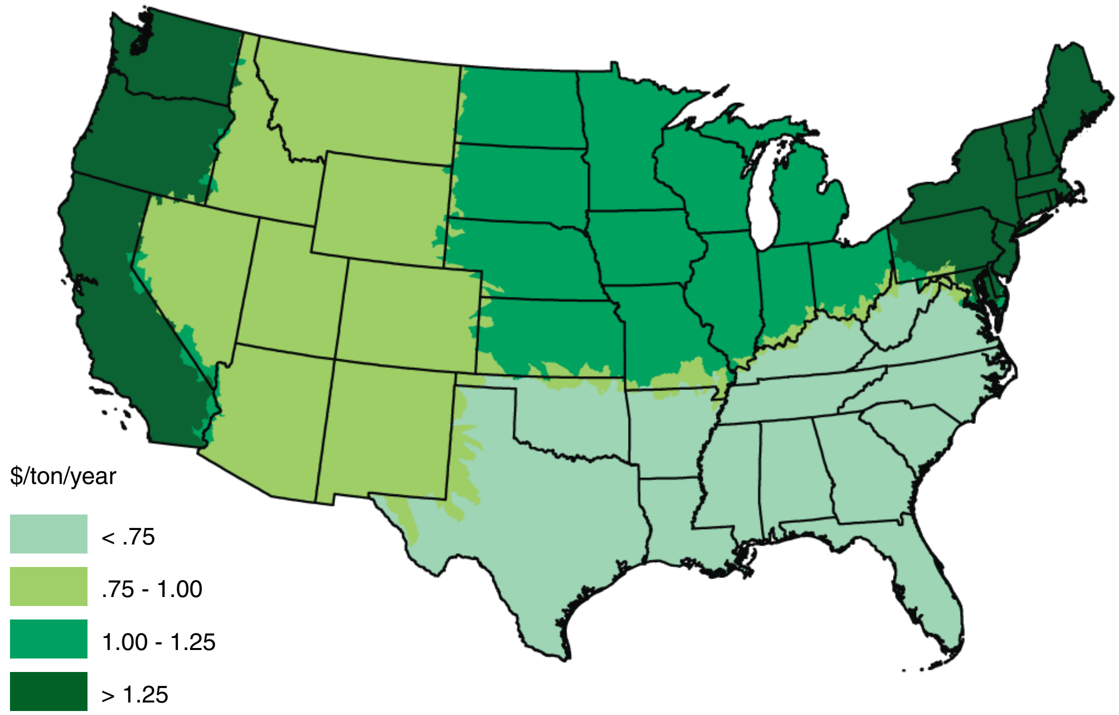


HUC-level[1] water-erosion benefit categories are: *reservoir services, navigation, water-based recreation, marine fisheries, freshwater fisheries, municipal industrial, steam electric, irrigation ditches, flood damages, soil productivity, road ditches*, and *municipal water treatment*. Only *reservoir services, navigation*, and *water-based recreation* are estimated at the HUC level. Other values are based on FPR-level[2] estimates.

[1]HUCs are watersheds defined by the U.S. Geological Survey's 8-digit hydrologic unit codes.
[2]FPRs are USDA's multi-state Farm Production Regions.

Figure 4
Range and distribution of all wind-erosion benefit values, by HUC[1]



HUC-level wind erosion benefit categories are *dust cleaning* and *soil productivity*. Values are based on FPR-level[2] estimates.

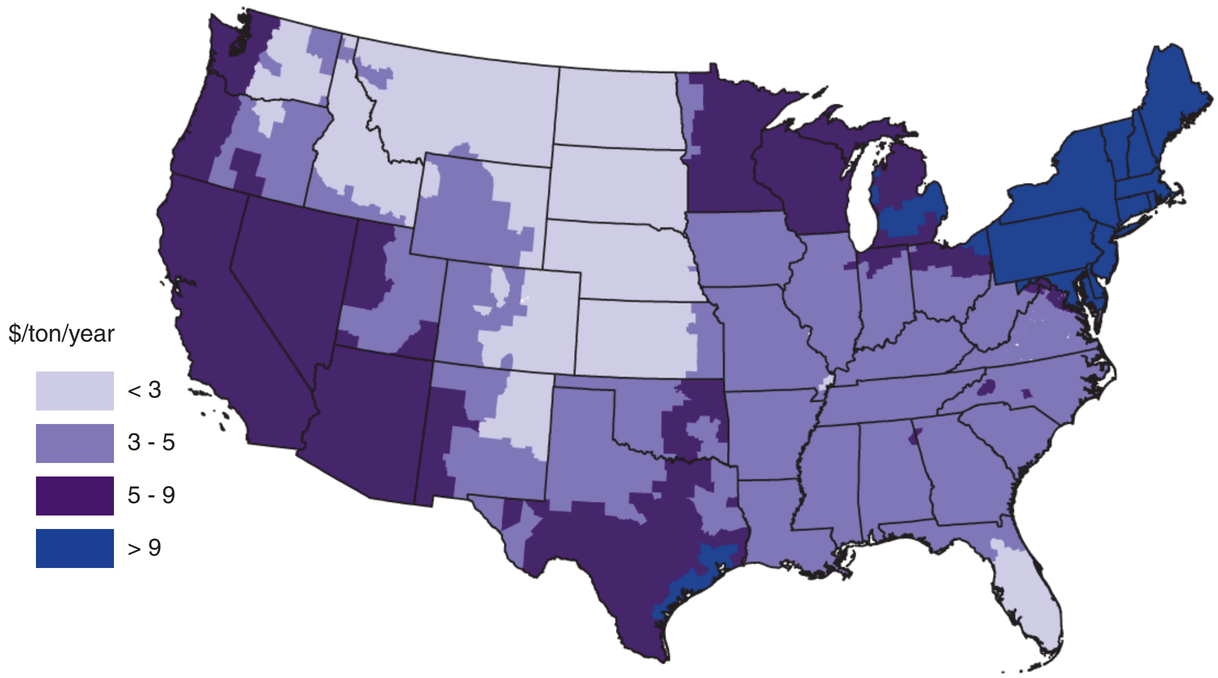
[1]HUCs are watersheds defined by the U.S. Geological Survey's 8-digit hydrologic unit codes.
[2]FPRs are USDA's multi-state Farm Production Regions.

value of two or more FPRs. When the HUC-level wind-erosion benefit values are summed, values range from $0.41 to $1.54 per ton.

The county-level estimates of the benefit values that are derived from HUC-level models (*reservoir services, navigation, and water-based recreation)* are erosion-weighted average values. Note that for counties that lie in a single HUC, the county-level values equal the HUC-level values. The county-level benefit values are, in effect, taken directly from the FPR-level estimates because counties do not cross FPR borders. The county-level sums of the water-erosion benefit estimates range from $1.70 to $18.24 per ton (fig. 5). The county-level sums of the wind erosion benefit values range from $0.41 to $1.54 per ton. Because both wind-erosion benefit values have been estimated at the FPR level, values follow FPR boundaries (fig. 6).

Although many of the benefit models were formulated some time ago, the values they generate are the most complete summary of soil erosion reduction benefits available. More accurate assessment of soil conservation benefits will be possible in the future if additional research improves the accuracy and geo-resolution of available estimates or expands upon the benefits that have been assessed to date.

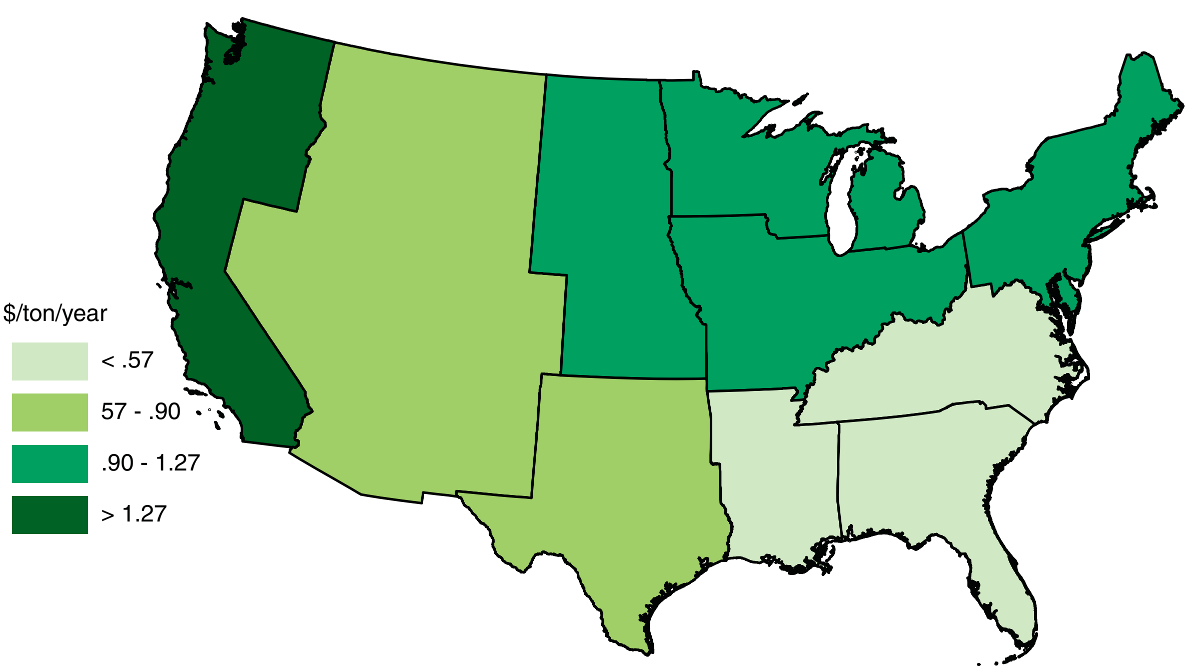
Figure 5
Range and distribution of all water-erosion benefit values, by county



County-level water-erosion benefit categories are: *reservoir services, navigation, water-based recreation, marine fisheries, freshwater fisheries, municipal industrial, steam electric, irrigation ditches, flood damages, soil productivity, road ditches*, and *municipal water treatment*. None are estimated at the county level. *Reservoir services, navigation*, and *water-based recreation* are estimated at the HUC level.[1] Other values are based on FPR-level estimates.[2]

[1]HUCs are watersheds defined by the U.S. Geological Survey's 8-digit hydrologic unit codes.
[2]FPRs are USDA's multi-state Farm Production Regions.

Figure 6
Range and distribution of all wind-erosion benefit values, by county



County-level wind erosion benefit categories are *dust cleaning* and *soil productivity*. Values are based on FPR-level[1] estimates.

[1]FPRs are USDA's multi-state Farm Production Regions.

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