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# Water Quality Benefits from the Conservation Reserve Program

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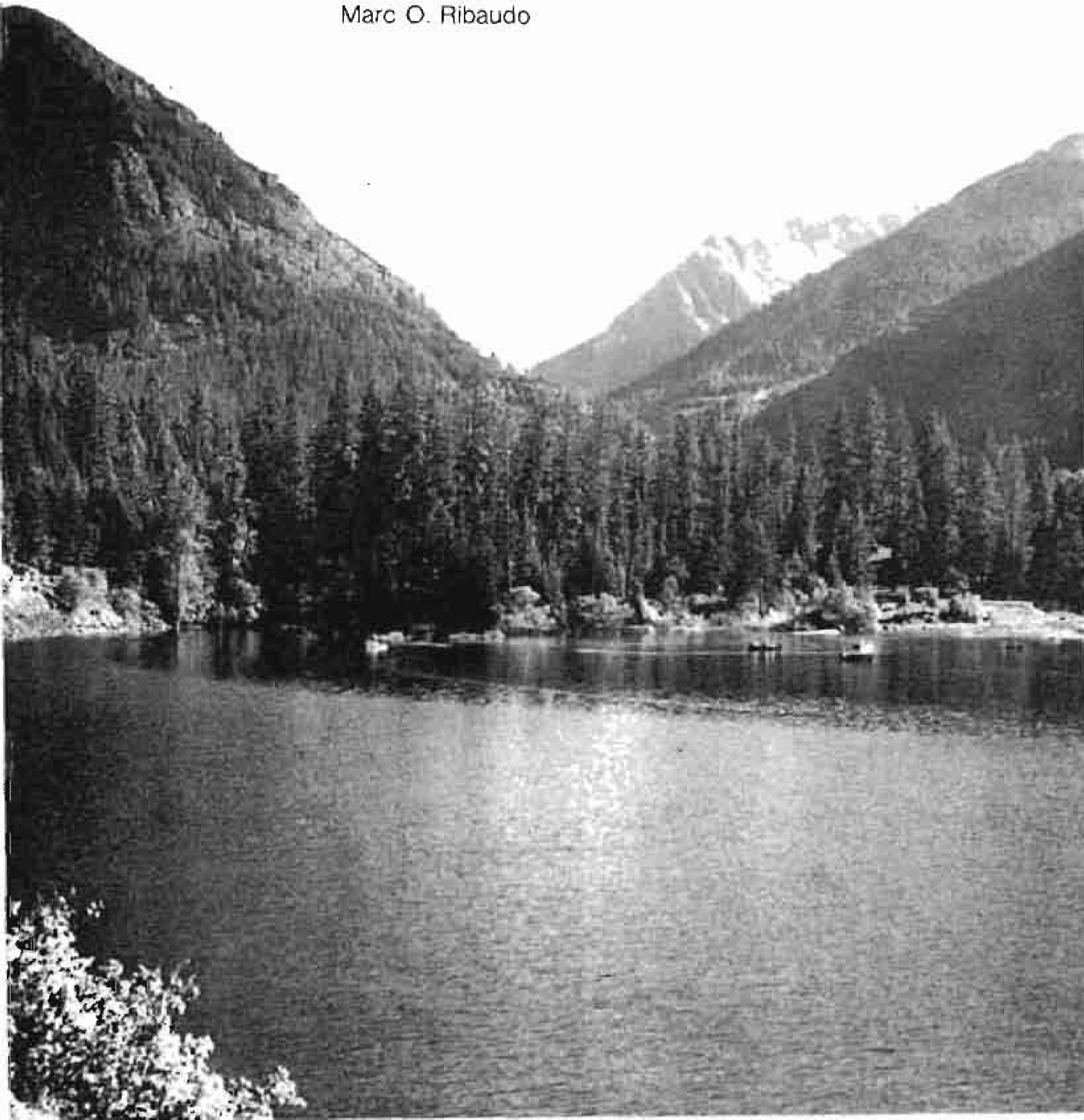

**WATER QUALITY BENEFITS FROM THE CONSERVATION RESERVE PROGRAM.** By Marc O. Ribaudo. Resources and Technology Division, Economic Research Service, U.S. Department of Agriculture. Agricultural Economic Report No. 606.

## ABSTRACT

The Conservation Reserve Program, a land retirement program designed to remove from production 40 to 45 million acres of highly erodible cropland, may generate an estimated $3.5 to $4 billion in water quality benefits. Potential benefits include lower water treatment costs, lower sediment removal costs, less flood damage, less damage to equipment which uses water, and increased recreational fishing. Benefits were estimated with a set of procedures that approximated the physical, chemical, biological, and economic links between soil erosion and water use.

Keywords: Benefits, nonpoint-source pollution, nutrients, sediment, soil erosion, soil conservation, water quality.

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## SUMMARY

The Conservation Reserve Program (CRP), a land retirement program designed to remove from production 40-45 million acres of highly erodible cropland, may generate an estimated $3.5 to $4 billion in water quality benefits. Potential benefits include lower water treatment costs, lower sediment removal costs, less flood damage, less damage to equipment which uses water, and increased recreational fishing. Benefits were estimated with a set of procedures that approximated the physical, chemical, biological, and economic linkages between soil erosion and water use.

Estimated per-acre benefits vary widely among regions, indicating differences in severity of erosion and demand for water services. The Delta, Appalachia, and Northeast regions have the highest per-acre benefits. Enrollment in the CRP is concentrated in the Southern Plains, Northern Plains, and Mountain regions, where per-acre benefits are relatively low. Water quality benefits could be increased by encouraging greater land enrollment east of the Mississippi River, where per-acre benefits are highest.

Per-acre water quality benefits from the CRP are likely to be seven times greater than those from traditional soil conservation programs because the CRP targets highly erodible land and takes it out of production.

# GLOSSARY

adsorb--To adhere to the surface of a solid.

best management practice--A practice or combination of practices found to be the most effective, practical means of preventing or reducing the amount of pollution generated by agriculture.

consumer surplus--Monetary value of a good or service to the purchaser.

demand--The amount of a good or service a consumer is willing to buy at a particular price.

erodibility--The susceptibility of a soil to erosion.

erosion--The wearing away of land by water or wind.

erosivity--The potential ability of rain to dislodge soil particles.

gross erosion--Total soil moved by water from all land forms.

Kjeldahl nitrogen--Organic forms of nitrogen, including ammonia.

nonpoint-source pollution--Entry of effluent into a water body from a broad area rather than from a concentrated entry point.

NTU--Nephelometric turbidity units. Measure of water clarity.

nutrient--Chemical that stimulates plant growth.

offsite benefits--Benefits from erosion control that occur downstream from a farm.

point-source pollution--Entry of effluent into a water body from a confined and distinct source.

pollutant--Any material present in the environment (air, water, and soil) in sufficient quantities to cause economic or physical harm.

sediment--Soil particles carried by water.

sheet and rill erosion--Soil erosion occurring from a thin layer of soil particles on the surface and from small channels which are removed during normal tillage operation.

soil conservation practice--Any step or combination of steps that prevents or reduces soil erosion.

streambank erosion--Erosion of stream channels.

surface water--Any lake, river, stream, estuary, or ocean.

turbidity--Lack of clarity in water caused by suspended sediment.

Universal Soil Loss Equation--Equation used for estimating the long-term average annual rate of sheet and rill erosion on a field.

water conveyance system--Any construction that transports water, including pipes and ditches.

# Water Quality Benefits from the Conservation Reserve Program

Marc O. Ribaudo*

## INTRODUCTION

Title XII of the 1985 Food Security Act authorized the Conservation Reserve Program (CRP), a program designed to curb erosion and clean up waterways (17).1/ This report estimates the economic benefits from cleaner water brought about by the CRP.

The CRP is a long-term land retirement program designed to help owners and operators of highly erodible cropland in conserving and improving the soil and water resources of their farms and ranches. The goal of the CRP is to remove from production 40-45 million acres of highly erodible cropland by 1990 and to put it into trees or grassland for a contract period of 10 years, leading to improved soil and water resources. An operator receives 50 percent of the cost of establishing permanent cover and yearly rental payments over the contract period to offset income loss.

Agricultural activities generate materials that can be carried into waterways by runoff and which can harm water users. Most agriculturally induced pollution is nonpoint-source pollution in which the specific source cannot be identified (18). Farm-generated pollutants include nutrients from chemical fertilizers and animal manure (primarily nitrogen and phosphorus), pesticides, sediment, and dissolved minerals and salts.

Sediment washing off cropland and into waterways can fill reservoirs, block navigation channels, interfere with water conveyance systems, harm aquatic plant life, and degrade recreational resources. Chemical pesticides and fertilizers are important agricultural inputs. But when these pesticides and nutrients find their way into waterways, they can harm plant and animal life. And if they reach high enough concentrations in drinking water, pesticides and fertilizer nitrates may endanger human health.

Chemical fertilizers and animal manure may promote the premature aging of lakes and estuaries, hurting recreation opportunities, municipal and industrial water

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1/Underscored numbers in parentheses refer to items cited in References at the end of this report.

supplies, and commercial fishing. Dissolved minerals and salts can clog household and industrial piping, and shorten the lifespan of appliances that use water.

## CONTROLLING EROSION IMPROVES WATER QUALITY

National studies suggest that agricultural nonpoint-source pollution harms portions of over two-thirds of the Nation's river basins (18). Recent assessments suggest that nonpoint-source pollution may prevent the United States from achieving its water quality goals even after planned point-source controls are put in place (14). Suspended sediment and nutrients generated from farming are cited as the most damaging nonpoint sources of harm to the U.S. environment (14). A survey of fisheries reports that agricultural nonpoint sources appear to influence water quality on more stream miles than do any other sources of pollutants. Controlling soil erosion and using agricultural "best management practices" are among the most effective ways to improve stream habitats (11).

Off-farm damage from cropland erosion, recent estimates indicate, may be greater than onfarm damage to crop yields (1, 2, 15). The first comprehensive estimates of the magnitude of offsite damage from soil erosion were made by Clark and others in 1981 (1). They estimated annual damage from all sources of soil erosion at $8.1 billion, nearly $3.5 billion of it from eroding cropland. Damage was done to water storage facilities, recreation facilities, navigation, commercial fishing, water conveyance facilities, water treatment facilities, and municipal and industrial users. Increased flooding from erosion also caused economic losses.

Potential for the CRP to bring about a major reduction in the discharge of agricultural pollutants into waterways is large, because of the large acreage involved and because only highly erodible land is eligible to be enrolled. A recent evaluation of soil conservation programs indicated that targeting soil conservation programs at the fastest eroding land would greatly increase offsite benefits and would likely result in a favorable benefit-cost ratio (15). It is, therefore, expected that the CRP will generate a significant level of offsite water quality benefits.

## LINKS BETWEEN EROSION AND DAMAGE

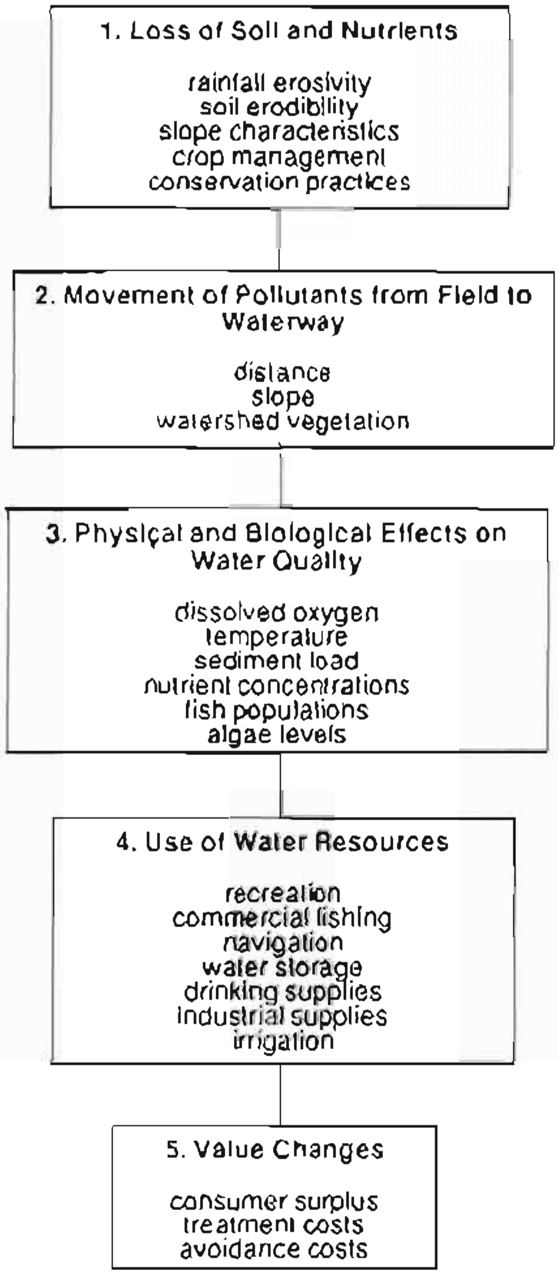
The relationship between soil erosion and offsite damage is a complex one, involving physical, biological, and economic links (fig. 1). One must understand these links to evaluate the offsite benefits from the CRP.

The first stage of erosion is one in which soil particles are dislodged by water and carried to the edge of the field. Soil loss is generally considered to be a function of rainfall erosivity, soil erodibility, slope, slope length, crop management, and conservation practice (10). Soil is not the only item carried off a field by runoff. Nutrients and pesticides are also transported. These chemicals can either be adsorbed to soil particles or dissolved in the runoff water.

The second link consists of soil and agrichemicals moving from the edge of the field to natural or constructed waterways. The amounts of sediment and chemicals that reach a waterway depend on factors such as distance, slope, and the vegetation characteristics of the watershed.

Figure 1

Links between soil erosion and offsite damage




The third link is between the agricultural pollutants discharged into waterways and water quality. Quality is expressed in physical and biological measures. Physical measures of water quality include dissolved oxygen, temperature, turbidity, pH, odor, nutrient concentrations, and concentrations of other chemicals. Biological measures of water quality include fish populations, algae levels, and zooplankton and bacterial concentrations.

The fourth link is how changes in water quality affect the use of water resources. The recreation potential for a body of water can be affected by changes in its biological characteristics and physical appearance. For instance, fewer fish, foul odors, algae blooms, and turbidity can all reduce the attractiveness of a recreation site. Suspended sediment, algae, and dissolved chemicals can increase the amount of filtering and treatment needed to purify water and water used for industry. Eroded soil can clog navigation channels and water conveyance systems. Sediment can fill reservoirs, affecting their ability to provide drinking water, electric power, or flood control. Sediment buildup may also result in the need to dredge or prematurely replace reservoirs. Stream beds clogged with sediment can lead to more frequent and severe flooding.

The fifth link is the economic relationship between water quality changes and human activity. It is expressed as changes in recreation demand, changes in profits among water-using industries, and changes in spending needed to counteract erosion's harmful effects.

## BENEFIT ESTIMATING PROCEDURES

Procedures developed for estimating the CRP's offsite benefits are based on these five links. The objective was to find ways to model these links so that the effects of decreased soil erosion on farm fields could be tracked to the eventual consequences on water users. I used farm production regions (FPR) for geographic units so that regional comparisons could be made (fig. 2). All benefits are reported in 1986 dollars, unless otherwise noted.

### First Link

When the analysis was conducted, five CRP signups had taken place, for contracts starting in 1986, in 1987, and in the early part of 1988. Approximately 23 million acres of cropland were enrolled (table 1). Sheet and rill erosion on this land was estimated to be reduced by 10.4 tons per year (5). The Universal Soil Loss Equation (USLE) was used to estimate how much sheet and rill erosion was reduced by converting cropland to grass or trees (21).

Future signups and erosion reductions were projected for the remainder of 1988, 1989, and 1990, based on the initial signup pattern (5). Table 1 also shows the projected regional distribution of the 45-million acre program and accompanying annual sheet and rill erosion reductions. Since contracts are for 10 years, these 45 million acres will all be enrolled in the program at the same time during the 6-year period 1990 through 1995. Maximum water quality improvements and benefits will be attained during this period. Sheet and rill erosion was estimated to be reduced by an average of 9.4 tons per acre per year for the duration of the entire program. The reason for the decline over the first five signups is that the most erodible land is assumed to be enrolled first.

Erosion reductions attributable to the CRP can be compared with gross erosion levels assumed to exist before the program began. Analysis rested on the underlying assumption that 1982 erosion levels would continue if there were no CRP. The most recent erosion data available were for 1982. They come from the National Resources Inventory (NRI) (16). Total annual water-induced erosion was estimated to be 4.9 billion tons (table 2). The CRP was estimated to reduce annual sheet and rill erosion by 422 million tons during the 6-year period when the most acreage would be under contract. This figure is an 8.6-percent decrease from preprogram levels.

Data used in estimating erosion were obtained from several sources. Data on sheet and rill erosion of nonfederal rangeland, cropland, pastureland,

Figure 2

Farm production regions

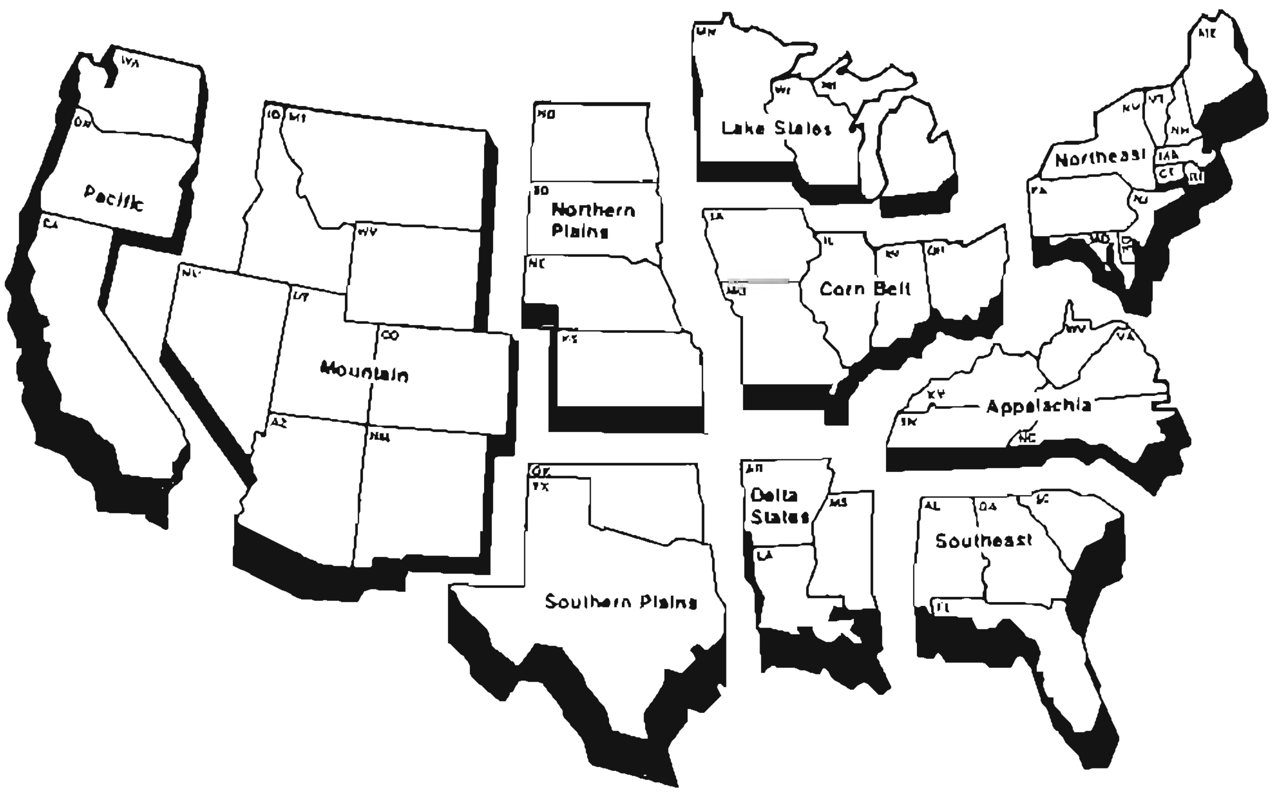



Table 1--CRP enrollment and annual erosion reductions, by region

| Region | CRP to date | | Projected CRP 1/ | |
|---|---|---|---|---|
| | Area | Soil saved | Area | Soil saved |
| | 1,000 acres | Million tons | 1,000 acres | Million tons |
| Appalachia | 759 | 21.4 | 1,969 | 45.4 |
| Corn Belt | 3,269 | 61.8 | 7,648 | 121.6 |
| Delta | 679 | 15.3 | 1,432 | 28.8 |
| Lake States | 1,983 | 16.8 | 3,788 | 29.4 |
| Mountain | 4,863 | 29.4 | 8,469 | 41.9 |
| Northeast | 109 | 1.5 | 730 | 8.1 |
| Northern Plains | 5,225 | 46.1 | 9,630 | 70.4 |
| Pacific | 1,468 | 11.7 | 2,649 | 18.8 |
| Southeast | 989 | 15.7 | 1,905 | 27.2 |
| Southern Plains | 3,653 | 18.7 | 6,779 | 30.3 |
| Total | 22,997 | 238.4 | 45,000 | 421.9 |

1/Projected enrollment assumes no changes in enrollment criteria.

forestland, pits, mines, quarries, and other rural land were obtained from the 1982 NRI, while data on erosion of gullies, streambanks, roads, and construction sites were obtained from the 1977 NRI. Data on erosion of Federal rangeland, forestland, and cropland were obtained from Resources for the Future (RFF) (7).

More recent estimates of baseline national erosion rates would have been useful for the analysis, but they do not exist. Erosion is known to have been reduced on some cropland because of initiatives such as the Agricultural Conservation Program, the Conservation Technical Assistance program, and the Great Plains Conservation Program and because some farmers are adopting soil conserving practices such as conservation tillage. Although it would be possible to adjust the 1982 NRI data to account for conservation practices used until 1986, it is not possible to account for changes in erosion on land that was never enrolled in conservation programs. Therefore, no attempt was made to update the NRI data.2/

## Second Link

Reduced soil erosion and fertilizer use affect the amounts of sediment and nutrients discharged into waterways. Table 3 shows base levels of suspended sediment (TSS), total Kjeldahl nitrogen (TKN), and total phosphorus (TP) that are discharged into waterways each year, as estimated by RFF (7). Discharges include materials attached to soil particles, nutrients dissolved in runoff, material from other nonpoint sources, and material originating from point sources such as sewage treatment plants. RFF estimated the discharge of materials associated with soil particles by estimating sediment delivery ratios and attached pollutant coefficients, then applying them to the soil erosion data (7). Sediment delivery ratios are a function of stream density and soil type

2/A new NRI was conducted in 1987, but the results are not yet available.

Table 2--Gross annual soil erosion in 1982, by region

| Region | Cropland | Pasture/range | Forest | Stream | Other | Total |
|---|---|---|---|---|---|---|
| | | | Million tons | | | |
| Appalachia | 181.9 | 47.6 | 69.6 | 36.6 | 150.1 | 485.9 |
| Corn Belt | 689.1 | 59.3 | 52.9 | 75.2 | 91.1 | 967.4 |
| Delta | 123.9 | 11.8 | 21.6 | 41.9 | 42.9 | 242.1 |
| Lake States | 129.8 | 5.9 | 10.8 | 10.8 | 23.3 | 180.6 |
| Mountain | 89.5 | 270.2 | 184.2 | 83.1 | 147.9 | 774.9 |
| Northeast | 67.5 | 6.2 | 18.2 | 23.5 | 71.2 | 186.6 |
| Northern Plains | 281.8 | 87.9 | 4.2 | 97.3 | 197.8 | 669.0 |
| Pacific | 66.6 | 91.8 | 384.4 | 73.4 | 62.4 | 678.6 |
| Southeast | 94.0 | 5.5 | 22.0 | 19.8 | 108.3 | 249.7 |
| Southern Plains | 112.4 | 165.0 | 16.2 | 91.2 | 105.2 | 490.1 |
| Total | 1,836.6 | 751.2 | 784.1 | 552.9 | 1,000.3 | 4,925.0 |

Attached pollutant coefficients are the ratios of the weight of the nutrients attached to soil particles to the weight of soil particles.

RFF used a nutrient simulation model to estimate the amount of materials dissolved in runoff from cropland. Nonpoint urban discharges were estimated using an urban runoff model. Information on discharges from point sources was obtained directly from U.S. Environmental Protection Agency discharge permits.

Shares of the discharged material originating from cropland are also shown (table 3). Cropland is a much greater contributor in some regions than in others. The CRP's potential effects on water quality appear to be greatest in regions where cropland's share of the material discharged is significant, such as in the Corn Belt, Lake States, Northern Plains, and Delta.

Declines in discharge of TSS, TKN, and TP brought about by the CRP were estimated by using the same information RFF used to estimate annual discharges. Estimates of erosion reductions attributable to the CRP were made for each of the 99 Aggregated Subareas (ASA's). ASA's are hydrologic units, usually the basins of major rivers, for which there are data on the discharge of TSS, TKN, and TP, and which are relevant to the study of water quality (fig. 3). Reductions in sediment discharge were estimated by applying the sediment delivery ratio for cropland in each ASA to the erosion reductions expected from the CRP. Declines in TKN and TP attached to sediment were estimated by applying attached pollutant coefficients for TKN and TP on cropland erosion in each ASA to the reductions in sediment discharge. Changes in TKN and TP discharged in dissolved form were then estimated by calculating the average discharge of these

Table 3--Annual discharge of suspended sediment, Kjeldahl nitrogen, and phosphorus, by region

| Region | Total TSS1/ | TSS from cropland | Total TKN2/ | TKN from cropland | Total TP3/ | TP from cropland |
|---|---|---|---|---|---|---|
| | Million tons | Percent | 1,000 tons | Percent | 1,000 tons | Percent |
| Appalachia | 275.5 | 32.2 | 670.8 | 34.6 | 148.1 | 26.7 |
| Corn Belt | 516.3 | 69.0 | 2,059.2 | 71.1 | 346.1 | 72.0 |
| Delta | 137.5 | 49.7 | 270.8 | 52.7 | 57.6 | 45.9 |
| Lake States | 72.4 | 64.0 | 454.9 | 56.1 | 51.9 | 51.7 |
| Mountain | 306.7 | 12.9 | 883.9 | 16.7 | 258.2 | 16.1 |
| Northeast | 99.7 | 30.2 | 589.0 | 21.4 | 135.0 | 24.6 |
| Northern Plains | 309.4 | 40.7 | 854.7 | 53.3 | 190.0 | 49.0 |
| Pacific | 183.5 | 15.7 | 713.9 | 10.7 | 396.2 | 9.8 |
| Southeast | 116.1 | 30.3 | 273.2 | 33.0 | 45.0 | 26.9 |
| Southern Plains | 265.2 | 20.5 | 454.0 | 24.6 | 75.0 | 22.2 |
| Total | 2,281.3 | 38.7 | 7,224.4 | 42.9 | 1,702.9 | 33.9 |

1/TSS = total suspended sediment.
2/TKN = total Kjeldahl nitrogen.
3/TP = total phosphorus.

Figure 3

## Aggregated subareas

materials per acre of cropland in each ASA (from RFF data) and applying the results to the number of acres under contract. The RFF data assume no nutrients are lost in dissolved form from forest or pasture. Streambank erosion was assumed not to increase in response to a decrease in surface sources of sediment. Table 4 shows the annual reductions in the discharge of TSS, TKN, and TP expected from the CRP when all 45 million acres are under contract.

## Third Link

CRP's effects on ambient water quality conditions are needed to estimate the benefits to water treatment plants and to recreation. The lack of a quantifiable relationship between discharge and ambient concentrations at the regional level has been an obstacle in past analyses.

This analysis surmounted that obstacle by estimating three models that link discharge to average concentrations at the ASA watershed level. Thus, ad hoc assumptions about the relationships between discharge of TKN, TP, and TSS and concentrations of these materials are avoided. The dependent variable in each model--average concentrations of TKN, TP, or TSS--was estimated for each ASA using data from the U.S. Geological Survey's (USGS) National Stream Quality Accounting Network (NASQUAN).

Each of 470 water quality monitoring stations was located in relation to an ASA. If a station was located near the border of two ASA's, it was assumed to be

Table 4--Maximum annual reductions in pollutant discharge resulting from the CRP, by region1/

| Region | TSS2/ | | TKN3/ | | TP4/ | |
|---|---|---|---|---|---|---|
| | 1,000 tons | Percent | 1,000 tons | Percent | 1,000 tons | Percent |
| Appalachia | 23,220 | 8.4 | 58.5 | 8.7 | 10.5 | 7.1 |
| Corn Belt | 61,678 | 12.0 | 249.1 | 12.1 | 41.2 | 11.9 |
| Delta | 16,427 | 11.9 | 36.1 | 13.3 | 6.1 | 10.6 |
| Lake States | 10,325 | 14.2 | 39.7 | 13.1 | 5.9 | 11.4 |
| Mountain | 20,421 | 6.8 | 70.6 | 8.0 | 20.1 | 7.8 |
| Northeast | 3,670 | 3.7 | 16.4 | 2.8 | 4.0 | 3.0 |
| Northern Plains | 33,980 | 11.0 | 123.1 | 14.4 | 25.2 | 13.3 |
| Pacific | 8,904 | 4.9 | 20.0 | 2.8 | 11.3 | 2.9 |
| Southeast | 12,310 | 10.6 | 30.7 | 11.2 | 3.5 | 7.8 |
| Southern Plains | 14,413 | 5.4 | 32.3 | 7.1 | 5.2 | 6.9 |
| Total | 205,348 | 9.0 | 696.5 | 9.6 | 133.1 | 7.8 |

1/Estimates based on complete CRP enrollment, in which 45 million acres are under contract.

2/TSS = total suspended sediment.

3/TKN = total Kjeldahl nitrogen.

4/TP = total phosphorus.

measuring the water quality of the upstream ASA. Average concentrations of TKN, TP, and TSS were calculated for each station using data from the years 1982 and 1983. If an ASA contained more than one station, station means were averaged to calculate an ASA mean. No weights were assigned to station means to account for differences in flow or drainage area. The averages were treated as the concentrations which would likely be encountered on any river or stream in the ASA at any time of year.

A drawback to using only NASQUAN data is that no monitoring stations are located on lakes, and lakes are an important recreation resource. However, there is no consistent national database for lake water quality, so it was assumed that NASQUAN data also reflect lake water quality.

The important explanatory variable in each equation was the amount, measured by weight, of material discharged into the waterways of an ASA each year from all sources. Discharge was expected to affect concentration positively.

The concentration of a material in a river system depends on both the amount of the material discharged and the volume of flow. Mean daily flow at the outlet of each ASA was included as an explanatory variable. This information was obtained from the U.S. Water Resources Council (19). Flow was expected to affect concentration negatively in each model.

Sediment and pollutants attached to sediment will settle out, if water flows slowly enough. If monitoring stations are consistently located downstream from reservoirs, measured concentrations are likely to be lower than expected, given upstream loadings. Total volume of water storage for an ASA was included in each equation to capture the influence of storage on concentration. This information was obtained from the U.S. Water Resources Council (19). Storage was expected to affect concentration negatively.

A log-linear function was selected to represent the relationships between material concentration and the explanatory variables:

$$Y = aX_1^{\beta_1}X_2^{\beta_2}X_3^{\beta_3} \quad (1)$$

where:

Y = material concentration (milligrams/liter)

$X_1$ = material discharge (weight/year)

$X_2$ = stream flow (volume/day)

$X_3$ = water storage (volume)

A desirable characteristic of this specification is that the marginal effect on concentration of a change in loadings is not necessarily independent of the level of flow and storage in an ASA. Using a linear function, the marginal effect would be the same for all ASA's.

Equation (1) was estimated separately for TSS, TP, and TKN. Each of the three equations was estimated using ordinary least squares regression. All three estimated equations were statistically significant at the 99-percent level, and the signs of the explanatory variables were as expected (table 5). Predictions of concentrations had wide variances, especially those for concentrations of TP and TKN. All explanatory variables but storage were significant at the 99-percent level.

Estimating statistically significant functions that conform to expectations was encouraging. It appears that, despite the use of highly aggregated data, the relationship between pollutant discharge and concentrations can still be observed. Although the estimated equations cannot be used to estimate concentrations precisely, they can be used to estimate changes in a water quality index that measures the general suitability of water resources for manufacturing and recreation.

## Fourth and Fifth Links

The fourth and fifth links are discussed together, since they are closely tied procedurally. The economic damage estimated to be caused by soil erosion are shown in tables 6 and 7. Damage to recreation, commercial fishing, municipal and industrial use, and steam power cooling was obtained from findings of Clark, Haverkamp, and Chapman (1). Damage to water storage was obtained from findings of Crowder (3). Damage to water treatment was obtained from findings of Holmes (9). Damage shown in tables 6 and 7 is assumed to be caused by erosion and discharges shown in table 2 and 3. Damage per ton reflects the regional differences in demand for water services. If one were targeting erosion controls based on maximizing water quality benefits regardless of the cost, regions with the highest damage per ton would be selected first.

The economic effects of diminished agricultural nonpoint-source pollution on roadside ditches, irrigation canals, navigation, water treatment facilities,

Table 5--Results of water quality model estimation

| Variable | Pollutant | | |
|---|---|---|---|
| | TSS1/ | TKN2/ | TP3/ |
| Intercept | 3.27* | -1.04* | -2.76* |
| | (.5)4/ | (.21) | (.34) |
| Discharge | .88* | .21* | .35* |
| | (.11) | (.05) | (.08) |
| Flow | -.40* | -.21* | -.22* |
| | (.07) | (.03) | (.05) |
| Storage | -.08 | -.01 | -.06 |
| | (.08) | (.03) | (.06) |
| Adjusted $R^2$ | .44 | .33 | .22 |

1/TSS = total suspended sediment.
2/TKN = total Kjeldahl nitrogen.
3/TP = total phosphorus.
4/Standard error in parentheses.
*Significant at the 1-percent level.

Table 6--Annual offsite damage from soil erosion, by damage category

| Damage category | Offsite damage | |
|---|---|---|
| | Best1/ | Range |
| | Million dollars | |
| Freshwater recreation | 2,080 | 826 - 6,559 |
| Marine recreation | 599 | 439 - 2,399 |
| Water storage | 1,090 | 654 - 1,524 |
| Navigation | 749 | 533 - 933 |
| Flooding | 978 | 653 - 1,546 |
| Roadside ditches | 535 | 268 - 804 |
| Irrigation ditches | 118 | 59 - 159 |
| Freshwater commercial fishing | 60 | 53 - 83 |
| Marine commercial fishing | 390 | 383 - 530 |
| Municipal water treatment | 964 | 496 - 1,432 |
| Municipal and industrial use | 1,196 | 665 - 1,599 |
| Steam power cooling | 24 | 21 - 34 |
| Total | 8,785 | 5,052 -17,605 |

1/Best estimate is the most likely extent of offsite damage.

Table 7--Offsite damage, by region

| Region | Offsite damage | | Damage per ton of erosion |
|---|---|---|---|
| | Best1/ | Range | |
| | - - - Million dollars - - - | | Dollars |
| Appalachia | 688 | 379 - 1,100 | 1.41 |
| Corn Belt | 1,111 | 546 - 1,968 | 1.15 |
| Delta States | 592 | 362 - 1,984 | 2.44 |
| Lake States | 676 | 361 - 1,085 | 3.74 |
| Mountain | 871 | 489 - 1,333 | 1.12 |
| Northeast | 1,317 | 786 - 2,632 | 7.06 |
| Northern Plains | 381 | 215 - 1,692 | .57 |
| Pacific | 1,680 | 1,037 - 3,228 | 2.48 |
| Southeast | 479 | 292 - 676 | 1.92 |
| Southern Plains | 990 | 565 - 1,907 | 2.02 |
| Total | 8,785 | 5,052 -17,605 | 1.78 |

1/Best estimate is the most likely extent of offsite damage.

municipal and industrial water use, flooding, water storage, and recreation were estimated. A variety of methods was used to estimate these effects. They fall into three general categories based on different definitions of benefits. Benefits can be defined in terms of changes in defensive expenditures, changes in production costs, or changes in consumer surplus.

Defensive expenditures are outlays made to prevent or counteract damage from pollutants. If defensive expenditures are a perfect substitute for pollution-induced reductions in service, then changes in defensive outlays that accompany changes in the pollution level will reveal marginal willingness to pay for improved water quality (6). Marginal willingness to pay, the amount an individual is willing to pay to acquire the stated quality change, is the desired measure of benefits. The goal of a benefits estimating approach is to estimate changes in defensive expenditures. Because there is no such thing as a perfect defense from pollution damage, reductions in defensive outlays likely underestimate true benefits (6).

Water quality can be a perfect substitute for an input in the production of a good or service. In this case, benefits from cleaner water can be estimated by measuring the change in production costs. Cost savings are a true measure of benefits in a case in which change in total costs does not affect marginal cost and output (6). Even if marginal cost is reduced, this approach could be used as a lower bound estimate of true benefits, but only if the change in output is small (6).

When water quality is a determinant of demand for a good such as recreation, benefits from cleaner water can be estimated by measuring the change in consumer surplus for the good as water quality improves. A change in quality causes the demand curve for the good to shift. The value of that change in quality, the change in consumer surplus, is measured by the change in the area beneath the demand curve. Change in consumer surplus can be estimated directly if the demand curve is known, or with a survey method which measures willingness to pay for the quality change.

### Roadside Ditches

Sediment carried off farms can fill roadside ditches and flood roads. The appropriate measure of benefits from reduced ditch sedimentation is the change in consumer and producer surpluses defined by the demand for and the supply of road transportation services.

Data for estimating changes in economic surplus were unavailable, so a procedure based on the defensive expenditures approach was developed instead. Changes in outlays that accompany changes in the level of sediment discharge reveal marginal willingness to pay for more road services, which is the appropriate measure of benefits. Ditch cleaning and road services are assumed to be perfect substitutes, and the level of ditch maintenance performed by public agencies is economically justified.

A damage function relating the annual costs of road maintenance to erosion and input costs was estimated to project benefits from reduced roadside ditch maintenance. Data on ditch maintenance costs were obtained from State highway departments. Total State sediment removal costs were specified as a function of gross erosion, rural road mileage, and the cost of removing a cubic yard of sediment. The equation represents the links between erosion and damage from ditch sedimentation.

Results indicated that each 1,000 tons of gross erosion translates into average ditch maintenance costs of $79. Annual benefits from reduced erosion under the CRP were estimated by multiplying erosion reductions (in 1,000-ton units) at the FPR level by $79. Results are probably underestimated, because ditch maintenance is probably an imperfect substitute for road services. Reduced sediment buildup in roadside ditches will increase transportation services as well as decrease maintenance costs. A range of benefits was estimated by using the endpoints of the 95-percent confidence interval around the estimated coefficient for gross erosion.

Irrigation Canals

Nutrients and sediment originating on fields can cause excessive sediment buildup or weed growth in irrigation canals, impeding water flow in the irrigation system. Estimates of defensive expenditures for weed control and ditch clearing were available for each FPR (13). Assuming that these expenditures are perfect substitutes for irrigation services allows one to equate benefits with reduction in operation and maintenance costs. A linear relationship between annual costs and erosion was assumed, in which a percentage decrease in erosion results in the same percentage decrease in maintenance costs. The percentage reduction in gross erosion from the levels described in table 2 were estimated for each FPR and applied to the damage estimates, producing an estimate of benefits. These benefits are probably underestimated, because irrigation canal maintenance is probably an imperfect substitute for irrigation services. The defensive expenditures approach does not capture the total increase in services provided by irrigation ditches. A range of benefits was calculated by repeating the procedure with high and low estimates of damage derived from estimates made by Clark, Haverkamp, and Chapman (1).

Navigation

Sediment deposited in major waterways can silt up navigation channels, hindering shipping. Only smaller ships may be able to negotiate channels, transit time may increase, and groundings may become more frequent. Channel dredging is one way to counteract sediment buildup, and it was assumed that dredging is a perfect substitute for shipping services. Benefits from reduced sediment discharge under the CRP could be estimated from the projected cut in dredging costs.

Estimates of annual dredging costs were available at the FPR level (13). A linear relationship between sediment discharge and annual dredging costs was assumed, one in which a percentage reduction in discharged sediment results in the same percentage reduction in dredging costs. The percentage decrease in the discharge of sediment from the levels described in table 3 were estimated for each FPR and applied to damage. The resulting reductions in damage are estimates of benefits. Results are probably underestimated, because dredging and water transportation services are probably imperfect substitutes. A range of benefits was estimated by repeating the procedure with high and low estimates of dredging costs derived from Clark, Haverkamp, and Chapman (1).

Water Treatment

If drinking water sources contain sediment, bacteria, and other materials, the water must be treated before it can be distributed. If lower concentrations of these pollutants reduce treatment costs, then the reductions are a measure of benefits of improved water quality. This line of reasoning follows the "cost savings in production" approach to measuring benefits from water quality improvements. Water quality is assumed to be a perfect substitute for water treatment in the production of drinking water. An increase in water quality leads to a decrease in factor input costs. If the quality of delivered water is not improved and if there is no change in the price of delivered water, then benefits are measured exactly by the drop in treatment costs. If the quality or price of delivered water changes, then account must be taken of changes in consumer surplus. It was assumed in this analysis that the price and quality of delivered water do not change when the quality of withdrawn water changes. The assertion seems to be a reasonable one for a utility like drinking water.

Annual benefits to the water treatment industry were estimated using a water treatment cost model developed by Holmes (9). A water treatment plant's costs were specified as a function of water production, influent water quality (turbidity), distribution costs, and the prices of other inputs. Using Holmes' model, the cost of treating 1 gallon of water to reduce turbidity 1 unit was calculated for each of the 99 ASA's.

Using equation (1), changes in TSS concentrations attributable to the CRP were estimated for each ASA. The changes in TSS concentrations were then converted to changes in turbidity (expressed in NTU's) using an equation estimated by Helvey, Tiedmann, and Anderson (8). The estimated change in turbidity for each ASA was applied to the per-unit treatment cost, resulting in an estimate of the change in treatment cost in each ASA for the average municipal water treatment plant. Cost reductions were then expanded to all treated water in each ASA. Finally, the results were aggregated to an FPR basis. A range of benefits was estimated by increasing and decreasing the per-unit treatment cost 50 percent.

Municipal and Industrial Use

Water delivered to municipalities for household use and surface water withdrawn by industry for cooling and manufacturing may contain dissolved salts and minerals that reduce the water's utility. For example, minerals and salts can clog or corrode pipes and shorten the life of boilers, water heaters, and household appliances (4). Water used in industrial processes such as papermaking and food processing usually must be high quality and thus must first be treated to remove potential contaminants. Any soil conservation effort that reduces erosion will also reduce dissolved minerals and salts in waterways.

The appropriate approach for estimating benefits of improved water quality would be to use a damage function or treatment cost function that includes mineral and salt concentrations as explanatory variables. Such functions were not available, however. Alternatively, estimates of total damage to industry and households from dissolved minerals and salts were available at the FPR level (13). This analysis assumed a linear relationship between annual damage and sediment discharged into waterways, whereby a percentage decrease in sediment discharge from the levels reported in table 3 result in the same percentage decrease in damage. The percentage decreases in discharged sediment attributable to the CRP were estimated for each FPR, then applied to damage estimates. The resulting reductions in damage are the benefits of improved water quality. A range of benefits was estimated by repeating the procedure with high and low estimates of damage derived by Clark, Haverkamp, and Chapman (1).

## Steam Cooling

Power plants often withdraw large amounts of raw water directly from waterways for cooling. Water containing nutrients can promote algae growth in the cooling system, reducing cooling efficiency. Suspended sediment can harm the cooling system's moving parts. Like municipal water treatment plants, power plants withdrawing poor-quality water may have to treat it. No treatment cost function was available, nor was there a damage function relating water quality to loss of cooling system efficiency. Annual damage estimates were available at the FPR level, however (13). The method for estimating benefits from CRP-induced water quality improvements was the same one employed for municipal and industrial use: the percentage reduction in sediment discharged in each FPR was applied to damage. A range of benefits was computed by repeating the procedure with high and low estimates of steam-generating power plant costs derived by Clark, Haverkamp, and Chapman (1).

## Flooding

Sediment in streams can increase frequency and severity of flooding. Sediment deposits can raise the stream bed, reducing the ability of the stream channel to handle high flows. Sediment suspended in flood waters can also cause damage when it is deposited outside the stream channel on roads, on farm fields, and in homes.

Two models are needed to estimate benefits from reduced sediment discharge. One is a model of the relationship between sediment discharge and flood frequency/flood heights. The other is a model linking flood frequency, flood height, and flood plain population density to economic damage. No such models were available for linking sediment discharge to flood damage. However, estimates of annual erosion related damage from flooding were available at the FPR level (13). The relationship between sediment discharge and damage was assumed to be the same as the relationship between sediment discharge and municipal/industrial use. Benefits were estimated by determining the percentage decrease in sediment discharge in each FPR from the levels reported in table 3, then applying the results to damage. A range of benefits was estimated by repeating the procedure with high and low estimates of flooding damage derived by Clark, Haverkamp, and Chapman (1).

## Water Storage

Dams built to store water slow the flow of water, causing sediment to settle out. As sediment builds up behind the dam, it reduces the reservoir's usable storage capacity, and may eventually fill it up entirely.

The appropriate measure of benefits is the cost of replacing lost reservoir capacity (3). Data on estimated annual replacement cost of lost reservoir storage capacity in each of the 10 FPR's were available (3). A linear relationship between annual damage and sediment discharge was assumed, one in which a percentage decrease in sediment discharge from the levels reported in table 3 result in the same percentage decrease in damage. Decreases in discharged sediment for each FPR were estimated, then applied to damage. The resulting reductions in damage are benefits of reduced sedimentation. A range of benefits was estimated based on the range of reservoir construction costs reported by Crowder (3).

Freshwater and Marine Recreation

As nonpoint-source pollution is reduced, fresh- and saltwater recreation increases. Recreational benefits hinge mainly on changes in ambient water quality.

Concentrations of nutrients and sediment affect the biological health of a water system. Nutrients promote algae and weed growth, which can hinder swimmers and boaters. Too many weeds and algae can also change the composition of fish populations. Highly desirable cold water sport fish are replaced by less desirable warm water species. Suspended sediment makes swimming and boating less appealing. Suspended sediment can harm the health of fish and limits their ability to find food. Spawning grounds can be destroyed when sediment settles out.

Estimating recreational benefits of improved water quality requires a model that links changes in water quality to changes in recreational activity and consumer surplus. Although data required to estimate such models are not generally available, data required to estimate a recreational fishing model were available.

The model consisted of two parts, representing the sequential decisions an individual is assumed to make in deciding how much to fish in a particular year. The first decision is whether or not to fish. The second decision, for those who decide to fish, is how often to fish. Both decisions are hypothesized to be functions of the supply and quality of water. Together, the two models can be used to estimate changes in fishing days from changes in water quality. A dollar value for changes in fishing days can be obtained from published sources (12). A value of $25 per fishing day was used.3/ A range of benefits was estimated by assuming that the lower bound would be 0 fishing benefits and the upper bound would be twice the estimated fishing benefits.

Freshwater and Marine Commercial Fishing

Offsite effects of soil erosion on commercial fisheries are essentially the same as those on recreational fishing. Pollutants inhibit the ability of water to support fisheries. A model linking water quality to commercial fishing success was not available. Estimates of damage to freshwater commercial fishing were available at the FPR level (13). Commercial fishing benefits were not estimated because links between water quality and damage to commercial fisheries were too complex to adapt to simple estimating procedures used earlier in this analysis. Moreover, it was felt that these benefits were likely to be small.

## RESULTS

Water quality benefits from the CRP were estimated for each year acreage would be enrolled (1986-99). The present value of the benefits generated by the initial five signups of 23 million acres ranged from $1.2 to $3 billion, with a best estimate of $2.05 billion, or about $89 per acre (table 8). Benefits were estimated with a 4-percent discount rate, the approximate long-term real rate of return on capital. Estimates were made under the assumption that land set aside

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3/See the Appendix for a description of the model, its estimation, and results.

for conservation would revert to crop production at the end of the CRP contract period.

Many assumptions had to be made to estimate benefits, and the accuracy of much of the data was uncertain. Actual benefits are expected to fall inside the range, with the best estimate being the most likely.

Per-acre benefits varied widely, ranging from $41.2 in the Northern Plains to $321.1 in the Delta. Per-acre benefits depend on both per-acre erosion decreases and demand for water services, indicated by the per-ton erosion damages (table 7). Per-acre erosion reductions were relatively high in the Corn Belt, but the damage per ton of erosion was very low. As a result, a region like the Northeast, characterized by modest per-acre reductions in erosion but high damage per ton of erosion, has much higher per-acre benefits.

Results show the need to know damage amounts as well as erosion rates when targeting conservation programs to improve water quality. Note that in the Mountain, Northern Plains, and Southern Plains regions, reducing wind erosion was a major goal of the CRP. While the benefits from reducing sheet and rill erosion are low in these regions, benefits from reducing wind erosion may be high.

Table 9 summarizes benefits based on damage category. The most interesting result is the zero benefit for recreational fishing. Recreational fishing benefits depend on achieving specific water quality threshold levels. The estimated erosion reductions for the first five CRP signups were insufficient to generate water quality improvements needed to influence fishing.

Table 8--Present value of offsite benefits of CRP over contract period, by region1/

| Region | Estimated benefits | | |
|---|---|---|---|
| | Best2/ | Range | Per acre |
| | - - - Million dollars - - - | | Dollars |
| Appalachia | 137 | 80 - 195 | 180.5 |
| Corn Belt | 267 | 148 - 386 | 81.6 |
| Delta States | 218 | 134 - 308 | 321.1 |
| Lake States | 255 | 146 - 362 | 128.5 |
| Mountain States | 326 | 177 - 477 | 67.0 |
| Northeast | 29 | 17 - 41 | 267.7 |
| Northern Plains | 215 | 114 - 323 | 41.2 |
| Pacific | 185 | 103 - 273 | 126.1 |
| Southeast | 174 | 104 - 249 | 176.1 |
| Southern Plains | 241 | 128 - 356 | 65.8 |
| Total | 2,047 | 1,151 -2,970 | 89.0 |

1/Estimated benefits are for the CRP contract period, based on 23 million acres enrolled in the first five signups.
2/Best estimate is the most likely extent of offsite benefit.

The present value of the estimated benefits for the entire 45-million acre program ranged between $2 and $5.5 billion, with a best estimate of about $3.7 billion, or nearly $82.6 per acre (table 10). Compared with the 23-million acre enrollment, per-acre benefits for total program acreage declined in most regions because the most erosive land is assumed to be enrolled first. Per-acre benefits in the Appalachian region, however, increased between the initial signups and the projected final enrollment. The reason for the increase is that recreational fishing benefits were realized for the projected CRP (table 11). The enrollment of 759,000 acres in the Appalachian region during the initial signups was insufficient to generate the necessary improvements in water quality. However, the projected enrollment of an additional 1.2 million acres, for a 2-million acre total, would increase recreational fishing. The Corn Belt also showed an increase in recreational fishing benefits.

Results can be compared with offsite benefits estimated for the more traditional soil conservation programs such as the Agricultural Conservation Program (ACP), the Conservation Technical Assistance program (CTA), and the Great Plains Conservation Program (GPCP). These programs are also voluntary, but are not targeted specifically at highly erodible land. As a result, these programs' per-acre soil erosion reductions and offsite benefits are less than those generated by the CRP.

A 1986 economic evaluation of ACP, CTA, and GPCP revealed that about 65 percent of the cropland enrolled in these programs in 1983 was eroding at less than 2T (13). (T is defined as the maximum rate of annual soil erosion that may occur and still permit a high level of crop productivity to be obtained economically and indefinitely (21)). Cropland had to be eroding at a rate exceeding 3T to be

Table 9--Present value of offsite benefits of CRP over contract period, by damage category1/

| Damage category | Estimated benefits: Best2/ | Estimated benefits: Range |
|---|---|---|
| | Million dollars | |
| Freshwater recreation | 0 | 0 - 0 |
| Water storage | 393 | 196 - 589 |
| Navigation | 272 | 193 - 339 |
| Flooding | 348 | 233 - 551 |
| Roadside ditches | 144 | 55 - 233 |
| Irrigation ditches | 27 | 14 - 37 |
| Municipal water treatment | 410 | 204 - 615 |
| Municipal and industrial use | 443 | 245 - 591 |
| Steam power cooling | 10 | 11 - 15 |
| Total | 2,047 | 1,151 -2,970 |

1/Estimated benefits are for the CRP contract period, based on 23 million acres enrolled in the first five signups.
2/Best estimate is the most likely extent of offsite benefit.

Table 10--Present value of offsite benefits of projected CRP over contract period, by region1/

| Region | Estimated benefits | | |
|---|---|---|---|
| | Best2/ | Range | Per acre |
| | - - Million dollars - - | | Dollars |
| Appalachia | 411 | 162 - 663 | 208.6 |
| Corn Belt | 607 | 284 - 930 | 79.3 |
| Delta States | 395 | 243 - 558 | 276.0 |
| Lake States | 435 | 249 - 617 | 114.8 |
| Mountain States | 477 | 258 - 699 | 56.3 |
| Northeast | 132 | 79 - 186 | 181.2 |
| Northern Plains | 321 | 170 - 482 | 33.4 |
| Pacific | 286 | 158 - 422 | 107.9 |
| Southeast | 293 | 175 - 419 | 153.8 |
| Southern Plains | 359 | 192 - 531 | 53.0 |
| Total | 3,716 | 1,970 -5,507 | 82.6 |

1/Estimated benefits are projected for the entire CRP program, based on full 45-million-acre enrollment.
2/Best estimate is the most likely extent of offsite benefit.

Table 11--Present value of offsite benefits of projected CRP over contract period, by damage category1/

| Damage category | Estimated benefits | |
|---|---|---|
| | Best2/ | Range |
| | Million dollars | |
| Freshwater recreation | 229 | 0 - 459 |
| Water storage | 634 | 317 - 951 |
| Navigation | 482 | 343 - 600 |
| Flooding | 603 | 403 - 954 |
| Roadside ditches | 246 | 94 - 397 |
| Irrigation ditches | 41 | 21 - 56 |
| Municipal water treatment | 666 | 333 - 999 |
| Municipal and industrial use | 795 | 442 -1,063 |
| Steam power cooling | 20 | 17 - 28 |
| Total | 3,716 | 1,970 -5,507 |

1/Estimated benefits are projected for the entire CRP program, based on full 45-million-acre enrollment.
2/Best estimate is the most likely extent of offsite benefit.

eligible for the CRP. Potential soil savings, therefore, are much greater for the CRP.

The CRP obtained the maximum erosion reductions possible by requiring that cropland be taken out of production and planted to trees or grass. More traditional soil conservation programs usually keep cropland under cultivation but require farmers to use conservation practices. Because forests and grassland hold down soil better than cropland, CRP would be expected to have less per-acre erosion than the traditional programs. Sheet and rill erosion on cropland enrolled in the CRP, for instance, will decrease an estimated 9.4 tons per acre a year, while sheet and rill erosion on cropland treated under traditional programs decreased only 3.3 tons per acre a year (13).

The CRP will generate higher per-acre benefits than traditional soil conservation programs because it targets cropland eroding at high rates and mandates that farmland be held out of production for 10 years. For instance, the CRP was estimated to generate nearly $82.6 per acre in offsite benefits (present value over the course of the contracts), while the traditional soil conservation programs were estimated to generate $11.62 (present value over the lifespans of the conservation practices adopted) (13).

The analysis examined the gross effects of the CRP on water quality, however, net effects may be lower. There are two reasons why. The first is that when farmers enroll in a commodity program, they must take some of their cropland out of production as part of the Acreage Reduction Program (ARP). Since a farmer participating in the CRP must retire a portion of his crop base, some of the land that is enrolled in the CRP would have been idled under the ARP.4/ Erosion reductions on this land should not be attributed to the CRP.

A second factor is the influence of the CRP and ARP on crop prices. ERS preliminary estimates indicate that the prices of some commodities may increase when all CRP acres are retired. If prices do increase, land could be taken out of pasture and fallow and put into production. The CRP's net effect will, therefore, be less because of this program slippage.

The net water quality benefits of the CRP were estimated under the assumption that there would have been no change in the rules of the ARP in the absence of CRP. Net benefits were estimated in the following way. Erosion reductions on ARP land enrolled in the CRP, and erosion increases on new cropland, were subtracted from the erosion reductions reported in table 1. Benefits were then recalculated. The discharge of agricultural pollutants from this cropland was estimated to cut offsite benefits by about $160 million, or nearly 4 percent (table 12). Regions with the largest percentage drops in benefits are the Lake States (7 percent) and Southern Plains (6 percent). The benefits, adjusted for slippage, are the appropriate values for evaluating water quality benefits from

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4/The crop base is the amount of acreage of program crops eligible for program benefits. A farm's acreage base for a crop is the average of planted and considered planted acreage to the crop in the previous 5 years, but not exceeding the average of planted and considered planted acreage in the preceding 2 years. Considered planted acreage is acreage idled under acreage reduction or paid diversion programs, acreage prevented from being planted due to a disaster, and underplanted acreage planted to nonprogram crops other than soybeans or extra long staple cotton.

Table 12--Offsite benefits of projected CRP adjusted for slippage, by region

| Region | Net reduction in CRP acres1/ | Estimated benefits |
|---|---|---|
| | 1,000 acres | Million dollars |
| Appalachia | 237.3 | 407 |
| Corn Belt | 1,505.3 | 584 |
| Delta States | 321.7 | 376 |
| Lake States | 1,041.7 | 406 |
| Mountain States | 1,298.2 | 458 |
| Northeast | 227.5 | 127 |
| Northern Plains | 1,687.2 | 306 |
| Pacific | 479.5 | 275 |
| Southeast | 334.8 | 280 |
| Southern Plains | 897.8 | 338 |
| Total | 8,031.0 | 3,557 |

1/Acres of cropland entering production due to the price increases and cropland which would have been in ARP.

the CRP. Net benefits could be higher or lower, depending on assumptions made about ARP and price response.

## CONCLUSIONS

The Conservation Reserve Program will generate $3.5 to $4 billion (present value) in water quality benefits if 45 million acres are successfully enrolled. Benefits will be less if enrollment is less. Benefits of cleaner water could be increased by encouraging enrollment of more cropland in regions east of the Mississippi River. Over half the cropland enrolled at the time of this analysis was in the Northern Plains, Southern Plains, and Mountain States, regions in which per-acre water quality benefits are lowest (table 13).

Water quality benefit estimates are not complete. Benefits related to swimming and commercial fishing were not estimated, nor were benefits from reduced pesticide use. Based on past experiences with DDT and other pesticides, the water quality and environmental benefits from reduced pesticide runoff may be substantial.

Benefit estimates rest on many assumptions, which may have caused overestimation or underestimation. Assumptions had to be made about the links between soil erosion and economic effects on water users. These included premises about the relationships between erosion and lake water quality, and about the effectiveness of defensive expenditures. Any inferences about the overall value of the CRP, therefore, should be made carefully and be based on the range of water quality benefits computed.

More research on how soil conservation affects water quality would greatly improve the ability of USDA and the States to protect water resources from nonpoint pollution. Better information on the relationships between pollutant discharge and surface water quality, for example, would enable analysts to predict water quality changes over broad regions. Additional research could yield answers on how much time elapses between conservation action and water quality change. And developing models to calculate flood and fisheries damage, harm to municipal and industrial water users, and participation rates of water recreationists would greatly improve the accuracy of benefit estimates.

Table 13--Summary of per-acre water quality benefit ranges, by region

| Region | CRP to date | Projected | Including slippage |
|---|---|---|---|
| | | Dollars | |
| Appalachia | 105.4 - 256.9 | 82.3 - 336.7 | 81.3 - 333.2 |
| Corn Belt | 45.3 - 118.1 | 37.1 - 121.6 | 35.7 - 117.0 |
| Delta States | 197.3 - 453.6 | 169.7 - 389.7 | 161.3 - 370.8 |
| Lake States | 73.6 - 182.6 | 65.7 - 162.9 | 61.2 - 152.1 |
| Mountain States | 36.4 - 98.1 | 30.5 - 82.5 | 29.3 - 79.2 |
| Northeast | 156.0 - 376.1 | 108.2 - 254.8 | 104.1 - 245.2 |
| Northern Plains | 21.8 - 61.8 | 17.6 - 50.1 | 16.8 - 47.7 |
| Pacific | 70.2 - 186.0 | 59.6 - 159.3 | 57.4 - 153.3 |
| Southeast | 105.2 - 251.8 | 91.9 - 219.9 | 87.7 - 210.0 |
| Southern Plains | 35.0 - 97.4 | 28.3 - 78.3 | 26.7 - 73.8 |
| Total | 50.0 - 129.1 | 43.8 - 122.4 | 41.9 - 117.1 |

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Benefits to recreational fishermen from water quality improvements were estimated with a sequential decision model outlined by Vaughan and Russell (20). Fishing activity can be described as a two-part decision on the part of an individual: whether or not to fish in a given year; if yes, how much to fish. Each decision was modeled at the national level as a function of socioeconomic variables, supply of surface water, and water quality. Together, these two models can be used to estimate changes in total days of fishing activity resulting from a change in water quality.

The major data source on recreational fishing behavior was the U.S. Fish and Wildlife Service's 1980 National Survey of Fishing, Hunting, and Wildlife-Associated Recreation (hereafter called the Hunting and Fishing survey). This survey consisted of two parts. The first, a screening survey, was conducted by phone on a sample of 340,000 individuals across the country. The survey measured participation in hunting, fishing, and other wildlife recreation activities of people 10 years old or over. The second part consisted of detailed personal interviews with a subsample of fishermen, hunters, and other wildlife recreation participants identified in the screening survey. About 30,000 fishermen were interviewed. This survey provided more detailed information on fishing habits, expenses, and success.

The regions studied were 129 residence regions defined for the Hunting and Fishing survey. Fishing activity and water quality variables used in the models were defined in terms of these regions. Home residence region was defined as the region in which the survey respondent resided. Adjacent residence region was defined as the total area of all residence regions bordering the home residence region.

## Participation Model

The participation model estimates the probability that an individual will fish at least once in a given year. The equation was specified as a logit model. The screening survey contained a question which asked if the respondent fished in 1980. The binary yes-no response is the dependent variable in the logit equation. No distinction was made between saltwater and freshwater fishing.

The explanatory variables in the model were water quality of home residence region, water quality of adjacent residence region, per-capita supply of water in home residence region, per-capita supply of water in adjacent residence region, whether the residence region is adjacent to the Great Lakes or the ocean, household income, urban or rural residence, whether one grew up in an urban or rural area, FPR of residence, age, and sex.

Water quality is the most important variable in the model, because it links nonpoint-source pollution loadings and changes in recreational activity. Three of the major pollutants generated by agriculture were chosen to represent water quality: total suspended sediment (TSS), total Kjeldahl nitrogen (TKN), and total phosphorus (TP). There are many other pollutants that affect fisheries, but these are the pollutants that nonpoint sources, especially agriculture, tend to generate.

Data on water quality were obtained from USGS's NASQUAN for the residence regions. NASQUAN data were used to specify the concentrations of TSS, TKN, and TP in each residence region. A 2-year average concentration of TSS, TKN, and TP was calculated for each NASQUAN station. If a region contained more than one NASQUAN station, a simple mean of the average concentrations was calculated. Eighteen regions had no NASQUAN station, so the observations from these regions were dropped from the analysis.

Concentrations of TSS, TKN, and TP were included in the model as an index. If any one of the pollutants were in high enough concentration to affect fishing behavior, the levels of the other pollutants were irrelevant. A dummy variable was used to represent whether regional TSS, TKN, or TP concentrations were over prespecified threshold levels. A threshold level is the point at which recreational use of water is assumed to become impaired (22). Thresholds used were TSS levels over 200 milligrams/liter (mg/l), TP levels over 0.2 mg/l, and TKN levels over 1.8 mg/l. If TSS was above its threshold, or if TKN and TP both were above their thresholds, then the dummy variable was assigned a value of 1. The average concentrations of TSS, TP, and TKN were also calculated for all adjacent home regions, and a 0-1 dummy variable was created in the same way as described above.

The model was estimated using 10,458 observations from the screening portion of the Hunting and Fishing survey. Appendix table 1 shows the modeling results. The model seems to have performed well. All variables except water quality of adjacent region, supply in adjacent region, and model chi-square is significant at the 1-percent level.

Two of the regional dummies were significant at the 10-percent level or better. The estimated model predicts a person's probability of fishing at least once a year, given the explanatory variables. The model can be used to estimate how an improvement in water quality affects the probability of fishing. The probability that an average person will fish can be estimated by entering the regional averages of the explanatory variables into the equation. Change in probability of fishing from an improvement in water quality can be estimated by entering the current and future indexes of water quality into the model. Multiplying an estimated increase in the probability of fishing by population results in the number of new fishermen attracted to the sport by better water quality.

## Visitation Model

The visitation model estimates the number of fishing trips a fisherman will make in 1 year. The number of days spent fishing in a year was specified to be a function of socioeconomic variables, water quality, and travel costs. However, since the demand for all sites a fisherman has the opportunity to visit is being modeled, including those he does not now visit, travel cost becomes a choice variable (6). The fisherman, therefore, faces two choices: how far to travel and how many visits to make. A recursive system of equations was specified to model this behavior. The choice variable, average miles, is an explanatory variable in the trip equation, and is itself a function of income and regional water quality. Distance was treated as a proxy for travel cost.

The number of days spent fishing and average distance were obtained from the fishing portion of the 1980 Hunting and Fishing survey. The other variables are identical to variables in the participation model. Number of fishing days was specified as a function of average miles traveled to all sites visited, water quality of home and adjacent regions, income, fishing experience, age, sex, and

Appendix table 1--Results of logit model estimation

| Variable | Mean | Coefficient | $\chi^2$ 1/ | Partial derivative |
|---|---|---|---|---|
| Intercept | NA | -2.210 | 386.43** | NA |
| Water quality of home region | .350 | .188 | 6.58** | .037 |
| Water quality of adjacent region | .366 | .078 | .88 | .015 |
| Water supply in home region | 2.440 | .017 | 3.66* | .003 |
| Water supply in adjacent region | 2.640 | .034 | 11.25** | .007 |
| Urban/rural | .675 | -.236 | 28.11** | -.055 |
| Upbringing | .237 | -.357 | 38.09** | -.068 |
| Ocean/Great Lakes | .523 | .234 | [illegible] | -.046 |
| Income | 20.850 | .012 | 60.64** | .002 |
| Age | 32.370 | .077 | 264.52** | .015 |
| Age squared | 1,525.300 | -.001 | 289.48** | -.0002 |
| Sex | .486 | 1.118 | 550.70** | .224 |
| Appalachia | .115 | .060 | .11 | .012 |
| Corn Belt | .153 | .393 | 19.28** | .079 |
| Delta | .045 | .388 | 9.37** | .077 |
| Lake States | .092 | .526 | 27.64** | .104 |
| Mountain | .053 | .207 | 2.16 | .041 |
| Northern Plains | .028 | .321 | 3.44* | .063 |
| Pacific | .161 | .440 | 20.52** | .087 |
| Southeast | .085 | .408 | 15.81** | .081 |
| Southern Plains | .097 | .457 | 14.80** | .090 |
| $R^2$ | NA | .081 | NA | NA |
| Model $\chi^2$ | NA | 1,090.94** | NA | NA |
| Somer's $D_{yx}$ | NA | .420 | NA | NA |

1/Chi-square statistic.
*Significant at 10-percent level.
**Significant at 1-percent level.
NA = Not applicable

FPR of residence. Average distance was specified as a function of income, water quality of home residence region, and water quality of adjacent residence region.

Each equation was estimated using weighted least squares regression. Appendix table 2 summarizes the results. The equation that calculates total trips was significant at the 1-percent level. All variables except age squared, the water quality variables, and the FPR dummy variables were significant at the 10-percent level. The $R^2$ was very low, but this is to be expected when using cross-sectional data. The signs of most of the estimated coefficients were as expected.

The average distance traveled for fishing was significant and had the expected negative influence on the participation level. Neither water quality of the home residence region nor water quality of adjacent residence region were significant. These results imply that the decision to fish is a function of the quality of water, but once a person decides to fish, other factors are more important in deciding how often to fish.

Based on the results of the models estimated, water quality improvements increase overall fishing activity by increasing the number of participants but not the number of trips per participant. Results could be a function of the coarseness of the data, however. Good-quality sites may be available in most regions identified as having poor water quality, weakening the relationship between distance and water quality.

Appendix table 2--Results of trip model estimation

| Variable | Coefficient value: Visit model | Coefficient value: Distance model |
|---|---|---|
| Intercept | 24.032<br>(6.31)**1/ | 33.471<br>(14.88)** |
| Water quality of home region | .350<br>(.210) | -2.378<br>(-1.07) |
| Water quality of adjacent region | -2.106<br>(-1.229) | 1.797<br>(.76) |
| Average distance | -.024<br>(-1.87)* | NA |
| Income | -.103<br>(-2.75)** | .588<br>(11.94)** |
| Experience | .196<br>(4.40)** | NA |
| Age | -.350<br>(-1.85)* | NA |
| Age squared | .003<br>(1.45) | NA |
| Sex | 3.837<br>(3.39)** | NA |
| Appalachia | -.733<br>(-.35) | -14.366<br>(-4.98)** |
| Corn Belt | -1.365<br>(-.65) | -14.074<br>(-4.87)** |
| Delta | 2.315<br>(.88) | -14.536<br>(-3.99)** |
| Lake States | .525<br>(.24) | 4.462<br>(1.50) |
| Mountain | -3.388<br>(-1.16) | 13.572<br>(3.37)** |
| Northern Plains | 1.936<br>(.56) | -.989<br>(-.21) |
| Pacific | -1.685<br>(-.80) | 4.660<br>(1.60) |
| Southeast | 6.056<br>(2.78)** | -18.410<br>(-6.20)** |
| Southern Plains | -.963<br>(-.36) | .599<br>(.16) |
| Adjusted $R^2$ | .023 | .100 |
| Number of observations | 3,284 | 3,296 |

1/Student-t in parentheses.
*Significant at 10-percent level.
**Significant at 1-percent level.
NA = Not applicable.



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