ECONOMIC DETERMINANTS FOR SEDIMENT MANAGEMENT ON A NORTH MISSISSIPPI WATERSHED 1/

by

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INTRODUCTION

Fluvial sediment and its many ramifications are of tremendous economic significance to our national economy. Annual damages in the United States from sediment and sediment related problems have been estimated at more than 500 million dollars.

Sediment, which is the end product of soil erosion as well as the geological process, may be defined as out-of-place soil material from a previously designated location. Damage occurs in many forms.

Sediment can plug channels, which creates or intensifies flooding. Infertile sediment deposited on fertile land reduces productivity of that land. Sediment deposited in reservoirs decreases the storage capacity needed for water supply and flood control. Increased turbidity of streams and rivers caused by sediment endangers fish and wildlife. Additional processing of sediment laden-water is necessary if that water is to be used for municipal or industrial purposes. Many other examples of sediment damage could be cited. Because of this tremendous damage from sediment the powerful forces that influence sediment production should be efficiently managed.

The sedimentation process originates in the watersheds. Although rates of sedimentation vary from one watershed to another, the basic factors that contribute to erosion are common to all watersheds. Therefore, the small watershed is the logical basic unit from which to study the entire sedimentation cycle. Each factor contributing to erosion must be evaluated in order to develop effective management and/or control of sedimentation.

Sediment can be trapped by natural or man-made barriers or a combination of both. One major way of minimizing the sediment burden is through proper watershed management. Practices which provide effective ground cover, improve permeability of the soil, and stabilize waterways will aid in efficient water conservation and help avoid excessive soil losses. Man-made structures, such as desilting dams, gully plugs, and other structures strategically placed, act as traps in reducing the quantity of sediment transported into a drainage system.

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THE SEDIMENT MANAGEMENT PROBLEM

The evaluation and solution of a sediment damage problem appears at first glance to be merely one of eliminating the source of trouble. This would involve complete control of the watershed through land use, man-made structures, or a combination of both. However, this approach merely accomodates the physical on-site aspects of the watershed without considering other possible alternatives or downstream consequences, or the total economics of developing an optimum or least const control program. Building a desilting reservoir or debris basin on the upper reaches of a drainage area will in all probability change the downstream hydrology. A drainage channel which was originally sediment lined and in a near-equilibrium condition will begin to degrade when the sediment load of the drainage stream is reduced. Sediment which had previously been deposited in the channel can be picked up and redeposited downstream, thus creating a more immediate problem.

The sediment management problem may be viewed or described according to the degree of controlled damage. Initial control, which must begin on the watershed itself, is in most instances supplemented with man-made structures to further reduce sediment movement off the watershed. Complete watershed control in an area of high erosion risk requires large capital investment, particularly so if the major protection is furnished by man-made structures. Difficulty in estimating the quantity of potential sediment and, consequently, the proper retention structure as to size and length of life, can result in an over designed structure, thereby involving unnecessary additional capital investment. On the other hand, under-designed structures may fill with sediment and lose their usefulness before a stabilized land condition is reached. The opportunity cost of a high level of watershed control through restricted land use is often too high. Realistically, a combination of improved land use and man-made structures should be utilized in most situations to control sediment discharge.

The various possible combination of practices for sediment management not only determine direct investments needed, but also influence total net returns from a given unit of land. Land use, in combination with sediment retention structures, offers numerous choices, such as; (1) minimum use of retention structures combined with maximum land acreage in conservation uses, (2) maximum use of retention structures combined with minimum acreage in conservation uses, and (3) a combination of structures and conservation acreages which falls somewhere between these two extremes. However, sediment management associated with each of the combination systems must be classified according to the total sediment management; that is, management within the watershed as well as downstream.

An economic assessment of sediment problems involves two distinct but related segments. One pertains directly to the watershed itself, and involves those economic consequences which affect only the watershed. The other deals with the downstream activities. While the two segments are interrelated, suitable practices and remedial measures useful on the watershed can produce undesirable downstream effects.

SEDIMENT MANAGEMENT - ECONOMIC AND PHYSICAL RELATIONSHIPS

Studies pertaining to economic and physical relationships within a waterhsed are being conducted on a 117-square-mile section of the Pigeon Roost Creek Watershed in North Mississippi (Figure 1). The primary economic emphasis of the study has been toward the identification and quantification of investment levels associated with the existing sediment management program within the watershed. Information gained through this effort will provide the basis for identifying the least social cost associated with sediment management. These social costs include, but are not limited to, (1) damages from sediment deposition on arable lands, (2) damages to arable lands from out-of-bank streamflow caused by sediment deposition in the channel bed, (3) damages to agricultural lands through gully formation, which limits further use of that land, and (4) the control measures to offset these damages.

Gross benefits resulting from the control measures can be defined as the difference between the damages with and without the control measures. The net benefits are represented by gross benefits less the cost of control measures. Investment levels involved in sediment retention structures and reforestation practices represent the on-site measures taken upon the watershed for that portion of the damage control.

In the following discussion, estimates for subwatershed investments during the designated time period are set forth. Investment levels for each subwatershed for sediment retention structures and reforestation are designated. The next phase of the research will examine the effectiveness of retention structures and reforestation practices in reducing sediment loads. These coefficients will be used in a broader analysis of methods to minimize social costs of sediment management.

The relationships among the many physical variables have been under study since 1958. Such features as precipitation, storm runoff, topography and the associated sediment yields have been measured from each of eleven subwatersheds within the area under investigation. Efforts are continuing to refine previous estimates for these physical relationships.

Prior to the 1950's, efforts to reduce soil erosion and sediment production were directed toward terracing the steeper slopes. Remnants of these terracing efforts, still evident as late as 1954, indicated an estimated 125.5 miles of terraces were constructed in this portion of the watershed. A period of inactivity followed the discontinuance of these efforts. Beginning in the mid-1950's and continuing into the 1960's, there was a renewed effort on sediment management, using a different approach. Capital investments involved in this effort were made primarily to construct sediment retention structures and to provide substantial changes in land use.

During the period from 1954 to 1966, an estimated 611 artificial barriers to retain and trap sediment were built within the study area of the watershed. Of this total, 522 were built between 1954 and 1957, and 89 were built between 1957 and 1966. These sediment retention structures varied in size from the small gully plug with a storage capacity of less than 1/2 acre-foot, to structures as large as 5 acre-feet or greater.

Of those structures completed during 1954-57, 201 were built with an estimated initial storage capacity of 1 acre-foot of sediment or less, and 164 were constructed with a storage capacity of 1 to 3 acre-feet. Of the remaining structures, 70 had an estimated storage capacity of 3 to 5 acre-feet, and 87 had an initial capacity above 5 acre-feet. Therefore by size, 38.5% of the structures installed in this period had a capacity of 1 acre-foot or less, 31.4% had a capacity of 1 to 3 acre-feet, 13.4% had a capacity of 3 to 5 acre-feet, and 16.7% had an initial capacity greater than 5 acre-feet.

The majority of those structures built in 1957-66 were relatively larger. Of the 89 structures installed, only 12.4% had a storage capacity of 1 acre-foot or less, 23.6% had a capacity of 1 to 3 acre-feet, 22.4% had a capacity of 3 to 5 acre-feet, and 41.6% had a capacity greater than 5 acre-feet.

Estimated construction costs of these retarding structures and the conservation measures associated with these structures varied from a low of $1.95 per acre for a watershed of 1,130 acres to a high of $11.46 per acre for a 512-acre watershed. The estimated construction costs for the 611 structures and related conservation practices under consideration, as shown in Table 1, is $345,469, or an average per-acre cost of $4.61 (Table 2) for the 74,900 acres in the Pigeon Roost Creek Watershed.

The number, as well as the size of the sediment retarding structures, provides some of the information needed in sediment management planning. Those structures with an initial storage capacity of 1 acre-foot or less are usually placed to concentrate on a localized condition needing immediate stabilization. Thus, the area protected from further erosion and additional sediment production is small. However, because of the high rate of sediment production associated with these problem areas, the initial step in sediment management must involve measures which reduce this source of sediment. Through the identification and classification of those retarding structures installed in the Pigeon Roost Watershed in 1954-66, it is evident that the first emphasis on sediment management was directed toward stabilizing individual problem areas. The primary purpose of 40% to 60% of the total structures installed was to stabilize soil in the individual problem areas. During 1957-66, the emphasis was placed on larger structures that would provide protection for greater land areas and supply additional sediment storage capacity. Installation of the larger structures did provide these benefits, but it also created some overlapping of purpose because of the previously built smaller structures.

LAND USE CHANGES

The measured changes in land use between 1960 and 1966, which for the most part were directed toward sediment management, were made on lands not in agricultural production. Therefore, changes in land use to

TABLE 1.--Total Cost Estimates for On-Site Sediment Management, Pigeon Roost Creek Watershed, 1954-66.

Watershed Number	Acres in Watershed	Costs per Watershed: Retarding Structures	Reforestation	Total	Total costs per watershed acre
	Acres	Dollars			
4	1/ 2,000	7,785	1,542	9,327	4.66
5	1,130	2,199	3,575	5,774	5.11
24	512	5,869	2,313	8,182	15.98
28	1,080	9,888	8,811	18,699	17.31
12	2/ 22,800	100,875	46,061	146,936	6.45
17	3/ 32,100	144,510	114,348	258,858	8.06
10	5,530	44,068	33,723	77,791	14.07
35	7,550	55,131	33,232	88,363	11.70
35A	1,090	5,950	2,992	8,942	8.20
32	4/ 20,000	121,969	95,117	217,086	10.85
17A	3,443	33,215	27,063	60,278	17.51
34	5/ 74,900	345,469	325,310	670,779	8.95
TOTAL	74,900	345,469	325,310	670,779	8.95

1/ Watershed boundary changed in 1965, additional acres allocated to watershed 12.

2/ Includes watersheds 4, 5, 24, 28, and 12.

3/ Includes watershed 12 and all land upstream.

4/ Includes watersheds 10, 34, 35A and 32.

5/ Includes all subwatersheds and 34.

TABLE 2.--Inventory of Sediment Retarding Structures, Pigeon Roost Creek Watershed, 1954-66.

Watershed Number	Acres in Watershed	Number of Retarding Structures	Watershed Acres per Structure	Cost per Watershed Acre
	Acres	Units	Acres	Dollars
4	1/ 2,000	12	167	3.89
5	1,130	4	283	1.95
24	512	11	47	11.46
28	1,080	8	135	9.16
12	2/ 22,800	174	131	4.42
17	3/ 32,100	255	126	4.50
10	5,530	93	60	7.97
35	7,550	99	76	7.30
35A	1,090	14	78	5.46
32	4/ 20,000	244	82	6.10
17A	3,443	50	69	9.65
34	5/ 74,900	611	123	4.61
TOTAL	74,900	611	123	4.61

_/ Reference to Table 1

facilitate sediment management did not reduce income opportunities to landowners, but in reality expanded these. Additional income possibilities include future timber harvests, and additional grazing resources. Consequently efforts toward sediment management were not economic tradeoff's within the existing farm enterprise but represented additions to the farming programs. Therefore, because additional income can be achieved through reforestation, its total cost should not be charged to sediment management.

The capital investments in sediment management directed toward changes in land use were principally for reforestation of those lands with extreme slopes or other erosion risk features. A comparison of land use patterns of 1960 and those of 1966 indicates a significant increase in the amount of land planted to marketable timber. An additional 13,920 acres were planted to timber during this period. The 1960 land use inventory showed that 15,542 acres, or 20.8% of the total land within this section of the Pigeon Roost Watershed was planted to timber. The 1966 inventory showed a total of 29,462 acres, or 39.4% of the total land area had been planted to timber.. This 18.6% increase in timbered acres was offset by a decrease in the number of idle acres. Idle acres were defined as those having existing ground cover including volunteer vegetation and/or unmarketable timber such as sweet gum, hickory, white oak, or blackjack oak.

An estimated additional investment of $325,310 was required for this reforestation. Estimates of the reforestation costs for the individual subwatersheds varied from a low of $0.77 per acre for a watershed of 2,000 acres to a high of $8.16 per acre for a watershed of 1,080 acres. The total overall cost to 1966 for the 74,900-acre watershed was $4.34 per acre (Table 3). Reforestation costs were influenced by both the number of acres planted to marketable timber and the number of acres of unmarketable timber which had to be removed to facilitate replanting.

Reforestation was, for the most part, limited to those lands with slopes of 8.0% or greater. Of the total land within the 74,900 acre Pigeon Roost Watershed, over half of that land (50.4%) had slopes of 8.0% or greater. Because of slope limitations, alternative uses other than timber production are not possible.

The amount of land within each subwatershed having a slope of 8.0% or greater varied from 33.6% of the total 1,090 acres in subwatershed 35A, as shown in Table 3, to 75.9% of the total 512 acres in subwatershed 24. Of those steeper lands, 67.1% had been reforested by 1966. Of the remaining acres with the steeper slopes, 8.1% were in pasture and 23.9% remained idle. Altogether, of those lands with slopes of 8.0% or greater, 75.2% had received treatment to prevent or reduce further erosion and sediment production. However, the amount of land with slopes of 8.0% or greater, treated within each subwatershed, varied from 51.2% to 95.9%, as shown in Table 3.

Of the four major land uses in the Pigeon Roost Watershed, cultivation, forest, idle, and pasture, only the amount of land devoted to cultivation remained relatively constant during the period under study.

TABLE 3.--Reforestation Costs and Location, Pigeon Roost Creek Watershed, 1954-66.

Watershed Number	Acres in Watershed	Reforestation Costs Per Watershed Acre	Percentage of Total Acres With Slopes of 8.0% of Greater	Percent of Acres with Slopes of 8.0% or Greater in Forest	
				1960	1966
	Acres	Dollars	Percent	Percent	
4	1/ 2,000	0.77	65.7	53.4	80.1
5	1,130	3.16	44.5	34.8	63.2
24	512	4.52	75.9	75.1	95.9
28	1,080	8.16	64.6	36.6	85.2
12	2/ 22,800	2.02	51.1	43.6	56.0
17	3/ 32,100	3.56	51.7	41.7	65.6
10	5,530	6.10	56.5	26.0	69.3
35	7,550	4.40	44.6	11.3	51.2
35A	1,090	2.75	33.6	30.1	59.0
32	4/ 20,000	4.76	47.9	20.7	60.8
17A	3,443	7.86	70.3	38.2	83.3
34	5/ 74,900	4.34	50.4	35.6	67.1
TOTAL	74,900	4.34	50.4	35.6	67.1

_/ Reference to Table 1.

The 1960 land inventory shows 21.97% of the total land area in cultivation, while the 1966 land use information shows 23.67%. This 1.7% increase for land in cultivation was about equally distributed over those lands with average slopes of 1.0% to 3.5%. However, it should be noted that approximately 95.0% of all the land in cultivation was limited to lands with average slopes of 3.5% or less. Aside from the usually recommended conservation practices on cultivated lands, no economic adjustments were made to specifically accommodate sediment management.

SEDIMENT MANAGEMENT AND ECONOMIC EFFICIENCY

The primary elements of a sediment management program have been installed in the Pigeon Roost Creek Watershed, but the economic efficiency of this program can only be appraised after the physical effects of individual elements have been estimated. These physical effects, like sediment damages themselves, are affected by stochastic weather variables, which increase the necessary period of observation. Climatic variations, antecedent soil moisture, season of the year, as well as changes in storage capacity of the retarding structures, have to be considered. Year-to-year variations, in precipitation, storm runoff, and sediment transport loads (Table 4) illustrate the need for defining the specific influence of each of the physical parameters.

However, because of the increased emphasis on sedimentation in conjunction with the overall environment, studies of efficient sediment management programs cannot be delayed until physical parameters are refined to a high degree of reliability. A reasonable approach to this dilemma is to integrate physical and economic parameters and relationships into a general model that can be updated and expanded as more reliable and supplemental information is obtained.

The cost-effectiveness of on-site sediment control is complex and difficult to define, but is essential when considering the perhaps even more significant off-site consequences, which include channel-dredging, streambank deterioration, water quality control, sediment as a carrier of chemical pollutants, and other environmental effects. An appropriate level of reaction to each of these separate consequences cannot be appraised independently. Efficiency is served when total social costs are minimized--not when the remaining damages and costs of control are minimized for each consequence.

While economic efficiency is a desirable goal, it is not the only consideration in developing an overall sediment management program. An economic analysis of a sediment management program should be broad enough to include consideration of both on- and off-site efficiency and equity. Additional analysis should provide information on the appropriateness of concentrating sediment management in selected sub-watersheds in contrast to applying a more uniform plan of action throughout the major watershed. However, any uniform plan or approach to sediment management must not neglect, or detract from, the necessary emphasis which must be placed on critical sediment source areas.

TABLE 4.--Precipitation, Storm Runoff, and Sediment Transport Loads, Pigeon Roost Creek Watershed, 1958-66[1/]

Year[2/]	Weighted Precipitation	Storm Runoff	Sediment Transport Loads	
	Inches	Inches	Tons Per Acre Per Year	Total Tons
1958	60.41	16.79	6.78	507,822
1959	42.88	9.39	2.78	208,222
1960	43.47	10.96	3.03	226,947
1961	47.51	12.12	3.67	274,883
1962	56.62	15.51	4.74	355,026
1963	38.60	7.53	2.34	175,266
1964	52.81	12.89	5.25	393,225
1965	52.08	19.89	7.25	543,025
1966	36.86	9.47	2.55	190,995
TOTAL				7,875,411

1/ Drainage area - 117.2 aquare miles.

2/ Based on a water year October 1 - September 30, Annual Reports, USDA, ARS, SWCRD, Sedimentation Laboratory, Oxford, Mississippi.

SUMMARY

The principal emphasis for management and/or control of sediment in the Pigeon Roost Creek Watershed of North Mississippi focused on retaining the sediment on the watershed. This was done by artificial barriers to trap and retain the sediment, and land use changes to reduce and prevent further soil losses off the watershed. Estimates of capital investment required to implement these techniques were developed as a first step in determining social cost associated with sediment management within the existing economic and physical conditions in the watershed.

The necessary economic determinants required to assess economic efficiency include not only the direct capital investments but also any adjustments in the farming enterprise which would affect economic returns. Estimates of direct capital investments in the sediment management program showed an average total cost of $8.95 per watershed acre for the 74,900 acres. Sediment-retarding structures accounted for $4.61 per acre to this total, and the reforestation program for $4.34. The increase in forested acres was not an economic trade-off since this land had previously been idle, and had been contributing little to the total farming enterprise. Also, there were no economic adjustments made on cultivated lands to specifically accommodate sediment management.

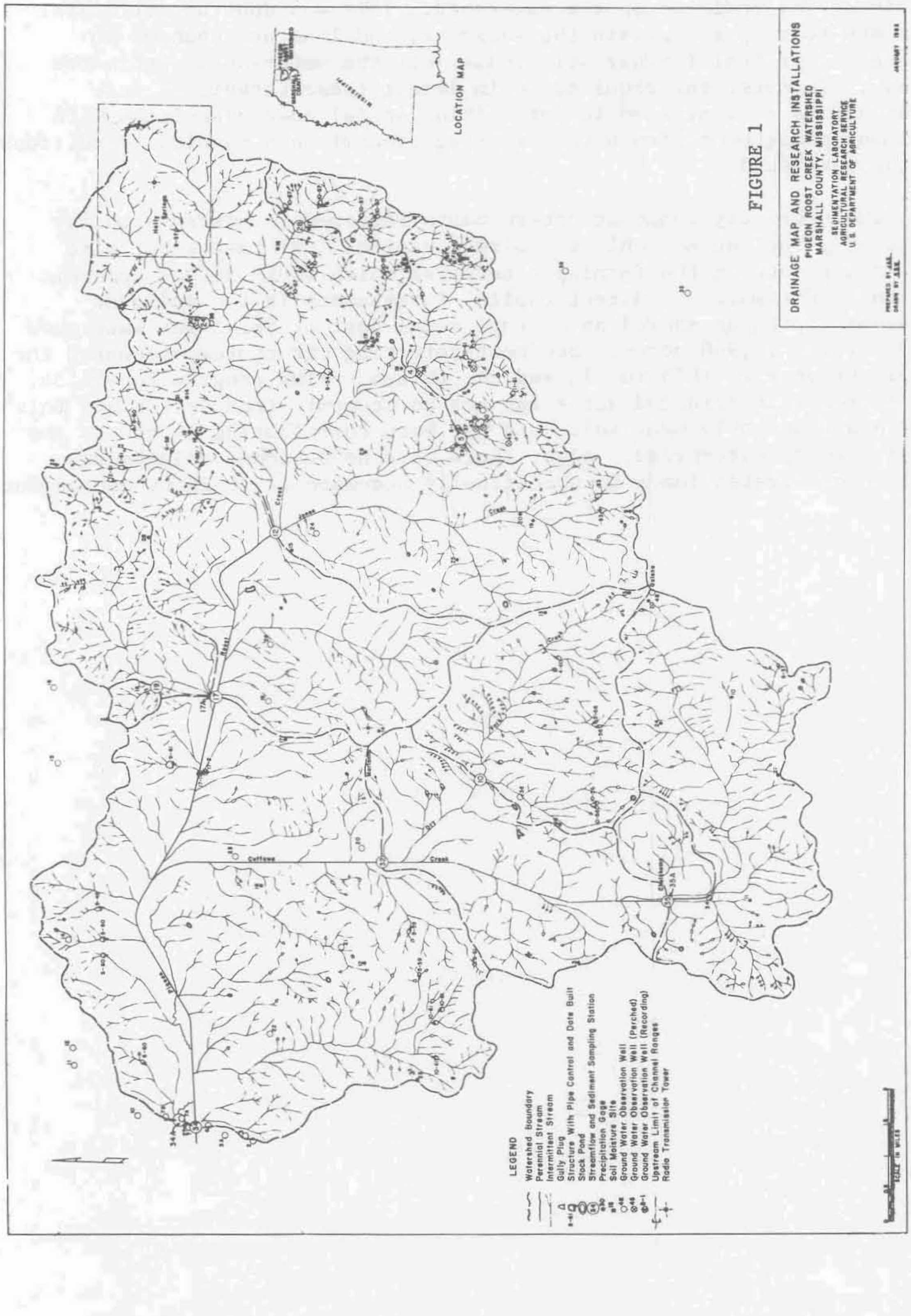

FIGURE 1

DRAINAGE MAP AND RESEARCH INSTALLATIONS
PIGEON ROOST CREEK WATERSHED
MARSHALL COUNTY, MISSISSIPPI

SEDIMENTATION LABORATORY
AGRICULTURAL RESEARCH SERVICE
U.S. DEPARTMENT OF AGRICULTURE