4th FISC

CONTENTS

Page

SECTION 2. EROSION AND SEDIMENT CONTROL

SECTION 2

EROSION AND SEDIMENT CONTROL

RATING EROSION SUSCEPTIBILITY

By Mark E. Van Der Puy, District Hydrologist, Phoenix District Office, U.S.D.I. Bureau of Land Management.

ABSTRACT

An Erosion Susceptibility Rating System was devised to provide land managers with an adequate and meaningful evaluation of current erosion conditions and erosion hazards as related to specific large scale resource management programs.

Using existing soil survey data, combined wind and water erosion hazard ratings can be developed to compare the relative effects of management alternatives on soil erosion. This method is particularly useful in comparing alternative routes for linear-type disturbances such as transmission line routes, gas pipelines and off-road vehicle races.

Erosion condition classification data is also available on 154 million acres of land administered by the BLM. By coupling erosion condition classifications with combined erosion hazard ratings, a dual component Erosion Susceptibility Rating System can be developed for particular watersheds. The effect of large scale resource management programs on particular watersheds can then be assessed. This method focuses on current or potential problem areas.

INTRODUCTION

Watershed specialists employed by the Bureau of Land Management or other agencies responsible for managing vast acreages of public land are often called upon to assess the environmental impact of large scale resource management programs. Typically, these specialists estimate changes in sediment yield or erosion as a function of changes in vegetative cover using the Pacific Southwest Inter-agency Committee (PSIAC) method or universal soil loss equation (USLE).

The problem with these approaches is that they rely on speculative cover values and involve time consuming calculations to generate numbers that mean very little to decision makers.

A practical method of assessing the impacts of proposed developments or management plans on the watershed system, specifically those impacts involving soil erosion and stream sedimentation, is yet to be established for large scale management areas as encountered in the BLM. This is evident in the variety of assessment formats used in the environmental assessment process.

APPROACHES TO IMPACT ASSESSMENT

Specialists assigned with the task of evaluating watershed impacts typically rely on the Universal Soil Loss Equation (Wischmeier and Smith, 1965) or the Pacific Southwest Inter-agency Committee (PSIAC, 1968) methods to quantify estimates of on-site erosion or sediment yield. An assessment of technical problems with these methodologies is beyond the scope of this paper; it is sufficient to note that there is considerable controversy regarding the applicability or adequacy of these methods for predicting erosion losses and sediment yield from arid and semi-arid rangelands.

When watershed specialists are requested to make their predictions, they inevitably focus on the parameter most likely to change: cover. Assuming existing cover values are available, the specialist must first speculate on changes in cover resulting from the proposed action; from this professional judgement lengthy calculations are then made for numerous watersheds or grazing allotments. The final product is units, either tons/acre/year or acre-feet/square mile of soil loss or sediment yield. The decision-making manager must ultimately be convinced of the significance of these units. He must weigh these units against grazing numbers or systems, miles of rights-of-way approved, or number of off-road vehicle (ORV) races authorized.

Krupin (1980) addressed the problem in a multi-parametric approach which discounted the value of calculating estimates of soil loss or sediment yield. He used a rather lengthy process which considered geomorphic, soil, vegetation, lithographic and related parameters in developing a susceptability rating for a unit of land. Managers could then base decisions on miles or square miles of land disturbed in areas with different susceptability ratings.

This direction in watershed impact assessment challenged the basic precept that quantification provides the best answers. The complexity and time requirement of the system used by Krupin, however, proves to be a disadvantage for very large land management areas.

EROSION HAZARD RATING

With the advent of Order 3 and 4 soil surveys on BLM lands, specialists have been given a valuable tool in assessing watershed impacts. Among the products of these soil surveys are mapped delineations of soil associations. Map Unit Descriptions (MUD's) describe each of these associations in a uniform format. Included in each MUD are evaluations of the wind and water erosion hazards of each major soil group found within the mapping unit.

Figures 1 and 2 are excerpts from the Nevada SCS Soils (Form 5) Guide USDA-SCS (1983). These demonstrate how the soil erodibility factor (K) is developed. The K factor is multiplied by slope (S) to determine the water erosion hazard as follows:

S X K	Water Erosion Hazard
4	Slight
4-8	Moderate
8	High

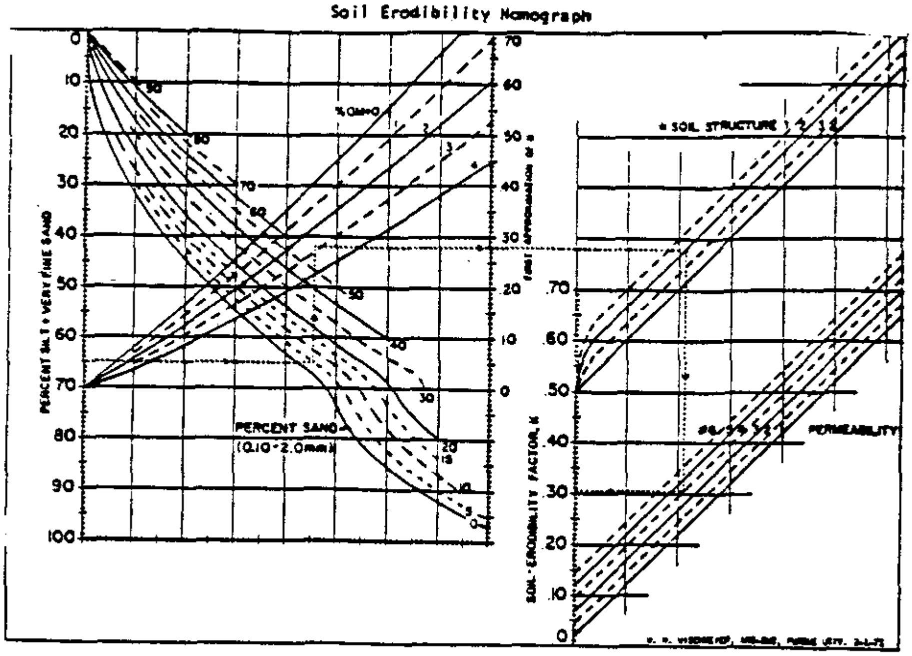
Evaluation of the wind erosion hazard is similar. The predominant soil textural class is used as illustrated in Figure 3 to determine the Wind Erodibility Group (WEG). A similar rating scheme as the water erosion hazard can be used as follows:

WEG	Wind Erosion Hazard
5-8	Slight
3,4	Moderate
1,2	High

Based on this soil survey information, combined erosion hazard ratings can be made for each MUD. A MUD with the dominant family having respective water and wind erosion hazards of high and moderate, for example, would have combined hazard rating of H/M. If there were two equally dominant taxonomic groups in the MUD, the range of hazard rating would be listed on tabulations or overlays as M-H/S-M.

Figure 1

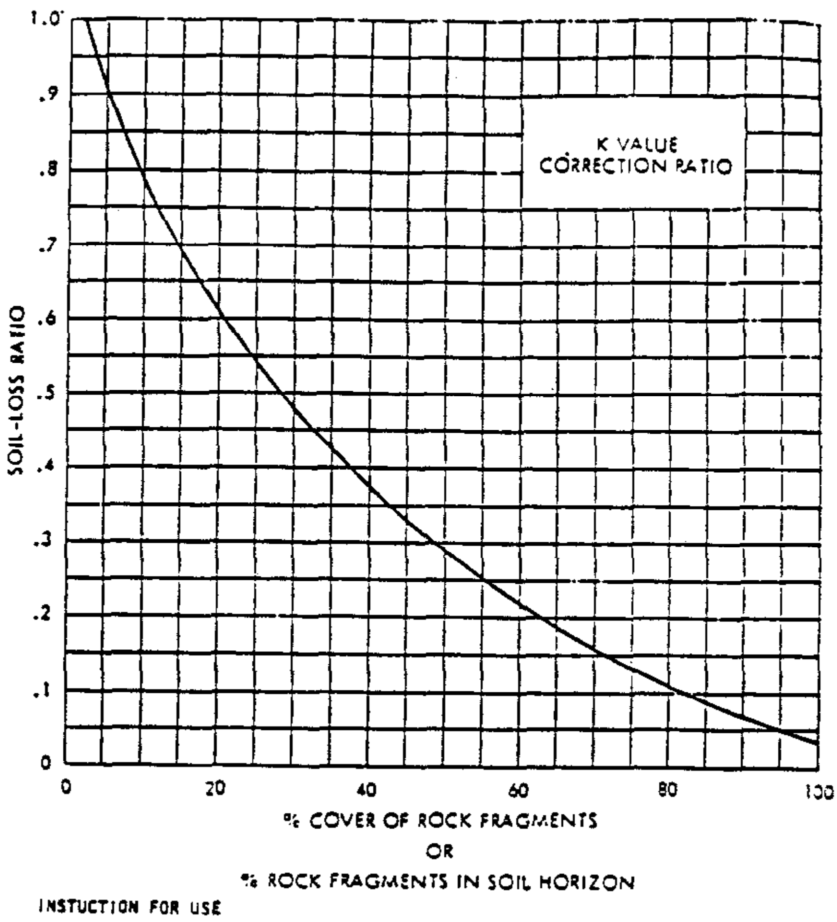
Soil Erodibility Nomograph



Reprinted from the Journal of Soil and Water Conservation
September-October 1971, Volume 26, Number 5

Figure 2

"K" Value Correction Ratio



INSTUCTION FOR USE

1. Average percent rock fragments for the horizon.
2. Go on vertical line to curve.
3. Go horizontally to SOIL-LOSS RATIO.
4. Multiply K from nomograph by S-LR to get corrected K.

Figure 3

Wind Erodibility Groups

The percent of soil aggregates or clods show a correlation for similar soil texture which has enabled the development of Wind Erodibility Groups (WEG). These groups are shown on the following table. WEG-1 is more erodible than WEG-2, and so on.

WEG	Predominant soil textural class 1/	Dry soil aggregate >0.84 mm (percent)	Erodibility "I" T/A/Yr.
1	Very fine, fine and medium sand (and dune sand). Single grain structure; vegetation difficult to establish.	3	220
2	Loamy very fine, fine, and medium sand. Dry clod structure (percent >0.84 mm) is weak; requires a combination of intensive practices to control wind erosion.	10	134
3	Fine, medium, and coarse sandy loams. Dry clod structure moderately stable; requires at least two measures to control wind erosion in regions with high and intermediate climatic factor.	25	86
4	Clays, silty clays (subject to granulation). Dry clod structure extremely variable due to contraction and swelling by freezing and thawing and wetting and drying; need a combination of at least two measures to control erosion.	25	86
4L	Clay and silty clay high in lime which is conducive to floculation and granulation.		
5	Loams, sandy clay loams, sandy clays. Dry clod structure quite stable; a combination of at least two measures is needed in a region with high climatic factor.	40	56
6	Silt loams and clay loams. Dry clod structure stable; requires a combination of at least two measures in a region with high climatic factor.	45	48
7	Silty clay loams, silt. Dry clod structure extremely stable; usually a single practice is sufficient to control wind erosion.	50	38
8	Soils (not usually suited for crops) because of wetness, extremely stony or very cobbly textures.	-	-

1/ For gravelly and cobbly textures reduce WEG 1 to 2 groups depending upon percent by weight. For very gravelly and very stony textures reduce WEG 2 to 3 groups depending upon percent by weight.

An overlay showing erosion hazard ratings could be used to evaluate the impacts of proposed developments and their alternatives. In routing transmission lines or ORV courses, for example, attempts can be made to minimize the miles disturbed in areas with high erosion hazard ratings. Comparison between alternatives can also be made by comparing the miles disturbed in each hazard group. This would provide the decision maker with a better idea of what the impacts are and how they could be reduced.

EROSION CONDITION CLASSIFICATIONS

The BLM's Watershed Conservation and Development System was initiated in 1970 as a six-phase system to identify and attain watershed objectives on specific geographic areas. Phase I consisted of field inventory, as outlined in BLM Manual 7322 and by Clark (1980).

As part of this inventory, the current erosion condition (soil surface factor, or SSF) was determined by evaluating seven surficial features including: soil movement, surface litter, surface rock, pedestalling, flow patterns, hills and gullies. Figure 4 illustrates how SSF values were obtained. Based on these SSF values, erosion condition classifications were then assigned: stable (SSF 0-20), slight (21-40), moderate (41-60), critical (61-80) and severe (81-100). Management objectives are greatly designed to reduce disturbance and increase cover in critical and severe watersheds.

Available data for erosion condition classifications is enormous. Each BLM District in the western United States has both summarizing tabulations and overlays depicting erosion conditions on each watershed, ranging from 20-400 mi.^{2}, with transects representing no more than 10 mi.^{2}. This data is available on approximately 154 million acres.

EROSION SUSCEPTIBILITY RATING SYSTEM

The Erosion Susceptibility Rating System consists of coupling the combined wind and water erosion hazard rating with the erosion condition classification for each watershed transect area. By comparing these two components with proposed uses of the land, protective measures or other management needs can be promulgated. Table 1 illustrates how the Erosion Susceptibility Rating System might be used.

Table 1

Erosion Susceptibility Rating System

Component		Protective Measure		
Erosion Condition Classification	Erosion Hazard Rating[a]	ORV	Grazing	Fire Suppression
Severe	High	1	3	4
Severe	Moderate	1	3	
Severe	Slight	1	3	
Critical	High	1	3	4
Critical	Moderate	2	3	
Critical	Slight	2	3	
Moderate	High	2		4
Moderate	Moderate	2		
Moderate	Slight			
Slight	High	2		4
Slight	Moderate			
Slight	Slight			
Stable	High	2		4
Stable	Moderate			
Stable	Slight			

[a]Representing the most severe of the wind and water erosion ratings for a particular mapping unit.

Protective Measures

1. Restrict all recreational ORV use to roads and trails.
2. Restrict organized or multi-vehicular ORV use to roads and trails.
3. Change management of grazing animals in such a way that vegetative and ground litter cover increase incrementally by 25%.
4. Consider these areas as high priority fire suppression zones.

Figure 4

Form 7310-12
(March 1973)

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF LAND MANAGEMENT

DETERMINATION OF EROSION CONDITION CLASS

SOIL SURFACE FACTORS (SSF)

By: RLK — Date: Sept. 10, 1968
Location: 27-04-003 WA
Transect T 1609121
Treatment affecting the SSF: Present O; W/O Mgt. Change □; Land Use Mgt. Change X; With Added Treatment Q.

SOIL MOVEMENT*	No visual evidence of movement 0 1 2 3	Some movement of soil particles 4 5	Moderate movement of soil is visible and recent. Slight terracing generally less than 1" in height. 6 7 8	Occurs with each event. Soil and debris deposited against minor obstructions. 9 10 11	Subsoil exposed over much of area, may have embryonic dunes and wind scoured depressions 12 13 14
SURFACE LITTER*	Accumulating in place 0 1 2 3	May show slight movement 4 5 6	Moderate movement is apparent, deposited against obstacles 7 8	Extreme movement apparent, large and numerous deposits against obstacles 9 10 11	Very little remaining (use care on low productive sites) 12 13 14
SURFACE ROCK*	If present, the distribution of fragments show no movement caused by wind or water 0 1 2	If present, coarse fragments have a truncated appearance or spotty distribution caused by wind or water 3 4 5	If present, fragments have a poorly developed distribution pattern caused by wind or water 6 7 8	If present, surface rock or fragments exhibit some movement and accumulation of smaller fragments behind obstacles 9 10 11	If present, surface rock or fragments are dissected by rills and gullies or are already washed away 12 13 14
PEDESTALLING*	No visual evidence of pedestalling 0 1 2 3	Slight pedestalling, in flow patterns 4 5 6	Small rock and plant pedestals occurring in flow patterns 7 8 9	Rocks and plants on pedestals generally evident, plant roots to 10% exposed 10 11	Most rocks and plants pedestalled and roots exposed 12 13 14
FLOW PATTERNS*	No visual evidence of flow patterns 0 1 2 3	Deposition of particles may be in evidence 4 5 6	Well defined, small, and few with intermittent deposits 7 8 9	Flow patterns contain silt and sand deposits and alluvial fans 10 11 12	Flow patterns are numerous and readily noticeable. May have large barren fan deposits. 13 14 15
RILLS	No visual evidence of rills 0 1 2 3	Some rills in evidence at infrequent intervals over 10' 4 5 6	Rills 1/2" to 6" deep occur in exposed places at approximately 10' intervals 7 8 9	Rills 1/2" to 6" deep occur in exposed area at intervals of 5 to 10'. 10 11 12	May be present at 3" to 6" deep at intervals less than 5' 13 14
GULLIES	May be present in stable condition. Vegetation on channel bed and side slopes 0 1 2 3	A few gullies in evidence which show little bed or slope erosion. Some vegetation is present on slopes. 4 5 6	Gullies are well developed with active erosion along less than 10% of their length. Some vegetation may be present. 7 8 9	Gullies are numerous and well developed with active erosion along 10 to 50% of their lengths or a few well developed gullies with active erosion along more than 50% of their length 10 11 12	Sharply incised gullies cover most of the area and over 50% are actively eroding 13 14 15

SITUATION	TOTAL	
		Present SSF, O = 19 + 21 = 40; W/O Mgt. Change, □ = 13 + 29 = 42;
		Land Use Mgt. Change, X = 6 + 23 = 29; With Added Treatment, Q = 13 + 9 = 22;

Erosion Condition Classes: Stable 0-20; Slight 21-40; Moderate 41-60; Critical 61-80; Severe 81-100

*(Instructions on reverse)

EXAMPLES

ITEM	EXAMPLE ONE			EXAMPLE TWO**			EXAMPLE THREE***		
	POTENTIALLY PRESENT	IDENTIFIED FACTORS	POSSIBLE FACTOR	POTENTIALLY PRESENT	IDENTIFIED FACTORS	POSSIBLE FACTOR	POTENTIALLY PRESENT	IDENTIFIED FACTORS	POSSIBLE FACTOR
Soil Movement	Yes	8	14	Yes	8	14	Yes	8	14
Surface Litter	Yes	9	14	Yes	9	14	Yes	9	14
Surface Rock	Yes	7	14	No	-	--	No	-	--
Pedestalling	Yes	10	14	Yes	10	14	Yes	10	14
Rills	Yes	8	14	Yes	8	14	No	-	--
Flow Patterns	Yes	10	15	Yes	10	15	Yes	10	15
Gullies	Yes	6	15	No	-	--	No	-	--
TOTAL		58	100		45	71		37	57
Total SSF		$\frac{58}{100} \times 100 = 58$			$\frac{45}{71} \times 100 = 63$			$\frac{37}{57} \times 100 = 65$	

GENERAL INSTRUCTIONS

District prepares one (1) copy and files in district with particular study under consideration.

Do *not* include items in computations which are not potentially present.

Identify numerical factor that most nearly describes the conditions observed by circling the factor given for each logical item.

**Wind and water are considered eroding agents when evaluating item*
***A soil with no rocks in its profile and no probability of gullying*
****A pumice soil area where no water erosion occurs*

SPECIFIC INSTRUCTIONS

Total all factors at bottom of page. Divide total identified factors by total possible factors for items considered and multiply by 100 in order to compute the SSF.

Situation – Describe situations being evaluated such as present, geologic, with mechanical treatment in effect for 10 years, under a 5 pasture livestock management system for last 8 years, etc.

Total – Total computed SSF.

One advantage of this system is that it can be developed prior to proposals for major activities on public lands, such as interstate transmission line corridors, multi-million acre grazing system, ORV courses hundreds of miles in length, etc. The specialists can evaluate each proposed action and develop protective measures specific to that action.

Another advantage is that most of the data is already available throughout the BLM, involving some 154 acres of public land. Erosion condition classifications have been available since the early 1970's. Order 4 soil surveys cover most of the areas administered by the BLM; more detailed Order 3 surveys are now underway.

Possibly the biggest advantage of this system is that it does not rely on speculation to generate numbers which are meaningless to decision makers. Rather, it focuses on identifying specific measures required to protect or improve current or potential problem areas.

Summary

Current approaches to assessing watershed impacts usually involve the USLE, PSIAC, or other methods which provide quantitative estimates of on-site erosion or sediment yield. In addition to the inherent weaknesses of these methods, the final product is usually a number which is meaningless to the decision maker.

An alternative to these approaches utilizes existing soil survey information. Soil Erosion Hazard Ratings can be used to route activities away from soils poorly suited to withstand surface disturbance. Specialists working on lands administered by the BLM also have available to them Erosion Condition Classification data. By coupling these existing pieces of data, specific measures can be identified to protect or enhance both current and potential problem areas.

REFERENCES

1. Clark, Ronnie, 1980, Erosion Condition Classification System, USDI BLM Technical Note 346, Denver, Colorado.

2. Krupin J. P., 1980, Nonpoint Source Water Quality Assessment Strategy. Symposium on Watershed Management, American Society of Civil Engineering, Boise, Idaho.

3. PSAIC (Pacific Southwest Inter-agency Committee), 1974, Erosion and Sediment Yield Methods, USDA SCS, Portland, Oregon.

4. USDA SCS, 1983, SCS-Soils-5 Guide, Nevada.

5. Wischmeier, W. H., and D. D. Smith, 1965, Predicting Rainfall-Erosion Losses from Cropland East of the Rocky Mountains, USDA Agr. Handbook 282, Washington, D.C.

SEDIMENT TRANSPORT IN THE BLUE CREEK WATERSHED

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ABSTRACT:

Illinois Environmental Protection Agency (IEPA) in cooperation with various U.S. Department of Agriculture (USDA) Agencies evaluated the water quality impacts of resource management systems (RMSs) implemented under the Agricultural Conservation Program (ACP) Special Water Quality Project in the Blue Creek Watershed. The monitoring program was designed to link water quality to what was happening on the land area.

Sediment data was temporally stratified to account for land management and historic precipitation pattern. Then to determine the effectiveness of the RMSs; implemented, sediment data were stratified by precipitation category so as to characterize the principal detachment mechanism. This paper reports the analysis of RMS impact upon sediment loads by detachment and management category.

INTRODUCTION:

Agriculture is the most widespread nonpoint source of water pollution in the Midwest (U.S. Environmental Protection Agency [USEPA] 1984). Initial planning efforts documented that agricultural activities were a major source of pollution in Illinois and mandated the development of plans to control this source of pollution. In Illinois, the most severe agriculture related pollution problem is from soil erosion resulting in lake sedimentation (IEPA 1979).

Soil erosion is defined as the detachment and movement of soil or rock fragments by wind, water, ice or gravity. Sediment is defined as solid materials which have been transported from their place of origin by erosion. Soil erosion is not synonymous with soil loss, nor is soil loss equal to sediment yield (Dunne, 1978). The sediment producing process involves soil detachment, transport and deposition. Sediment is a significant pollutant in Illinois because of its physical properties, potential chemical interactions and total loads.

Because of serious potential environmental problems associated with sediment, and limited knowledge concerning sediment origin, transport, deposition and control technology, the IEPA initiated a comprehensive monitoring program in an agricultural watershed in West Central Illinois. The Blue Creek Watershed in Pike County, Illinois was selected to demonstrate the effects of RMSs upon water quality. The project area was designated an ACP Special Water Quality Project Area; this program provided financial assistance to land owners/operators for the implementation of RMSs. IEPA in cooperation with USDA Agencies, the Agricultural Stabilization and Conservation Service and the Soil Conservation Service (SCS), evaluated the impact of RMSs implemented under the ACP Project in the Blue Creek Watershed from May 1980 to September 1982.

This paper presents the analysis of 29 months of data on sediment loading dynamics in the watershed. Sediment loading information is correlated with agricultural crop management periods and precipitation categories. Finally, observations are made concerning sediment production during the different management seasons.

SITE DESCRIPTION:

The Blue Creek Watershed encompasses 2,839 hectares. It drains into Pittsfield City Lake through Blue Creek and its numerous tributaries. Pittsfield City Lake was constructed in 1961 by SCS as a multiple purpose reservoir. It is utilized for recreation, flood control and as a water supply for the City of Pittsfield. Approximately 4,400 people depend on the lake for a water supply.

Land use in the Blue Creek Watershed is predominantly agricultural (92 percent). Cultivation of row crops and production of livestock are the principal agricultural activities in the watershed. The predominant crop is corn (47.7 percent of the cropland acreage). Soybeans, wheat, and grasses are also important crops. The terrain is hilly, and it has a high soil loss potential due to its steep slopes, fine-textured soils and agricultural land use management practices. For a more detailed description of the Blue Creek Watershed and Pittsfield City Lake, refer to Blue Creek Watershed Project, May 1979 to October 1980 (Davenport 1981).

MONITORING METHODS:

The physical, biological and chemical characteristics of the Blue Creek Watershed were studied from May 1980 to September 1982. A comprehensive monitoring network for the entire watershed was established by IEPA to document the basic hydrological, meterological and water quality factors of the project area during 1980. The duration, timing, and quantity of water borne sediment was evaluated to determine the impact of RMS implementation on the water quality/quantity budget.

The main stem of the Blue Creek Watershed was monitored at two locations (Stations C and B) representing 50 and 70 percent of the watershed drainage area, respectively. Lake overflow is monitored at Station A (Figure 1). At Station C, automated event sampling was supplemented by daily grab sampling. Standard methods (APHA 1980, IEPA 1981, Holtan 1968) were utilized for all water quality/quantity data collection and analyses.

Precipitation was measured at five locations in the watershed using weighing-type rain gauges. For monthly and rainfall related precipitation, the values of all five rain gauges were averaged.

DATA ANALYSIS:

Data analysis was conducted with procedures available in Statistical Package for the Social Sciences (Nie 1975). An important component in the data analysis process was the stratification of data. The simple lumping of data over a period of time had limited use in this evaluation. In order to determine cause/effect relationships between sediment transport and land use/management, the sediment data had to be defined in more specific terms, directly related to its source and transport.

Three analysis periods based on the amount of surface residue, precipitation pattern and timing of agricultural land management activities were established for temporal stratification. There were some variations in period length from year to year due to climatic variances. In general these analysis periods were:

Period 1 (P1) -- April to June:

Fertilizer application, seedbed preparation and crop establishment are principal land management activities during this period. About 34 percent of annual precipitation occurs during P1; severe thunderstorms are likely to occur during this time.

Period 2 (P2) -- July to November:

Reproduction and maturation of the crops are the principal activities. Forty-four percent of the annual precipitation occurs during P2; precipitation during the last half of this period is often high and is usually caused by frontal systems that produce low intensity rain storms of long duration.

Period 3 (P3) -- December to March:

Harvesting and residue management are the principal management activities during this period. Precipitation during P3 accounts for slightly more than 21 percent of the total and usually occurs as snowfall.

Once temporal stratification was completed, data were categorized by three initiation/transport mechanism categories (Davenport 1983). These categories were:

Baseflow: This consists of non-precipitation induced flow and is considered as the normal day-to-day flow (Viessman 1977).
Rainfall and snowmelt runoff: This category consists of runoff events, whose rainfall is less than Wischmeier's (1965) definition of a storm or snowmelt runoff. Wischmeier (1965) defined a storm as a rain shower equal to or greater than 1.27 cm, separated from other showers by six hours or more.
Storm Event: Rainfall runoff events whose rainfall characteristics meet Wischmeier's definition of a storm event.

RESULTS AND DISCUSSION:

Suspended sediment transport (Table 1) showed a definite "upstream -- downstream" trend with lower quantities measured downstream. This indicates that as watershed size increases, the relative sediment sured at Station B (downstream) was 45 percent of Station C's (upstream) quantity (Figure 1). The flow constriction device, a causeway and bridge at Station B, causes differential velocities in storm flow to occur between Stations B and C, thus allowing the suspended matter to settle out in the channel. The sediment storage area upstream from Station B had a design capacity of 50 years, a sedimentation survey showed it had lost 95 percent of its sediment storage capacity because of deposition in just 19 years (Bogner 1979).

Figure 1. Map of Water Quality Stations in the Blue Creek Watershed in Pike County, Illinois

TABLE 1

Monthly sediment load and precipitation summary within the Blue Creek Watershed. Sediment load by station in tonnes:

ANALYSIS		STATIONS			PRECIPITATION
Period	Month	A	B	C	(cm)
80-1	May	2.5	28.2	15.9	4.21
	June	8.0	564.2	1983.3	6.48
80-2	July	0.0	1.1	0.5	4.63
	Aug	1.1	52.1	152.4	10.44
	Sept	4.9	52.2	459.2	13.78
	Oct	1.4	6.2	1.8	7.62
	Nov	0.0	0.5	0.1	1.27
80-3	Dec	1.1	43.4	27.4	0.64
	Jan	0.0	0.1	0.4	1.60
	Feb	2.2	2.5	12.3	3.10
	Mar	7.9	4.6	23.2	5.97
81-1	Apr	102.2	196.7	1863.0	14.88
	May	113.5	1287.9	2321.1	17.30
	June	70.7	1865.2	5330.7	17.37
81-2	July	177.8	3888.9	6634.8	36.45
	Aug	27.8	9.3	4.3	4.50
	Sept	10.3	3.3	2.5	1.70
	Oct	19.0	1106.8	1236.4	10.77
	Nov	15.7	6.4	12.2	6.50
81-3	Dec	6.3	1.6	4.7	2.18
	Jan	0.0	12.0	372.1	8.15
	Feb	0.0	20.5	971.0	2.56
	Mar	47.2	164.5	171.4	6.43
82-1	Apr	64.6	24.7	7.1	7.37
	May	62.3	199.2	519.7	9.65
	June	74.3	1168.6	1194.7	9.98
82-2	July	34.8	556.1	791.0	12.83
	Aug	18.0	7.3	62.2	8.86
	Sept	29.0	20.9	18.8	6.43

Duration analysis was employed to demonstrate that a large proportion of Blue Creek's sediment load was carried during a short period of time. In the Blue Creek Watershed during 1982, approximately 92 percent of the sediment load transported past Station C occurred in 5 percent (within an overall duration equivalent to 20 days) of the year. During 1980 and 1981, 82 percent and 94 percent of the load was transported in 9 percent and 6 percent of the measured time, respectively.

Walling (1977) documented that for the Cass River, Michigan, approximately 80 percent the suspended sediment was carried in 5 percent of the year. Seasonal distribution of yield at each station reflects the interaction of precipitation (type), flow regime, and sediment availability (surface cover). Priest (1972) documented seasonal differences in the functional relationship between sediment and surface runoff, hence the interactions mentioned above.

Ursic and Dendy (1982), concluded that both annual runoff and sediment yield are attributable to land use and cover. In June 1980; 1,983.3 tonnes of suspended sediment were transported past Station C and 6.48 cm of rainfall were measured. In September 1982; 18.8 tonnes of suspended sediment were transported past Station C while 6.43 cm of rainfall were measured (Table 2). The 0.05 cm difference in rainfall doesn't fully explain the 1964.5 tonnes difference in suspended sediment transported. The difference in tonnage can be related to surface cover. There was little or no surface cover during June 1980 due to planting activities, whereas in September 1982 there was full crop canopy development.This agrees with Burwell's (1975) findings, that most annual losses of sediment occur in the two months following corn planting when the clean-tilled soil surface is most susceptible to soil erosion. An example of the importance of variation in rainfall type came as storm events totaled 22.76 cm during P1-1980 and during P1-1981 86 percent of the rainfall came as storm events and totaled 48.64 cm. Differences in loadings during these periods; P1-1980 loadings were only 18 percent of that measured during P1-1981 (Table 2). This difference is associated with the 53 percent difference in total rainfall and the 12 percent increase in storm related precipitation.

The large variability in sediment loads between months indicates that sediment export was not limited by the transport capacity of the stream but by movement of soil particles from the land to the stream channel network. The load transported from November 1980 to February 1981 illustrates the exhaustion effect operating through a series of months (Table 2). Basically, this means the streamflow has transported available sediment and the stream is functioning as a closed system. Monthly sediment yield/stream discharge relationships between sediment load and streamflow energy vary by month. Monthly differences in this functional relationship result from antecedent environmental conditions. Antecedent conditions influence the amount of soil which will be eroded and transported as sediment for a given amount of precipitation and surface runoff.

TABLE 2

Monthly distribution of sediment and streamflow at Station C by analysis period:

ANALYSES Period	Month	SEDIMENT LOAD (Tonnes)	STREAMFLOW (cms-Day)
80-1	May	15.9	1.01
	June	1983.3	1.67
80-2	July	0.5	0.08
	Aug	152.4	0.67
	Sept	459.2	1.96
	Oct	1.8	1.13
	Nov	0.1	0.10
80-3	Dec	27.4	0.63
	Jan	0.4	0.10
	Feb	12.3	0.68
	Mar	23.2	0.45
81-1	Apr	1863.0	3.97
	May	2321.1	9.17
	June	5330.7	9.08
81-2	July	6634.9	44.59
	Aug	4.3	0.91
	Sep	2.5	0.53
	Oct	1236.4	4.40
	Nov	12.1	0.97
81-3	Dec	4.7	0.76
	Jan	372.1	9.33
	Feb	971.0	16.00
	Mar	171.4	6.57
82-1	Apr	7.1	3.06
	May	519.7	3.34
	June	1194.7	5.58
82-2	July	791.0	4.85
	Aug	62.2	1.00
	Sep	18.8	1.18

Differences in magnitude of monthly sediment loads for P3 result from the interaction of snowmelt runoff and the resulting re-entrainment of channel material. Since the volume of snowmelt runoff is dependent upon antecedent climatic conditions of winter, the amount of snow accumulation is a dominant factor determining sediment loads during P3. The low sediment transport for P3-1980 resulted from the lack of snow accumulation and resultant low snowmelt runoff. The extremely high P3-1981 sediment transport indicated that snowmelt runoff had occurred in sufficient quantities and that it was the dominant source of surface runoff during P3.

Most of the sediment moving past Station C was transported by storm-event runoff, one of three initiation/transport categories (Table 3). The percentage of sediment yield by transport category varied monthly. Analysis of the data indicates that the watershed exhibits the potential for sediment yield, but requires a heavy rain (greater than 1.27 cm over 6 hours) to start an increase in sediment yield. This phenomena agrees with McGuinness's

(1971) findings, concerning sediment transport in Ohio. This results from rainfall being the principal detachment mechanism of soil particles during P1 and P2; rainfall thus drives the entire erosion process from upland areas.

TABLE 3

Monthly distribution of sediment load (tonnes) by initiation/transport category at Station C by analysis period.

Period	Month	Baseflow	Non-Storm Runoff	Storm Runoff
80-1	May	1.74	4.23	9.88
	June	1.47	154.29	1827.61
80-2	July	0.15	0.38	0.00
	Aug	0.28	11.95	140.19
	Sept	1.53	1.46	456.22
	Oct	0.16	0.06	1.60
	Nov	0.04	0.00	0.00
80-3	Dec	27.39	0.00	0.00
	Jan	0.36	0.00	0.00
	Feb	0.02	0.00	0.00
	Mar	0.41	0.01	22.76
81-1	Apr	46.72	0.15	1816.13
	May	15.07	2.08	2303.89
	June	9.32	565.60	4756.31
81-2	July	10.32	15.27	6609.31
	Aug	3.75	0.53	0.00
	Sept	2.36	0.09	0.00
	Oct	10.39	0.26	1225.81
	Nov	1.25	10.92	0.00
81-3	Dec	4.69	0.02	0.00
	Jan	13.85	310.19	48.07
	Feb	78.00	835.85	57.14
	Mar	16.85	150.56	4.04
82-1	Apr	4.40	1.49	1.16
	May	13.35	6.29	499.87
	June	10.05	4.34	1181.13
82-2	July	4.13	3.07	783.76
	Aug	0.74	0.47	61.01
	Sept	16.33	0.08	2.39

In a comparison of the relative amounts of direct runoff and sediment yield associated with periods of large storms (greater than 2.54 cm over 6 hours) vs. small storms(1.27 -2.54 cm over 6 hours), the amount of runoff and sediment yield associated with small storms is much less than that associated with large storms. The smaller storms are responsible, on the average, for about 8 percent of the annual sediment load. Priest (1965) documented the storm size related effects in an earlier study. Ninety percent of the load transported during the 29 month monitoring period occurred as a result of large storms.

Snowmelt sediment load was important during P3-1981; in January it accounted for 11 percent of the monthly load, in February 54 percent of the monthly load and in March 67 percent of the monthly load (Table 3). During P3-1980 it was negligible. In-stream snowmelt sediment load suggests the re-entrainment of channel sediment. Because the snow cover protects the soil, rainfall on snow does not cause erosion. Thus the sediment load must be from re-entrainment of previously detached soil or concentrated flow erosion. The decreased sediment load in April and May 1982 as compared to the same period in 1981 suggests the possibility of a flushing of sediment during snowmelt (accounting for the extra sediment load in January, February and March 1982). Hamlett (1982) demonstrated that for streams, snowmelt sediment load was more important at the field level than in terms of the stream's total sediment load. At the field level, he indicated snowmelt runoff was important and a sizeable portion of total annual runoff, yet erosion and sediment movement was minimal. This results from soil detachment occurring only from overland flow and not raindrop impact.

As noted earlier raindrop impact is the major force in soil detachment (Young, 1973). Since to be classified in the storm runoff category, precipitation must have occurred that generated sufficient energy to detach soil particles thus initiating the erosion process. If conditions were equal except rainfall, higher rainfall would result in higher sediment concentrations. Rainfall was 15 percent higher during P1-1982 than P1-1980. Land management conditions changed from P1-1980 through P1-1982 with the implementation of RMSs, 3.5 percent of Station C's drainage was treated by May 1980 whereas 14.5 percent was treated by April 1982. The majority of RMSs installed in this drainage basin were adjacent to Blue Creek or its tributaries. The RMSs most commonly installed was a conservation tillage system with necessary support practices. The decrease in sediment loading between P1-1980 and P1-1982 could have resulted from the implementation of RMSs on critical sediment source ares.

Since the size of the source area for runoff expands and contracts according to rainfall rates and the capacity of soil to retain and release (Dunne 1978), then the source area for sediment expands and contracts proportionately. Under the variable source concept, areas closest to the stream are more responsive to sediment detachment and transport to the watercourse than the upland areas, so land treatment for water quality purposes should concentrated on these lands.

CONCLUSIONS:

Based on the variable source concept and the findings of the monitoring effort within the Blue Creek, the following land treatment recommendations are made. RMSs must be implemented to slow runoff velocity and volume at the edge of fields to reduce sediment carrying capacity of snowmelt runoff. A water quality land treatment zone must be established where only those fields immediately adjacent to the stream network are treated so as to slow runoff velocity and volume (water management). To ensure water quality benefits (i.e., decreased sediment loading) land treatment within this zone must also reduce soil erosion. A multiple purpose RMS must be implemented for the offsite and onsite benefits of water management and erosion control. Conservation practices such as conservation tillage, contour farming, grassed waterways, diversions, sediment basins, and terraces have this effect (Humenik 1982).

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HISTORICAL BLM MANCOS SHALE MANAGEMENT IN NW, CO.

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ABSTRACT

The Bureau of Land Management (BLM) has been implementing salinity and erosion control structures in the Lower Wolf Creek (LWC) watershed for the past 40 years. The LWC watershed has a semi-arid climate and sparse vegetation. It is characterized by highly erodible Mancos Shale, a marine sedimentary formation that is exposed on the surface and contains a high concentration of soluble salts. In this 31,858-ha (78,720-acre) watershed, about 80 projects have been completed to reduce erosion which accelerated because of overgrazing by cattle, sheep, and horses, from approximately 1897 to 1936. Project work was started in 1938 by the Civilian Conservation Corps (CCC) and has continued sporadically by the BLM to the present. Stabilization techniques include contour furrows, reseedings, spreader dikes, detention and retention dams, pit reservoirs, and gully plugs.

Many of the original erosion control projects have silted full, but most are still functional in slowing runoff velocities and depositing sediment. Some of the old reservoirs have spillways that are too steep, and the spillways are eroding into the existing reservoirs and are threatening the stability of the stored sediment.

In 1984 the Lower Wolf Creek Watershed Management Plan (LWC WMP) was written to develop a systematic approach to salinity and erosion control from the discontinuous and continuous gully systems on the Mancos Shale Formation. The watershed was divided into treatment units for project implementation. Hypalon drop structures and new pit reservoirs are being designed for construction in 1985, and in the future, as funds become available for salinity control, and for the establishment of riparian habitat.

I. INTRODUCTION

The watershed is located in Rio Blanco and Moffat counties in northwest Colorado. The watershed is approximately 65 miles west of Craig, Colorado and 20 miles east of the Dinosaur National Monument Headquarters. Wolf Creek is a tributary to the White River, which is a major subbasin of the Colorado River System.

The LWC WMP was developed to systematically improve water quality by reducing runoff and downstream delivery of salts, sediment, and improving vegetation cover. The LWC WMP was needed because past watershed uses resulted in decreased vegetation cover and accelerated surface runoff and erosion, beginning the formation of large, active gully systems. A regional change in climatic conditions in the 1800s combined with past management could have accelerated erosion. While numerous management actions have been taken to improve watershed conditions since the passage of the Taylor Grazing Act in 1936, there are many areas where additional watershed improvement is required. The purpose of this paper is to review watershed conditions in LWC, describe past management techniques, and explain present plans to improve watershed conditions in LWC.

II. HISTORICAL BACKGROUND

In 1897 settlers moved into the area with herds of cattle. At that time, according to eyewitness accounts, there were no major gullies and the drainages were subirrigated and grassy (Zandy Mobley 1985). Around 1900, large herds of longhorn cattle, numbering 2,000 to 3,000 head, were brought up from the south to take advantage of the free open range. In about 1912 bands of sheep were moved into the area, starting major range wars and almost denuding the desirable native perennial vegetation. Settlement of the area continued until about WWI. During this time livestock numbers were too high and were on the range year around. There were also many wild horses, which may have caused more damage than the cattle and sheep (Zandy, Mobley 1985). The last wild horses were removed from this area in the mid 1960s. The problem of unregulated grazing was alleviated when livestock numbers were reduced as a result of the Taylor Grazing Act. Subsequent intensive management of grazing permits through implementation of the White River Resource Area Grazing EIS has also helped stabilize the watershed.

In 1938 the CCC built a 200 man camp 3 miles west of the watershed at Massadona. The camp was closed in 1942 following the outbreak of WWII. Projects completed by the CCC included: construction of roads and reservoirs, spring developments, and fencing.

In 1964, the Divide Creek tributary, approximately 1,593 ha (3,936 acres) or five percent of LWC watershed, was classified as a Resource Conservation Area (RCA). The purpose of the RCA was to demonstrate various practices and land treatment measures in improving forage conditions and reducing runoff, thereby increasing grazing capacity and decreasing erosion and sedimentation. This site was chosen for two reasons. First, the area had been used very heavily by cattle and sheep as a winter and spring range resulting in depressed range conditions. Overgrazing, coupled with intense thunderstorms typical of desert ecosystems, had accelerated the erosion rates on this area (USDI, BLM 1964). Second, the work that had already been completed in this RCA was a good starting place to demonstrate the effectiveness of the various conservation practices. Maintenance was needed on existing projects and would be done at the same time new work was being completed. Contour furrowing, check dams, spreader dikes, and seedings were recommended in the RCA plan and implemented to reduce erosion and improve the range for livestock and wildlife use.

III. DESCRIPTION OF WATERSHED

A. Topography and Geology

The LWC watershed consists of broad plateaus, steep escarpments, rolling hills, rough canyon lands, and gently sloping valleys. Elevations range from a low of 1,791 m (5,460 feet mean sea level) at the mouth of Wolf Creek to a high of 2,387 m (7,277 feet) in the extreme northeastern portion of the watershed along Elk Springs Ridge. Slopes throughout the watershed tend to be steep to very steep near the borders and gradually flattens toward the central portion of the basin. The aspect of the basin is predominantly sloping to the south. Approximately 75 percent of the lower watershed is made up of Mancos Shale or sediments deposited by weathering of Mancos Shale.

B. Climate

The area is located in a semi-arid, continental climate regime. Annual precipitation in the center of the watershed is highly variable ranging from 18 cm to 35 cm (7 to 14 inches) depending on the elevation. The average annual precipitation for the WMP area is approximately 23 cm (9 inches). Less than half of the annual precipitation comes from scattered spring and intense short-duration summer thunderstorms. Snowfall amounts vary, averaging 91.5 cm (36 inches), and snow is commonly redistributed by wind. The limited data indicate that evaporation far exceeds precipitation, with the driest conditions occurring in mid-summer. The average annual moisture deficit is high, more than 127 cm (50 inches).

C. Soils

The soil resources within the WMP area are extremely variable, depending on parent materials, elevation, slope, aspect, past climate, and time in place.

Soil erosion is controlled by many factors, including climate, vegetation cover, inherent erodibility of the soil, and past and present land use. Of these factors, land use and plant cover are most directly under human control. Most of the erosion in the watershed occurs during spring snowmelt and intense summer thunderstorms both of which cause runoff and flash flooding. Many of the streams are deeply incised and continue to erode from gully migration (head cutting) upstream and from caving in of channel banks.

Sediment yields are indexed according to Colorado Land Use Commission (1974) and the SCS (1979) data on sediment yield and erosion potential, respectively. Watershed sediment yields vary from 476 to 1,428 $m^3/km^2/yr$ (1 to 3 ac-ft/mi^2/yr) on badlands and severely eroding lands to 47.6 to 95.2 $m^3/km^2/yr$ (0.1 to 0.2 ac-ft/mi^2/yr) on sagebrush parks. Most of the watershed is classified as highly eroding rangeland with sediment yields averaging 238 to 476 $m^3/km^2/yr$ (0.5 to 1.0 ac-ft/mi^2/yr). Large active gullies may yield up to 766 to 1,533 m^3/bank km/yr (1.0 to 2.0 ac-ft/bank mile/yr) of sediment.

D. Hydrology

Lower Wolf Creek consists of the main stem of Wolf Creek and four main intermittent tributaries.

Tributary	Area	Percentage of WMP area
Coal Creek	7,646 ha (18,893 acres)	24%
East Fork	3,823 ha (9,446 acres)	12%
Middle Fork	7,327 ha (18,106 acres)	23%
Divide Creek	1,593 ha (3,936 acres)	5%
Main Stem	11,469 ha (28,339 acres)	36%
	31,858 ha (78,720 acres)	100%

The lands within these watersheds typically yield small amounts of water per year, usually less than one inch per square mile. High runoff generally occurs from mid-March through mid-June and is caused almost solely by melting of the higher elevation snowpack.

The runoff from the watershed provides a medium for salt and sediment transport. Salts are dissolved from the soil surface by runoff, from evaporates in channels, and from sediment particles being transported in channel flow. Groundwater from the saline geologic formations in the watershed typically contain salts in concentrations two to three times greater than that in surface discharges.

Natural flowing perennial springs are quite sparse in the lower watershed. Only four springs are known to flow continuously throughout the year. These are saline springs emerging through the Mancos Shale, both in the upper central portion of the LWC watershed and from the upper reaches of Coal Creek.

E. Vegetation and Livestock

The majority of the native salt desert plants make their main growth from mid-April to the end of June, primarily on stored winter moisture. Cool season plants are favored because of the June droughts and the best growth is made following spring thaw and again in early fall following late summer rains. The area is generally dry from mid-June to mid-August. Sometimes there is fall growth from late summer rain in August and September. There are wide yearly and seasonal fluctuations in forage production (Blaisdell and Holmgren 1984).

The project area encompasses nine grazing allotments, which are used primarily by sheep however some cattle are also on the range during the winter and spring (November-May). Some use also occurs at other times during the year, although most grazing is finished by May 30 within the watershed area.

IV. ANALYSIS OF PAST WATERSHED RESTORATION

Gully rehabilitation began in the late 1930s as a method of restoring equilibrium in the deteriorated watersheds (Heede and De Bano 1984). However, this seems to be a false or static equilibrium since the gully systems have lowered the base level of the major drainages. The present challenge is to raise the base level and recharge the alluvial aquifers, wherever possible, using small structures, or lower the runoff to the new base level without head cutting.

The older reservoirs are generally three to four times larger than what is being designed and constructed today. This size difference could be the result of differences in procedures for determining hydrologic feasibility or present construction costs could be a limiting factor.

The original reservoirs have stabilized the gullies upstream from the structures for a distance of 33 m (100 feet) to almost 1.6 k (1 mile). More in-depth study is required to relate the channel gradient and watershed area to the distance upstream the channel can be stabilized by a working structure.

Very few of the older projects have actually recharged the alluvium sufficiently to create perennial seeps in these ephemeral drainages. However, the vegetation stabilization, primarily upstream and to a lesser degree downstream, has been frequently achieved, thereby accomplishing the objectives of gully rehabilitation. Riparian vegetation has frequently become naturally established around the storage area of the existing reservoirs, creating a diversity of wildlife habitat, especially around the few reservoirs which have been fenced to exclude livestock.

A problem with some of the old structures is spillways that drop too steeply into the original channels. Present feasibility analysis not only includes soils (texture, depth, and gypsum content), and hydrology runoff calculations, but also engineering suitability for spillways. The spillways are designed to divert runoff into stable side channels with well established stands of western wheatgrass. The location of a suitable spillway is often the most limiting factor in locating feasible project locations. Because of the additional cost of drop structures natural spillways are being used in the design.

The vegetation manipulations completed about 20 years ago involved contour furrowing and drill seeding a monoculture of crested wheatgrass. This practice has worked very well to stabilize broad, gently sloping alluvial fans, except the crested wheatgrass has formed a thick stand and has kept the desirable native perennials from invading the sites. The contour furrows are presently very obscure having leveled off. However, the crested wheat is still evident in the furrows rows in which it became established.

The gully plugs which are over 20 years old, have also worked well to stabilize the tributary drainages on 5 to 30 percent slopes. The older gully plugs have silted in and have naturally revegetated in the bottoms, but are functioning to slow runoff velocities. Future plans include constructing new gully plugs in between the old plugs in a few drainages which are still actively eroding below the existing plugs.

The spreader dikes which were constructed on broad alluvial drainages with slopes less than five percent and headwater areas less than 20 ha (50 acres) have generally worked very well to stabilize gullies both up and downstream. The upstream sides have become stabilized by the natural spreading of western wheatgrass. The borrow material for the dikes came from the downstream side of the dikes which has been beneficial. The major problems with the dikes was building them in areas with too large of drainage areas, greater than 20 ha (50 acres) and building them too long about 328 m (1,000 feet). The dikes should have been shorter and designed with spillways to divert the water around the ends of the dikes and into the dikes below. Placing silt fence fabric in the existing dike spillways is planned to halt the gully migration which is presently occurring around the ends of a few of the dikes. With future dikes the upstream channel should be leveled off so that the runoff is not as concentrated when it reaches the dikes (Bruce Van Haveren 1985).

V. CURRENT TREATMENT PLANS

The objectives of the LWC WMP will be accomplished by using the following treatments and recommendations.

1) A maintenance program will be implemented to lengthen the life span of structures that have silted in.

2) New reservoirs will be constructed in areas still actively eroding, and where old reservoirs have failed and it would be cheaper to build new

structures than repair the old ones. These new structures will be designed to reduce the peak flows, trap and retain sediment from saline soils and decrease erosive forces of runoff in the channels and gullies. They will also provide additional water sources for improved distribution of livestock and riparian habitat for wildlife.

3) Vegetation manipulations (burning and spraying) combined with land treatments (contour furrows) will be conducted on bottom lands and gently sloping uplands presently dominated by invader plant species. The goal of these manipulations will be to increase vegetation cover of native perennials, vigor, production, and water infiltration.

4) Seeding of native grasses and forbs will be done on all construction sites and critical sites susceptible to direct flows to enhance vegetation cover. If necessary, fertilizing and mulching will be recommended as site specific needs are identified for rapid establishment of perennial vegetation.

5) Roads will be maintained using waterbars where active erosion is evident. Ditches and crowning, is not recommended in this area, since ditches tend to cause additional erosion.

6) Constructing fences may be proposed to reduce pressure on overgrazed sites, thus providing better distribution of forage use.

7) ORV use will be controlled through BLM district policy.

VI. IMPLEMENTATION

To implement the watershed goals and objectives of the management plan, the LWC watershed was divided into treatment units. Each treatment unit has a unique natural landscape. Stratification is based on the predominant physical characteristics such as landforms, soils, vegetation, and topography as grouped by SCS range sites, salt and sediment source areas, and locations where controlling processes can be managed. The treatment units are ranked by priority which is based on both the sediment and salt production rating and treatability of the area. Table 1 includes the types of structures and vegetation manipulations planned for each treatment unit. The type of treatment is determined by the soil characteristics and land form. Table 2 provides some sample benefit/cost data.

The following descriptions are for the five treatment units (TU). Those broad areas can be used to compare the suitability of large areas for general land uses. Areas of suitable soils can be identified on the detailed survey maps and from field investigations.

Mancos Shale Uplands - (TU 1). These soils occur on gently sloping to steep low hills, ridges, and toe slopes in the center of the watershed. They are shallow to moderately deep (10 to 40 inches deep) and well drained, have a low available water holding capacity. These soils formed in-place on gypsiferous Mancos Shale and have silty clay textures. They are moderately to strongly affected by salt and alkali, containing approximately three percent salt by weight. In some areas these soils are severely eroded. The vegetation is mainly salt-tolerant, semi-desert shrubs and salina wildrye.

TABLE 1 - LOWER WOLF CREEK WATERSHED TREATMENT UNITS

Treatment Unit	Percentage of Watershed	Description	Treatments Recommended	Salt Production	Priority
Mancos Shale Uplands	42	Mancos shale ridges, gentle to moderate slopes, sparse vegetation, and shallow soil.	Gully plugs, contour furrows, grassed waterways, pit reservoirs, vegetation manipulation, spreader dikes.	High	1
Mancos Alluvium	24	Small drainages and dissected benches and fans at the base of Mancos Shale outcrops and grassed waterways.	Pit reservoirs, spreader dikes, vegetation manipulations.	High	2
Gullied Alluvium	4	Major gullied bottomlands.	Large detention reservoirs and riparian planting.	Moderate to high	3
Sagebrush Uplands and Pinyon-Juniper Woodland	7	Upland big sagebrush sites on sandstone around perimeter or watershed.	Vegetation manipulation and small check dams and pit reservoirs.	Low	4
Steep Slope Areas	23	Steep, inaccessible slops and shallow, heavy-textured soil.	None	Moderate to high	5

TABLE 2 - BENEFIT-COST DATA BY WATERSHED TREATMENT

Treatment	Cost	Structures per sq. km	Life of Project	Sediment Storage Capacity	Salt Retention	Retention Benefit	Benefit/Cost Ratio
Contour Furrow	$ 2,350 per sq km	10' spacing	10	8,520 tonne/sq km	256 tonne/sq km	$ 15,972/sq km	6.80
Gully Plug	$ 1,770 per sq km	865	15	6,050 tonne/sq km	181 tonne/sq km	$ 11,293/sq km	6.38
Pit Reservoir	$ 1,000 ea.	3	25	.03 ha-m	11.0 tonne	$ 686	.69
Retention Dam	$ 5,000 ea.	2	25	.41 ha-m	147 tonne	$ 9,171	1.83
Detention Dam	$60,000 ea.	0.1	50	5 ha-m	1,758 tonne	$109,682	1.83

Assumptions:
Conversion Factors:
One hectare-meter of sediment weighs 11,878 tonne
3 percent sediment from Mancos Shale equals the weight of salt
1 tonne of salt retained equals $62.39 benefit downstream (Kleinman A.P. and F.B. Brown, 1980)
Contour furrows calculated from $35/hr tractor and operator traveling 4 mph on 10' spacing.
Benefit/cost ratio was calculated using an interest rate equaling 13 percent.

Saltbush communities are characterized by low growing, widely spaced plants that vary in species composition and density. Mat saltbush occurs on the very shallow soils on ridgetops, then grades into shadscale on the moderately deep soils on sideslopes.

Mancos Alluvium - (TU 2). These soils occur along the major drainages and side tributaries on nearly level to gently sloping sites. They are generally of recent deposition and lack development. They formed in mixed alluvium from shale and sandstone. The soils are deep (greater than 60 inches) and well drained. The alluvium from shale are silty clay, silty clay loam, and clay loam textures and are generally calcareous throughout. They are slightly to moderately affected by salt and alkali. The alluvium derived from sandstone is stratified, medium to coarse textured and can have rock fragments throughout the profile. Greasewood and big sagebrush occur both in dense and open stands with varying amounts of understory vegetation.

Gullied Land - (TU 3). These soils occur on terraces, benches, valley sideslopes, and eroding stream courses throughout the WMP area. The gullied land is typically a network of deep, wide, and active gullies extending up stream courses. About 75 percent of the surface layer has eroded away over much of the area. Parts of the subsoil and underlying layers also may have eroded. Gullies may be up to 50 feet deep and 100 feet wide. The bottoms of the five major drainage channels are often grassy or shrubby and are rarely wet.

Sagebrush Uplands and Pinyon-Juniper Woodlands - (TU 4). These soils occur on the periphery of the watershed in areas where the soil developed on sandstone parent material in gently sloping areas and include numerous entrenched narrow valleys that have very steep slopes. The soil profile contains many stones and is generally calcareous throughout. The soils are generally well drained, with a low available water holding capacity. The native vegetation is mainly pinyon, juniper, mountain brush, and sagebrush.

Steep Slope Areas - (TU 5). Steep slope areas consist of bedrock outcroppings and badlands. The badlands area occurs on rolling to very steep, nearly barren mountainsides, low hills, ridgetops, and canyon sides. The badlands are very shallow and exhibit no significant soil characteristics. The soil material consists of residuum derived primarily from highly calcareous and gypsiferous shale. The native vegetation is mainly very sparse, low desert shrub and grasses.

Maintenance of existing structures often requires halting headcuts that are migrating up the spillways and threatening the reservoir structure. Industrial grade reinforced hypalon lined drop structures are presently being used in this watershed since they are the most cost effective compared to using rock covered slopes, cement drop structures and weirs, metal piling drops, and corrugated sheet metal drops. The cost per foot of drop, for structures in LWC has been estimated at $380 for hypalon, $1,280 for cement and $1,870 for rock. The cost for rock structure would be substantially reduced if a native rock source were available.

The hypalon drop structures are placed in existing reservoir spillways after the steep-sided spillways are shaped with a dozer, creating 3:1 side slopes and a 4:1 slope in the channel bottom. The hypalon is then keyed in around the entire periphery, using a 2-foot wide and 2-foot deep trench, dug by backhoe. Once the hypalon is placed in the trench, the replaced soil material is compacted into the key.

Criteria used for the determination of the new construction project sites are related to the size of the watershed and the location of active gullies. Pit reservoirs ranging in size from 1,000 to 3,000 cubic yards are being implemented in watersheds with greater than 4 ha (10 acres) of drainage area. The pits are located in flat alluvial bottoms upstream from headcuts, which are migrating upstream and threatening the productivity of the alluvial bottoms. Active gully migration can be reversed by preventing the runoff from entering the system and diverting the water out of the pits into adjacent stable side draws.

Gully plugs are being built in the headwaters of small drainages with less than 2 ha (5 acres) of drainage. The gully plugs are small, uncompacted earthen check dam structures with an embankment that is no greater than 5 m (15 feet) in width and 3.3 m (10 feet) in height. They are constructed by two or three passes with a lowered dozer blade, creating small pits. An engineered spillway is not required on these structures because of their small size and since they are built in a series. The excess runoff is expected to flow around either side of the gully plug.

The life span of gully plugs is estimated at 5 years. In many cases, the silted in gully plugs would be revegetated naturally or reseeded, and new gully plugs could be built above or below the old ones if additional stabilization is needed. A series of gully plugs is the most desirable form of salinity control in this watershed because they are inexpensive and can be placed almost anywhere. These structures are very cost effective, having a benefit/cost ratio of approximately 3:1 to 6:1.

VII. MONITORING AND STUDIES

The type of study or monitoring needed to determine the success of treatments is based on an individual basis. The most efficient and cheapest method of measuring the sediment yield is to measure the finished dimensions of each pit and then measure from a reference point on the original ground surface to the top of the sediment. At that time, the salt content is also measured using an instant electrical conductivity (EC) meter. In 1985, sedimentation test plots were established to quantify runoff volumes and sediment transport. There are no results from the Lower Wolf Creek project at this time, because it will be several years before the project is fully implemented.

VIII. SUMMARY AND CONCLUSIONS

The development of plans for salt and sediment control on western rangelands requires (1) the establishment of resource management objectives, (2) the identification and quantification of manageable hydrologic processes, (3) the investigation of cause-and-effect relationships, (4) the stratification of treatment areas, and (5) the selections and evaluations of alternative treatment techniques. BLM prefers to incorporate salt and sediment control objectives as part of management plans for grazing, wildlife management, and other resource activities. When objectives cannot be met this way, techniques, including vegetation management and mechanical and structural treatments, may be used in the control of salt and sediment problems. Almost all salt and sediment control techniques influence multiple resource values. Because of the topographic position of public lands in the high sediment and salt-producing watersheds, BLM prefers to use small projects and to concentrate its control efforts in the headwaters (Jackson et al. 1985).

Salinity reduction was the primary management objective for the LWC watershed however, riparian habitat is also created by these projects. Treatment techniques selected were designed to trap and retain runoff and sediment from saline soils. The LWC watershed activity plan is in its third year of implementation. Initial treatments included large reservoir repair and maintenance, including hypalon drop structures, pit reservoirs, gully checks, and earthen retention dams. These initial treatments have been applied to the high-priority treatment units. As a step in determining the cost effectiveness of the project, benefit/cost (B/C) ratios were determined for each structural treatment type, using salinity control as the primary benefit. This information was used in the project planning to ensure that the overall mix of treatments had a positive B/C ratio.

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SEDIMENT AND FORESTRY PRACTICES IN THE SOUTH

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ABSTRACT

An average annual base rate for sediment concentrations in flows from small catchments of undisturbed southern pine is applicable to a wide diversity of Southern soils and topography. Catchment studies of forestry practices have determined the range and duration of changes in sediment concentrations, and allow comparisons of alternatives. Planting pine can decrease sediment concentrations to the base rate in less than 5 years. Pine forests can be harvested with minimum, short-lived sediment impacts, but where channels are nonresistant, flow increases after harvesting can impair downstream water quality. Intensive mechanical site preparation can result in short-term sediment characteristics approaching those for cultivated lands. This information can help define "best management practices," the approach currently advocated to protect the quality of southern surface waters, and can help meet the mandates of the National Forest Management Act.

INTRODUCTION

Early research on erosion and sedimentation in the southern United States concentrated on the loss of soil productivity, the destruction of arable land, and the problems of sediment entering stream channels and other surface waters. Forest water-quality issues were recognized, but it was not until 1972, with the enactment of the Federal Water Pollution Control Act Amendments (Public Law 92-500), that water quality became a national concern and water-quality goals were legislated.

Sediment is the most important pollutant of southern waters. A liability in itself, sediment also accounts for the majority of nutrients removed by water. The fertility of forest lands is a vital concern to forest land managers. For the National Forests, the National Forest Management Act mandates that these public lands will be managed to maintain and improve site productivity. Public law 92-500 also directed the States to develop water-quality standards. Information on the quality of water flowing from relatively undisturbed forest lands was meager, and such information was needed to assess changes due to forestry practices as well as to develop reasonable control strategies. These needs prompted new research on forested catchments in a number of Southern States. This paper discusses sediment characteristics for small catchments of not recently disturbed forests of southern pine--particularly loblolly pine (*Pinus taeda* L.), the South's most important tree species--and presents recent findings on the magnitude and duration of changes associated with silvicultural practices. The information largely represents contributions of organic and inorganic particulates from forested slopes and ephemeral-intermittent channels. Most of the studies cited do not include sediment from forest roads. One reason small catchments were used is that they minimize the confounding effects of channel erosion, although it is recognized that even on undisturbed catchments of a few acres, much of the sediment may be contributed by channels. Because most southern streams have erodable channels, the implications of changes in flow characteristics due to forestry practices on downstream water quality are discussed.

THE SOUTHERN PINERY

The 12 Southern States now produce almost half of the nation's wood fiber, and the demand is projected to increase substantially over the next several decades (USDA Forest Service, 1982). Pine species predominate on 65 million of the 188 million acres of southern commercial forest land and comprise up to one-half the stocking on some 36 million additional acres (Murphy and Knight, 1974). To meet anticipated demand, a large portion of low-quality hardwoods occupying some 70 million acres unsuited for hardwood production would need to be replaced with southern pine (Southern Forest Resource Analysis Committee, 1969).

The three forest management activities most likely to increase sediment in runoff are logging, site preparation for pine regeneration, and road construction. The harvesting and regeneration activities that are considered in this paper are important because of the extensive acreages under even-aged management, the short rotation periods of 17-35 years, and the widespread use of heavy equipment to prepare sites. Soil and water hazards related to these activities vary among physiographic provinces, but are most severe on the hilly topography of the Piedmont and the Coastal Plains. After forest clearing and decades of abusive row-crop agriculture in these areas, millions of acres were abandoned, while forest lands were subjected to exploitative harvesting, frequent burning, and overgrazing. Of the 120 million acres of forest land in the Coastal Plain, 22 million acres have been subjected to accelerated erosion (McClurkin, 1967). Excessive runoff and sediment from eroding lands contributed to downstream damage, covered minor flood plains, and created sand-filled channels that are important sources of sediment today.

SEDIMENT YIELDS VERSUS SEDIMENT CONCENTRATIONS

This paper recommends the use of annual discharge-weighted sediment concentrations (sum of sediment yields divided by sum of stormflow volumes) to establish water-quality standards for undisturbed southern pine forests and to evaluate the effects of forestry practices. One standard is applicable to the Piedmont and upper Coastal Plain; another to the mountains and lower Coastal Plain. The recommendation is based on the analyses of a large number of data sets from small catchments of pine forests that had not been disturbed recently. Almost without exception, sediment concentrations were independent of individual or annual stormflow volumes, and annual sediment yields were largely a linear function of the volume of flow.

The major effects of forest practices usually occur during the first year after disturbance. Because catchment studies to evaluate sediment effects of various practices are seldom replicated in time, sediment yields during the first post-treatment year are variable, depending on the amount and characteristics of rainfall during that particular year. Annual precipitation over much of the South averages about 50 inches, but can vary from less than 40 inches to over 80 inches, and the variation greatly affects water and sediment yields. Even when studies have been replicated, water yields, and hence sediment yields, can vary widely among similarly treated catchments, while sediment concentrations are more uniform. In one study, expressing soil loss as concentrations reduced coefficients of variation from about 100 percent to about 50 percent (Douglass and Goodwin, 1980).

Thus, annual concentrations are preferred to compare sediment characteristics among southern physiographic areas and forest types and to evaluate forestry practices. Sediment concentrations vary less than sediment yields and thus facilitate comparisons among and within studies.

BASE RATES OF SEDIMENT CONCENTRATIONS

In establishing any realistic water-quality standard it is necessary to know the natural background level, or base rate. An early attempt involving seven small (3- to 7-acre) headwater catchments of loblolly pine plantations provided an estimate of mean annual sediment concentration (Ursic and Duffy, 1972). A linear regression of average annual sediment yields in tons/acre/year predicted from mean annual runoff explained 76 percent of the variation ($r^2 = 0.761$). The slope of the regression, or sediment concentration, was 0.0066 ton/acre-inch (ton/AI) of flow. During the 5 years of record, annual rainfall among catchments ranged from 38 to 71 inches; stormflow volumes from 0.04 to 13.6 inches; sediment yields, 0.002 to 0.113 ton/acre/year; sediment concentrations from 0.002 to 0.033 ton/AI; and runoff as a percent of rainfall from 0.1 to 24.1.

The original data base of this study was later expanded to a total of 88 years and 10 catchments and included 3 catchments of mature shortleaf pine (*Pinus echinata* Mill.) (Ursic, 1977). Annual concentrations for the shortleaf pine catchments (n = 30) did not differ statistically from those for the other pine catchments (n = 58). The overall mean of 0.007 ton/AI (62 ppm) confirmed the earlier estimate and was applicable to natural pine stands. The standard error of this mean is ± 0.0008. Based on this information, an average annual concentration of 0.007 ton/AI was recommended as the natural background level for pine types in the hilly Coastal Plain.

To further define natural background levels, records for two other forest land cover types were compiled. One record was for 3 catchments of abandoned land with a dense cover of native grass (*Andropogon* spp.), representing unstocked forest land. The other cover type was represented by 3 catchments of poorly stocked upland hardwoods (Ursic, 1969, 1970). Records for 22 years were available for each cover type. Average annual sediment concentrations between these two types did not differ statistically. Overall, the concentration averaged 0.026 ton/AI, almost four times that of the pine types, and defined a discrete population of erosion potential (Ursic, 1977). Establishing pine on 4 of these catchments decreased sediment concentrations to the base level in about 5 years (Ursic, 1985).

Ton per acre-inch of flow may seem an odd expression for sediment concentrations from forest lands, but it facilitates comparisons with other land uses. Plots, with soils similar to those on the pine catchments, were kept in continuous fallow to estimate their erosion potential. They eroded at rates of 3.5 ton/AI of runoff and 80 tons/acre annually (McGregor et al., 1969). Croplands in the area typically erode at rates of 0.5 to 1.0 ton/AI.

Subsequent catchment studies in the hilly Coastal Plain and Piedmont appear to substantiate the base rate recommended for undisturbed pine cover types. Average annual concentrations for 14 data sets from 12 studies ranged from 0.002 to 0.012 ton/AI and, either weighted by study-years or unweighted, averaged 0.006 ton/AI. The studies included 37 catchments and represent 189 years of record. Excluded from this mean is an 88-acre catchment in Tennessee with an average annual concentration of 0.088 ton/AI. This higher rate was due to channel erosion (Table 1).

Much of the sediment from small pine catchments comes not from the forested slopes, but from erosion of the minor channels developed during former land uses. The low sediment concentration from pine catchments is attributed to more of the network of minor channels being covered by litter. Pine litter forms a loose, interwoven cover that reduces flow velocities and is not as easily dislodged by flowing water as other litter types. Storm-to-storm variations stem from the occasional flushing together of litter in channels with accumulated sediment. Thus, sediment concentrations for large, individual stormflow events sometimes exceed the suggested base rate by a factor of 10 or more. Such natural variation helps explain the poor correlation of sediment concentrations with stormflow volumes and should be considered in any monitoring effort.

Table 1. Representative base rates of average annual sediment concentrations.

Location and Cover type	References[1/]	Drainage areas	Catchments	Duration	Annual water yields	Annual sediment yields	Sediment concentrations
		acres	number	years	inches	lbs/acre	ton/acre-inch
		Coastal Plain Uplands					
East Texas							
Loblolly-shortleaf	1	6	3	3	0.8	13	0.007
Southeast Arkansas							
Flatwoods	2	6-10	9	1	2.7	42	.007
Loblolly-shortleaf		6-10	3	3	6.5	21	.002
Southwest Arkansas							
Athens Plateau	3	5-11	9	1	6.1	41	.005
Loblolly-shortleaf		7	3	3	8.4	79	.005
North Mississippi							
5- to 15-yr-old loblolly	4	2.5	2	11	0-15.0	0-125	.006
10- to 15-yr-old loblolly	4	2.1	2	6	0-18.5	0-42	.002
39-yr-old loblolly	5	4-7	5	5	6.5	163	.012
Mature shortleaf	6	3.3-4.6	3	10	0.3-19.0	1-360	.007
Depleted hardwoods	7	2.6	1	21	3.4-17.8	35-175	.018
Depleted hardwoods	8	2.1-2.6	3	5	4.8 (1.2-13.1)	200 (30-620)	.021
Abandoned fields	9	2.6	1	22	0.8-9.4	3-1089	.032
Abandoned fields	10	2.5	3	4	6.9 (1.2-20.7)	283 (26-1089)	.020
Tennessee							
Loblolly pine	11	88	1	5	5	--	.088[2/]
29- and 37-yr-old loblolly	12	0.4-1.4	4	4.5	--	--	.009
		Piedmont					
North Carolina	13	0.5-1.6	4	3	1.5	20	.007
South Carolina							
40-yr-old loblolly	14	1.5-3.1	3	6.5	2.8	17	.003
Virginia							
Virginia pine	15	4	1	1.5	--	--	.003
Georgia							
Loblolly pine	16	105	1	4	10	82	.004
		Coastal Plain Wetlands					
South Carolina							
Hardwoods	17	--	1	1	--	--	< .001
15-yr-old loblolly	17	--	1	1	--	--	.001
Carolina Bay	17	5,600	1	1	--	--	.002
Florida							
40-yr-old slash pine	18	121	1	5	7	--	.001
		Mountains					
Arkansas							
Ozark Plateau							
Hardwoods	19	4-6	3	9	2.3	20	.004
Ouachita Mountains							
Shortleaf pine	20	1-2	3	7	6.6	12	.001
Oklahoma							
Ouachita Mountains							
Shortleaf pine	21	4-10	3	4	7.5	16	.001
Oklahoma-Arkansas							
Ouachita Mountains							
Shortleaf pine	22	10-15	3	3	12.6	28	.001

1/ 1. DeHaven et al., 1984; 2. Beasley and Granillo, 1985a; 3. Beasley and Granillo, 1985b; 4. Ursic, 1985; 5. Schreiber and Duffy, 1982; 6. Ursic, 1977; 7. Ursic, 1982; 8. Ursic, 1970; 9. Ursic, unpublished; 10. Ursic, 1969; 11. Ursic, 1975; 12. McClurkin et al., 1985; 13. Douglass and Goodwin, 1980; 14. Van Lear et al., 1985; 15. Fox et al., 1983; 16. Hewlett, 1979; 17. Askew and Williams, 1984; 18. Riekerk, 1985; 19. Rogerson, 1976; 20. Rogerson, 1985; 21. Miller, 1984; 22. Miller et al., 1985.

2/ Largely contributions from gully channels.

Sediment concentrations from pine catchments are lower where channels are more resistant to erosion than channels in the Piedmont and Coastal Plain. Annual sediment concentrations for three 4- to 10-acre catchments in the Ouachita Mountains of eastern Oklahoma over a 4-year period (Miller, 1984), for three 10- to 15-acre catchments in the Ouachita Mountains of western Arkansas over a 3-year period (Miller et al., 1985), and for each of three smaller catchments in the Ouachita Mountains of Arkansas over a 9-year period (Rogerson, 1985) all averaged 0.001 ton/AI (Table 1).

Similar to differences between pine and hardwood types in Mississippi, sediment concentrations during 9 years for three 4- to 6-acre catchments of hardwoods in the Ozark Plateau in Arkansas also averaged four times greater than for pine types--0.004 versus 0.001 ton/AI (Table 1).

Sediment concentrations for forests in the lower Coastal Plain wetlands are lower due to minimum stream gradients. They range from 0.001 to 0.002 ton/AI (Table 1).

EFFECTS OF FORESTRY PRACTICES

Sediment yields can be increased by larger volumes of flow, by an increase in concentrations, or by a combination of these changes. Cutting or using herbicides to deaden the forest without removal increases the amount of water available for streamflow and deep recharge, but seldom affects sediment concentrations to any degree. Any increases of sediment concentrations result from channel erosion, since overland flow seldom occurs without soil disturbance, and rainfall energy is dissipated by the forest floor.

Pine cover types are burned by prescription to control hardwoods, and pine sites are burned to prepare them for natural or artificial regeneration. Prescribed burns of 40-year-old pine plantations in the Piedmont did not significantly change sediment concentrations. Concentrations after one and two burns averaged 0.004 and 0.002 ton/AI, respectively (Douglass and Van Lear, 1983) (Table 2).

Intense, pre-planting burns of grass-herbaceous covers did not increase sediment concentrations in the mountains, but concentrations in the Coastal Plain were significantly increased by reactivated gullies and channels. Burning poor-quality hardwood catchments and deadening the hardwoods also significantly increased sediment concentrations in the Coastal Plain. However, neither of these increases lasted for more than 2 years (Table 2).

Harvesting, including clearfelling, did not significantly increase sediment concentrations in the mountains. Harvesting, excluding roads, in the Piedmont and Coastal Plain caused insignificant or small increases in sediment concentrations that were of short duration. Annual concentrations ranged from 0.003 to 0.041 ton/AI the first year. They were highest for eroded catchments, but all returned to the base level in 3 years (Table 2).

Increases of sediment concentrations following sequences of treatments that included mechanical site preparation were lowest in the mountains where they did not exceed 0.014 ton/AI during the first year after treatment. First-year concentrations in the Piedmont and Coastal Plain Hills ranged from 0.003 ton/AI in east Texas to as much as 0.32 ton/AI for catchments with steep slopes (25-40 percent) or for catchments with histories of severe erosion. The concentrations declined substantially after the first year, but it appears that treatments that caused the largest increases will persist for more than 3 years (Table 3).

Sediment concentrations increase when forestry practices expose a large proportion of the soils on a catchment. Here rainfall energy impacting on bare soils comes into play and causes overland flow that detaches, entrains,

Table 2. Sediment concentrations following burning and harvesting practices.

Location and Cover type	Reference 1/	Treatments	Drainage areas acres	Catchments number	Years after treatment number	Mean 2/,3/ annual water yields inches	Mean 2/,3/ annual sediment yields lbs/acre	Mean 2/,3/ annual sediment concentrations ton/acre-inch
				Prescribed Burning				
Piedmont								
South Carolina 40-yr-old loblolly	1	Two burns for natural regeneration	1.5-3.1	4	1.5	3.9 ns	39 ns	0.004 ns
				4	1	5.2 ns	59 ns	.004 ns
Coastal Plain								
Mississippi Grass cover	2	Intense preplanting burn	2.4	1	1st 2nd 3rd	9.2* 4.5* 4.7*	5,759* 519* 47 ns	.443*4/ .058* .005 ns
			2.6	1	1st 2nd 3rd	18.5 ns 11.9 ns 11.1 ns	1,542* 88 ns 33 ns	.063* .004 ns .002 ns
Depleted hardwoods	3	Burn, deaden hardwoods, plant pine	2.1	1	1st 2nd 3rd	7.4* 5.7* 5.2*	1,179* 390 ns 84 ns	.080* .034 ns .008 ns
			2.1	1	1st 2nd 3rd	15.0* 10.0* 9.3*	868* 408* 128*	.029* .020* .007 ns
Ouachita Mountains								
Arkansas Grass cover	4	Intensive preplanting burn	1.4	1	4	--	--	.006 ns 5/
				Harvesting				
Piedmont								
Virginia Virginia pine	5	Clearcut with roads & landings	4-9	3	1.5	--	--	.040
South Carolina 40-yr-old loblolly	1,6	Clearcut and 3rd burn	1.5-3.1	3	1st 2nd 3rd	8.6* 2.7 ns 6.8*	135* 21 ns 44 ns	.008* .003 ns .003 ns
Coastal Plain and Foothills								
Arkansas (SE) Pine-hardwoods	7	Clearcut, chemical hardwood control, replant	5-11	3	1st 2nd 3rd	6.2 ns 15.6 ns 10.2 ns	224 ns 183 ns 80 ns	.015 ns .005 ns .003 ns
Coastal Plain								
Arkansas (SE) Flatwoods	8	Selection cut of pine and all hardwoods	6-10	3	1st 2nd 3rd	2.0 ns 13.3 ns 5.7 ns	12 ns 23 ns 13 ns	.003 ns .001 ns .001 ns
Mississippi 15-yr-old loblolly	9	Clearcut and replant	2-3	4	2	5.4* (2.8-10.8)	147 (27-284)	.013 (0.005-0.029)
Tennessee 30- & 40- yr-old loblolly	10	Clearcut and replant	1	4	4.5	2.3	86	.021 (0.005-0.041)
Ouachita Mountains								
Arkansas Shortleaf pine	11,12	Clearcut and hardwood control	1.4	1	1st 2nd 3rd	15.4 10.7 12.0	117* 6 ns 13 ns	.004 .001 < .001
		Shelterwood & hardwood control	1.3	1	1st 2nd 3rd	9.7 7.6 11.5	31 ns 5 ns 11 ns	.002 .001 < .001
		Remove shelterwood	1	1	4	--	--	.003 ns 5/
Arkansas-Oklahoma Shortleaf pine	13	Selection cut and hardwood control	10-15	3	1st 2nd 3rd	12.4 ns 10.1 ns 28.1 ns	32 32 75	.001 .002 .001

1/ 1. Douglass and Van Lear, 1983; 2. Ursic, 1969; 3. Ursic, 1970; 4. Lawson, 1985; 5. Fox et al., 1983; 6. Van Lear et al., 1985; 7. Beasley and Granillo, 1985b; 8. Beasley and Granillo, 1985a; 9. Ursic, 1985; 10. McClurkin et al., 1985; 11 & 12. Rogerson [In Press] and Lawson, 1985; 13. Miller et al., 1985.
2/ Ranges in parentheses.
3/ *Significant change at 0.05 level of probability; ns, non-significant.
4/ Burning reactivated healed gully.
5/ Estimated from turbidity measurements.

Table 3. Sediment concentrations following mechanical site preparation practices.

Location and Cover type	Reference 1/	Treatments	Drainage areas acres	Catchments number	Years after treatment number	Mean 2/ annual water yields inches	Mean 2/ annual sediment yields lbs/acre	Mean 2/ annual sediment concentrations ton/acre-inch
				Mechanical Site Preparation				
Piedmont								
North Carolina	1	Shear, burn, replant	1-2	4	1st 2nd 3rd	4.4 6.5 4.6	3,123 1,173 562	0.324 .062 .042
		Shear, windrow, burn, disk, replant	1-2	4	1st 2nd 3rd	15.2 10.4 10.6	8,680 6,233 4,495	.286 .274 .178
		Shear, burn, disk, cover crop, replant	1-2	4	1st 2nd 3rd	3.4 2.5 3.2	642 118 71	.079 .025 .016
Georgia Loblolly pine	2	Clearcut, double chop, machine plant	80	1	3.3	--	--	.044*
Coastal Plain								
Mississippi Pine-hardwood	3	Clearcut, shear, windrow, burn, cover crop, replant	2	1	1st 2nd	17.8* 11.0*	11,420* 1,980*	.322* .090*
		Above plus bedding on contour	2	1	1st 2nd	20.0* 9.3*	12,710* 4,940*	.318* .266*
		Clearcut, chop, burn, cover crop, replant	2	1	1st 2nd	20.0* 13.6*	11,180* 2,060*	.280* .076*
Texas Loblolly-shortleaf	4,5	Clearcut, windrow, burn, replant	6	3	1st 2nd 3rd 4th	5.8* 2.0* 2.5* 2.3*	2,620* 71* 31 ns 128*	.227* .018* .006 ns .027*
		Clearcut, chop, replant	6	3	1st 2nd 3rd 4th	3.2* 1.4* 1.8 ns 1.3*	22 ns 5 ns 5 ns 16 ns	.003 ns .002 ns .001 ns .006 ns
Arkansas (SE) Flatwoods Loblolly-shortleaf	6	Clearcut, shear, windrow, burn, replant	6-10	3	1st 2nd 3rd	5.2* 17.6 ns 12.9 ns	236* 56* 74 ns	.023* .002* .003 ns
Florida Wetlands Slash pine	7	Clearcut, double-chop, bed, machine plant	141	1	5	6.0	--	.001
		Clearcut, burn, windrow, harrow, bed, machine plant	346	1	5	8.3	--	.003
Coastal Plain and Foothills								
Arkansas (SW) Loblolly-shortleaf	8	Clearcut, shear, windrow, replant	5-11	3	1st 2nd 3rd	12.8* 24.0 ns 19.7*	477* 897 ns 275 ns	.014 ns .015 ns .015 ns
Ouachita Mountains								
Oklahoma Shortleaf	9	Clearcut, tree-crush, burn, rip soil, replant	4-10	3	1st 2nd 3rd 4th	8.85 ns 4.37* 5.35 ns 8.70 ns	252* 31* 13* 38 ns	.014 .004 .001 .002
Arkansas Shortleaf	10	Clearcut, chop, burn, replant	10-15	3	1st 2nd 3rd	12.4 ns 10.8 ns 29.8 ns	211* 80 ns 158 ns	.008* .004 ns .003 ns

1/ 1. Douglass and Goodwin, 1980; 2. Hewlett, 1979; 3. Beasley, 1979; 4. DeHaven et al., 1984; 5. Blackburn et al., 1985; 6. Beasley and Granillo, 1985a; 7. Riekerk, 1985; 8. Beasley and Granillo, 1985b; 9. Miller, 1984; 10. Miller et al., 1985.
2/ *Significant change at 0.05 level of probability; ns, non-significant.

and delivers soil to channels. Douglass and Goodwin (1980) concluded that percent ground cover was the single most important factor affecting annual sediment concentrations. Sediment concentrations increased rapidly as cover dropped below 40 percent.

Sequences of treatments that grossly disturb soils are not suitable for Piedmont and Coastal Plain sites with slopes exceeding 20 percent or for those that have been severely eroded. Cover crops ameliorate the consequences of such treatments. Techniques that create potential detention-retention storage such as roller-chopping are desirable, but may pose a substantial risk on steep slopes. Tree crushing left contour-oriented soil depressions of sufficient volume to store 0.75 inch of water and sediment in a north Mississippi plot study. The storage opportunity for some 100 tons/acre of sediment was almost fully utilized within 2 years and, although stormflow volumes increased, sediment concentrations were not greatly affected (Ursic, unpublished). In the Ouachita Mountains of Oklahoma, tree crushing plus ripping soils on the contour increased water yields the second year but not the first, reflecting the initial storage opportunity created (Table 3).

Discussion so far is largely limited to changes immediately off-site but a broader context of the effect of forestry practices deserves mention.

DOWNSTREAM IMPLICATIONS OF FORESTRY PRACTICES

Compared to regulatory forest practice acts adopted by the westernmost states, the approach promulgated in the Southern States is that of voluntary Best Management Practices (BMP's). Evaluation of BMP's is based on the quality of water leaving a particular forest area that has been subjected to some disturbance. However, increases of stormflow volumes and characteristics, not increases of sediment concentrations, may be the dominant factor affecting water quality downstream from the site disturbed.

The quality of water from forested lands in the Coastal Plain progressively degrades as it continues downstream. Water from small ephemeral channels flows to larger channels, which today are major sources of sediment because they are typically aggraded, sand-textured, and sensitive to the erosive power of flowing water. Many streams are reestablishing channel stability by removing large quantities of alluvium of anthropogenic origin. For example, the average annual sediment concentration from an 88-acre catchment of loblolly pine was 13 times higher than the 0.007 ton/AI base rate for small headwater areas, due primarily to channel erosion (Ursic, 1975). Increases in stormflow volumes also affect reaches of larger, first- and second-order streams where channels can erode at the rate of 1 ton per foot of channel annually, and 1 mile of channel can contribute sediment loads equivalent to 6 tons/acre/year from an entire watershed (Murphey and Grissinger, 1985).

Forestry practices that remove a large part of the biomass cause increases in stormflow volumes that persist longer than corresponding increases in sediment concentrations. Loblolly pine established on eroded, abandoned-field catchments in north Mississippi reduced annual stormflow volumes by about 50 percent after plantation age 9. After the pine was clearcut at age 15, rates and volumes of flow reverted to pre-planting levels. Replacing depleted upland hardwoods with loblolly pine on less eroded catchments in a companion study decreased annual stormflow volumes from an average of 83 percent after age 12 or 13 to only 50 percent after clear felling at age 15 (Ursic, 1985). Decreases of sediment concentrations to the base rate achieved by the pine were interrupted only briefly by harvesting. However, with increased rates and volumes of flow after harvesting, part of all of the improvement of water quality in downstream sand channels was probably nullified. These studies suggest a delay in final harvest, especially for plantations established on severely eroded landscapes, as a desirable BMP if downstream effects are to be considered. Clear cutting 40-year-old pine on similar sites in Tennessee resulted in only minor increases of stormflow volumes (Table 2).

There may be more factors that come into play when final harvesting is delayed. Recent research indicates a strong affinity of small burrowing mammals for pine types. The storage opportunity their burrows create increases with time and is believed to be an important factor in stormflow reductions (Esher et al., 1981).

Another concern for the forest manager is how the export of soil and chemical nutrients affects long-term productivity. Sufficient information is available to evaluate nutrient gains from the atmosphere and nutrient losses in the biomass removed. Overriding such changes are the losses of dissolved nutrients and, especially, the nutrient losses removed with sediment (Duffy, 1985).

A rough evaluation of the potential for increasing stormflow volumes in the hilly Coastal Plain pinery is shown in Table 4. The erosion history is important. Large differences exist among available options, e.g., mechanical site preparation versus the use of herbicides to replace hardwoods with pine. Careful planning is necessary when harvesting severely eroded sites. A further breakdown of the many options among sequences and activities of mechanical site practices is feasible. Rating systems such as Table 4 can provide quantification to aid the forest manager in selecting alternatives.

Table 4. Potential for increasing stormflow volumes in the hilly Coastal Plain pinery.

Forest practice	Stormflow increases 1/	Erosion history 2/	Duration of increases 3/	Rank 4/	Relative rank 5/
Mechanical site preparation	1	1	1	1	100
		2	1	2	50
		3	2	6	17
Harvesting pine	3	1	2	6	17
		2	3	18	6
		3	3	27	4
Herbicides 6/	3	1	3	9	11
		2	3	18	6
		3	3	27	4
Prescribed burning	4	1	4	16	6
		2	4	32	3
		3	4	48	2
Temporary access	1		1	1	100

1/ 1 = largest increases in stormflow volumes; 4 = slight to no change.
2/ 1 = severe
2 = moderate
3 = slight
3/ 1 = > 7 years
2 = 5-7 years
3 = 3-5 years
4 = < 3 years
4/ Rank = stormflow increase X erosion history X duration of increases.
5/ Reciprocal of rank X 100, 100 indicates maximum increase in stormflow volumes.
6/ Used when replacing poor-quality hardwoods with pine.

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EVALUATION OF EMBANKMENT DAMAGE AND PROTECTION

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ABSTRACT

The objectives of this study are to conduct laboratory tests and develop a methodology to quantitatively determine embankment damage and assess protective measures. During the study, available literature and field data were collected and analyzed. Embankment overtopping tests were conducted. The embankments used in this study are 6 ft (1.8 m) high, 10 to 22 ft (3.0 to 6.7 m) in crest width, and 3 ft (0.9 m) in length, with slope varying from 2:1 to 3:1. The embankment surfaces include both with and without protective measures (pavement, grass, mattresses, Geoweb, soil cement, Enkamat, and others). The flood overtopping conditions include overtopping depths ranging from 0.5 to 4 ft (0.15 to 1.22 m), discharges ranging from 1 to 25 cfs/ft (0.1 to 2.32 cms/m) and tailwater conditions ranging from 10% water-surface drop to free fall. A computer model was developed to determine hydraulics of overtopping flow and associated erosion damage. This model is being verified using field data and laboratory test results. The preliminary study results are presented in this paper.

INTRODUCTION

When flood water overtops an embankment, erosion of the embankment will occur if the hydraulic erosive force exceeds the strength of the embankment. The erosive force is governed by the flow discharge, overtopping and tailwater depths, and embankment slope. The resisting strength is affected by the embankment material, the construction methods, and the surface-protection measures. There are little data available for quantitatively determining embankment damage due to flood overtopping and evaluating the effectiveness of various protective measures to reduce the erosion rate. The objective of this study is to develop a methodology to determine embankment damage and assess protective measures by reviewing valuable literature and field data and by conducting large-scale embankment tests.

LABORATORY FACILITIES AND TEST CONDITIONS

A test facility was constructed for conducting the large-scale embankment tests. The discharge required for the testing was provided using a pumping plant capable of providing 85 cfs (2.41 cms) to the flume. With minor modifications, an additional 20 to 30 cfs can be supplied through the use of a 300-hp electric pump. The flume is 90-ft (27.4 m) long, 11-ft (3.4 m) high, and 3-ft (0.9 m) wide. The discharge rate in the flume was determined through the use of a calibrated flow meter located at the inlet pipe. A point gage was used for measuring the elevation of the bed and water surface. The velocity measurements were taken by a March-McBirney 201 electromagnetic water-current meter capable of measuring velocities from 0 to 20 ft/s (0-6.1 m/s).

The following flow overtopping test conditions were conducted during the study: (1) soil types: Type I soil (40% sand; 60% silt and clay; plasticity index 11.7); Type II soil (59% sand; 41% silt and clay; plasticity index 5.7); (2) overtopping depths: 0.5 ft (0.15 m), 1.0 ft (0.30 m), 2.0 ft (0.61 m), and 4.0 ft (1.22 m); (3) tailwater drop: 10%, 20%, 40%, 70%, and free fall; and (4) surface cover and protective measures: bare soil, pavement on roadway surface, grass, rock-filled mattresses, soil cement, Geoweb, and Enkamat on embankment slope. The tests were run from 10 to 20 hours or until the embankment was severely eroded.

HYDRAULICS AND EROSION OF OVERTOPPING FLOW

Flow Pattern

Various flow patterns have been observed as water flows over an embankment. These flow patterns were classified by Kindsvater (1964) as free and submerged flow. Free flow is subclassified into plunging flow and surface flow. Plunging flow occurs when the jet plunges under the tailwater surface, producing a submerged hydraulic jump on the downstream slope. Surface flow occurs when the jet separates from the roadway surface at the downstream shoulder and rides over the tailwater surface. The plunging flow generally causes more embankment erosion than the surface flow. The tailwater level limit of the transition for plunging flow to surface flow occurs between 0.5 to 0.7 of the overtopping depth. Using limited rigid embankment test data for surface flow, the local flow velocity over the downstream slope surface

$$V_r \simeq 0.5\ V_u \qquad (1)$$

where V_u is the average velocity at the upper edge of the embankment slope. For plunging flow

$$V_r = 0.5\ V_u \qquad (2)$$

where V_u is the averaged flow velocity immediated upstream of a hydraulic jump. For free fall, V_r is the same as the local depth average velocity. The local shear stress is related to local velocity by:

$$\tau = \frac{1}{8} f \rho V_r^2 \qquad (3)$$

where f is the Darcy-Weisbach coefficient and ρ is the water density.

Discharge Equations

For the free flow over an embankment, the most generally accepted discharge equation is

$$q = C\ H_1^{3/2}$$

where q is the discharge per unit width, C is a discharge coefficient, and H_1 is the total head above the embankment crest. For the free flow case, the coefficient C is fairly constant, but does vary somewhat depending on the overtopping depth, h, and the ratio of h/L where L is the total roadway width. Kindsvater (1964) developed graphs giving the discharge coefficient for the free flow under various geometries of embankment and roughness. Our large-scale embankment tests have confirmed that the free flow discharge coefficient is fairly constant ranging from 3.0 to 3.1, except at very low overtopping depth where the C value can be as low as 2.8. For the submerged flow case, the basic equation uses a different coefficient C_s:

$$q = C_s \, H_1^{3/2} \qquad (4)$$

where C_s is the discharge coefficient for submerged flow, which depends on the relative tailwater depth, t/H, and the surface roughness (Kindsvater, 1964).

Tailwater Effects on Erosion Patterns

The primary mode of embankment failure due to flood overtopping begins by erosion of the downstream shoulder and slope. As water flows over the roadway, it accelerates near the break point between the roadway shoulder and the downstream slope. Embankment is scoured from the area near the break point, forming a nick point which scours upstream. Another mode of failure occurs when the toe of the embankment slopes erodes. As the toe is eroded, the material above it becomes unstable and more erodible as erosion works its way up the embankment in the form of a headcut of slide. Results from the tests conducted during the study showed that the first type of erosion, shoulder erosion, occurs for higher tailwater levels (Figure 1), while the second type, toe erosion, occurs for low-tailwater or free-fall conditions (Figure 2).

DEVELOPMENT OF A COMPUTER MODEL

A computer model was developed to determine hydraulic conditions and erosion of embankment due to flood overtopping. Figure 3 shows a flow chart of this computer model. Some of the steps are self-explanatory. Steps 2, 12, and 14 are explained in more detail:

Step 2. Input embankment soil/structure characteristics and erosion equations. Figure 4 shows an example embankment with pavement and grass. This embankment is considered to contain four layers: pavement, gravel base, grass cover, and base soil. The critical shear stresses, Manning's n , and thicknesses of these layers at each computation section are input. When one layer is eroded, the critical shear stress and Manning's n for the immediate lower layer are utilized for next time-step computation. The equation form proposed by the Agricultural Research Laboratory is utilized to compute erosion rate:

$$E = K \, (\tau - \tau_c)^a \qquad (5)$$

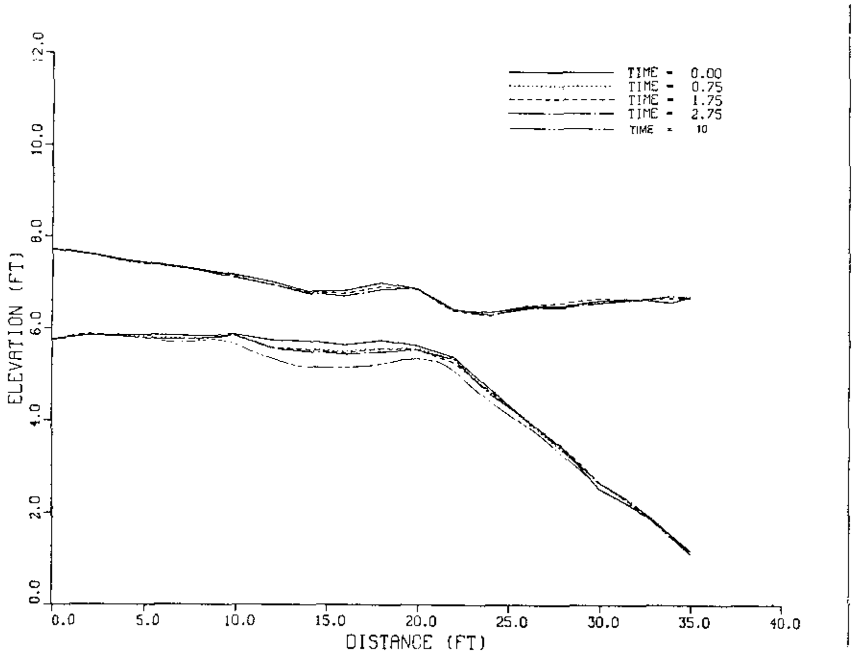

Figure 1. Water surface and bed profiles for high-tailwater level (70% drop).

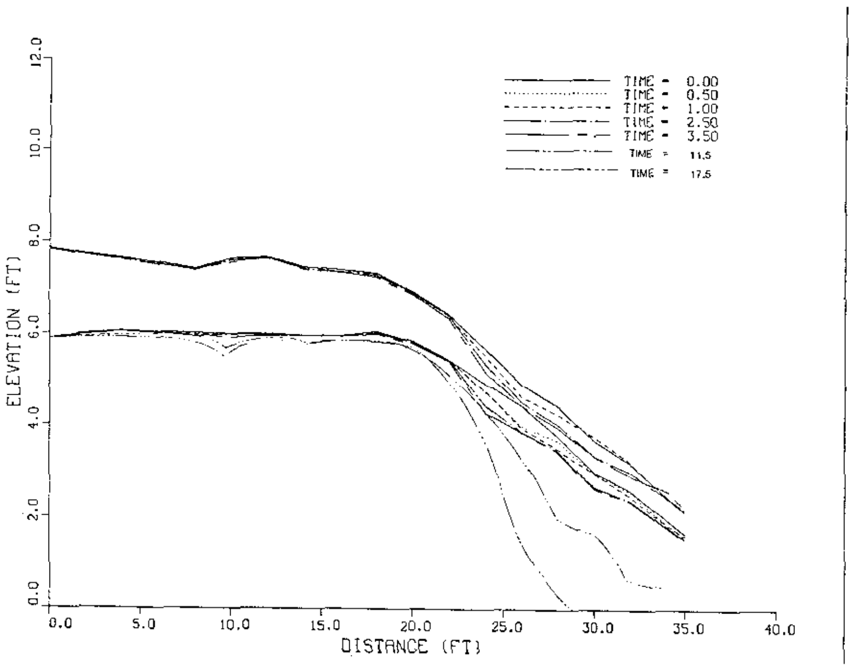

Figure 2. Water surface and bed profiles for free fall.

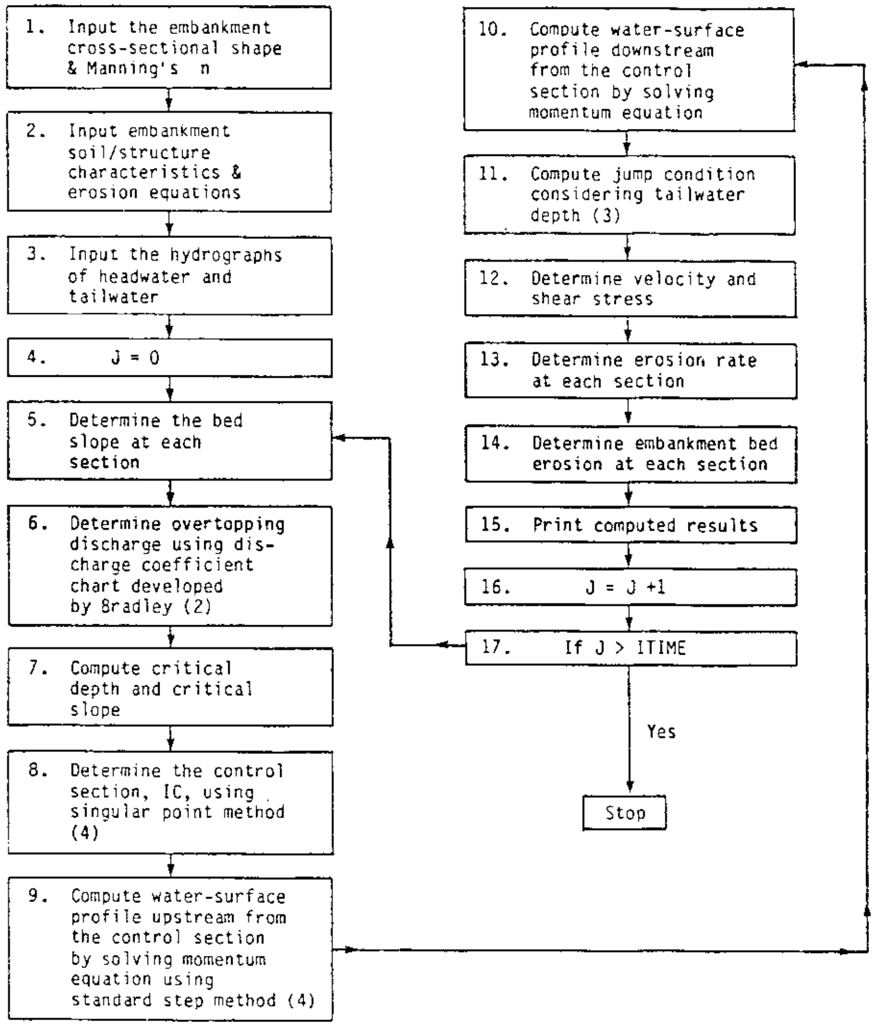

Figure 3. Flow chart of the computer model EMBANK.

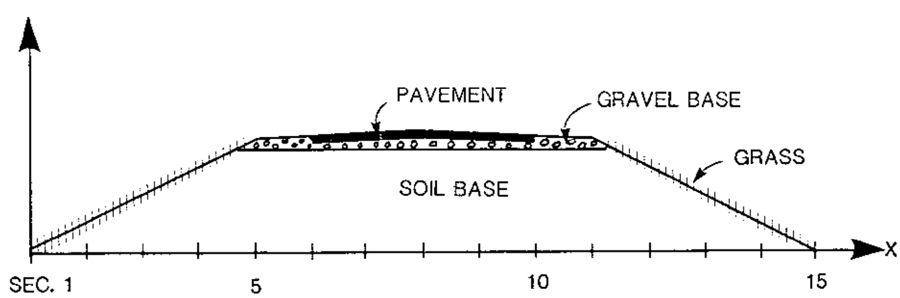

Figure 4. Example embankment.

where E is the erosion rate in $ft^3/ft^2/sec$, τ and τ_c are effective shear and critical shear stress, respectively, in lbs/ft^2, and K and a are empirical coefficients. Using the equation developed by Ariathurai and Arulanandam (1978) for cohesive soil, $K = 0.00005$ and $a = 1.0$. Using Meyer-Peter, Muller method (1948) for noncohesive soil, $K = 0.00005$ and $a = 1.5$.

Step 12. Determine the flow mode and then compute local velocity and shear stress to be utilized in Equation 5 for computing erosion rate.

Step 14. Determine embankment bed erosion at each computational section during a time step. For grass, gravel, or soil surface, the bed erosion depth is computed by

$$\Delta Z = E \, \Delta t \qquad (6)$$

where E is the erosion rate from Equation 5 and Δt is the time step duration. For paved sections, it is assumed that damage to the pavement is not due to direct flow erosion, but is due to the erosion undermining the roadway base and cantilevering the pavement.

CALIBRATIONS OF THE COMPUTER MODEL

The computer model was calibrated first using the flow data collected from the rigid embankment runs. Measured water-surface profile from 12 rigid embankment runs were compared with the computed profiles. Figure 5 shows an example of this comparison. In general, the agreement is good. Secondly, the field data collected at seven sites in Arkansas, two sites in Missouri, and two sites in Wyoming were utilized to verify the applicability of the developed computer model. The critical shear stress was determined from Shields diagram for noncohesive soil. For cohesive soil (Smerdon and Bensley, 1959).

$$\tau_c = 0.034 \, (PI)^{0.84} \qquad (7)$$

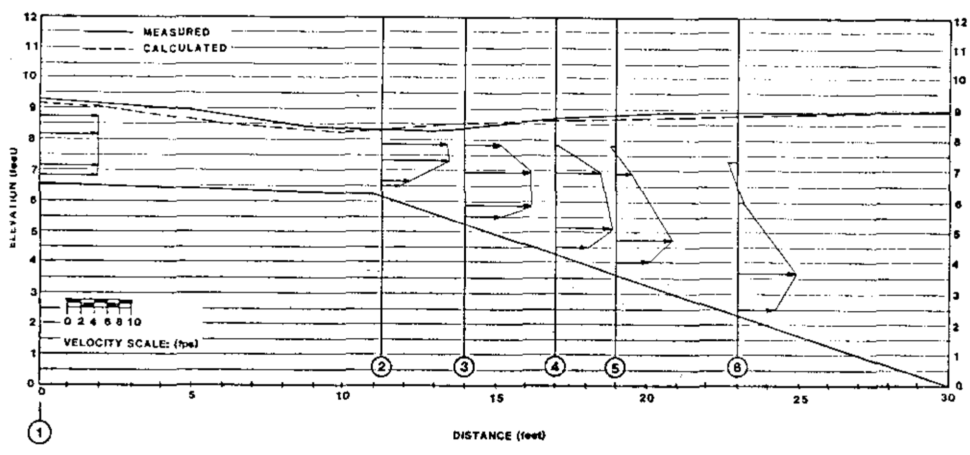

Figure 5. Comparison between measured and computed water-surface profile.

where PI is the plasticity index and τ_c is in lbs/ft^2. For grass cover, τ_c = 0.35 lbs/ft^2 (1.71 Kg/m^2), corresponding to a permissible velocity of 6 ft/s (1.83 m/s) and a Darcy-Weisbach coefficient of 0.04. Figure 6 shows the comparison between the measured and computed embankment damage. The agreement is reasonable. This computer model is being refined using the large-scale test results collected from this study.

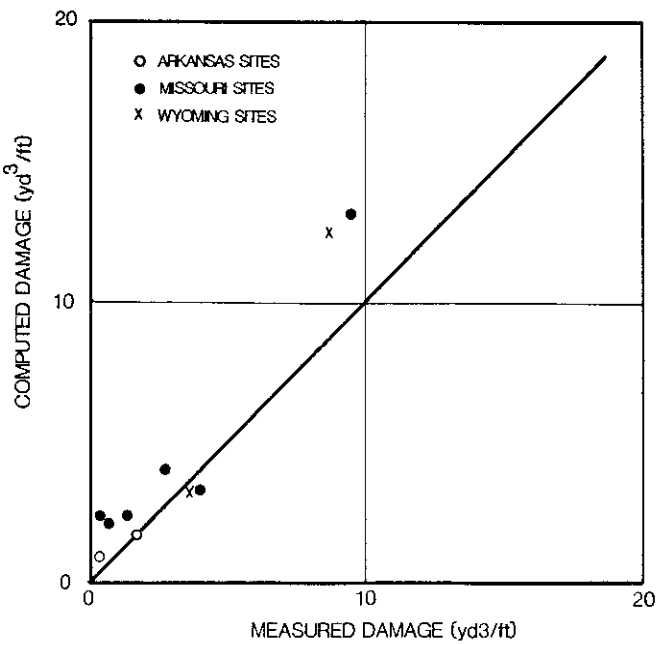

Figure 6. Comparison between measured and computed embankment damage due to flood overtopping.

DEVELOPMENT OF NOMOGRAPHS FOR EMBANKMENT EROSION

The computer model calibrated in the previous section was applied to develop nomographs for estimating embankment erosion under various conditions: base soils consisting of either sand soil or cohesive soil; embankment heights ranging from 2.5 ft to 15 ft; overtopping depths range from 1 to 10 ft; ratio of tailwater depth to overtopping depth ranged from free fall to 0.9. The computed erosion rates were plotted on Figure 7 for five-foot clay base embankments. This figure and other charts developed for other types of soils base are being evaluated using the large-scale embankment tests.

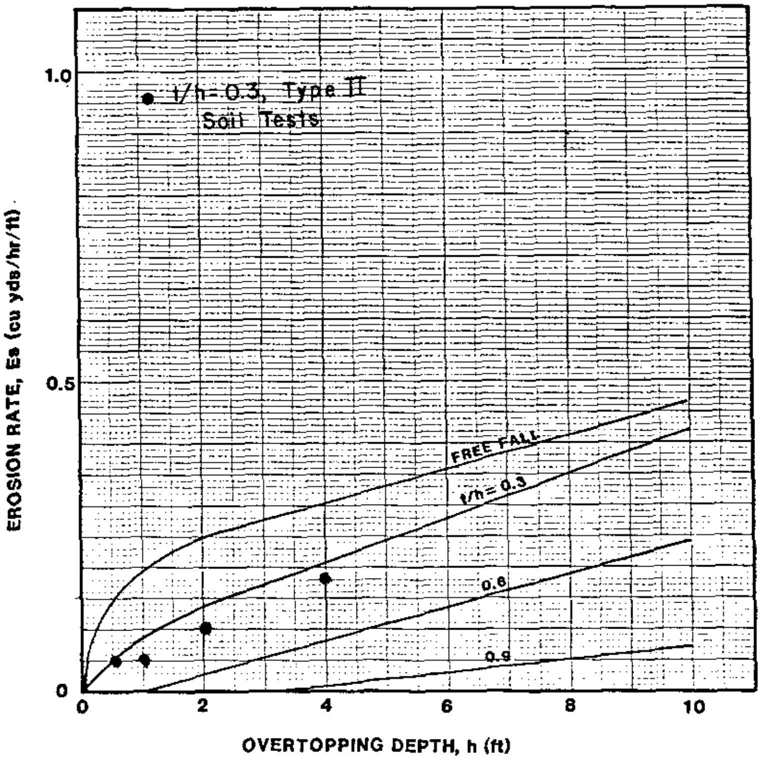

Figure 7. Erosion rate for 5-foot clay-base embankment.

The procedure to use these nomographs is:

1. Select design headwater depth h and tailwater depth t above the embankment crest.
2. Compute t/h.
3. Enter h and t/h to Figure 7 (for cohesive base soil) to determine erosion rate E_s.
4. Determine adjustment factor r from Figure 8, if the embankment height is different from 5 ft.
5. Compute the erosion rate: $E = r\ E_s$.

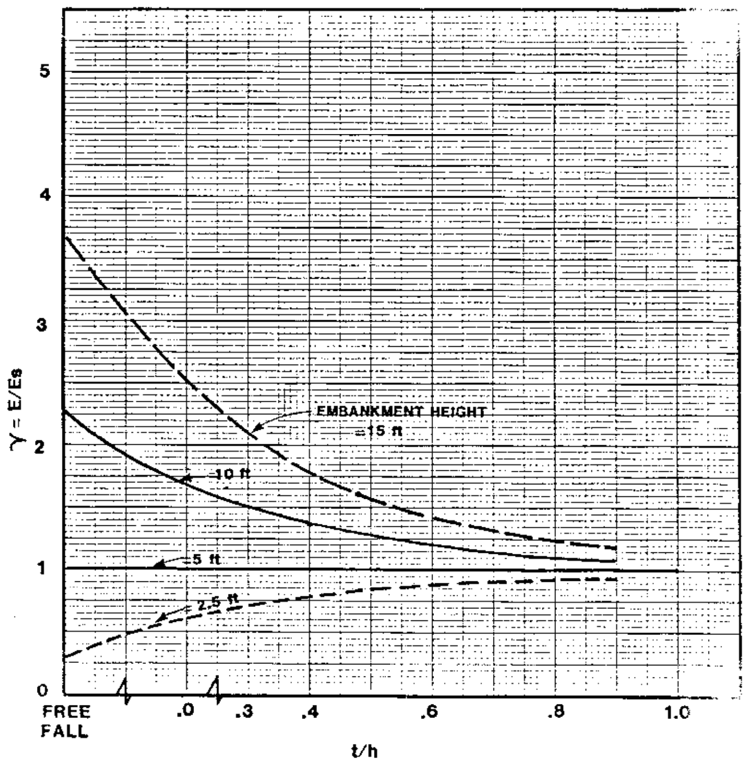

Figure 8. Erosion factor considering embankment height.

EVALUATION OF PROTECTIVE MEASURES

Rock-filled mattresses, Geoweb and soil cement were tested to evaluate their ability to protect the embankment under free fall conditions up to four feet (1.22 m) overtopping depth. Mattresses and soil cement were found to be effective for protecting embankment. However, there was a concern that excess high velocity (more than 20 ft/s, 6.1 m/s) could cause local scour downstream of the protected embankment. Adequate energy dissipation should be provided in this area. The failure mechanism associated with gabion mattresses appears to be related to the movement of rocks within the mattress. As the rocks move to the downstream section of each mattress diaphragm, the liner installed beneath the mattress is exposed. Although a properly installed liner still affords some erosion protection of the embankment material, the moment the liner becomes exposed could be considered as the failure symptom for gabion mattresses.

Geoweb protective system tested in this study was formed by using Geoweb (expendature honeycomb structure) directly on the filter cloth which covered the bare-soil embankment, and then filled the honeycomb cell with 1- to 2-inch gravel. This Geoweb system was found to be ineffective to protect embankments from damage by flood of more than 2 ft overtopping depth. Some modifications, such as changing filling material or capping filling material with asphalt or soil cement may improve its performance.

Even though the pavement on roadway was not installed at first to be a protective measure, it was found from the results of the tests run that the pavement reduces the rate of erosion as much as 50 percent for submerged flow conditions. For free fall conditions, the effectiveness of pavement for protection would be less.

ACKNOWLEDGEMENT

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CHANGES IN ALLUVIAL DEPOSITS, UPPER GRAND CANYON

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ABSTRACT

Sandy alluvial deposits along the Colorado River in the Grand Canyon are an important environmental resource, particularly as campsites for the approximately 15,000 persons who each year raft the river through Grand Canyon National Park. Three types of deposits associated with major zones of flow separation below channel constrictions can be distinguished—deposits near the point of separation of downstream flow from the channel banks, deposits in the center of the principal eddy formed by the flow separation, and deposits near the point of reattachment of downstream flow to the banks. A fourth type, the upper-pool deposit, is associated with eddies and low-velocity areas above many constrictions. Analysis of large-scale topographic changes in these deposits from 1973 to 1984 along 20 river miles shows that (1) the location of deposits that are used as major campsites has not changed and (2) several smaller deposits have apparently been eroded. Most deposits that have apparently eroded are reattachment deposits; however, most major campsites are separation deposits.

OVERVIEW

The Grand Canyon is in northern Arizona and extends for about 280 river miles from Lees Ferry to the Grand Wash Cliffs (J. B. Graf and others, "Sediment Studies in Grand Canyon, Arizona", Fig. 1, this volume). This report follows local usage as to locations in the Grand Canyon and therefore river distances and locations are given in river miles below Lees Ferry. All other units are in the S.I. system. The first 235 miles (mi) below Lees Ferry are free-flowing stream, and the lower 45 mi are part of Lake Mead Reservoir. Lees Ferry is 15 mi downstream from Glen Canyon Dam. The 225 mi between Lees Ferry and the confluence with Diamond Creek constitute the study area of the overall investigation. This report is based on data collected in the 20-mile reach immediately below Lees Ferry.

Flow-separation zones—eddies—are an important feature of the Colorado River in the Grand Canyon. Throughout the river corridor, debris fans at tributary mouths partially block the river's course and the river narrows and steepens as it flows around these fans (Fig. 1). Debris fans create the Grand Canyon's famous rapids, although large rapids are not associated with all constrictions. In pools upstream from most constrictions, main current velocites decrease and small eddies may occur. Large eddies commonly develop downstream from constrictions.

The predominant size of debris transported by the Colorado River is medium and finer sizes of sand—less than 0.50 millimeter (mm) in diameter. Transported sand is temporarily stored in main-channel pools and bars, channel bank deposits, and flow-separation zones. R. P. Wilson ("Sonar Patterns of Colorado River Bed, Grand Canyon," this volume) has identified sand deposits that floor many main-channel pools.

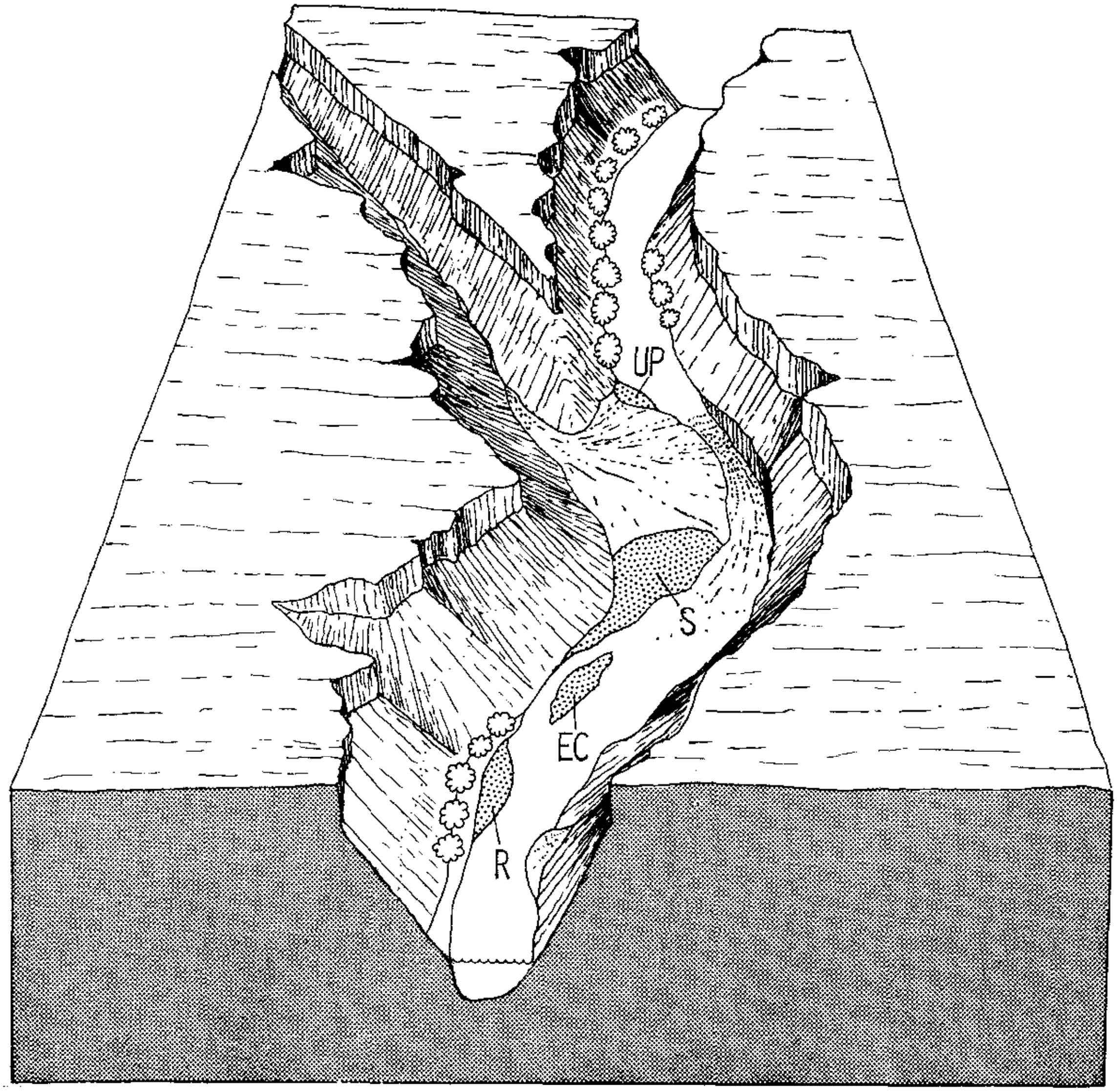

Fig. 1. Association of sandy alluvial deposits with debris fans and rapids. UP, upper-pool deposits; S, separation deposits; EC, eddy-center deposits; R, reattachment deposits. Adapted from Hamblin and Rigby (1968, Fig. 2).

The depth of flow in eddies varies greatly, from a few meters to about 25 meters, and the sand bed of many shallow eddies is exposed at low flow. Eddy bank deposits, as well as bed deposits of shallow eddies, are the prime campsites for the approximately 15,000 persons who each year raft the Colorado River.

PREVIOUS STUDIES

A large amount of data about sand-deposit characteristics along the Colorado River exists for the Grand Canyon. These data include ground photographs and replications beginning with the second John Wesley Powell expedition in 1872 (Weeden and others, 1975; Turner and Karpiscak, 1980), aerial photographs taken approximately once every decade since the 1950's, and ground surveys and replications begun in the mid-1970's (Howard, 1975; Howard and Dolan, 1981; Beus and others, 1984). Laursen and others (1976) predicted that sandy alluvial deposits would be largely eroded in about 200 years following completion of Glen Canyon Dam; however, Howard and Dolan (1981) suggested that sandy deposits had stabilized to the river regime characteristic of the late 1970's. Brian and Thomas (1984) reported net erosion of deposits between Lees Ferry and Kanab Creek (river mile 143) following the high flows of 1983. Their survey was conducted during average discharges of about 710 cubic meters per second (m^3/s) or 25,000 cubic feet per second (ft^3/s); however, they compared their results with a survey of campsites conducted in 1975, for those deposits exposed at about 170 m^3/s (6,000 ft^3/s) discharge (Weeden and others, 1975).

PRESENT STUDY

Field data have been collected primarily during three river expeditions (May-June, August, and October 1985). On each trip, approximately 7 days were spent in the part of the upper Grand Canyon described in this report. Daily discharge during the fall trip fluctuated between 160 and 560 m^3/s (5,600 and 20,000 ft^3/s). Flows during the first two trips were essentially steady, averaging 1,240 and 850 m^3/s (44,000 and 30,000 ft^3/s), respectively. Flows during the spring trip are characteristic of the low range of "high flows," and flows during the summer trip are considered moderate. Maximum release of Glen Canyon Dam for hydroelectric-power operations is 880 m^3/s (31,000 ft^3/s). Higher releases involve use of a bypass tube or spillways and can be as great as 2,830 m^3/s (100,000 ft^3/s). Discharges of 160 m^3/s are considered low by boaters.

Surficial deposits have been mapped at a scale of 1:4000 using aerial photography as a base. Sandy deposits existing in 1973 have been mapped on earlier air photographs. Location of river banks and patterns of surface flow (location of eddies and flow directions) have been mapped in many reaches at the low, moderate, and high flows described above. These data are analyzed in this report in a preliminary fashion. Other data not discussed here that have been collected on these expeditions include sedimentologic data from trenches, topographic and water-surface slope surveys, photographs of reoccupied sites, current velocities, and depth of scour measurements.

CLASSIFICATION OF DEPOSITS

Topographic and sedimentologic observations of sand deposits have been analyzed and a classification developed. The classification is intended to serve as a basis for organizing and evaluating data on the history of changes in alluvial deposits throughout the Grand Canyon. The classification system distinguishes deposits on the basis of general form and relation of form to the flow field that exists at times when a particular deposit has been observed or is presumed to be mobilized (Figs. 1 and 2). Three principal types of deposits directly associated with flow-separation zones have been recognized—(1) deposits below constrictions near the point of separation of downstream flow from the channel banks (separation deposits); (2) deposits below constrictions near the point of reattachment of downstream flow to the banks (reattachment

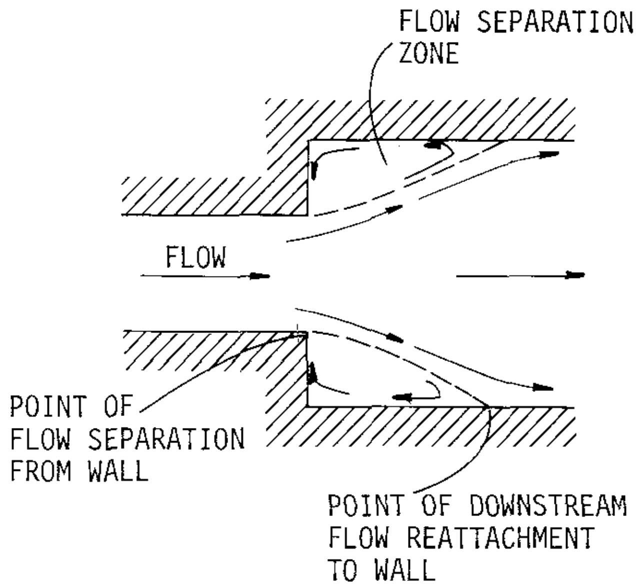

Fig. 2. Flow patterns at a channel expansion.

deposits); and (3) bed deposits in the central low velocity core of eddies (eddy-center deposits). Deposits are also associated with eddies and low-velocity areas upstream from constrictions (upper-pool deposits). Exposure at low flow of the bed of complete eddy systems shows that deposits of the first three types may grade into one another. As an example of the occurrence of these deposits, Figs. 3 and 4 show a photograph and map of the Badger Rapids area, the location of sandy deposits, and the location of eddies at low and high discharges.

Upper-pool deposits are bank deposits located at the margin of the channel in the slow-moving water upstream from many constrictions (Figs. 1 and 4). These deposits generally are overgrown by tamarisk. Where these deposits have open zones of sand among the woody vegetation, they are used by campers, particularly where other deposits are not found, such as in Upper Granite Gorge near Phantom Ranch.

Deposits located at sites of flow separation below channel constrictions are the deposits most commonly used for campsites in the river corridor (Figs. 1, 3, and 4). These deposits are common, mantle downstream portions of debris fans, and typically extend into the channel. Preliminary analysis of sedimentologic data suggest that these deposits originally form in secondary eddies and low-velocity portions of the separation zone environment but are not part of the main recirculating eddy. Interpretation of current directions that created the primary deposit suggest that typically bars develop in a secondary eddy and then migrate shoreward until attached to the nearby debris fan. Waves generated by rapids may significantly alter the shape of the primary deposit.

Deposits at sites of downstream flow reattachment to the bank are located in the downstream portion of an eddy (Figs. 1 and 4). These deposits

Fig. 3. Downstream part of Badger Rapids, July 30, 1985, 1630 hours, discharge about 800 cubic meters per second (30,000 cubic feet per second). Separation deposits mantle Badger debris fan in foreground and Jackass debris fan on opposite bank. Raft is 10 meters in length. Photograph by Ruth Gardner.

generally do not mantle coarse debris fans. Current directions of primary deposits indicate that the upstream portion of these bars is deposited by upstream currents and the downstream portion is formed by downstream currents.

Sandy deposits also are found in the center of many eddies, although these deposits may be exposed only at very low discharges (Fig. 1). All deposit types do not exist at each flow-separation zone. The relation between channel constriction form, characteristics of separation zones, and existence of sand deposits is under investigation.

ANALYSIS OF CHANGES IN ALLUVIAL DEPOSITS

The first 20 miles of river corridor below Lees Ferry have been evaluated for change during 1973-1984. In this part of the Grand Canyon, the Colorado River progressively cuts through Paleozoic sedimentary rocks, and the Kaibab Limestone, Toroweap Formation, Coconino Sandstone, Hermit Shale, and Supai Group are exposed. The first 20 miles can be divided into three subreaches on the basis of river corridor

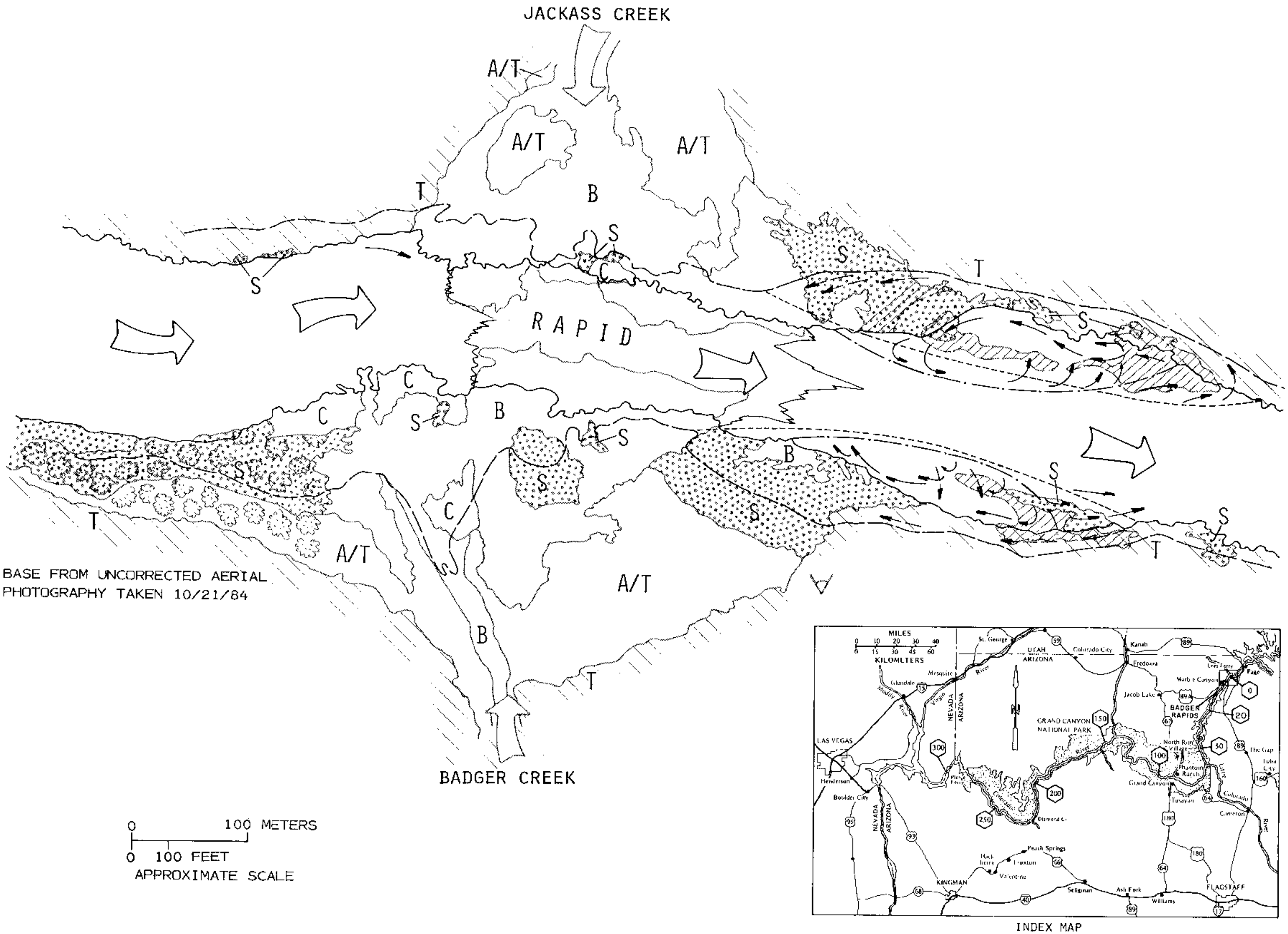

Fig. 4. Surficial geology and flow patterns of Badger Rapids area.

EXPLANATION

S — RIVER-DEPOSITED OR REWORKED FINE TO MEDIUM SAND (1984)

A/T — AEOLIAN SAND OR TERRACE DEPOSITS—Silt and fine sand, well sorted

B — TRIBUTARY DEBRIS FAN—Boulders, cobbles, gravel, sand, poorly sorted; boulders generally cover greater than 50 percent of surface area except for present streambed of tributary

C — COBBLES AND GRAVEL

T — TALUS

ADDITIONAL RIVER-DEPOSITED SAND (1973)

EDGE OF WATER

- Low flow, October 5, 1985, discharge about 160 cubic meters per second
- High flow, May 20, 1985, discharge about 1,250 cubic meters per second

SHEAR ZONE BETWEEN DOWNSTREAM EDDY AND MAIN DOWNSTREAM CURRENT

- Low flow
- High flow

GENERALIZED SURFACE-FLOW DIRECTIONS IN MAIN EDDIES

- Low flow
- High flow
- Main-current flow direction

RAPID — LIMIT OF BREAKING WAVES (WHITE WATER) AT LOW FLOW—At high flow, breaking waves in main current extend downstream to a point opposite approximate center of eddies

DENSE STANDS OF TAMARISK

PHOTOGRAPH SITE FOR FIG. 3 AND APPROXIMATE FIELD OF VIEW OF PHOTOGRAPH

Fig. 4

characteristics—a mixed lithology area, the upper Supai gorge, and the lower Supai gorge (Table 1). The mixed lithology area is a reach of variable river corridor conditions, but about half of this reach is lined by sandy alluvium mantling talus. Many of these deposits are not usable for campsites because they are narrow, support a heavy overgrowth of tamarisk, and typically have steep cutbanks. The upper Supai gorge is notable for the absence of sand-deposition sites because the river flows in a vertically walled sandstone inner gorge. The lower Supai gorge is lined by talus, the channel is wide, and campsites are more abundant.

Table 1. Characteristics of the river corridor.

Reach	River miles below Lees Ferry	Typical top channel widths[1] (meters)	Typical thalweg channel depths[1] (meters)	Channel slope of reach[2]
Mixed lithology area	0-11.5	65-115	6-15	0.00097
Upper Supai gorge	11.5-18.6	45-80	8-18	0.0013
Lower Supai gorge	18.6-20.2	60-75	12-16	0.00047

[1]Based on fathometer cross sections in reaches of uniform downstream flow surveyed at 810 m^3/s, April 28 and 29, 1984, (Wilson, this volume).

[2]Computed from Birdseye (1923).

Sandy deposits existing in 1973 and 1984 were classified by size and deposit type. Small campsites generally are 185 to 560 square meters (m^2) in area, medium campsites range to about 1,900 m^2, and large campsites have a greater surface area. Respectively, these areas are considered to accomodate parties of 10 to 20 persons, 21 to 30, and more than 30 and are consistent with the categories of campsite size used by Brian and Thomas (1984). Campsite sizes were evaluated in terms of low, moderate, and high discharge. Because stage data at these deposits are not available for 1973, only low-flow availability of campsites in 1973 was assessed. Campsites that do not exist at both low and moderate discharges are of limited use by boaters because, under fluctuating power-generation operations, campsites may be inundated while in use or moored boats may be beached or must be moved. Low-discharge small campsites have not been regularly inventoried by the National Park Service (Weeden and others, 1975; Brian and Thomas, 1984); however, comparison in the number and size of these deposits provides a broader data base on changes in alluvial deposits. Low-discharge small campsites should be considered emergency campsites only. Comparisons in the availability of various size alluvial deposits for campsites are shown in Table 2.

Table 2. Usable sand deposits by type, Lees Ferry to river mile 20, 1973 and 1984.

[S, small campsite; M, medium campsite; L, large campsite. Number in parentheses is number of campsites with accessibility problems caused by steep cutbanks or difficult boat moorings]

Year and flow level	Deposit types												Total		
	Upper pool			Separation			Reattachment			Other					
	S	M	L	S	M	L	S	M	L	S	M	L	S	M	L
Mixed lithology area															
1973 (low)	3 (3)	1 (1)	0	8 (4)	3	3 (1)	12	3	0	11 (6)	1	1	34	8	4
1984 (low)	3 (3)	1 (1)	0	6 (4)	4	4 (1)	10	3	0	11 (6)	1	2	30	9	6
1984 (moderate)	3 (1)	0	0	6 (2)	1	3 (1)	3 (1)	0	0	6 (5)	1	0	18	2	3
1984 (high)	0	0	0	2	0	3	1	0	0	4	0	0	7	0	3
Upper Supai gorge															
1973 (low)	0	0	0	3	4	0	1	1	0	1	0	0	5	5	0
1984 (low)	0	0	0	4	3	0	2	0	0	1	0	0	7	3	0
1984 (moderate)	0	0	0	2	2	0	0	0	0	0	0	0	2	2	0
1984 (high)	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0
Lower Supai gorge															
1973 (low)	1	0	0	2	1	1	5	2	1	0	0	0	8	3	2
1984 (low)	1	0	0	3	0	1	2	1	0	0	0	0	6	1	1
1984 (moderate)	1	0	0	0	1	0	2	0	0	0	0	0	3	1	0
1984 (high)	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0

CONCLUSIONS

Many types of deposits can be used as campsites, especially small campsites at low discharges. In the mixed lithology area, about a third of the total number of low-discharge small campsites are reattachment deposits and a third are separation deposits. Accessibility problems exist at many of the latter. Medium- and large-size campsites—those of importance to most river users—whether exposed at low, moderate, or high discharges, are mostly separation deposits. Only one non-separation deposit (river mile 1.9) is available at moderate flows. In the upper Supai gorge, separation deposits are most important at all discharges; in the lower Supai gorge, separation and reattachment deposits are both important.

From 1973 to 1984, the number of reattachment deposits available as low-discharge small campsites in the mixed lithology area decreased slightly. The number of small campsites that are separation deposits decreased but the size of two campsites increased. In the upper Supai gorge, the total number of deposits remained the same; however, there was a slight decrease in their size. In lower Supai gorge, the total number of reattachment deposits decreased greatly although the size and number of other deposits remained essentially the same.

Overall, these data suggest a tendency for reattachment deposits to be more susceptible to long-term erosion. The volume of sand the changes represent cannot be estimated at this time because data are unavailable as to the thickness of sand removed or deposited. Integration of this analysis with photographic, topographic, fathometer, and sonar data may permit such an estimate in the future.

No attempt is made here to assess the cause of these changes. Between 1973 and 1984, several high flows, unprecedented for the post-Glen Canyon Dam era, occurred. Further analysis, particularly of sedimentologic data, may indicate the association of observed changes in sand deposits with changes in flow. Mapping of flow patterns at different discharges indicates that patterns change greatest at reattachment sites, which may account for their greater susceptibility to erosion when discharges vary widely. Mechanisms of readjustment of deposits formed in 1983 may be identified during a special fluctuating-flow study period in fall and winter 1985 and 1986.

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