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VIII. Watersheds: Sediment Quality, Coastal and Estuary Sedimentation and the 1993 Midwest Flood

VIII. WATERSHEDS: SEDIMENT QUALITY, COASTAL AND ESTUARY SEDIMENTATION, AND THE 1993 MIDWEST FLOOD

SIMULATION OF CONTAMINATED SEDIMENT TRANSPORT IN WHITE OAK CREEK BASIN

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__Abstract.__ This paper presents a systematic approach to management of the contaminated sediments in the White Oak Creek watershed at Oak Ridge National Laboratory near Oak Ridge, Tennessee. The primary contaminant of concern is radioactive cesium-137 (^{137}Cs), which binds to soil and sediment particles. The key components in the approach include an intensive sampling and monitoring system for flood events; modeling of hydrological processes, sediment transport, and contaminant flux movement; and a decision framework with a detailed human health risk analysis. Emphasis is placed on modeling of watershed rainfall-runoff and contaminated sediment transport during flooding periods using the Hydrologic Simulation Program-Fortran (HSPF) model. Because a large number of parameters are required in HSPF modeling, the major effort in the modeling process is the calibration of model parameters to make simulation results and measured values agree as closely as possible. An optimization model incorporating the concepts of an expert system was developed to improve calibration results and efficiency. Over a five-year simulation period, the simulated flows match the observed values well. Simulated total amount of sediment loads at various locations during storms match with the observed values within a factor of 1.5. Simulated annual releases of ^{137}Cs off-site locations match the data within a factor of 2 for the five-year period. The comprehensive modeling approach can provide a valuable tool for decision makers to quantitatively analyze sediment erosion, deposition, and transport; exposure risk related to radionuclides in contaminated sediment; and various management strategies.

INTRODUCTION

__Background.__ The U.S. Department of Energy's Oak Ridge National Laboratory (ORNL) is located in the White Oak Creek basin near Oak Ridge, Tennessee. Over a period of 50 years, the operation of and waste disposal activities at ORNL have resulted in an accumulation of ^{137}Cs and other radionuclide contaminants that are bound to sediments distributed in the White Oak Creek basin. The contaminated sediments are primarily located along the floodplains and in White Oak Lake near the basin outlet (Clapp et al. 1994 and Oakes et al. 1982). To assess the long-term potential risk to human populations downstream of White Oak Creek because of exposure to ^{137}Cs from local flood events, a predictive model is critically important for simulating contaminated-sediment erosion, deposition, and transport in the White Oak Creek basin. The model is a key component within an overall risk assessment system, shown in Figure 1. Currently, available information suggests that no appreciable off-site risk exists, but the effects of extreme floods must be estimated and documented. Furthermore, management options (e.g., leaving the contaminated sediments as they are, stabilizing stream banks and the lake bed, building sediment-

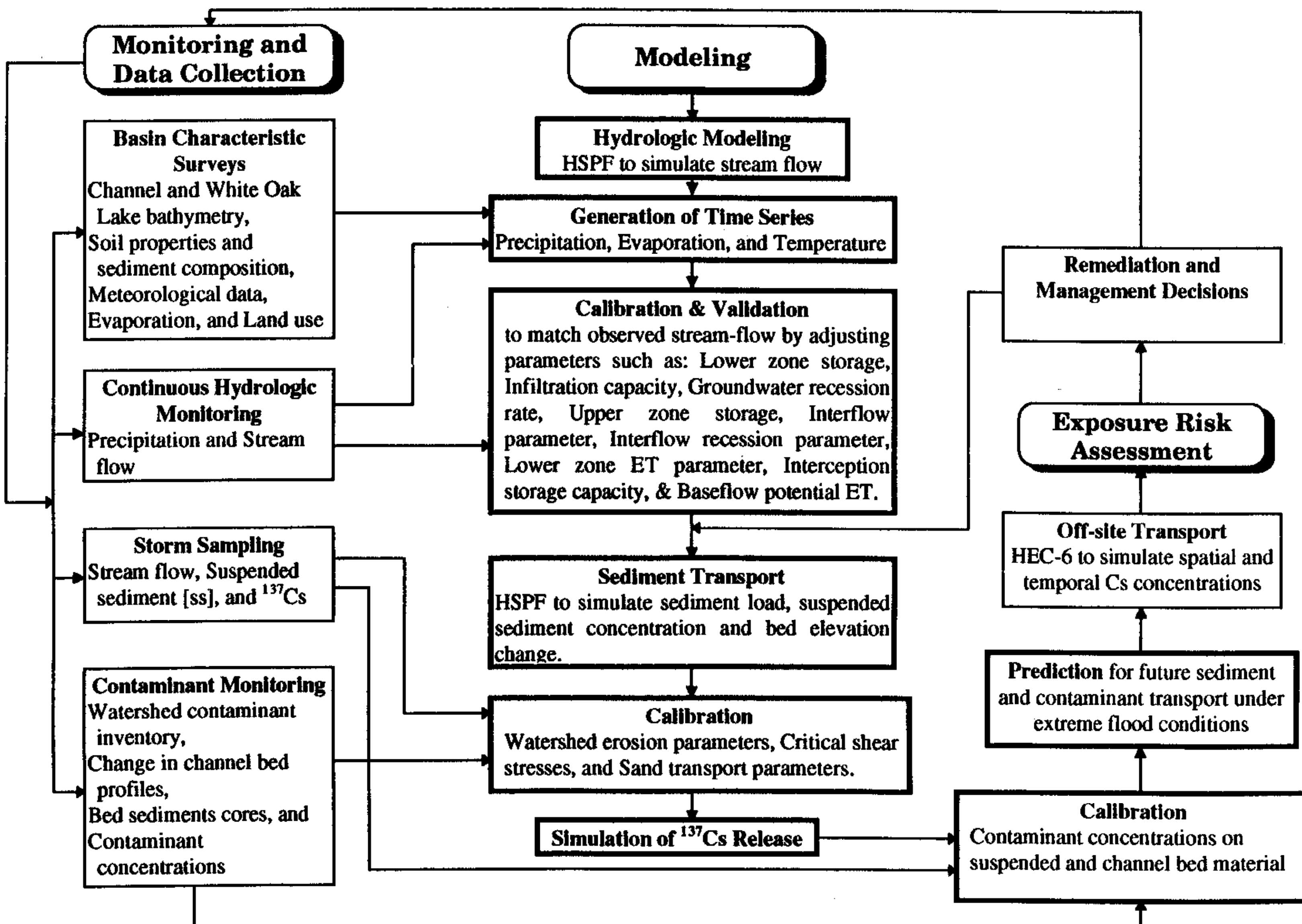

Figure 1. Flowchart of Contaminated Sediment Transport Modeling and Exposure Risk Assessment

retention check dams) must be assessed. Possible changes in the watershed from future development must also be assessed. However, the management issues and risk assessment are beyond the scope of this paper.

Purpose. The purpose of this paper is to describe the watershed model used in the project and an advancement in model calibration that we developed. This paper pertains to the modeling components that are shown in the bold boxes in Figure 1. Other parts of the projects are intensive storm sampling, erosion studies, and risk-assessment modeling.

METHOD

A comprehensive, continuous watershed model, Hydrologic Simulation Program-Fortran (HSPF) (Bicknell et al. 1993), was applied to the White Oak Creek basin to simulate various hydrological processes, sediment transport, and the movement of ^{137}Cs. The simulated stream flow and contaminant release at White Oak Dam from HSPF are inputs to HEC-6 (Hydrologic Engineering Center 1993) for simulation of off-site contaminated sediment transport in the Clinch River a place where the public can be exposed to water and sediments. We have modified HEC-6 to account for variable contamination layers in the sediments in stream channels. A risk assessment model uses HEC-6 output information of contaminant concentrations to assess long-term human exposure risks.

Basin Description. The White Oak Creek basin area is about 16 km^2 (Figure 2) with 80% forest, 10% riparian, and 10% developed area such as buildings, roads, and parking lots. Slope of the primary channels is in a range from 1/1000 to 4/1000. Average annual precipitation is 137 cm. Rainfall data were collected from six rain gauges within or near the boundary of White Oak Creek basin.

Physical Representation. In the HSPF modeling approach, a land segment is a subdivision of the watershed, and reaches or reservoirs link the land segments together (Bicknell et al. 1993). As shown in Figures 2 and 3, White Oak Creek basin is represented by four pervious land segments (PLS1 to PLS4) that are connected through seven channel reaches (reaches 2 to 8). The drainage area, channel reach length, location of the end of reach, and stream-flow gage station corresponding to each PLS are listed in Table 1.

New Approach to Hydrologic Calibrations. The purpose of hydrologic model calibration is to adjust model parameters in a systematic fashion so that computed and observed values (e.g., water surface elevation, total flow rates, velocities) agree as closely as possible. A large number of parameters are required in the HSPF model; thus, calibration is a key component in the modeling processes. A calibration methodology was developed by combining an expert system and a nonlinear-optimization model. The expert system incorporates calibration strategies (Donigian et al. 1984) with direct observations of the watershed's hydrologic behavior (Oakes et al. 1982) and determines the sequence in which to calibrate parameters. The nonlinear-optimization model (Lasdon and Waren 1989) determines the values of the parameters by minimizing the absolute difference between the computed and observed stream flow at the outlet of each pervious land segment. The first three-year period of a five-year record of flows was used for model calibration and the last two years of data were used for model validation (without changing in model parameters for validation runs). Each subcatchment (i.e., PLS) was calibrated independently.

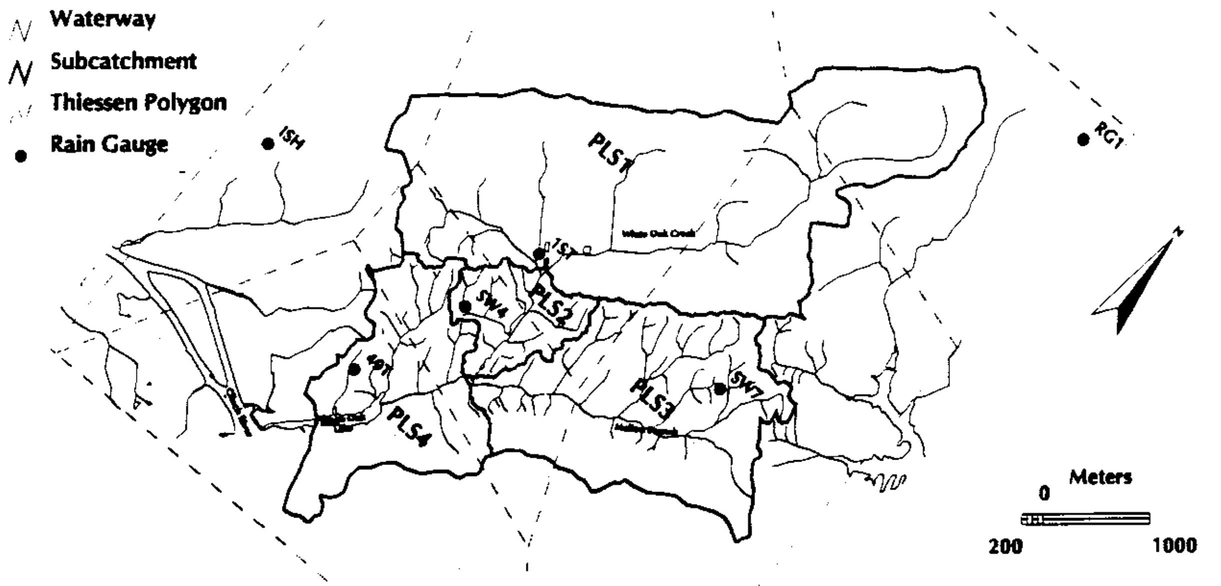

Figure 2. White Oak Creek Watershed Map and Rain Gauges with Theissen Polygons for Estimation of Rainfall Distribution

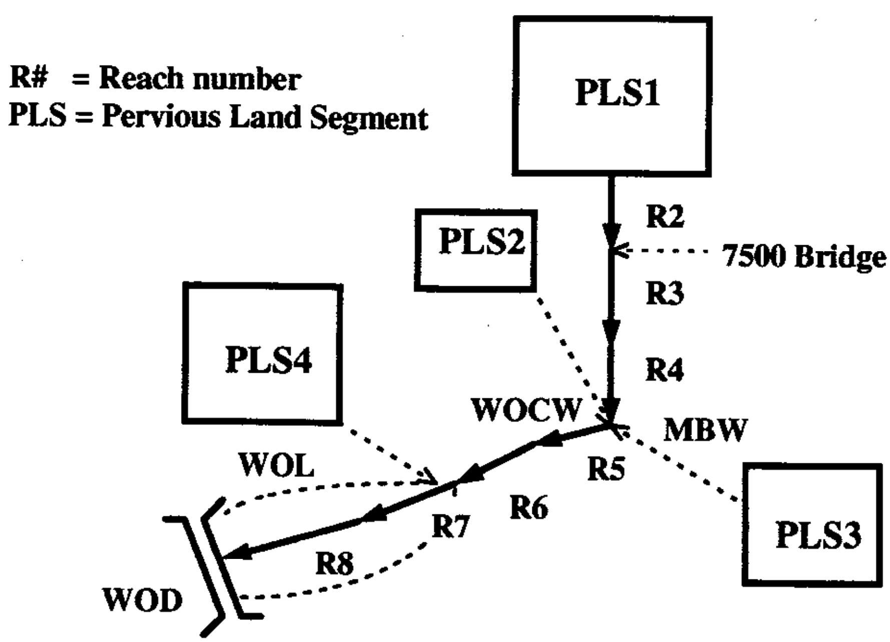

Figure 3. Schematic Sketch of the Model Elements Representing White Oak Creek Watershed

<u>Calibration Strategy for Sediment Transport Modeling.</u> A three-step approach was taken for calibrating the contaminated-sediment transport model. First, the model was calibrated to match

the sediment concentration and load at each reach with data collected during five storms. The primary calibration parameters used are coefficients in a watershed gully erosion equation; coefficients in sand transport equations; and critical shear stresses for silt and clay. Next, the simulated changes in channel depth were compared with the measured channel cross-sectional profiles to determine the changes in sediment deposition and resuspension at a particular reach; this led to refinement in the critical shear stresses for clay and silt, channel grain sizes, and sediment composition. Third, the contaminant release from the basin was calibrated by adjusting potency factors for contaminant concentrations on suspended and channel bed.

Table 1. Pervious Land Segments and Channel/Lake Reaches for White Oak Creek Watershed

PLS	Reach/ Reservoirs	River Mile WOC	Location	Drainage Area (acre)	Stream Flow Gage Station
1	2	2.21-2.18	7500 Bridge	2099	7500 bridge
2	3	2.18-1.90	Inter. Pond	204.8	White Oak Creek Weir
	4	1.90-1.63	WOC Weir		
3			MBW	960	Melton Branch Weir
4	5	1.63-1.40		672	White Oak Dam
	6	1.40-1.48			
	7	1.18-0.83	WOC Lake		
	8	0.83-0.60	WOD		

RESULTS

Overall, the simulated flows match the observed values for a five-year simulation period well. Figure 4 shows an example of the flow simulation results at the White Oak Dam. The average difference in annual water balance between the simulated and observed values is 2.08%. The preliminary calibration results at present indicate that

(1) the simulated total amount of sediment loads at various locations match the observed values within a factor of 1.5 for five storms that occurred in 1993-94.

(2) the pattern of simulated channel bed (cross-sectional profile) changes due to deposition and/or erosion does not match the observed data at some locations.

(3) the simulated annual releases of ^{137}Cs to off-site locations match data within a factor of 2 for 1990-94.

CONCLUSIONS

The comprehensive modeling approach can provide a valuable tool for decision makers to quantitatively analyze (1) sediment erosion, deposition, and transport; (2) exposure risk related to radionuclides in contaminated sediment; and (3) various management strategies. This approach to modeling can, for example, assist engineers and managers wherever industries have left a legacy of widespread contaminated sediments.

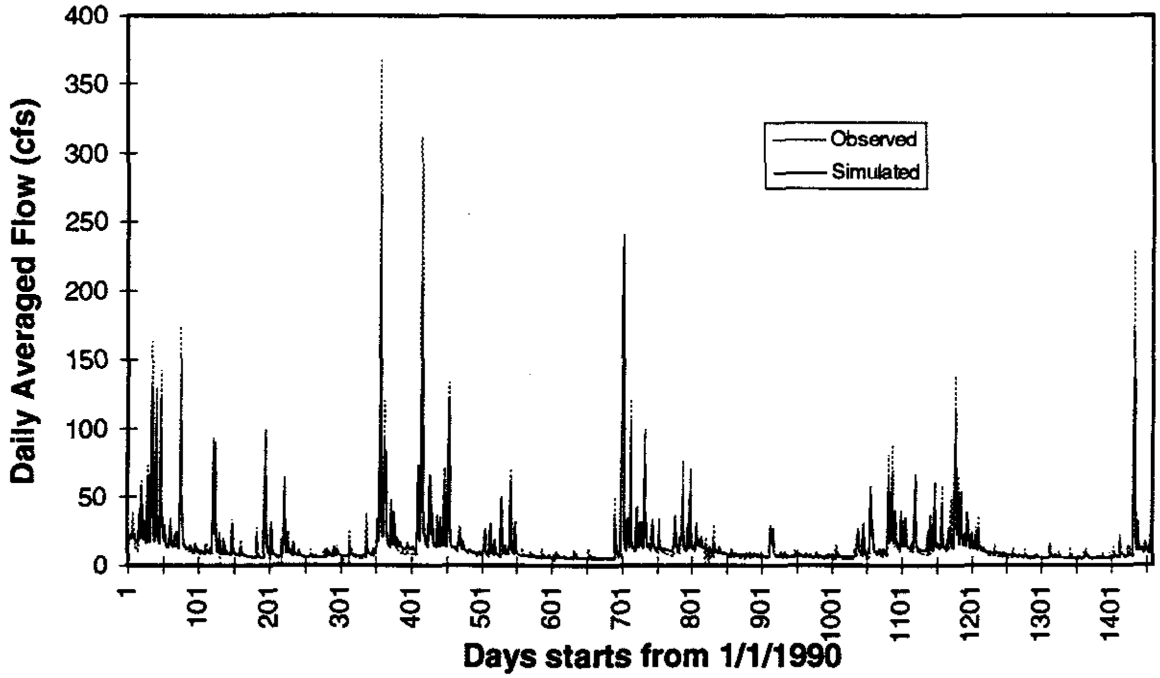

Figure 4. Simulated vs. Observed Flow at White Oak Creek Dam

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HAS THE US SEDIMENT POLLUTION PROBLEM BEEN SOLVED?

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Introduction

The solution to sediment pollution problems is simple: control erosion. Controlling all soil erosion is probably not possible and would effect significant ecosystem changes. Conservation farming practices significantly reduce amounts of sediment produced, but the sediment that is produced is of smaller particle size that is an efficient carrier of some chemicals. Additionally, some sources of sediment are not easily controlled, such as classic gullies and streambank erosion. These are often beyond the capabilities or control of individual land users to fix. Western parts of the country also experience high rates of "geologic" erosion, on lands that are not cultivated or disturbed by human activities. The Badlands of South Dakota are an example of very high natural, geologic, or background erosion rates.

The mental linkage of sediment damages to erosion processes is fundamental to any plans formulated to protect ecosystems. Published literature, as well as resource protection plans, use a variety of terms with ambiguity, such as *soil loss, erosion, sediment, siltation, sediment production, sediment yield,* and *sediment delivery.* The solution to the confusion is to provide both sides of the equation: when *sediment* is reported, then the reader should also have a sense of the magnitude and distribution of erosion processes that produced it.

Statement of US Sedimentation Problem

- **Sediment continues to be the greatest pollutant of waters of the US by volume.**

The presence of sediment in suspension causes abrasion of turbines and delicate plant and animal tissues. It takes up space and thereby depletes usable water volume. Sediment covers spawning areas, coats aquatic plants and floodplain crops and vegetation, and changes the quality of covered topsoil.

The USEPA concluded in its "Final Report to Congress on Section 319 of the Clean Water Act (1989)" (USEPA, 1992) that:

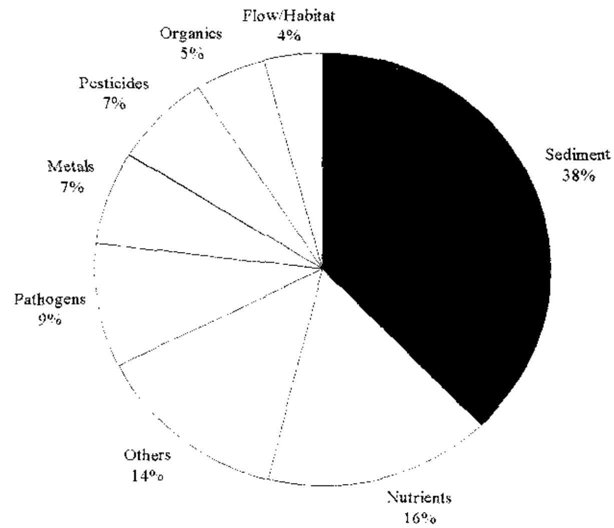
- o *Agriculture continues to be the single largest contributor to nonpoint source problems in the nation. It is the leading source of impacts to rivers, lakes, and wetlands.*

- o *Siltation and nutrients are the pollutants responsible for most of the nonpoint source impacts to the nation's surface waters. Rivers, lakes, estuaries, and wetlands are all affected primarily by one of these two pollutants.*

According to the same report, agriculture is the nation's largest contributor to nonpoint source pollution, with 41% of all nonpoint source pollution attributed by states to this source. The 305(b) report of 1988 also showed that agriculture is the leading source of water pollution in the United States, even when point source impacts are included in the analysis. Non-irrigated crop production and livestock are the primary contributors and are highest in the Midwest. Range land and irrigated cropland are significant sources of pollution in Western states.

In its 1992 Water Quality Inventory Report to Congress, USEPA indicates that sediment affects 45% of over 220,000 impaired stream miles in the states reporting causes of pollution (USEPA, 1994). The same report indicates that agriculture affects 72% of impaired river miles.

Figure 1. Pollutants Impacting Use Support to Rivers (33 States Reporting). Source: USEPA, 1992



The National Academy of Sciences states that agriculture contributes 64% of all pollution to rivers, and sediment comprises 47% of all pollutants in rivers (National Academy of Sciences, 1993).

Sediment is the major pollutant affecting rivers and streams in the country, as shown in Figure 1, with the greatest state share of the sediment problem in Missouri (USEPA, 1992).

US Erosion Rates

- **Sheet and rill erosion rates have decreased significantly for the period 1982 through 1992.**

About one billion tons of soil have been saved due to soil conservation plans implemented on highly erodible land (HEL) and the Conservation Reserve Program (CRP) under the provisions of the Food Security Act of 1989 (USDA, 1994). The changes in the landscape are visible and striking and represent a large source of sediment and attached chemicals that is now being held in place.

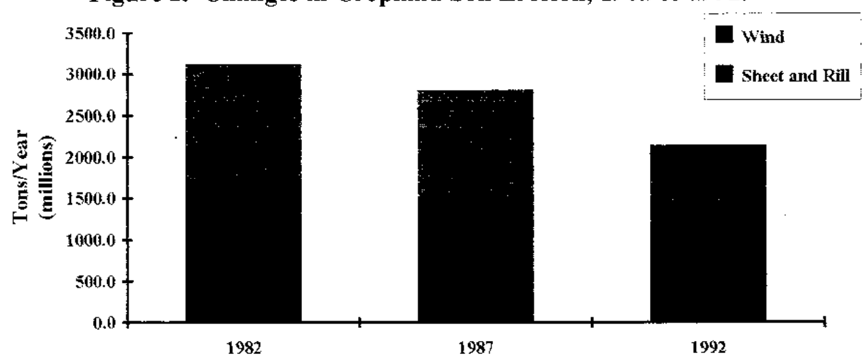
The Conservation Technology Information Center collected information on the adoption of conservation tillage during the period 1982 to 1988. These surveys showed increases in the use of conservation tillage practices as follows: Northeast, from 18 to 42%; Midwest, from 34 to 42%; Great Plains, from 10 to 23%. These areas correspond to the USGS-measured decreases in suspended sediment yields.

Figure 2 shows that cropland erosion has decreased by about one billion tons or about 31% for the ten-year period, 1982 through 1992. The decrease in erosion is attributable to conversion of cropland for less erosive uses, such as (CRP), and an overall increase in the use of conservation tillage methods.

Figures 3 and 4 show changes in cropland acreage, which amounts to about a 9 percent reduction for the 10 year period. Most of these acres became CRP land and other rural land, as shown in Figure 4. Through the provisions of the Conservation Reserve Program, permanent vegetative cover is maintained, which dramatically reduces soil erosion rates.

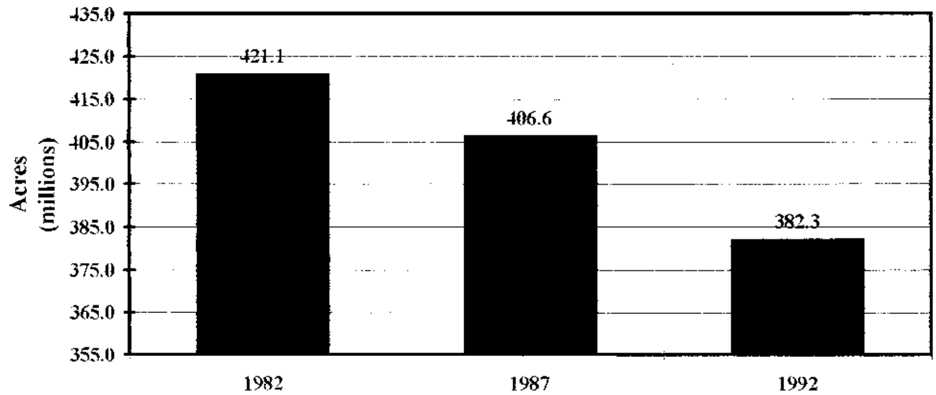
The Natural Resources Inventory (NRI) data, however, only describe the magnitudes of wind erosion and sheet and rill forms of water erosion. Gully erosion and streambank erosion are not included. Ephemeral gully erosion on cropland is essentially eliminated on CRP lands, which has been documented by plot studies at rates as high as 250 tons per acre. All forms of upland erosion are reduced on croplands under conservation tillage management or those enrolled as CRP land.

Figure 2. Changes in Cropland Soil Erosion, 1982 to 1992.



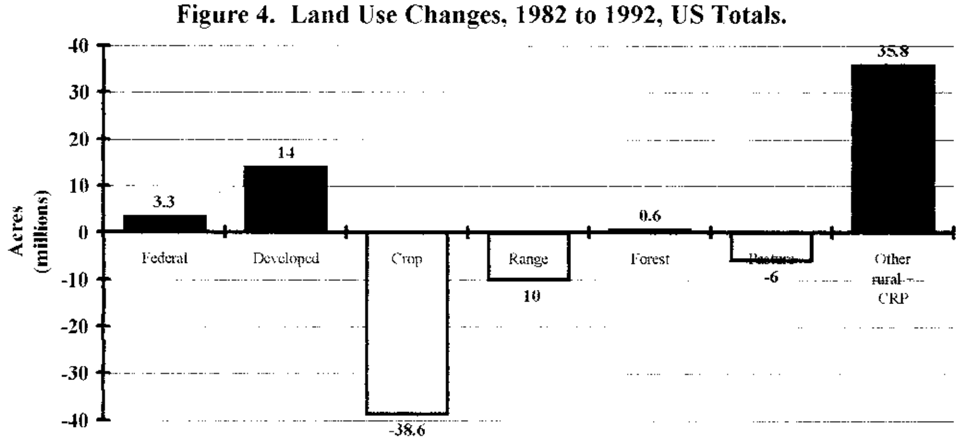
Source: 1992 National Resources Inventory

Figure 3. Change in Cropland Acreage, 1982 to 1992, US Totals.



Source: 1992 National Resources Inventory

Figure 4. Land Use Changes, 1982 to 1992, US Totals.



Source: 1992 National Resources Inventory

USGS Sediment Measurements

- **Overall, suspended sediment loads have decreased in the US for the period 1980 through 1989.**

Table 1 shows the changes in suspended sediment yield in tons/square mile/year and annual percent changes during the 1980 to 1989 time period (USGS, 1993), for which the USGS analyzed suspended sediment data collected at 324 stations and concluded the following:

- Highest suspended sediment concentrations were in the west-central part of US.
- Average concentrations were in the 100 to 500 mg/l range.
- Highest concentrations of sediment were recorded in drainage areas with high percentage of range and agricultural land (Alexander, written communication, 1994)(SCS, 1989).
- Stations with downward trends in concentrations are greater than those with increasing concentrations.
- Steepest downward trends in sediment concentrations were in areas dominated by range land and agricultural land, in areas where increased local, state, and federal soil conservation efforts were planned and implemented.
- Sheet and rill erosion decreased by 13 percent on rural land between 1982 and 1987 (SCS, 1989).

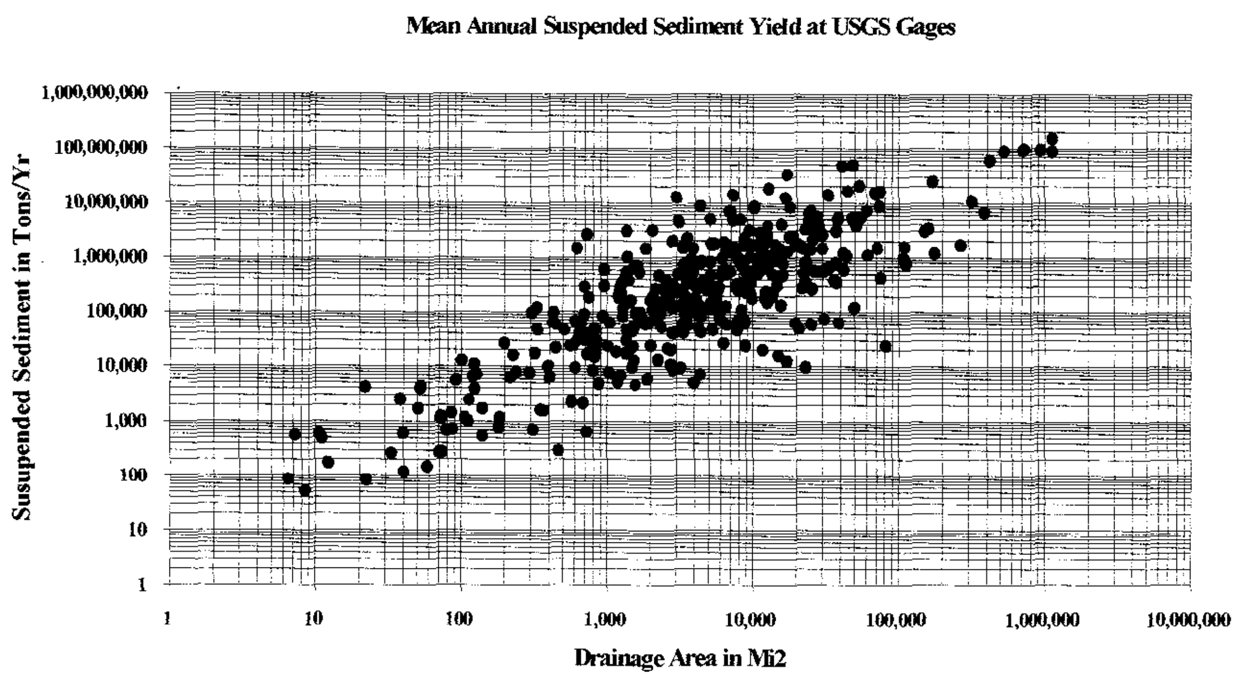
Table 1. Change in Yield of Suspended Sediments in the United States, 1980--1989

Water Resources Region	Yield in tons per square mile per year	Percentage change per year
North Atlantic	32	-0.4
South Atlantic-Gulf	20	+0.2
Great Lakes	36	+0.5
Ohio-Tennessee	85	-1.3
Upper Mississippi	102	-1.3
Lower Mississippi	111	-1.2
Souris-Red-Rainy	4	+1.2
Missouri	45	-0.2
Arkansas-White-Red	31	-0.7
Texas-Gulf-Rio Grande	15	-0.6
Colorado	92	-0.8
Great Basin	21	-0.2
Pacific Northwest	40	-0.1
California	21	-0.6

Source: National Water Summary 1990-91, USGS Water Supply Paper 2400, 1993.

Figure 5 displays the mean annual suspended sediment yield in tons for the period 1990 through 1991. The data show a good correlation between sediment yield and drainage area.

Figure 5. Mean Annual Suspended Sediment Yield at USGS Gages by Drainage Area, in Tons/Yr.



Reservoir Sedimentation Surveys

- **Reservoir sediment surveys show increasing sedimentation rates for the period 1970 through 1985, but surveys are limited for the last ten years.**

It has been estimated that "about 880 million tons of agricultural soils are deposited into American reservoirs and aquatic systems each year" (Pimentel, et. al., 1995).

Based on over 4,000 sediment survey records, sediment deposition rates are increasing (Steffen, 1994). The rate of accumulation in reservoirs in the United States averaged about 0.11 acre-feet per square mile per year (acre-feet/mi^2/year) prior to 1930. One acre-foot is equal to a prism of sediment 1 foot thick over one acre, or 43,560 cubic feet. From 1930 to 1950, this rate almost doubled to 0.20 acre-feet/mi^2/year. The rate for the 1970 to 1985 period is 0.66 acre-feet/mi^2/year, which is six times the pre-1930's rate (Table 2 and Figures 6 and 7).

Figure 6. Number of Surveyed Reservoirs by Drainage Area Class

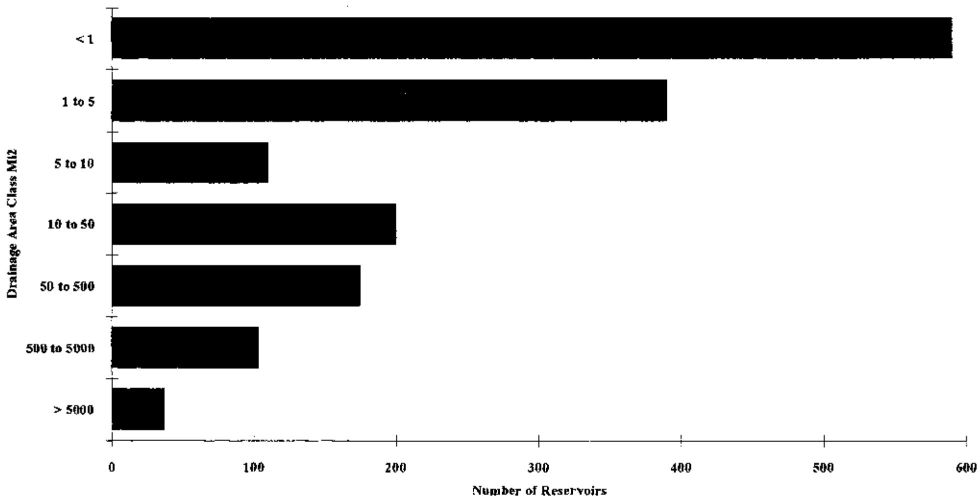


Table 1 showed changes in suspended sediment loads measured at USGS gages, with most water resources regions showing decreases of from 1 to 12 percent for the period 1980 through 1989. Three regions, however, showed increased sediment loads of from 2 to 12 percent for the same period. Direct comparison of these measured sediment loads to the changes in cropland erosion shown in Figure 2 is not possible since rates of erosion are not equal to the amount of sediment yielded from that erosion. This is due to sediment entrainment in fields, along drainageways, and in water bodies in watersheds.

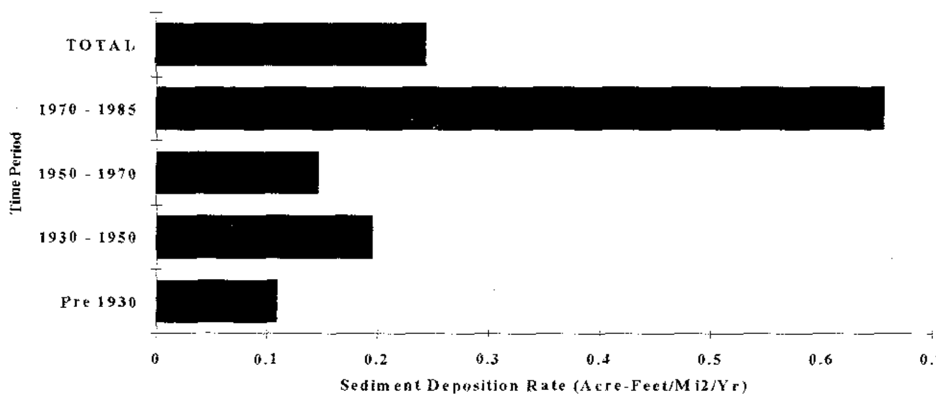
Table 2. Reservoir Sediment Deposition Rates by Time Periods.

Time Period	Sediment Deposition Rates		Number of Reservoir Surveys
	(ac-ft/yr)	(ac-ft/mi^2/yr)	
Pre 1930	15,001	0.109	19
1930 - 1950	181,624	0.196	871
1950 - 1970	201,096	0.147	2,257
1970 - 1985	191,613	0.657	994
TOTAL	459,154	0.244	4,141

The dramatic increase in the unit-area rate of sediment production during the 1970 through 1985 time period can be attributed to the rapid adoption of soybeans and farm policies that promoted maximum agricultural production (Figure 7). The continuation of these rates, or increases or decreases, is largely unknown due to the sparse amount of reservoir sediment survey data since 1985.

Surveys of sediment accumulations in reservoirs in the US have declined significantly since the early 1980's. Increased labor cost is likely one of the main reasons that fewer surveys are performed. Advanced technology such as global positioning systems linked with modern fathometers and computers is available to perform surveys faster, more efficiently, and more accurately, but these systems are not yet in widespread use.

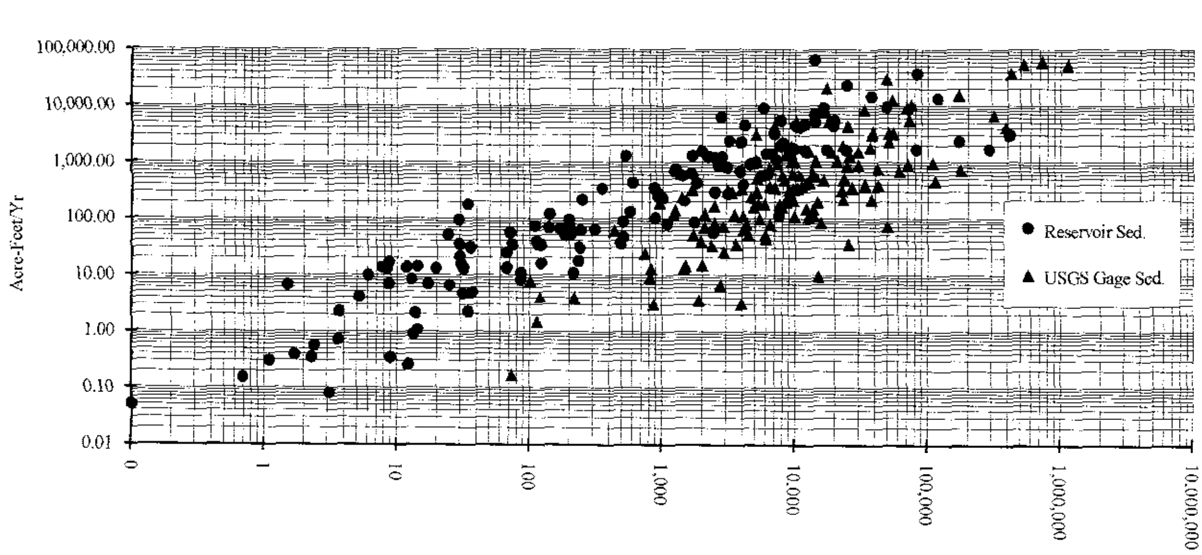
Figure 7. Reservoir Sedimentation Rates by Time Period in Acre-Feet per Square Mile per Year.



Sediment Measurements Compared: USGS Gages and Reservoir Surveys

Figure 8 shows that, in general, reservoir sedimentation rates have been at higher rates than for sediment loads measured at USGS gage stations. The reasons for this include (1) the reservoir sedimentation survey data are older than the USGS gage data, and (2) reservoirs trap a high percentage of all of the sediment that is transported into them, including bedload and suspended load. Note also that reservoir sediment accumulation rates are available for much smaller drainage areas.

Figure 8. Reservoir Sediment Deposition Rates and USGS Gage Suspended Sediment Loads



Conclusions

- Sheet and rill erosion rates on agricultural lands have decreased significantly for the period 1982 through 1992 due to increased adoption of conservation tillage methods, increased soil erosion protection afforded by the Food Security Act of 1989, and land use conversions. Inventories do not provide information on changes in rates of other erosion (streambank, gully, etc.).
- Suspended sediment loads have decreased for the period 1980 through 1989, according to USGS gage measurements.
- Reservoir sediment surveys show a dramatic increase in sedimentation rates for the period 1970 through 1985. Sediment survey records since the early 1980's are sparse, however, and do not provide a clear picture of the magnitude of current sedimentation rates.

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CHEMICAL QUALITY OF OVERBANK SEDIMENT DEPOSITED BY THE 1993 FLOODS AND STREAMBED SEDIMENT IN MAJOR STREAMS AT SELECTED SITES IN EASTERN NEBRASKA

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ABSTRACT: The chemical quality of overbank sediment deposited by the 1993 floods downstream of three potential contamination sources in eastern Nebraska was examined in 1994. The chemical quality of streambed sediment deposited during periods of nonflood discharge also was examined at 10 sites on 9 major streams in eastern Nebraska in 1994. The sediment samples were analyzed for nutrients, total carbon, trace metals, industrial organic compounds, polychlorinated biphenols, total recoverable petroleum hydrocarbons, pesticides, and grain size.

The overbank-sediment deposits deposited during the 1993 floods contained slightly larger concentrations of nearly all analyzed constituents than did the streambed-sediment samples collected nearby. Organic nitrogen was the dominant nutrient in both the overbank and streambed samples with median concentrations of 900 and 600 milligrams per kilogram, respectively. Sediment from one overbank site, located near an agricultural-chemical storage facility that had been flooded, contained large concentrations of herbicides and trace amounts of several semivolatile organic compounds.

Moderate to large concentrations of ammonium, organic nitrogen, and phosphorus were present in streambed-sediment samples from major streams in the eastern half of Nebraska and appeared to be associated with clay-sized particles. The streambed-sediment samples contained no detectable concentrations of semivolatile organic compounds. Four samples contained trace amounts of polychlorinated biphenols and six samples contained total recoverable petroleum hydrocarbons. Organochlorine pesticides were detected in trace amounts in 80 percent of the streambed-sediment samples. Triazine and/or other commonly-used herbicides were present in 65 percent of the streambed-sediment samples. All contaminants appeared to be associated with finer textured sediments.

INTRODUCTION

The floods of 1993 caused considerable damage to the southern and eastern part of Nebraska. Levees were broken, topsoil from valuable farmland was frequently eroded away or covered with thick layers of sand and silt, bridges were washed out, and local landfills and waste treatment lagoons were inundated. It has been hypothesized that sediments deposited in the summer of 1993 contained elevated concentrations of nutrients, trace metals, industrial organic compounds, petroleum products, and pesticides because of increased surface runoff and flooding of landfills and waste impoundments.

Currently, little is known about the quality of flood-deposited sediment along the major streams in Nebraska. Furthermore, very little sediment-quality data during low-flow conditions exist for these streams and rivers to compare with flood-deposited sediment-quality data. Therefore, two questions are raised. First, are there detectable concentrations of potentially harmful constituents in flood-deposited sediments, especially in areas downstream of flooded landfills, sewage treatment plants, and industrial waste impoundments? Second, what is the quality of stream sediment being deposited under nonflood discharges in the major streams and rivers in eastern Nebraska and how do these sediments compare to the flood-deposited sediments?

The purpose of this study was to determine the quality of 1993 flood-deposited sediments at selected sites downstream of potential contamination sources and to determine the baseline quality of stream sediment in major drainage basins across the eastern half of the State. Specific objectives are: (1) to determine if overbank sediments deposited by the 1993 floods downstream of potential sources of contamination had elevated concentrations of selected nutrients, trace metals, pesticides, and/or industrial organic compounds compared to streambed material from the same streams deposited during periods of nonflood discharge, and (2) to determine the chemical quality of streambed sediment deposited during periods of nonflood discharge from sites on ten major streams that drain the eastern half of Nebraska. This abstract is an interim summary and interpretation of data collected during the fall of 1994.

APPROACH

To accomplish the first objective, three communities that were flooded in 1993 were identified that represented these potential sources of contamination: a community landfill and waste-treatment lagoon, an agricultural-chemical storage facility, and an industrial waste disposal area (fig. 1). Sediments downstream of these sites would be expected to have an increased likelihood of contamination relative to stream reaches that are without potential contamination sources.

Nine sites downstream of the three potential contamination sources (3 sites near each community) were selected for collection of overbank sediment deposited during the 1993 floods. These sites were above the high-water levels of the spring floods of 1994 and were identified by the presence of large quantities of flood debris. The actual sediment-collection sites were usually depressions or traps, where finer sediments were deposited as the floodwater receded. Although the sites were selected because they appeared to be isolated from the likelihood of additional sediment contamination following the 1993 floods, natural processes may have altered the original concentrations of contaminants in the overbank sediments between the time they were deposited and sampled.

Sediment samples were collected to a depth of about 35 centimeters using hand-held tools. The top 2-4 centimeters of each overbank-sediment sample, which might have been contaminated by air-born particulates (Goolsby and others, 1993), was removed using a polytetrafluoroethylene spatula. The sediment samples were analyzed for selected nutrients, total carbon, trace metals, organic industrial compounds, total PCBs (polychlorinated biphenols), TRPHs (total recoverable petroleum hydrocarbons), pesticides, and grain size. Streambed-sediment samples also were collected within a few miles downstream of the three potential contamination sites on the Missouri River, Weeping Water Creek, and the Big Blue River in the same manner as described below.

To accomplish the second objective, nine streambed-sediment collection sites were identified on the eight major streams that drain the eastern half of Nebraska (fig. 1). The Missouri River near Rulo also was added to this list in addition to its use as a comparison site to overbank-sediment samples because the sediment quality of the river was believed to be more representative of conditions throughout the basin above this point than of the localized area of potential contamination. All but two of the streambed-sediment collection sites (the Platte River near Wood River and the Missouri River near Rulo) were located near the mouth of the stream so that the sediment-quality data would be representative of the entire basin. Fine-textured sediment, which tends to collect contaminants through sorption, is more likely to be deposited in the downstream parts of the basins, where the stream gradient is relatively flat. The sites also were relatively close to stream-gaging stations operated by the U.S. Geological Survey, so that stream sediment concentrations could be related to stream discharges. Sampling was done at least 0.4 kilometers upstream of any bridges to avoid nonrepresentative particulate contamination.

Sediment samples were collected at the 12 sites (9 baseline streams and 3 streams near the overbank collection sites) twice during low-flow conditions. Samples were collected at each site during the fall of 1994. A transect across each of the streams or rivers was defined and samples were collected at a minimum of 10 equally-spaced intervals using a hand-operated, 60-centimeter, stainless-steel sediment corer with both stainless steel and plastic core-barrel liners and head pieces for the collection of inorganic and organic constituents, respectively. The samples collected along the ten transects were composited. Additionally, a single streambed-sediment sample was collected at a point in each transect where the largest concentration of fine sediment was found. This sample was not composited and, because of the tendency of various constituents to sorb onto fines, was referred to as the "worst-case" sample. The worst-case samples were analyzed for the same constituents as the composited streambed and overbank-sediment samples.

Cores collected for nutrient and organic analyses were stored at 4 degrees Celsius. Within 3-5 hours of collection, sediment samples collected for nutrient, trace metal, total carbon, triazine herbicide, and grain-size analyses were homogenized using an uncoated, stainless-steel industrial food processor. An uncoated food processor was used because the analytical detection limit for the trace metals was in the milligram-per-kilogram range and most trace metals of interest would not be influenced. Sediment samples collected for semivolatile industrial compounds and for total recoverable petroleum hydrocarbons analyses were not homogenized.

Total recoverable petroleum hydrocarbons were analyzed by Midwest Laboratories in Omaha, Nebraska.

Triazine and other commonly used herbicides were analyzed by the U.S. Geological Survey's Organic Research Group in Lawrence, Kansas, using a method described by Thurman and others (1990). All remaining analyses were performed by the U.S. Geological Survey's National Water Quality Laboratory in Arvada, Colorado, using methods described by Fishman and Friedman (1989), Wershaw and others (1987), Lichte and others (1987), and Foreman and others (1995). Eleven percent of all samples submitted for analyses were quality assurance samples. These samples consisted of blanks, duplicates, and spikes of known concentrations.

RESULTS AND DISCUSSION

Overbank and Nearby Streambed-Sediment Analyses: Generally, the overbank- and nearby streambed-sediment samples did not contain large concentrations of most targeted constituents although trace concentrations of a number of anthropogenic compounds were present in both types of samples. A statistical summary of the constituents detected in the overbank and nearby streambed-sediment samples in the same area as the overbank samples is presented in table 1. The overbank-sediment samples did tend to contain slightly larger concentrations of most constituents than did the nearby streambed-sediment samples.

Overbank-sediment samples were finer textured than those collected from the streambed. The overbank-sediment samples had median percent weights of clay, silt, and sand of 25, 59, and 3 percent, respectively. The streambed-sediment samples contained median percent weights of clay, silt, and sand of 15, 56, and 28, respectively. Larger concentrations of fines in the overbank-sediment samples were expected because they were deposited at low points on the flood plain as the floodwater receded, with little chance for the sediment to be remobilized later. Also, fines tend to be removed from streambed sediments even at relatively small stream discharges. This abundance of fines in the overbank-sediment samples and the tendency of many constituents to sorb to finer grained materials may partially explain the slightly larger concentrations of most constituents in the overbank-sediment samples.

The overbank-sediment samples contained larger median concentrations of all nutrients except ammonium, which was probably oxidized in the overbank-sediment samples, than did the streambed-sediment samples. Concentrations of organic nitrogen and ammonium were the dominant forms of nitrogen in both the overbank- and streambed-sediment samples. These concentrations were roughly comparable to concentrations observed by Tindall and others (1994), downgradient of a municipal sewage-sludge disposal area in Colorado. This suggests that sewage might be the dominant source of nitrogen in the Nebraska overbank sediments. Larger concentrations of nitrite plus nitrate and of phosphorus in the overbank-sediment samples may reflect the proximity to agricultural lands that are treated with nitrogen and phosphorus fertilizers and, in one case, the proximity to an agricultural-chemical storage facility that was flooded.

Trace metals were present in very small concentrations at most sites in both the overbank- and streambed-sediment samples. Two of the overbank-sediment samples from the community with the flooded agricultural-chemical storage facility contained lead concentrations larger than 200 mg/kg (milligram per kilogram) and one of the sites contained zinc concentrations of 440 mg/kg. The overbank-sediment samples contained slightly larger concentrations of most trace metals than did the streambed-sediment samples. The trace metals arsenic, cadmium, chromium, copper, lead, mercury, and selenium were either not detected or were detected in concentrations near the analytical detection limits of 0.02 to 10 mg/kg.

Semivolatile compounds were detected only in one sediment sample. Trace amounts (200 to 550 μg/kg (milligram per kilogram)) of benzo-b fluoranthene, benzo-k fluoranthene, and pyrene were found in one overbank-sediment sample near the community with the agricultural-chemical storage facility. These compounds are associated with the heavier fraction of petroleum compounds. This was the only overbank site that contained detectable amounts of TRPH (505 mg/kg). None of the nearby streambed-sediment samples collected contained detectable concentrations of either semivolatile compounds or TRPH.

PCBs were detected in overbank-sediment samples near each of the three communities at concentrations near the 1 μg/kg analytical detection limit. PCBs also were present in concentrations near the detection limit in streambed samples near two of the communities.

Organochlorine pesticides, aldrin, DDT, and its derivatives DDD and DDE, were detected in both overbank- and streambed-sediment samples (table 1). Again, concentrations were frequently near the detection limits and the number of compounds detected and their concentrations were generally larger in the overbank-sediment samples than in the streambed samples. The overbank sediment site closest to the agricultural-chemical storage facility contained the most detected pesticides and the largest concentrations of those pesticides relative to the other overbank sites. Specifically, this site contained 120 µg/kg of chlordane, which was found near the 1 µg/kg detection limit at the other sampling sites. All samples from the overbank sites had very small, but detectable concentrations of DDT and its derivatives. These compounds also were frequently detected in the streambed-sediment samples collected near the overbank sites.

Triazine and other commonly used herbicides were detected in all overbank- and nearby streambed-sediment samples. An overbank-sediment sample collected near the community with the agricultural-chemical storage facility contained the largest herbicide concentrations including 819 µg/kg alachlor, 576 µg/kg cyanazine, 270 µg/kg atrazine, and 186 µg/kg metolachlor in addition to smaller concentrations of simazine, propazine, propachlor, deethylatrazine, deisopropylatrazine, and prometryn. Alachlor, atrazine, and metolachlor were present in most of the overbank-sediment samples with median concentrations of 5.8, 3.8, and 2.6 µg/kg, respectively.

<u>**Streambed-Sediment Analyses:**</u> A statistical summary of the constituents detected in samples collected from ten sites (including the Missouri River site) is presented table 2. In nearly all cases, the concentrations of constituents in the worst-case streambed-sediment samples were 2 to 3 times larger than those in the composited streambed-sediment samples.

Concentrations of total carbon and all nutrients except nitrite plus nitrate were detected in all streambed-sediment samples at the ten sites. Organic nitrogen was the dominant nutrient present in the streambed-sediment samples, with concentrations ranging from less than 20 to 1,300 mg/kg, which was similar to concentrations in the overbank-sediment samples. Again, these concentrations suggest sewage as a possible nutrient source. Detectable concentrations of nitrite plus nitrate were found in only five samples. One was a composite sample from the Missouri River and four were worst-case samples from the Elkhorn, Big Blue, Little Nemaha, and Loup Rivers. Streams that had sediment with the largest concentrations of nutrients and total carbon were the Big and Little Nemaha Rivers, the Big Blue River, and the Platte River near Louisville. Sediment samples from these sites also contained larger percentages of clay-sized particles than from the other sites.

Concentrations of arsenic, chromium, copper, lead, and mercury near the analytical detection limits of 0.02 to 10 mg/kg were present in many of the streambed-sediment samples. As with nutrients and total carbon, these constituents tended to be present in slightly larger concentrations at streambed-sediment sampling sites on the Big and Little Nemaha Rivers, the Big Blue River, and the Platte River near Louisville. Again the worst-case samples usually contained slightly larger concentrations of these constituents.

Semivolatile organic compounds were not detected in any streambed-sediment samples from the ten sites. TRPHs were detected in streambed-sediment samples from both the composited and worst-case samples from the Big Blue River, Big Nemaha River, and the Platte River near Louisville in concentrations as large as 98 mg/kg. PCBs were present near the analytical detection limit in composite and worst-case samples from streambed-sediment collection sites on the Missouri, Big Blue, and Big Nemaha Rivers.

The organochlorine pesticides aldrin, DDT and its derivatives DDD and DDE, and heptachlor were near the analytical detection limits in streambed-sediment samples. Trace amounts of DDE were detected in 8 of the 10 worst-case and 5 of the 10 composited streambed-sediment samples. Worst-case samples from the Platte River near Louisville and the Missouri River near Rulo contained DDT and both of its derivatives. The largest concentration of DDT was 0.9 mg/kg and was in the worst-case sample from the Platte River near Louisville.

The herbicides alachlor, atrazine, ametryn, and metolachlor were detected in about 30 percent of the composited streambed-sediment samples and in about 65 percent of the worst-case samples. Median concentrations for these herbicides ranged from 1.0 to 1.4 µg/kg in the worst-case samples. The constituents with the largest concentrations were alachlor and atrazine, with maximum values of 25.7 and 11.6 µg/kg, respectively. The largest concentrations of these herbicides were found in sediment samples from the Big Nemaha, Little Nemaha, and Big Blue Rivers; these also were the sites with the largest percentages of clay-sized particles. Curiously, the largest concentration of atrazine was found in the composited streambed-sediment sample from the Little Nemaha River; however, the concentration of atrazine in the worst-case streambed-sediment sample was just slightly lower than the concentration in the composite sample. The Platte River near Wood River was the only site in which neither the composite nor the worst-case sediment samples contained detectable concentrations of herbicides. Samples from this site also contained the smallest percentage of clay-sized particles of all of the sites.

More than 25 million pounds of herbicides (active ingredients) are applied annually to croplands in Nebraska (S.T. Kamble, University of Nebraska, oral commun., 1995) and as much as 3 percent of the amounts applied are believed to be transported into streams in the Midwest through surface runoff, soil erosion (Goolsby and others, 1993), and precipitation (Goolsby and Battaglin, 1993). Therefore, a significant mass of herbicides may be associated with streambed sediment and additions may be made to this mass annually.

SUMMARY AND CONCLUSIONS

Overbank sediment deposited during the 1993 floods at three communities in eastern Nebraska generally appeared to contain slightly larger concentrations of certain constituents of concern than did streambed-sediment samples from nearby streams and from other major streams in the eastern half of the State. One overbank-sediment sample, which was collected within several hundred meters of a possible contamination source, contained concentrations of contaminants that were much larger than the streambed-sediment samples. However, results suggest that much of the overbank sediment deposited by the 1993 floods probably does not contain more than trace-level concentrations of contaminants.

Based on the results of streambed-sediment samples collected from the ten principal streams in the eastern half of the State, which includes the Missouri River near Rulo, moderate to large concentrations of ammonium, organic nitrogen, and phosphorus were associated with the finer fraction of streambed sediment. Larger organic nitrogen and ammonium concentrations found in some streambed-sediment samples may have resulted from either the flooding of sewage lagoons or sewage disposal in the streams. Trace metals were present in small concentrations in most of the sediment samples.

Semivolatile organic compounds were not commonly detected in streambed-sediment samples from the ten sites. PCBs in streambed-sediment samples from four streams were at concentrations near the analytical detection limit. This scarcity of detections is probably due to the general lack of source materials within the basins. The presence of TRPHs in the streambed sediment is more common.

Organochlorine pesticides or their metabolites were detected in 80 percent of the streambed-sediment samples and in 100 percent of the overbank-sediment samples in low concentrations. These pesticides are not in use today and their presence in streambed sediment is most likely the result of soil erosion from agricultural and other areas where these pesticides were used in the past. The presence of these pesticides in most of the stream basins is an indication of the previous widespread use of these products.

Triazine and other commonly used herbicides were detected in 65 percent of the streambed-sediment samples from the major streams. Thus, a considerable mass of herbicides associated with streambed sediments apparently exists in most larger stream basins and significant amounts of herbicides may be added to this mass each year. Currently, it is unknown how much of this herbicide-sediment mass is static and how much simply passes through the streams and rivers of the State annually.

Finer textured sediments tend to serve as a sink for nutrients, trace metals, and organic compounds. It is presently unclear if streams such as the Big and Little Nemaha Rivers, the Platte River near Louisville, and the Big Blue River serve as conduits for larger quantities of these elements and compounds than other streams, or if the abundance of clay-sized particles in these streambeds is merely more efficient at capturing the contaminants than the coarser sediment that characterizes the other sampled streambeds.

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Table 1.--Statistical summary of nutrient, trace metal, total recoverable petroleum hydrocarbons, PCBs, and selected pesticide data for overbank and streambed-sediment samples from sites near three flooded communities and adjacent streams in eastern Nebraska, fall 1994

[Upper number is the overbank value, lower number is the adjacent streambed value; concentrations are in milligrams per kilogram except as indicated; µg/kg, micrograms per kilogram; <, less than. Other constituents analyzed but not detected were selenium, endosulfan, endrin, hexachlorobenzene, hexachlorobutadiene, lindane, methoxychlor, mirex, perthane, and toxaphene.]

Constituent	Number of samples	Number of detections	Concentration: Minimum	25th Percentile	Median	75th Percentile	Maximum
Ammonium, as N	9	9	3	3.8	4.8	7.8	13
	6	6	1.8	10.2	25	50	56.0
Organic nitrogen and	9	9	430	765	900	1,200	2,000
ammonium, as N	6	5	<20	122	600	795	990
Nitrite plus Nitrate, as N	9	8	<2	4	9	18	37
	6	2	<2	<2	<2	2	3
Phosphorus	9	9	360	425	600	830	2,200
	6	6	110	140	396	450	570
Carbon, total	9	9	9.005	11,000	12,000	19,500	33,0000
	6	6	2.700	3,150	8,600	15,500	17,000
Arsenic	9	9	2	2	3	5	6
	6	6	2	2	2	4	4
Aluminum	9	9	6,300	8,300	9,400	13,000	17,000
	6	6	2,700	3,200	6,500	9,000	9,900
Bromine	9	9	230	270	300	440	490
	6	4	<10	<10	220	270	280
Cadmium	9	1	<1	<1	<1	<1	1
Chromium	9	9	9	9	10	20	20
	6	6	3	4	8	10	10
Cobalt	9	4	<5	<5	<5	10	20
	6	1	<5	<5	<5	<5	<5

Table 1.--Statistical summary of nutrient, trace metal, total recoverable petroleum hydrocarbons, PCBs, and selected pesticide data for overbank and streambed-sediment samples from sites near three flooded communities and adjacent streams in eastern Nebraska, fall 1994--Continued

Constituent	Number of samples	Number of detections	Concentration				
			Minimum	25th Percentile	Median	75th Percentile	Maximum
Copper	9	9	9	10	14	20	27
	6	6	1	2	8	11	12
Iron	9	9	8,700	9,200	11,000	19,500	98,000
	6	6	3,800	3,800	8,200	11,000	11,000
Lead	9	8	<10	10	10	20	40
	6	4	<10	<10	10	10	210
Manganese	9	9	320	360	460	670	860
	6	6	120	150	420	720	880
	9	9	.02	.02	.03	.04	.05
Mercury	6	4	<.01	<.01	.02	.02	.02
Strontium	9	9	24	26	30	45	70
	6	6	10	14	22	31	49
Zinc	9	9	37	42	61	150	440
	6	6	9	13	34	41	43
PCBs, total	9	7	<1	<1	1	1	3
in µg/kg	6	2	<1	<1	<1	2	3
TRPH	9	1	<20	<20	<20	<20	505
	6	0	<20	<20	<20	<20	<20
Aldrin,	9	2	<.1	<.1	<.1	<.1	.8
in µg/kg	6	1	<.1	<.1	<.1	<.1	.1
Chlordane,	9	6	<1	<1	<1	1.5	120
in µg/kg	6	0	<1	<1	<1	<1	<1
DDD,	9	8	<.1	.1	.2	.4	.6
in µg/kg	6	2	<.1	<.1	<.1	.2	.3
DDE,	9	8	<.1	.1	.2	.4	.6
in µg/kg	6	4	<.1	<.1	.2	.2	.2
DDT,	9	9	<.1	.2	.2	.3	2.8
in µg/kg	6	1	<.1	<.1	<.1	<.1	.2
Dieldrin,	9	8	<.4	1	1	2	38
in µg/kg	6	0	<.4	<.4	<.4	<.4	<.4
Heptachlor,	9	1	<.1	<.1	<.1	<.1	.7
in µg/kg	6	0	<.1	<.1	<.1	<.1	<.1
Heptachlor epoxide,	9	2	<.1	<.1	<.1	<.1	.8
in µg/kg	6		<.1	<.1	<.1	<.1	<.1
Alachlor,	9	8	<.5	1.2	5.8	16.4	819
in µg/kg	6	2	<.5	<.5	<.5	1.7	3.5
Atrazine,	9	9	1.9	3.0	3.8	24	270
in µg/kg	6	6	<.5	<.5	0.2	1.9	2.1
Ametryn,	9	1	<.5	<.5	<.5	<.5	1.2
in µg/kg	6	2	<.5	<.5	<.5	1.2	1.9
Metolachlor,	9	7	<.5	0.2	2.6	4.0	186
in µg/kg	6	2	<.5	<.5	<.5	1.0	1.2
Cyanazine,	9	1	<.5	<.5	<.5	<.5	576
in µg/kg	6	0	<.5	<.5	<.5	<.5	<.5
Cyanazine amide,	9	1	<.5	<.5	<.5	<.5	250
in µg/kg	6	0	<.5	<.5	<.5	<.5	<.5

Table 2.--Statistical summary of nutrient, trace metal, total recoverable petroleum hydrocarbons, PCBs, and selected pesticide data for streambed-sediment samples from 10 streams and rivers in eastern Nebraska, fall 1994

[Upper number is the composited sample value; lower number is the worst-case sample value; concentrations are in milligrams per kilogram except as indicated; <, less than; µg/kg, micrograms er kilogram. Other constituents analyzed but not detected were selenium, dieldrin, endosulfan, endrin, heptachlor epoxide, hexachlor benzene, hexachlorobutadiene, lindane, methoxychlor, mirex, perthane, toxaphene, simazine, propazine, cyanazine, cyanazine amide, propachlor, deethylatrazine, deisopropylatrazine, metribuzin, prometryn, prometon, terbutryn, and acetochlor.]

Constituent	Number of samples	Number of detections	Concentration				
			Minimum	25th Percentile	Median	75th Percentile	Maximum
Ammonium as N	10	10	1.8	5.20	9.35	54.5	110
	10	10	13.0	27.8	46.0	91.2	120
Organic nitrogen and	10	7	<20	<20	25.0	855	1,300
ammonium, as N	10	10	330	560	670	1,200	1,200
Nitrite plus nitrate, as N	10	1	<2	<2	<2	<2	3
	10	4	<2	<2	<2	2.5	35
Phosphorus	10	10	52	54.2	165	397	470
	10	10	120	240	320	455	480
Carbon, total	10	10	300	1,600	3,400	11,000	28,000
	10	10	4,100	6,500	8,600	11,000	12,000
Arsenic	10	8	<1	1	2	4	6
	10	10	1	2	4	5	6
Aluminum	10	10	1,500	1,900	2,600	8,400	13,000
	10	10	2,300	3,800	5,400	7,800	14,000
Bromine	10	1	<2	<10	<10	<10	<10
	10	1	<2	<1C	<10	<10	<10
Chromium	10	10	2	2	4	10	10
	10	10	2	5	7	9	10
Cobalt	10	1	<5	<5	<5	<5	10
	10	1	<5	<5	<5	<5	10
Copper	10	10	1	1	2	11	15
	10	10	2	6	8	11	16
Iron	10	10	1,500	1,900	4,000	10,000	13,000
	10	10	600	3,800	9,100	11,000	12,000
Lead	10	4	<0	<10	<10	<10	10
	10	4	<10	<10	<10	<10	10
Manganese	10	10	33	100	120	458	560
	10	10	41	160	460	550	640
Mercury	10	4	<.01	<0.01	<0.01	0.02	0.03
	10	7	<.01	<.01	0.1	.02	0.02
Strontium	10	10	9	10	16	32	46
	10	10	20	23	30	42	63
Zinc	10	10	1	4.0	9.0	42	54
	10	10	7	22	28	44	49
PBCs, total,	10	2	<1	<1	<1	<1	1
in µg/kg	10	2	<1	<1	<1	<1	3
TRPH	10	3	<20	<20	<20	24	79
	10	3	<20	<20	<20	31	98
Aldrin,	10	2	<.1	<.1	<.1	<.1	.2
in µg/kg	10	5	<.1	<.1	<.1	.1	.2
DDD,	10	2	<.1	<.1	<.1	<.1	.2
in µg/kg	10	4	<.1	<.1	<.1	.2	.3

Table 2.--Statistical summary of nutrient, trace metal, total recoverable petroleum hydrocarbons, PCBs, and selected pesticide data for streambed-sediment samples from 10 streams and rivers in eastern Nebraska, fall 1994--Continued

Constituent	Number of samples	Number of detections	Concentration				
			Minimum	25th Percentile	Median	75th Percentile	Maximum
DDE,	10	5	<.1	<.1	<.1	.2	.2
in µg/kg	10	8	<.1	.1	.2	.2	.3
DDT,	10	0	<.1	<.1	<.1	<.1	<.1
in µg/kg	10	2	<.1	<.1	<.1	<.1	.9
Heptachlor,	10	0	<.1	<.1	<.1	<.1	<.1
in µg/kg	10	1	<.1	<.1	<.1	<.1	.2
Alachlor,	10	3	<.5	<.5	<.5	8.6	22.1
in µg/kg	10	7	<.5	<.5	1.2	11.0	25.7
Atrazine,	10	3	<.5	<.5	<.5	1.4	11.6
in µg/kg	10	7	<.5	<.5	1.0	4.7	7.8
Ametryn,	10	3	<.5	<.5	<.5	2.9	4.2
in µg/kg	10	6	<.5	<.5	1.4	3.0	4.4
Metolachlor,	10	3	<.5	<.5	<.5	2.6	5.6
in µg/kg	10	7	<.5	<.5	1.0	2.8	4.5

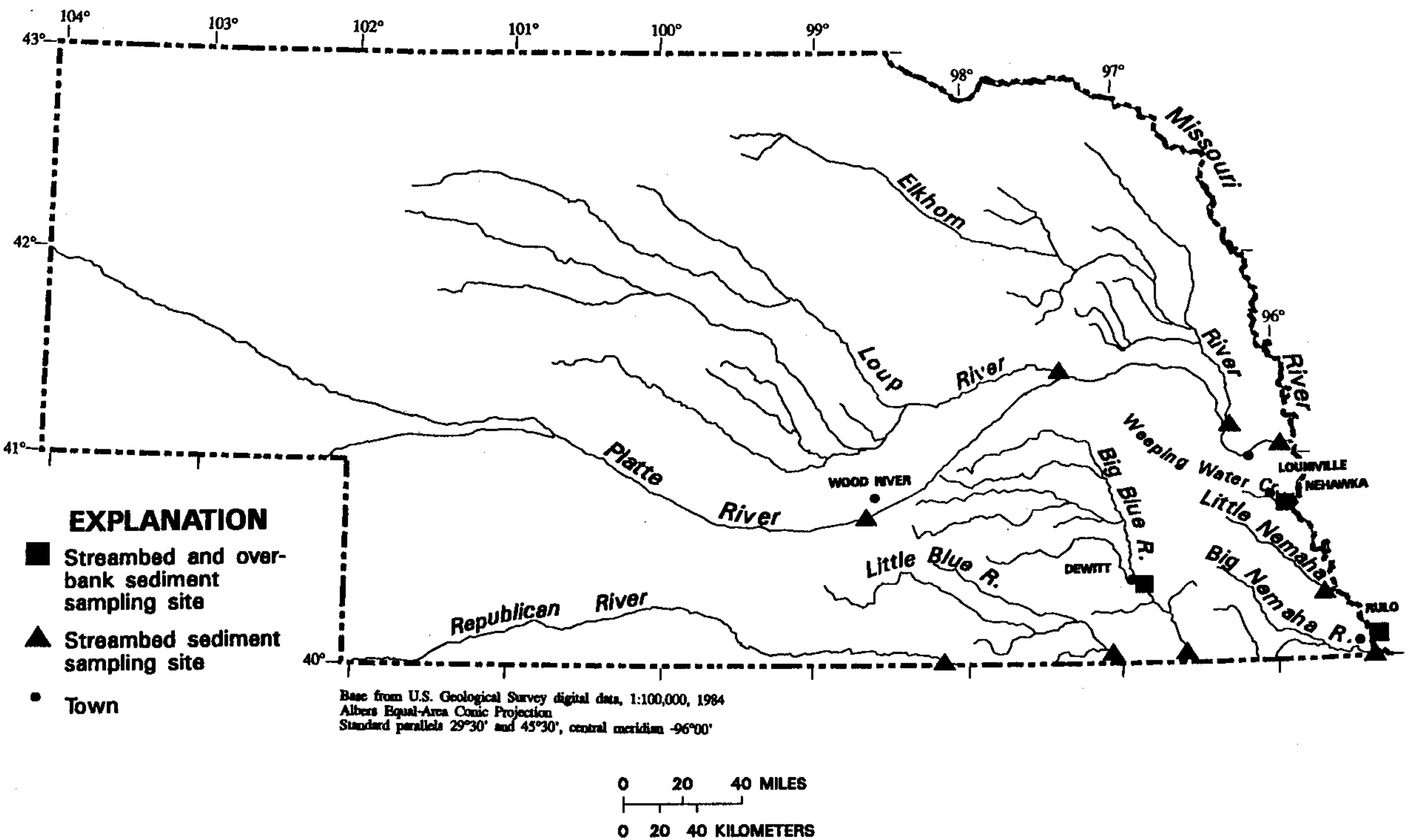


Figure 1. -- Locations of overbank and streambed sediment-quality sampling sites in Nebraska, fall 1994.

AN APPROACH FOR PLANNING AND MANAGING MONITORING ACTIVITIES FOR MAJOR FLOOD EVENTS

By Working Group on Flood Event Water Quality Monitoring, Subcommittee on Water Quality: Mary L. Belefski, U.S. EPA, Washington, D.C., Senior Author; Joanne Kurklin, U.S. Geological Survey, Oklahoma City, OK; Richard Urban, Tennessee Valley Authority, Chattanooga, TN; Jim Yahnke, U.S. Bureau of Reclamation, Denver, CO; Jim Cook, Bureau of Mines, Washington, D.C.

INTRODUCTION

In 1993, the Midwest floods highlighted, among other things, the need for water-quality monitoring during major floods. Although some of the issues in the 1993 floods were specific to the affected area, some general conclusions can be drawn. Water-quality conditions related to major floods have the potential to affect both human and environmental health. Public concerns over water quality that were raised in the 1993 flood are tied to questions such as: "Is the water safe for human contact?"; "Is the water safe to drink?"; and "How will the fish be affected?" Existing routine plans for water-quality monitoring did not address such concerns adequately.

Human health as related to water quality can be directly affected by floods in several ways. Contaminants from both point and non-point sources have the potential to affect public water supplies. Contaminated water at a surface water supply intake can interrupt the function of a water supply system with accompanying public health and related economic consequences. Flood flows outside the channel have the potential to contaminate both public and private ground-water supplies. There are also concerns related to body contact with potentially polluted water in flooded areas.

In addition to its effects on human health, water-borne contamination has the potential to produce environmental damage that may affect endangered species, critical habitats, or agricultural activities. Each of these affects has the potential to produce unforeseen economic impacts that may not be evident to the casual observer.

The Mississippi River Flood of 1993 caused significant changes to the landscape throughout the Midwest and ultimately to the Gulf of Mexico. The flood sent large volumes of fresh water down the Mississippi River during a period of the year normally characterized by lower flows in the Mississippi, thus the timing of the flooding was a critical factor in determining the impact on the marine environment. The higher stream flow in the lower Mississippi River resulted in increased loadings of nutrients and agricultural chemicals, higher-than-normal oceanic surface temperatures, lower-than-normal surface salinities, changes in phytoplankton numbers and species composition, and increases in the area of low-oxygen bottom waters on the Texas-Louisiana shelf. The effects of the fresh water inflow were detected not only in the northern Gulf of Mexico but also at the Florida Keys and along the U.S. East Coast.

In order to respond to human and environmental health issues and concerns raised since the 1993 Midwest Flood, the Subcommittee on Water Quality, Interagency Advisory Committee on Water Data, established the Working Group on Flood Event Water Quality Monitoring (FEWQM), to serve as the principal mechanism for the development of a Federal plan for coordinating water-quality monitoring among Federal, State, Tribal, and local agencies during major floods. The Working Group developed a guidance document which addressed comments received on a draft document, especially those from areas affected by the 1993 Midwest Flood.

Major floods carry large volumes of sediment which can also include large volumes of contaminants, either in a particulate form or adsorbed to sediment particles. The monitoring action plan does not specifically address contaminated sediments or their transport and deposition. However, any water monitoring plan could be adapted to include sediments especially if the planning group determined that the monitoring of sediments was important for specific areas.

Several significant conclusions were drawn from the 1993 experiences. One conclusion was that the lack of an assured funding source for both Federal and State agencies impeded their abilities to sample during the early periods of the flood. Funds made available after the declaration of the emergency or disaster were too late to cover sampling during the early flood phases. As a result there was a concern that high contaminant concentrations that often flushed out during the first stages of a flood were missed completely. A second conclusion was that lack of a coordinated plan could result in duplicate sampling by different agencies, while other sampling opportunities were missed. A third conclusion was that the turnaround time for analytical results, especially those that were related to public health, were too long. A final conclusion was that a coordinated effort was needed for dissemination of water quality information as soon as it became available.

RECOMMENDATIONS

As defined in the final guidance a major flood is one that is likely to prompt a Federal Disaster Declaration and a Federal response. The emergency components of the Federal government respond only after the President declares that an emergency or a major disaster has occurred and the Federal Response Plan (FRP) is activated. A disaster is defined as an event that, in the determination of the President, causes damage of sufficient severity and magnitude to warrant major disaster assistance by the Federal Government to supplement the efforts and available resources of States, Tribal agencies, local governments, and disaster-relief organizations in alleviating the damage, loss, hardship, or suffering caused by the event.

Floods, unlike tornados or earthquakes, can have a slow onslaught. The initial flood may not require Federal assistance. However, the severity of the event may increase over time causing a major flood that warrants a Presidential disaster declaration. The following are the recommendations for each of the four flood periods identified in the final guidance:

- Before any flooding occurs (**pre-flood**), coordination among local, State, Tribal, and Federal emergency planning and water quality decision makers is essential to determine the needs and resources available for water quality monitoring activities during a flood.

- During a flood, **existing** resources at the local, State, and Tribal levels and Federal agencies at the field level are the primary sources of funding for flood monitoring activities.

- During a **major flood** that requires a Presidential Disaster Declaration, and that activates the FRP and the necessary Departments and agencies, coordination needs to occur between the local, State, and Tribal agencies conducting water quality monitoring activities and those Federal Departments and agencies that can assist with the effort.

- The **post-flood** period occurs after the flood waters recede and return to their normal seasonal levels. A post flood analysis and critique is vital to the success of future response efforts.

ACTION PLAN DEVELOPMENT AND IMPLEMENTATION

Activities related to a flood can occur during four different periods (pre-flood, flood, major flood, and post-flood) that affect decisions made at the State, Tribal, local, and Federal levels for coordination, resource availability, and assistance from FEMA. These activities and related decision processes are depicted in the overall action plan in Figures 1 and 2. Activities at **ALL** flood periods or phases require collaboration at the community, state/tribal, regional, and federal levels.

Pre-Flood Activities: The pre-flood is defined as the time between the forecast and onset of the flood. During this period there are several activities which need to be coordinated and addressed. These activities include:

- Identify potential flood areas.
- Identify Federal agencies having flood water quality monitoring concerns in the potential flood areas and invite them to any flood emergency planning or implementation meetings or discussions.
- Identify water quality programs of Federal (local offices), State, Tribal, and local agencies.

Figure 1 -- Action Plan Development for Flood Event Monitoring

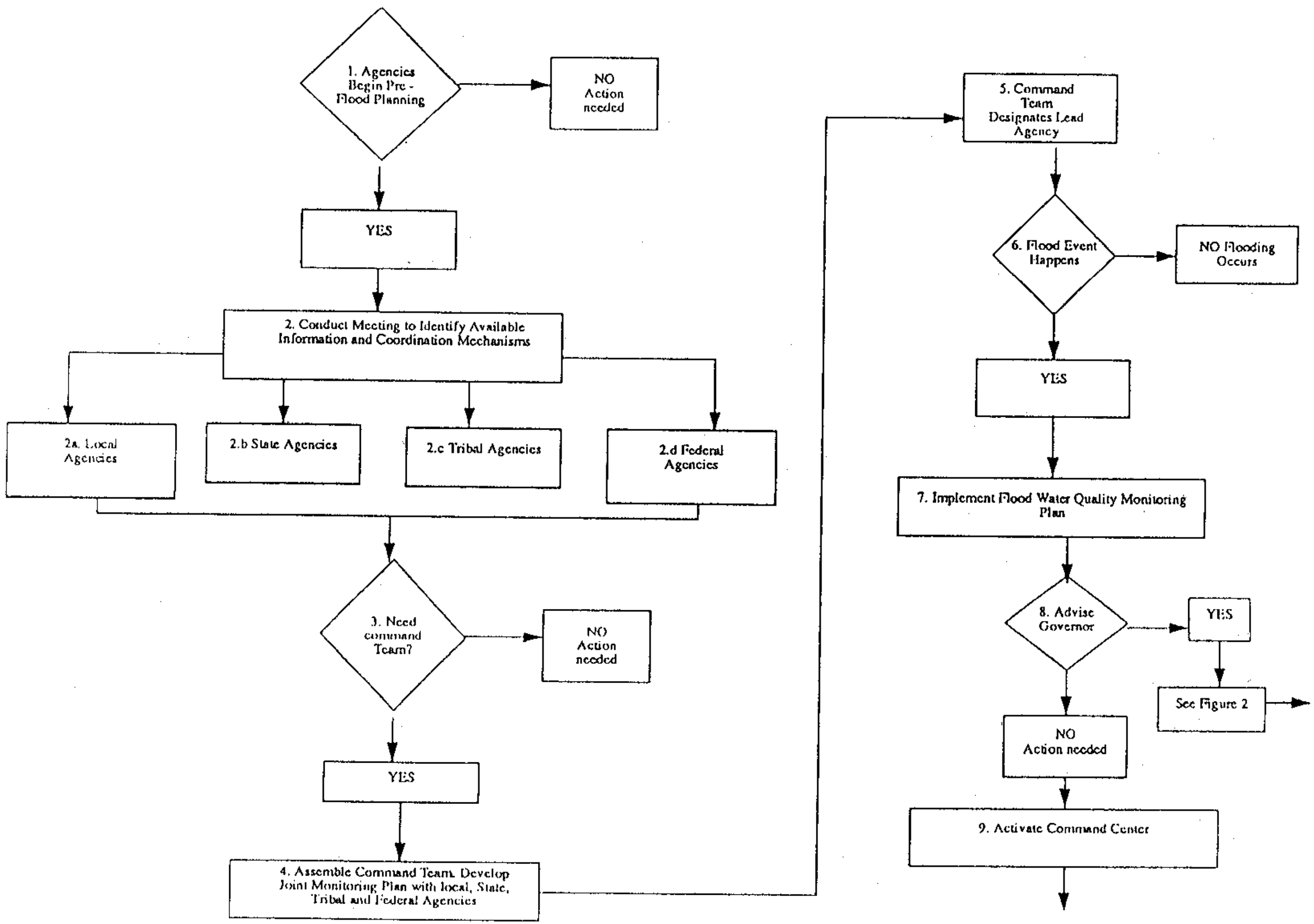


Figure 1 -- Action Plan Development for Flood Event Monitoring (continued)

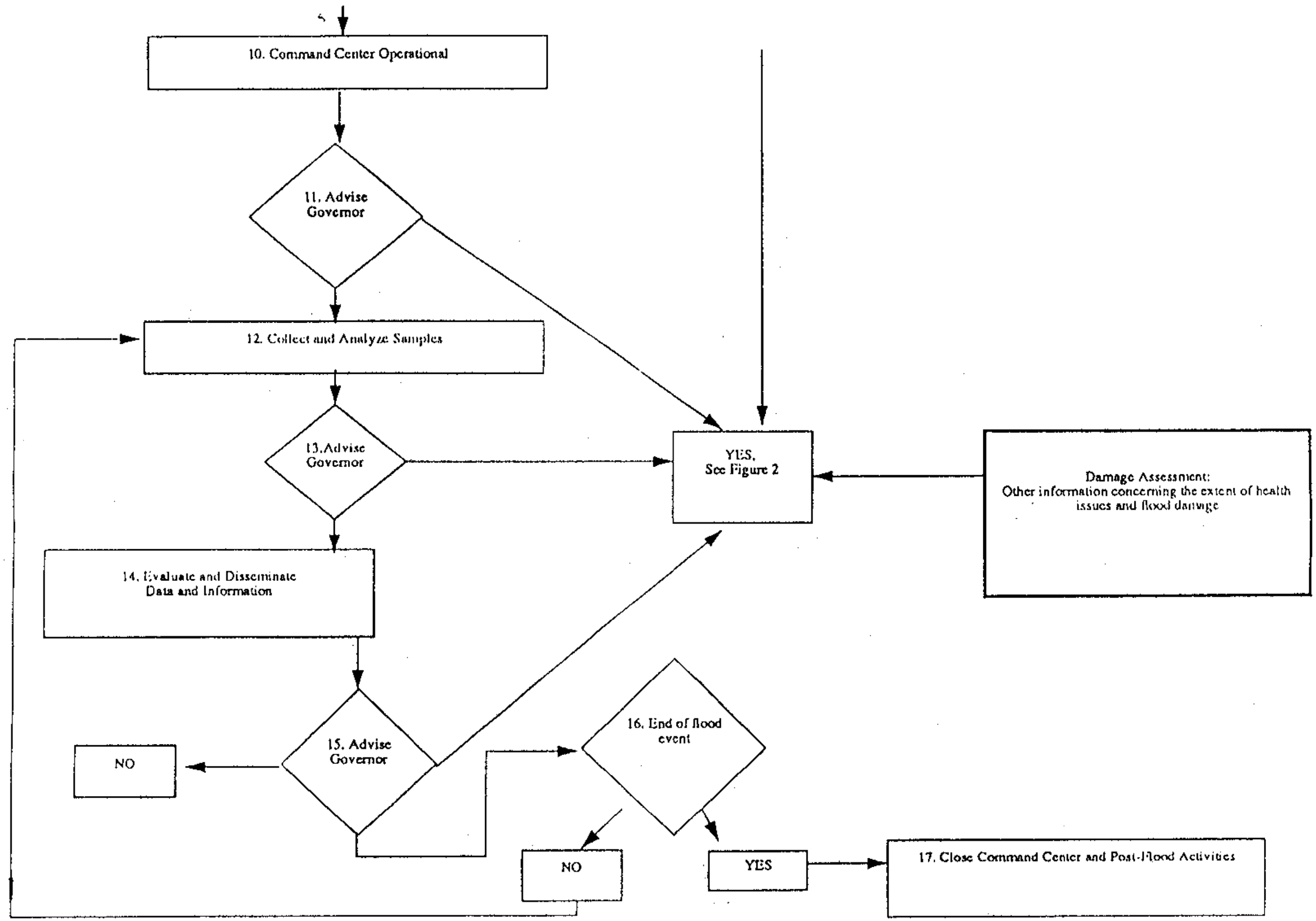
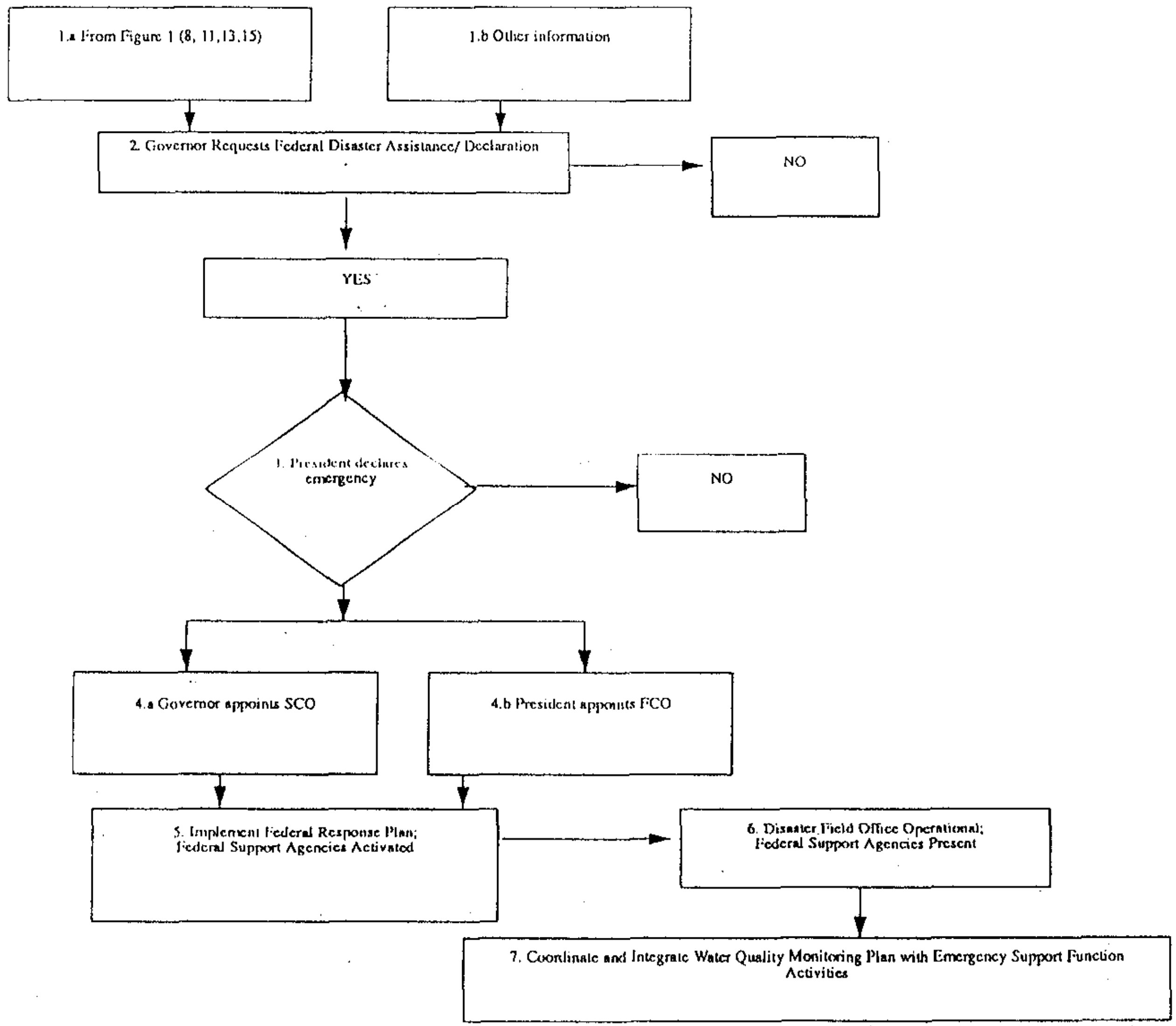


Figure 2 -- Action Plan Development for Emergency Declaration



- Discuss the relation between water quality monitoring efforts to address public health questions and long-term environmental health concerns.
- Prioritize sampling efforts that will provide the data required to answer as many public health and environmental concerns as possible.
- Identify the need for or interest in forming a Command Team or Command Center for water quality monitoring during a flood.
- Identify availability of resources; consider sharing of resources to the extent possible among agencies.

Flood Activities: The flood is defined as the period when flooding is occurring. Activities which need to be addressed during this time include the following:
- Decide on when to implement the monitoring plan in connection with any other emergency event activities.
- Implement the monitoring plan, if necessary, which includes:
  - Activating a command center;
  - Collecting and analyzing samples; and
  - Evaluating and disseminating data and information.
- Consider advising the Governor to request Federal assistance for a disaster situation.

Major Flood Activities: A major flood is one that is likely to prompt a Federal Disaster Declaration and a Federal response. During a major flood the following activities occur:
- The President declares an emergency.
- The Governor appoints a State Coordinating Officer (SCO).
- The President appoints a Federal Coordinating Officer (FCO).
- Implementation of the Federal Response Plan; Federal support agencies activated.
- Opening of operational disaster field office with Federal support agencies present
- Coordination and integration of water quality monitoring plan with emergency support function activities.

Post-Flood Activities: The post-flood is defined as the period when waters recede to normal seasonal levels and flood related water quality monitoring activities are no longer necessary. During this time the water quality monitoring group does the following:
- Analyzes the data and considers further activities or studies.
- Critiques the pre-flood and flood activities.
- Modifies the water quality plan as needed.
- Assigns writing responsibilities for report on water quality as related to flood.
- Disseminates the report as related to the flood.

RESOURCES

The availability of funding for the period between the forecast of a flood emergency and a Presidential disaster declaration is a major issue. Pre-flood activities are assumed to be funded within existing local, State, Tribal, and Federal agency budgets. During a major flood, water quality activity funding can be requested by States from FEMA following the declaration of an emergency by the President. Any monitoring needed for sediments should be included in any resource planning activities. The planning group should determine what sediment monitoring is needed during each flood period and request funding from the State and Federal agencies as applicable.

In its final guidance, the working group also recommended two alternatives for obtaining funding for the period between the flood forecast and a Presidential disaster declaration of emergency, which could be considered at the Federal level. These alternatives include:

1. Establishing a permanent revolving fund for flood-event water quality sampling within a designated Federal agency; or

2. Amending existing legislation such as the Stafford Act so the FEMA could reimburse Federal, State, Tribal, or local agencies for pre-declaration flood water quality monitoring activities.

SAMPLE COLLECTION & SAFETY ISSUES

Several issues concerning sample collection and safety need to be addressed during flood water quality monitoring planning and implementation. With respect to sampling, the number and types of constituents for sampling need to be identified. To assist this process, Figure 3 provides an approach for determining the major water quality monitoring constituents by land uses. Samples are obtained to evaluate the chemical, physical, and biological quality of the water. Also, the sampling sites for both surface and ground water need to be identified. During flood periods, ideal sites might not be accessible and alternates need to be considered. For sampling, both the sampling techniques and types of equipment need to be determined for both the surface water and ground water samples. Sediment sampling should also be considered. To the extent possible, quality control practices should be followed. It is recommended that a minimum of 10 percent of the samples analyzed be quality control samples. In particular, any deviations from standard practices should be documented in field notes.

With respect to health and safety, the monitoring group needs to have all appropriate immunizations and be trained on the use of boating equipment and first aid. When sampling from bridges and cableways a minimum of three people are required at all times during floods. Because of the high flood velocities, sampling will probably be done off the downstream side of the bridge; thus, while two people are sampling or processing, the other person must be watching upstream, looking for debris and other objects that might be a danger to personnel and equipment. If any hazardous materials or wastes are found by the sampling team, certified personnel should be contacted.

All data collected must be reviewed and the results released as soon as possible because during the flood period there is an intense interest in any data bearing on public health issues. Until the data can be thoroughly checked, it should be released as "unpublished, subject to revision." For the release of flood-related information, one spokesperson should be appointed by the command team leader. This will help to control the release of information in a coordinated manner to the media and general public.

FEDERAL IMPLEMENTATION OF THE FINAL GUIDANCE

For future major flood events, the working group plans on working with the primary agencies responsible for the relevant Emergency Support Functions (ESFs) which could consider and recognize any water quality monitoring activities. Of the 12 ESFs identified in The Federal Response Plan developed by the Federal Emergency Management Agency (FEMA) (U.S. Government Printing Office: 1993-718-749/61117), three functions relate to the monitoring activities. The lead and other agencies assigned to work on ESF #3 - Public Works and Engineering, ESF #8 - Health and Medical Services Annex, and ESF #10 - Hazardous Materials Annex would be encouraged to incorporate water quality monitoring activities including appropriate sediment sampling as recognized activities within the scope of their functions.

Figure 3.--An Approach For Determining Major Water Quality Monitoring Constituents By Land Use During A Major Flood Event

CONSTITUENTS		LAND USES					
		Agriculture	Urban	Industrial	Mining	Forest	Hazardous Materials Storage
HUMAN HEALTH	Bacteria	X	X				
	Nitrate	X					
ENVIRONMENTAL HEALTH	Pesticides	X	X			X	
	Priority Organics			X			X
	Metals	X	X	X	X		X
	Suspended Sediment	X	X		X	X	
	Field Parameter	X[a]	X[a]	X[a]	X[a]	X[a]	X[a]
	Major Ions	X[a]	X[a]	X[a]	X[a]	X[a]	X[a]
	Site Specific Factors	X	X	X	X	X	X

[a] Standard water quality parameters collected by USGS for field investigations.

Field Parameters: specific conductance, pH, water temperature, air temperature, dissolved oxygen, and alkalinity.

Major Ions: calcium, magnesium, sodium, potassium, chloride, sulfate, residue on evaporation, and nutrients.

SEDIMENT AND HYDRAULIC DATA COLLECTED DURING THE UPPER MISSISSIPPI RIVER SYSTEM FLOOD OF 1993

By Robert R. Holmes, Jr., Hydraulic Engineer, and Kevin A. Oberg, Hydrologist, U.S. Geological Survey, Urbana, Illinois

Abstract: Sediment and hydraulic data were collected by the U.S. Geological Survey during the 1993 Flood on the upper Mississippi River system (hereafter referred to as "the Flood") at various locations including six streamflow-gaging stations on the Illinois, Missouri, and Mississippi Rivers. The hydraulic and suspended-sediment data were collected based on conventional methods and a Broadband acoustic Doppler current profiler (BB-ADCP). Many levees were overtopped and breached on the Illinois, Missouri, and Mississippi Rivers. Point measurements of deposition and scour were made near many of the levee-break complexes on the flood plains of the Missouri and Mississippi Rivers immediately after the Flood receded.

UPPER MISSISSIPPI RIVER SYSTEM FLOOD OF 1993

The 1993 flood in the upper Mississippi River system ("the Flood") was the result of excessive precipitation for many months over much of the upper Midwestern United States (Wahl and others, 1993). Streamflows exceeded the 100-year flood at many locations and record peak discharges were reported at more than 40 streamflow-gaging stations operated by the U.S. Geological Survey (USGS) (Parrett and others, 1993).

The record flooding mobilized, transported, and deposited large quantities of sediment throughout the upper Mississippi River system. The Mississippi River system transports more water and sediment to the oceans than any other river in North America (Meade and others, 1990). The Flood created many opportunities to collect data and test new data-collection techniques under unique hydrologic conditions. This paper describes the type of data and techniques used during the Flood.

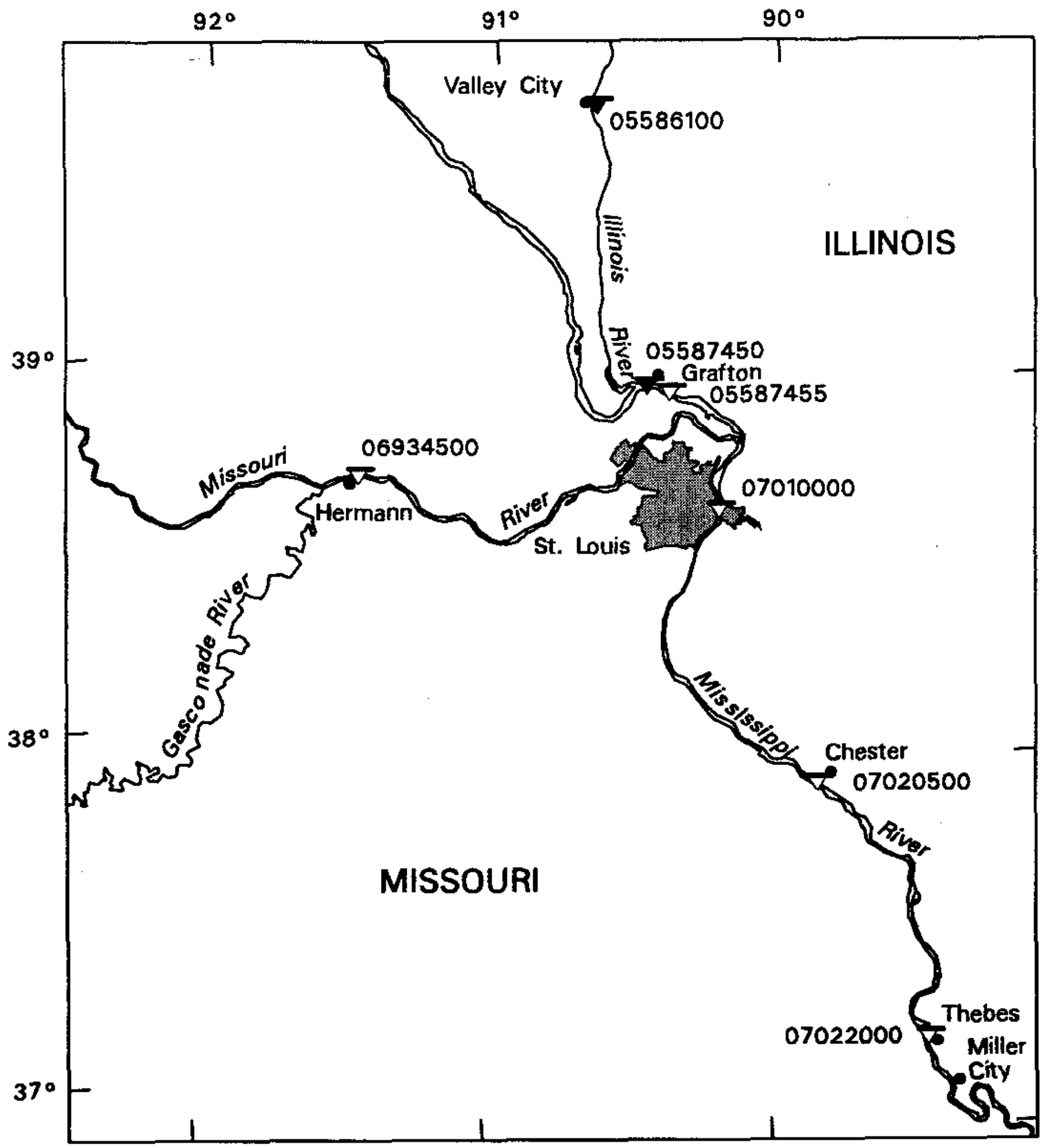
SEDIMENT AND HYDRAULIC DATA

A part of the upper Mississippi River system where the sediment and hydraulic data were collected is shown in figure 1. In this region, sediment data are collected by the USGS at six streamflow-gaging stations (Illinois River at Valley City, Illinois; Mississippi River at Grafton, Illinois; Missouri River at Hermann, Missouri; Mississippi River at St. Louis, Missouri; Mississippi River at Chester, Illinois; and Mississippi River at Thebes, Illinois). Daily sediment discharge is computed at five of these gaging stations. For the other station, Missouri River at Hermann, Missouri (06934500), the sediment data collected are not adequate to compute daily sediment loads, so only an estimate of the sediment load for specific time periods can be made.

Special measurements were made with a Broadband acoustic Doppler current profiler (BB-ADCP) at various sites along the upper Mississippi River system to compare with conventional Price AA discharge measurements (Buchanan and Somers, 1969). In addition, BB-ADCP measurements were made at a levee break on the Mississippi River at Miller City, Illinois (fig. 1) in which water depths, velocities (in three dimensions) and discharge were measured.

After the flood receded, erosional facies and depositional zones of several levee breaks on the Missouri and Mississippi Rivers were visited. Point measurements of depositional amounts were made as part of a field reconnaissance.

Suspended Sediment, Bed Material, and Water Velocities: Suspended-sediment-concentration data were collected with either a US P-61 or US P-63 suspended-sediment sampler. Local observers on contract with the USGS collected samples daily at the Illinois River at Valley City, Illinois; and the Mississippi River stations at Grafton, Chester, and Thebes. USGS personnel collected daily samples at the Mississippi River at St. Louis station. These samples were collected from a fixed location in the cross section, and were adjusted to represent the average concentration for the entire cross section. Multi-vertical suspended-sediment samples were collected by USGS personnel with either a US P-63 or US P-61 sampler suspended from specially fabricated booms (an example of the apparatus used at the Mississippi River at Thebes, Illinois is shown in fig. 2) at 5 to 10 locations in the cross



Base from U.S. Geological Survey
1:200,000 Digital Data
Albers Equal-Area Conic projection
Standard parallels 33° and 45°, central meridian -89°

0 20 40 MILES
0 20 40 KILOMETERS

EXPLANATION

07022000 ▽ STREAMFLOW-GAGING AND SEDIMENT STATION AND NUMBER

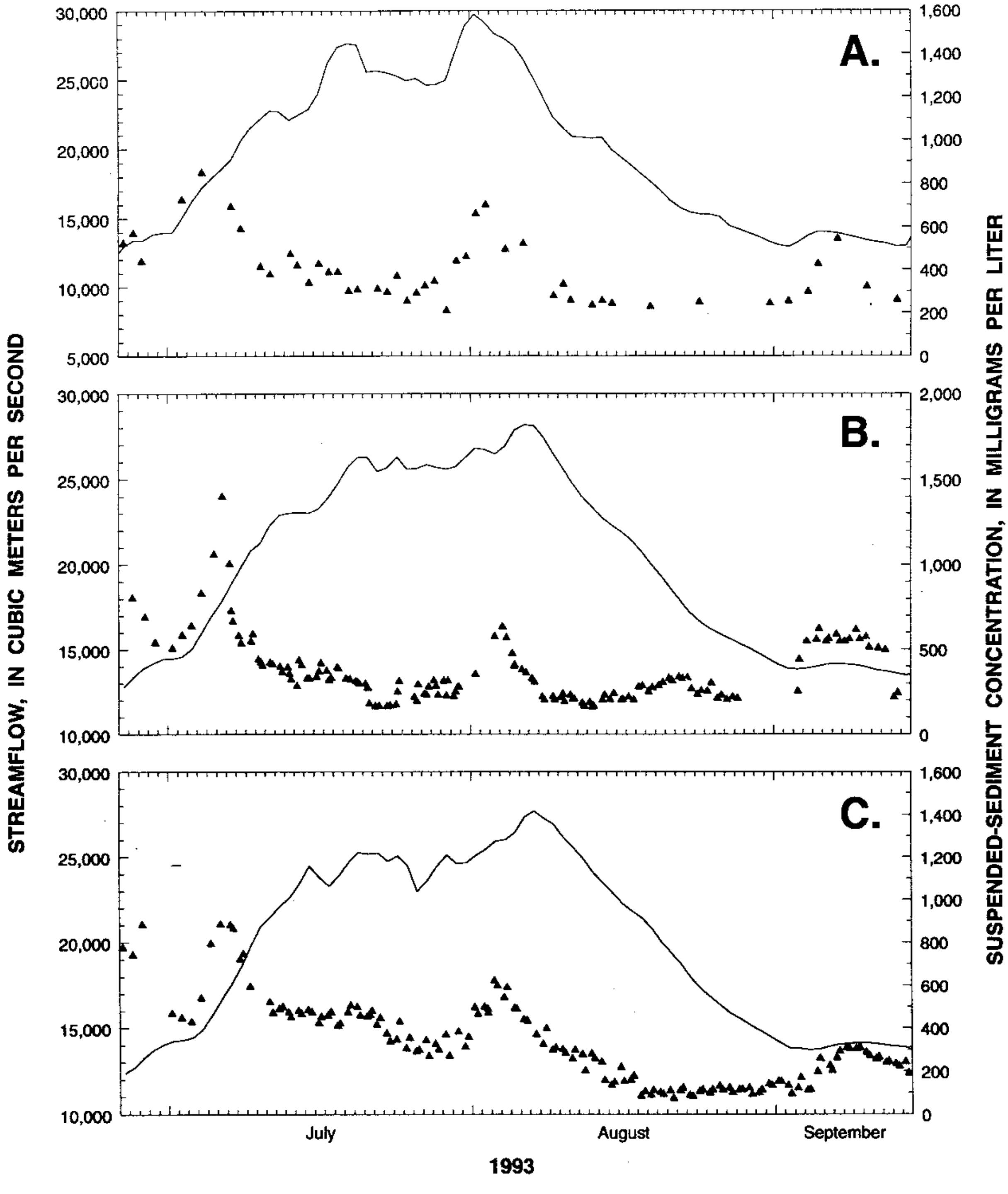
05587450 ▼ STREAMFLOW-GAGING STATION AND NUMBER

Figure 1. Location of selected streamflow-gaging and sediment stations on the lower Illinois, lower Missouri, and upper Mississippi Rivers

Figure 2. Specially fabricated monorail system apparatus under the Thebes, Illinois railroad bridge for collection of sediment and hydraulic data on the Missippi River.

section. The multi-vertical samples were then used to adjust the concentrations determined from data collected by the observers. The sediment concentration and streamflow hydrographs for the Mississippi River sediment stations at St. Louis, Missouri, and Chester and Thebes, Illinois are shown in figure 3. The sediment concentration peaked well before the streamflow at all three of these stations.

The total suspended-sediment load for the period from June 26 to September 14, 1993, (the period the Mississippi River at St. Louis, Missouri was continuously above flood stage) for the six stations is listed in table 1. The combination of suspended-sediment loads for the Missouri River at Hermann, Missouri (06934500) and the Mississippi River below Grafton, Illinois (05587455) was 22 million metric tons greater than the load transported



EXPLANATION

—— STREAMFLOW

▲ SUSPENDED-SEDIMENT CONCENTRATION

Figure 3. Streamflow hydrographs and suspended-sediment sample concentrations for the Mississippi River from June 26 to September 14, 1993. A, St. Louis, Missouri; B, Chester, Illinois; C, Thebes, Illinois.

past the downstream station on the Mississippi River at St. Louis, Missouri (07010000). Holmes (1995) discusses possible causes for this occurrence. The most probable cause appears to be a smaller river slope on the Mississippi River than the Missouri River, resulting in a decrease in transport energy.

Table 1. Suspended-sediment loads for selected sediment stations in the upper Mississippi River system, June 26 to September 14, 1993

Station	Suspended-Sediment Load (metric tons)
Illinois River at Valley City, Illinois (05586100)	944,000
Mississippi River at Grafton, Illinois (05587455)	7,000,000
Missouri River at Hermann, Missouri (06934500)	70,000,000
Mississippi River at St. Louis, Missouri (07010000)	55,000,000
Mississippi River at Chester, Illinois (07020500)	52,000,000
Mississippi River at Thebes, Illinois (07022000)	51,000,000

The backscatter from the BB-ADCP is a measure of the amount of suspended matter in the water column (Oberg and Mueller, 1994). As a result, some investigators have experimented with BB-ADCP's to determine suspended-sediment concentrations (Thevenot and Kraus, 1993; and Fagerburg and Pratt, 1994). No backscatter data were collected during the 1993 flood; however, during the most recent Mississippi River flood in the Spring of 1995, a limited data set was collected at the confluence of the Missouri and Mississippi Rivers. The sediment concentration during the 1995 flood at this location changed significantly from one side of the river to the other. The suspended-sediment concentration of the Missouri River was eight times that of the upper Mississippi River. Point samples of suspended sediment were collected at various locations in the cross section and compared to the backscatter from concurrent BB-ADCP data. The relation of BB-ADCP backscatter and suspended-sediment concentration is shown in figure 4.

Collection of bed-material samples, with a US BM-54 sampler, were only possible when done from a boat. The 45 kilogram BM-54 could not be properly lowered to the streambed from a fixed platform, because high velocities and water depths exceeding 18 meters caused extreme downstream drifting. The sampler was lowered into the water until it was approximately 5 meters above the streambed. The boat was then allowed to drift downstream with the current until the sampler cable was vertical. At that point, the sampler was quickly lowered and a sample was collected. This was repeated at each of 10 locations in a cross section. Results from the bed material samples are presented in Holmes (1995).

Water-velocity data were collected with both conventional AA-Price current meters and by BB-ADCP's, which have only been used to collect streamflow in discharge in upland rivers for about five years. On the basis of conventional AA-Price current meters, maximum velocities for the Missouri River at St. Charles, Missouri approached 5.8 meters per second in a constricted, leveed reach of the lower Missouri River. The boat mounted BB-ADCP was able to collect three-dimensional water velocities throughout the water column, in a faster and more efficient manner than with the AA-Price current meters. The discharge measured by the BB-ADCP matched that of conventional fixed-platform measurements within 1 percent (Oberg and Mueller, 1994). Velocities in excess of 4.26 meters per second were measured with the BB-ADCP during the flood on the Mississippi River.

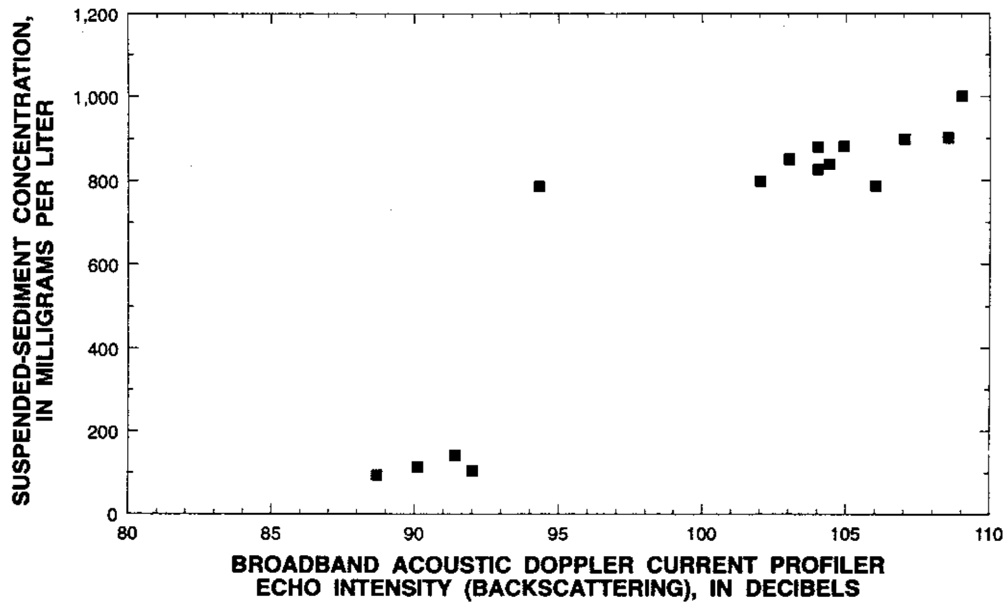


Figure 4. Broadband acoustic Doppler current profiler echo intensity and associated suspended-sediment concentration at the confluence of the Missouri and Mississippi Rivers, 1995.

Bedload: Direct sampling of bedload was attempted in the St. Louis Harbor of the Mississippi River using an experimental TR-2 bedload sampler (Dallas Childers, USGS, written commun.) with a 45 kilogram Columbus sounding weight strapped to the top of the sampler to provide extra weight. An attempt was made to lower the sampler to the river bed with a barge mounted crane. However, the attempt was unsuccessful as the sampler drifted downstream without touching the streambed because of the amount of drag on the sampler.

Although direct measurement of bedload was not done, Holmes (1995) estimated the bedload for various discharges to be about 5 percent of the suspended-sediment load, from three theoretical bedload equations. In addition, some data were collected that give insight into the bedload transport of the Mississippi River at St. Louis, Missouri. Using a 1200-kHz BB-ADCP, Oberg and Mueller (1994) tied off to a stationary barge in the St. Louis Harbor to determine the bottom tracking capability of the BB-ADCP. Because the frequency of the 1200-kHz BB-ADCP was not acoustically powerful enough to penetrate the mobile bed layer, an upstream boat speed of 0.60 meter per second was recorded. Because the boat was stationary, this velocity was presumably that of the mobile bed, or grain velocity. The U.S. Army Corps of Engineers, St. Louis District, collected bathymetric data in the same area of the St. Louis Harbor as the work by Oberg and Mueller (1994) during the 1993 flood. This detailed bathymetric data indicated that, on average, the dune height of the bed forms was approximately 2.3 meters.

Floodplain Sedimentation: The design limits of levees along the Missouri and Mississippi Rivers were exceeded and the levees were overtopped for much of the Illinois and Mississippi Rivers and most of the Missouri River. The build up of energy head on the river side of the levee, resulted in very high energy flow situations when these levees were overtopped or failed. Levee breaks created large scour holes and became large conduits that pumped large amounts of sand from the main channel onto the flood plain. Measurements were made with the AA-Price current meter from both the bridge and a boat in the flood plain of the Missouri River at Hermann, Missouri. These measurements indicated that as much as one-half of the 21,200 cubic meters per second total discharge of the Missouri River was in the flood plain, which was 1.5 miles wide. After the 1993 flood receded from the flood plains, field visits were made to various levee break areas in the Missouri and Mississippi Rivers. Depths of up to 4 meters of sand were present on the flood plains downstream from these levee breaks. Preliminary estimates from these visits indicated that as much as 35 million metric tons of sediment were deposited on the Missouri River flood plain from Hermann, Missouri to St. Louis, Missouri (Holmes, 1995). From aerial reconnaissance and field visits, more numerous scour holes and greater amounts of sand deposition were present on the Missouri River flood plain when compared with the Mississippi River flood plain.

Immediately after the levee break on the Mississippi River at Miller City, Illinois, during the 1993 flood, the USGS began making discharge measurements at the break with a BB-ADCP. At one point during the flood, as much as one-quarter of the 26,000 cubic meters per second total discharge of the Mississippi River was diverted through the Miller City levee break, threatening to alter the course of the Mississippi River in that area. The scour hole was more than 25 meters deep with maximum velocities approaching 3 meters per second. Turbulent eddies present in the flow made boat measurement extremely hazardous. Vertical velocities in excess of 0.5 meter per second were measured near the downstream end of the scour hole. The thalweg of the scour hole progressed approximately 2 kilometers onto the flood plain before the recession of the flood stopped the advance.

SUMMARY

The 1993 Flood in the upper Mississippi River system was an extreme hydrologic event caused by excessive rainfall over many months. Sediment and hydraulic data were collected at several locations on the lower Illinois, lower Missouri, and upper Mississippi Rivers, especially at six USGS stream-gaging stations. Sediment data were collected and loads computed at these stations. Water velocity, depth and discharge data were collected with both conventional AA-Price current meters and with the Broadband acoustic Doppler current profiler (BB-ADCP). Streamflow data collected with the BB-ADCP matched conventional discharge measurements within 1 percent. An attempt was made during the most recent 1995 flooding on the Mississippi River to correlate the BB-ADCP backscattering with suspended-sediment concentration.

Direct sampling of bedload during the 1993 Flood in the St. Louis Harbor on the Mississippi River was unsuccessful. However, bed form geometry and grain velocity data were collected.

A number of high energy levee breaks occurred on the Illinois, Missouri and Mississippi Rivers. These levee breaks created large scour holes and became conduits for sand to be pumped onto the flood plain in large quantities. Discharge measurements made on the Missouri River at Hermann, Missouri, indicated that one-half of the total discharge was flowing over the flood plain. Measurements of the flood plain deposition were made at several locations on the Missouri and Mississippi Rivers after the flood receded. Discharge measurements were made inside the levee break at Miller City, Illinois, on the Mississippi River soon after the initial break. These measurements indicated that as much as one-quarter of the total Mississippi River flow was diverted across the flood plain.

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OVERBANK SCOUR CAN BE CONTROLLED! CASE STUDY: DRY BAYOU-THOMPSON BEND MISSISSIPPI COUNTY, SOUTHEAST, MISSOURI

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ABSTRACT

Dry Bayou - Thompson Bend is located on the right descending bank of the Mississippi River between river miles 30.0 and 4.5, above the confluence of the Mississippi and Ohio Rivers. The river flows in a broad sweeping reverse curve in this reach, and encompasses approximately 10,000 acres of valuable agricultural land. At the throat of the bend, the overland distance is approximately one mile. The distance along the thalweg is approximately 14 miles. During flood events, the river naturally tries to take the shortest path, straight across Thompson Bend. The normal slope along the thalweg is 7 feet, or about 0.5 feet/mile. When flows cross the bend, the 7 foot drop occurs across approximately 2 miles, producing a slope approaching 3.5 feet/mile.

In the early 1980's, severe erosion of the upper bankline began along the right descending bank in the upper reaches of the bendway. In addition, localized areas of severe surface erosion was being experienced throughout the bend. Continued erosion at the rate ongoing(estimated at 40,000 tons/acre/event) in the early 1980's could have allowed for development of a chute cut-off across the bend. This would have caused navigation to become impossible due to the steep slopes and resulting high velocities in the new channel across the bend, would have destroyed thousands of acres of valuable farmland, and changed the river regime for miles upstream and downstream. The entire inland waterway navigation system would have been severely effected.

This paper will discuss in detail how this situation developed, what was done to control it, and how it was severely tested in the Great Flood of 1993, and also the flood events which occurred in 1994 and 1995. It will clearly illustrate that overbank scour can be controlled by dedicating a very small percentage of tillable land to the development of well designed tree screens, and in conjunction with planting certain types of crops at key locations, can almost entirely eliminate surface erosion.

INTRODUCTION

The Dry Bayou-Thompson Bend area is shown on Figure 1. During flood events significant amounts of water flow across the bend. In June of 1995, flow measurements across the throat of the bend indicated that 70,500 cubic feet per second(cfs) entered the bend. This represents 9.50% of the total Mississippi River flow of 740,000 cfs.

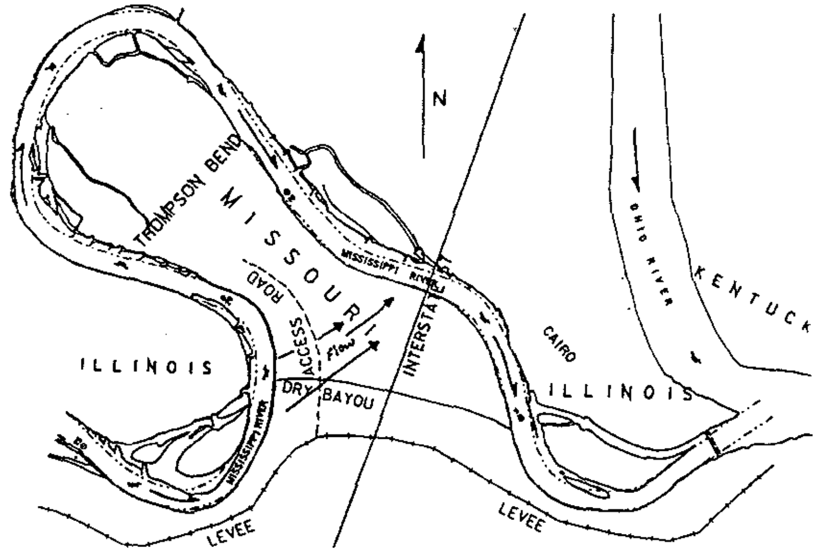

Figure 1 - Location Map

Significant overbank erosion became a concern in the early 1980's when numerous overbank flows occurred. During the three decades prior to 1980, overbank flows occurred very infrequently, with many years between events. This allowed a natural healing to take place, and if isolated bank line blow-outs occurred, provided sufficient time for repairs before the next event.

There were nine overbank flow events between May 1981 and March 1985. Analysis of aerial photographs indicated that between 1948 and 1979, over 76 percent of the natural vegetation had been removed. In 1948, approximately 5900 acres of the 10,000 acre bend were vegetated, compared to 1400 acres in 1979. Not only were flood events occurring twice a year, but also little natural vegetation remained to reduce velocities and minimize scour. Natural healing and man-made repairs could not keep up with the re-occurring damages.

In 1981, three barges broke loose from their tow and entered the bend at Dry Bayou, river mile(r.m.) 22.0(R). Recovery efforts resulted in significant damage to the bankline, inviting increasing amounts of water into the bend. By 1985, approximately 2,000 feet of the right descending bank of the Mississippi River at r.m. 22.0 had been degraded approximately 10 feet. Also, the narrow line of trees and natural vegetation which had provided a minimum amount of protection, had been destroyed. Figure 2 is an aerial photo of this area. The overbank scour extended landward over 5000 feet, with erosion depths approaching 5 feet in some areas. The Soil Conservation Service estimated that 40,000 tons of top soil was being eroded in each flood event.

It was apparent that one of the world's mightiest rivers was now in control of the fate of Thompson Bend. Without some innovative corrective protection, the Mississippi would do what it had been doing for millions of years prior to man's attempt to control it for navigation purposes. It was in the process of forming a chute type cut-off across the bend. If allowed to continue, the cut-off would destroy many thousands of acres of valuable agricultural land, and would make navigation upstream of Cairo on the Mississippi River impossible.

Figure 2 - Dry Bayou, April 1985, river mile 22.0(R). Note: towboat is 1200 feet long.

CORRECTIVE MEASURES

In 1984 a plan was developed to control and minimize the scour. The Corps would reconstruct and maintain the top bank of the river with rock, the landowners, organized under the Buffalo Bend Levee Corporation(see acknowledgments at end of paper), would initiate a re-vegetation program, and the Corps would closely monitor the bend to ensure the measures being implemented were actually retarding overbank scour and preserving the integrity of the bend.

After the spring high-water of 1985, landowners initiated their re-vegetation program. Based on meetings with representatives of the Corps, the Missouri Department of Conservation(MDC), the Department of Agriculture, and Westvaco(a private forestry company), a three phased plan was developed. The first phase, initiated immediately after the water receded, allowed natural vegetation to re-develop in key locations. The two main areas were directly landward of the two scour holes at r.m. 22.0(R), and on either side of the Thompson Bend access road, at the throat of the bend(see figure 1). The second phase consisted of ensuring that all land subjected to significant velocities during overbank flows was protected at all times. This consisted of either planting winter wheat, or planting milo in rows perpendicular to the flow patterns. When the milo was harvested, the stalks were not plowed under, but allowed to remain standing until planting began the next year. The third phase was planting trees in strategically placed locations across the bend. The tree cuttings were planted in February and March of 1986. Initially, 53,000 cuttings, mostly a hybrid Cottonwood variety with lesser amounts of Green Ash and Pecan, were planted. The trees were planted in 100-foot wide strips, five rows per strip, spaced on ten foot centers. Several different test plots, established under the direction of MDC, were also established and are being monitored and analyzed to determine which species are superior in regards to growth rates and resistance to damage from frequent inundation.

The tree screens were designed so that overland flow would have to pass through at least two, and sometimes three tree screens, locally called "lines of defense". Special attention was directed to the throat of the bend since this area receives the most flow and experiences the highest velocities. Since the initial planting, over 50,000 additional trees have been planted. Over 125 acres of prime agricultural land has been taken out of production and planted with trees or allowed to revegetate. Figure 3 is a 1989 aerial photograph showing the established tree screens and vegetation.

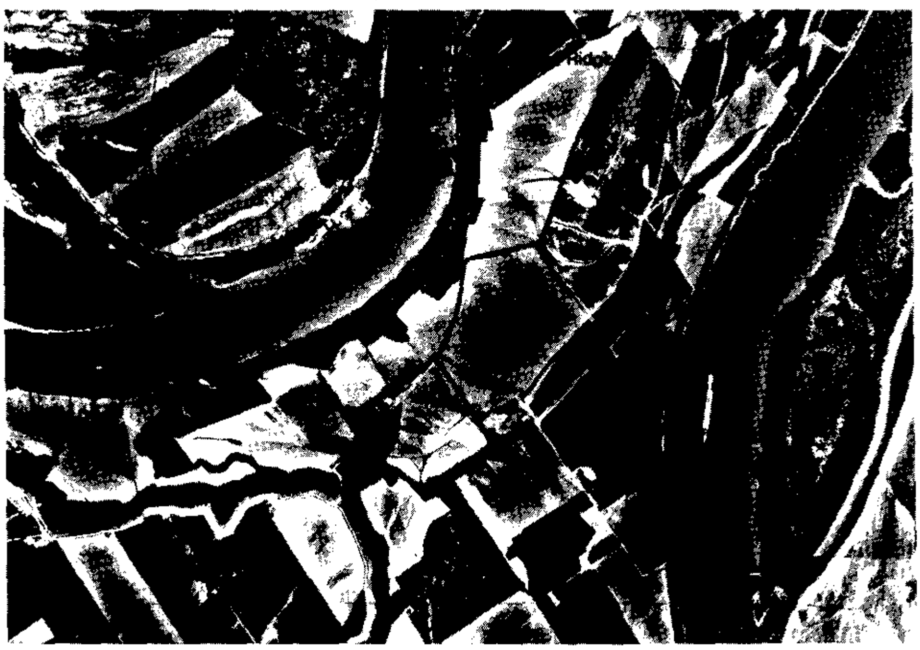

Figure 3 - 1989 photograph showing location of tree screens and vegetation.

EVALUATION

Since the corrective measures were implemented in early 1986, major floods occurred in the fall of 1986, spring of 1990, spring and summer of 1993, spring of 1994, and again in the spring of 1995. The crest(at Cape Girardeau, Missouri) and duration of overbank flow for each event is summarized below:

	Stage*	Duration
Fall 1986	42.1	17 days
Spring 1990	39.6	13 days
Great Flood of 1993	47.9	130 days
Spring 1994	41.9	15 days
Spring 1995	46.7	38 days

*Overland flow occurs at a stage of between 35 and 36 feet on the Cape gage.

The fall flood of 1986 gave the vegetation its first severe test. The natural vegetation had had just over one year to get established, and the tree cuttings just one growing season. They had sprouted to an average of just 2 to 3 feet in height. The corrective measures performed exceptionally. Figure 4 is an aerial photo of the same area as shown on Figure 2. The reduction in overall surface scour patterns is clearly evident. On ground

Figure 4 - Same area as figure 2 after October 1986 flood. Note lack of visible scour.

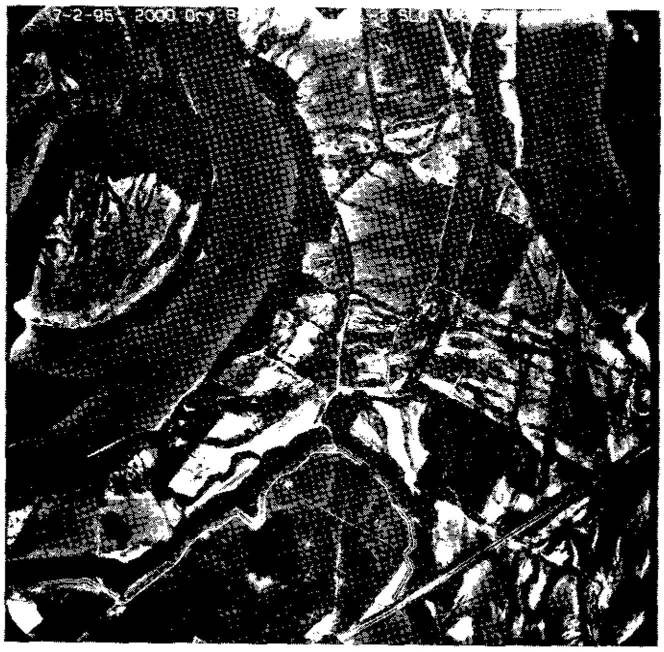

Figure 5 - July 1995 aerial photograph showing flow path across bend and areas devoid of tree screens and/or vegetation.

EFFECT OF TREE SCREENS ON VELOCITIES

During the flood event of 1995, velocity and flow measurements were made along various ranges in Thompson Bend with an Acoustic Doppler Current Profiler. The data clearly illustrate the effectiveness that vegetation has on reducing velocities. The data indicate an average of a 2 to 1 reduction in the velocities from the upstream to the downstream side of the tree screens. Maximum velocities in areas not affected by tree screens approached 10 feet per second. The scour threshold velocity of the unprotected soil in the Bend is between 4 and 5 feet per second. Thus with the 2 to 1 reduction, one can easily see why minimal scour occurred.

Analysis of this data and future data will continue. A set of guidelines will be established which will relate variables such as width of screens, density of trees in screen, tree type, and entrance velocity to expected velocity reduction. This data will allow the minimum amount of tillable land to be taken out of production and established in tree screens of sufficient size to reduce velocities below the scour threshold velocity.

SUMMARY

Thompson Bend has clearly illustrated the vital importance vegetation has on controlling overbank scour. In the early 1980's, the pre-vegetation period, overbank scour occurred of such magnitude that it was likely a chute-type cutoff would occur across the throat of the bend if the scour was left unchecked. The re-vegetation process began in 1985 and early 1986. The results were immediately evident during the fall flood of 1986. Very little erosion was observed. The area was tested again in the flood of 1990, when very little erosion occurred. The Bend also suffered very little visible damage during the Great Flood of 1993, when record high stages occurred, and the duration of the overland flows reached an unprecedented 130 days. However, the flood took its toll on the vegetation. Numerous trees that were inundated for most of the 130 days died. The flood of 1994 did not allow any significant re-vegetation to occur. Subsequently, the flood of 1995, the second highest ever at Cape Girardeau, produced some visible scour for the first time since the re-vegetation was initiated. However, the erosion was very minor compared to the massive amounts of scour which occurred in the early 1980's.

As this paper is being prepared in August of 1995, meetings are being planned to get supplemental tree planting started again this winter. Approximately 10 to 15 thousand trees will have to be planted to replace those lost in the last three years. Additional areas are also being evaluated for tree planting. The flood of 1995, while causing some minor damage, also indicated weak areas that may be susceptible to damage in future floods. An attempt will be made to also reinforce these areas.

Additional data analysis and collection of future data will result in the establishment of some basic recommendations for establishment of tree screens. Each location will be site specific, with each having its own individualistic characteristics which will influence the required protection needed. But with proper design and cooperation between all effected entities, this area has shown that overbank scour can be controlled.

ACKNOWLEDGEMENTS

The views expressed herein are those of the authors, and not necessarily those of the U.S. Army Corps of Engineers.

The project has not been possible without the concentrated, organized effort of the landowners who were organized with "one voice", under the Buffalo Bend Levee Corporation. A project of this magnitude can not have factions splintering off in different directions. The landowners worked as a close knit group, knowing if there was one weak link, everyone else's land could be subjected to massive scour. Space limits mentioning all families involved(our apologies to those not mentioned), but the Adkisson, Drinkwater, Goodin, Hillhouse, Kirkpatrick, Lankheit, and Rolwing families all participated in this project, and many thanks are directed their way.

A very special thanks goes to Ms. Liz Anderson, Co-editor of The Enterprise Courier newspaper, published in Charleston, Missouri, for her review of the context of this paper.

SEDIMENTATION IN SCOUR HOLES - A PRELIMINARY REPORT

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Abstract: Part of the legacy left behind by the Great Flood of 93 are the numerous scour holes formed when the levees were overtopped and eroded. Some of the "blew holes" were immediately adjacent to the Missouri and Mississippi Rivers, others were several miles from the rivers. A cooperative effort of the Natural Resources Conservation Service (NRCS), Missouri Department of Conservation (MDC), and the U.S. Fish and Wildlife Service, is preserving many of these as part of the Emergency Wetland Reserve Program. The NRCS, MDC and U.S. Army Corps of Engineers (COE) have surveyed 17 of the scour holes as part of a long term monitoring program along the Missouri River flood plain. The long term objective of this and other studies is to monitor the scour holes to determine sedimentation rates and the value of the scour holes and adjacent areas as fish and wildlife habitat. Surveys of the scour areas were made with electronic total stations. Office work involved processing the survey data and plotting topographic maps by Eagle Point Advantage Series (Version 13) for AutoCad (Version 12) software. The initial surveys of the scour holes in the study were completed prior to the Flood of 95, a near record flood event in most of the study area. Plans are to resurvey the scour holes during the fall and winter, 1995/1996

INTRODUCTION

The shear magnitude of the changes left behind in the Missouri River flood plain by the 1993 flood is striking. Among the more dramatic of these changes are the scour areas and associated sediment splays. Galat et al (1995) classifies the types of scours as connected (to the river) or isolated (non-connected). Most scour holes were associated with levee breaks (Scientific Assessment & Strategy Team, 1994). If the break occurred on the primary levee close to the river, the resulting scour hole usually remained connected to the river. Where levee breaks occurred in secondary levees further back from the river, the resulting scour holes were often non-connected. Some of the non-connected scour holes are on the river side of the levee, and subject to flooding when the river reaches flood stage. Other non-connected scour holes are the on the flood plain side of the levee, and therefore protected from flooding. Connected entrance scours are typically at the upstream margin of meander bends or channel crossovers where flood flow concentrates (Galat et al 1995). Exit scours normally formed where floodwaters exited the floodplain, moving back into the river.

Several agencies are currently involved in research and data collection related to the scour holes and adjacent wetlands and deposition splays. In addition to the NRCS, these include (but not limited to) the University of Missouri-Columbia for investigation of limnology, soils, and vegetation; the COE for morphology studies related to connected scour holes; the National Biological Survey for use of scour holes by fish; and the MDC for studies including fish, birds, vegetation and invertebrates. The NRCS has been involved mostly in collection of soil data and morphology studies of non-connected scour holes.

Surveys of the scour holes and adjacent areas began the winter of 1994. Criteria for the selection of study areas was random. Many of the scour areas in the study were enrolled as possible candidates in USDA's Emergency Wetland Reserve Program (not all sites ultimately were accepted).

The study area for most of the ongoing research projects is the Missouri River and adjacent flood plain from Hartsburg to Kansas City, Missouri. Within this area were 29 connected scours and 18 non-connected scours (some of which were connected during high water via a drainage ditch or tube with a flap gate). This paper will report preliminary information on 7 of the non-connected and 10 of the connected scour holes.

SURVEY PROCEDURES

Field surveys of the non-connected scour areas were conducted October 11 through October 27, 1994. The non-connected scour holes were normally field surveyed by a 3 person field crew using a Sokkia Set 2 total station and Sokkia SDR33 data collector. A typical survey would have one person on the instrument/data collector and 2 rod persons. A major time element for most of the non-connected was setting the initial benchmarks. Many of the benchmarks originally established by the COE and others along the river were destroyed by the floods. Temporary benchmarks had to be established close to the scour areas. Many times, this required bringing in elevations from USGS benchmarks several miles away. Experiments were made using Global Positioning System (GPS) units, but we were unable to achieve the desired vertical accuracy with the units available at the time of survey.

The normal procedure was to first survey the water line inside the scour area, and the approximate old field level. The remaining survey points were collected on foot for the land areas, or using a 14 ft. flat-bottomed boat for the water filled scour areas. Survey points were taken on approximately a 100 ft. survey grid. Water depths were recorded using a weighted tape, measuring to a point on the gunwale of the boat. Survey shots were taken to a triple prism fixed on a tripod on the boat. The tape reading was added to the prism height above the gunwale of the boat and recorded in the data collector. Total survey time varied from about 1.5 days for the smaller sites to about 3 days for the larger, more complex scours. Likewise, the number of survey points varied from 143 for NC-5 to 736 for NC-8. Survey data from the data collector was downloaded to a portable computer in the field following completion of the survey for a scour area.

Connected scour areas were surveyed from November 11 to December 23, 1994 by the COE using total stations. Data was collected and recorded in field note books. The notes were later transcribed by NRCS personnel into a spreadsheet program and saved as an ASCII file. The data was transferred into the Eagle Point Advantage software, reduced and plotted. Plots were ground-truthed using aerial photographs of the scour areas taken by MDC on September 11, 1994. Corrections were made of obvious errant shots and incorrectly entered field data. It normally took about 4 to 6 hours of office time to produce usable plots for each individual scour area.

RESULTS

Topographic maps have been generated for all of the scour areas listed in Table 1. Figure 1 shows the locations of 3 typical scour areas located along the Missouri River in central Missouri. Non-connected scour area NC-11 is an example of a relatively small scour area. (Figure 2). The present Missouri River channel is less than 1/4 mile from the scour hole, and the hole is on the river side of the levee. Thus any out of bank flows will impact the scour hole.

Table 1. Summary of Data for Connected and Non-Connected Scour Areas

Site	Maximum Depth (ft.)	Surface Area (Acres)	Volume (ft.^{3})
Non-Connected			
NC-4	52	17.35	11.4 million
NC-5	43	5.86	4.5 million
NC-8	57	80.32	47.6 million
NC-11	57	9.75	8.2 million
NC-12	53	12.87	9.7 million
NC-16	34	8.56	4.8 million
NC-17	23	31.35	9.5 million
Connected			
S-2	39	16.10	10.2 million
S-10	24	9.15	4.1 million
S-11	38	13.16	9.2 million
S-13	41	39.13	13.7 million
S-14	21	11,21	5.6 million
S-15	24	94.80	23.2 million
S-19	20	63.88	303.7 million
S-21	25	10.06	6.1 million
S-23	13	6.44	1.9 million
S-26	15	6.02	2.0 million

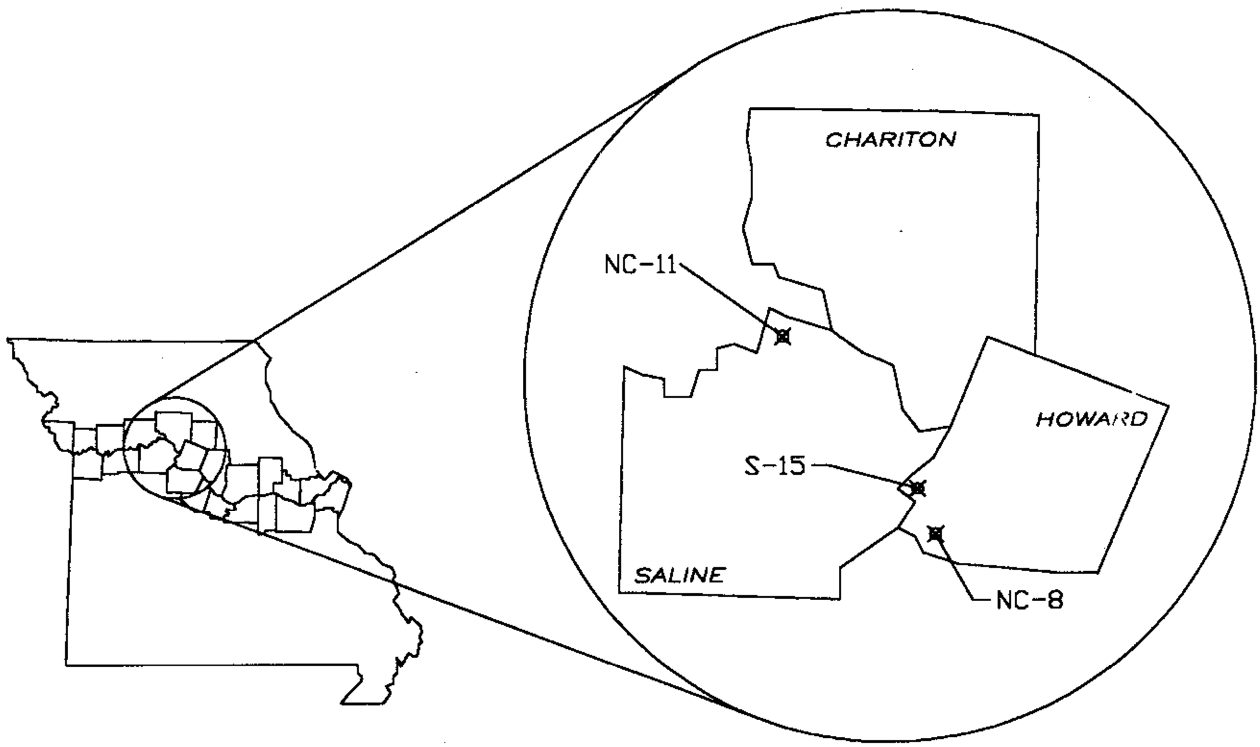

Figure 1 - Location of Typical Scour Areas

NC-8 (Figure 3) is a large non-connected scour area located more than one mile from the Missouri River. The scour occurred where floodwaters moving across the floodplain breached a tie-back levee along Salt Creek. The scour area is considered on the flood plain side of the levee, as the Missouri River would have to overtop or breach the levee to flow into the scour. Salt Creek flows freely into the scour area from the top (north) of Figure 3. The creek flows out to the south (bottom) through a gated pipe in the levee.

Connected scour area S-15 (Figure 4) is a large entrance scour located at the upper end of the Lisbon Bottom meander bend. Galat et al (1995) use the scour area to discuss how differences in geomorphic mode of formation influence the scour features. Overflow from the river breached a river bank levee, forming an elongated, relatively shallow scour covering a large area (about 95 acres). S-15 has about 10 times the surface area of NC-11, but only about 3 times the volume.

This paper is a preliminary report on work in progress. Follow-up surveys of the scour areas are tentatively scheduled for the late fall/early winter of 1995/1996. Plans are to use essentially the same survey techniques as the original surveys.

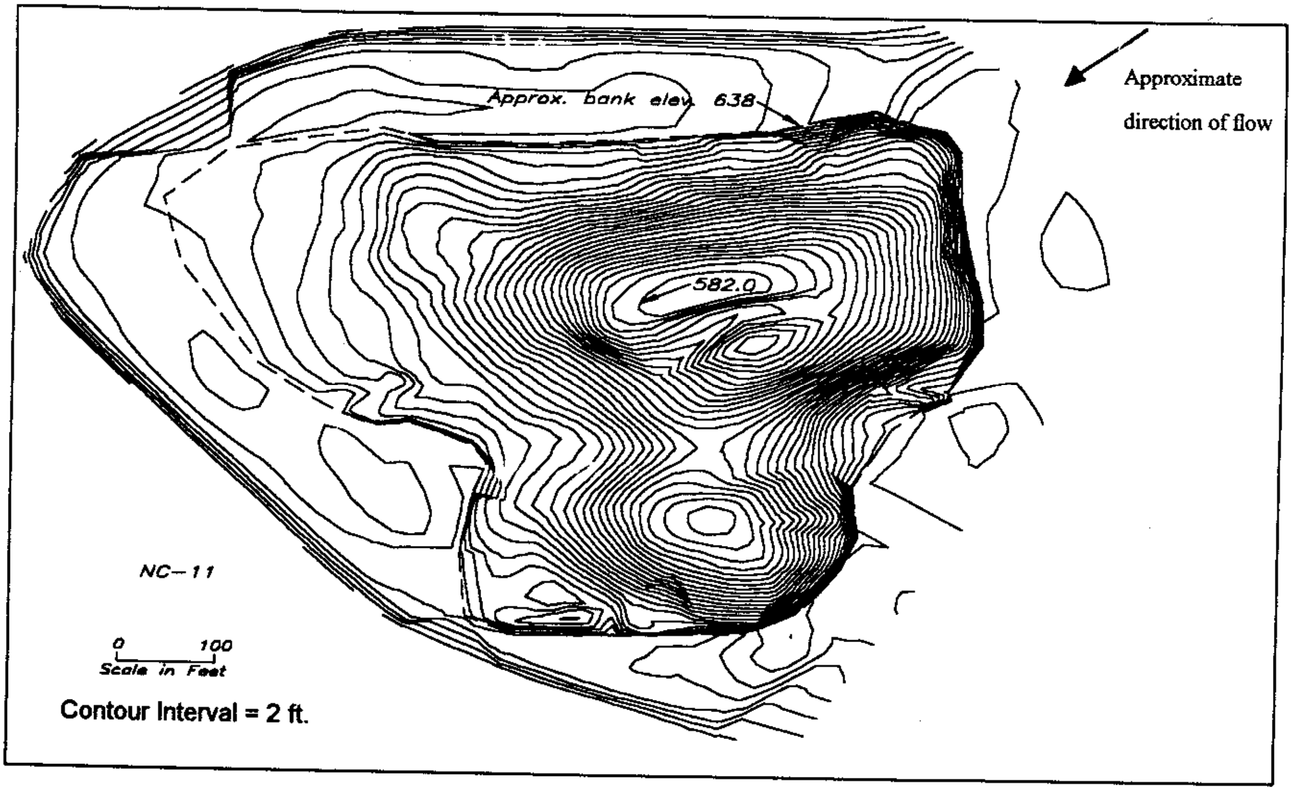

Figure 2 - Non Connected Scour NC-11

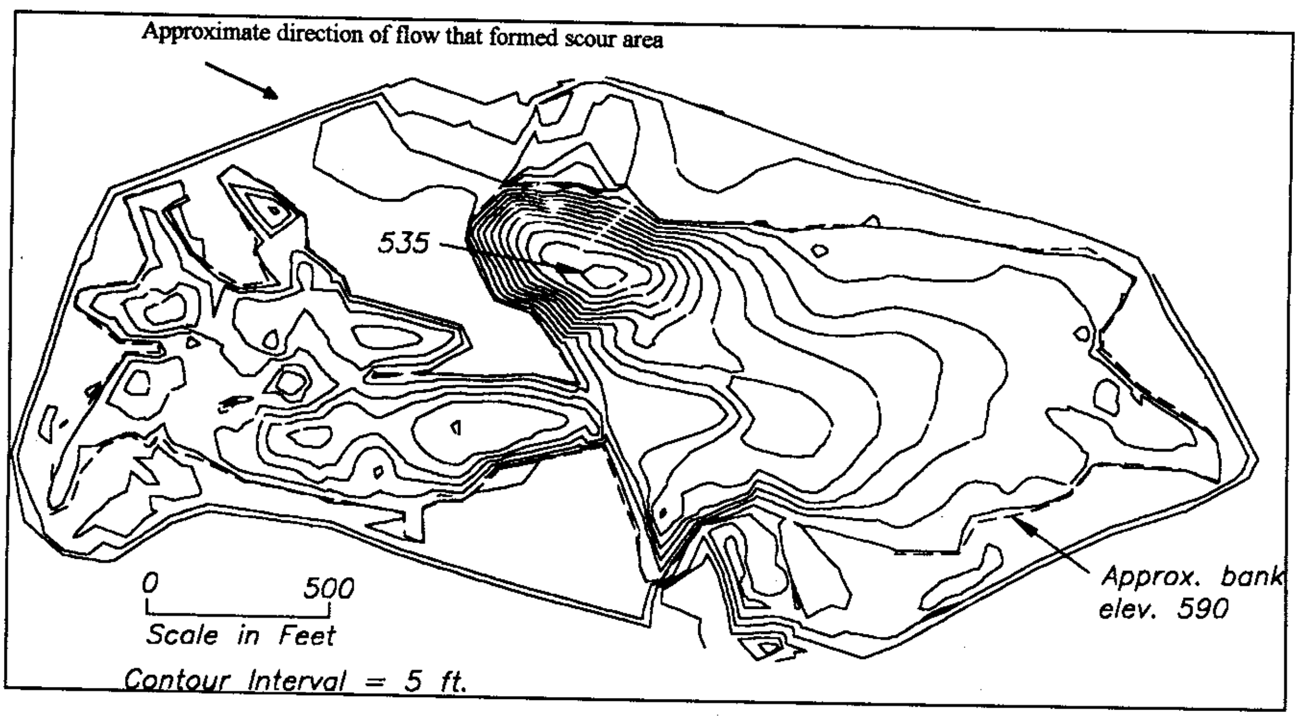

Figure 3 - Non-Connected Scour NC-8

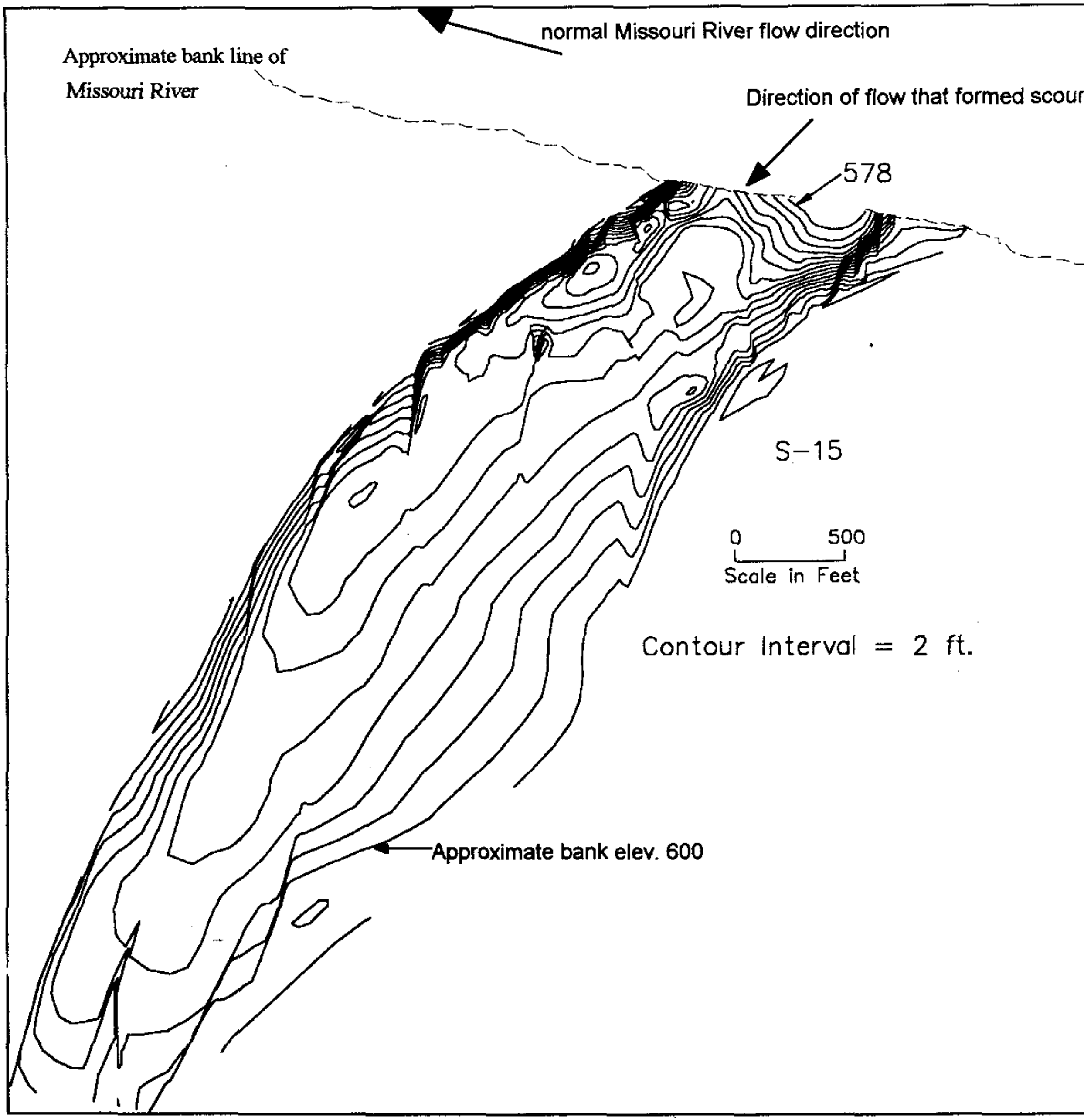

Figure 4 - Connected Scour S-15

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STANDARDIZATION OF THE ANALYSIS AND PREDICTION OF COASTAL SHORELINE EVOLUTION

By Mark B. Gravens, Research Hydraulic Engineer, Coastal Engineering Research Center, Vicksburg, Mississippi

INTRODUCTION

Shoreline change models in general, and GENESIS (GENEralized model for SImulating Shoreline change) in particular, are designed to describe the long-term planform evolution of the beach in the course of its approach to an equilibrium in response to imposed wave conditions, boundary conditions, configurations of coastal structures, and other engineering activities. In recent years, numerical shoreline change models have become an increasingly popular tool for investigating the impacts of proposed coastal projects. State and federal regulatory programs are frequently requiring estimates of project performance and renourishment volumes over a 50-year project lifetime. Shoreline change models are ideally suited for meeting these requirements. Shoreline change models enable the effective analysis and evaluation of coastal projects, specifically the long-term fate of beach fills, feeder beaches, renourishment cycles, and coastal structures designed to enhance the longevity of placed beach fill material.

The accuracy and reliability of a shoreline position change simulation are directly related to the quality and completeness of the input data sets. With regard to GENESIS, operation of the model requires preparation of as many as seven input data files. These input data streams include model setup specifications (spatial and temporal ranges of the simulation, and model calibration parameters), project reach specification (boundary conditions, coastal structures, and beach fill configurations), shoreline position data, and a time history of wave information.

Preparation and analysis of the input and output data streams occupy a substantial portion, perhaps a majority, of the time spent on a GENESIS project. The importance of this aspect of the modeling process cannot be overemphasized for two reasons:

> *The data organization and analysis process itself forms the first and necessary level in understanding coastal processes at the project site.*
>
> *The simulation results must be interpreted within the context of regional and local coastal processes, and the natural variability of the coastal system.*

Preparation of the data streams needed to run GENESIS and interpretation of simulation results form the backbone of the process of conceptualizing a project. The degree of success in a shoreline change modeling effort to a large extent depends on preparation and analysis of the input data that almost always requires use of computer programs. This paper is dedicated to a discussion of a collection of computer programs designed to automate this process. The programs discussed herein have been assembled into a personal computer (PC) based modeling system known within the Corps of Engineers as the Shoreline Modeling System (SMS) (Gravens 1992).

The SMS contains two major coastal processes numerical models, GENESIS (Hanson and Kraus 1989; Gravens, Kraus and Hanson 1991, Gravens 1992) and RCPWAVE (Ebersole 1985; Ebersole, Cialone and Prater 1986). Visualization programs for processing output from these models are included in the SMS. The SMS also contains a suite of 13 system-support programs for data preparation and analysis. These system-support programs automate the analysis and preparation tasks from the user's original data source to input data sets (files) for GENESIS.

SHORELINE POSITION ANALYSIS

GENESIS requires the input of shoreline position data at regularly spaced intervals measured perpendicularly from a baseline oriented along the general trend of the shoreline. The engineer's original source of shoreline position data is typically obtained from drawings or maps derived either from surveys or aerial photographs. These data are subsequently digitized with respect to a rectilinear coordinate system, such as state plane coordinates, through the use of computer-aided drafting software. These shoreline position data must ultimately be transformed to the local coordinate system used by GENESIS. The sequential execution of three of four generalized computer programs (SHORLROT, CUINTP, LINTP, and WTSHO) automate the coordinate system transformation and formatting of the data for input to GENESIS.

The procedure involves three stages. First, the program SHORLROT is used to rotate the digitized shoreline position data into the GENESIS coordinate system and translate the origin as prescribed by the modeler interactively. The second stage involves interpolation of even-interval shoreline position data from the digitized data set. Here the user may choose between linear (LINTP) and cubic (CUINTP) interpolation. The third stage of this procedure involves the program WTSHO which reads the interpolated shoreline position data and writes a shoreline position input specification in the format required by GENESIS. Figure 1 provides a schematic illustration in the form of a flow chart for program usage in the shoreline data preparation procedure.

Note, in Figure 1, that output from one program serves as input to another program and that the analysis proceeds from the engineer's original data source to input for GENESIS. This procedure is used to automate the generation of three (two shoreline position data files and the sea wall position file) of the up to seven input files required to run GENESIS.

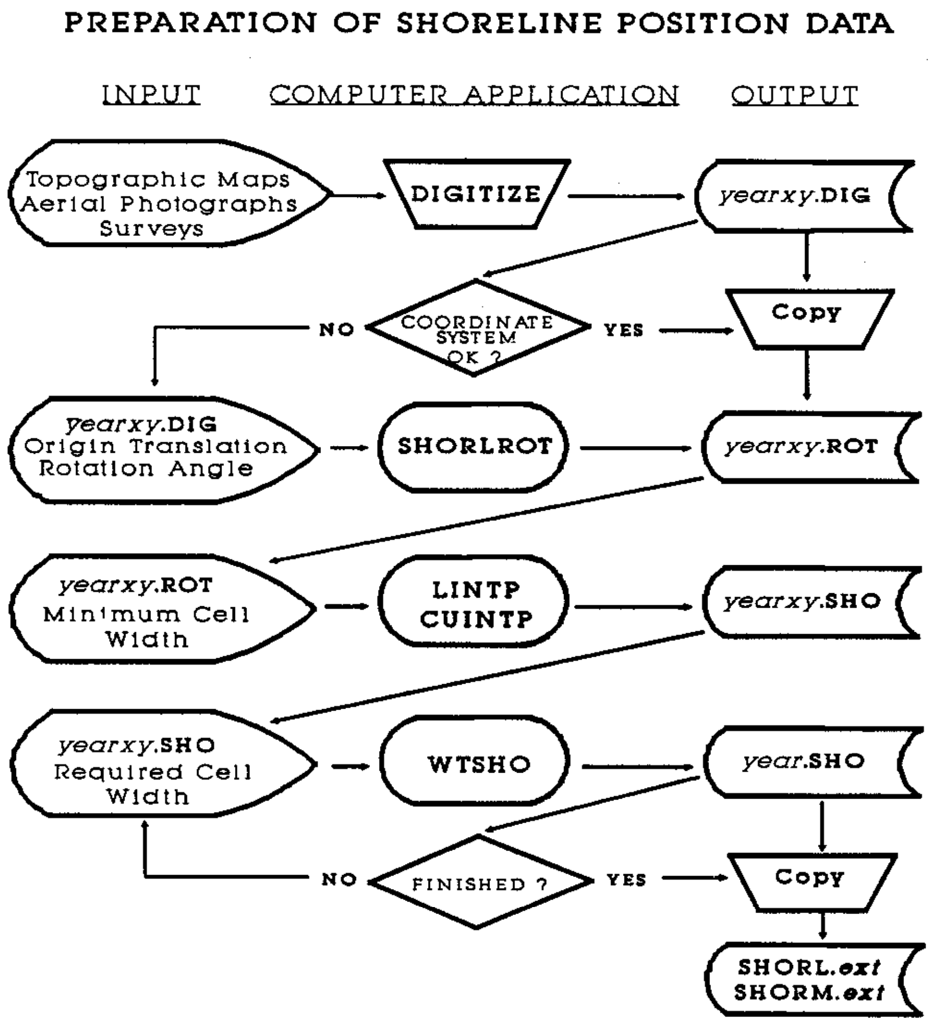

Figure 1. Shoreline data preparation procedure

OFFSHORE WAVE DATA ANALYSIS

GENESIS requires input of a time series of incident wave conditions which serve as the primary environmental driving force for the calculation of longshore sand transport and shoreline change (also influenced by boundary conditions and simulated coastal structures). Therefore, the quality and completeness of the input wave conditions directly impact the accuracy and reliability of predicted shoreline positions. Furthermore, analysis of offshore wave conditions prior to running GENESIS can eliminate much of the uncertainty associated with the outcome (in terms of the magnitude and direction of the longshore sand transport rate) of a GENESIS simulation.

Within the Corps of Engineers, the most extensive and comprehensive source for continuous long-term wave data derives from the numerically generated hindcast wave estimates compiled by the Wave Information Study (WIS). Consequently, the WIS estimates are almost exclusively used in shoreline change modeling efforts within the Corps. The wave data analysis programs presented herein accept, as input, wave data in the standard WIS format.

At a given hindcast station, the WIS hindcast provides estimates of the significant wave height, peak and mean spectral wave period, and direction of propagation as well as primary and secondary wave components (if two distinct wave components can be identified in the 2D frequency-direction wave energy density spectra) at 3-hour intervals. These hindcasts are available for the period from 1956 through 1993 in the Atlantic, from 1956 through 1975 in the Pacific and Gulf of Mexico, and from 1956 through 1987 in the Great Lakes.

Various analyses and transformations of the wave data must be performed prior to conducting a shoreline change simulation using GENESIS. Consideration must be given to the water depth associated with the data (GENESIS requires input of the water depth associated with the offshore wave time series) and wave sheltering by nearby land masses or shoals. Typically, this requires a transformation of the wave information from one water depth to a shallower depth, and the transformation may include the sheltering of wave energy from specific directions. The computer program WAVETRAN was designed to enable GENESIS users to perform these types of transformations. WAVETRAN was originally developed to produce shallow water wave information from deepwater hindcast wave estimates. The methodology for this spectral wave transformation procedure is described by Jensen (1983).

Having completed this initial transformation of the wave data from deepwater to some intermediate water depth (the typical water depth associated with the offshore wave time series input to GENESIS is approximately 20 m), it is recommended that the transformed time series be used to compute potential longshore sand transport rates. The program SEDTRAN uses the energy flux method together with input wave conditions from a time series to estimate the potential longshore sand transport rate. Although the shoreline change model GENESIS provides a is more sophisticated calculation of transport rates by accounting for local shoreline orientations varying in time and space and simulating the effect of coastal structures on the waves and longshore transport within the project reach, the potential transport rates calculated by SEDTRAN enables the development of a reasonable first estimate of the longshore sand transport rate and sediment budget.

Because GENESIS computes longshore sand transport rates and shoreline change on a time step basis (the typical time step used in GENESIS simulations is 6 hr), significant computational effort can be saved if calm or otherwise physically irrelevant wave events are eliminated from (or flagged in) the offshore wave time series input to GENESIS. The program RCRIT computes the potential for a wave of given height, period, and direction, to produce a longshore discharge of water in excess of a critical discharge rate required for significant longshore sand transport. Wave events that are below the threshold are flagged such that GENESIS interprets them as calm events. Kraus, Hanson, and Larson (1988) introduced this threshold to objectively eliminate wave events expected to produce negligible longshore transport, and therefore not significant to long-term shoreline change. The justification for the threshold criteria, first reported by Kraus and Dean (1987), is based on the results of field experiments performed on a medium sand beach. Complete descriptions of the field experiments and listings of the data are given in Coastal Engineering Research Center (CERC) technical reports (Kraus, Gingerich, and Rosati 1989; Rosati, Gingerich, and Kraus 1990).

Two other utility and file handling programs (WTWAVTS and WTWAVES) are involved in the analysis and preparation of offshore wave data for input to GENESIS. The program WTWAVTS enables the modeler to either select a portion of a wave time series from a single file and write it to another file, or to append several files containing individual wave time series to obtain a single file containing a longer time series. The program WTWAVES reads an offshore wave time series and reformats the data for input to GENESIS.

Figure 2 shows a flow diagram for the complete analysis and preparation of offshore wave data. This diagram presents the recommended sequence and usage of the analysis programs introduced above. The first task in a typical analysis is to obtain a WIS wave hindcast time series. The starting point of the analysis is to perform a preliminary transformation of the deep water wave data to satisfy site-specific conditions (specific shoreline orientation, nearshore water depth and wave energy sheltering) using the program WAVETRAN. Depending on the alongshore extent and geological setting of the area of interest, wave data from more than one hindcast station (or more than one WAVETRAN transformation) may be required.

WAVETRAN runs should be performed for shoreline orientations encountered along the region of interest. If a nearshore wave transformation model such as RCPWAVE will be applied in the project study, the water depth specified in the WAVETRAN runs should correspond to the average water depth along the offshore boundary of the RCPWAVE grid, and the specified shoreline orientation should correspond to the alongshore axis of the bathymetry grid.

The third task of the analysis involves the program SEDTRAN. A SEDTRAN run should be performed for each of the unique wave time series created in the second task. This will enable development of a regional potential longshore sand transport sediment budget that should provide insight to the regional processes (magnitude and direction of sand transport rates for various shoreline orientations) at work along the project reach.

WAVE DATA ANALYSIS STAGE 1
(REGIONAL ANALYSIS)

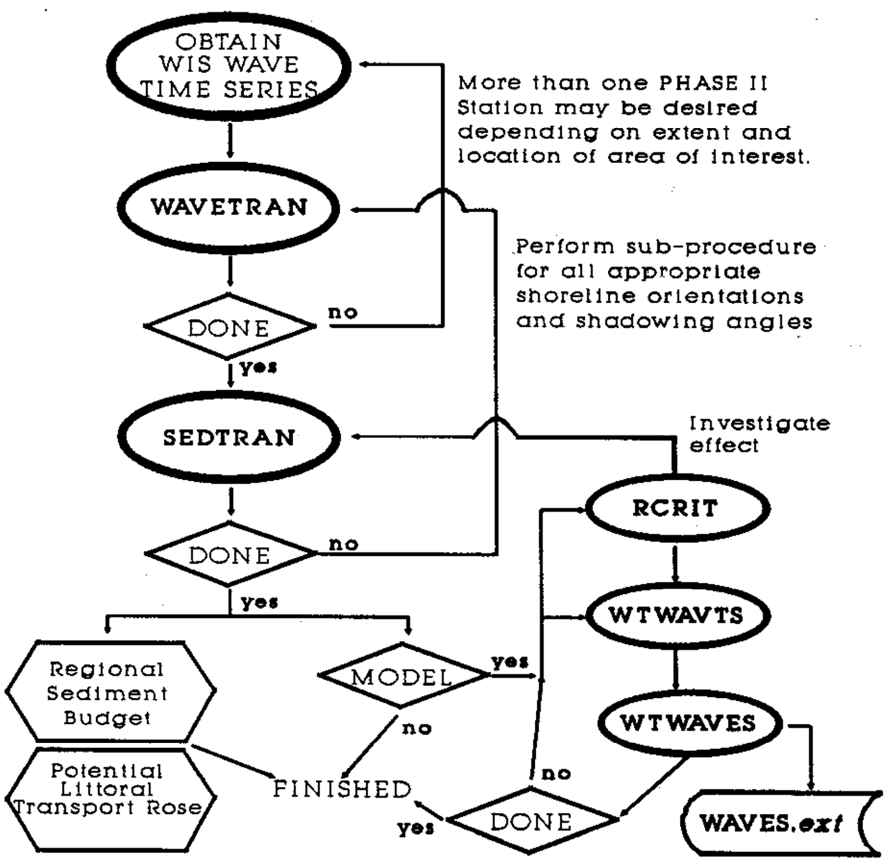

Figure 2 Wave data analysis Stage 1 (regional analysis)

The analysis up to this point has been general and is a recommended procedure for evaluating regional potential longshore sand transport processes regardless of whether numerical shoreline change modeling with GENESIS will be applied. If, however, the intention is to apply GENESIS, the next task would involve using the program RCRIT to eliminate offshore traveling and insignificant waves from the offshore wave time series. After processing the wave time series through the program RCRIT, potential longshore sand transport rates should be re-calculated using the program SEDTRAN (particularly in low wave energy environments). This procedure will enable investigation of the effects of RCRIT on potential longshore sand transport rate calculations.

The next task is to compile a wave time series for the specific simulation time interval for which shoreline change will be modeled. The program WTWAVTS performs this task. After generating the required time series of wave conditions, the program WTWAVES converts the time series to the GENESIS input format and coordinate system. This task concludes preparation of offshore wave data for application of GENESIS.

The offshore wave data analysis, combined with the shoreline position analysis described previously and outlined in Figure 1, will result in the preparation of three or four (if a seawall will be simulated) of the four or five input files required to run GENESIS in a scoping mode application.

NEARSHORE WAVE DATA ANALYSIS

In this section, procedures for refining and expanding the wave data analysis initiated in the previous section are presented. These procedures pertain specifically to use of an external wave transformation model (RCPWAVE) as opposed to the simplified internal wave transformation model contained within GENESIS. Use of an external wave transformation model that accounts for wave transformation over an irregular nearshore bathymetry is recommended for design mode application of GENESIS, whereas the internal wave transformation is usually sufficient for scoping mode applications.

RCPWAVE provides a steady-state solution of the wave field over the 2D RCPWAVE computation grid. The wave height and angle at each grid cell along the nearshore reference line are functions of the water depth (a constant) and the offshore wave height, period, and angle. The input nearshore wave data requirements of GENESIS are pre-breaking wave height, angle, and water depth alongshore (and wave period, which is obtained from the offshore wave event). Consequently, RCPWAVE generates much more information (wave characteristics over the entire 2D RCPWAVE grid) than is required by GENESIS. In fact, GENESIS only requires the wave height and angle and corresponding water depth at one (RCPWAVE) offshore grid cell for each of the alongshore cells within the project reach.

Because RCPWAVE is based on monochromatic wave theory, the equations governing wave refraction and shoaling are independent of wave height, and nearshore wave transformation simulations can be performed using a unit wave height as the offshore input, leaving only two dependent variables, offshore wave period and wave angle. Therefore, if the time series of offshore wave conditions is categorized into wave angle bands and period bands (with a resolution such that the difference in the transformation of wave events at the limits of the angle-period bands is small), relatively few (typically between 40 and 90) nearshore wave transformation simulations can approximate nearshore wave characteristics for the entire offshore wave time series. The RCPWAVE solution by this approach consists of a wave height transformation coefficient and wave angle at each grid cell for each of the offshore wave angle-period band combinations.

Four generalized computer programs are introduced; first to analyze the offshore wave time series, then to translate RCPWAVE output into GENESIS input, and finally to estimate longshore sand transport rates using the RCPWAVE output. The first program, WHEREWAV, categorizes wave events in the offshore time series by wave period (referred to as "period bands") and direction of wave propagation (referred to as "angle bands"), and reports various statistical properties of each of the period and angle band categories. This information is then used to define the number of nearshore wave transformation simulations required to describe the offshore time series. Considering that there could be as many as 2920 unique offshore wave events in a typical GENESIS simulation using a 6-hr time step and a one-year-long offshore wave time series consisting of two wave conditions per time step, the shoreline modeler must make some assumptions concerning nearshore wave transformation and the number of simulations required. The program WHEREWAV was designed to aid in the selection of representative classes of offshore wave conditions for which nearshore wave transformation simulations should be performed. The approach is based on procedures developed and employed in numerous shoreline change studies conducted at CERC.

WHEREWAV input requirements, beyond specification of the input and output file names, include: 1) input file format; 2) convention of wave angles; and 3) shoreline orientation with respect to north. Output for each angle band includes: 1) the number of events occurring within the angle band; 2) the overall average wave angle; 3) the overall average wave height; and 4) the period bands encountered within the angle band. Likewise, output for each period band includes: 1) the number of events occurring within the period band; 2) the overall average wave period; 3) the overall average wave height; and 4) the angle bands encountered within the period band. With this information the shoreline modeler can evaluate the number of nearshore wave transformation simulations required to describe the transformation of the offshore wave time series to the nearshore reference line.

The second program, WTNSWAV, reads nearshore wave information (wave height transformation coefficient and direction of propagation) along a nearshore reference line from a RCPWAVE output file and writes a nearshore wave data base file for input to GENESIS. The data in the nearshore wave data base consist of an offshore wave identification key (which relates the nearshore wave information to offshore waves occurring from a specific angle-period band), followed by a set of nearshore wave height transformation coefficients and wave angles that correspond to wave conditions along the nearshore reference line for a specific RCPWAVE run. These data are listed sequentially in the nearshore wave data base for each of the angle-period band wave conditions transformed using RCPWAVE.

The third program, WTDEPTH reads water depth information (along the nearshore reference line) from a RCPWAVE output file and writes the nearshore reference line depth specification for input to GENESIS. The data consist of water depths corresponding to the nearshore reference wave data points contained in the nearshore wave data base file.

The fourth program, NSTRAN, calculates potential longshore sand transport rates from an input offshore time series, a data base of nearshore wave conditions, and reference nearshore water depths. This program enables refinement of the regional sand transport budget developed in the offshore wave analysis procedures to a more local (project level) potential longshore sand transport sediment budget. Input to NSTRAN includes: (1) an offshore wave time series generated by the program WTWAVES; (2) a nearshore wave data base generated by the program WTNSWAV; and (3) a nearshore depth file generated by the program WTDEPTH. These three input files, together with user-specified input of the time step and, number of events per time step in the offshore wave time series, provide the necessary input for the computations to proceed. NSTRAN also checks for completeness of the nearshore wave data base. This quality check of the nearshore wave data base is possible because the offshore and nearshore wave data are related (through angle-period band categorization) in NSTRAN in the same way as they are in GENESIS.

Figure 3 shows a flow diagram for the nearshore wave data analysis procedure. As indicated in Figure 3, the analysis of nearshore wave data begins with completion of the analysis of the offshore wave data as outlined in Figure 2.

The first step in the analysis involves running the program WHEREWAV. Output from this program defines the number and specific wave conditions that should be transformed from offshore to the nearshore reference line using the wave transformation model RCPWAVE. The second step involves performing the required RCPWAVE simulations. This step often involves several individual simulations.

The third and fourth steps in the analysis involve using the programs WTNSWAV and WTDEPTH. Both programs read output from RCPWAVE and write data in a format suitable for input to GENESIS. Specifically, the program WTNSWAV writes the nearshore wave information data base that becomes input to GENESIS. The program WTDEPTH writes the nearshore reference depths to a file which again becomes input to GENESIS.

WAVE DATA ANALYSIS STAGE 2 (LOCAL ANALYSIS)

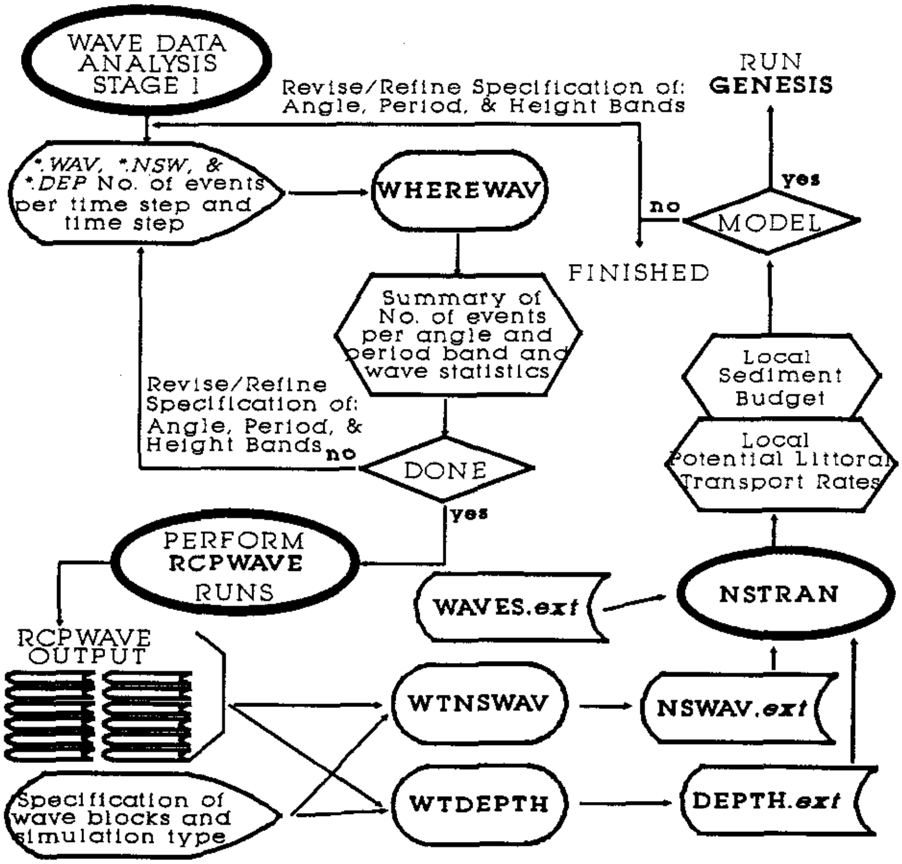

Figure 3 Wave data analysis Stage 2 (local analysis)

The fifth and final step in the analysis is the calculation of potential longshore sand transport rates based on the nearshore wave data base, and requires the program NSTRAN. The result of this step will allow the user to develop a local sediment budget and identify gradients in the longshore sand transport rate that will indicate zones susceptible to shoreline erosion or accretion.

The above analysis, when combined with the shoreline analysis outlined in Figure 1 and the offshore wave data analysis procedure outlined in Figure 2, will result in the preparation of all the input data files required for operating GENESIS in the design mode. The final input file required for operating GENESIS is the model setup file.

The model setup file contains the instructions that control the shoreline change simulation and is the principal interface between the modeler and GENESIS. These instructions include the spatial and temporal ranges of the simulation, structure and beach fill configurations, values of model calibration parameters, and simulation times when output is desired. The organization of the model setup file is in the form of requests for information in a series of lines that are arranged in sections according to general subject. This format has proven to be an efficient and easily understood method for obtaining general model setup parameters.

CONCLUDING REMARKS

Two major numerical models (GENESIS and RCPWAVE), for investigating coastal processes have previously been developed. Their dissemination to field offices within the Corps and private industry must be accompanied with the appropriate technical documentation and additional tools (data analysis, preparation, and visualization programs) required to enable users with limited knowledge of computer programming and numerical methods to apply the models correctly and efficiently. These supplemental computer programs and documentation of application techniques grounded in successful prototype applications are considered essential for wide acceptance and application of a numerical model. If possible, the numerical models and supporting p grams should be packaged and distributed as a complete system. The material presented herein represents an approach taken toward these goals with respect to the numerical shoreline change model GENESIS.

ACKNOWLEDGMENTS

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SCOUR ANALYSIS FOR A DYNAMIC INLET: A CASE STUDY OF THE PROPOSED BONNER BRIDGE SPANNING OREGON INLET, NORTH CAROLINA

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Abstract

A scour analysis was performed for the bridge type study of the proposed Bonner Bridge crossing of Oregon Inlet, North Carolina. Oregon Inlet is subject to frequent storm attack from both hurricanes and northeasters. The analysis includes a hydrologic investigation in order to determine storm stage hydrographs for a design northeaster, 100-year hurricane, and a 500-year hurricane. DYNLET, a one dimensional hydraulic model, was used to model velocity and stage conditions at Oregon Inlet. The hydraulic modeling results were then incorporated into a generalized scour analysis that examined various contraction and pier scour scenarios, including partially submerged pile caps.

INTRODUCTION

The proposed Bonner Bridge over the Oregon Inlet will connect Bodie and Pea/Hatteras Islands in Dare County, North Carolina. Spanning approximately 12,800 feet, the proposed bridge will carry two lanes of traffic. The proposed bridge will replace the current Herbert C. Bonner Bridge which opened to traffic in 1963. The bridge serves as the only means for vehicular transportation between Pea/Hatteras Island and the mainland and plays a key role in evacuation of the island. As many as 10,000 vehicles use the bridge each day during the tourist season. Bonner Bridge also carries electrical power to Pea/Hatteras Island. Disruption of Bonner Bridge, which happened following a 1991 storm, hinders Pea/Hatteras Island storm evacuation and causes extensive losses to area commerce.

SITE DESCRIPTION

Oregon Inlet is located between Bodie and Pea/Hatteras Islands, which are two of the islands forming a group of barrier islands lying just off the North Carolina mainland 1. These barrier islands are a popular tourist destination and are referred to as the Outer Banks of North Carolina. Bonner Bridge, carrying N.C. Route 12, is the only land link for Pea/Hatteras Island.

The Atlantic Ocean lies on the east side of the islands, while a system of shallow sounds lies on the inland side. Oregon Inlet links Pamlico Sound to the Atlantic. Pamlico Sound is approximately 8 miles wide in the Oregon Inlet area.

Oregon Inlet itself historically ranges from 2,100 feet to 6,670 feet wide at its narrowest point and contains a channel that is approximately 30 feet deep. The U.S. Army Corps of Engineers (Corps) has regularly dredged the channel since 1962, because it is the only link between the Sound and the ocean for over 100 miles. In recent years an annual average of 550,000 cubic yards of material has been dredged from the Inlet. In 1989, in order to stabilize the shore at the south abutment of the existing bridge, the North Carolina Department of Transportation constructed a large terminal groin, along the south shore of the Inlet.

HYDROLOGY

Oregon Inlet is in a very dynamic environment that leads to complex hydraulic conditions. Potential scour at Bonner Bridge depends primarily on three variables: water depth, flow velocity, and angle of attack. The hydrologic investigation produced data that aided in establishing parameters to calculate water surface elevation at the inlet. The water surface elevation is constantly changing at coastal locations, and these changes contribute to flow into (flood tide) or out of (ebb tide) Oregon Inlet. The more rapid the rise or fall in water level, the greater the velocities are through the Inlet. Two factors contribute to substantial changes in water surface elevations and velocities within the Inlet, they are:

- Tidal action causes constant flood or ebb flow through the Inlet.

- Storm surge can significantly increase Atlantic Coast water surface elevations over relatively short periods of time.

Spring and mean tides were the two tidal scenarios used in modeling Oregon Inlet. The two tides each have a tidal period of 12.42 hours. Mean tide has an amplitude of approximately 1.0 feet at Oregon Inlet. Spring tide has an amplitude of approximately 1.2 feet at the Inlet.

Storm surge is the relatively large local rise in water level that occurs during a significant storm event. Storm surge tends to be the most damaging force at Oregon Inlet. Storm surges are caused by a combination of the extremely low pressure associated with a severe storm and high winds that literally "pile" water onto the coast. Surges are particularly damaging because water levels can rise as much as 12 feet in as short a time period as 6 hours. These rapid rises in water levels contribute to extremely high velocities in the Inlet. The highest surge water surface elevations occur when the storm surge peaks during the high tide.

Hurricanes and northeasters are the two primary types of major storms plaguing the North Carolina coast. Hurricanes are the more severe storms and have relatively long return periods for intense storms. Hurricane surges may range from approximately 3 to 11.5 feet and arrive in 6 to 12 hours. Although northeasters lack the severity of hurricanes, they tend to be more damaging because the storms are more frequent and may last for up to a week and include several tidal cycles. Typically, northeaster surges may vary from approximately 1.5 to 6 feet and peak in a 12 to 24 hour time period.

The goal of the hydrologic analysis was to obtain probable storm stage hydrographs for a significant northeaster, a 100-year hurricane, and a 500-year hurricane. Stage data from NOAA, the Corps, and the USGS was analyzed and found to contain no significant storm events. Due to the lack of storm stage data, synthetic storms were developed for each of the three storm scenarios. The FHWA recommended procedure for developing storm surges was used to produce synthetic storm stage hydrographs. The procedure uses several hurricane parameters to estimate the maximum and minimum duration storms. Radius to maximum winds, forward speed, maximum surge height for each return period, and mean tide amplitude are the required parameters and were obtained from the FEMA Flood Insurance Study for Dare County, North Carolina (FEMA, 1993). The computer program Storm Surge Elevation (SSEL) was used to develop eight prototype storms for both the 100-year and 500-year hurricanes (Cialone, 1993). It is expected that surge hydrographs from actual 100-year hurricanes would fall within the storm spectrum shown in Figure 1.

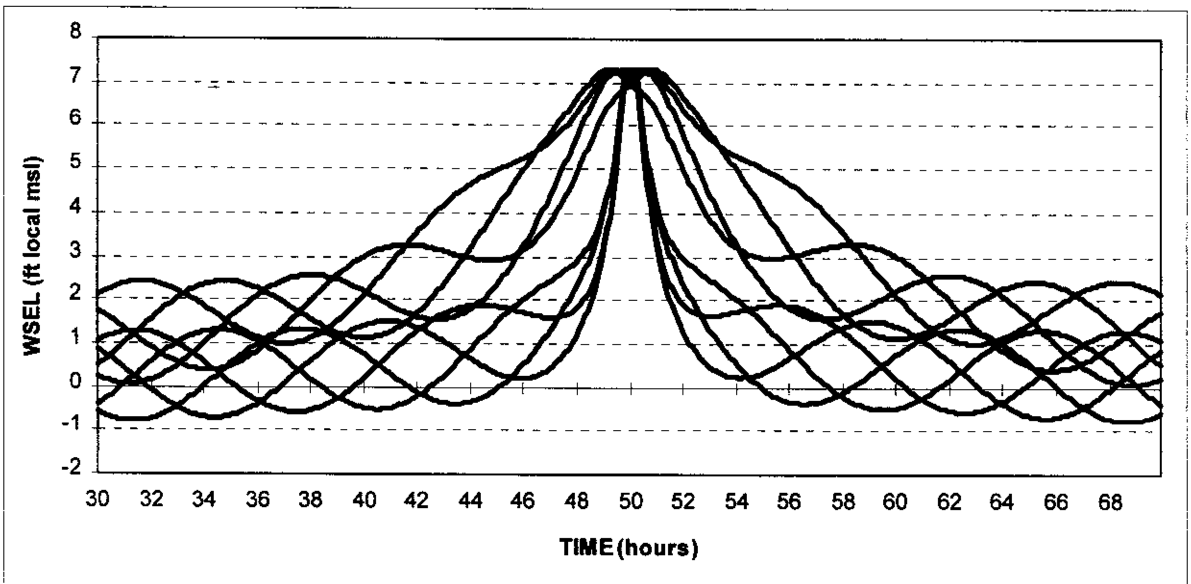

Figure 1 : 100-Year Hurricane Surge Hydrograph

There is no established methodology for developing stage hydrographs associated with northeasters. Because wind action is the main cause of northeaster storm surge, northeaster storm surge was assumed to develop linearly. Typically northeasters peak within 12 to 24 hours. Four different storm surges were developed with surge peaks arriving at 12, 16, 20 and 24 hours. Each surge was added to the spring tide, because the worst case northeaster surge occurs when the surge peaks during a spring tide. There are five Dolan-Davis Scale northeaster classifications, ranging from a relatively weak Class 1 to an extremely damaging Class 5 (Dolan, 1992). A Class 4 northeaster was used as the significant northeaster for modeling because it has a return frequency much greater than the Class 5 storm and is still highly damaging.

Table 1 summarizes the maximum storm surge elevation associated with each of the three storms.

Table 1 : Maximum Surge for Each Storm Including High Tide

Northeaster	100-Year Hurricane	500-Year Hurricane
4.9 feet local MSL	7.3 feet local MSL	8.0 feet local MSL

HYDRAULIC ANALYSIS

The U.S. Army Corps of Engineers computer model, DYNLET 2.01, was used for the hydraulic analysis of Oregon Inlet (Cialone, 1993). DYNLET was designed to model the dynamic, or time dependent, behavior of tidal flows at inlets. Output contains velocities and water level elevations at various selected points in the Inlet and back bay system. The model solves the full one-dimensional, shallow water equations employing an implicit finite-difference technique.

DYNLET models an inlet-bay system composed of channels that are linked at junctions. Each channel is formed by a series of cross sections which are relatively perpendicular to the flow in the channel. End cross sections are assigned a specified boundary condition. The model is then solved for flow and water surface elevations versus time at each cross section.

Modeling Procedure

A base map was created by combining NOAA Nautical Charts and the Corps' bathymetric map of the Inlet. The nautical charts have bathymetric readings for the Atlantic Ocean and the Sound, while the Corps' map has detailed bathymetric readings for Oregon Inlet. A solution domain for DYNLET to accurately model Oregon Inlet was established with the aid of the maps.

Three channels were established to represent the solution domain, from the Atlantic Ocean, through the Inlet, and into the Pamlico and Albemarle Sounds. Channel One begins in the Atlantic Ocean, approximately 14,600 feet east of Bonner Bridge, and extends to a point in the Pamlico Sound approximately 34,800 feet west of Bonner Bridge. Channel Two begins at the west end of Channel One and extends approximately 150,000 feet north into Albemarle Sound. Channel Three begins at the junction of the other channels and extends approximately 150,000 feet south into Pamlico Sound.

Cross sections were placed approximately normal to the flow within each channel. Nineteen cross sections were used to describe Channel 1 from the Atlantic, through Oregon Inlet and into Pamlico Sound. The cross sections are spaced at 1,100 feet intervals through the Inlet. The intervals gradually increase on either side of the Inlet. Channel Two is composed of five, equally spaced cross sections. Channel 2 starts at the junction with Channel 1, extends north through Croatan Sound and into Albemarle Sound. Channel Three is also composed of five, equally spaced cross sections. Channel 3 extends south from the junction with Channels 1 and 2, running along Pamlico Sound. The entire model combines the three channels into a composite system consisting of 31 cross sections and one junction.

Cross sections were incorporated into a data file with station and elevation assigned to various points along the cross section. Cumulative distance along the channel was provided for each cross section. Manning's roughness coefficients were assigned to each point on the cross section. A Manning's roughness coefficient of 0.020 was assigned to all submerged, sandy areas in the Atlantic and the Inlet itself. The submerged stations located in the Sound have a slightly higher Manning's roughness coefficient of 0.025 to account for minor vegetation. All overland stations have a Manning's roughness coefficient of 0.055.

Boundary Conditions

Each of the three channels has a free end requiring a boundary condition. The free end of Channel 1 lies in the Atlantic Ocean and was supplied with a stage hydrograph as a boundary condition. Each storm stage hydrograph developed in the hydrologic analysis forms a particular boundary condition for the free end of Channel 1.

The free ends of Channels 2 and 3 are located in Albemarle and Pamlico Sounds, respectively. The exact conditions at these boundaries are unknown. In order to accurately model the Inlet conditions, the sound boundaries were assigned a zero flow boundary condition and were located far away from the Inlet. In reality there is flow at the sound boundaries, but because stage data was unavailable, the boundaries were placed at a sufficient distance from the Inlet to negate any modeling problems.

Hydraulic Modeling

Bonner Bridge was divided into four sections for analysis. The South Section is at the southern end and extends approximately 1,400 feet northward from the abutment on the bank of Pea/Hatteras Island. The next section, termed the Navigation Section, extends from the end of the South Section to a point approximately 5,000 feet northward. The North Section extends approximately 300 feet northward, from the north end of the Navigation Section to the bank of Bodie Island. The Overland Section extends approximately 6,100 feet northward, from the bank of Bodie Island to the north abutment of Bonner Bridge.

Simulations for each of the eight scenarios for the 100-year hurricane are performed. A representative point in the main channel was located where velocities approaching maximum were expected under a variety of conditions. Maximum velocities at the representative point were compared in order to select the worst case scenario for the 100-year hurricane. As shown in Table 2, the velocities at the representative point in the main channel vary from 7.17 feet per second (fps) to 8.99 fps, a difference of approximately 25 percent. Storm Scenario 3 produced the highest velocities for the 100-year hurricane. Because the hydrographs for the 500-year hurricane are similar to the 100-year storm, Storm Scenario 3 was selected as the worst case storm for the 500-year hurricane.

Table 2 : Maximum Velocities for Each 100-Year Storm Scenario

Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7	Scenario 8
8.95 fps	7.92 fps	8.99 fps	7.75 fps	8.65 fps	7.17 fps	8.60 fps	7.34 fps

Each of the four northeaster storm scenarios was analyzed with DYNLET and maximum velocities at the same representative point were compared. The storm surge peak arriving in 12 hours produces the highest velocities, although all of the northeasters produce similar velocities.

Maximum velocity at each of the four bridge sections was found for the selected storm scenarios. The overall maximum velocity was applied to each of the four bridge sections.

All modeled storms assumed surge arrives perpendicular to the Oregon Inlet channel. Although actual storms may arrive from a range of directions, accurately estimating the maximum possible angle of attack at the bridge accounts for varying storm directions. Angles of attack were estimated by determining potential angles through which an approaching storm could pass through the inlet and still strike the bridge piers. Plan views of the inlet dating back to 1909 were utilized to calculate historical maximum angles of attack. The worst case storm direction was assumed by selecting maximum angles of attack.

Results

Maximum velocity, maximum angle of attack, and maximum water surface elevation were found for each storm event. As displayed in Table 3, maximum water surface elevation occurring at the bridge ranges from 2.5 feet local MSL for the design northeaster to 4.5 feet local MSL for the 500-year hurricane. The angle of attack remains the same for each storm because the assumption is made that the surge for each storm approaches perpendicular to Channel 1. The highest velocities occur in the South and Navigation Sections, while the North and Overland Sections have relatively low velocities for each storm.

Table 3 : Hydraulic Analysis Results - Maximum Values

Storm Event	WSEL	BONNER BRIDGE SECTION							
		South		Navigation		North		Overland	
		V	Angle	V	Angle	V	Angle	V	Angle
	(feet)	(fps)	(deg.)	(fps)	(deg.)	(fps)	(deg.)	(fps)	(deg.)
Design Northeaster	2.5	5.0	38	6.8	24	2.0	62	0.8	33
100-Year Hurricane	3.9	7.8	38	9.8	24	3.3	62	1.4	33
500-Year Hurricane	4.5	8.6	38	10.6	24	3.7	62	1.6	33

SCOUR ANALYSIS

A scour analysis of the proposed conditions was performed for the design northeaster, 100-year hurricane, and 500-year hurricane. The potential for scour damage to the bridge piers was evaluated using the guidelines and procedures presented in HEC-18 (Richardson, 1993).

Long-Term Trends

The depth of Oregon Inlet constantly varies depending on the storm climate. Historically, the channel depth ranges from approximately 5 feet to nearly 45 feet. Average depth within the main channel is approximately 30 feet. Although channel depth varies greatly, no long term trends were seen in the available data that dates back to 1909. Frequent large storms tend to enlarge the Inlet, while the Inlet rebuilds during calm periods.

Contraction Scour

During the periods of rapid surge rise and fall, velocities exceed the critical velocity for very fine sand particles, thereby creating a live bed condition. Although high velocities may induce live-bed conditions within the inlet, the distribution of velocities within the inlet are highly variable. Peak velocities range from approximately 7 feet per second to approximately 23 feet per second within the contracted section. Additionally, there are wide variations in velocity from cross section to cross section. Thus, live bed scour conditions are not likely to fully develop through the inlet. Therefore, the clear-water equation for contraction scour may be applicable at the site. Because the choice of clear water or live-bed contraction scour equations is a subjective one, both methodologies were considered.

Table 4 shows the predicted contraction scour using both methodologies. Contraction scour affects only the South, Navigation and North Sections of the proposed bridge, because these sections are located in the actual Inlet. No contraction occurs within the overland section.

Table 4 : Depth of Contraction Scour

Scour Equation	Design Northeaster	100-Year Hurricane	500-Year Hurricane
Live Bed	**8.4 feet**	**9.2 feet**	**9.5 feet**
Clear Water	**66.5 feet**	**121.2 feet**	**139.5 feet**

As displayed in Table 4, the clear water methodology produces scour estimates that are not considered realistic. Cross sections of Oregon Inlet dating back to 1909 show a maximum channel depth of 45 feet. Since 1899, 12 hurricanes have struck in the near vicinity of Oregon Inlet. Hurricane Donna, which struck Oregon Inlet in September, 1960, produced a sound side surge of 7.5 feet, approximately corresponding to a 100-year event. No severe contraction scour, such as indicated by the clear water estimates, resulted from Hurricane Donna or the other 11 hurricanes.

For live-bed conditions, the upstream width was selected at a point where a channel width can be measured between the groin tip and the shore of Bodie Island. Moving further out to sea causes the cross section width to become infinite and the live-bed contraction scour equation is no longer applicable. Flow through the contracted section was assumed equal to flow through the upstream section. No overbank flow was assumed, although during the larger storm events some overbank flow is present.

Maximum contraction scour occurs at the narrowest section through Oregon Inlet. Bonner Bridge is not located in the contracted section, but is located further inland in an area of expansion. By including contraction scour in the total scour estimate, contraction scour was conservatively assumed to propagate to Bonner Bridge, located 3,300 feet away from the contracted section. In actuality, the effects of the contraction should be nearly dissipated at the bridge site. Also, because of the short peak flow duration, maximum contraction scour as computed using either of the contraction scour equations will, in most cases, not develop.

The natural tendency is for the Inlet to fill during calm periods if the Corps stops dredging. If the Inlet is allowed to partially fill, contraction scour measured from the bed may increase substantially over the predicted values. However, the overall contraction scour depth measured from mean sea level is not expected to increase, because the inlet will attempt to reach the same state of equilibrium as predicted in the contraction scour calculations.

Local Scour

HEC-18 recommends the Colorado State University (CSU) equation to estimate maximum pier scour depths. The basic input parameters are flow depth, pier shape, Froude number, pier width, and angle of attack. Local pier scour may increase in the event that the pile cap is exposed to flow. The bottom of the pile cap is located at elevation 2.0 feet MSL, and therefore is partially exposed to flow during peak storm surge for each storm event.

In the event that the pile cap is exposed to flow, the width and length of the pile cap are substituted as the dimensions of the pier and the HEC-18 methodology for scour caused by an exposed footing is used. The exposed footing computations utilize a revised flow velocity representative of the flow velocity experienced by the pile cap. The revised velocity, V_f and the exposed depth, Y_f are then substituted into the CSU equation.

As displayed in Figure 2, four different pier scour computations were made for Bonner Bridge:

1. The **pile group** calculations were made using total flow depth, the effective width of the pile group, which is 22.5 feet, and the effective pile group length of 40.5 feet.
2. The **full depth** calculations assumed that the pile cap extends to the bed, forming a singular pier with the dimensions of the pile cap, 31.5 feet wide and 85.5 feet long. Total flow depth was used in the calculations.
3. The **obstructed depth** calculations were made with the exposed footing scour methodology which uses revised flow velocity, exposed depth, the pile cap width, and the pile cap length. For the obstructed depth calculations, the exposed depth is the flow depth obstructed by the pile cap, which is simply the maximum surge elevation minus the 2.0 feet MSL elevation of the pile cap bottom.
4. The **cap height** calculations also employed the exposed footing scour methodology, but used the 12 foot pile cap height for the exposed depth rather than the portion actually exposed to flow.

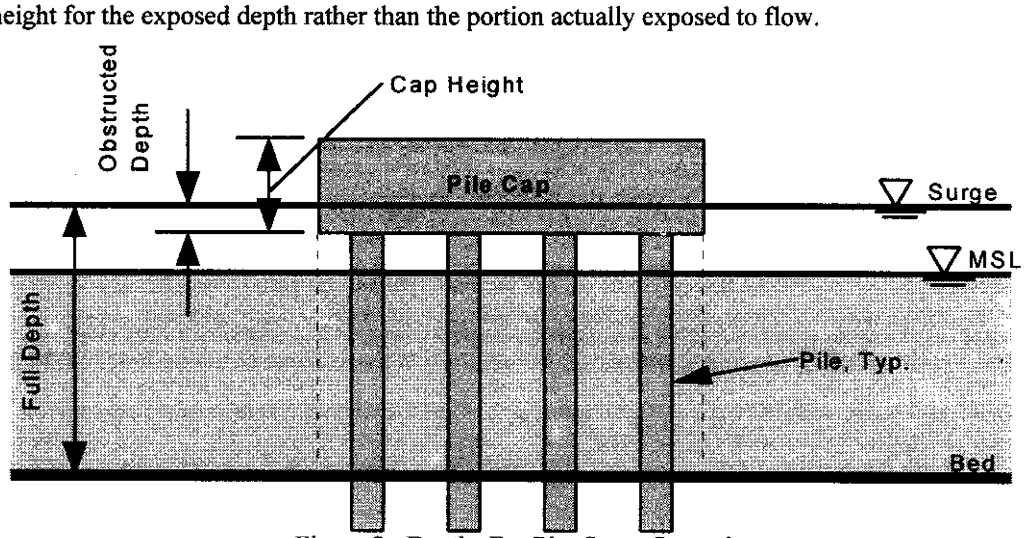

Figure 2 : Depths For Pier Scour Scenarios

Total flow depths are the sum of the approximate channel depth at the point of highest velocity plus the surge elevation at the bridge. Channel depths were taken from the Corps' January 1990 bathymetric map. Angle of attack is the maximum angle estimated for each section.

The predicted pier scour depths were conservatively taken as the greater depth from either the pile group calculations or the obstructed depth calculations. The obstructed depth method was chosen over the cap height and full depth methods because it portrays the actual conditions more closely. Because the bottom of the pile cap is approximately 2.0 feet above mean sea level, only that portion of the surge above +2.0 feet elevation will strike the pile cap. It is unrealistic and overly conservative to use the actual 12 foot pile cap height or extend the pile cap the entire depth of the water column because the flow never encounters more than the 2.5 feet of pile cap height (max 500-year surge height of 4.5 feet MSL minus the 2.0 feet MSL pile cap bottom elevation).

As shown in Table 5, pier scour was predicted for each of the four bridge sections. The recommended scour estimates are highlighted. The 100-year hurricane pier scour depths for the South and Navigation Sections are approximately 9 feet greater than at the same locations for the design northeaster. The scour estimates for the 500-year hurricane are only slightly greater than the 100-year scour estimates.

Table 5 : Pier Scour for Northeaster and 100-Year Hurricane (feet)

Northeaster	Scour Assumption	SOUTH	NAVIGATION	NORTH	OVERLAND
	Total Flow Depth	26.1	26	12.7	2.5
	Pile Group	41.5	45.9	24.2	6.9
	Obstructed Depth	33.2	35.3	23.3	10.1
	Cap Height	58.1	61.8	40.7	13.4
	Full Depth	66.3	70.4	41.1	13.4

100 Year	Scour Assumption	SOUTH	NAVIGATION	NORTH	OVERLAND
	Total Flow Depth	27.5	27.4	14.1	3.9
	Pile Group	50.7	54.4	30.5	9.5
	Obstructed Depth	51.0	52.7	36.7	16.3
	Cap Height	70.3	72.5	50.6	18.5
	Full Depth	80.9	83.4	52.0	18.5

Total Scour

Total scour was estimated as the sum of any long term trends, contraction scour, and pier scour. Because long-term effects are not likely to be significant, total scour at the proposed bridge is simply the sum of contraction and pier scour. The 100-year hurricane yields more severe scour than the design northeaster for all bridge sections, thereby making the 100-year hurricane the critical design storm.

As summarized in Table 6, the greatest scour is predicted for the South and Navigation Sections. Scour predicted for the design northeaster is approximately 11 to 38 percent less than the 100-year hurricane.

Table 6 : Maximum Predicted Scour at Proposed Bonner Bridge (Feet)

Design Northeaster	**South**	**Navigation**	**North**	**Overland**
Contraction Scour	8.4	8.4	8.4	0
Pier Scour	41.5	45.9	24.2	10.1
Total Scour Depth (below mud line)	**49.9**	**54.3**	**32.6**	**10.1**

Table 6, continued

100-Year Hurricane	South	Navigation	North	Overland
Contraction Scour	9.2	9.2	9.2	0
Pier Scour	51.0	54.4	36.7	16.3
Total Scour Depth (below mud line)	**63.7**	**64.0**	**45.9**	**16.3**
500-Year Hurricane	**South**	**Navigation**	**North**	**Overland**
Contraction Scour	9.5	9.5	9.5	0
Pier Scour	55.7	56.9	40.5	18.0
Total Scour Depth (below mud line)	**65.2**	**66.4**	**50.0**	**18.0**

CONCLUSION

The scour analysis performed for the bridge type study adequately models the conditions at the proposed Bonner Bridge crossing of Oregon Inlet. Because of the nature of a bridge type study, exact pier locations were unknown therefore generalizations were made to estimate potential scour. The bridge site was divided into four areas having distinct hydraulic conditions and worst case scour was calculated for a representative pier in each section.

DYNLET hydraulic modeling software offers a relatively straight forward method to model unsteady flow through inlets. Engineers and scientists will find DYNLET similar to other one dimensional hydraulic modeling software with the exception that unsteady flow can be modeled. The computed output, of stage and velocity at each time interval for every station in each modeled cross section is extremely valuable for local scour calculations.

Several findings are of particular importance. The 100-year hurricane causes worse scour at the proposed Bonner Bridge than the design northeaster. Although severe northeasters may cause more damage to the coastline than some hurricanes, hurricanes have the potential to cause greater scour because of higher velocities encountered with hurricane storm surge. Historical data shows contraction scour at Oregon Inlet seems to be resulting from live-bed conditions. Based on the HEC-18 equations, the partial submergence of a pile cap may or may not increase potential scour. Pier scour calculations need to be performed for both the pile group and the submerged portion of the pile cap to determine worst case localized scour. The results, although generalized, represent reasonable scour predictions upon which decisions for the bridge type study and preliminary design may be based.

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Numerical Modeling of Estuarine Topography Change in the West Coast of Taiwan

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Abstract: A two-dimensional model, which includes the effects of tide, wave, and river inflow was developed to simulate the topographical change near the river mouth. In order to understand the characteristic of topographical change near the Chou-Shui River Mouth in the west coast of Taiwan, the field datas taken by Tainan Hydraulics Laboratory were applied to determine the model domain and the conditions of simulations. The parameters used in the numerical model were calibrated by the observed tidal current data, and the results show that the topographical changes inside and outside the surf zone and in the river delta are dominated by wave, tidal current, and river inflow, respectively. The topographical changes outside the surf zone is insignificant. The amount of topographical changes inside the surf zone and river delta arre proportional to the strengths of wave and river discharge. Generally, the simulation results show quite reasonably.

INTRODUCTION

The mouth of a river is the place where the river meets the ocean. In this area, the interaction of the physical forces from both the land and the ocean causes special forms of sediment transport and bathymetry. River mouths have always been the centers of human activities. In Taiwan, due to the rapid growth of business and industry in recent years, productive activities in the coastal area increase greatly, which causes man-made changes to the environment besides the natural processes. There are about 60 rivers open their mouths along the 500 kilometer coast-line in the west coast of Taiwan, which means, about every 8 kilometers average, there will be one river flow from east to west, and this should have considerable influences in the change of the coastal environment. Furthermore, from observations, tidal currents as well as monsoon waves in the Taiwan Strait are also responsible for the coastal changes. In the present research, floods, tides, and waves are the main factors considered in establishing a numerical model to predict the sediment transport and changes in bathymetry for future planning for river or coastal engineering in Taiwan.

In the previous works, Young and Lin (1989) applied a two-dimensional plan model to study the topographical changes. In their model, the flow field at the river mouth was assumed to follow the Gaussian distribution, and the changes of water level and tidal currents were neglected. Shieh (1989) applied a numerical model to study topographical changes in the river-dominated type river mouth, but wave and tidal effect were both not included in the model. Watanabe (1982), De Vriend (1987), Lin (1993), and Yamashida (1981) all considered that coastal sediment transport were caused only by wave induced long shore current. Danish Hydraulic Institute (1992) simulate with one-line coastal evolution model the topographical changes of the coastal area of the Yun-Lin county under the combined actions of wave and tidal current, but the effect of river inflow was not included in the model.

The mathematical model set up in this paper includes four sub-model, i.e. wave model, hydrodynamic model, sediment transport model, and topographical change model. The Cartesian coordinate system used in the mathematical model is illustrated in Fig. 1 The equation of each model are described below.

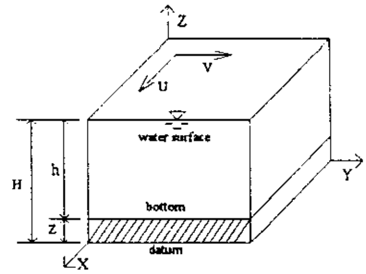


Fig. 1. The Coordinate System of the Governing Equation

Wave Model: Berkoff (1972,1976) derived an elliptic equation approximating complete wave transformation process for linear waves over an arbitrary bathymetry constrained only to have mild slope . The mild slope equation can be expressed in the form

$$\frac{1}{a}\left\{\frac{\partial^2 a}{\partial x^2}+\frac{\partial^2 a}{\partial y^2}+\frac{1}{CC_g}\left[\nabla a\cdot\nabla(CC_g)\right]\right\}+K^2-|\nabla s|^2=0 \tag{1}$$

$$\frac{\partial}{\partial x}(a^2CC_g|\nabla s|\cdot\cos\theta)-\frac{\partial}{\partial y}(a^2CC_g|\nabla s|\cdot\sin\theta)=0 \tag{2}$$

where C=the wave celerity; C_g=the group velocity; $a=\frac{gH_w}{2\sigma}$, H_w=the wave height; σ=the angular frequency; s= the phase function; K= the wave number; θ= the wave direction angle.
The irrotationality of the phase function yields the following expression

$$\frac{\partial}{\partial x}(|\nabla s|\cdot\sin\theta)-\frac{\partial}{\partial y}(|\nabla s|\cdot\cos\theta)=0 \tag{3}$$

The above governing equations are only valid outside the surf zone. Waves break when their height reaches a limiting value relative to their length to the water depth. Le Mehaute and Koh(1967) suggested the following equation for describing breaking wave based on theoretical analysis.

$$\frac{H_b}{L_b}=0.142\tanh\left(\frac{2\pi h_b}{L_b}\right) \tag{4}$$

where H_b = the breaking wave height; h_b =the breaking water depth; L_b=the wave length at breaking point.
Dally et al. (1984) introduced the following energy dissipation equation to evaluate wave height after breaking.

$$\nabla\cdot(a^2CC_g\nabla s)=-\frac{\kappa}{h}\left\{a^2CC_g|\nabla s|-\left[\left(\frac{g}{2a}\right)^2\gamma^2h^2CC_g|\nabla s|\right]_s\right\} \tag{5}$$

where the subscript s denotes the physical quantity within the surf zone, and conventionally k =0.2, γ=0.4.

Hydrodynamic Model: The flow field in river and coastal area is simulated by a two-dimensional depth averaged continuity and momentum equation as follows:

$$\frac{\partial h}{\partial t}+\frac{\partial(Uh)}{\partial x}+\frac{\partial(Vh)}{\partial y}=0 \tag{6}$$

$$\frac{\partial U}{\partial t}+U\frac{\partial U}{\partial x}+V\frac{\partial U}{\partial y}=-g\frac{\partial H}{\partial x}-F_x+M_x-R_x \tag{7}$$

$$\frac{\partial V}{\partial t}+U\frac{\partial V}{\partial x}+V\frac{\partial V}{\partial y}=-g\frac{\partial H}{\partial y}-F_y+M_y-R_y \tag{8}$$

where h = water depth; H = water surface level; U and V = depth-average flow velocity in the x and y direction; F_x and F_y = bottom friction terms in the x and y direction; M_x and M_y = lateral mixing terms in the x and y direction; R_x and R_y = radiation stress terms in the x and y direction.

The bottom friction for Nishimura's(1982) relationship are

$$F_x = \frac{C_f}{h}\left\{(W + \frac{w_b^2}{W}\cos^2\theta)U + \frac{w_b^2}{W}\cos\theta\cdot\sin\theta\cdot V\right\} \tag{9}$$

$$F_y = \frac{C_f}{h}\left\{\frac{w_b^2}{W}\cos\theta\cdot\sin\theta\cdot U + (W + \frac{w_b^2}{W}\sin^2\theta)V\right\} \tag{10}$$

in which

$$W = \frac{1}{2}\left\{\sqrt{U^2 + V^2 + w_b^2 + 2(U\cos\theta + V\sin\theta)w_b} + \sqrt{U^2 + V^2 + w_b^2 - 2(U\cos\theta + V\sin\theta)w_b}\right\} \tag{11}$$

$$w_b = \frac{\sigma H_w}{\pi \sinh kh} \tag{12}$$

where C_f=roughness coefficient in the wave-current coexist field.

The lateral mixing terms are

$$M_x = \frac{\partial}{\partial x}(\varepsilon\frac{\partial U}{\partial x}) + \frac{\partial}{\partial y}(\varepsilon\frac{\partial U}{\partial y}) \tag{13}$$

$$M_y = \frac{\partial}{\partial x}(\varepsilon\frac{\partial V}{\partial x}) + \frac{\partial}{\partial y}(\varepsilon\frac{\partial V}{\partial y}) \tag{14}$$

where ε is the dispersive coefficient which can be expressed as(Longuet-Higgins, 1970)

$$\varepsilon = Nl\sqrt{gh} \tag{15}$$

$$l = h/\tan\beta \tag{16}$$

where N=0.01 in this study; β = bottom slope.

The radiation stress terms are

$$R_x = \frac{1}{\rho h}(\frac{\partial S_{xx}}{\partial x} + \frac{\partial S_{xy}}{\partial y}) \tag{17}$$

$$R_y = \frac{1}{\rho h}(\frac{\partial S_{yx}}{\partial x} + \frac{\partial S_{yy}}{\partial y}) \tag{18}$$

where $S_{xx}, S_{xy}, S_{yx}, S_{yy}$ = radiation stress component, which can be expressed as(Longuet-Higgins & Stewart, 1964)

$$\begin{bmatrix} S_{xx} & S_{xy} \\ S_{yx} & S_{yy} \end{bmatrix} = E\begin{bmatrix} n\cos^2\theta + \frac{1}{2}(2n-1) & \frac{n}{2}\sin 2\theta \\ \frac{n}{2}\sin 2\theta & n\sin^2\theta + \frac{1}{2}(2n-1) \end{bmatrix} \tag{19}$$

where $E = \frac{1}{8}\rho g H_w^2$; $n = C_g/C$.

Sediment Transport Model: According to field investigation, the suspended load in the Chou-Shui River is very fine and does not contribute directly to change in bottom elevation, and is neglected in this paper. The sediment transport rate in a wave-current coexist field is calculated by Watanabe's(1984) formula as follows:

$$q_x = F_c U \tag{20}$$

$$q_y = F_c V \tag{21}$$

where $F_c = A_c(u_*^2 - u_{*c}^2)/g$, $0.1 < A_c < 1$; u_* = shear velocity; u_{*c} = critical shear velocity of sediment. The shear velocity is calculated by Eqs(22) and critical shear velocity is calculated by Iwagaki's(1956) formula as Eqs(23).

$$u_* = \sqrt{\frac{\tau_b}{\rho}} = \sqrt{\frac{\rho h \sqrt{F_x^2 + F_y^2}}{\rho}} = h^{1/2}(F_x^2 + F_y^2)^{1/4} \tag{22}$$

$$u_{*c} = \frac{\sqrt{8.41 \times (d/10)^{11/32}}}{100} \qquad 0.065mm < d < 0.565mm \tag{23}$$

Topographical Change Model: The topographical change can be evaluated by the following equations:

$$\frac{\partial z}{\partial t} + \frac{1}{1-\lambda}\left(\frac{\partial q_x}{\partial x} + \frac{\partial q_y}{\partial y}\right) = 0 \tag{24}$$

where q_x and q_y= sediment transport rate in the x and y direction; λ = porosity of bed material ($\lambda = 0.4$ in this study).

NUMERICAL SIMULATION

Numerical Scheme: A leap-frog scheme within explicit finite difference method is applied in this study for solving those governing equations in hydrodynamic model and topographical change model. Numerical scheme of the RCP wave model (US Army Corp of Engineer, 1986) is used for solving those wave equations in this study. The wave field computation, flow field computation and topographical computation are uncoupled.

Stability Analysis: The governing equations in hydrodynamic model and topographical model are discreted by explicit finite difference method, and hence the stability of model must satisfy the Coururant-Friedrichs-Lewy (CFL) condition, i.e. Courant number $C_r < 1$.

$$C_r = \frac{\left(\left|U \pm \sqrt{gh}\right|_{max}, \left|V \pm \sqrt{gh}\right|_{max}\right)_{max} \cdot \Delta t}{(\Delta x, \Delta y)_{min}} < 1 \tag{25}$$

However, eqs(25) is just a necessary condition, not a sufficient condition. By the results of stability analysis, the maximum Courant number can reach up to 0.3 under waves, tide, and river flow coexist in the numerical model.

Flow Chart of Numerical Simulation: Flow chart of numerical simulation is shown as Fig. 2. The required wave field and accompanying radiation stress are first computed under a tidal level and then the tide and wave induced flow field is calculated by the hydrodynamic model, moreover, sediment transport and resultant topography changes are calculated after the flow field computation. The tidal level change and the topography change will influence both wave and current ,calling for an additional computation loop. Since wave and tide coexist in the computational domain, the influence of tidal level change on wave field should be considered. In this study, wave field is recomputed every time interval of 30 minutes. Therefore,the wave field is kept in

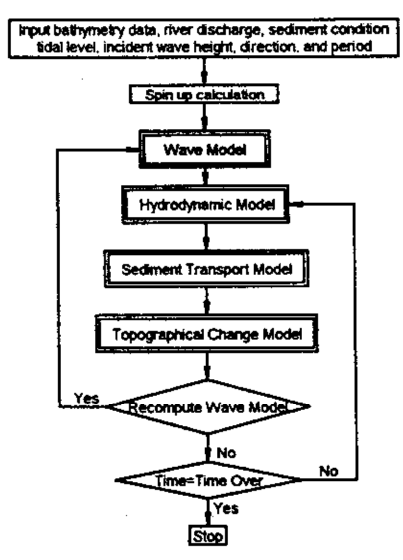


Fig. 2. Computation Flow chart

same condition during the 30 minutes interval and then is renewed in the next 30 minutes interval. Spin up calculation of the wave field and flow field continue for seven tidal periods untill the velocities and water depths at every computational grids are convergence.

Boundary Condition: Boundaries in this study can be illustrated as Fig. 3. They include the river boundary B_1, river flood plan boundary B_2, wall boundary B_3, side boundary B_4, offshore boundary B_5 and tidal flat boundary B_6. Their conditions are prescribed as follows:

1. Boundary condition of B_1 (river boundary) is considered as the hydrograph of discharge.
2. Boundary condition of B_3 (wall boundary) is considered as the non-slip condition.
3. Boundary condition of B_4 (side boundary) is considered as the water level change and is calculated by the following equations:

$$H = H_{tide} + \overline{\eta} \tag{26}$$

where H_{tide} = tidal level; $\overline{\eta}$ = wave setup and setdown, which can be expressed as follows:

$$H_{tide} = A\cos(\omega t - \phi) \tag{27}$$

$$\overline{\eta} = -\frac{1}{8}\frac{H_w^2 k}{\sinh 2kh} \ (outside\ surf\ zone)\ , \ \frac{d\overline{\eta}}{dx} = \frac{\tan\beta}{(1+\frac{8}{3}\gamma^2)} \ (inside\ surf\ zone) \tag{28}$$

where A =amplitude of tidal components; ω= angular frequency of tidal components; ϕ = phase lag.

4. The offshore boundary B_5 is located in a sufficient deep region where far from the wave breaking line. The height,direction and period of incident wave and the tidal level variation are used as the boundary condition of B_5.
5. The treatment of tidal flat and river flood plain is carried out by means of a moving boundary technique which may be stated as follow:

After computing new velocity in the hydrodynamic model, the water depth in every grid is checked whether it reached a critical depth or not. The value of new velocities at four side of grid are all accepted only if the water depth in that grid is deeper than the critical depth, otherwise only the velocity toward the grid can be kept, those velocities flow out the grid are set to be zero. Physically, this means that there can be flow towards dry point but there can not be any flow from the dry point.

6. The condition of sediment transport on each boundaries is assumed to be in equilibrium state.

Computational Domain: The computational domain in this study as shown in Fig. 4 includes coastal area from the place which is 5 km north of Fan-Yuan to the south at San-Tyau-Lun. The distance from the northern to the southern is about 34 km. Also, the western boundary reaches the line of 35 m water depth. The Tzyh-Chyang B. is chosen as the river boundary, from river mouth to the Tzyh-Chyang B. is around 15 km.

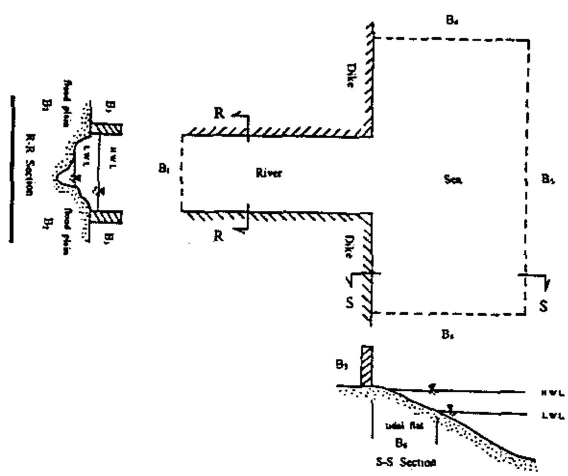


Fig. 3. Sketch of Computational Boundary

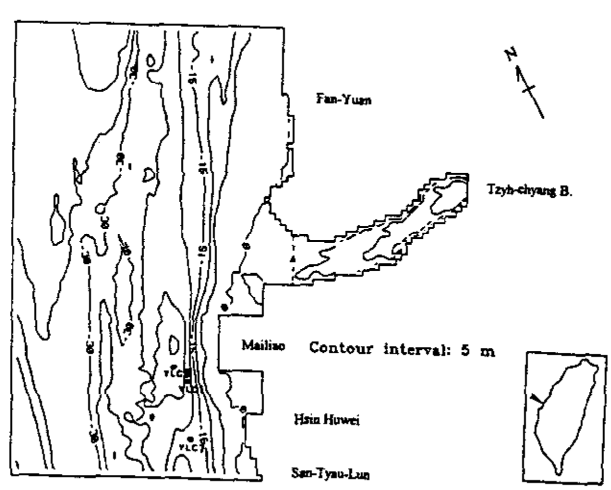


Fig. 4. Computational Domain

Computational Condition: Six cases have been simulated in this study, their computational conditions are presented in Table 1. The incident wave conditions in the study area are characterized by a fairly constant wave climate with significant height $H_w = 1.7$ m and period $T = 6.3$ sec. However, during period with extreme winter monsoon winds, the wave can reach heights up to $H_w = 3$ m and $T = 8.5$ sec. The main wave direction is NNE. The inflows from the river boundary are Q=2500 cms and 500 cms to represent the discharge in the period of wet and dry seasons, respectively. In calculating sand transportation, the influence of wash load to the topography change will not be considered. The conditions of sediment transport in the river boundary and the southern or nothern boundary in coastal area is taking the quantity to b n a state of equilibrium. The grain size of sediment on the river bed and sea bottom is assumed to be $d_m = 0.22$ mm according to field investigation. From the field investigation the dominated tidal component in the study area is M_2 tide , the M_2 component of tide records at San-Tyau-Lan could be applied on the southern boundary. However, the northern and western boundary should be interpolated from the corresponding M_2 tide at Fang-Yuan station and San-Tyau-Lun station. Not only the tide condition should be applied to the southern and northern boundary conditions, but also the wave induced setup and setdown ought to be in the consideration.

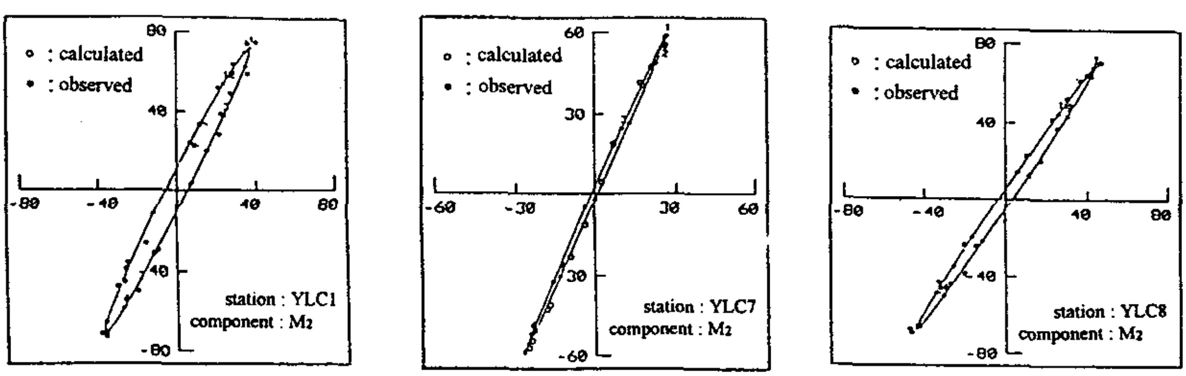
The grids size in wave model is 50m by 50m, and 400m by 400m in hydrodynamic model. The iteration time step Δt is 5 seconds in hydrodynamic model and 30 minutes in wave model. Before the actual simulation, the model must be spined up by 3 days' computation.

	Wave condition			*Rive condition*	*Tide condition*					*Sediment condition*	*Spin up time (day)*	*Simulation time (day)*
	H_w (m)	θ (direction)	T (sec)	Q (cms)	A_F (m)	A_S (m)	ω (°/hr)	ϕ_F (°)	ϕ_S (°)	d_m (mm)		
A	no waves			500								
B	1.7	NNW	6.3	500								
C	3.0	NNW	8.5	500								
D	no waves			2500	1.37	0.91	28.98	335.6	323.1	0.22	3	2
E	1.7	NNW	6.3	2500								
F	3.0	NNW	8.5	2500								

Table 1. Computational Condition

*subscript F denotes Fan-Yuan *
subscript S denotes San-Tyau-Lun

Calibration and Verification: There are three tidal current observation points in the study area were investigated in July 1992 by the Tainan Hydraulics Laboratory. The corresponding locations are shown in Fig. 4. Fig. 5 shows the results of calibration and verification. These figures shows that the simulation coincides with the observation results.



(a). Results of Calibration (b). Results of Verification (c). Results of Verification

Fig. 5. Results of Calibration and Verification

Results of Flow Field Simulation: Fig. 6 shows relationships between tidal level change and flow field variation in case F. Fig. 6-(a) shows the flow field in the period of spring tides. The main flow of Chou Shui River tends to move northward of maximum speed 1.5 m/s and the blank in the south bank of river represents the dry flood plain. It is seen that the maximum speed of offshore tidal currents is almost zero and the longshore currents move southwestward of maximum speed 0.7 m/s. The offshore tidal currents tends to move southwestward of maximum speed 1 m/s in the period of ebb tides as shown in Fig. 6-(b), but the longshore currents still move southwestward. The rip currents also happen in the period of ebb tides at tidal flat. Fig. 6-(c) shows that the tidal currents at offshore become nearly zero in the period of neap tides. As well as moving southwestward the longshore currents also have northeastward components. The blank in the nearshore area represents the exposed tidal flat. In Fig. 6-(d) the flow field which is in the period of flood tides. The tidal current at offshore change to move northeastward, and the maximum current speed is around 1.2 m/s.

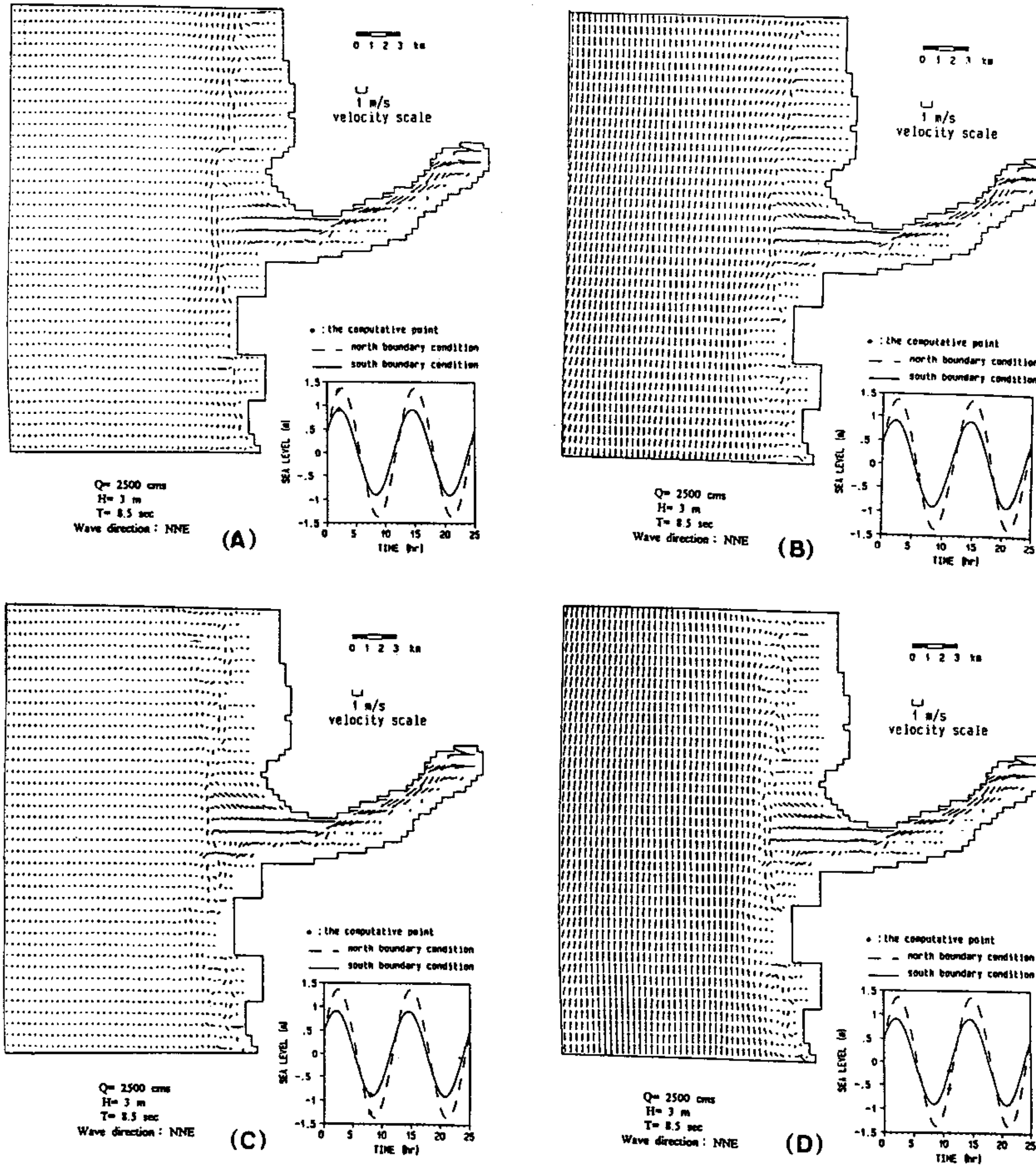


Fig. 6. Flow Field with Different Tidal Phase in Case F

Results of Topographical Change Simulation: Fig. 7 ~ 9 give the simulation results of topographical change in case A ~ C. These cases have the same tidal conditions and river discharge but different wave height. From these figures it is seen that the topographical change is very similar at delta area of river mouth and tends to move northward. The results also indicate that the delta formed at river mouth of Chou Shui River is probably dominated by the river flow and tide conditior. Nevertheless, the topographical changes at offshore area show the same trend under the same conditions of tide, so it is probable that the changes of topography account for tidal current. There are differences between these figures at nearshore area. It accounts for the difference in wave height. The higher the incident wave is, the more seriously the nearshore topography change. Thus the topographical changes inside the surf zone could be dominated by waves. Fig. 10 shows the simulation results of topographical change in case F. By comparing this figure to Fig. 7~ 9 respectively, the difference only shows on the deformation of delta at river mouth.

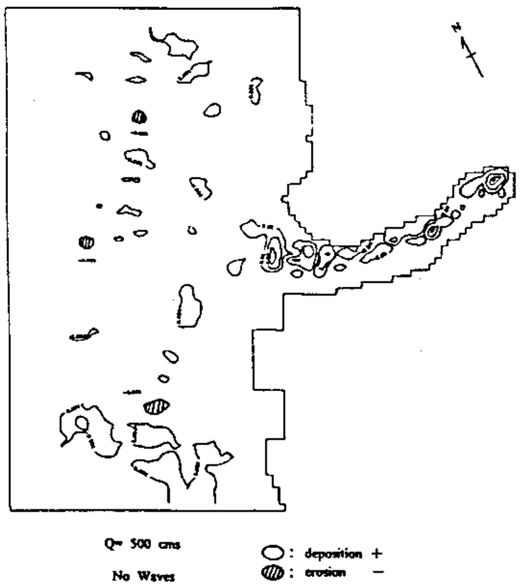


Fig. 7. The Computational Results of the Topography in Case A

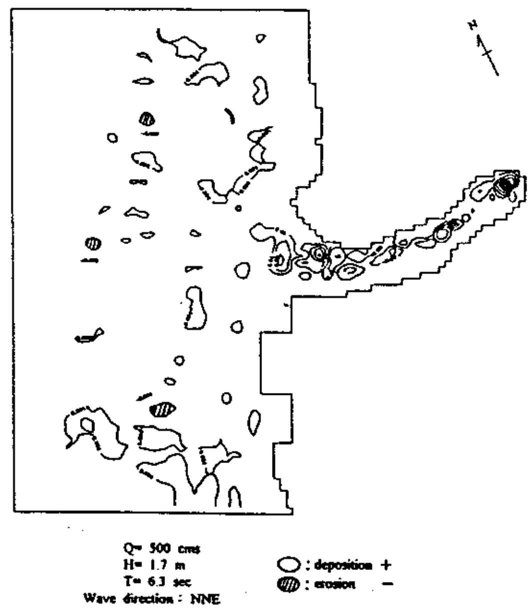


Fig. 8. The Computational Results of the Topography in Case B

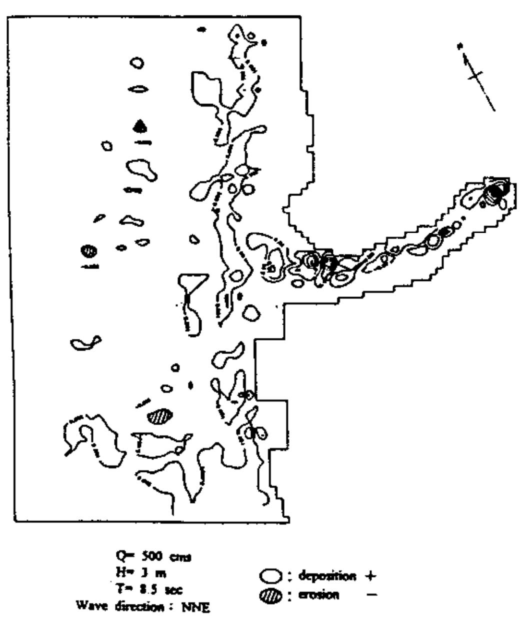


Fig. 9. The Computational Results of the Topography in Case C

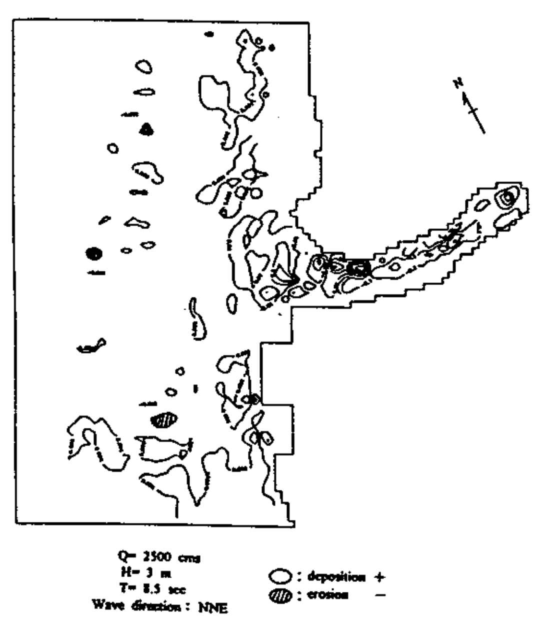


Fig. 10. The Computational Results of the Topography in Case F

CONCLUSION

1. Based on the results from field survey, it is seen that there are three dynamic conditions correlated to the changes of topography in this study area. The first is that the Chou Shui River brings a large quantity of sediment into the sea in wet season. The second is owing to the strong tidal current at the river mouth of Chou Shui River. The third accounts for the longshore current caused by northeasterly monsoon. No one could be neglected in discussing the topographic changes.
2. In this study, a two-dimension numerical model was developed to simulate the topographical changes in consideration of the interaction among tides, waves and river flow. The model has been calibrated and verified by applying the observed tidal current records.
3. The tidal currents in the offshore area tend to move northeastward in the period of flood tides and move southwestward in the period of ebb tides. The tidal current can reach the speed of 1.2 m/s. On tidal flat, the onshore and offshore current occured in the period of flood and ebb tides, respectively.
4. When the wave is assumed to have height of 3 m and direction on NNE, the longshore currents mainly move southwestward and reach the speed of 0.8 m/s. Whereas, in the period of flood tides, the surf zone tend to move toward the shore.
5. The scope of deposition at the river mouth depend on the river discharge. The bigger the discharge is, the wider area could be affected.
6. The topographical changes caused by waves primarily take place at surf zone in the form of deposition.
7. The numerical results show that the tidal currents are strong enough to transport the sediment, but the tidal induce topographical changes are not so obvious in the periodic motion of tidal currents.
8. It is concluded that the topographical changes in this study area are dominated by tidal currents outside the surf zone and by waves inside the surf zone. The effect of river is mainly on the delta area at river mouth.
9. It should be pointed out that the interactions between wave and current were only considered on the influence of wave to current, but the wave field affected by current were not considered. Also, the reflection caused by structures is not take into account, neither. These are important issues in our succeeded study to make this numerical model more suitable on simulating the practical situations.

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SEDIMENTATION ANALYSIS OF A CHANNEL OUTLET TO THE OCEAN

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Abstract: A sedimentation investigation using HEC-6 was conducted to study the impact of sediment laden flows on the performance of the outlet of a proposed supercritical flood control channel which outlets directly to the ocean. This paper discusses the methodology of this analysis and the results which indicated that the project should not go forward as conceived without some form of positive debris control.

INTRODUCTION

General: The US Army Engineer District, Los Angeles (USAEDLA), proposed to improve the lower reach of Mission Creek, located in Santa Barbara County, California. A rectangular concrete channel was designed to convey the 100-year peak flow of 7900 cfs at supercritical flow (USAEDLA, 1986).

Several sediment related problems were identified during the detailed design phase of the project. One problem included the impact of bed load movement on the hydraulic roughness of the supercritical, concrete channel and is discussed in previous papers and reports. The other major problem was the impact of the debris load on the functionability of the channel outlet at the beach.

This paper discusses the sedimentation analysis of the channel outlet which was performed to determine the magnitude of the problem. In general, the analysis was conducted with an experimental version of the HEC-6 model from WES. Measurements of bedload transport for the creek do not exist which complicated the analysis of the outlet since the numerical model could not be verified. Thus, several assumptions and sensitivity analyses were conducted to increase the confidence in the computed results and are discussed herein.

Description of Study Area: The Mission Creek watershed comprises about 11.5 square miles and is located in a narrow coastal area which extends from the Santa Ynez mountains on the north to the Pacific Ocean on the South. Mission Creek is a relatively steep ephemeral stream with a vertical drop of about 3750 feet in about 8 miles. At approximately the 500 foot elevation, the creek is joined by its main tributary, Rattlesnake Creek. In the headwater areas, stream gradients are as steep as 2600 feet per mile and average 1000 feet per mile. In the lower reaches, on the alluvial plain below the foothills, average slopes are about 150 feet per mile. The profiles of Mission and Rattlesnake Creeks are shown on Figure 1.

In 1964, the Los Angeles District constructed two small debris basins in the upper reaches of Mission and Rattlesnake Creeks as an emergency measure to reduce debris delivery resulting from a fire in the watershed. The locations of these basins are shown on Figure 1. These basins are relatively small and do not provide significant protection to the proposed project reach. Additionally, the basins are separated from the project reach by about four miles of natural channel.

Two sections of Mission Creek were improved with concrete-lined, supercritical trapezoidal channels by the California Department of Transportation (Cal Trans) in 1934 and 1964 (see Figure 1). The Corps' proposed concrete channel would adjoin the existing downstream concrete channel and would convey flows 1.1 miles to the Pacific Ocean. The right-of-way along the channel alignment is minimal which necessitated use of the supercritical rectangular channel.

Debris Problem: The Mission Creek watershed is capable of supplying large-sized material for sediment transport. Since positive debris control was not included as part of the project, a significant volume of sediment, including cobbles and boulders, may enter the flood control channel unimpeded. The purpose of this investigation was to determine the impact of the sediment load on the performance of the proposed channel near the outlet and to determine if the channel outlet would flush the sand plug located at the beach. It was expected that the

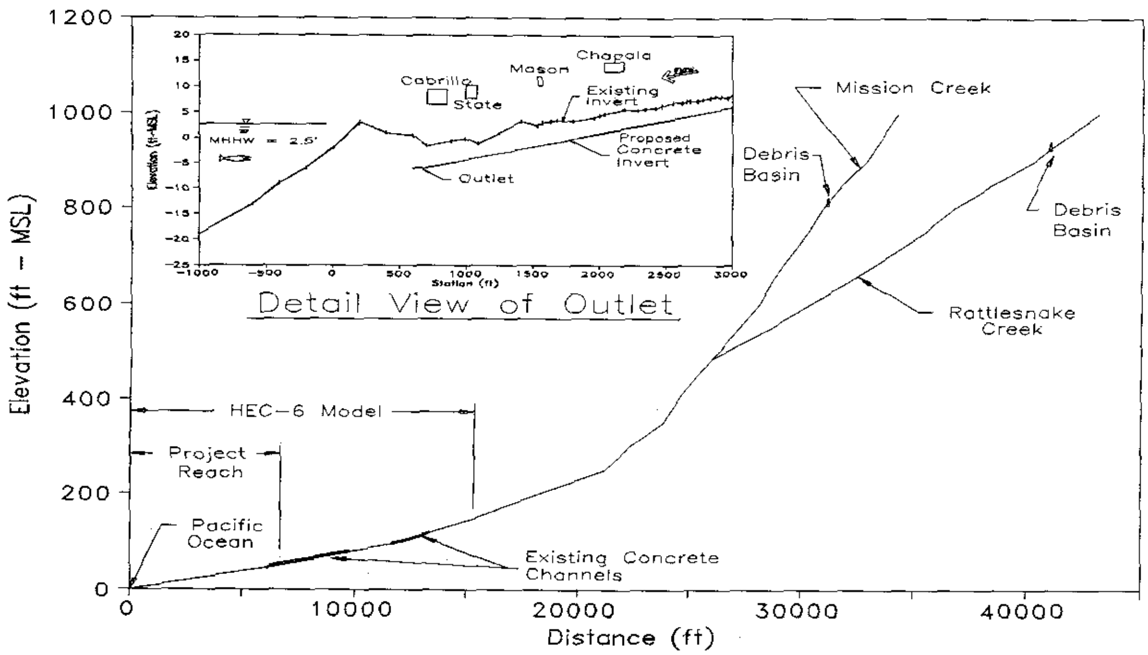

Figure 1. Thalweg profile of Mission and Rattlesnake Creeks

functionability of the outlet might be hampered by the upstream sediment load coupled with the relatively low elevation (i.e. -6.0 ft MSL) of the channel invert at the beach.

METHODOLOGY OF SEDIMENTATION INVESTIGATION

General Approach: This analysis was performed by routing a 100-year balanced hydrograph (histograph) through the proposed concrete-lined channel, the existing concrete-lined Cal Trans channels, and the natural channel upstream of the project reach. The sediment routing was performed with a special version of HEC-6.

The Model: A research version of the HEC-6 (i.e. HEC-6W) one-dimensional sedimentation program was used to develop the numerical models for this study. This version of the program allows for transport of individual grain sizes larger than 64 mm along with sand and gravel sizes. The numerical model extends from a location approximately 1600 feet offshore to a location approximately 3.3 miles inland. All of the HEC-6W computer simulations discussed herein were performed on the CRAY YM-P supercomputer located at the Information Technology Laboratory at WES. It has been observed that the results of these numerical analyses may be sensitive to the computer platform that the HEC-6W program is run on.

Downstream Water Surface Elevation: The starting water surface elevation at the downstream end of the numerical model was based on the mean sea level (i.e. 0.0 ft MSL) for the antecedent flows and on the mean higher high water (MHHW) level (i.e. 2.5 ft MSL) of the Pacific Ocean for the simulation of the 100-year flood. Variation of the tide was not included in the model.

Channel Roughness: A Manning's n-value of 0.050 was used in the natural sections of the sediment supply reach. Through the concrete-lined reaches of the channel, an n-value of 0.014 was used with the exception of the lower 1200 feet of channel. On the beach and in the ocean, a Manning's n-value of 0.025 was used.

Special attention was given to the appropriate roughness coefficient of the lower 1200 feet of channel near the outlet. This was required since the roughness value may vary greatly depending on the presence of sediment deposits in the concrete channel. For example, if the channel is relatively clear of sediment deposits, an n-value of about 0.014 would be appropriate. Whereas, if sediment deposits exist completely covering the concrete invert, a higher roughness value may be appropriate to account for the increase in roughness due to grain and bed form roughness.

At the time of this study, the version of the HEC-6W program used in this analysis did not have a procedure to simulate the change in hydraulic roughness for a fixed bed (i.e. concrete invert) due to sediment deposition or removal by scour. Therefore, the approach used in this analysis assumed an "average" n-value of 0.022 for the channel section near the outlet. This value was based on an assumption that the invert would have some sediment deposits (i.e. possibly due to antecedent events) and would represent a reasonable composite n-value for the bed and channel walls. This n-value was held constant during the entire flood simulation. Sensitivity analyses were conducted to test the impact of the channel n-value on the final results and are discussed below.

It should be noted that the channel geometry used in the model at the beginning of the flood simulation (i.e. prior to the antecedent flows) was based on an assumption that the concrete channel would be clear of sediment deposits due to annual O&M activities.

__Transport Function__: A combination of the Toffaleti and Meyer-Peter and Müller transport functions was used for this study. Additional transport functions were used in the numerical model and tested for sensitivity and the results are discussed below in the section titled Sensitivity Analysis.

__Sediment Gradation__: Sediment sizes utilized in this model ranged from very fine sand (VFS) through small boulders (SB). Silt and clay transport was not considered in this analysis. Various bed material gradations were used in the numerical model to account for the relative coarsening of the bed material from the beach to the sediment supply reach near Oak Park. The sediment gradation curves are shown in Figure 2.

__Sediment Inflow__: Measurements of suspended or bed-load sediment do not exist for Mission Creek. Therefore, the sand and gravel inflow to the numerical model was calculated assuming equilibrium sediment inflow using average hydraulic parameters in the supply reach and the average upstream bed material gradation shown in Figure 2. The equilibrium sediment transport capacities were computed with the sediment transport module of the Hydraulic Design Package for Flood Control Channels (SAM) developed at WES (WES, Draft 1993).

__Antecedent Flows__: Antecedent flows were added to the 100-year flood histograph in order to account for sediment deposition in the concrete channel prior to the main 100-year flood event. The antecedent flows were based on the USGS gage record for the period of October 1, 1977 through the recession of the January 16, 1978 flood. This sequence of flows was selected since it was observed to be representative of the worst case antecedent flows for the period of record.

The numerical simulation was conducted with the assumption that any deposition in the concrete channel due to antecedent flows would not be removed prior to the occurrence of the 100-year flood. This assumption was based on operation and maintenance experience in the USAEDLA for other flood control channels similar to lower Mission Creek. During prototype operations it was expected that sufficient time may not exist to clear the channel of sediment deposits between major flood events.

__Model Adjustment and Circumstantiation__: Adjustment and circumstantiation of the model was not realistically possible due to a lack of prototype data. However, a cursory study to verify the model was conducted. This study was based on simulating the sedimentation processes of the existing lower Mission Creek for the period of record from about April 1990 to May 1993.

The model simulated all discharges greater than 10 cfs during the period. At the end of the simulation, the computed bed elevations at several bridges were compared to observed elevations (i.e. based on bridge clearances measured in the field) and indicated a general agreement between the simulated results and the prototype. Thus, based on the four year period, it appeared that the model was correctly reproducing the sedimentation processes of lower Mission Creek.

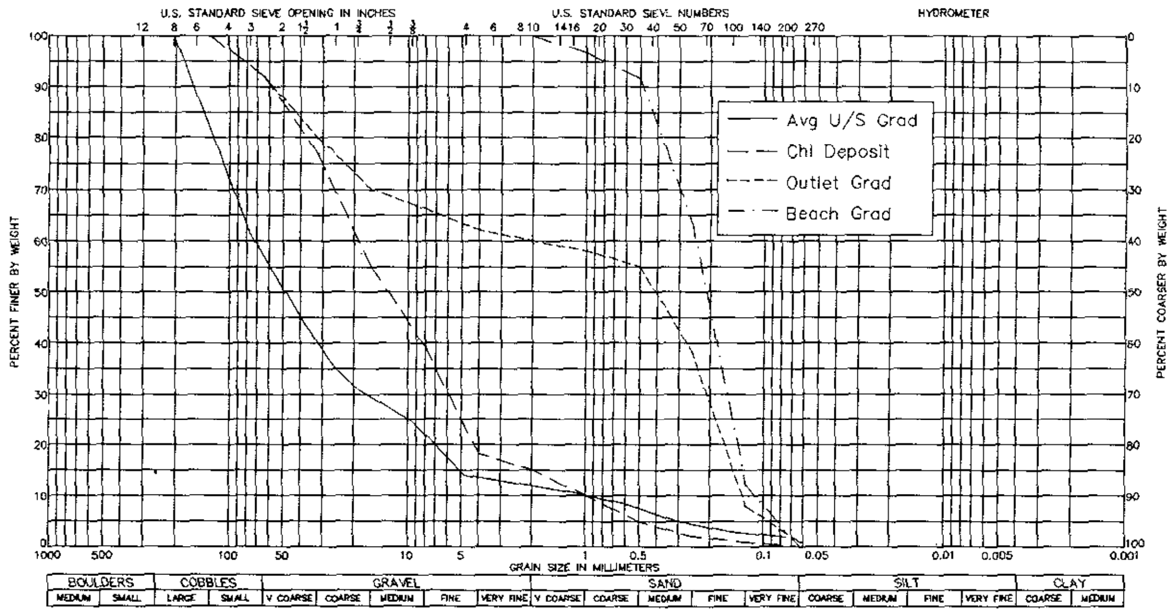

Figure 2. Bed material gradations for outlet analysis

However, due to the short period studied, it should be noted that the results from this cursory study are probably more qualitative than quantitative. That is, the maximum flow rate during the simulated period was 1300 cfs and the maximum flow rate for the 100-year flood is 7900 cfs. Thus, the model was not verified for large flood events.

Results: Results for the sediment routing of the 100-year flood, shown in Figure 3, indicate that by the time of the peak of the 100-year flood, sediment would deposit in the channel outlet to a depth of about 5 feet. The sediment deposit would reduce the capacity of the channel outlet to the point where flood flows would not be contained. At the end of the flood, approximately 53 percent of the deposit was composed of sand and 47 percent was composed of gravel. Cobbles and boulders comprised an insignificant portion of the deposit.

The basic problem is that the channel is required to outlet onto the beach at the relatively low elevation of -6.0 feet MSL. This low elevation is required in order for flows to pass safely under the most downstream bridges (i.e. State Street and Cabrillo Boulevard). Given this low elevation, low flows would tend to flow in the subcritical regime for the downstream 1200 feet due to the tailwater of the Pacific Ocean. Only the highest flows would have sufficient energy to force the hydraulic jump to occur downstream of the channel on the dumped stone energy dissipator.

The analysis shows that deposition of sediment in the concrete channel is expected to occur during low flows through the rising limb of the hydrograph. These low flows make up about 99 percent of the total flood hydrograph (i.e. antecedent and 100-year flows). Even with no sediment deposits in the channel, supercritical flow occurs only for discharges of about 4000 cfs and greater. However, these high flows are of insufficient duration to completely clear the channel before the peak flow arrives.

Sensitivity Analysis: It was especially important to determine the model's sensitivity to sediment inflow because of the lack of prototype sediment inflow data. Simulations of the design flood were conducted using four additional sediment transport functions. Since suspended sediment data were not available for comparison with calculated transport rates, numerical model results were interpreted considering the model's sensitivity to the transport function. Additional sensitivity tests were conducted which included varying the channel roughness coefficient near the channel outlet and evaluating possible effects from the downstream water surface elevation.

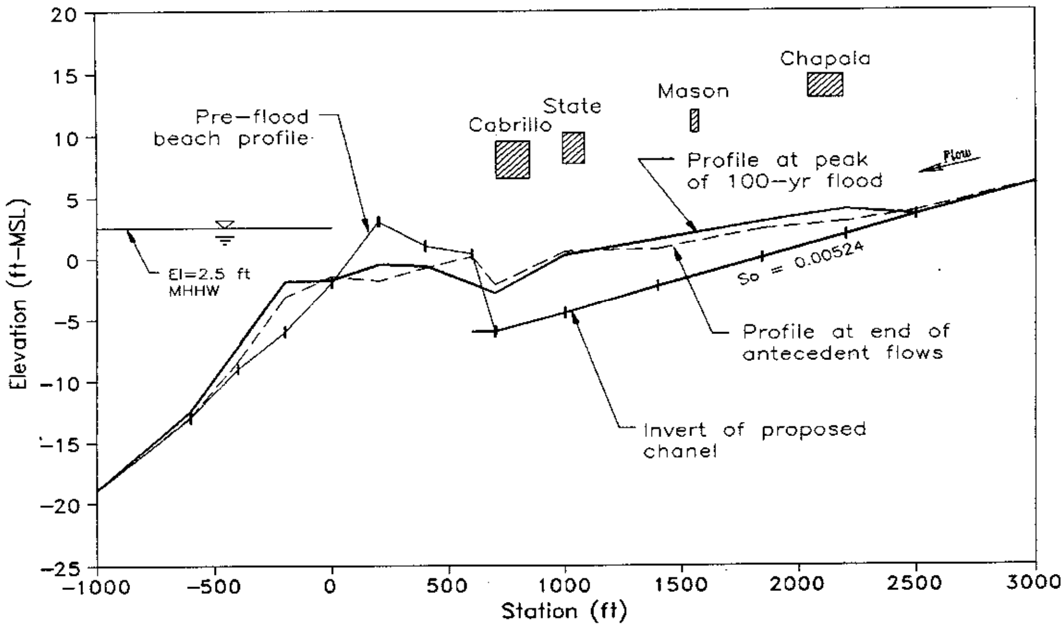

Figure 3. Bed profile for results of sediment routing at channel outlet

Sediment Inflow - Transport Function: The sensitivity analysis consisted of testing various sediment transport functions. The additional transport functions included a combination of the Toffaleti and Schoklitsch functions, Yang's unit stream power function, Madden's (1985) modification to Laursen's (1958) function and Copeland's (1989) modification to Laursen's (1958) function. Madden's 1985 modification of Laursen's function adapted Laursen's function for higher Froude numbers and included Toffaleti's river data and Guy, Simons, and Richardson's flume data. Copeland's modification to Laursen's (1958) function included Brownlie's data and incorporated data for transport of gravels in addition to the sand data used to develop the original Laursen function. The Laursen-Copeland function is very sensitive to the fraction of fine and very fine sand present in the bed. This function is best used when measurements of suspended sediment are available to confirm calculated concentrations of fine material.

As expected, different results were obtained for different sediment transport formulae. However, a similar result was obtained for all transport formulae in that sediment deposition occurs in the lower end of the channel and channel outlet. The deposition occurs such that the capacity of the channel is significantly reduced and the peak flow would not be contained by the proposed project. Depths of deposition computed by these sensitivity tests range from 3.0 to 6.7 feet in the channel outlet by the time of the peak of the 100-year flood. An example of the results for the combination of the Toffaleti and Schoklitsch functions and the Laursen-Copeland function are shown in Figures 4 and 5, respectively.

Roughness Coefficient: This sensitivity analysis was performed to evaluate the impact of a low roughness value in the deposition zone of the channel outlet. Specifically, a Manning's n-value of 0.014 was used throughout the proposed concrete-lined channel instead of the 0.022 value used in the tests discussed above. The combination of the Toffaleti and Meyer-Peter and Müller transport function was used for this test. Results of this test are shown in Figure 6 and indicate that by the time of the peak of the 100-year flood, deposition would occur to a depth of up to 4.2 feet in the channel outlet. This represents a decrease in sediment depth of 0.8 ft and demonstrates that the depth of sediment deposition in the channel outlet is somewhat sensitive to the roughness value assumed in the deposition zone. However, this test also verifies that even if an extremely low roughness value is assumed near the outlet, significant deposition would occur in the downstream end of the proposed channel and outlet decreasing the channel capacity such that the 100-year flood would not be contained.

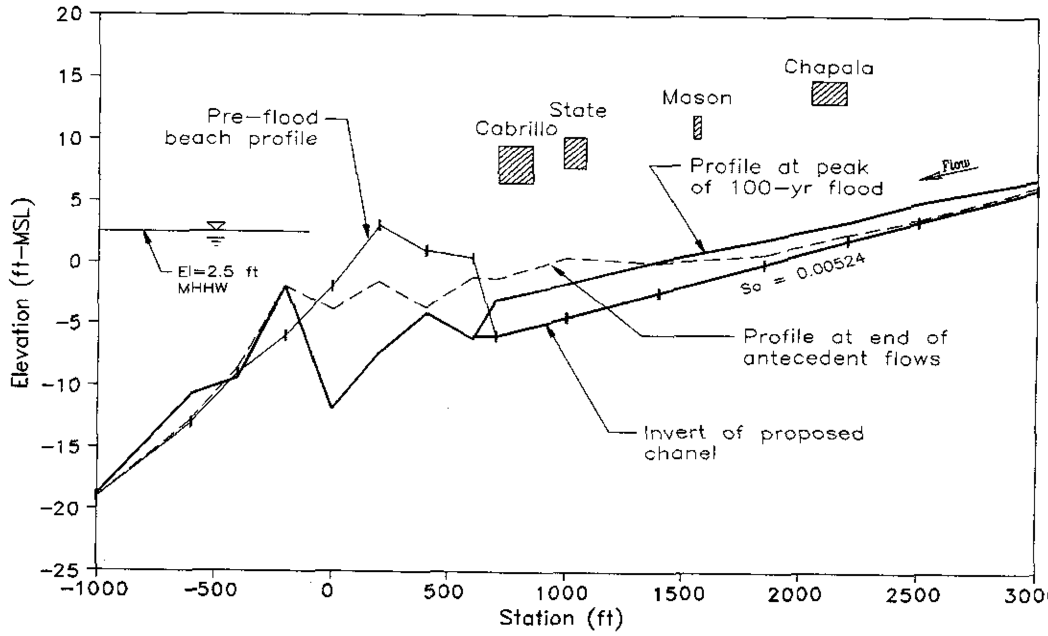

Figure 4. Bed profile for results of sensitivity analysis at channel outlet for combination of Toffaleti and Schoklitsch functions

Downstream Water Surface Elevation: This sensitivity analysis was performed to evaluate the impact of a lower tailwater elevation at the downstream end of the proposed channel. Specifically, a tailwater elevation of 0.0 ft (MSL) was used throughout the numerical simulation of the antecedent and 100-year flows instead of the 2.5 ft

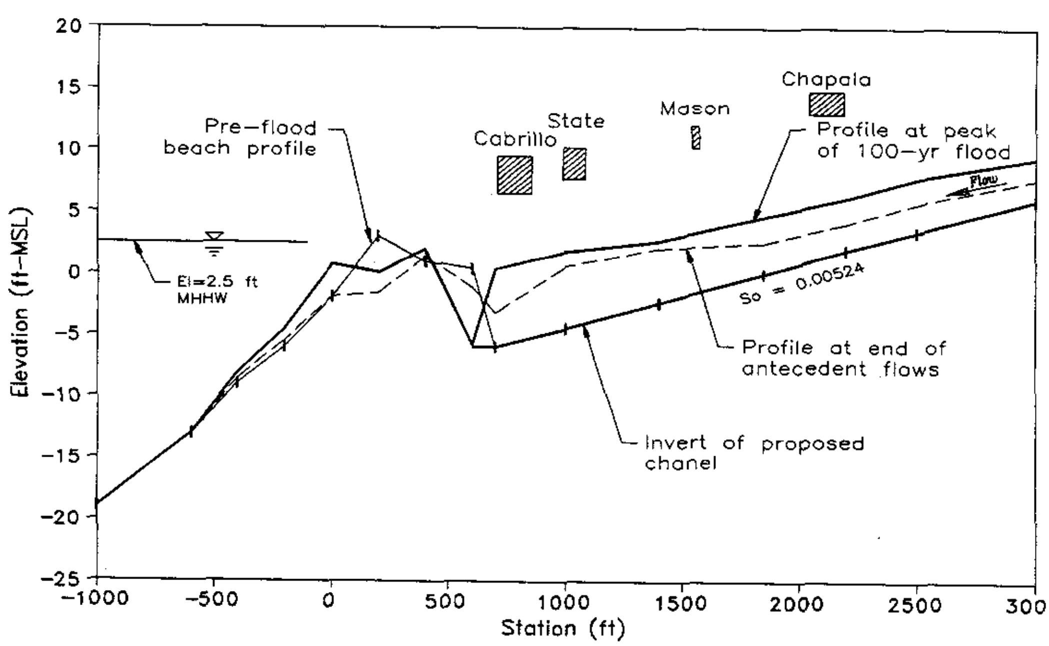

Figure 5. Bed profile for results of sensitivity analysis at channel outlet for Laursen-Copeland function

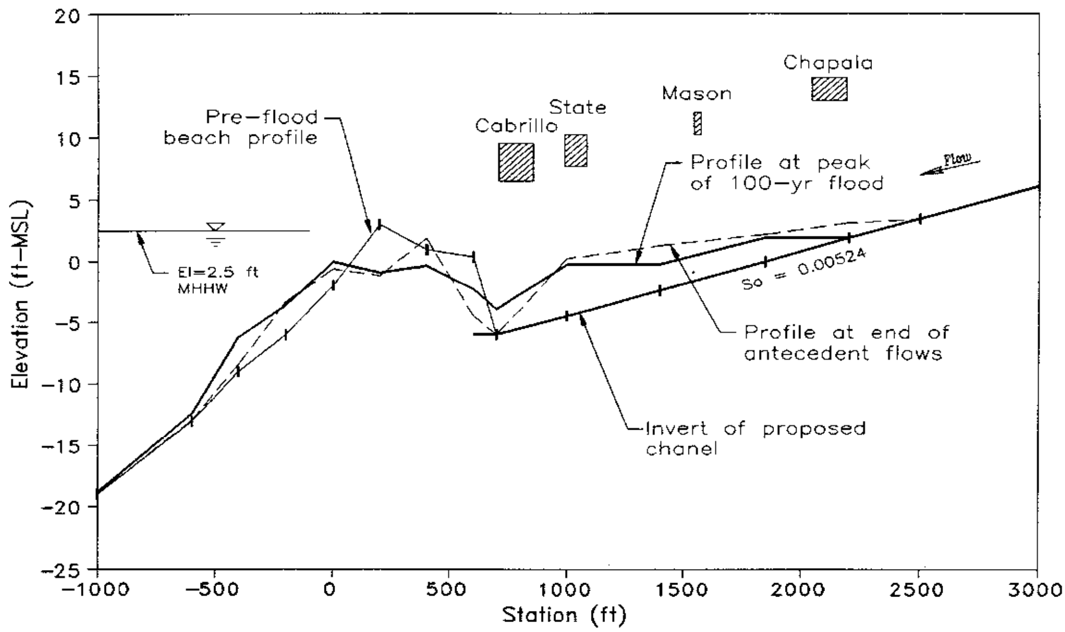

Figure 6. Bed profile for results of sensitivity analysis for low roughness value in outlet

(MSL) value used in the tests discussed above. The combination of the Toffaleti and Meyer-Peter and Müller transport function was used for this test. Results of this test are shown in Figure 7 and indicate that by the time of the peak of the 100-year flood, deposition would occur to a depth of up to 3.4 feet in the channel outlet. This represents a decrease in sediment depth of 1.6 ft and demonstrates that the depth of sediment deposition in the channel outlet is probably more sensitive to the assumed tailwater elevation of the Pacific Ocean than the roughness value of the channel outlet. However, this test also verifies that significant deposition would occur in the channel outlet decreasing the channel capacity to the point that the 100-year flood would not be contained.

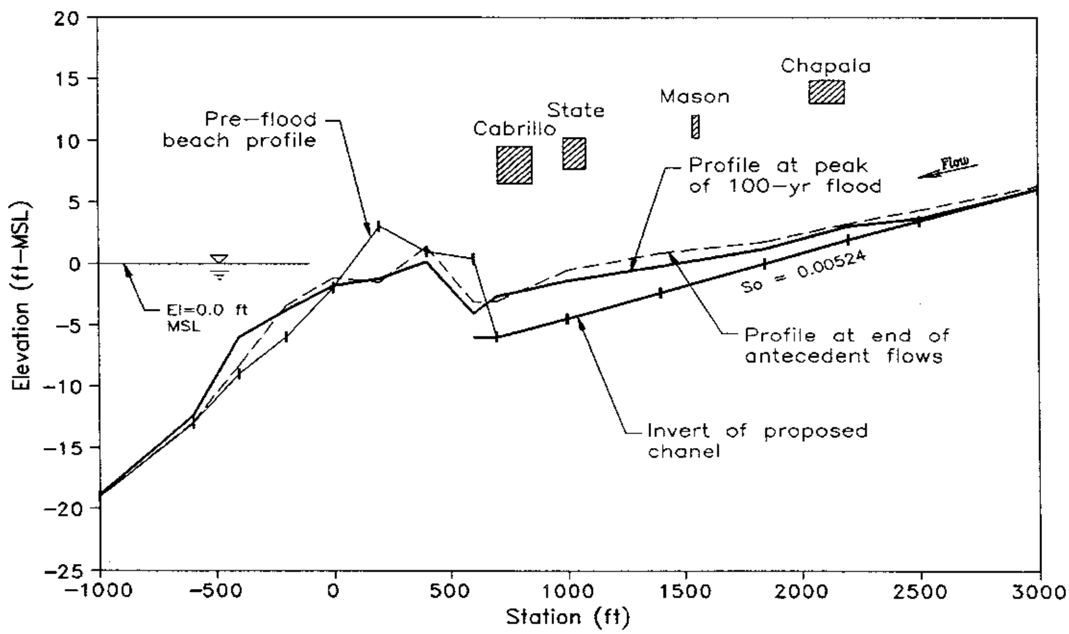

Figure 7. Bed profile for results of sensitivity analysis for low tailwater elevation

CONCLUSIONS AND RECOMMENDATIONS

Detailed hydraulic and sedimentation analyses have been conducted for the proposed channel improvement for lower Mission Creek. The results of the sedimentation analysis indicate that sediment would deposit in the downstream end of the channel prior to and during the 100-year flood decreasing the channel capacity such that the peak 100-year flowrate would not be contained.

The main problem with the proposed design is due to a combination of factors including: 1) the channel is required to outlet onto the beach at the relatively low elevation of -6.0 ft (MSL) in order for the channel to convey flood flows under the low cords of the State Street and Cabrillo Boulevard bridges; and 2) positive debris control is not included as part of the proposed channel design. Hence, it is possible that large volumes of sediment may enter the channel and plug the channel outlet.

Based on the results of this analysis, the Corps of Engineers concluded that construction of the proposed project should not go on unless the debris problem is resolved. The alternative solutions to the debris problem were beyond the scope of this analysis. However, the project is currently under study by the Corps wherein alternative designs are being considered which would convey a smaller flood (e.g. a flood ranging from 15- to 25 years) and its corresponding reduced sediment load.

Since adjustment and circumstantiation of the numerical models was not possible due to a lack of prototype data, a sediment sampling and monitoring program be developed and implemented for Mission Creek. This program would conceivably consist of collecting suspended and bed material samples from Mission Creek during flood events. Additionally, significant changes in the channel geometry following flood events should be documented in terms of detailed topography. Results from the sampling program could be compared to computed results and used to adjust and verify the numerical models and decrease the uncertainty in the rates and volumes of sediment transport.

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THE MISSISSIPPI DELTA MANAGEMENT SYSTEMS EVALUATION AREA (MSEA) PROJECT

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Abstract: Maintaining a high level of crop production without negatively affecting water quality continues to be a major challenge to the U. S. agricultural industry. This is especially true for the physiographic region known as the Mississippi Delta, one of the most fertile and productive agricultural areas in the U. S. Agricultural chemicals such as pesticides and fertilizers are used extensively. In addition to the potential pollution problems with these chemicals, excessive amounts of sediment transport also contributes to the pollution. The purpose of this project is to assess how agricultural activities affect the ecological health of Delta watersheds, evaluate the quality of surface and ground water in the Mississippi Delta, and increase the knowledge to design and evaluate Best Management Practices (BMPs) as components of farming systems that reduce agricultural contamination of ground and surface water. In addition, educational and public awareness programs will be developed. The selected study sites consist of three Delta oxbow lake watersheds. Cotton is the primary crop in each watershed, and all three watersheds contain riparian zones. One watershed will serve as a control, while the other two watersheds will be used to implement BMPs. This water quality study is unique in that whole watershed (closed systems) studies are coupled with oxbow lakes to measure agricultural productivity, economics, and effects of improvement on water resources. Study areas are small enough to bring improvements to a significant portion of each watershed such that changes in water quality can be measurably affected. The Mississippi Delta MSEA Project is cooperatively conducted by a consortium of local, state, and federal agencies.

INTRODUCTION

The Problem: Modern U. S. agriculture has introduced agrichemicals into land, water, and air resources and has produced environmental health hazards. For example, nitrate used in fertilizers has been associated with human health problems, particularly in infants. Some widely used pesticides are thought to be linked to cancer, neurotoxicity, and birth defects. Furthermore, pesticides in surface water impair aquatic, terrestrial, and wetland ecosystems.

Agriculture in the southern United States is especially challenging. Pests are intense in the humid subtropical climate of the South, crops, and management systems which increases dependence on pesticides. These factors, in combination with high rainfall and runoff potential increase the chances for greater chemical movement through the environment. Little cover remains after harvest, which leaves the soil unprotected against excessive erosion during the period of the year with greatest runoff. Many of the region's lakes and steams have been severely impacted by past agricultural practices.

In addition to the potential pollution problems that exist with chemicals, excessive amounts of sediment transport may contribute to off-site ecological damage. In addition, the higher amounts of rainfall provide increased opportunities for the downward movement of agrichemicals to ground water.

THE MSEA PERSPECTIVE

In the late 1970's emphasis was placed on point sources of agricultural pollution such as the treatment and handling of animal wastes (Swader and Adams, 1994). In 1977 United States Department of Agriculture (USDA)/Environmental Protection Agency (EPA) established the Model Implementation Program followed by the USDA Rural Clean Water Program of the early 1980's. The overall thrust of these programs was to research, demonstrate, and stimulate the adoption of Best Management Practices (Swader and Adams, 1994). In the late 1980's there was an increase in concern regarding the presence of agrichemicals in water resources and, in particular, ground water. As a result, the Presidential Water Quality Initiative soon followed under which the USDA Water Quality Program was initiated in 1990 (Swader and Adams, 1994). As part of the USDA Water Quality Program, USDA in cooperation with United States Geological Survey (USGS), and other federal, state, and local agencies, established Management Systems Evaluation Areas (MSEAs) in five midwestern states. The objective of the MSEA program was to develop demonstration projects to accelerate the transfer and adoption of innovative technologies to protect water quality with emphasis on ground water quality (CAST, 1992).

The current Mississippi water quality initiative was started in 1992 when a few agencies in Mississippi started discussing possible research in the Delta that would assess the effects of agricultural activities on water quality. As a result of this interest, the Mississippi District USGS sponsored a roundtable discussion on project possibilities in Jackson, Mississippi in October of 1992 that was attended by several federal, state, local agencies as well as private organizations. At this meeting a presentation was made on the USGS water quality project in western Tennessee, the Beaver Creek Project. Shortly thereafter, in February 1993, a tour and on - site briefing of the Beaver Creek Project was held. After the Beaver Creek tour, the Mississippi District of USGS drafted an initial Delta water quality research proposal. Following a second roundtable meeting in Jackson, Mississippi in May, 1993, a series of follow-up meetings was held between USGS, Natural Resources Conservation Service (NRCS), Agricultural Research Service (ARS), and EPA. In these meetings project objectives, approach, and the involvement of different federal, state, and local agencies were clarified and resolved. In November, 1993, USGS, ARS National Sedimentation Laboratory, and ARS national program staff identified the MSEA framework as the preferred approach to ensure involvement of all federal, state, local, and private interests in a cooperative project. The key ARS and USGS MSEA leaders were identified and first met in Oxford, Mississippi in December, 1993. A technical steering committee composed of reprsentatives from organizations established in early 1994 to provide technical leadership to the project.

THE MISSISSIPPI DELTA MSEA PROJECT

Purpose: The purpose of this project is to assess the extent and nature of agricultural activities on the quality of surface and ground water in the Mississippi Delta, and increase the knowledge to design and evaluate BMPs as components of farming systems. In addition, the project will develop educational and public awareness programs to reduce agricultural contamination of ground and surface water.

Scope: Scope of the project calls for a deterministic, holistic approach for a 5-year water quality and aquatic resource investigation of three Delta oxbow lake watersheds, 1000 acres or less in size. Economic, sociological, and environmental assessments of agricultural practices will be evaluated at the farm/watershed scale. The research investigation will be conducted in collaboration with a consortium of local, state, and federal agencies.

Approach: The project is planned to consist of three oxbow lakes and their watersheds. In one, "standard" farming practices will be employed. In the second, Natural Resources Conservation Service (NRCS) and Consolidated Farm Service Agency (CFSA) will cooperate to develop a farm plan using well-accepted practices for the Mississippi Delta region. In the third, no-tillage and engineering practices which seem to offer great potential benefits at low cost will be tested. Study areas are small enough to bring improvements to a significant portion of the watershed so that changes in water quality should be measurable. The criteria reduced chemical concentrations in field runoff, reduced chemical concentrations in watershed lakes, condition of lake ecosystems, and chemical residues in fish will be used to demonstration improvement.

Objectives: The Mississippi Delta MSEA project has seven major objectives:

1. Assessment. Evaluate the effects of conventional and alternative farming systems on hydrology, erosion, nutrients, and pesticides in surface runoff and chemical movement within the crop root and unsaturated zone. Further evaluate these effects on water quality, ecological processes, and fisheries resources in oxbow lakes associated with current and alternative farming systems.

2. Component. Evaluate the effects of basic soil and plant processes on pesticide fate and transport. Determine the effect of basic soil processes on macropore and crack development. Determine the effects of riparian zones on the fate and transport of pesticides and nutrients. Investigate the hydrologic interaction between Delta oxbow lakes, ground water, and the Mississippi River.

3. Sampling Protocol. Develop, test, and implement intensive monitoring strategies to assess the effects of agricultural activities on water quality and aquatic resources.

4. Farming System. Develop and evaluate innovative cropping systems for high intensity crops like cotton. Evaluate ultra-low volume application techniques as a way of pesticide application to cropping systems. Investigate the application of winter cover crops with cotton and other crops to reduce erosion. Develop and assess drainage network BMPs.

5. Modeling. Evaluate the performance of models used by NRCS and other agencies in developing water plans and management recommendations. Determine differences in measured responses between large and small watersheds and identify causes. Improve the accuracy of model predictions by developing new components. Develop model components that predict macropore and crack flow in Delta soils subject to shrinkage and swelling phenomena.

6. Socioeconomic. Measure the potential effects of watershed-wide adoption of alternative farming systems and practices on production, farm income, water quality, and aquatic resources. Assess the effects of the MSEA project on landowners/farmers attitudes and behaviors regarding the use of alternative farming systems and the activities of local conservation districts, NRCS, university extension, and other related agencies. Assess information sources of farmers/landowners regarding current and alternative farming systems and evaluate the effectiveness of communication on environmental issues and sound BMPs.

7. Extension. Increase awareness and adoption among farmers and land users of practical and profitable farming systems and practices that protect and enhance surface and ground water quality and associated aquatic resources.

Organization, Administration, Agencies: The Mississippi Delta MSEA Project is cooperatively administered by a consortium of local, state, and federal agencies. Participating agencies include USDA-Agricultural Research Service (ARS); United States Geological Survey (USGS); Mississippi State University (MSU); Mississippi Department of Environmental Quality (MDEQ); USDA-Natural Resources Conservation Service (NRCS); USDA-Consolidated Farm Service Agency (CFSA); University of Mississippi (UM); Mississippi Agricultural and Forestry Experiment Stations (MAFES); Yazoo Mississippi Delta Joint Water Management District (YMD); the Soil and Water Conservation Commission; Delta Council; Mississippi Farm Bureau Federation; the U. S. Fish and Wildlife Service; and Delta Wildlife Foundation. Several committees have been organized to ensure successful completion of project objectives. Technical leadership of the project is guided by co-chairmen from the USDA-ARS, USGS, and MSU within the framework of a Technical Steering Committee advises representative of the participating agencies. In addition, a much larger Advisory Committee on project goals and design, and to communicate project milestones. Both committees have organized smaller sub-committees to carry out specific tasks.

Study Area. During March and May 1994, a Site Selection Committee located three study watersheds for the MSEA project based on a list of "ideal" criteria. Some of these criteria were: cotton as the primary crop, oxbow lakes < 30 acres in size, riparian zones, watersheds about 1,000 acres, and land owners and operators willing to commit to the MSEA project for a five year period. Initially over thirty-five watersheds were identified, which were narrowed to six. After subsequent meetings and field trips, the committee recommended the following oxbow lake watersheds in Sunflower and Leflore Counties in west-central Mississippi (Figure 1).

1. *Beasley Lake Watershed* (Sunflower County). The total drainage area of this watershed is about 800-1,000 acres, and the surface area of the lake is about 40 acres. Soils are generally loam texture, with cotton as the predominant crop. The watershed has a large riparian zone area on the east side of the lake.

2. *Thighman Lake Watershed* (Sunflower County). The total drainage area of this lake is about 1,800-2,000 acres, which makes this watershed the largest of the three. The surface area of the lake is about 20 acres. Soil texture in the watershed vary from a loam to a very heavy clay. The predominant crop in this watershed is cotton. Other crops include soybeans and rice. Catfish are grown in ponds.

3. *Deep Hollow Lake Watershed* (Leflore County). The total drainage area of this watershed is about 400 acres, making this watershed the smallest of the three. The surface area of the lake is about 20 acres. Two-thirds of the watershed has loam type soils with a loam texture that are are in cotton production. Soybeans are

produced on heavier clay soils in the watershed. The west side of the watershed is defined by the east levee of the Yazoo River. The entire lake is surrounded by a riparian zone.

Another committee studied the watersheds and recommended BMPs that will be used for the MSEA project. This committee, composed of scientists, agency field representatives, and producers, evaluated current and proposed study watershed "farm plans" developed by local NRCS staff. The committee working with the study area producers proposed the BMPs that will be used in the study.

Cooperative Research: Cooperation in this research effort is achieved through interaction of participating agencies in meetings of the Technical Steering Committee, Advisory Committee and their appointed sub-committees. Early in the planning process, sub-committees of the Technical Steering Committee identified the following lead research agencies and their respective MSEA research responsibilities.

LEAD RESEARCH AGENCIES AND PROJECTS

USDA - Agricultural Research Service: The National Sedimentation Laboratory at Oxford, Mississippi proposes research in the ecological health of Delta oxbow lakes, vertical crack development in heavy clay Delta soils, and the quality of shallow ground water. The Application and Production Technology Research Unit and the Southern Weed Science Laboratory at Stoneville, Mississippi will focus on chemical application technology and the influence of tillage systems on pesticide sorption and microbial populations. Research proposed by the Soil and Water Research Unit at Baton Rouge, Louisiana is concerned with the effect of BMPs on insecticide loadings to surface runoff and the use of weather forecasts to predict the best time for pesticide applications.

U.S. Geological Survey: Research by the USGS will assess the effects of agricultural activities on surface water quality and the reduction of peak surface water concentrations of sediment, pesticides, and plant nutrients. Water quality and stream monitoring stations will be established in each of three study watersheds. Runoff samples will be collected frequently during storm events to define pollutant concentration distributions. A paired-basin approach will be used to compare data collected from the two BMP watersheds to the control watershed. Extensive statistical analyses will be used to determine the effectiveness of the BMP watersheds in improving the water quality of the lakes. The data base will be used in the evaluation of models to assess agricultural nonpoint pollution and implement BMPs.

Mississippi State University: Research proposed by Mississippi State University crosses a wide range of research disciplines. Their research will monitor the off-site movement of agrichemicals in runoff and will aid in the evaluation of BMPs. Co-related research will evaluate the effectiveness of site-specific herbicide and fertilizer management as a BMP. Other research will assess the biological response and impact of agrichemicals on Delta oxbow lake fisheries. Finally, extension activities will increase the awareness and adaptation among land owners of practical and profitable farming systems. Socioeconomic research will measure the potential impacts of watershed-wide adoption of alternative farming systems.

SUMMARY

The purpose of a Management Systems Evaluation Area (MSEA) is to assess the impact of agricultural activities on water quality and ecological health at the watershed level, develop alternative farming methods to reduce dependency on agricultural chemicals, increase the knowledge to design and evaluate BMPs as components to farming systems, and accelerate the transfer and adoption of BMPs and alternative farming systems.

The research activities that will be conducted in association with the Mississippi Delta MSEA Project will produce a database useful to management agencies in making sound environmental decisions concerning agricultural nonpoint pollution in the Mississippi Delta. Other anticipated benefits and research products associated with the MSEA project include:

1. Data will be collected to understand the behavior of farm chemicals in the environment and their effect on surface and subsurface water quality, and the resultant influence on aquatic resources in Delta oxbow lakes.

2. Environmentally sound and economically profitable BMPs and farming systems that are socially acceptable to local producers will be identified as well as the knowledge required to implement those systems.

3. The ability of riparian zones to assimilate and transfer agrichemicals will be evaluated; and

4. An understanding of producer behaviors and perceptions of economic and natural resources benefits of alternative farming systems will be evaluated.

"All programs and services of the U. S. Department of Agriculture are offered on a nondiscriminatory basis without regard to race, color, national origin, religion, sex, marital status, or handicap."

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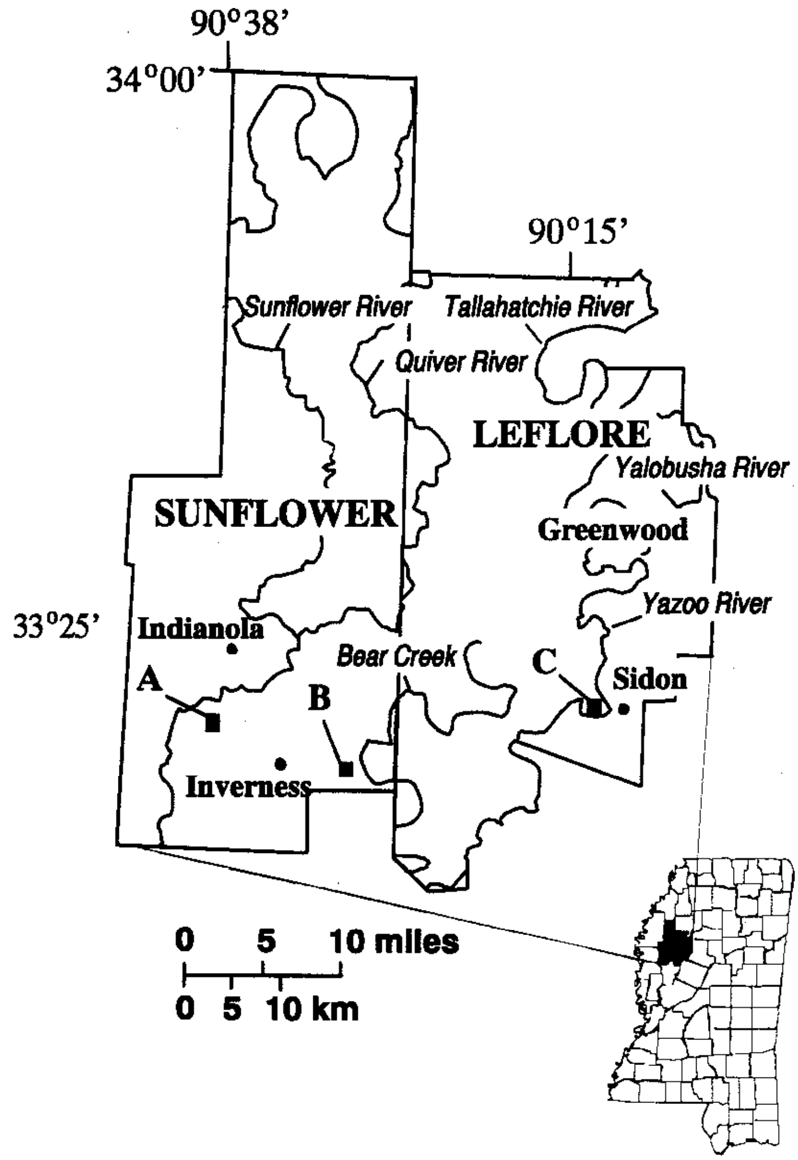

Figure 1. Mississippi Delta MSEA study watershed locations: A) Beasley Lake watershed; B) Thighman Lake watershed; C) Deep Hollow Lake watershed.

SEDIMENTATION ANALYSES TO ASSESS WATERSHED MANAGEMENT

by Kathleen Sherman, Environmental Protection Specialist, Federal Energy Regulatory Commission, Washington, D.C.1/

Abstract

The Federal Energy Regulatory Commission (Commission) is responsible for processing applications for licensing nonfederal hydropower and issuing orders licensing such projects. Where development of multiple hydropower projects within a river basin is proposed, the Commission also examines the potential for cumulative effects to environmental resources.

A case study is the Nooksack River Basin in the state of Washington, where 6 projects were proposed for construction and an existing project was proposed to be expanded. The 6 proposed projects are located on tributaries to the Nooksack River; the existing project is located on the mainstem river. One area of cumulative impact analysis examined the potential effects of increased sedimentation on anadromous (migrating) fish, such as salmon, which have depressed stocks and spawn and rear in the affected tributaries as well as the mainstem river.

Sediment sources within the tributary subwatersheds include natural sources such as landslides and glaciers as well as man-induced sources, primarily logging and related roads. The magnitude of potential sediment generated from construction of the projects was determined on a site-specific basis including measures contained in erosion and slope stability control measures proposed for the projects. A "worst-case" scenario during project operation was investigated by evaluating a hypothetical pipeline rupture based on site-specific slope stability, length of pipeline, and the presence of intervening vegetation that could filter water from a rupture before entering the stream.

Results of the analysis show that the estimated amount of sediments produced by construction are low for all projects, ranging from 0.004 percent to 1 percent of existing sediment yields in the respective subwatersheds. Overall, construction at all 7 projects was estimated to be 0.02 percent of the annual sediment yield to the Nooksack River for these subwatersheds (additional sediment input from other tributaries to the river was not estimated).

The estimated amounts of sediment that could be delivered to the streams from a single pipeline rupture ranged from 200 to 8,400 tons. For 5 of the projects, a potential pipeline rupture would produce less than 5 percent of the existing annual sediment yields in the respective subwatersheds. For 2 projects, however, a potential pipeline rupture could produce 45 and 104 percent of the existing annual sediment yield to those tributary streams. If this occurred during low stream flows--such that large amounts of eroded sediments were only slowly diluted and flushed from the vicinity--anadromous fish eggs, fry, and juveniles could be affected by turbidity

1/ The opinions and views in this paper are my own and do not necessarily represent the views of the Federal Energy Regulatory Commission.

and sedimentation in the lower portion of the streams and possibly for some distance downstream in the mainstem river.

Overall, the sediment produced by potential pipeline ruptures a all 7 proposed projects is estimated to be about 3.4 percent of the estimated existing sediment yield for these subwatersheds to the mainstem river. While this comparatively small addition would be unlikely to have widespread effects on reproduction of anadromous fish in the Nooksack River downstream of the projects, it could have localized impacts.

INTRODUCTION

Construction of the proposed projects would generate fine sediments from disturbance of erodible soils, disturbance of the stream bed from instream construction and construction of project facilities and related roads. Fine sediments could also be generated during project operation by chronic additional runoff of erodible materials along roads and project rights-of-way, changes in stream flows that alter the stability of erodible stream banks, or by a rupture of the project pipeline during project operation. Pipelines at the proposed projects range from 4,000 to 13,000 feet in length and 24 to 60 inches in diameter, and so contain a large volume of water that could erode large volumes of sediments that could enter adjacent waterways. Some of the pipelines at proposed projects also cross known or potentially unstable areas that could contribute to the potential for pipeline rupture (Federal Energy Regulatory Commission, 1994).

An important component in evaluating impacts to anadromous fish spawning grounds and habitat is the potential for each project to generate fine sediments that could smother fish eggs, hinder fry emergence, fill in voids used by juveniles to overwinter, and fill in pools used for summer rearing. It is generally accepted that an inverse relationship exists between the amount of fine sediments in spawning or rearing areas and fish survival and abundance (Stowell et al., 1983).

Major storm flows (especially rain-on snow events) can cause instability and channel shifting, that results in extensive loss of salmon redds (where spawning fish deposit their eggs) through erosion or burial under sediment and other debris. Less severe storms can flush sediments out of the tributaries, and affect downstream mainstem spawning areas through sedimentation of side-channel sloughs (Federal Energy Regulatory Commission, 1994).

An important element in analyzing risks to spawning gravel in the Nooksack River tributaries and mainstem is to estimate when and how much added silt from construction and operation of the proposed facilities is excessive in relation to the existing gravel and streamflows. While there are no accepted thresholds levels of sedimentation by which to judge sediment suitability, the literature suggests that 20 percent fines could be used as a threshold beyond which survival may approach zero, and that 10 percent fines is a reasonable target for attaining 50 percent survival (Chapman, 1988).

Avoiding additional siltation during known egg incubation times via timing of construction activities and effective erosion and sediment control plan are the most effective preventative measures. However, there is an inherent conflict in timing between construction activities and salmon spawning because instream construction of the diversion and intake structure would occur during low water periods in summer. Sediment deposition will likely occur in the downstream, lower-gradient areas. Though of short duration, this may affect the incubation success of 1 or 2 broods of fish. Nonetheless, because spawning preferences are usually for locations with flow rates of 0.5 to 2.5 feet per second, the fines would probably not settle on the areas most useful for spawning (Federal Energy Regulatory Commission, 1994).

Predicted amounts of sediment generated by construction and operation of the proposed projects were compared to existing sediment yields of the subwatersheds where the projects are located, in order to assess the magnitude of potential impacts to the affected creeks as well as to the Nooksack River (Federal Energy Regulatory Commission, 1994).

METHODS

Estimating Existing Sediment Load

The Nooksack River and its tributaries receive a poorly-sorted sediment load that ranges in particle size from silt to boulders. Most of this sediment is carried by flows at or above bankfull stage, which in most years occurs for only a few days. The coarser fraction of the load, consisting mostly of gravels and cobbles, travels slowly and intermittently as bedload, and is deposited for various periods of time creating riffles and point bars along the channel (Federal Energy Regulatory Commission, 1994).

The background sediment yield and composition of sediments for a river (or a tributary stream where a project is proposed), were evaluated by considering existing land use in the watershed (or subwatershed), geologic characteristics, composition of soils and mass wasting deposits, and composition of the stream substrate (Federal Energy Regulatory Commission, 1994).

In some subwatersheds such as Wells Creek, glaciers contribute large volumes of sediments. The average annual sediment influx into Wells Creek was estimated to be 112,135 tons/year. Of this total, 109,000 tons was estimated to be produced by a glacier and surrounding eroding terrain. A large portion of this sediment is fine-grained material transported during the summer glacial melt season; another portion is coarser sediment, produced and transported during winter heavy rainfall events, or high flow events. Mass wasting and surface erosion was estimated to contribute another 600 tons of sediment per year; other logged and forested slopes in the Wells Creek subwatershed were estimated to produce between 1,200 and 1,935 tons of sediment per year (Westbrook, 1988).

Once fine-grained sediment enters the Nooksack River, most stays in suspension until it reaches River Mile (RM) 15.4; most of the fine-grained sediment is deposited in the lower reaches of the Nooksack River downstream from RM 15.4 (Westbrook, 1988). The proposed projects are located in the upper watershed of the Nooksack River. For example, the Wells Creek project is located on RM 3.4 on Wells Creek, which discharges into RM 62.8 on the North Fork of the Nooksack River.

Identification of current sources of sediment, their approximate annual contribution to the stream, and the grain-size distribution, involved mapping sediment sources on aerial photographs, field observations and measurements of landslide volumes, and sieve analysis to determine composition. Sediment yield rates for areas of various land types and uses, such as for glaciers and logged areas, were also used when predicting the existing sediment yield. Grain-size distribution of bed material was based on samples collected from the stream channel (Dunne, 1984; Westbrook, 1988).

Estimating Sediment Yield from Project Construction and Operation

The amount and type of sediments that may be generated from a project by land-disturbing construction activities was estimated by first quantifying the expected erosion. This was done by considering the amount of disturbed area and by sampling soils and unconsolidated deposits at the project site. Soils in the Nooksack River basin generally contain about one third fine-grained material (fraction by weight) (Federal Energy Regulatory Commission, 1994). Estimates of erosion were made by using the Universal Soil Loss Equation (American Society of Civil Engineers, 1975; Weichmeir et al., 1971). A sediment delivery ratio was used to predict the amount of eroded material expected to reach the stream based on proximity of land-disturbing activities to the stream (Darrach, 1978).

Estimates were also made by using rates of sediment yield developed for road construction in the Olympic National Forest (construction of project pipelines is assumed to be similar to road construction) (Reid, 1981). As neither model accounts for erosion from slope failure or mass movement, a "worst-case" evaluation of sediment input to a stream is based on actual site conditions, and considers size and composition of potentially unstable areas and their proximity to the stream.

Estimates of sediment generated from pipeline rupture was related to the length of the proposed pipeline (and associated volume of water in the pipeline) as well as the presence of known or suspected unstable areas crossed by the proposed pipeline. It was assumed that water in a pipeline at the time of rupture would be capable of sluicing a volume of soil equal to its own weight and that additional water is prevented from entering the pipeline by a pressure-sensitive automatic shut-off valve at the intake structure. Site-specific characteristics considered included locations of currently unstable slopes, locations of subwatershed tributaries, thickness of overburden, percent fine-grained soils in the overburden, presence of fractured rock, groundwater conditions, steep slopes, pipeline-tributary crossings, and proximity of the pipeline to the diverted reach of the stream. Volume of water in the pipeline was estimated from the most likely rupture location (based on site-specific characteristics) and location of the diversion structure (Federal Energy Regulatory Commission, 1994).

The estimate of the amount of sediment expected to reach the stream from land-disturbing construction activities was then compared to the existing sediment load in order to predict a magnitude of increase in sediment yield. This estimate gives a general indication of the potential severity of impacts to aquatic habitat from sediment generated from constructing a project (Federal Energy Regulatory Commission, 1994).

RESULTS

The estimated amounts of sediment produced by construction was low to negligible for all projects. Pipeline ruptures were estimated to generate less than 5 percent of the existing annual sediment yields for most projects in the respective subwatersheds, but sediment generated by a worst-case pipeline rupture was substantial for two projects (Table 1).

Over all, construction of the 7 proposed projects was estimated to add 123 tons of sediment to the Nooksack River, an increase of 0.02 percent over the total estimated sediment yield for all 7 creeks. The estimated amounts of sediment that would be added to the streams ranged from 200 to 8,400 tons. Estimated increases in existing sediment yields for sediment generated by construction of these projects ranged from 0.004 to 1.0 percent and from 0.9 to 104 percent for a single, worst-case pipeline rupture compared to existing annual sediment yields in the respective watersheds. Overall, the total potential sediment produced by worst-case pipeline ruptures at all 7 proposed projects would be about 19,900 tons, or 3 percent of the estimated existing sediment yield for these watersheds (Table 1)(Federal Energy Regulatory Commission, 1994).

If a pipeline rupture occurred at the proposed Deadhorse Creek Project (predicted increase of 45 percent over existing sediment load) or at the proposed Canyon Creek Project (predicted increase of 104 percent over existing sediment load) during low stream flows, such that large amounts of eroded sediments were only slowly diluted and flushed from the vicinity, fish eggs, fry, and juveniles could be adversely affected by turbidity and sedimentation in the lower portions of the creeks and potentially for some distance downstream in the North Fork Nooksack River (Federal Energy Regulatory Commission, 1994).

While the potential for erosion varies among the proposed projects, impacts are generally expected to be contained within the affected creeks and at the mouths of the creeks where they discharge into the Nooksack River. Fine-grained sediments entering the Nooksack River is swept far downstream after it enters the main channel of the river. Because of streams that contain glacial meltwater containing large amounts of fine sediments, steep terrain, the presence of thick glacial soils, and logging activity, background sedimentation in the Nooksack River Basin is comparatively high. While short-term sediment delivery to creeks affected by the proposed projects is expected to increase somewhat during project construction, predicted increases in sediment yield is negligible. Even if construction of several projects occurred concurrently, it appears unlikely that measurable increases in sedimentation to the Nooksack River would occur (Federal Energy Regulatory Commission, 1994).

If a landslide-induced pipeline were to occur at any project and result in a large erosion scarp that could not be stabilized, sediment would continue to be delivered from the scarp to the creek, where it could cause adverse effects to aquatic habitat. If a steep scarp were next to the creek and the creek continued to erode and undercut the material, this could cause more long-term and potentially substantial impacts (Federal Energy Regulatory Commission, 1994).

Table 1. Comparisons for each project in the Nooksack River Basin of estimated existing annual sediment yield, sediment yield from construction, and sediment yield from an single, worst-case pipeline rupture (Federal Energy Regulatory Commission, 1994).

Project	Existing annual sediment yield (tons/year)	Construction-related sediment yield (tons)	Percent Increase	Sediment yield from pipeline rupture (tons)	Percent Increase
Nooksack Falls	270,000	10	0.004%	2,400	0.9%
Boulder Creek	4,600	46	1.0%	200	4%
Deadhorse Creek	2,900	8	0.3%	1,300	45%
Canyon Creek	8,100	39	0.5%	8,400	104%
Wells Creek	112,000	10	0.009%	2,500	2%
Glacier Creek	180,000	10	0.005%	3,400	2%
Canyon Lake Creek	-	-	-	1,600	-
Total	577,600	123	0.02%	19,900	3%

CONCLUSION

The sedimentation analyses conducted for these projects were useful for assessing watershed management by providing tools for evaluating both project-specific and cumulative impacts to aquatic habitat from sediments generated by construction of multiple hydropower projects and from worst-case pipeline ruptures during project operation. While predicted increases in sedimentation in the mainstem Nooksack River were low for both construction and operation of the seven proposed projects, this sedimentation analysis provided sufficient detail to identify two projects that could potentially add substantial sediment to the affected creeks from a worst-case pipeline rupture, which could in turn adversely affect aquatic resources.

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NUTRIENT CHARACTERISTICS OF TRAPPED SEDIMENTS RESULTING FROM PRESCRIBED FIRE

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Abstract: Sediments derived from four prescribed burned watersheds in central Arizona were trapped in catchments constructed within the channel and their nutrient content determined for two hydrologic events. Watersheds were selected post-burn based on the percent of area burned: control, 20% burn, 40% burn and 80% burn. The overstory vegetation on the watersheds was comprised of mixed stands of ponderosa pine (*Pinus ponderosa*), with a midstory of *Juniperus* and *Quercus* species. The principal shrubs were typical Arizona chaparral species such as *Quercus grisea*, *Arctostaphylos pungens*, and *Cercocarpus betuloides*. Analyses were made of pH, major cations, P, NO_3-N, and SO_4-S. Sodium (Na) concentrations were low across all treatments, but magnesium (Mg), potassium (K) and calcium (Ca) concentrations were proportionately higher with respect to intensity of burn. Mg concentrations were 2-9 times higher in the 40% and 80% burn, respectively, compared to control or 20% burn. K and Ca concentrations were twice as high in the 40% and 80% burn, respectively, compared to the control or 20% burn. Differences between treatments were attributed to size of area burned. Burn areas of 40% or greater in size yielded magnitudes greater nutrient content in sediments delivered to the stream channel. Results indicate a potential for reduced site productivity on uplands and nutrient loading of the riparian.

INTRODUCTION

Prescribed burns usually have minimal hydrologic impact on watersheds because the surface vegetation, litter, and forest floor is only partially consumed. Fire often causes increased overland flow and greater peak runoff and total discharge, factors responsible for transporting sediment from the site (Tiedemann et al. 1979). Fire also causes rapid mineralization and mobilization of nutrients. Because of the natural variability found in Southwest ecosystems, the fire influence continuum, which land managers face in this area, is quite broad. Nutrient loss from uplands may reduce site productivity (Gifford et al. 1976) and nutrient gains in riparian habitats may have mixed effects, such as increased aquatic biotic productivity or eutrophication (Wetzel 1983).

Of all natural resources, water is probably the most sensitive to disturbance of vegetation and soil. Water responses depend on the intensity and severity of burning and the proportion of the watershed burned. Where vegetation is destroyed, interception and evapotranspiration are reduced. Where the organic layers of the forest floor are consumed and mineral soil exposed, infiltration and water storage capacities are reduced providing the potential for increasing overland flow and greater sediment transport capacity. The duration of effects from burning range from very short periods to many decades, depending on the intensity of the fire itself and rate of vegetation recovery.

Sedimentation studies have largely focused on sediments and not on nutrients (Bolton et al. 1991). A few simulation studies on ecosystems of New Mexico and Arizona have been conducted (Ward and Bolton 1991, Bolton et al. 1991). Others have addressed the potential of Southwestern systems to transport heavy metals (Gosz et al. 1980), while some have examined runoff (Gottfried and DeBano 1988). The objectives of this study were to quantify losses of nutrients associated with sediments derived from four prescribed burned watersheds in central Arizona.

METHODS

Study Area: The study area is located in northwestern Gila County, the geographic center of Arizona, immediately below the Mogollon Rim escarpment. The physiography is characterized by mesas, rolling hills, and part of the Mexican Highland section of the Basin and Range physiographic province described by Fenneman (1931). Elevations range from 1740 m in the upper watersheds to about 1585 m in the chaparral. Precipitation is bimodal (summer and winter) with localized monsoon summer showers and low intensity winter storms. Nearly 65% of total precipitation occurs in winter, primarily as snow. Mean annual precipitation is 635 mm with a range of 550 to 760. Mean annual temperature averages 14°C and ranges from -10°C to 32°C. The drainages are ephemeral and drain southward into the Verde River system of central Arizona.

The vegetation consists of a mixture of ponderosa pine and Great Basin Conifer Woodland in the upper and mid-sections of the area and stands of chaparral in the lower reaches. Ponderosa pine (*Pinus ponderosa*) is the dominant tree with mixed understory of Gambel oak (*Quercus gambelii*), gray oak (*Q. grisea*), Arizona white oak (*Q. arizonica*), and Emory oak (*Q. emoryii*). Woodland species include alligator juniper (*Juniperus deppeana)*, Rocky Mountain juniper (*J. monosperma*), and pinyon (*Pinus edulis*). The chaparral is characterized by mixed stands of pointleaf manzanita (*Arctostaphylos pungens*), birchleaf mountainmohagany (*Cercocarpus betuloides*), Wright silktassel (*Garrya wrightii)* skunkbush sumac (*Rhus trilobata*), shrub live oak (*Quercus turbinella*), and cane cholla (*Opuntia spinosior*). The riparian plant communities are characterized chiefly by stands of bigtooth maple (*Acer grandidentatum*), with associated species of Arizona alder (*Alnus oblongifolia*), boxelder (*Acer negundo*), and Arizona walnut (*Juglans major*). Principal herbaceous plants include sideoats grama (*Bouteloua curtipendula*), blue grama (*B. gracilis*), and Fendler's bluegrass (*Poa fendeleriana*).

Experimental Design/Analyses: The area (612 ha) was prescribed burned in early fall of 1989 using drip torches. The fire burned in a mosaic pattern which permitted selection of 4 watersheds as treatment areas. Treatment watersheds were selected post-fire based on the percent of area burned. Treatments included an unburned control watershed, a 20% burn, 40% burn, and an 80% burn. Each treatment contained similar proportions of vegetation species. A catchment basin was constructed in each treatment for the purpose of capturing sediments. All catchments were constructed in headwater reaches of the watershed so as to have: 1) the ability to capture all sediments from any given storm; and 2) such that catchments were within the approximate vegetation type, elevation, and geology. Sediments were sampled from each basin after each major storm event (August 1990 and Sept 1990) and the basin emptied thereafter. Core samples were randomly collected from each basin so as to comprise the full depth of the sediment column. Ten 500 cc core samples were used to comprise a composite sample, and ten composite samples were collected for each treatment and event. Composite samples were chemically analyzed for cations, bicarbonate phosphorus (P), sulfate-sulfur (SO_4-S), nitrate-nitrogen (NO_3-N), and pH as per Black et al. (1965). Differences between and within treatments were determined using Duncan's multiple range test statistic. Two storm events of magnitude greater than 20 mm produced sediment quantities between 60-80 % of the catchments capacity (~ 100 m^3) and are used to illustrate differences in nutrient losses from the various burn treatments.

RESULTS

Storm Events and Sediments: The first storm event with sufficient rainfall to produce runoff and deliver sediments to the catchments occurred on August 11, 1990. The storm produced 30 mm of precipitation within a 3-hour period and resulted in a net production of sediments ranging from a mean of 0.032 m^3/ha in the control to 0.373 m^3/ha in the 80% burn (Figure 1). Total rainfall for the month was 119 mm. The second storm occurred on September 20, 1990 and produced a rainfall amount of 14 mm. Although the total precipitation of the storm was much less, previous rainfall (18 mm) two days prior had recharged the watershed sufficiently to produce good runoff. This storm produced a lesser amount of sediments compared to the previous (Table 1). Total rainfall for this month was 41 mm.

Fire Intensity vs Burn Area: The intensity of individual burns or degree of biomass consumed was not monitored owing to the erratic fire behavior which resulted in a mosaic of burned patches. However, fire intensities in the chaparral appeared greatest, followed by the pinyon-juniper-oak woodland, and the mixed ponderosa pine type. This observation is based on the volume of standing woody plants that were consumed. Herein, results are interpreted relative to percent of area burned. Consumption of woody plants was mixed in the burned areas with only chaparral species being fully consumed. Large trees remained relatively unaffected with minor scorching from the heat of nearby burning brush and herbaceous species. Litter and herbaceous species comprised the majority of fuel in the mixed ponderosa woodland type.

Calcium: No significant differences in the concentration of Ca were detected between the control and 20% burn treatment for events 1 and 2 (Table 1). Ca concentrations were of nearly the same magnitude. However, significant differences were observed between the control, the 20% burn, and the 40% and 80% burn treatments. Nearly twice as much Ca was found in the sediments emanating from the 40% and 80% burns. There were no significant differences in Ca concentration between the 40% and 80% burns. The data suggest a greater nutrient loss from the more severe burns. DeBano and Conrad (1978) reported a translocation of 45 kg/ha of Ca to the soil surface during a prescribed chaparral burn and a sunsequent loss of about 67 kg/ha of Ca through erosion and runoff. This suggests that not only are soluble cations deposited in the ash lost following burning but that some of these elements in the burned and unburned litter and litter can also be eroded away.

Magnesium: Significant differences in Mg concentrations were noted between the control, the 20% burn, and the 40% and 80% burn, as well as between the 40% burn and the 80% burn (Table 1), suggesting that effects were incremental relative to the percent of area burned. In addition, differences between events were also present in the 40% and 80% treatments. Mg concentrations were 2-3 times higher under the 40% burn and 5-9 times higher under the 80% burn treatment. Differences between events were mixed with a 66% higher concentration in event 1 under the 40% burn, and about 55% less in event 1 compared to event 2 under the 80% burn. DeBano and Conrad (1978) reported a translocation of 14 kg/ha of Mg to the soil surface during a prescribed chaparral burn and a loss of about 32 kg/ha Mg through erosion and runoff.

Potassium: The same pattern of nutrient concentration and differences between treatments as with Ca were noted for potassium (K) (Table 1). In general, K levels were about twice as great in the 40% and 80% burn treatments than in the control and 20% burn. K seems to have a special role in nutrient recycling during fire because a large proportion of this element is contained in the plants and litter. About 73%, or 287 kg/ha, of the K in chaparral is found in the plants and litter (DeBano and Conrad 1978). During a prescribed burn, about 15% (44 kg/ha) of the K in the plants is deposited as ash on the soil surface and another 15% is lost--possibly by volatilization. An additional 10% is also lost by erosion and runoff after the fire.

Sodium: Exchangeable Na levels were low and significant differences were observed only between the control, the 20% and the 40% burn treatments (Table 1). Na concentrations for the 80% burn were only slightly higher than those of the control or 20% burn. DeBano and Conrad (1978) reported a translocation of 5 kg/ha of Na to the soil surface during a prescribed burn in chaparral and about 5 kg/ha of Na are lost by erosion and runoff.

Bicarbonate-Phosphorus: Significant increases in bicarbonate phosphorus (P) loss were noted between all burn treatments and the control. A significant difference was also seen in P between events on the 20% burn (Table 1). Loss of P from uplands has been attributed to post-fire erosional sequences in California chaparral (DeBano and Conrad 1978). About 5% (32 kg/ha) of the P in this vegetation type is concentrated in the smaller plant stems and litter that are easily consumed by the fire. Almost all P in the plants is returned to the soil surface as ash during prescribed burning. Saa et al. (1994) report the intensity of the burn also affects P forms and their distribution in the soil. Moderate burns caused high levels of inorganic P to be found in eroded sediments. Total annual P losses may range from 1.42 kg/ha (control plots) to 4.35 kg/ha on moderate burns, to 9.10 kg/ha on severely burned plots. This implies a strong potential for eutrophication of receiving waters. Rainfall simulation studies on unburned pinyon-juniper and ponderosa pine vegetation types report a nutrient loss of 0.82 mg/l (0.16 kg/ha) to 2.2 mg/l (0.30 kg/ha) of total P, respectively (Bolton et al. 1991).

Sulfate-Sulfur: Treatment differences for SO_4-S were consistent with other nutrients examined above for the 40% and 80% burns relative to the control (Table 1). However a significant reduction in concentration was observed for event 1 between the 20% burn and control. Significant reductions were also detected between events on the 40% and 80% burns. In general SO_4-S levels were higher in the first event.

Nitrate-Nitrogen: Treatment differences for NO_3-N were evident only for the 80% burn treatment. Because of its mobility, it is suspected that NO_3-N was primarily lost in runoff and to a lesser extent as losses associated with the sediments. Prescribed burning in California chaparral results in losses of N by volatilization and erosion (DeBano and Conrad 1978). Although this loss represents only 11% (161 kg/ha) of the N in the plants, litter, and upper 10 cm of soil, frequently burned sites would soon be devoid of N if this amount were lost during each fire without a mechanism for replacing it. We know that precipitation contains some N, although this input amount is probably minimal. A more important mechanism seems to be nitrogen-fixing organisms. Some shrubs develop root nodules capable of fixing up to 60 kg/ha of N annually under optimum conditions and other post-fire leguminous herbs undoubtedly also fix N (DeBano and Conrad 1978). Nitrogen fixation by non-symbiotic organisms may also replenish N after a fire, although this source has received little study. Rainfall simulation studies on unburned pinyon-juniper and ponderosa pine vegetation types report a nutrient loss of 2.56 mg/l (0.49 kg/ha) to 3.46 mg/l (0.53 kg/ha) of total N, respectively (Bolton et al. 1991). Nitrate-N, ammonium-N (NH_4-N), and organic N are the most commonly studied forms of nitrogen as indicators of effects of disturbance or land management activities on water quality (Tiedemann et al. 1979).

pH: No treatment differences were detected fof pH, although pH was slightly higher in the 20% burn but lower in the 40% burn and in the first event for the 80% burn. The slight reductions may be in response to the higher SO_4-S and P levels in these respective treatments.

DISCUSSION

Prescribed burning probably has its greatest influence, hydrologically, on infiltration and, consequently, on overland flow potential. Because of natural variation in moisture conditions, prescribed burns normally produce a mosaic pattern of consumed organic matter and, consequently, produce various degrees of influence on water storage capacities and infiltration rates within an area. If properly executed, prescribed burning will not significantly affect, either spatially or temporally, the integrated overland flow and streamflow regime of a watershed.

Overland flow following prescribed burning is directly related to slope steepness and indirectly related to the rate at which disturbed areas are revegetated (Wright et al. 1976). Vegetation does not usually develop as rapidly or uniformly on steep slopes, as on more moderate slopes.

Light, intense burns can significantly decrease infiltration capacities in the ponderosa pine forest type (Zwolinski 1971). Infiltration data often show a prominent depression after the start of water application caused by soil nonwettability or water-repellency. Restoration of the infiltration capacity to near normal occurs during the winter, however, because of repeated freezing and thawing of the soil. A significant increase in soil bulk density can also be obtained following a heavy burn but not usually after light burning. Removal of organic material probably causes a breakdown in soil structure, resulting in a more compacted surface soil. Any factors resulting in increased overland flow will have a direct influence on erosion potential.

Erosion in the arid Southwest must be viewed as an unsteady or discontinuous process which transports sediment from a source and through a channel system with intermittent periods of storage (Wolman 1977). This episodic transport process is more characteristic of arid or semiarid climate than of humid regions because the major cause of erosion in the Southwest is the "big" storm. These big storms move materials from various sources, including the material temporarily stored in channels system. The disproportionate amount of sediment and debris moved during these major storms makes it difficult to define a "normal rate" of erosion either in the undisturbed or treated condition (DeBano 1977). Sediment yield post-fire is more apt to be a transport-limited process for the first 2 years, thereafter returning to a more typical supply-limited phenomena (Bolin and Ward 1987).

Sediment Losses of Nutrients: Sediment losses of N and cations after logging and burning timber in Oregon are similar to solution losses for N and much lower than solution losses for major cations (Tiedemann et al. 1979). Under similar situations in Montana, sediment is the primary source of loss for P, Ca, Mg, and K (DeByle and Packer (1972). Sediment losses of N, P, and cations in California chaparral can exceed those lost in solution after a wildfire (DeBano and Conrad 1978). However, total losses of nutrients (in sediment and solution) is generally a minor proportion (0.7-8%) of the total nutrient capital on site. However, most fire studies are short term (<2-3 years) and little is known of the potential long term losses. Nutrients with a low volatilization temperature (N, P, and S) are apt to have greater losses to the atmosphere, whereas those with high volatilization (Ca, Mg, and K) are generally left behind in the ash (Covington and Sackett 1988). In this study soil losses from upland sites were observed to approximate 3-4 inches over 4 years on the 40% and 80% burns. This is significant considering that the soils are shallow with an average depth of 3-5 cm.

Effects of Burning on Nutrients: Nutrients in small live twigs or dead plant material of chaparral species are either released in a highly soluble form and deposited on the soil surface or are lost by volatilization during fire (DeBano and Conrad 1978). These highly soluble plant nutrients on the soil surface may be used for plant growth or are easily lost by erosion. Above-normal movement of nutrients to streams by surface erosion and leaching has the potential for impairing surface water quality for municipal purposes, causing eutrophication of aquatic habitats, and lowering site productivity.

Effects of Nutrient Enrichment on Riparian Habitats: The effects of nutrient enrichment of surface waters is well documented (Vollenweider 1980). Southwestern riparian ecosystems have not been extensively studied. Grimm and Fisher (1986) report nitrogen is most often limiting in southwestern streams during summer low flows, in contrast to streams of the eastern United States where P is more limited. Phosphorus appears to be more common owing to the parent geology being largely volcanic (Dillon and Kirchner 1975). In another study, Gottfried and DeBano (1988) reported nutrient changes of streamflow from prescribed burned ponderosa pine sites in the White Mountains to be of little consequence, probably owing to the small percent of area (43%) burned. Recent reviews by Baker (1988) also emphasized the paucity of information on fire effects on riparian habitats.

MANAGEMENT IMPLICATIONS

Fire can be used economically in managing and manipulating vegetation, often in an ecologically sound manner. Mechanical means of preparing seedbeds are expensive, and spraying with herbicides is not only expensive but also controversial. Initially, however, fire may need to be used in combination with other improvement methods. Costs of fire suppression are increasing every year. Risk of wildfire can be reduced by the use of prescribed burning. A study of 26,000 ha of prescribed burn in Arizona showed that 82% fewer fires occurred in the 3 years following control burning (Hedden 1957). Prescribed burning in some forest situations may result in some pruning of the lower tree branches and some reduction of stems and fuelwood. These factors often contribute to increases in environmental esthetics, better accessibility for recreational uses, increases in nutrient availability for plant growth, improved wildlife habitat, and a reduction in insect and disease damage.

Most land managers in the Southwest have responsibility for at least two or three vegetation types, and the influence of burning in these various ecosystems are usually different. Generally, hydrologic responses after burning change proportionally with precipitation and are minor where annual precipitation is less than 460 mm (Hibbert 1979). This precipitation criteria applies to all desertscrub types, the semidesert grasslands, and much of the conifer woodland type. Therefore, only the montane conifer, much of the interior chaparral, and some of the conifer woodland type with annual precipitation regimes above 460 mm have the potential of exhibiting much of a hydrologic response to burning.

Because of the natural variability found in Southwest forest environments and in burning situations, fire influences are viewed as a continuum, with effects of prescribed burning at one extreme and wildfire at the other. Each burning situation, whether a prescribed burn or wildfire, will result in a mosaic pattern of site conditions. Land managers, consequently, must often deal with a wide spectrum of fire influence on a given burned area. However, with increased knowledge and its implementation, perhaps more time and money can be expended on the prescribed burning end of the scale.

Light, prescribed burns usually have minimal hydrologic impact on watersheds as the result of partial burning of the surface vegetation, litter, and forest floor as shown in this study. Prescribed burns which are apt to deliver sediments to riparian areas should encompass less than 40% of the total area when site productivity and surface water quality are of concern.

Most of the streamflow in the Southwest comes during the spring runoff period. Therefore, any increases due to burning will normally be added to flowing streams. Consequently, it may be difficult to detect or measure effects of fire any significant distance below even severely burned areas. Most evidence suggests that, even after wildfires, responses in streamflow and sediment yields drop to near pre-burn levels within 3 to 5 years.

Often nutrient losses following fire are not great compared to the total amount of nutrients on the site. However, what affect the periodic losses of nutrients have on "watershed condition" or what "cumulative effects" these losses have on site productivity are not well established (Baker and Jemison 1992). On one hand you may create a nutrient impoverished condition on the uplands and an eutrophication condition in the riparian zone.

Prescribed burning can be used as a management tool in the various vegetation types found in the Southwest. However, land managers must always be aware of the delicate balance that exists within the soil-plant-water-atmosphere system and how easily it can be, either positively or negatively, influenced by fire. Two major gaps in our knowledge are: the cumulative effects of burning on watershed condition, and the effects of burning on riparian habitat. These two areas must be studied before the full potential of prescribed burning can be realized.

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Table 1. Mean nutrient concentrations (ppm) of sediments delivered to stream channels from 2 storm events post-fire for each treatment. Significant differences ($p < 0.05$) between the control and treatments across each event are indicated with the subscript a. Significant differences between other treatments are subscripted as follows: 20% (b), and 40% (c), and within treatment differences between events with (x). Values for event 1 are listed above those of event 2.

PARAMETER	CONTROL	20% BURN	40% BURN	80% BURN
EXCH. Ca	4335 4109	4171 4362	10,140ab 8692ab	7480ab 9332ab
EXCH. Mg	144 131	131 140	469ab 311abx	701abc 1289abcx
EXCH. K	316 297	236 238	624ab 534ab	518ab 555ab
EXCH. Na	23 22	23 22	47ab 34ab	28 29
BICARB. P	36 45	91a 19ax	144ab 130ab	117ab 101ab
SO_4-S	32 26	17a 17	133ab 47abx	89abc 55abx
NO_3-N	10 9	6 6	9 5	71abc 20abcx
pH	7.6 7.6	7.7 7.7	7.4 7.3	7.4 7.6

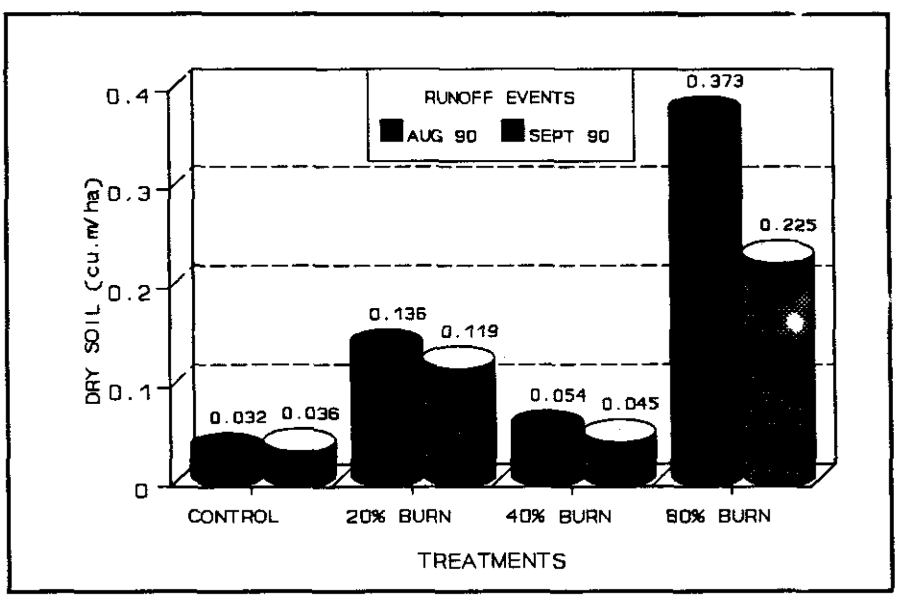

Figure 1. Sediment quantities delivered to catchments after 2 major runoff events for each treatment.