SUSPENDED SEDIMENT IN FOUR NORTH MISSISSIPPI RESERVOIRS[1/]

by

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ABSTRACT

The suspended sediment concentrations at the major inflows and the outflows of four North Mississippi (Arkabutla, Sardis, Enid, and Grenada), reservoirs were measured weekly beginning May, 1973. Sediment concentrations within the four reservoir water bodies were monitored regularly between July 1973 and November 1974. These data are presented and compared with weekly accumulated precipitation on each reservoir's watershed. For two representative cases, the influence of the total suspended solids on physical reservoir phenomena was analyzed.

INTRODUCTION

Four, large, flood-control reservoirs in northern Mississippi--Sardis, Arkabutla, Enid, and Grenada--were constructed and are operated by the U. S. Army Corps of Engineers as multipurpose structures since they provide incidental recreation, conservation, water supply, and navigation benefits (1, 2, 3, 4). These reservoirs receive water from highly erodible watersheds which annually receive about 130 cm of precipitation. Agriculture is an important land use on these watersheds and thus, the runoff water carries fine sediments in suspension into the reservoirs. While the larger sized sediments are deposited in the deltas of the reservoirs, the finer sediments are carried into and mixed with the reservoir waters.

Sediment particles, particularly the smaller clay sized particles, influence the natural physical, chemical, and biological ecosystem in reservoirs. Solar radiation penetrating the water for heating and photosynthetic processes is drastically reduced by the backscattering from the suspended particles so that a substantial part of the incident solar energy is rejected from the reservoir. Sediment particles, particularly very fine clay particles may serve as vehicles for transporting agricultural chemicals (5). Large concentrations of suspended sediment particles affect the apparent density of the suspending water producing density currents.

These reservoirs have been studied previously by McGaha and his coworkers (6) (7) (8). Hydrologic information, like daily stage, volume, and outflow and monthly water quality, are routinely collected and made available in summary form from the Corps of Engineers. The National

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Weather Service maintains limited meteorological stations on the watersheds from which data are available.

This study was made to investigate the annual cycles of suspended sediment into, out of, and within the reservoirs, and to investigate this influence on density-related physical processes.

RESERVOIR DESCRIPTION

For this study, the morphometry was reduced to a one-dimensional, stage-volume relationship (5) for each reservoir.

$$V_h = C_v h^n \qquad [1]$$

where V_h = reservoir volume below stage h

h = stage above deepest point in reservoir

C_v = reservoir volume coefficient

n = stage-capacity exponent

Table 1 presents watershed and reservoir data including values of C_v and n.

PROCEDURES AND METHODS

Since May 1973, samples have been collected weekly from the principal rivers emptying into the reservoirs and from the reservoir outflow in the stilling basin just downstream from the hydraulic jump. Between July 1973, and November 1974, in situ measurements of temperature profile, solar radiation (incident and reflected), and Secchi depth were obtained from several sites in each reservoir. Water samples also were obtained at each site for later laboratory analysis with a 1-l Kemmerer-style water sampling bottle. Secchi depth measurements were made in the standard manner using a standard 20 cm disk with alternate black and white quadrants. The water temperatures were measured at 0.5-m intervals with a Yellow Springs Instrument MO 46TV thermistor thermometer* and with a submersible probe on a 15-cable.

The incident and reflected solar radiation were measured using an ISCO Model SR Spectroradiometer with a 2.95-m light pipe equipped with a diffusing screen. The spectroradiometer was calibrated and checked regularly using an ISCO Model SRC Spectroradiometer calibrator. Solar radiation was measured in microwatts per square centimeter per nanometer (μ watts cm^{-2} nm^{-1}). Reflected solar radiation was measured perpendicularly 20 to 50 cm from the water surface. At each site incident solar radiation was measured first at 180° from the water surface. Both reflected and incident solar radiation measurements were made at 25 nm

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* Names of products or companies are provided for information only and do not constitute an endorsement or preferential use by the U. S. Department of Agriculture.

intervals from 400 to 750 nm and at 50 nm intervals from 750 to 1550 nm. All solar radiation measurements were made on clear days and within 2-hr of solar noon.

The concentration of total solids (TS) in the surface waters, expressed in parts per million (ppm), was determined from two surface water samples collected at each site. A 100-ml aliquot from each sample was evaporated to dryness in a weighing beaker and the remaining TS determined. Dissolved solids (DS) were determined by filtering a 100-ml aliquot through a 0.45 micron filter and evaporating to dryness. The total suspended solids (TSS) was determined by taking the difference between TS and DS.

RESULTS AND DISCUSSION

Figures 1 through 4 show the time records of the concentrations of TS in the inflows and outflows (primarily clay sediments) along with rainfall records for the four reservoirs. The rainfall records are weekly cumulative values from official stations at Holly Springs on the Arkabutla watershed, Abbeville on the Sardis, Water Valley on the Enid, and Calhoun City on the Grenada.

The TS concentration values on any given date were smoothed by calculating running averages derived from the previous five weekly samples. This smoothing was considered desirable to emphasize long term tendencies in the data. As expected, TS concentration in the incoming rivers varied more than in the outflowing water. The averaging effect of the lake produced more moderate concentration fluctuations in the outflowing water.

Figure 5 shows the TSS in the surface waters of the reservoirs. The trends expressed are similar to those of the TS in the outflowing waters (Figs. 1 to 4). The TSS concentrations of Enid and Sardis were very similar; Grenada had approximately 50% more than them, while Arkabutla had significantly more TSS than any of the other three.

One reason for this is the basic design of the reservoirs. A significant parameter is the ratio of flood pool capacity to mean annual runoff. Values of these for Arkabutla, Sardis, Enid, and Grenada are 0.492, 0.946, 1.079, 0.971, respectively. Annually basis the water replacement rate in Sardis, Enid, and Grenada is approximately once yearly, while that for Arkabutla is about twice yearly. Actually the flushing rate is greater since the reservoirs are managed much lower than at flood pool stage.

The currents and mixing processes are the result of three major sources of energy input: advected energy from the inlet streams, solar radiation, and wind. On the relatively large reservoirs, the inlet streams are not important as compared with the wind and solar radiation. Energy is transferred through the surface either as heat or as mechanical work by the wind shear stress on the water surface.

Usually, Arkabutla is virtually unstratified throughout the year, while the other reservoirs develop strong stratification during the summer (May through August) (9). In addition, Arkabutla is somewhat shallower than the other reservoirs. In a strongly stratified lake, the energy and momentum delivered to the reservoir by the wind is concentrated in the epilimnion (the mixed layer near the surface) leaving the hypolimnion (the layer below the thermocline) relatively undisturbed. In the deeper lakes, long periods of stratification during the summer confine turbulent mixing to the surface layer. Once sediment particles enter the hypolimnion, they are essentially trapped and continue to settle out. On calm days the particles in the epilimnion will settle across the thermocline and thus strongly stratified lakes will clear significantly. In Arkabutla the wind continuously mixes the shallow lake during the entire year which keeps the sediment in suspension.

During an unusual year, 1973, the water levels in Arkabutla during May, June, and July were near flood pool depth, allowing strong stratification to develop. The lake cleared considerably and during early September an average of only 22 ppm TSS was measured in the surface waters and the Secchi depth (a rough measure of water clarity) was 0.8. During a more usual year, 1974, in early September, 60 ppm TSS and a Secchi depth of 0.5 was measured. The reservoir during May, June, and July, 1974 was maintained at the ordinary levels.

An example of an interaction between TS and a physical lake process was a density flow observed in Arkabutla on November 21, 1974. Samples and measurements were obtained at three sites, 0.8, 2.5, and 5 km away from the outlet tower at the dam on a line toward the mouth of the Coldwater River. Higher concentrations of TS and an obvious difference in the clarity of the water were noted as the distance increased from the outlet in the direction of the Coldwater river. Measurements with the spectroradiometer indicate definite differences. Figure 6 shows that the corrected reflectance (ratio of the reflected to incident radiant energy spectra from the three sites significantly depends upon the TSS concentration in the surface waters. In small agricultural reservoirs this effect results in sediment laden ponds with uniform sediment distribution being cooler than relatively clear ponds, if all other circumstances are the same (10).

Three factors acting simultaneously affect the density of water. Temperature has a definite and well known influence. The thermal stratification of lakes, already discussed, is a consequence of this fact. Dissolved substances in water is another factor. Chemically stratified lakes with fresh water epilimnions and saline hypolimnions are examples. Entrained particulates such as sediment particles directly affect the fluid density in proportion to concentration is still another example.

In some lakes and reservoirs, one or more factors may be neglected because of its small influence as compared with the remaining factors. A small increase or decrease in density is determined by

$$\Delta\rho = \frac{\partial\rho(T)}{\partial T}\Delta T + \frac{\partial\rho(s)}{\partial s}\Delta s + \frac{\partial\rho(c)}{\partial c}\Delta c \qquad [2]$$

where $\rho(T)$ = functional relationships of density with temperature

T = temperature

$\rho(s)$ = functional relationship of density with dissolved substances

s = DS concentration

$\rho(c)$ = functional relationship of density with suspended particles

c = TSS concentration.

In the four reservoirs studied, density processes were generally influenced by temperature and TS concentration. The DS concentrations were generally low (<50 ppm) and uniform within each reservoir studied.

From the Arkabutla data of November 21, 1974, interactions between the temperature and the TSS and their influence on the fluid density were apparent. The temperature and TS profiles (Fig. 7) show significant differences between sites, with TS concentrations and temperatures increasing with distance from the reservoirs outlet structure. When the total density at a particular depth was computed from the TS and temperature measurements and the resulting density profiles examined, the temperature and TS have interacted so as to nearly eliminate density differences in the horizontal direction. In the vertical direction the density stratification was such that a density flow containing large TSS concentrations was traveling along the surface of the reservoir. The warm, sediment laden water on the surface was the result of recent runoff from a large precipitation event 2 days earlier.

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4. Corps of Engineers, Report of Sedimentation Resurvey, Grenada Reservoir, Vicksburg District, U. S. Army Corps of Engineers, August 1966.

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Table I

Reservoir Description

	Arkabutla	Sardis	Enid	Grenada
Date Placed in Operation	Nov. 1945	Aug. 1940	Feb. 1953	Jan. 1954
Watershed Area, km^2	2590	4001	1450	3419
Principal Inlet River	Coldwater	Little Tallahatchie	Yocona	Yalobusha, Skuna
Mean Annual Runoff, m^3	1.30×10^9	2.05×10^9	0.76×10^9	1.70×10^9
Flood Pool Capacity, m^3	0.64×10^9	1.94×10^9	0.815×10^9	1.65×10^9
Maximum Flood Pool Depth, m	14.9	23.5	22.3	21.6
Maximum Conservation Pool Depth, m	6.1	9.1	10.7	10.1
Average Flood Pool Depth, m	4.8	8.2	7.2	6.3
Average Conservation Pool Depth, m	1.9	2.9	2.9	2.7
Flood Pool Area, km^2	135	237	113	262
Conservation Pool Area, km^2	20.7	39.7	24.8	39.7
n	3.19	2.99	3.38	3.63
C_V	2.13	3.59	0.33	0.26

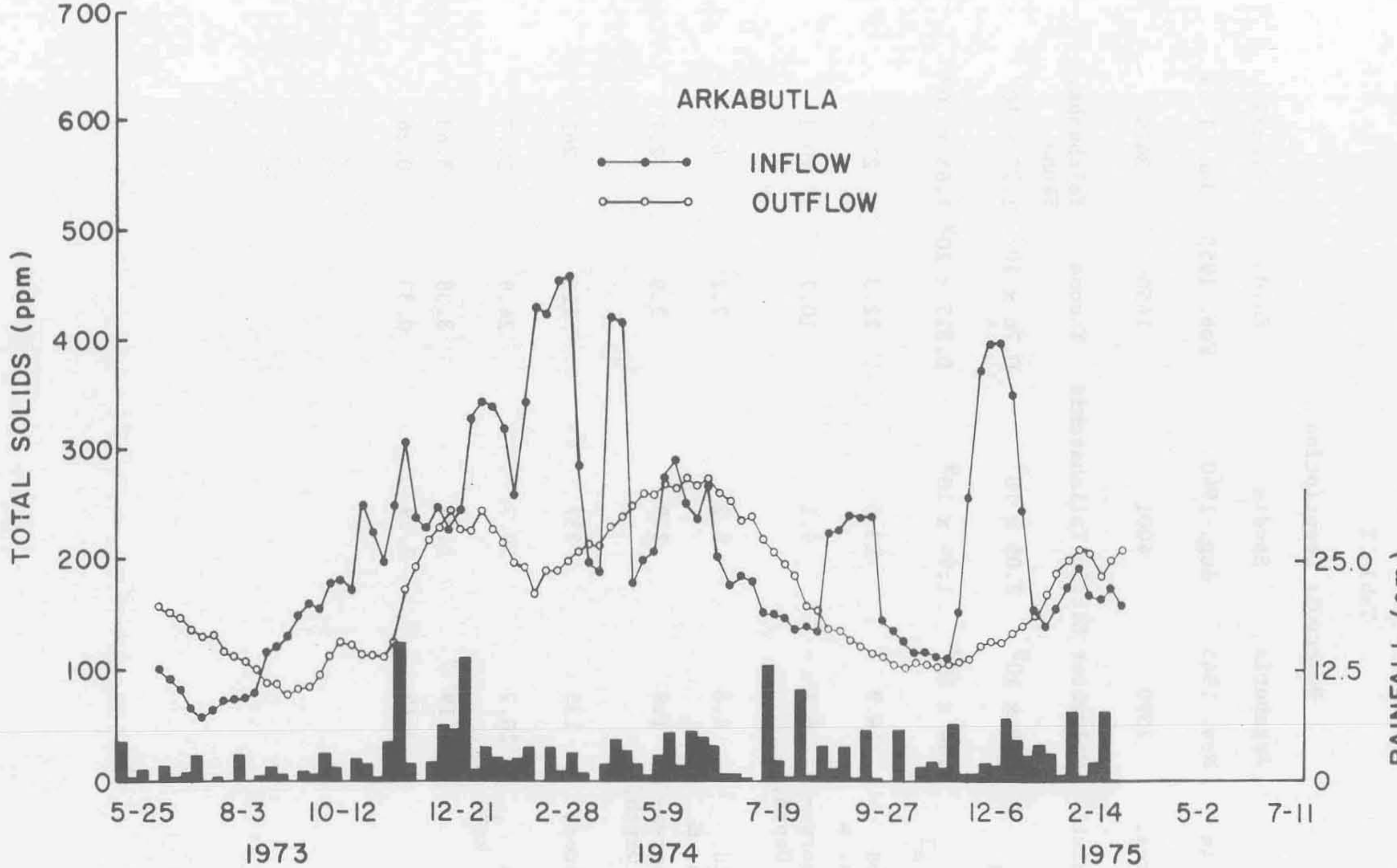

Fig. 1 Concentrations of Total Solids in the Inflow and Outflows and Precipitation on the Arkabutla Watershed.

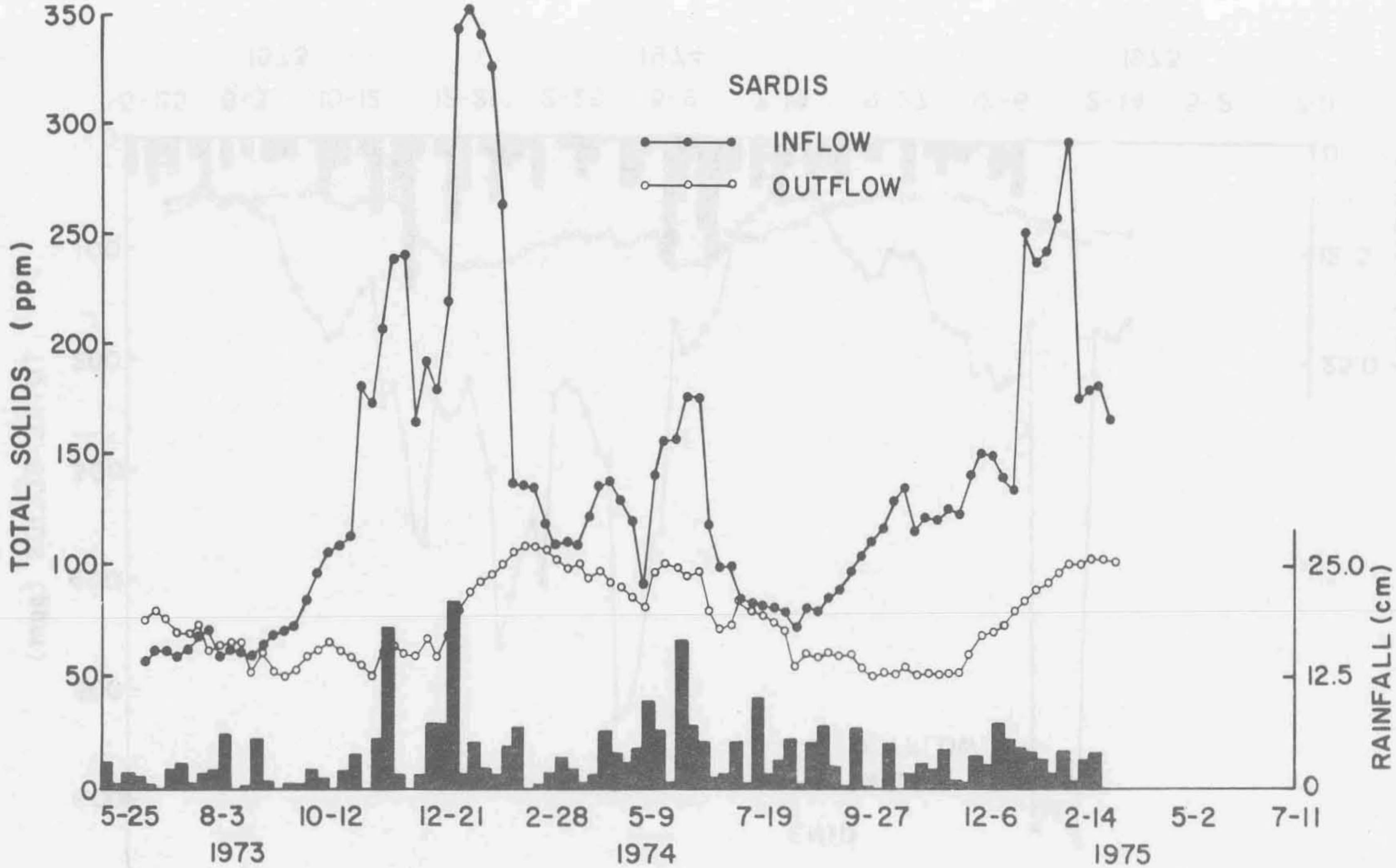

Fig. 2 Concentration of Total Solids in the Inflow and Outflows and Precipitation on the Sardis Watershed.

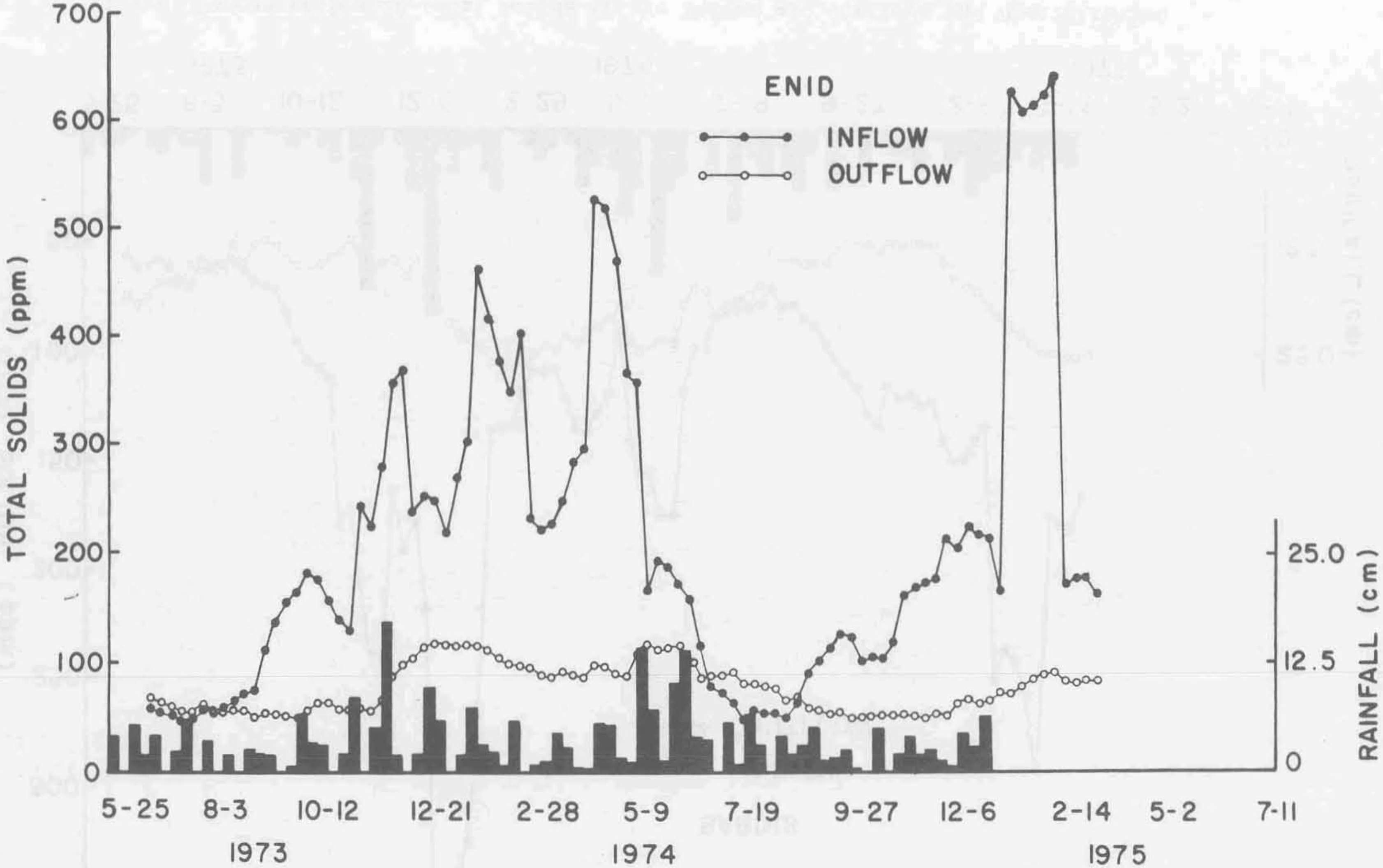

Fig. 3 Concentrations of Total Solids in the Inflow and Outflows and Precipitation on the Enid Watershed.

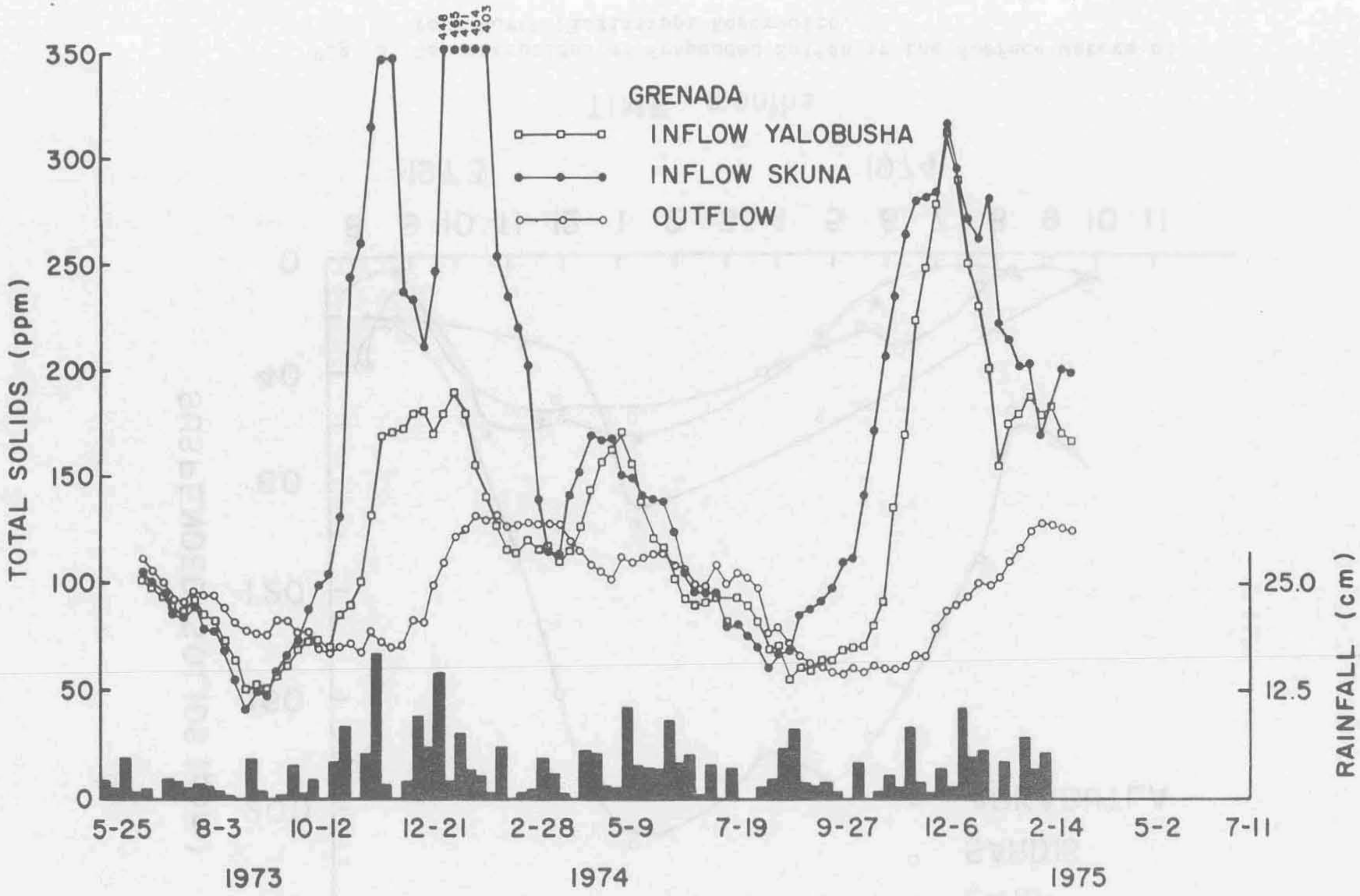

Fig. 4 Concentrations of Total Solids in the Inflow and Outflows and Precipitation on the Arkabutla Watershed.

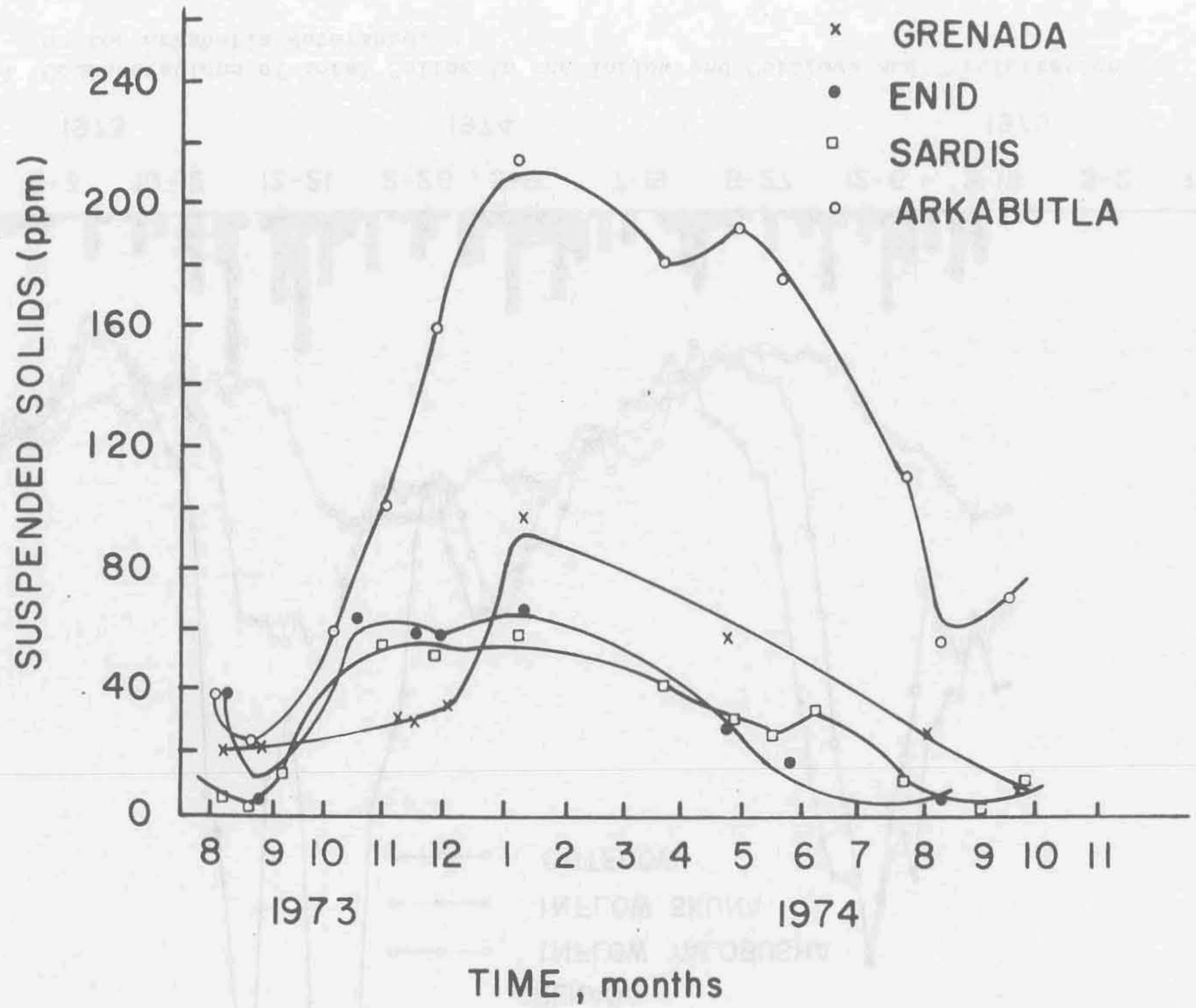

Fig. 5 Concentrations of Suspended Solids in the Surface Waters of Four North Mississippi Reservoirs.

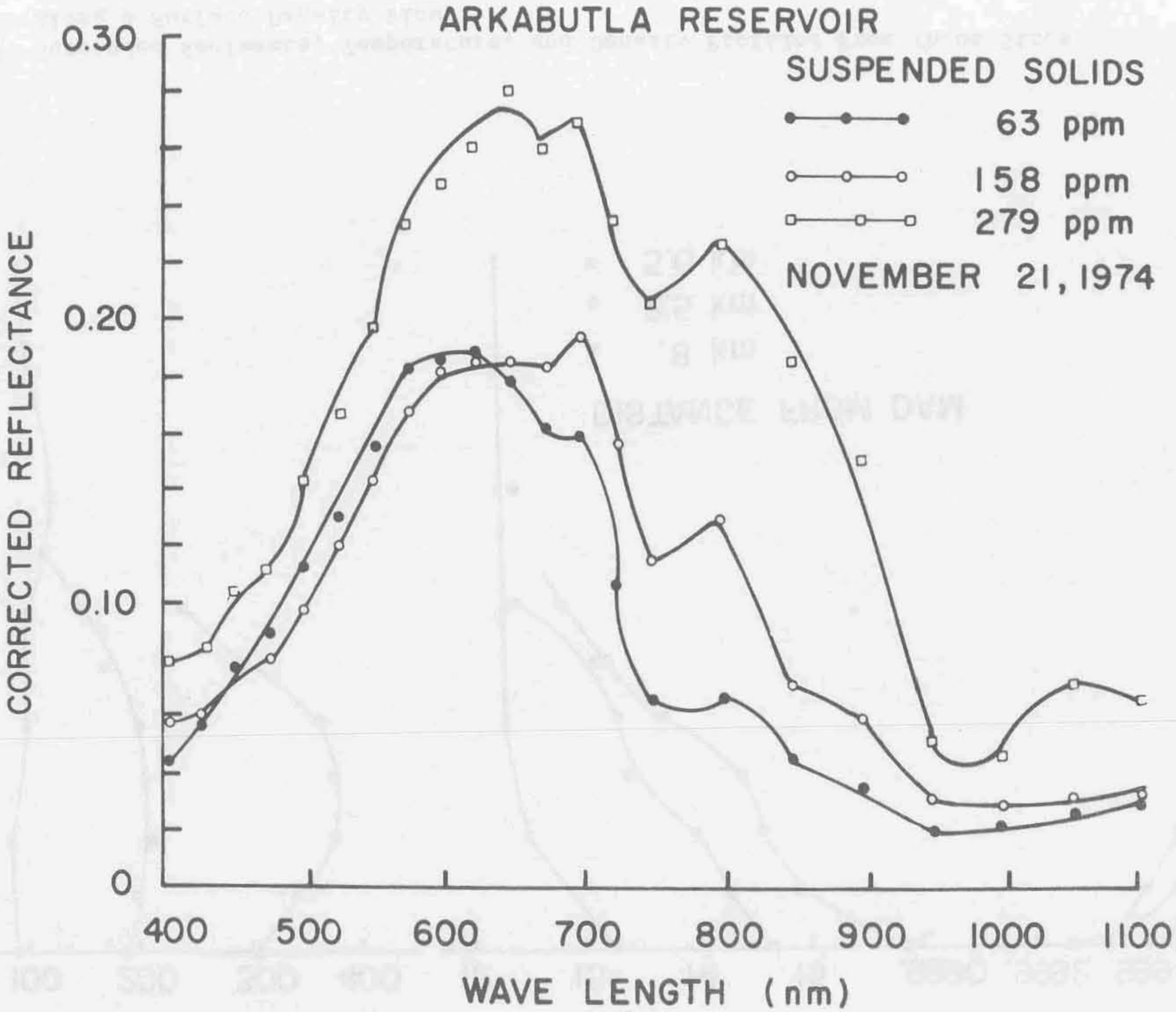

Fig. 6 Reflectance Spectra from Three Sites Along a Surface Density Flow.

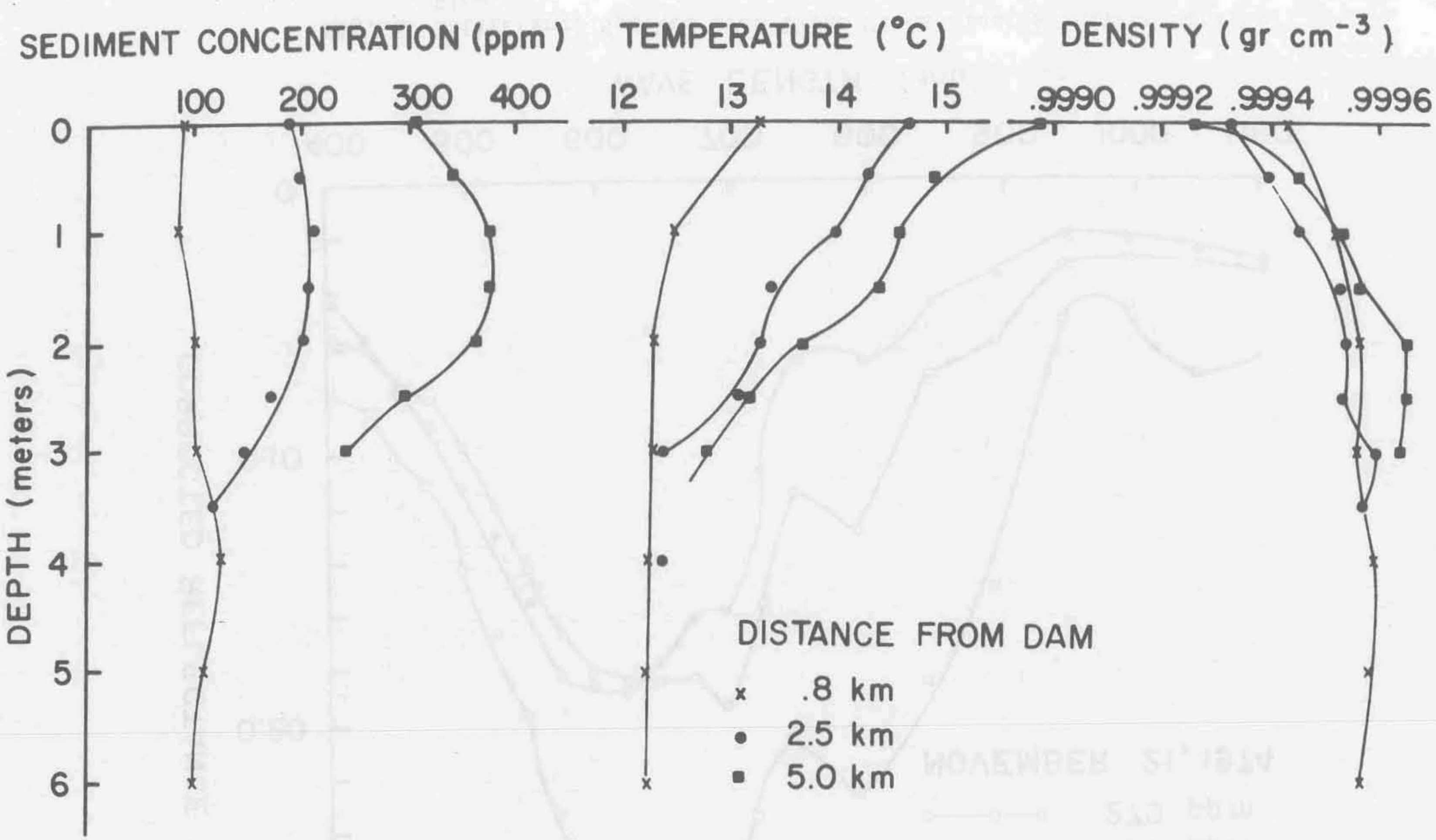

Fig. 7 Suspended Sediments, Temperature, and Density Profiles From Three Sites Along a Surface Density Flow.