SUSPENDED SEDIMENT IN THE AMAZON RIVER AND ITS TRIBUTARIES IN BRAZIL DURING 1982-84

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CONVERSION FACTORS

The SI (International System) units used in this report may be converted to inch-pound units by the following conversion factors:

Multiply SI units	By	To obtain inch-pound units
kilometer (km)	0.621	mile (mi)
meter (m)	3.28	foot (ft)
centimeter (cm)	0.394	inch (in)
millimeter (mm)	0.0394	inch (in)
metric ton (1000 kg)	1.10	short ton (2000 lb)
kilogram (kg)	2.20	pound (lb)
gram (g)	0.0353	ounce (oz), avoirdupois
milligram (mg)	0.0000353	ounce (oz), avoirdupois
liter (L)	0.264	gallon (gal)
milliliter (mL)	0.0338	ounce (oz), fluid
cubic meter per second (m^3/s)	35.3	cubic foot per second (ft^3/s)

Convert degrees Celsius (^oC) to degrees Fahrenheit (^oF) by the relation;

$$^oF = 9/5(^oC) + 32$$

SUSPENDED SEDIMENT IN THE AMAZON RIVER AND ITS TRIBUTARIES IN BRAZIL DURING 1982-84

By Robert H. Meade

ABSTRACT

Suspended sediment was collected during 1982-84 from the Rio Solimões-Amazonas (Amazon River) and its major tributaries on eight downriver sampling cruises between Rio Içá and the town of Óbidos, Brazil, and more frequently at a fixed time-series station near the city of Manaus. About 180 discharge-weighted composite samples were collected from 34 cross sections by depth-integrated sampling, using the equal-width-increment (equal-transit-rate) method. Suspended sand was sieved from each composite sample in the field, weighed in the laboratory, and analyzed for particle size by wet sieving. Concentrations of suspended silt and clay were determined by filtering representative subsamples of each cross-section composite. Concentrations of suspended sediment decreased down the Rio Solimões-Amazonas mainstem. Concentrations in the mainstem during wet season were only 2 to 4 times those during dry season. The annual cycle of suspended-sediment concentration is markedly out of phase with the annual cycle of water discharge; graphed relations of sediment discharge versus water discharge form clockwise loops rather than straight lines or simple curves. Sampling errors were within ± 10 percent for total suspended sediment and within ± 20 percent for suspended sands. Errors involved in field processing and laboratory analysis were smaller than the sampling errors. Data are presented in tables in sufficient detail and with sufficient supportive description that they may serve as baseline information for the assessment of the effects of future changes in the Amazon basin.

INTRODUCTION

Few comprehensive collections of data describe the spatial and temporal variations of suspended sediment in the Amazon River basin. During the early 1960s, Gibbs (1965, 1967) sampled the Amazon and its most important tributaries at different seasons of the annual runoff cycle, and provided the first comprehensive summary of the areal and temporal distributions of suspended sediment in the Amazon basin. By necessity, however, most of Gibbs' samples were collected from the river surface and did not reflect the greater concentrations and coarser size fractions of sediment in suspension near the river bed. Gibbs therefore underestimated the quantities and particle sizes of suspended sediment being transported by the Amazon and some of its tributaries. During 1969-70, Schmidt (1972) collected a 1-year series of monthly samples at a station on the Amazon mainstem that showed the annual cycle of variation of suspended sediment. Like Gibbs, however, Schmidt was constrained to working only with samples collected from the river surface, and the concentrations he measured represented only a fraction of the total suspended-sediment load. During 1976-77, investigators from the U.S. Geological Survey collected suspended sediment with equipment that was capable of providing point samples and depth-integrated samples from all river depths in the Amazon basin. Data from these samples provided the first descriptions of the vertical and

lateral variations of suspended sediment in the Amazon, as well as a new estimate (8 to 9 x 10^8 metric tons per year--nearly double that of Gibbs) of the discharge of suspended sediment to the ocean (Curtis and others, 1979, 1982; Meade and others, 1979a-d). The 1976-77 samples, however, were all collected at or near high water and did not represent the suspended-sediment characteristics of the river during other parts of the annual runoff cycle.

During 1982-84, a series of samples was collected to remedy some of the shortcomings of the earlier data. The samples of this latest series, reported herein, were depth-integrated composites which yielded discharge-weighted concentrations that could be used, in conjunction with measurements of river discharge, to compute the fluxes of suspended sediment. Furthermore, the data were collected repeatedly at enough different locations and during enough different parts of the runoff cycle to begin to describe the spatial and seasonal variations of suspended-sediment loads in some detail. A recent report based on these data (Meade and others, 1985) describes seasonal patterns of storage and remobilization of suspended sediment and presents a newer estimate (11 to 13 x 10^8 metric tons per year) of the discharge of suspended sediment to the ocean.

Purpose and Scope

The present report is a compilation of the basic data on suspended sediment collected during 1982-84. First, it describes the sediment-sampling equipment and procedures, the shipboard procedures for separating suspended sediment from river water, and the laboratory procedures for determining the concentrations and particle sizes of suspended sediment. The data themselves are listed in tables. Then follows a brief descriptive presentation of some of the more coherent results, and a discussion of the errors involved in collecting, processing, and analyzing the suspended sediment. Data on the bed material collected from the Rio Solimões-Amazonas and its tributaries during some of the same sampling excursions are presented in the companion report by Mertes and Meade (1985).

Acknowledgments

The collection and analysis of the samples described in this report were part of the first phase of the CAMREX program (Carbon in the Amazon River Experiment) that was initiated, organized, and led by J. E. Richey of the College of Ocean and Fisheries Science and the Quaternary Research Center of the University of Washington (UW), Seattle. The successes of the CAMREX program are due in large measure to Richey's vision and audacity, as well as his entrepreneurial and diplomatic skills. The collection of the samples was funded mainly by Grant DEB-801-7522 from the U.S. National Science Foundation and the following Brazilian organizations: Instituto Nacional de Pesquisas da Amazônia (INPA; Henrique Bergamin, Director), Centro de Energia Nuclear na Agricultura (CENA; Eneas Salati, Director) of the Universidade de São Paulo, and Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq). The analysis of the samples, and my participation in the CAMREX program, were funded by the U.S. Geological Survey. I thank all these people and organizations for their collaboration and support.

Additional thanks go to: C. C. Cranston and C. F. Nordin, Jr. (U.S. Geological Survey) for designing and building the special sampling equipment; Captain M. R. de Souza, Engineer A. M. da Silva, P. I. de Almeida, U. de M. Santos, and the crew of INPA research vessel L/M Amanai for their invaluable contributions to the sampling program; A. H. Devol, B. R. Forsberg, J. I. Hedges, L. A. K. Mertes and J. E. Richey (UW), A. C. Tancredi and R. L. Victoria (CENA), for collecting suspended sediment during the four mainstem sampling cruises on which I was not present; B. R. Forsberg (UW) for collecting the time-series samples at Ilha Machantaria; L. A. Martinelli and Jefferson Mortatti (CENA) for collecting samples from Rio Madeira during April 1984; J. R. Ertel (UW) for centrifuging silt-and-clay samples on the cruise of February-March 1984; C. L. Stewart and M. J. Werito (U.S. Geological Survey) for particle-size analyses of suspended sands; H. R. Allen, W. J. Matthes, and D. R. Rankin (U.S. Geological Survey) for particle-size analyses of silts and clays; J. I. Hedges and W. A. Clark (UW), for providing copies of their data for use in table 6 and figure 8; S. C. Conceição and José Rayol of Companhia de Pesquisas de Recursos Minerais (CPRM) and J. R. G. Natividade of Departamento Nacional de Aguas e Energia Elétrica (DNAEE) for river-stage and river-discharge data; D. E. Hillier and D. W. Hubbell (U.S. Geological Survey) and C. F. Nordin, Jr. (now at Colorado State University) for comments on the manuscript.

SAMPLING STRATEGIES AND LOCATIONS

Two basic strategies guided the sampling during 1982-84. The first strategy involved repeated cruises that, beginning at the section farthest upriver, measured and sampled a 1950-km reach of the Rio Solimões-Amazonas mainstem, as well as major tributaries, in downriver sequence. By repeating measurements and samplings every 4 months or so, we hoped to obtain data that would allow us to understand the downriver routing of water, sediment, and other constituents. The other strategy involved more frequent time-series sampling at a single cross section, in order to relate the variations in sediment and other constituents to variations in river stage and water discharge.

All the river cross sections we sampled during 1982-84 are shown in figure 1 and are listed with their location in table 1. Wherever possible, the latitudes and longitudes of the sampled sections were obtained from the second editions of the 1:100,000-scale navigation charts of the Rio Solimões-Amazonas published by the Brazilian Navy (Marinha do Brasil), whose chart numbers and publication dates are listed in table 1. For cross sections of tributary rivers for which navigational charts were not available, coordinates were obtained from side-looking-airborne-radar mosaics (scale 1:250,000) published by PROJETO RADAMBRASIL from imagery collected in 1971-72. Coordinates obtained from the navigation charts and the radar mosaics usually agree within 0.5 minute. Coordinates listed in table 1 are for the midpoints of the sampled sections.

The time-series section is located on Rio Solimões immediately upriver of Ilha Machantaria (called "Ilha dos Mouras" on the Brazilian naval charts), 27 km upriver of the confluence with Rio Negro. This sampling section is at the same location used for the earlier time series by Schmidt

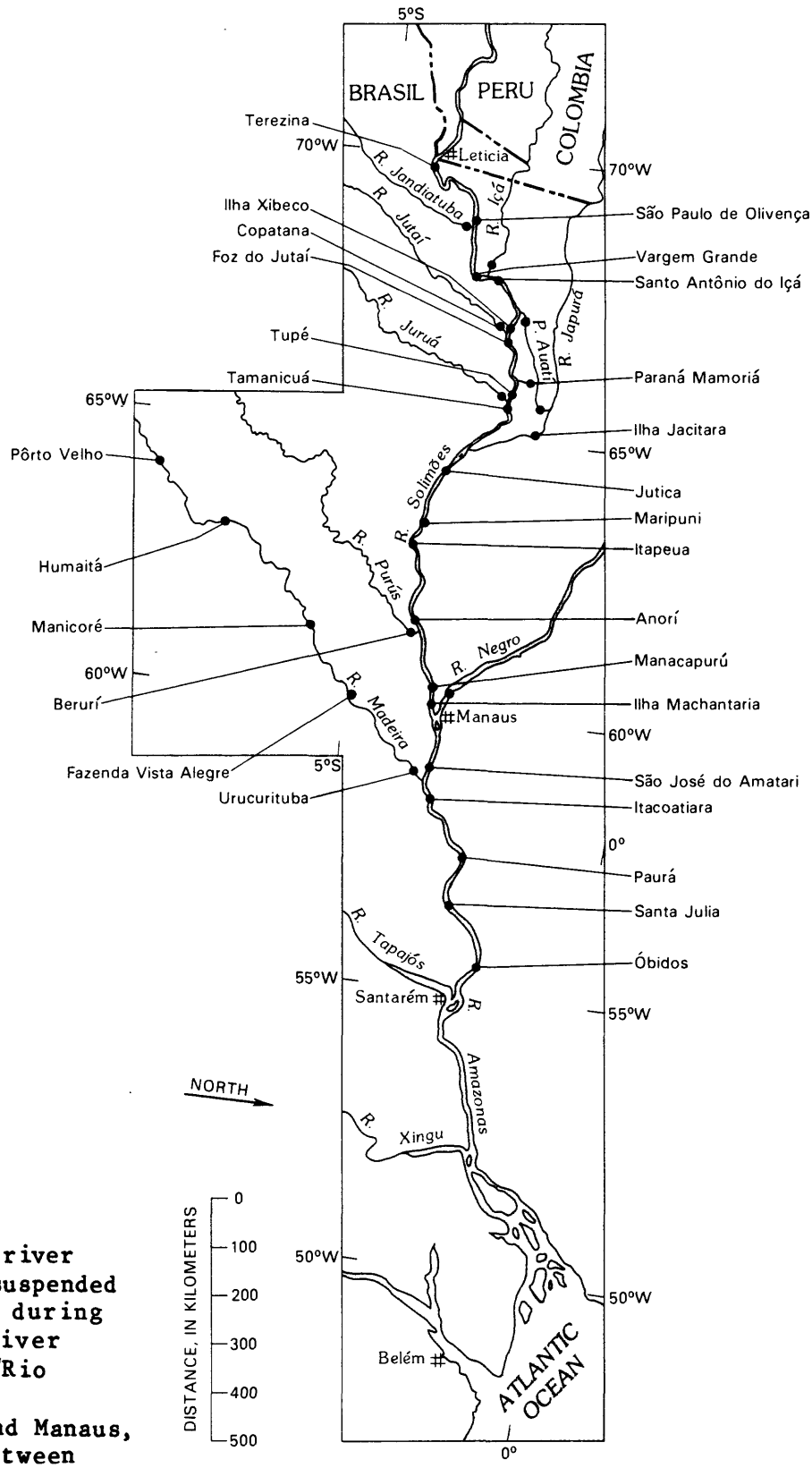


Figure 1.--Location of river cross sections where suspended sediment was sampled during 1982-84. The Amazon River mainstem is called "Rio Solimões" between the Peru-Brazil border and Manaus, and "Rio Amazonas" between Manaus and the Atlantic Ocean.

Table 1. Sampled sections on the Rio Solimões-Amazonas and its tributaries, listed in downstream order. (DNAEE, Departamento Nacional de Aguas e Energia Elétrica; km, kilometer)

River and sampling section	South latitude	West longitude	Brazilian Naval chart (and year published)	RADAM Mosaic	Remarks
Rio Solimões at Terezina	4°21.6′	69°43.0′	4114B (1980)		DNAEE section
Rio Solimões at São Paulo de Olivença	3°26.9′	68°55.2′	4113B (1980)		DNAEE section
Rio Jandiatuba, 13 km above mouth	3°30.5′	68°52.1′		SA19ZC	
Rio Solimões at Vargem Grande	3°16.7	67°55.7	4113A (1980)		17 km above mouth of Rio Içá
Rio Içá, 20 km above mouth	3°06.4′	68°06.8′	4113A (1980)		
Rio Solimões below Santo Antônio do Içá	3°02.2′	67°53.4′	4113A (1980)		DNAEE section; 14 km below mouth of Rio Içá
Rio Solimões at Ilha Xibeco	2°43.1′	66°55.6′	4112B (1980)		22 km above mouth of Rio Jutaí
Rio Jutaí at Copatana	2°50.7′	66°55.8′		SA19ZB	DNAEE section; 20 km above mouth
Rio Solimões below Foz do Jutaí	2°41.1′	66°39.4′	4112A (1980)		13 km below mouth of Rio Jutaí
Rio Solimões below Tupé	2°30.0′	65°50.5′	4111B (1979)		17 km above mouth of Rio Juruá
Rio Juruá, 16 km above mouth	2°41.9′	65°47.5′		SA20YA	
Rio Solimões at Tamanicuá	2°39.9′	65°38.3′	4111B (1979)		10 km below mouth of Rio Juruá
Paraná Auatí, 2 km below P. Bugari	2°28.3′	67°14.7′		SA19ZB	24 km down Paraná Auatí from junction with Rio Solimões
Paraná Mamoriá, 2 km above P. Auatí	2°10.5′	66°29.7′		SA19ZB	Paraná Mamoriá also called Paraná Aiupiá
Paraná Auatí, 17 km above Rio Japurá	1°57.3′	65°43.8′		SA20VC	
Rio Japurá at Ilha Jacitara	1°55.0′	65°16.4′		SA20VC	180 km above mouth
Rio Solimões at Jutica	3°34.8′	64°17.6′	4109B (1979)		56 km below lowest mouth of Rio Japurá
Rio Solimões at Maripuni	3°55.3′	63°16.0′	4109A (1979)		1 km below mouth of Paraná do Copeá
Rio Solimões below Itapeua	4°01.8′	62°59.8′	4108B (1979)		5 km below DNAEE section
Rio Solimões at Anorí	3°48.3′	61°37.9′	4108A (1979)		22 km above mouth of Rio Purús
Rio Purús below Berurí	3°51.2′	61°23.0′		SA20ZD	22 km above mouth
Rio Solimões below Manacapurú	3°19.4′	60°32.7′	4107A (1979)		DNAEE section
Rio Solimões at Ilha Machantaria	3°17.1′	60°01.7′	4107A (1979)		Time-series section; 27 km above mouth of Rio Negro
Rio Negro at narrows above Manaus	3°03.6′	60°18.8′		SA20ZD	35 km above Manaus
Rio Amazonas above São José do Amatari	3°14.2′	59°00.3′	4106A (1970)		30 km above mouth of Rio Madeira
Rio Madeira at Pôrto Velho	8°46′	63°55′		SC20VB	DNAEE section; 1055 km above mouth
Rio Madeira at Humaitá	7°30′	63°01′		SB20YD	DNAEE section; 810 km above mouth
Rio Madeira at Manicoré	5°49′	61°18′		SB20XD	DNAEE section; 460 km above mouth
Rio Madeira at Fazenda Vista Alegre	4°54.2′	60°02.5′	4503A (1982)		DNAEE section; 260 km above mouth
Rio Madeira at Urucurituba	3°32.5′	58°54.8′	4501A (1982)		28 km above mouth
Rio Amazonas at Itacoatiara	3°09.7′	58°26.0′	4106A (1970)		45 km below mouth of Rio Madeira
Rio Amazonas at Costa do Paurá	2°23.0′	57°26.8′	4105A (1970)		
Rio Amazonas at Santa Julia	2°25.0′	56°27.7′	4104B (1972)		
Rio Amazonas at Óbidos	1°56.2′	55°30.5′	4104A (1972)		DNAEE section

(1972), and it is near enough to the INPA laboratory in Manaus that it can be sampled conveniently in a day. Twenty-five suspended-sediment samples were collected at Ilha Machantaria between January 1983 and February 1985.

Eighteen cross sections (11 on the Rio Solimões-Amazonas mainstem and 7 on major tributaries) were sampled during most of the 8 downriver sampling cruises that were completed from Vargem Grande to Óbidos (fig. 1) between April 1982 and July 1984. The 18 cross sections are those for which 5 to 9 analyses are listed in table 2. Wherever possible, we sampled the DNAEE gaging sections, where river stage is recorded twice daily and water discharge is measured periodically by CPRM or Hidrologia S. A., so that our measurements could be related to the longer and more detailed series of hydrologic data. Most of the other mainstem sections are located a few kilometers upriver of tributaries. The timing of the eight downriver sampling cruises, relative to river stages in the upper, middle, and lower parts of the sampled reach, is shown in figure 2.

The other 15 sections listed in table 1 are those in which only 1 or 2 samples were collected during 1982-84. Most of these sections were sampled during the first two downriver cruises and then abandoned, either because they were considered redundant in the temporal and spatial context of the CAMREX program, or because they were immediately downstream of mainstem-tributary confluences where the incomplete mixing of waters of markedly different chemical and sedimentary character could interfere with accurate sampling. Four of the listed sections on Rio Madeira were sampled only once, during a special cruise by CENA personnel in April 1984.

SAMPLING EQUIPMENT AND PROCEDURES

Each of the sediment samples reported herein was a depth-integrated composite from which we determined the discharge-weighted concentration of suspended sediment being transported by the river through the sampled cross section. The combination of variable-speed hydraulic winch, collapsible-bag sampler, and velocity meter used to sample the Amazon during 1982-84 was identical to the equipment described by Nordin and others (1983) in all respects but one: in place of the Ott-type meter, we used a Price-type AA meter to measure velocity (Buchanan and Somers, 1969, p. 4-6; Rantz and others, 1982, p. 85-87). Photographs of the equipment are shown by Nordin and others (1983) and Richey and others (in press).

The collapsible-bag sampler used during 1982-84 is identical in principle to the one described by Stevens and others (1980) that was modified slightly for use in sampling the Amazon in 1977 (Meade and others, 1979a, 1979d). The newest sampler consists of an 8-L plastic outer-support bottle, with a molded cap and nozzle, that is fitted in a steel frame. The molded cap was designed to be used with the U.S. D-77 sampler and is shown by Szalona (1982, fig. 1 only; the solenoid value shown in the other figures of Szalona's report was not used in sampling the Amazon). The cap is basically a streamlined adaptor, threaded to allow for the insertion of a nozzle in the forward end and attachment to the support bottle at the back end. The nozzle is tapered to insure isokinetic sampling. The bottle is perforated on its shoulder and base so that water

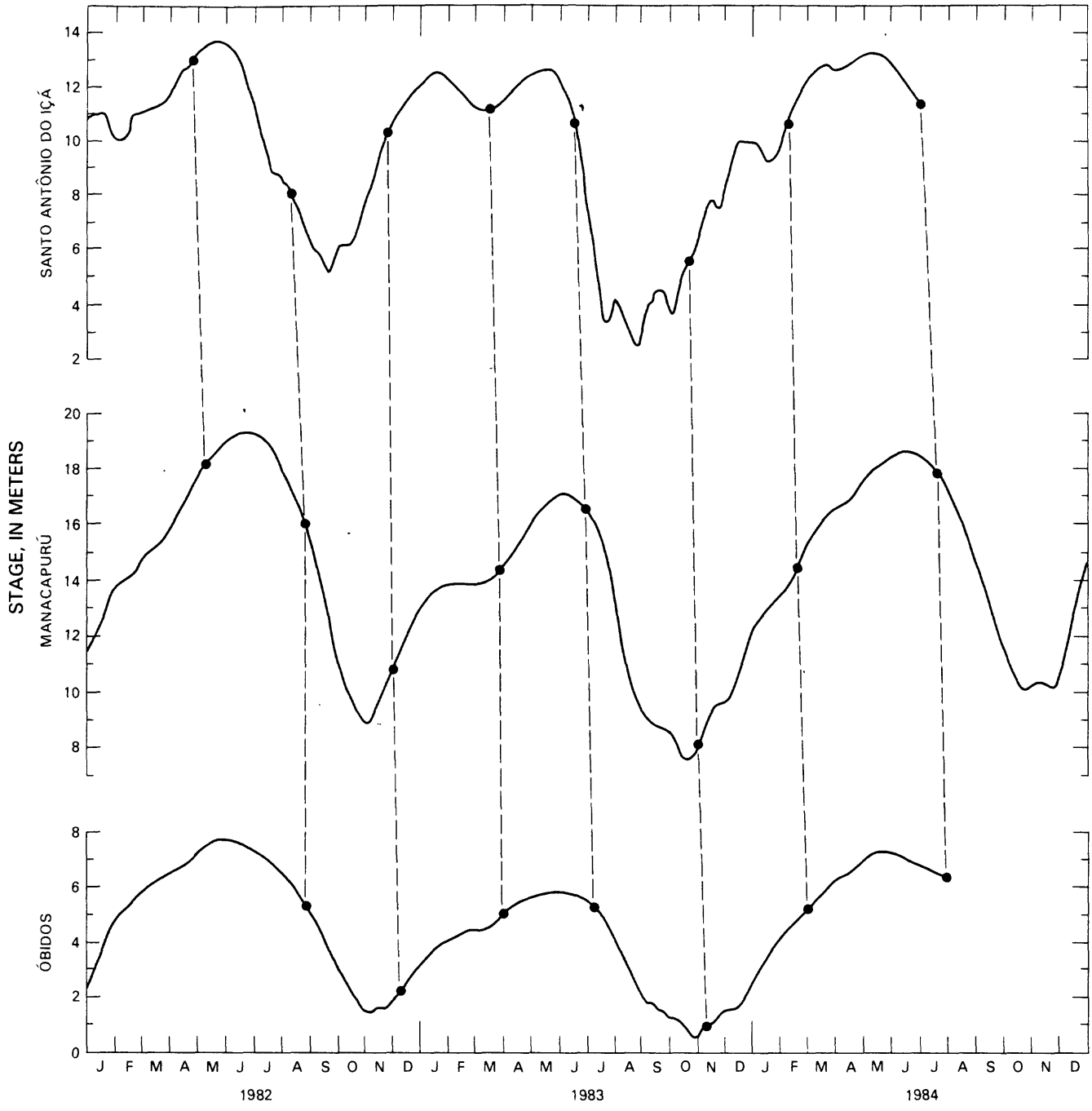


Figure 2.--Daily river stage at three gages on the Rio Solimões-Amazonas mainstem, showing (by solid circles and dashed lines) dates of eight downriver cruises during which suspended sediment was sampled, 1982-84. Stage data were provided by José Rayol, S. C. Conceição, J.R.G. Natividade and by local observers: Antônio and Analisa Fereira (Santo Antônio do Içá), Raimundo A. de Oliveira (Manacapurú), Francisco S. and Raimundo S. Nunes (Óbidos). River stages are not referenced to the same datum at all three gages.

can enter it freely and surround the flexible sample container. The sample containers used during 1982-84 were nylon-film food bags (Reynolds oven-cooking bags,[1/] 35 by 50 cm) from which the air had been evacuated. The bag was folded lengthwise into loose accordion pleats and inserted, closed end first, into the bottle. The open end of the bag was folded back over the threads of the bottle and held in place by screwing on the cap.

During sampling, the bottle was held in the steel frame by a length of elastic shock cord. At the angle at which the sampler rests in its frame, the 8-L sampler can collect a volume of 6.0 to 6.5 L before it overfills. Below the steel frame was suspended a 136-kg sounding weight of the Columbus type (Buchanan and Somers, 1969, p. 11-13; Rantz and others, 1982, p. 102). In this configuration, the vertical distance between the sampler nozzle and the bottom of the sounding weight was 44 cm; this distance represents the height of the unsampled zone at the river bed.

As the sampler is submerged in the river, water flows through the nozzle into the plastic bag, which opens up as it fills. Because the sampler is lowered to the bottom of the river and raised to the surface at a uniform vertical rate, and because the water flows into the nozzle at ambient velocity, the resulting sample is weighted according to velocity. In our operation, the sampler was emptied and the bag was rinsed after every lowering.

The basic sampling procedure was the equal-width-increment (EWI) method, which is described as the equal-transit-rate (ETR) method by Guy and Norman (1970, p. 32-33). By this method, a sequence of verticals is sampled by depth integration to obtain a composite sample. The verticals are equally spaced across the width of the river, and the same vertical transit rate is used to collect the samples at all verticals in the cross section. The resulting composite sample is therefore weighted according to both the lateral and vertical distributions of discharge in the cross section. In practice, the choice of a uniform vertical transit rate is a compromise between going slowly enough in the slower (and usually shallower) parts of the cross section to avoid grossly distorting the pattern of flow into the sampler nozzle and going rapidly enough in the faster and deeper parts of the section to avoid overfilling the sampler (Guy and Norman, 1970, p. 33; Nordin and others, 1983, p. 1153). In our sampling, we routinely tried (and usually succeeded in) keeping the vertical transit rate less than 0.2 times the mean velocity at any vertical.

In the 1982-84 program, 9-vertical composite samples were collected in the Rio Solimões-Amazonas mainstem and 5-vertical or 7-vertical composites were collected in most tributaries. By the time of the third downriver cruise (November-December 1982), we had settled on the sampling pattern shown in figure 3, a variant of the EWI sampling method wherein verticals sampled for suspended sediment were alternated with verticals sampled for chemical analysis. Locations in the cross section were found by measuring

[1/] Use of commercial product names is for identification purposes only, and does not constitute any endorsement by the U.S. Geological Survey.

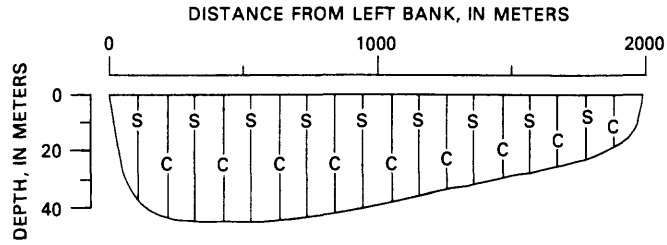


Figure 3.--Spacing of sampled verticals in idealized cross section of the Rio Solimões-Amazonas mainstem, as used on all downstream sampling cruises between November 1982 and July 1984. Samples collected at verticals labeled "S" were included in the composite that was analyzed for suspended sediment. Those labeled "C" were included in the chemistry composite.

sextant angles between markers placed along the bank a known distance apart (Richey and others, in press). During the first two downriver cruises, and during all the samplings of the time-series section at Ilha Machantaria, the sediment and chemistry samples were collected by paired lowerings at the same verticals. On the first of the downriver cruises (April-May 1982), and for all the samples collected at Ilha Machantaria, the verticals were spaced evenly across the channel by the visual judgment of the boat pilot. On the second downriver cruise (August-September 1982), the cross-channel distances were located by sextant angles.

SHIPBOARD PROCESSING OF SAMPLES

Samples were processed as soon as they were brought aboard the research vessel. The alternation of sediment and chemistry samples allowed time for one type of sample to be processed while the other type was being collected. The two types of samples were processed somewhat differently, and both procedures are described here.

An essential apparatus used during the shipboard processing was the U.S. Geological Survey's churn-type sample splitter. Because it has not been described in the published technical literature (even though it has been used extensively for nearly a decade), a short description is appropriate here. The churn splitters are made in two sizes, 8 L and 14 L, both of which share the same design. The outer part of the splitter is a sturdy polycarbonate cylinder with a removable flat lid. A spigot is located on the side of the cylinder a few centimeters above the base. Inside the splitter is a circular horizontal paddle, slightly smaller in diameter than the inside diameter of the cylinder. The paddle rests on the base of the cylinder when it is not being used. Projecting upward from the center of the paddle is a solid rod, about 2 cm in diameter, that protrudes

through a hole in the center of the lid. The paddle itself is perforated by a dozen or so circular holes, 3 to 4 cm in diameter.

To use the splitter, a sample is poured in, and the rod and paddle are agitated vertically. After a sample has been stirred by pumping the paddle at a vertical rate of about 25 cm per second for 30 to 60 seconds, and while the pumping is continued, representative subsamples can be taken from the spigot. The splitter is capable of maintaining a uniform suspension of sediment particles finer than 0.063 mm. Coarser particles, however, are not mixed evenly by the splitter.

Processing Suspended-Sediment Samples

As soon as the sediment sampler bottle was brought aboard at each vertical, it was rinsed to remove the sand particles that may have adhered to the outside of the collapsible bag. The sediment sample was then poured into a 4-L graduated cylinder so the volume of water could be measured and recorded. As part of this step, the sample was poured through a 0.063-mm sieve to remove all sand. The collapsible bag was then removed from the sampler bottle, and its remaining contents were washed through the sieve and into the graduate. As the sampling progressed, the suspensions that passed the sieve were composited in one or two 14-L churn splitters (2 splitters usually were required at a typical cross section, where the aggregate volume of the composite sample was 20 to 25 L). At the end of the sampling for the section, the sand in the sieve was rinsed gently several times with supernatant water from the churn splitter to wash through the silt particles that may have remained on the sieve. After passing through the sieve, the wash water and silt particles were returned to the appropriate splitter. The sand was then transferred from the sieve into a small bottle to be transported to Denver for weighing and particle-size analysis.

Proportional fractions from the two 14-L splitters (proportional, that is, to the volumes in the 2 splitters) were combined into one 8-L splitter to make the final composite sample from which representative subsamples were taken to measure concentrations of suspended sediment finer than 0.063 mm. After their volumes were recorded, the subsamples were filtered under vacuum through preweighed pairs of Millipore HA filters having a diameter of 47 mm and a nominal pore size of 0.00045 mm. The lower filter of each pair was a blank that was carried through the same filtering, drying, and weighing steps as the upper filter on which the suspended sediment was caught. Three or more subsamples from each cross-section composite usually were filtered separately aboard ship. The filters were dried for an hour or more at 40°C in a small shipboard oven. Each pair of filters was then sealed into a separate polystyrene Petri dish to be transported to the laboratory in Denver.

After all the sand had been removed and all the desired subsamples had been taken for filtering, the remaining suspension finer than 0.063 mm usually was discarded. On several occasions, however, the remaining fine sediment was concentrated further by passing the suspension through a Sharples continuous-flow supercentrifuge, and the resulting sample was bottled for later use in particle-size analysis. Because the

supercentrifuge allowed some of the very finest particles to pass through and be discharged with the effluent water, representative samples of the effluent were filtered to provide correction factors for the subsequent particle-size analyses.

Processing Chemistry Samples

The chemistry and suspended-sediment samples were collected and processed completely separately from each other. Chemical and sedimentological analyses could not be performed on the same sample (or subsamples of the same sample) because both required large and separate samples of suspended sand--sedimentologically, for particle-size and petrographic analyses; chemically, for destructive analysis of organic constituents. However, subsamples of some of the chemistry composites were used to estimate errors in sediment sampling. Insofar as they pertain to the discussion of suspended sediment, some of the steps for processing the chemistry samples are described here.

Whereas the suspended-sediment samples were subjected to the same shipboard routine during all the samplings of 1982-84, the processing of the chemistry samples was changed and improved during the first few downriver cruises. However, the following procedures were used on the chemistry samples during all cruises. As soon as it was brought aboard, the chemistry sample from each vertical was first poured into a large graduate so its volume could be recorded. It was not poured through a sieve, so sand was not separated at this stage. As the sampling progressed, each sample was added to the composite that was accumulated in one or (usually) two 14-L churn splitters. At the end of the sampling for each cross section, a number of representative subsamples were taken for different chemical analyses. All the material that remained in the splitters was then poured and washed through a 0.063-mm sieve to separate the sand, which was then bottled, dried at 40°C in a shipboard oven, and then sealed for transfer to the University of Washington in Seattle for organic analysis. The fine suspended sediment that passed the sieve was recovered in the flow-through centrifuge.

Several new steps were added to the processing of the chemistry samples during the early downriver cruises. Beginning with the fourth cruise (March-April 1983), 100 mL of the supernatant water collected at each vertical was poured off for separate analysis, before the sample was added to the composite. Beginning with the fifth cruise (June-July 1983), proportional fractions from the two 14-L churn splitters were combined into a single 8-L splitter before subsamples were taken for the various analyses. Prior to the fifth cruise, subsamples had been taken by combining, in each instance, proportional fractions from the two 14-L splitters.

LABORATORY PROCESSING OF SAMPLES

Weighing of Filters and Sand Samples

Tare weights of the filters were determined before the sampling cruises. The filters (Millipore type HA with diameters of 47 mm and nominal pore sizes of 0.00045 mm) were placed, in pairs, into separately-numbered covered Petri dishes, where they were allowed to equilibrate for a few days in the laboratory. They then were weighed individually on a microbalance to ± 0.1 mg, and their weights were recorded. During all weighings, a 500-microcurie polonium source was used to decrease electrostatic attraction. The tared pairs then were returned to their Petri dishes. From this stage until the final weighing, each pair of filters was treated as a single filter through all the procedural steps in the field.

When the filters were returned to Denver, they were taken separately from their Petri dishes, dried overnight in an oven at 105° to 110°C, allowed to cool to room temperature in a desiccator, and reweighed. The change in weight of the lower blank filter (usually a loss of 1 to 2 mg from the tare weight) was used as a correction on the weight of the upper filter, which contained the sediment. Using the volume of water that had passed through the filter, as recorded in the field, the weight of the sediment was converted to concentration, in milligrams per liter.

Three to four subsamples from each composite sample usually were filtered in the field. After the final weighings and computations, the concentrations of suspended sediment caught on all 3 or 4 filters usually agreed within ± 3 percent (and almost always within ± 5 percent) of the mean value. The concentration of sediment finer than 0.063 mm from these samples reported in table 2 are the mean values. In instances where the concentration determined on one filter differed markedly from those determined on the other 2 or 3 filters, the disparate value was not included in the calculation of the mean--on the presumption that a filter tare weight or subsample volume had been misrecorded (see discussion of "Laboratory error", below).

The sand samples were washed from their bottles into tared evaporating dishes, dried overnight at 80°C, allowed to cool to room temperature in a desiccator, and weighed on a microbalance. As no attempt was made to remove organic particles, the concentrations of the sands reported in table 2 include a few percent of organic detritus.

Size Analysis of Sand

The particle-size distribution of suspended sediment coarser than 0.063 mm was analyzed by wet sieving through a nest of sieves having openings of 0.50, 0.25, 0.125, and 0.063 mm. The total of the weights of the individual sand-size fractions served as a double check on the initial sand weighing described in the previous paragraph. If any material passed the 0.063-mm sieve during the size analysis, the concentration it represented was subtracted from the initial sand concentraton and added to the final concentraton of sediment finer than 0.063mm (table 2)--on the

presumption that the sand sample had not been washed completely in the field.

Size Analysis of Silt and Clay

The distributions of particle sizes finer than 0.063 mm were determined in only a few selected samples. These samples all had been screened through a 0.063-mm sieve and concentrated in a flow-through centrifuge aboard ship. The concentration of the very finest sediment that passed through the centrifuge was determined by filtering a representative volume of the centrifuge effluent; this concentration was added to the concentration determined in the laboratory for the finest size fraction (finer than 0.002 mm, table 4).

In the Denver laboratory, the samples that had been concentrated by centrifuge in the field were resuspended as thick slurries and poured into a small ore-type splitter to be divided into four approximately equal parts. Splits were sent for size analysis to the U.S. Geological Survey laboratories in Iowa City, Iowa, and Albuquerque, New Mexico. More than half the analyses were made in Iowa City, using a SediGraph 5000 D (Micromeritics, Inc., Norcross, Georgia), in which the settling rates of particles within the Stokes range are measured in an X-ray beam (Schiebe and others, 1983; Stein, 1985; Welch and others, 1979). As the SediGraph technique is nondestructive, pipette analyses could be made of some of the same samples in the Iowa City laboratory, following the procedures described by Guy (1969). Pipette analyses of splits of a few of the samples also were made in Albuquerque, following the same procedures. The distributions of particle sizes finer than 0.063 mm, as listed in table 4, are subject to several large errors, which are discussed later in the report under "Centifuge losses" and "Laboratory error".

SUSPENDED-SEDIMENT DATA

The data for the suspended-sediment samples collected during 1982-84--concentrations and discharges of various size fractions in transport--are listed in table 2. Water discharges listed in the second column of table 2 were determined in three ways: those labeled "M" were measured at the time of sampling by the procedures described by Richey and others (in press); those labeled "G" were computed from stage readings on a nearby river gage and the stage-discharge relation developed for that gage by CPRM-DNAEE; those labeled "E" were estimated either by interpolation between measured and gaged discharges or by making a few rapid measurements of velocity, width, and depth in a cross section. The concentrations of suspended sediment listed in each size category in table 2 are cumulative: for example, the concentration "coarser than 0.063 mm" is not only the material between 0.063 and 0.125 mm, but the total of all size categories coarser than 0.063 mm.

The results of five measurements made during 1976-77 are also presented in table 2. These five are the only ones of our previous measurements whose quality is comparable to the 1982-84 series, and they are included here to complete the compilation of data from which suspended-sediment discharges can be computed within similar limits of accuracy.

Table 2.--Concentrations and discharges of suspended sediment in the Rio Solimões-Amazonas and its tributaries, as measured in composite depth-integrated samples. Water-discharge data mostly from Richey and others (in press); basic concentration analyses by R. H. Meade; sand-size analyses by M. J. Werito and C. L. Stewart. (m^3/s, cubic meters per second; mg/L, milligrams per liter; mm, millimeter; t/d, metric tons per day; km, kilometer; M, measured; G, from gage height and stage-discharge relation; E, estimated; DNAEE, Departamento Nacional de Aguas e Energia Elétrica).

Date	Water discharge (m^3/s)	Number of verticals in sediment composite	Concentration of suspended sediment (mg/L)						Discharge of suspended sediment (10^3t/d)		
			Total	Finer than 0.063 mm	Coarser than 0.063 mm	Coarser than 0.125 mm	Coarser than 0.25 mm	Coarser than 0.50 mm	Total	Finer than 0.063 mm	Coarser than 0.063 mm
RIO SOLIMÕES AT TEREZINA (DNAEE SECTION)											
04/29/82	68,000G	8	320	216	104	55	8	2	1880	1270	610
RIO SOLIMÕES AT SÃO PAULO DE OLIVENÇA (DNAEE SECTION)											
05/22/77	70,100G	5	275	187	88	45	10	--	1660	1130	530
04/30/82	68,100G	7	411	234	177	111	32	2	2420	1380	1040
RIO JANDIATUBA, 13 KM ABOVE MOUTH											
04/30/82	1,060M	5	26	26	0.2	--	--	--	2	2	--
RIO SOLIMÕES AT VARGEM GRANDE											
05/01/82	69,700E	7	487	282	205	141	17	1	2930	1700	1230
08/14/82	31,700M	7	276	217	59	20	3	0.6	760	600	160
11/27/82	57,100M	9	606	470	136	68	12	0.7	2990	2320	670
03/22/83	52,400M	9	528	436	92	52	16	0.6	2390	1970	420
06/27/83	38,750M	9	340	299	41	16	8	0.4	1140	1000	140
10/27/83	26,600M	9	276	232	44	8	2	0.7	630	530	100
02/14/84	51,500M	9	592	486	106	54	10	1	2630	2160	470
07/10/84	48,000M	9	323	253	70	37	11	0.4	1340	1050	290
RIO IÇÁ, 20 KM ABOVE MOUTH											
05/01/82	6,880M	5	46	42	4	2	0.7	0.3	27	25	2
08/15/82	7,300M	5	106	68	38	34	18	1	67	43	24
11/28/82	7,300M	7	97	94	3	2	0.6	0.2	61	59	2
03/23/83	6,400M	7	90	88	2	--	--	--	50	49	1
06/28/83	9,140M	7	87	71	16	9	2	0.3	69	56	13
10/27/83	5,800M	7	121	99	22	13	2	0.8	61	50	17
02/15/84	7,300M	7	68	63	5	2	0.3	0.1	43	40	3
07/11/84	8,400M	7	72	65	7	3	0.8	0.2	52	47	5
RIO SOLIMÕES BELOW SANTO ANTÔNIO DO IÇÁ (DNAEE SECTION)											
05/23/77	79,500G	5	245	152	93	53	5	--	1680	1040	640
05/02/82	77,200G	9	384	236	148	97	29	1	2560	1570	990
08/16/82	38,900G	11	211	154	57	30	6	0.5	710	520	190
11/29/82	65,400M	9	499	398	101	41	10	0.8	2820	2250	570
03/23/83	59,600M	9	441	371	70	39	5	0.4	2270	1910	360
06/26/83	48,250M	9	301	251	50	26	5	0.4	1260	1050	210
10/28/83	32,600M	9	237	179	58	24	4	0.9	670	500	170
02/15/84	59,500M	9	513	420	93	47	9	0.4	2640	2160	480
07/09/84	56,400M	9	282	218	64	33	6	0.4	1370	1060	310
RIO SOLIMÕES AT ILHA XIBECO											
05/03/82	77,000E	7	315	235	80	42	5	0.5	2100	1560	530
08/17/82	38,700M	7	208	150	58	25	2	0.3	700	500	200
11/30/82	66,600M	9	548	419	129	61	7	0.8	3150	2410	740
03/24/83	60,400M	9	458	379	79	22	4	0.6	2390	1980	410
06/29/83	52,250M	9	288	233	55	23	2	0.3	1300	1050	250
10/29/83	32,200M	9	304	216	88	49	5	0.7	850	600	250
02/16/84	61,400M	9	541	442	99	43	8	1	2870	2340	530
07/12/84	57,000M	9	280	223	57	27	2	0.4	1380	1100	280

Table 2.--Concentrations and discharges of suspended sediment in the Rio Solimões-Amazonas and its tributaries, as measured in composite depth-integrated samples--continued.

Date	Water discharge (m^3/s)	Number of verticals in sediment composite	Concentration of suspended sediment (mg/L)						Discharge of suspended sediment ($10^3t/d$)		
			Total	Finer than 0.063 mm	Coarser than 0.063 mm	Coarser than 0.125 mm	Coarser than 0.25 mm	Coarser than 0.50 mm	Total	Finer than 0.063 mm	Coarser than 0.063 mm
RIO JUTAÍ AT COPATANA (DNAEE SECTION)											
05/03/82	7,000G	4	12	10.6	1.7				7	6	1
08/18/82	2,200M	4	--	--	1.9	--	--	--	--	--	0.4
11/30/82	2,580M	5	25	25	0.5	--	--	--	6	6	0.1
03/24/83	3,900M	5	20	20	0.4	--	--	--	7	7	0.1
06/29/83	4,200M	5	14	14	0.3	--	--	--	5	5	0.1
10/29/83	1,400M	5	32	32	0.3	--	--	--	4	4	<0.1
02/17/84	3,800M	5	14	14	0.4	--	--	--	5	5	0.1
07/12/84	3,300M	4	10	10	0.1	--	--	--	3	3	<0.1
RIO SOLIMÕES BELOW FOZ DO JUTAÍ											
05/04/82	84,000E	9	349	227	122	69	9	1	2530	1650	880
08/18/82	41,000M	9	--	--	53	15	1	0.3	--	--	190
RIO SOLIMÕES BELOW TUPÉ											
05/05/82	84,000E	7	336	235	101	58	12	1	2430	1700	730
08/19/82	40,300M	7	215	185	30	10	1	0.5	750	640	110
12/01/82	62,700M	9	555	419	136	53	5	0.9	3010	2270	740
03/25/83	63,100M	9	420	338	82	40	8	0.7	2290	1840	450
06/30/83	59,500M	9	287	234	53	22	3	0.4	1470	1200	270
10/30/83	33,900M	9	274	211	63	24	2	0.6	800	620	180
02/18/84	63,100M	9	533	414	119	56	9	0.8	2910	2260	650
07/13/84	59,900M	9	245	201	44	20	6	0.5	1270	1040	230
RIO JURUÁ, 16 KM ABOVE MOUTH											
05/05/82	4,650M	7	60	46	14	9	0.8	0.1	24	18	6
08/19/82	1,700M	5	119	117	2	--	--	--	17	17	0.3
12/01/82	3,920M	5	403	400	3	1	0.4	0.2	136	135	1
03/25/83	5,600M	5	173	122	51	32	5	1	84	59	25
07/01/83	3,100M	5	186	186	0.4	--	--	--	49	49	0.1
10/31/83	900M	5	67	66	0.7	--	--	--	5	5	<0.1
02/18/84	5,200M	5	290	270	20	13	2	0.1	129	120	9
07/13/84	4,800M	5	129	121	8	3	0.5	0.2	53	50	3
RIO SOLIMÕES AT TAMANICUÁ											
05/06/82	88,000E	9	294	188	106	74	16	1	2240	1430	810
08/20/82	44,900M	9	220	188	32	8	2	0.3	850	730	120
PARANÁ AUATÍ, 2 KM BELOW PARANÁ BUGARI											
02/13/84	860E	1	407	342	65	19	1	0.3	30	25	5
PARANÁ MAMORIÁ, 2 KM ABOVE PARANÁ AUATÍ											
02/12/84	1,400E	1	297	282	15	6	2	0.3	36	34	2
PARANÁ AUATÍ, 17 KM ABOVE RIO JAPURÁ											
02/11/84	2,000E	1	180	175	5	--	--	--	31	30	1
07/07/84	--	1	8	8	--	--	--	--	--	--	--
RIO JAPURÁ AT ILHA JACITARA											
03/19/83	9,000M	7	51	51	0.3	--	--	--	40	40	0.2
06/23/83	19,200M	7	50	46	4	2	0.6	0.1	83	76	7
10/22/83	14,700M	7	74	63	11	5	1	0.2	94	80	14
02/10/84	12,800M	7	57	55	2	1	0.2	--	63	61	2
07/06/84	16,700M	7	43	40	3	2	0.6	0.2	62	58	4

Table 2.--Concentrations and discharges of suspended sediment in the Rio Solimões-Amazonas and its tributaries, as measured in composite depth-integrated samples--continued.

Date	Water discharge (m^3/s)	Number of verticals in sediment composite	Concentration of suspended sediment (mg/L)						Discharge of suspended sediment (10^3t/d)		
			Total	Finer than 0.063 mm	Coarser than 0.063 mm	Coarser than 0.125 mm	Coarser than 0.25 mm	Coarser than 0.50 mm	Total	Finer than 0.063 mm	Coarser than 0.063 mm
RIO SOLIMÕES AT JUTICA											
05/07/82	96,000E	9	262	175	87	47	17	0.7	2170	1450	720
08/22/82	78,000M	9	178	136	42	18	2	0.4	1200	920	280
12/03/82	71,300M	9	501	379	122	59	7	0.8	3080	2330	750
03/27/83	76,100M	9	383	321	62	31	9	0.8	2520	2110	410
07/03/83	81,100M	9	196	153	43	21	4	0.2	1370	1070	300
11/01/83	50,700M	9	246	184	62	25	4	0.7	1080	810	270
02/21/84	81,700M	9	400	329	71	39	9	0.5	2820	2320	500
07/14/84	84,400M	9	187	126	61	31	8	0.9	1360	920	440
RIO SOLIMÕES AT MARIPUNI											
05/08/82	104,500E	9	180	142	38	14	4	0.2	1630	1280	340
08/23/82	86,600M	9	191	137	54	28	4	0.2	1430	1030	400
RIO SOLIMÕES BELOW ITAPEUA											
05/09/82	104,500G	9	246	164	82	47	8	0.8	2220	1480	740
08/24/82	86,600M	9	186	149	37	17	6	0.2	1390	1110	280
12/05/82	80,800M	9	461	371	90	22	3	1	3220	2590	630
03/28/83	89,500M	9	348	285	63	30	4	0.6	2690	2200	490
07/04/83	95,700M	9	230	172	58	29	4	0.6	1900	1420	480
11/03/83	51,800M	9	221	189	32	--	--	--	990	850	140
02/22/84	85,200M	9	376	311	65	28	3	0.3	2770	2290	480
07/19/84	104,500M	9	182	134	48	22	4	0.3	1640	1210	430
RIO SOLIMÕES AT ANORÍ											
05/10/82	105,000E	7	224	160	64	34	5	0.6	2030	1450	580
08/25/82	85,300M	9	178	139	39	17	4	0.3	1310	1020	290
12/06/82	75,700M	9	481	376	105	42	8	1	3150	2460	690
03/29/83	84,300M	9	--	--	62	33	7	0.7	--	--	450
07/05/83	99,500M	9	216	165	51	27	7	0.5	1860	1420	440
11/04/83	54,500M	9	254	213	41	17	3	0.8	1200	1000	200
02/23/84	85,950M	9	372	296	76	38	7	0.6	2760	2200	560
07/20/84	105,100M	9	168	121	47	24	4	0.4	1530	1100	430
RIO PURÚS BELOW BERURÍ											
05/10/82	20,000E	4	65	51	14	4	1	0.1	112	88	24
08/25/82	10,900M	5	24	22	2	0.9	0.3	tr	23	21	2
12/06/82	5,010M	5	103	103	0.2	--	--	--	45	45	0.1
03/29/83	14,300M	5	146	143	3	0.8	0.4	0.1	180	180	3
07/05/83	15,060M	5	40	38	2	--	--	--	52	50	2
11/04/83	2,800M	5	46	46	0.1	--	--	--	11	11	<0.1
02/23/84	10,700M	5	170	170	0.2	--	--	--	160	160	0.2
07/20/84	16,200M	5	19	18	1	--	--	--	26	25	1
RIO SOLIMÕES BELOW MANACAPURÚ (DNAEE SECTION)											
05/27/77	133,000M	7	203	143	60	29	5	--	2330	1640	690
05/11/82	125,000G	9	207	148	59	28	5	0.5	2240	1600	640
08/26/82	110,000G	9	129	105	24	8	1	0.2	1230	1000	230
12/07/82	82,600M	9	417	351	66	24	4	0.7	2970	2500	470
03/30/83	98,500M	9	309	259	50	21	4	0.5	2630	2200	430
07/06/83	112,700M	9	191	146	45	21	4	0.4	1860	1420	440
11/05/83	56,000M	9	225	184	41	17	1	0.4	1090	890	200
02/24/84	100,900M	9	345	287	58	27	4	1	3010	2500	510
07/21/84	119,500M	9	156	115	41	15	3	0.2	1610	1180	430

Table 2.--Concentrations and discharges of suspended sediment in the Rio Solimões-Amazonas and its tributaries, as measured in composite depth-integrated samples--continued.

Date	Water discharge (m^3/s)	Number of verticals in sediment composite	Concentration of suspended sediment (mg/L)						Discharge of suspended sediment (10^3t/d)		
			Total	Finer than 0.063 mm	Coarser than 0.063 mm	Coarser than 0.125 mm	Coarser than 0.25 mm	Coarser than 0.50 mm	Total	Finer than 0.063 mm	Coarser than 0.063 mm
RIO SOLIMÕES AT ILHA MACHANTARIA											
01/17/83	91,500G	9	--	--	44	12	3	1	--	--	350
01/27/83	92,900G	9	347	278	69	25	5	0.5	2780	2230	550
02/08/83	93,600G	9	327	264	63	23	4	0.6	2640	2130	510
02/21/83	93,500G	9	319	248	71	28	6	0.8	2580	2000	580
03/03/83	93,000G	9	298	237	61	25	4	0.6	2390	1900	490
06/07/83	116,300G	9	235	181	54	25	5	0.6	2360	1820	540
07/21/83	103,900G	9	181	140	41	18	2	0.2	1620	1250	370
08/11/83	82,100G	9	125	110	15	4	0.6	0.2	890	780	110
09/10/83	65,600G	9	113	100	13	2	0.3	0.1	644	570	74
09/20/83	64,900G	9	135	116	19	4	0.5	0.1	760	650	110
09/30/83	63,900G	9	146	134	12	3	0.8	0.5	806	740	66
12/16/83	72,900G	9	300	254	46	14	3	0.5	1890	1600	290
01/03/84	83,000G	9	349	288	61	28	6	0.6	2500	2060	440
01/19/84	87,900G	9	299	249	50	24	5	0.4	2270	1890	380
03/20/84	109,000G	9	290	222	68	31	5	0.5	2730	2090	640
04/05/84	112,000G	9	247	175	72	37	8	0.5	2390	1690	700
09/13/84	93,900G	9	148	124	24	7	2	0.3	1200	1010	190
09/27/84	84,800G	9	153	134	19	4	1	0.4	1120	980	140
10/10/84	76,000G	9	131	121	10	2	0.4	0.1	860	790	70
10/25/84	70,700G	9	172	155	17	2	0.4	0.1	1050	950	100
11/07/84	72,000G	9	244	218	26	4	1	0.3	1520	1360	160
11/23/84	72,500G	9	188	171	17	3	0.6	0.1	1180	1070	110
12/05/84	71,100G	9	201	180	21	4	2	0.4	1240	1110	130
12/18/84	82,000E	9	385	346	39	10	2	0.4	2730	2450	280
02/13/85	93,500G	9	213	187	26	8	0.8	0.3	1720	1510	210
RIO NEGRO AT NARROWS ABOVE MANAUS											
05/12/82	59,000M	4	7	7	~0	--	--	--	36	36	~0
08/27/82	40,300M	4	8	8	0.4	--	--	--	29	28	1
12/08/82	5,000E	3	6	6	0.1	--	--	--	3	3	<0.1
03/31/83	8,300M		10	10	~0	--	--	--	7	7	~0
07/07/83	32,200M	3	5	5	~0	--	--	--	14	14	~0
02/28/84	28,000E	1	5	5	~0	--	--	--	12	12	~0
07/22/84	46,300M	7	8	8	0.2	--	--	--	33	32	0.8
RIO AMAZONAS ABOVE SÃO JOSÉ DO AMATARI											
09/01/82	139,000M	9	142	109	33	13	2	0.2	1710	1310	400
12/10/82	90,600M	9	265	252	13	5	1	0.3	2070	1970	100
04/05/83	107,100M	9	226	212	14	5	1	0.3	2090	1960	130
07/11/83	147,000M	9	175	135	40	15	2	0.3	2220	1710	510
11/10/83	75,300M	9	145	133	12	5	0.7	0.2	940	860	80
02/29/84	129,000M	9	247	225	22	7	1	0.4	2750	2510	240
07/27/84	174,300M	9	158	107	51	20	4	0.5	2380	1610	770
RIO MADEIRA AT PÔRTO VELHO (DNAEE SECTION)											
04/21/84	42,000M	7	791	522	269	119	8	1.0	2870	1890	980
RIO MADEIRA AT HUMAITÁ (DNAEE SECTION)											
04/24/84	44,000G	7	583	392	191	75	9	0.8	2220	1490	730
RIO MADEIRA AT MANICORÉ (DNAEE SECTION)											
04/26/84	53,500G	7	370	250	120	41	10	0.7	1710	1160	550
RIO MADEIRA AT FAZENDA VISTA ALEGRE (DNAEE SECTION)											
04/27/84	55,000G	7	443	241	202	85	14	0.8	2110	1150	960

Table 2.--Concentrations and discharges of suspended sediment in the Rio Solimões-Amazonas and its tributaries, as measured in composite depth-integrated samples--continued.

Date	Water discharge (m^3/s)	Number of verticals in sediment composite	Concentration of suspended sediment (mg/L)						Discharge of suspended sediment ($10^3 t/d$)		
			Total	Finer than 0.063 mm	Coarser than 0.063 mm	Coarser than 0.125 mm	Coarser than 0.25 mm	Coarser than 0.50 mm	Total	Finer than 0.063 mm	Coarser than 0.063 mm
RIO MADEIRA AT URUCURITUBA											
09/02/82	13,700M	7	80	79	0.5	--	--	--	95	94	1
12/11/82	23,100M	7	677	619	58	2	0.5	0.2	1350	1230	120
04/06/83	48,400M	7	738	604	134	35	3	0.4	3090	2530	560
07/12/83	24,700M	7	179	171	8	2	0.3	0.1	380	360	16
11/11/83	6,800M	7	91	90	1	--	--	--	54	53	1
03/01/84	42,100M	7	891	771	120	57	3	0.6	3240	2800	440
04/29/84	58,100M	7	454	319	135	40	4	0.4	2280	1600	680
07/27/84	19,300M	7	64	64	0.2	--	--	--	110	110	0.3
RIO AMAZONAS AT ITACOATIARA											
09/02/82	146,100M	9	154	120	34	9	2	0.2	1940	1510	430
RIO AMAZONAS AT COSTA DO PAURÁ											
09/03/82	158,000M	9	149	129	20	5	0.6	0.1	2040	1770	270
12/12/82	120,000M	9	290	275	15	6	1	0.2	3010	2850	160
04/07/83	159,000M	9	308	279	29	11	1	0.2	4230	3830	400
07/13/83	171,000M	9	231	184	47	12	2	0.4	3410	2720	690
11/12/83	81,700M	9	106	97	9	3	0.6	0.4	750	690	60
03/02/84	165,700M	9	408	373	35	7	2	0.4	5840	5340	500
07/28/84	201,600M	9	182	138	44	14	3	0.4	3170	2400	770
RIO AMAZONAS AT SANTA JULIA											
09/04/82	162,000M	9	177	140	37	14	1	0.2	2470	1950	520
RIO AMAZONAS AT ÓBIDOS (DNAEE SECTION)											
06/15/76	230,000M	8	180	120	60	--	--	--	3600	2400	1200
06/02/77	220,000E	7	236	185	51	12	2	--	4490	3520	970
09/05/82	168,000G	9	188	145	43	--	--	--	2730	2100	630
12/13/82	123,000M	9	249	238	11	4	0.8	0.2	2650	2530	120
04/12/83	167,000M	9	285	256	29	8	0.6	0.1	4110	3690	420
07/15/83	177,000M	9	216	188	28	8	1	0.4	3310	2880	430
11/14/83	91,700M	9	93	88	5	1	0.4	0.2	740	700	40
03/04/84	177,000M	9	385	345	40	14	2	0.3	5890	5280	610
07/31/84	202,900M	9	195	148	47	17	1	0.3	3410	2590	820

The single measurement of 1976 is based on 37 individual point samples that were collected in a single day from Rio Amazonas at Óbidos (fig. 7; lower three graphs). The four measurements made during 1977 each consisted of 5 to 7 individual depth-integrated measurements from which discharge-weighted composite concentrations could be computed. The basic data for all five measurements are listed in the earlier report by Meade and others (1979a, p. 18-24).

Downriver Changes in Suspended-Sediment Concentration

As pointed out by Gibbs (1965, 1967), suspended-sediment concentrations decrease downriver in the Rio Solimões-Amazonas mainstem through the progressive dilution of the large sediment concentrations derived from the Andes by flow from less-concentrated tributaries that drain the lowlands of Brazil. The dashed lines in figure 4 show the patterns of downstream decrease that Gibbs inferred for wet, intermediate, and dry seasons of the annual runoff cycle. The circles in the figure show data collected during wet and dry seasons in 1982-84.

Data collected during the wet-season cruise of February-March 1984 (solid circles, fig. 4) agree closely with Gibbs' wet-season curve between the mouths of Rio Içá and Rio Madeira. Below Rio Madeira, however, the concentrations of suspended sediment that we measured were about twice the wet-season concentrations inferred by Gibbs, who evidently did not take into account that Rio Madeira, which transports large sediment loads from the Andes of Bolivia, is capable of doubling the sediment discharge of the lower Amazon during wet seasons (Meade and others, 1985).

The greatest disagreement between Gibbs' curves and our data, however, occurred during the dry seasons of 1982-83. The data collected during these dry seasons (open circles, fig. 4) plotted along Gibbs' "intermediate" curve; none of our dry-season data plotted on Gibbs' dry-season curve. At least two possible reasons could account for this difference. First, if the tabulated data in his 1965 doctoral dissertation are an accurate guide, Gibbs collected most of his samples from tributaries, and he apparently inferred the concentrations in the mainstem from concentrations he observed in the tributaries. The 1982-84 data in table 2 show that, whereas maximum concentrations of suspended sediment in some tributaries (Rio Juruá, Rio Purús, and Rio Madeira) can exceed minimum concentrations by a factor near 10, the maximum concentrations in the Rio Solimões-Amazonas mainstem are only 2 to 4 times the minimum concentrations at the same cross sections. By basing his conclusions mainly on tributary data, therefore, Gibbs easily could have overestimated the contrasts between wet-season and dry-season concentrations in the mainstem.

Surface versus Depth-Integrated Concentrations

The second possible reason for Gibbs' apparent underestimate of the suspended sediment in the Solimões-Amazonas mainstem during dry season is the difference between surface and depth-integrated concentrations. Gibbs collected most of his samples from the river surface and then "corrected"

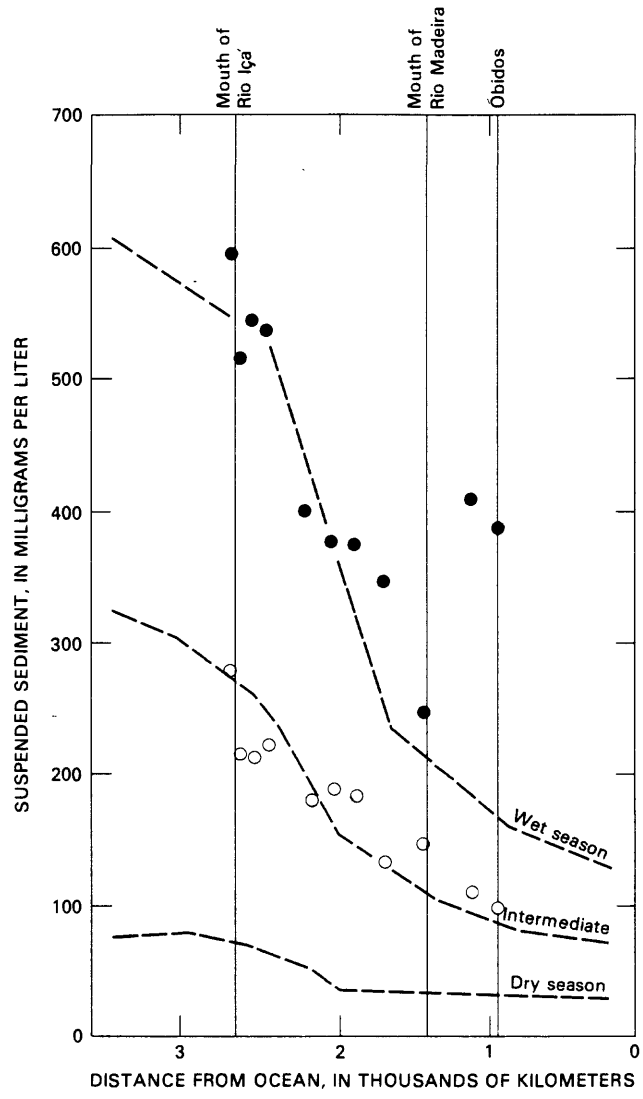


Figure 4.--Variations of suspended-sediment concentration with distance along the Rio Solimões-Amazonas mainstem. The dashed lines show the downstream decreases in sediment concentration during different seasons of the annual runoff cycle, as inferred by Gibbs (1965, 1967). The circles show concentrations measured during 1982-84; dark circles, wet-season cruise of February-March 1984; open circles, minimum concentration measured during dry season (either August-September 1982 or October-November 1983).

their concentrations by assuming that ". . . samples taken at 0.9 total depth had only a 20 percent greater concentration than the surface sample" (Gibbs, 1967, p. 1209). More recent data show that this assumption probably was wrong.

Data collected near the peak of the high-water season of 1977 showed the concentrations of even the suspended silt and clay (finer than 0.053 mm, in this case) to be twice as great in depth-integrated samples as in surface samples collected at the same locations (Curtis and others, 1979, 1982). When suspended sand was considered along with the suspended silt and clay, the difference between total depth-integrated and surface concentrations was even larger (Meade and others, 1979a, p. 17-30). More germane to the present discussion, however, is a series of measurements that represents conditions during the dry season.

During the low-water cruise of October-November 1983, while the usual depth-integrated composite was being collected at each cross section, a composite sample also was collected at the river surface. At each of the verticals sampled for sediment, 0.5 L of water was dipped from the river surface and poured into an 8-L churn splitter. This resulted in a spatially-weighted (rather than discharge-weighted) composite of the surface water in the cross section. The surface samples contained very little sand, and no attempt was made to separate their sand fractions. At the completion of the sampling for the section, two representative subsamples were drawn from the splitter and filtered as described above under "Processing suspended-sediment samples". The concentrations determined from the two subsamples at any one section always agreed within 6 mg/L (usually within 4 mg/L). Mean concentrations in the surface water at each section are listed in table 3, where they can be compared with the concentrations in the depth-integrated composites. At the mainstem sections, the surface concentrations averaged about one-half the depth-integrated concentrations. In the tributaries, the contrast was not as great--especially in those tributaries (Rio Jutaí, Rio Juruá, Rio Purús) where the suspended sediment typically is very fine grained and, therefore, fairly uniformly mixed from the bed to the surface of the river.

Table 3.--Comparisons of concentrations of suspended sediment in concurrently-collected surface and depth-integrated composite samples, Rio Amazonas and tributaries, October-November 1983. Samples collected and filtered in the field by L.A.K. Mertes; laboratory analyses by R. H. Meade. (mg/L, milligrams per liter; mm, millimeters)

Section	Concentration of suspended sediment (mg/L)		
	Surface (total only)	Depth-integrated	
		Total	<0.063 mm
Rio Solimões-Amazonas			
Vargem Grande	131	276	232
Santo Antônio do Içá	117	237	179
Ilha Xibeco	139	304	216
Tupé	143	274	211
Jutica	128	246	184
Itapeua	90	221	189
Anorí	158	254	213
Manacapurú	98	225	184
São José do Amatari	80	145	133
Costa do Paurá	64	106	97
Obidos	61	93	88
Tributaries			
Rio Içá	84	121	99
Rio Jutaí	28	32	32
Rio Juruá	56	67	66
Rio Japurá	41	74	63
Rio Purús	41	46	46
Rio Madeira	76	91	90

Particle Sizes of Suspended Sediment

Complete particle-size analyses of selected samples collected during 1982-84, most of which represent the rising-stage period of high sediment concentration during February-March 1984, are listed in table 4. Only the samples from Rio Amazonas at Óbidos (including one collected at peak discharge in 1977 and reported by Meade and others, 1979a, p. 31) were collected at enough different river stages to suggest the range of variation in the size distributions of suspended silt and clay particles:

Stage and date	Percent finer than indicated size			Median diameter (mm)
	0.002 mm	0.016 mm	0.063 mm	
Rising stages				
12/13/82	50	86	96	0.0020
03/04/84	53	77	90	.0015
Peak or falling stages				
06/03/77	20	42	77	.021
07/15/83	28	57	87	.011

From these few data, one might infer that suspended sediment at Óbidos tends to be finer grained on rising stages than on peak or falling stages, and that median diameters of suspended sediment at different river stages might differ by a factor as great as 10.

The particles transported by Rio Juruá and Rio Purús are exceptionally fine (table 4). Approximately three-quarters of the suspended sediment collected from these rivers during February 1984 consisted of particles finer than 0.002 mm. These numbers agree with visual observations, made while processing samples collected at other times, that the silt and clay fractions suspended in these rivers are especially fine grained. They also correspond with the observation by Gibbs (1965, p. 94) and Irion (1983a, 1983b) that the suspended sediment of these two rivers is particularly rich in montmorillonite-type (smectite-type) clay minerals, which usually occur in extremely fine particles. Also very fine grained are the suspended sediments in Rio Jutaí and Rio Negro; the fineness of their particle sizes, however, is related mostly to the very small concentrations of inorganic suspended sediment and the greater proportions of finely divided organic matter carried by these two blackwater rivers (Sioli, 1957).

Substantially more particle-size analyses were made for suspended sand than for silt and clay, and their results are shown in table 2. The sand in suspension was mostly very fine to fine (0.063-0.25 mm). In the samples collected during 1982-84, the material coarser than 0.25 mm rarely exceeded 5 percent of the total suspended sediment and never exceeded 20 percent of

Table 4.--Complete particle-size distributions of selected suspended-sediment samples, Rio Solimões-Amazonas and principal tributaries. Sizes coarser than 0.063 mm analyzed by wet-sieve methods (C.L. Stewart, analyst). Sizes finer than 0.063 mm analyzed by methods indicated (W. J. Matthes, H. R. Allen, and D. R. Rankin, analysts). (m^3/s, cubic meters per second; mg/L, milligrams per liter; mm, millimeters).

Date	Water discharge (m^3/s)	Suspended-sediment concentration (mg/L)	Method of analysis of sizes finer than 0.063 mm[1/]	Percent finer than indicated size, in millimeters								
				0.002	0.004	0.008	0.016	0.031	0.063	0.125	0.25	0.50
RIO SOLIMÕES AT ILHA XIBECO												
02/16/84	61,400	541	P(IC)	56	62	67	75	79	82	92	98.5	99.8
			Sdgr	46	58	69	75	80				
RIO SOLIMÕES BELOW TUPÉ												
02/18/84	63,100	533	Sdgr	33	44	55	66	75	78	89	98.3	99.8
RIO JURUÁ, 16 KILOMETERS ABOVE MOUTH												
02/18/84	5,200	290	P(IC)	79	82	84	88	90	93	96	99.3	100
			Sdgr	78	85	88	89	91				
RIO SOLIMÕES BELOW ITAPEUA												
02/22/84	85,200	376	Sdgr	40	49	61	70	79	83	93	99.2	99.9
RIO PURÚS BELOW BERURÍ												
02/23/84	10,700	170	Sdgr	78	90	96	99.3	99.9	99.9	100		
RIO SOLIMÕES BELOW MANACAPURÚ (DNAEE SECTION)												
02/24/84	100,900	345	P(IC)	48	48	59	66	75	83	92	98.8	99.7
			Sdgr	45	55	65	72	80				
RIO AMAZONAS ABOVE SÃO JOSÉ DO AMATARI												
02/29/84	129,000	247	Sdgr	46	58	70	79	86	91	97	99.6	99.8
RIO MADEIRA AT URUCURITUBA												
12/11/82	23,100	677	P(A)	27	38	55	69	81	91	99.7	99.9	100
03/01/84	42,100	891	P(IC)	33	36	43	60	78	87	94	99.7	99.9
			Sdgr	29	39	52	69	82				
RIO AMAZONAS AT COSTA DO PAURÁ												
03/02/84	165,700	408	Sdgr	43	56	69	82	89	91	98.3	99.5	99.9
RIO AMAZONAS AT ÓBIDOS (DNAEE SECTION)												
12/13/82	123,000	249	P(A)	45	55	70	83	92	96	98.4	99.6	99.9
			P(IC)	54	62	75	85	93				
			Sdgr	51	64	76	89	94				
07/15/83	177,000	216	P(A)	24	28	41	56	64	87	96	99.5	99.8
			P(IC)	32	38	43	53	68				
			Sdgr	28	37	44	62	77				
03/04/84	177,000	385	P(IC)	57	64	69	75	85	90	96	99.5	99.9
			Sdgr	48	59	70	79	86				

[1/] P(IC) = pipette (Iowa City); P(A) = pipette (Albuquerque); Sdgr = sedigraph

the suspended sand. Furthermore, a visibly significant fraction of the suspended material coarser than 0.25 mm consisted of organic detritus. Virtually all the suspended matter coarser than 0.50 mm was organic detritus.

The sizes of the sand particles in suspension in the Rio Solimões-Amazonas mainstem decrease slightly in the downriver direction. Only in the upper half of the study reach, between Vargem Grande and Anorí, does material coarser than 0.25 mm ever account for more than 10 percent, or material coarser than 0.125 mm ever account for more than one-half, of the total sand coarser than 0.063 mm. In the lower mainstem, between Manacapurú and Obidos, material coarser than 0.25 mm is always less than 10 percent, and material coarser than 0.125 mm is always less than one-half, of the total sand in suspension.

Seasonal Changes in Suspended-Sediment Concentration

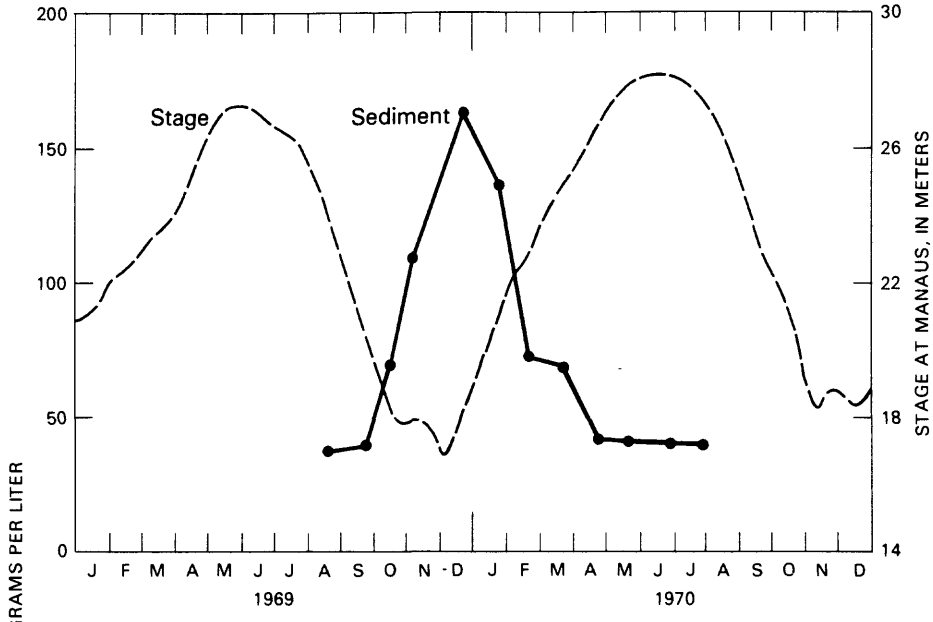
Sufficient data are available from the time-series section of Rio Solimões at Ilha Machantaria (24 samples collected during 1982-84) to show the seasonal cycle of variation in suspended-sediment concentration. An earlier time series of suspended-sediment data was obtained in the Machantaria section by Schmidt (1972), who collected monthly samples during a year-long period in 1969-70. Although Schmidt analyzed only single samples collected from the water surface in midriver, his data (fig. 5, upper graph) clearly show some of the same seasonal pattern of variation in suspended-sediment concentration that is evident in our depth-integrated samples (fig. 5, lower graph). Included in the lower graph with our data from Ilha Machantaria are 8 data points that represent composite depth-integrated samples collected from Rio Solimões at Manacapurú, 60 km upriver. The two sections are similar enough that their data can be combined in figure 5 without introducing significant error.

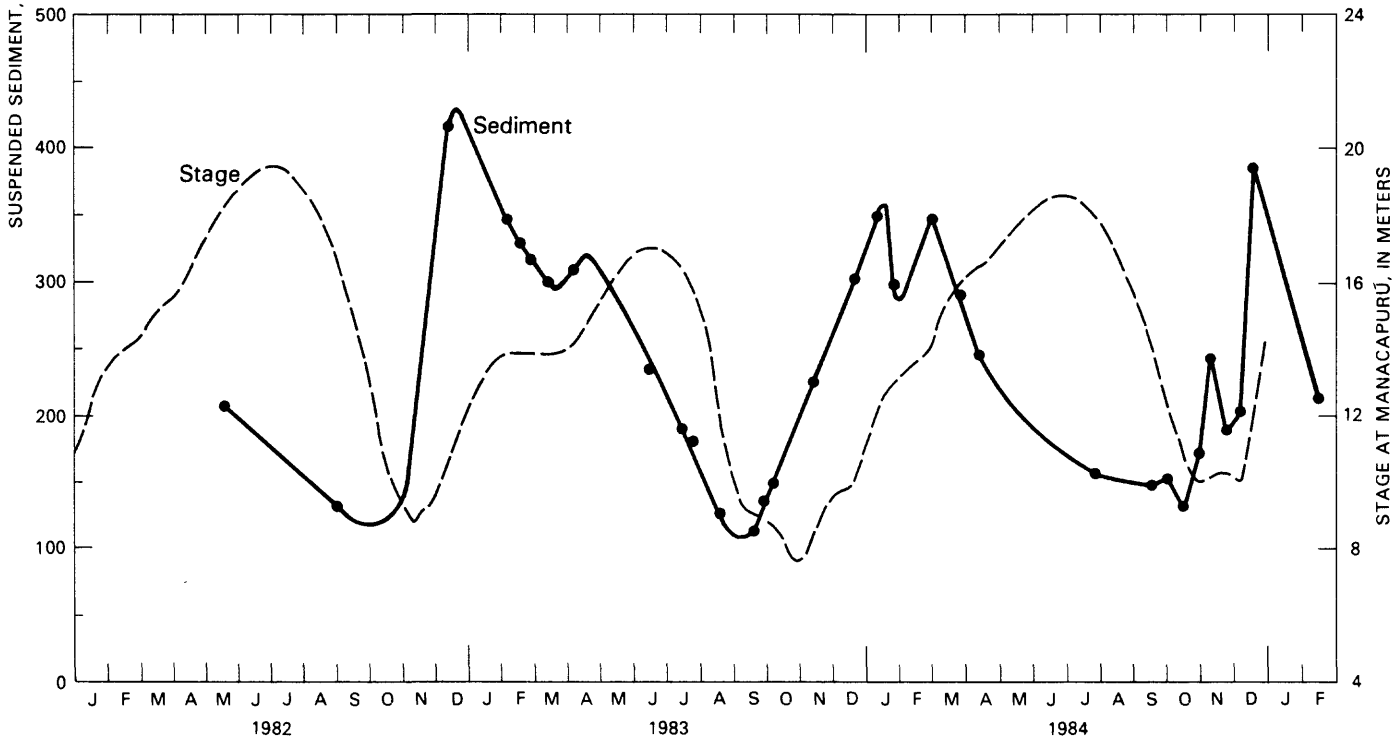
The peaks and valleys of sediment concentration are out of phase with the peaks and valleys of river stage. Maximum concentrations of suspended sediment in this part of Rio Solimões occur in December or January, near the beginning of the annual rise in river stage, and half a year earlier than the peak stage. Secondary peaks of sediment concentration (April 1983, February-March 1984, November 1984) seem to be related to secondary increases in the rate of rise of the river stage. The minimum concentrations of suspended sediment precede the lowest stages by a month or two.

Seasonal Changes in Suspended-Sediment Discharge

Because the peaks and valleys of sediment concentration and water discharge are offset in time from each other, the graphed relations of sediment discharge versus water discharge form clockwise loops rather than straight lines or smooth curves (fig. 6). Such clockwise looped relations between sediment discharge and water discharge are typical of other large rivers such as the Orinoco and Mississippi (Meade and others, 1983; Robbins, 1977, figs. 39-41) as well as of many other rivers of moderate and

Figure 5. -- Variations of suspended-sediment concentration and river stage, Rio Solimões at Ilha Machantaria. Upper graph, Samples collected from water surface at midriver, 1969-70 (Schmidt, 1972); daily river stage from PORTOBRAS gage, Rio Negro at Manaus. Lower graph, Composite depth-integrated samples, 1982-85, including eight samples collected at Manacapurú; daily river stage from CPRM-DNAEE gage, Rio Solimões at Manacapurú. All Machantaria samples 1983-85 collected and filtered by B. R. Forsberg.
Note that the scale of suspended concentration in the upper graph is expanded relative to the scale in the lower graph, to reflect the observation that suspended sediment in this part of Rio Solimões is typically two to three times more concentrated in depth-integrated samples than in samples collected near the river surface. River-stage data from Manaus are used in the upper graph because the Manacapurú gage was not in operation in 1969-70. Comparison of stage data collected daily since 1972 at both gages shows that the two gage records are nearly identical; even though the Manaus gage is nominally in Rio Negro, the river levels recorded at Manaus reflect the levels of the Rio Solimões-Amazonas mainstem rather than the levels of the upper Rio Negro. The two gage records, however, are not referenced to the same zero datum.


Stage
Sediment
200
150
100
50
0
30
26
22
18
14
J F M A M J J A S O N D J F M A M J J A S O N D
1969
1970
STAGE AT MANAUS, IN METERS


Stage
Sediment
500
400
300
200
100
0
24
20
16
12
8
4
J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D J F
1982
1983
1984
SUSPENDED SEDIMENT, IN MILLIGRAMS PER LITER
STAGE AT MANACAPURÚ, IN METERS

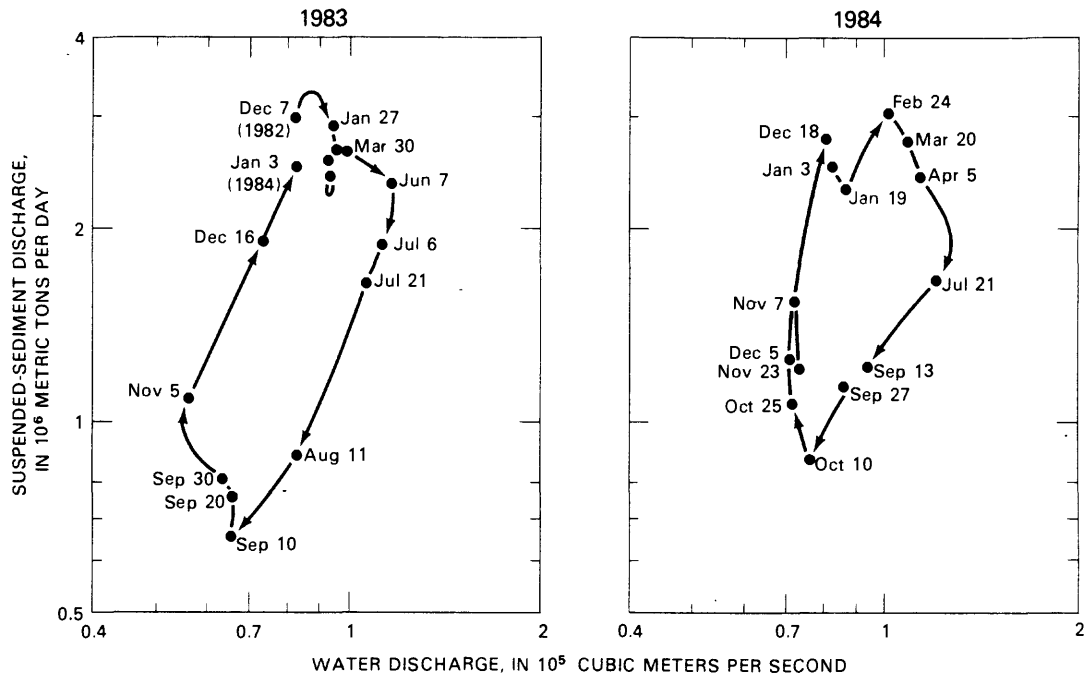


Figure 6.--Relations between sediment discharge and water discharge, Rio Solimões at Machantaria-Manacapurú during 1983 (left) and 1984 (right). Six of the data points represent measured discharges of water and sediment at Manacapurú. Twenty-three data points represent measured sediment concentrations at Ilha Machantaria and discharges calculated from the stage-discharge relation developed by CPRM-DNAEE at the Manacapurú gage. Ilha Machantaria samples collected and filtered by B. R. Forsberg.

smaller size (see, for example, Nordin and Beverage, 1965, Temple and Sundborg, 1972, and Walling, 1977). This relation usually is explained as the "depletion" or "exhaustion" effect: fine-grained sediment, which is stored on channel beds and along river banks during low-water periods, is in plentiful supply as the river begins its annual rise, but the stored material is soon resuspended, and it eventually becomes depleted before the river reaches its maximum discharge. Further discussion of the combined seasonal and spatial distributions of suspended-sediment discharge can be found in the interpretive paper by Meade and others (1985).

SOURCES AND MAGNITUDES OF ERRORS

As this report contains baseline data in sufficient quantity and of sufficient quality to be of eventual use in measuring the effects on suspended sediment of future changes in the Amazon River basin, it is appropriate here to explore the limits of error in the data. In general, the largest errors in these data are sampling errors. Most of the errors involved in processing and analyzing the samples are smaller than the errors involved in collecting the samples from the rivers.

Sampling Error

The basic problem of sampling sediment in any river is to overcome the heterogeneity of the distributions of velocity and suspended-sediment concentration in the cross section. Examples of the heterogeneity of suspended concentrations in two cross sections of the Solimões-Amazonas mainstem are shown in figure 7. The vertical and lateral distributions of suspended-sediment concentration were defined by 33 to 37 point samples collected in different parts of the cross sections, and they show the nonuniformity of concentrations of total suspended sediment, suspended sand (>0.063 mm), and suspended silt and clay (<0.063 mm). To overcome this heterogeneity, we used the equal-width-increment (equal-transit-rate) sampling method and specially-designed sampling equipment. The sampling error to be discussed here corresponds to the "spatial error" discussed in the recent analysis by Burkham (1985).

Data were collected during two of the downriver cruises to try to answer the question: What sampling errors can be expected in using nine-vertical depth-integrated composites to measure the concentrations of suspended sediment in the Amazon? At first glance, this question seems to be directly accessible because alternating nine-vertical composites were collected at each mainstem section (fig. 3), and we should be able to assess the consistency of sampling by comparing similar measurements made in the two composites. In practice, however, the differences in the way the two composites were processed aboard ship interfered with the direct assessment of sampling error. Nevertheless, subsamples of the two composites were compared, on the presumption that at least part of the differences we observed would be due to sampling error.

The most important difference between the two shipboard precedures that affects the assessment of sampling error is in the processing of suspended sand. Whereas the sand in the sediment sample was separated before the rest of the sample was placed into a churn splitter, the sand in the chemistry sample was poured directly into a churn splitter. The U.S. Geological Survey churn splitters do not distribute sand grains evenly because the stirring action does not entirely overcome the tendency for sand grains to settle. This sets up a gradient in the splitter where sand is more concentrated near the bottom (where the spigot is) than near the top. Subsamples drawn from the spigot therefore will contain greater proportions of sand than does the suspension in the splitter. And in any comparison of subsamples drawn from churn splitters that contained the two

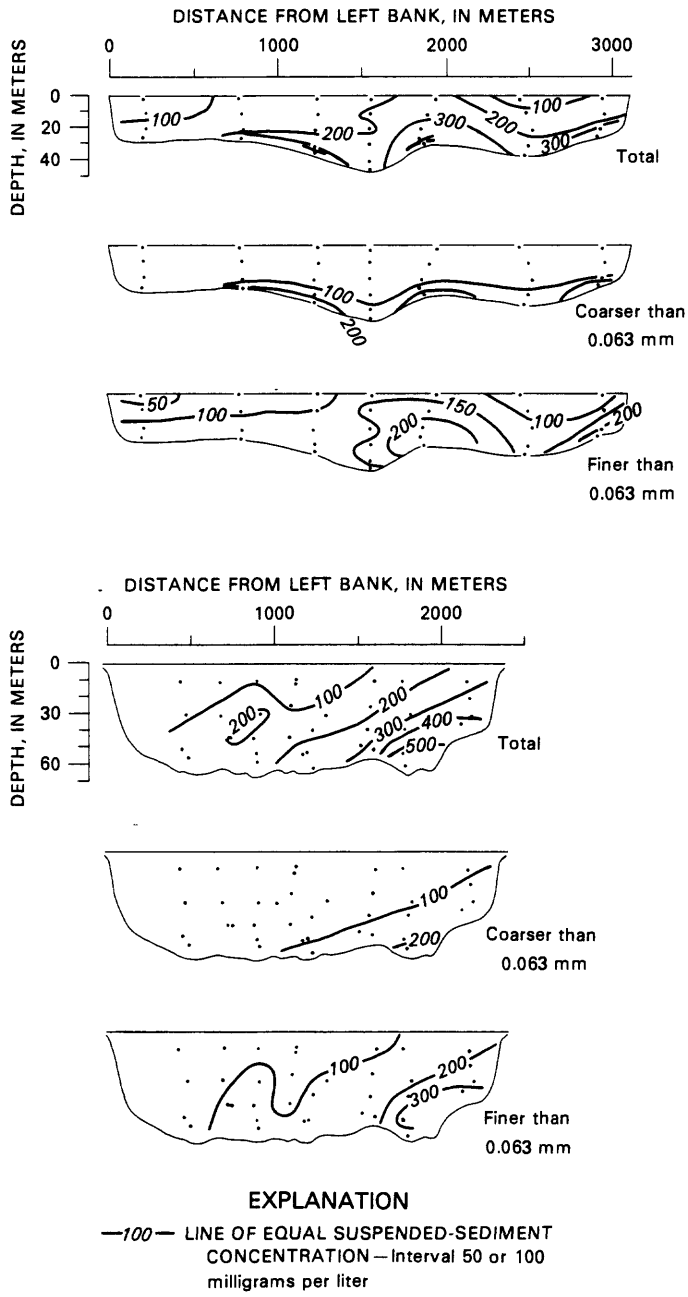


Figure 7.--Cross sections of the Rio Solimões-Amazonas mainstem during high-water seasons, showing vertical and lateral heterogeneity of suspended-sediment concentrations. Upper three graphs, Rio Solimões below Manacapurú, May 27, 1977 (Meade and others, 1979a, p. 21; 1979d, p. 480). Lower three graphs, Rio Amazonas at Óbidos, June 15, 1976 (Meade and others, 1979a, p 22-23).

different composites, the subsamples from the chemistry composite would be expected to have consistently larger suspended concentrations than those drawn from the sediment composite. The comparative data in table 5 bear out this expectation.

The consistent bias in the measured data (table 5) toward greater concentrations in the chemistry composite, in contrast to the random variation one would expect from pure sampling error, indicates that procedural differences consistently overshadowed the sampling differences. So the most conservative analysis we can make of these comparisons is to assume that the observed difference in each pair of concentrations is due entirely to sampling error. If we assume further that the 18 comparisons in table 5 are representative, that the "true" discharge-weighted mean concentration in each cross section is the mean of the two determinations, and that the sampling error is the difference between the "true" mean and the concentration in the sediment sample, we can describe the distribution of sampling error as follows: The sampled concentration of total suspended

Table 5.--Comparisons of concentrations of total suspended sediment in separate depth-integrated composite samples collected concurrently for sediment and chemical analysis, Rio Solimões-Amazonas and selected tributaries. Analyst: R. H. Meade (mg/L, milligrams per liter)

	Concentration of suspended sediment (mg/L)			
	November-December 1982		June-July 1983	
Section	Sediment	Chemistry	Sediment	Chemistry
Rio Solimões-Amazonas (9-vertical composites)				
Ilha Xibeco	548	641	--	--
Tupé	555	608	--	--
Jutica	501	505	--	--
Itapeua	461	466	--	--
Anorí	481	501	216	253
Manacapurú	417	410	191	229
Ilha Machantaria	--	--	181	209
São José do Amatari	265	266	175	185
Costa do Paurá	290	305	231	241
Óbidos	249	258	216	229
Tributaries (7-vertical composites)				
Rio Içá	--	--	87	95
Rio Madeira	677	706	179	179

sediment was within 2 percent of the true concentration at one-third of the sections, within 5 percent at three-quarters of the sections, and within 10 percent at all the sections.

The largest component of error should be related to the sampling of suspended sand, whose distribution in time and space is notoriously irregular. Furthermore, the sampling error for suspended sand can be assessed more readily here because more comparative data are available and the procedural differences do not seem to overwhelm the sampling error. The concentrations of suspended sand in the sediment composites were determined by sieving the samples as soon as they were collected. The concentrations of suspended sand in the chemistry composites were determined by sieving all the sand that remained in the splitters after the various subsamples had been withdrawn. Two subsampling routines that were used in the chemistry procedure during the last 5 downriver cruises tended to offset each other in their effects on the sand concentration in the remaining composite: the decanting of 100 mL of sand-free water from the sample at each vertical tended to concentrate the sand in the remaining composite; the withdrawal of representative fractions and subsamples from the splitter spigots tended to decrease the concentration of sand in the remaining composite. Therefore, the remaining composite probably had a less biased sand concentration than either the decanted supernatant or the subsamples drawn from the splitter spigots. In figure 8, which shows the differences between the sand concentrations determined in the two composites at 56 sections sampled during the last 5 downriver sampling cruises, the scatter of points is mostly random and can be taken to represent mostly sampling error. If we assume, as before, that the "true" discharge-weighted mean sand concentration in each cross section is the mean of the two determinations, and that the sampling error is the difference between the "true" mean and the sand concentration in the sediment composite, then the error in sand concentration can be described: The measured sand concentration was within 5 percent of the true mean in 59 percent of the sections, within 10 percent in 84 percent of the sections, within 15 percent in 96 percent of the sections, and within 20 percent in all the sections.

Processing Error and Centrifuge Losses

The main sources of error in the shipboard processing of sediment samples were related to the use of the churn splitter or to the rinsing of labware during the filtering process. Although the churn splitter is a simple device, it requires some care in its operation. If the paddle is pumped too slowly or for too short a time before subsamples are withdrawn, the subsamples will not be sufficiently mixed and their concentrations will not be representative. The other procedural step that requires special attention is the thorough rinsing of all containers, graduates, and filter funnels with which the filtered subsample has come in contact; all the silt grains in the subsample need to be rinsed meticulously off the labware and onto the filter. Large errors related to these two procedural steps were confined mostly to the early downriver cruises (especially August-September 1982) and to the first few samples collected at Ilha Machantaria. They were due to operator inexperience and were soon rectified.

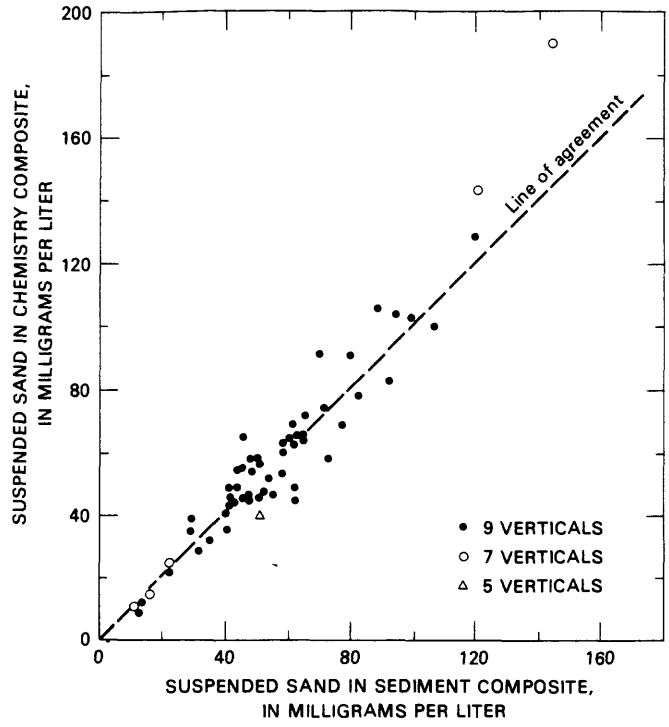


Figure 8.--Concentrations of suspended sand as determined in sediment and chemistry composites collected in 56 cross sections during downriver cruises of March-April, June-July, and October-November 1983, and February-March and July 1984. Concentrations less than 10 mg/L not included in graph. Sand concentrations in sediment samples are those in field-washed samples (initial weighing), whose processing is comparable to that of the sands in the chemistry samples. Sand concentrations in chemistry samples analyzed by W. A. Clark, J. Stern, and J. I. Hedges.

The magnitudes of the errors related to the splitting and filtering procedures were evaluated mainly by comparing the concentrations that were determined in the 3 to 4 filtered subsamples from each sample. If one of the subsample concentrations was markedly different from the other 2 or 3, it was not included in the final computation of the mean concentration finer than 0.063 mm for that sample. If all 3 or 4 values disagreed with each other by widely disparate amounts, the entire sample was discounted and no value was included for the concentration finer than 0.063 mm in table 2. After these adjustments were made, the procedural errors in the data for concentrations finer than 0.063 mm could be summarized as follows. In 104 samples collected during downriver cruises from the Rio Solimões-Amazonas mainstem and from Rio Madeira, the individual subsample concentrations agreed with their mean concentrations within 1 percent in nearly one-half (49) of the samples, within 3 percent in three-quarters (80) of the samples, and within 5 percent in all but two (102) of the samples. In 24 samples from the section at Ilha Machantaria, the individual subsample concentrations agreed with their means within 3 percent in one-half the samples, within 5 percent in three-quarters of the

samples, and within 11 percent in all the samples. In the samples collected from tributaries, where concentrations usually were much smaller, the percentage differences between subsample concentrations generally were larger. Expressed in terms of concentration rather than percentage, in 43 tributary samples (not including the Rio Madeira): individual subsample concentrations were within 1 mg/L of their means in one-half the samples, within 2 mg/L in three-quarters of the samples, within 5 mg/L in nine-tenths of the samples, and within 7 mg/L in all the samples.

The centrifuging procedure that was used to recover silt and clay for particle-size analysis involved some loss of material. Whether this loss was selective of particular size fractions is not certain, but a set of measurements on samples collected during the downriver cruise of February-March 1984 suggests that losses can be 10 to 20 percent of the suspended sediment finer than 0.063 mm.

The sand and silt-clay concentrations determined in the chemistry and sediment composites collected during the cruise of February-March 1984 are presented in table 6. Sand concentrations in both composites were determined by sieving and weighing. Silt-clay concentrations, however, were determined differently in the two composites: those in the sediment composite were determined by filtering and weighing; those in the chemistry composite were determined by centrifuging and weighing. The flow-through supercentrifuge yields three separate fractions: (1) The concentrated sample that is collected in the centifuge cylinder, (2) the "reject" sample that drains out the bottom of the centrifuge when the machine is turned off, and (3) the flow-through effluent that passes through the centrifuge and whose concentration of suspended sediment was determined by filtering a representative half liter. The concentrations of sand from the chemistry and sediment samples show a random scatter relative to each other that can be attributed mostly to sampling error. The concentrations of the silt-clay samples (the last two columns in table 6) show a nonrandom bias. Those in the sediment composites are consistently 10 to 20 percent greater than those in the centrifuged chemistry composite.

The differences in the measured silt-clay concentrations must be due either to a systematic error that causes an apparent increase in the concentration in the sediment sample or to a systematic loss of material at some stage of the centrifuging process. The only conceivable step of the sediment procedure that could result in a nonrandom increase of 10-20 percent in the concentration of silt and clay would involve the churn splitter. That is, perhaps the coarsest silt grains could have settled in the churn splitter, as sand grains do, to give erroneously large concentrations to the subsamples that were withdrawn from the spigot to be filtered. This possibility was eliminated, however, in a controlled experiment. When 2.95 g of mostly coarse silt (100 percent finer than 0.063 mm, 27 percent finer than 0.031 mm, 14 percent finer than 0.016 mm) was suspended in 10.0 L of water in a 14-L churn splitter, 5 subsamples drawn from the spigot had a mean concentration of 301 mg/L (range 299 to 302 mg/L), or an error of only 2 percent. We suspect that the large differences in silt-clay concentration in the last two columns of table 6 represent centrifuge loss. In particular, we suspect that the systematically lower recovery from the centrifuge procedure results, at

Table 6.--Comparisons of concentrations of suspended sand (coarser than 0.063 mm) and suspended silt plus clay (finer than 0.063 mm) as determined in chemistry and sediment composites during February-March 1984. Chemistry composites sieved and centrifuged by J. R. Ertel; analyses by W. A. Clark and J. I. Hedges. Sediment composites and centrifuge effluents sieved, filtered and analyzed by R. H. Meade. (mg/L, milligrams per liter).

Section	Concentration of suspended sand (mg/L)		Concentration of suspended silt and clay (mg/L)				
			Centrifuged chemistry composite				Filtered sediment composite silt-clay[1/]
	Chemistry composite	Sediment composite[1/]	Concentrate	Reject	Effluent	Total silt-clay	
Rio Solimões-Amazonas							
Vargem Grande	99	106	330	45	5	380	486
Santo Antônio do Içá	103	94	295	70	5	370	419
Ilha Xibeco	102	99	282	49	4	335	442
Tupé	128	119	280	62	14	356	414
Jutica	57	72	225	55	9	289	328
Itapeua	71	65	222	45	5	272	311
Anorí	68	77	218	44	5	267	295
Manacapurú	62	58	200	45	8	253	287
São José do Amatari	22	22	166	29	6	201	225
Costa do Paurá	31	35	236	72	8	316	373
Óbidos	35	40	243	45	9	297	345
Tributaries							
Rio Içá	1	5	46	4	5	55	63
Rio Jutaí	0	0.4	5	0	5	10	14
Rio Juruá	22	20	220	12	8	240	270
Rio Japurá	0.4	2	37	2	3	42	55
Rio Purús	0	0.2	141	1	11	153	170
Rio Madeira	143	120	510	179	8	697	771

[1/] Small disagreements (± 1 mg/L) with data in table 2 because values in table 2 were corrected after sand samples were wet sieved.

least in part, from transfer losses that occur when the concentrated sample is scraped out of the centrifuge cylinder with a spatula or the "reject" sample is transferred to a weighing vial (J. I. Hedges, written communication, 1985). However, we are not sure whether these losses are selective of certain size fractions. At this point, the analyses of all particle-size fractions finer than 0.031 mm reported in table 4 need to be considered subject to a possible error of 10 to 20 percent, because the samples used in these analyses were concentrated by the centrifuge.

Laboratory Error

The filter-weighing procedure for determining concentrations finer than 0.063 mm contains several opportunities for error. The determination of the concentration of each filtered subsample depends on four accurate weighings (two tare weights and two final weights) on a microbalance and on one accurate reading of the volume of water filtered. If a mistake is made in recording either the tare weight of the upper paired filter (on which the sediment is eventually collected) or the volume of water filtered, the mistake cannot be discovered or corrected during the final weighing process. Errors in filter weighing were assessed in the same way as the processing errors, by comparing the concentrations determined on the three to four filters from each sample. The filter-weighing error is included in the processing error described above.

Most of the samples of suspended sand listed in table 2 were measured twice. The initial weights were obtained soon after the samples arrived in the Denver laboratory. The second weighing was part of the wet-seive analysis of sand-particle sizes. Because of the inevitable loss of sand grains into the sieve meshes and the floating off of some organic particles, the sum of the sieved weights usually was 2 to 3 percent (rarely more than 5 percent) less than the initial weight. In calculating the concentrations in the different sand-size fractions reported in table 2, the initial sand weights were assumed to be correct and the sieving loss was distributed proportionally.

The laboratory error in the size analyses of the suspended sands probably was small because the sample quantities were fairly large. The sand samples from the mainstem sections usually ranged between 0.2 and 2.0 g, and they were weighed on a microbalance to $\pm$ 0.1 mg--that is, to several more significant digits than were reported in table 2. Less sand was collected from some of the tributaries, but the absolute error involved was small because the sand concentrations were small. The range of laboratory error in the concentrations reported for the different sand fractions in table 2 is probably no more than $\pm$ 2 to 3 mg/L, which is well within the range of the sampling error for sand.

Errors in the particle-size analyses of silt and clay, on the other hand, probably are large. In addition to the unknown error related to probable centrifuge loss, fairly large differences can be related to the techniques used to measure the size distributions. Listed in table 4 are analyses that show differences of about 10 percent between different methods used in the same laboratory or between different laboratories using the same method. Considering these laboratory errors and the uncertainties

involved in concentrating the material in the field by centrifuge, the analyses of sizes finer than 0.031 mm listed in table 4 should be used mostly for internal comparisons and be used for other purposes only with circumspection.

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