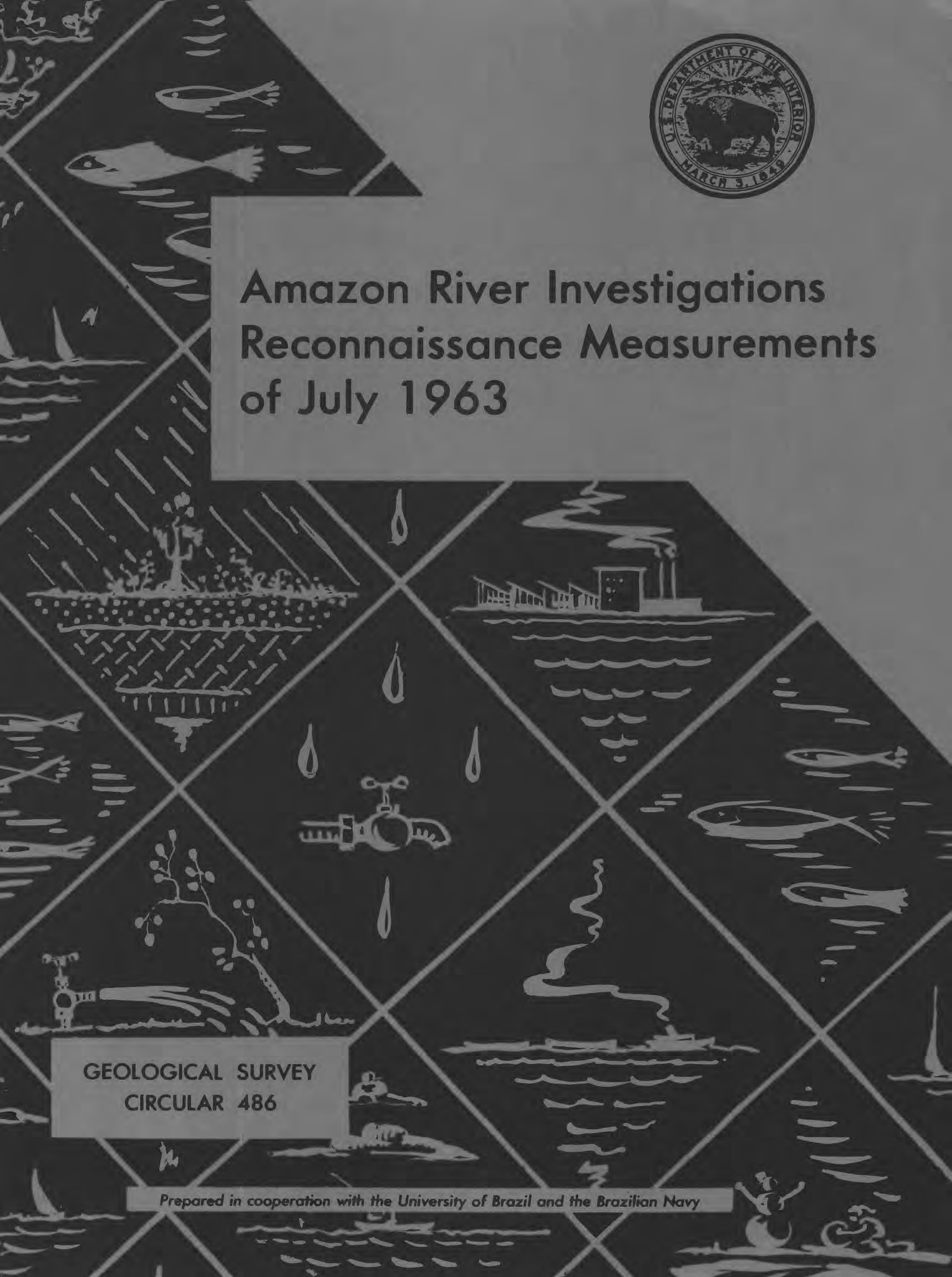

# Amazon River Investigations Reconnaissance Measurements of July 1963

GEOLOGICAL SURVEY
CIRCULAR 486

*Prepared in cooperation with the University of Brazil and the Brazilian Navy*

# Amazon River Investigations Reconnaissance Measurements of July 1963

By R. E. Oltman, H. O'R. Sternberg (University of Brazil),
F. C. Ames, and L. C. Davis, Jr.

GEOLOGICAL SURVEY CIRCULAR 486

*Prepared in cooperation with the University of Brazil and the Brazilian Navy*

*Washington 1964*

**United States Department of the Interior**
STEWART L. UDALL, *Secretary*

**Geological Survey**
William T. Pecora, *Director*

First printing 1964
Second printing 1967

*Free on application to the U.S. Geological Survey, Washington, D.C. 20242*

## CONTENTS



## ILLUSTRATIONS



## TABLES

# Amazon River Investigations Reconnaissance Measurements of July 1963

By R. E. Oltman, H. O'R. Sternberg,[1] F. C. Ames and L. C. Davis, Jr.

**ABSTRACT**

The first measurements of the flow of the Amazon River were made in July 1963 as a joint project of the University of Brazil, the Brazilian Navy, and the U.S. Geological Survey. The discharge of the Amazon River at Obidos was 7,640,000 cfs at an annual flood stage somewhat lower than the average. For comparison the maximum known discharge of the Mississippi River at Vicksburg is about 2,300,000 cfs. Dissolved-solids concentrations and sediment loads of the Amazon River and of several major tributaries were found to be low.

## INTRODUCTION

The discharge of water, solutes, and suspended sediment of the Amazon River (Rio Amazonas) to the Atlantic Ocean is estimated to be a significant part of the total discharge from all the continents to the oceans. Parde (1956, p. 14) reviewed several estimates of the Amazon flow at Obidos and concluded that "the mean ought to exceed 90,000 cubic meters per second (3,178,000 cfs) and possibly 100,000 cubic meters per second (3,531,000 cfs)."

The average annual runoff from the continents to the oceans has been estimated by Durum and others (1960) to be about 40 million cfs (cubic feet per second). Thus at Obidos, the estimated average discharge of the Amazon River, which at that point drains an area of 1,945,000[2] square miles in contrast to the 2,368,000[2] square miles it drains at its mouth, is about 9 percent of the estimated average continental discharge into the oceans. Assuming equal yield from all parts of the basin, the average discharge of the Amazon at its mouth might be as much as 11 percent of the average world runoff to the oceans.

In 1957, the International Association of Scientific Hydrology (IASH) adopted a program of computation of the riverborne dissolved solids carried to the oceans. The studies carried out under that program showed that the lack of data for discharge and dissolved solids of the Amazon River seriously hampered the precision of results. In May 1961, Luna B. Leopold, chief hydrologist of the U.S. Geological Survey, Walter B. Langbein, staff scientist of the U.S. Geological Survey, and Prof. H. O'R. Sternberg, Director, Centro de Pesquisas de Geografia do Brazil, University of Brazil (Rio de Janeiro), jointly proposed a plan for measuring the flow, solute load, and sediment concentration of the Amazon River so that greater refinement in the worldwide analysis of flow and dissolved solids could be attained. In June 1963 arrangements were completed for an Amazon reconnaissance gaging to be conducted as a joint project of the Centro de Pesquisas de Geografia do Brazil, University of Brazil; the U.S. Geological Survey; and the Diretoria de Hidrografia e Navegacao of the Brazilian Navy.

The lower Amazon is little affected by short-period flood events, but has a smooth annual cycle of changing flow. It rises slowly for about 8 months from a minimum in late October or early November to a maximum in June and falls in about 4 months to the next low.

The channel width ranges from about 1 mile in some of the narrower reaches to 2 or 3 miles for long stretches, and up to 5 or 6 miles in some places. The depth ranges from 20 to 40 feet in the north and south channels near the mouth, to more than 300 feet in some of the narrower reaches at least as far upstream as the Rio Madeira. In spite of the tremendous size of the channel, the annual high flow inundates much of the flood plain to

[1] University of Brazil.
[2] From Encyclopedia Britannica, 1960.

depths ranging from a few inches to several feet.

The flood plain is generally very flat and ranges in width from a few hundred feet to many miles. The lower levels of this flood plain are perpetually wet and swampy and contain many large, shallow lakes. These lakes rise and fall with the river through mazes of small streams and distributary channels known as furos and paranas. These lakes and channels store enough water to have a substantial dampening influence on discharge fluctuations and a stabilizing influence on water quality.

The lower parts of several large tributaries to the lower Amazon, notably the Rio Negro, Rio Tapajós and Rio Xingú, are virtually lakes in what appear to be submerged valleys rather than true river channels. The actual mouths of these streams are only a mile or so wide, but the water-surface widths above the mouths range from 5 to 10 miles for distances of 50 to 100 miles. These "lakes" also exert major stabilizing influences on fluctuations of runoff and water quality.

The reconnaissance investigations provided for measurement of water discharge, sediment concentrations, and dissolved-solids concentrations at two locations on the Amazon—Obidos and Manaus. Obidos was a logical selection because stage observations were made there from 1928 to 1947 and because it is at or near the upstream limit of tidal effect.

The waters of the Amazon fork and rejoin enclosing long strings of alluvial islands, which split the stream into a master channel and one or several side channels known as paranás. In the vicinity of Manaus, one such channel is the Paraná do Careiro, which diverges from the main stream just above the mouth of the Rio Negro and rejoins the main stream about 25 miles downvalley. It has been suggested that the Amazon is tending to preempt the bed of the Careiro, increasing the caliber of this channel while progressively abandoning its present course to the north (Moraes, 1926).

The dilation in cross section that the channel of the Careiro would have to undergo in order to carry the entire flow of the Amazon, if this event were ever to occur, would be at the expense of the densely settled strip of land fronting on or contiguous to the Careiro. The problem has been considered by Sternberg (1956), but the lack of any information regarding streamflow and the distribution of sediment load in the area of study prevented a solution.

Arrangements were accordingly made to measure the flow and to collect material for sediment concentration studies in the Manaus-Careiro area under more favorable conditions than those under which Sternberg (1956, p. 48) obtained some 20 concentration figures with the use of improved equipment in 1948 and 1950, in the "black," sediment-poor waters of the Negro and the "white" silt-bearing waters of the Amazon and the Careiro.

In July 1963 the first measurements were made at high flow of discharge, dissolved-solids concentrations, and sediment loads. Because of the worldwide interest in the Amazon the results of the first measurements are being made available in this report before the second (low-flow) series of measurements, started in October 1963, are analyzed. A complete analysis of the results of the reconnaissance program will be reported later.

The essential information collected during July 1963 and comments helpful in understanding the methods of data collection are presented in sections following "Acknowledgments." The section "Procedures for measuring discharge" contains a description of the general methods and the detailed procedure followed. A similar section, "Procedures for observing water quality," is provided. Results of discharge measurements and water-quality observations are given in separate sections.

## ACKNOWLEDGMENTS

The Amazon measurements could not have been made without the cooperation of the Brazilian Navy. The key role of Vice Adm. Helio Garnier Sampaio, Diretoria de Hidrografia e Navegacao, Ministerio da Marinha, in arranging for the use of the corvette *Mearim* and the assignment of Lt. Comdr. Almir Dantas (an expert hydrographer and English-Portugese interpreter) to the project is gratefully acknowledged. Dr. Fernando Andrade, Professor Sternberg's assistant, arranged important conferences with several Brazilian government officials who furnished information on gage locations, gage records, and charts of the Manaus region. Doctor Carvalho, Vice President of the Conselho Nacional Pesquisos, was most helpful in furnishing advice about Amazon River conditions based on personal knowledge gained from 12 earlier expeditions to the Manaus region. Alfred Bodenlos, chief of the U.S. Geological Survey party in Brazil (U.S. AID Mission), was instrumental in arranging many contacts with key Brazilian officials and in getting needed scientific materials. The Office of Naval Research, U.S. Navy, furnished transportation on Military Air Transport Service from Charleston, N.C., to Rio de Janiero and return for the four-man Geological Survey gaging team. The officers and men of the corvette *Mearim* under the command of Lt. Comdr. Milton Carvalho are commended for the extremely efficient handling of the ship during the tedious stream observations. Walter Langbein of the U.S. Geological Survey was a key man in initial negotiations to start the project and in seeing that it was consummated.

## PROCEDURES FOR MEASURING DISCHARGE

Measurement of discharge followed the standard procedures in use by the Geological Survey in the domestic program. Point-velocity observations were made with a Price AA current meter suspended forward of the ship's bow from an 1/8-inch diameter two-conductor cable and located 1 foot above the bottom of a streamlined 300-pound lead sounding weight. A calibrated electric-powered winch of 2½-foot drum circumference was used to raise and lower the meter for soundings and for meter settings. Angular departure of the cable from vertical was measured by an indicator applied to the suspension cable at the pulley located at the outboard end of the horizontal-winch support. The vertical-angle observations were used to calculate the true sounded depth, which was compared with depths recorded by the ship's fathometer or a portable fathometer.

Distance from the initial point on right or left bank was measured with tellurometer equipment under the direct supervision of G. R. Staeffler, U.S. Geological Survey. The master tellurometer was set up on the foredeck of the corvette immediately astern of the sounding winch. The remote tellurometer was set on the most favorable bank at the end of the cross section chosen for observations. An auxiliary tellurometer circuit permitted communication between operators of the master and remote tellurometers. A theodolite placed next to the remote tellurometer was used to measure any upstream or downstream movement of the ship during velocity observations in case the ship could not be held exactly on the cross section. The theodolite operator relayed angle observations to the note keeper aboard ship through a two-way portable voice radio. A portable fathometer recorded soundings during the measurement to supplement those taken by the ship's fathometer, and by the cable-weight suspension.

The step-by-step procedure in measurement of discharge was as follows:

1. The best cross section available in a long reach of river adjacent to the gage site was selected on the basis of combined uniformity of section bed profile and alinement of surface velocities normal to the section. The ship's fathometer was used for sounding the many cross sections considered.

2. Remote tellurometer and theodolite were set on the most favorable bank at the end of the chosen cross section.

3. The ship was brought to the desired location of first vertical on cross section by using required rudder and propellor settings. The ship's gyrocompass with auxiliary sighting telescope was used to place the ship on section.

4. When the ship had stabilized on section at first vertical, tellurometer reading of distance from remote instrument was taken and observations of any lateral movement from first vertical were continued while sounding and metering velocities in vertical.

5. Soundings were taken with the meter-weight suspension and checked with portable fathometer.

6. If vertical angle of the sounding line was significant, it was used to correct the sounding taken with meter-weight suspension.

7. Meter was set at 80 percent of water depth from water surface.

8. At given signal, counting of meter revolutions, theodolite observation of upstream or downstream movement of meter suspension,

and tellurometer observations of the lateral position of ship parallel to cross section were started.

9. Meter revolutions were counted for more than 40 seconds.

10. At signal from meter-revolutions counter, observations of upstream-downstream and lateral movements were stopped at exact end of velocity observation.

11. Meter was raised to 20 percent of depth and theodolite-tellurometer observations were repeated during observation of velocity at that point.

12. Ship proceeded to second vertical on cross section and the tellurometer observer furnished the approximate distance of lateral movement.

13. The types of measurements made at the first vertical were repeated at second vertical.

14. Process was continued until entire cross section was traversed, during the course of which, measurements were made at 20 to 24 verticals.

15. Observed velocity at each point in cross section was adjusted by vector analysis for the movement of ship during observation.

16. Discharge measurement was computed.

## RESULTS OF DISCHARGE MEASUREMENTS

Figure 1 shows the general location of the measuring sections near Obidos and Manaus. Figure 2 is a large scale map showing the locations of the Manaus gage and the measuring sections in the vicinity of Manaus. For the measurements on the Rio Negro and the Paraná do Careiro, a Brazilian Army launch was used in place of the corvette *Mearim*, which could not easily be held on station owing to the prevailing velocity of flow. A small channel, the Paraná do Autaz-Miri, which carries an insignificant part of the total flow of the Rio Solimões, was not measured because of difficulty of access. Results of all discharge measurements are summarized in table 1.

The soundings and mean measured velocity in the vertical at sounding locations for each measurement are plotted in figure 3. The detailed variation of velocity with depth was measured near the middle of the Obidos cross section and at two verticals in the cross section of the Amazon near Manaus. Of those two verticals, one (Sta. 4740) is representative of the Rio Solimões water, and the other (Sta. 1810) of the Rio Negro water. The observed data are listed in table 2. Point velocities were observed for 40 to 50 seconds. The effect of pulsations is noticeable in the scatter of velocities about any curve one may try fitting to the data.

The July 1963 measurement of the Amazon near Manaus (A) was made at stage 26.46 meters on the staff gage on the Rio Negro in Manaus. Because the slope of water surface of the Amazon is so small (a total fall of 65 meters in the 3,000 kilometers from the Peruvian border to the sea has been reported by Soares in 1956), the water stage observed at the Manaus gage is valid for the Amazon River below the junction of the Rio Negro and the Rio Solimões. How does the stage of 26.46 meters compare with the 1963 crest and other annual crests? The 1963 crest stage of 27.31 meters occurred June 17 to 19. Average-stage hydrographs by decades for the period 1903–52 in comparison with the stage hydrograph of the outstanding flood year of 1953 are shown in figure 4 for the Manaus gage. The great regularity of seasonal flows is readily apparent. In the period 1902–53, the highest annual stage, 29.70 meters, occurred June 6, 1953 and the lowest annual flood stage, 21.77 meters, occurred July 5–7, 1926. The 1963 crest of 27.31 meters is seen by reference to figure 4 to be nearly equal to the average maximum stage (27.4 meters) for the period 1903–52.

Comparison of the Obidos measured discharge with pertinent data for the Mississippi at Vicksburg, Miss., the most downstream gaging station on North America's largest river, indicates the relative magnitude of the Amazon River flow.

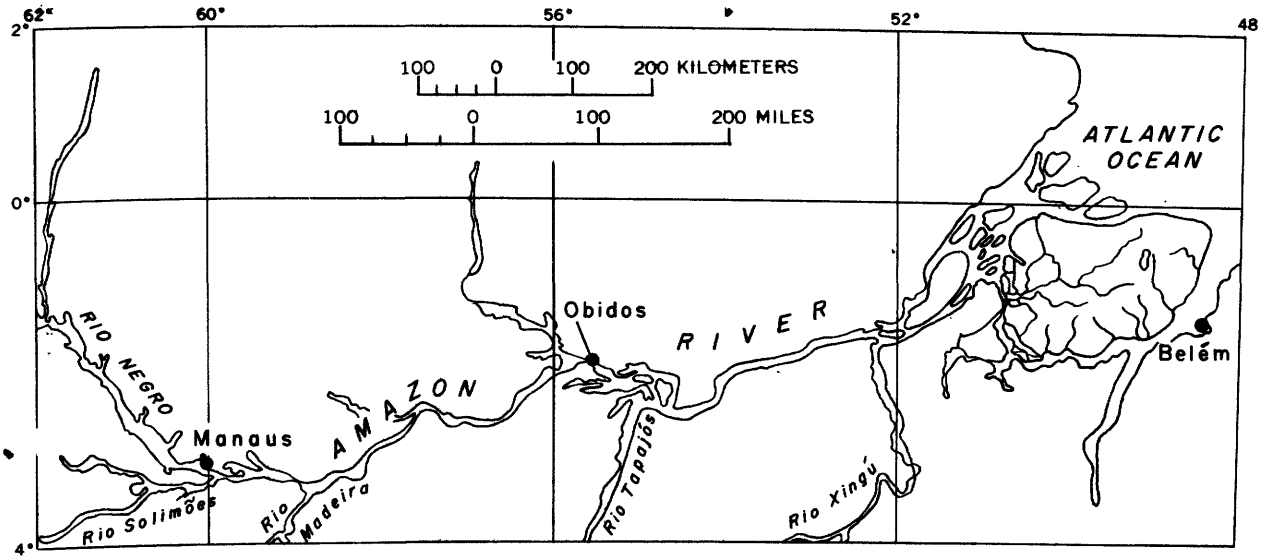


Figure 1.—Map showing the reach in which observations were made.

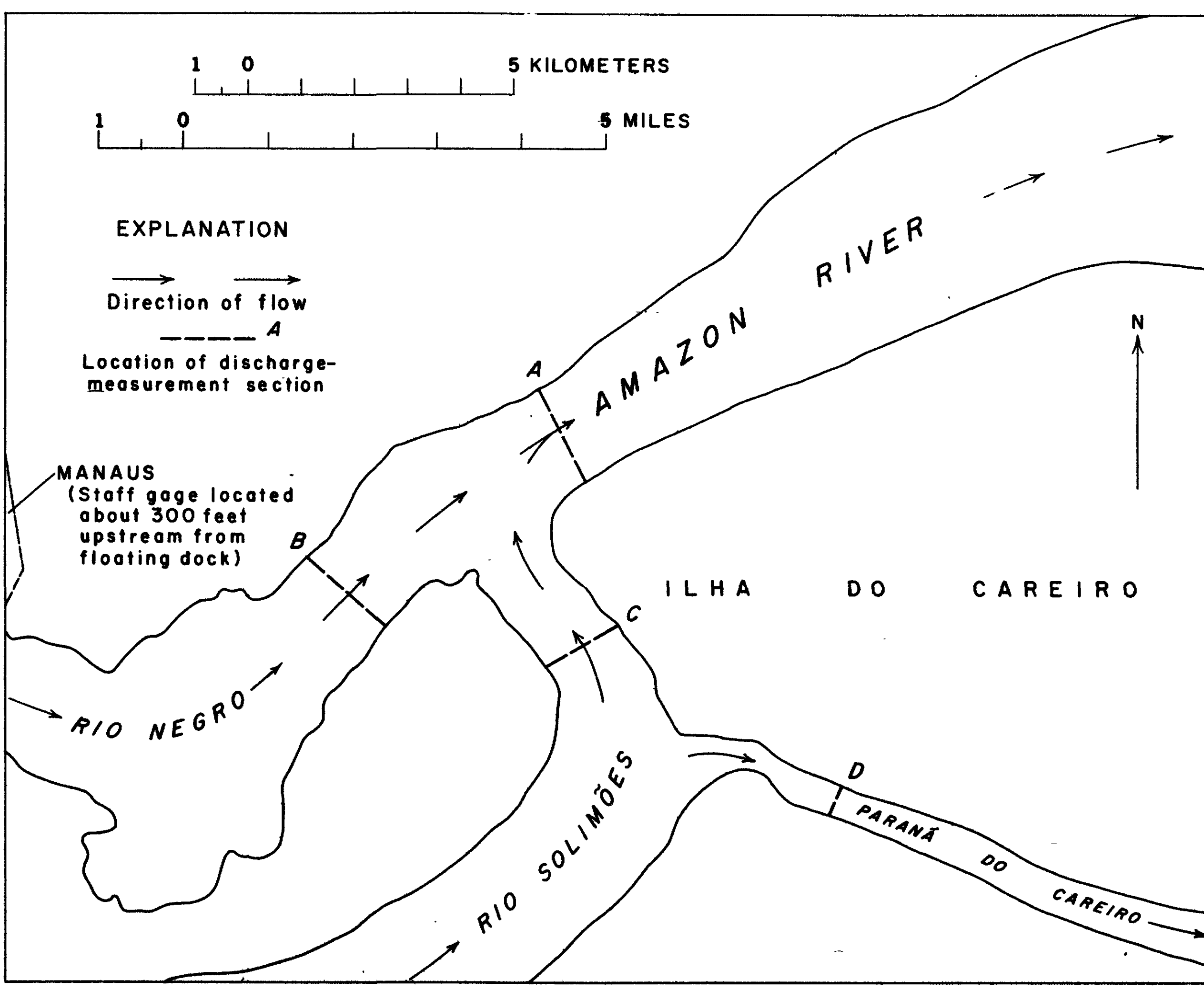


Figure 2.—Map showing location of measuring sections in vicinity of Manaus.

Table 1.— *Summary of measurements of the Amazon River and tributaries*

| Stream | Location (Letter designates location on fig. 2) | Date | Stage[1](m) | Section properties | | | Discharge (cfs)— | |
|---|---|---|---|---|---|---|---|---|
| | | | | Width (ft) | Area ($10^3ft^2$) | Mean velocity (fps) | Measured | Total |
| | | 1963 | | | | | | |
| Amazon River | Near Obidos | July 16 | 5.8 | 7,500 | 1,184 | 6.45 | 7,640,000 | --------- |
| Do | Near Manaus (A) | 20 | 26.46 | 6,880 | 922 | 5.72 | 5,260,000 | --------- |
| Parana do Careiro. | (D) | 22 | 26.35 | 2,240 | 160 | 4.43 | 710,000 | --------- |
| Rio Negro | (B) | 22 | 26.34 | 7,730 | 890 | 2.65 | 2,360,000 | --------- |
| Rio Solimões | (C) | 23 | 26.29 | 5,920 | 746 | 3.98 | 2,970,000 | --------- |
| Amazon River | Below Manaus(A+D) | ------- | --------- | ----- | ------ | -------- | --------- | 5,970,000 |
| Rio Solimões | Near Manaus (C+D) | ------- | --------- | ----- | ------ | -------- | --------- | 3,680,000 |

[1]Obidos gage destroyed in 1953. Stage recovered approximately from levels based on gage datum scaled from photograph of original gage against background of building still in place in July 1963. Manaus gage readings used for Amazon, Negro, Solimões, and Paraná do Careiro measurements. The Manaus gage is tied in with an arbitarary bench mark = 100.000 m, set in the steps of the Municipal Prefecture; gage readings are usually referred to sea level, on the basis of a mark on the steps leading to the Parish Church (Matriz), which is assumed to lie at an altitude of 35.874 m, according to observations made many years ago under the direction of Samuel Pereira, an engineer in charge of the Manaus Sanitation Comm. Whereas such an altitude cannot by any means be considered to be a precise datum point, observations may be provisionally referred to it.

Table 2.—*Variation of velocity in vertical*

| Obidos | | Manaus (Sta. 1810) | | Manaus (Sta. 4740) | |
|---|---|---|---|---|---|
| Depth of observation (ft) | Velocity (fps) | Depth of observation (ft) | Velocity (fps) | Depth of observation (ft) | Velocity (fps) |
| 2 | 7.44 | 3 | 7.18 | 3 | 7.41 |
| 17 | 7.53 | 14 | 7.17 | 20 | 7.36 |
| 35 | 7.62 | 29 | 7.35 | 41 | 6.26 |
| 52 | 7.62 | 43 | 7.02 | 62 | 6.16 |
| 71 | 7.28 | 57 | 7.68 | 83 | 6.39 |
| 87 | 7.62 | 71 | 7.21 | 101 | 7.53 |
| 104 | 6.97 | 81 | 7.19 | 121 | 6.97 |
| 117 | 7.28 | 93 | 6.55 | 142 | 5.64 |
| 133 | 5.96 | 106 | 6.52 | 158 | 5.35 |
| 150 | 6.07 | 119 | 6.92 | 179 | 6.20 |
| 160 | 3.74 | 133 | 6.18 | 194 | 4.32 |
| Bottom at 171 | | Bottom at 147 | | Bottom at 198 | |

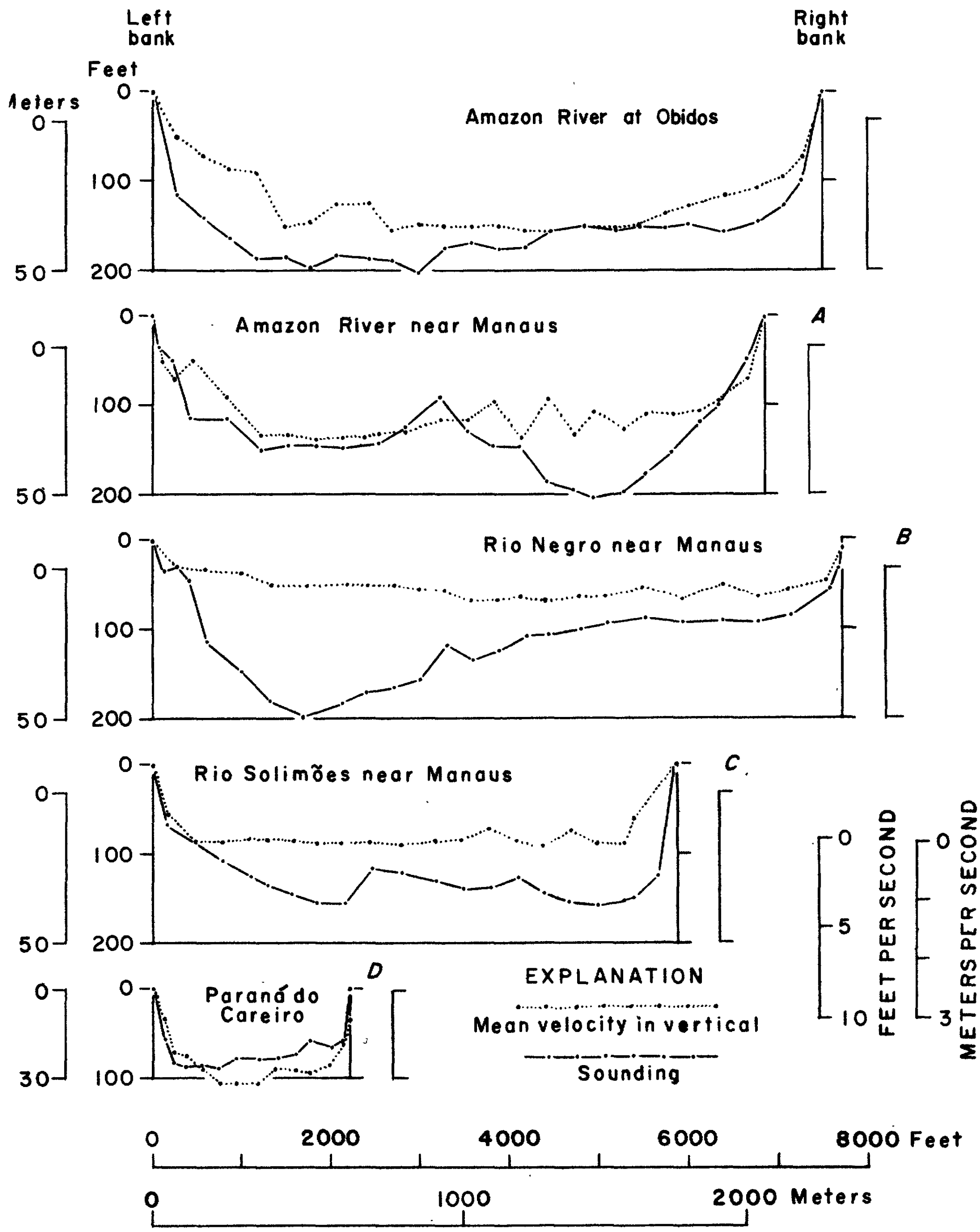


**Figure 3.—Cross sections and mean velocity in verticals at measuring sites.**

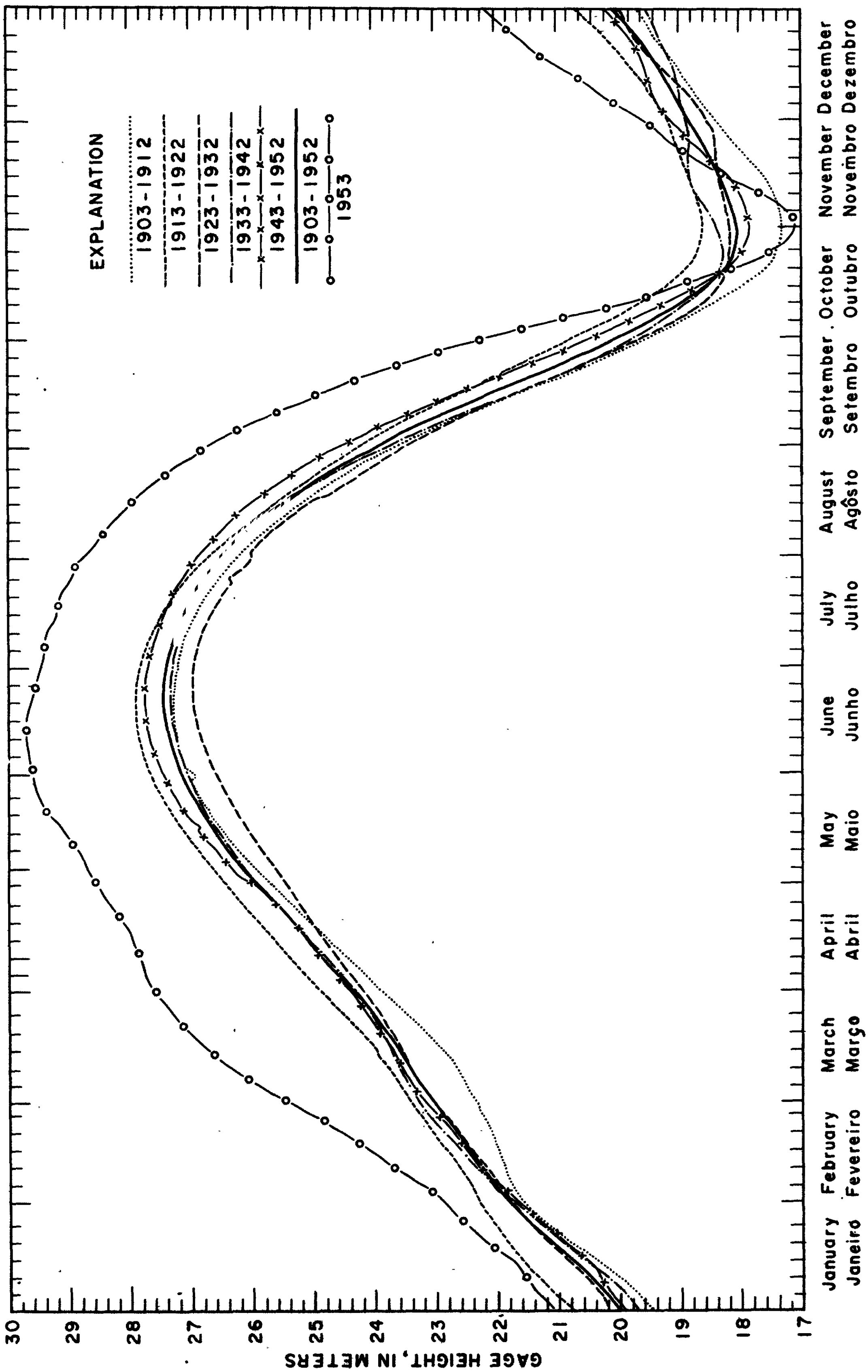


Figure 4.—Daily river stages at Manaus for the period 1903–52 by decades, and for the year 1953.

*Mississippi River at Vicksburg, Miss.*

| | |
|---|---|
| Drainage area ........................ | 1,144,500 sq mi |
| Max. known discharge (approx) and date. | 2,300,000 cfs...May 1927 |
| Avg. discharge (33 yr) ............ | 560,200 cfs |

*Amazon River at Obidos*

| | |
|---|---|
| Drainage area ........................ | 1,945,000 sq mi |
| Measured discharge and date ..... | 7,600,000 cfs..July 16, 1963 |
| Probable max. discharge (approx) and year. | 10,000,000 cfs..1953 |

## PROCEDURES FOR OBSERVING WATER QUALITY

Water-quality data were obtained to supply reconnaissance-type information on: (1) The magnitude of dissolved solids and suspended-sediment concentrations and loads carried by the lower Amazon; (2) variations in these factors along the river; and (3) possible thermal or salinity stratification.

Data were obtained in the 700-mile reach of river from the junction of the Rio Negro with the Rio Solimões (Amazon River) near Manaus to long 52° W., where the river divides into two main outlet channels; along the south channel to the Ilha Maritiapina, thence along a series of "estreitos" (inlets) to the Rio Para, and along that river to Belém. Observations were made from the Brazilian corvette *Mearim* as the ship traveled upstream July 10–18 and downstream July 26–29. Samples for field observations were taken at or near the water surface at intervals along the main channel, in the mouths of the Rio Tapajós and Rio Madeira, and at various depths at the cross sections where discharge measurements were made near Obidos and near Manaus. Samples for detailed chemical analyses were taken at or near the surface at the measuring sections near Obidos and near Manaus and in the mouths of the Rio Tapajós and Rio Madeira. Suspended-sediment samples were taken at several depths at the measuring cross sections, and bed-material samples were taken at the same sections.

The chemical-quality samples at the surface were taken in an open container suspended near the bow of the ship. Most of these samples were collected while the ship was moving at speeds of 5 to 13 knots. The chemical-quality samples at depth were taken in an oceanographic sampler consisting of an open tube allowing through flow of water until closed at the desired depth by sponge rubber, ball-type valves. Suspended-sediment samples were taken in 1 pint containers in a U.S. P-61 suspended-sediment sampler with a 3/16-inch diameter nozzle. This sampler is the point-integrating type, with an electrically operated valve opened only at the desired depth and held open only long enough to collect 300 to 400 cubic centimeters of sample. Bed-material samples were taken with an oceanographic clamshell type bottom sampler. Temperature-depth profiles were obtained with a bathythermograph.

All the devices for obtaining data at depth were suspended from the bow of the ship with the same cable and reel equipment used for the discharge measurements.

The field observations included direct readings of temperature, specific conductance, and pH, plus titrations for alkalinity and dissolved oxygen. These observations are tabulated along with companion observations of air temperatures and altimeter readings.

Water temperatures were measured with a mercury thermometer graduated in degrees Fahrenheit, and (or) from the trace produced on a glass slide in the bathythermograph. Specific conductance was read on a portable conductivity meter with a manual temperature compensator and a platinum electrode-conductivity cell having a constant of 0.10. Readings of pH were made on a portable pH meter (Beckman Model N) with standard electrodes. Frequent checks were made using standard buffer solutions at pH 7.0 and pH 4.0. Titrations to determine alkalinity and dissolved oxygen were performed according to standard methods used by the Geological Survey (described in Water-Supply Paper 1454).

Laboratory analyses of samples, to be conducted in the future, will include determination of concentrations of the common major dissolved constituents, the presence and concentration of several minor elements, and of gross radioactivity; in addition, radium and uranium contents will be determined, if possible. Suspended-sediment samples will be analysed for sediment concentration. The concentrations of suspended sediment that have already been obtained were less than anticipated, and it was not feasible to concentrate or to ship the large volumes of sample that would have been required to provide sufficient sediment for analyses of particle-size distributions and mineralogy. None of the samples have arrived at the laboratory as of this writing (October 1963); results of analyses will be included in a subsequent report.

## RESULTS OF WATER-QUALITY OBSERVATIONS

Various reports on the Amazon indicate that the exposed rocks of the headwater areas are quite resistant to chemical weathering, and that the soils of the high-rainfall areas have been almost completely leached of readily soluble minerals. As a result, a low dissolved-solids concentration is to be expected at all discharges. This was found to be true from the high-flow observations made during July 1963. The specific conductance (in micromhos per centimeter) ranged from 52.8 at the mouth of the Rio Solimões to only 9 in the Rio Negro at Manaus. (See table 3.)

The waters of the two streams flow side by side for many miles in the common channel below the junction, and mix very slowly. At the high discharge observed in July, the Rio Negro water was virtually sediment free but was colored almost black by organic material, whereas the Rio Solimoes water was quite turbid and gray brown or yellow brown in color. Thus, the degree of mixing at the surface was readily discernible. A distinct though irregular and fluctuating interface between the two waters persisted for at least 12 miles below the junction. For several miles beyond this reach, the surface of the intermingling had a mottled appearance, and the sizes of the patches decreased rapidly downstream. Where mixing was fairly well advanced, the turbidity had a curdled or stippled appearance, indicating some reaction between the two waters and some flocculation of the fine sediments. Specific conductance and pH readings indicate that mixing was not entirely uniform for at least 70 miles below the junction.

In the absence of chemical or ion-exchange reactions between two dissimilar streams, the proportionality of specific conductance in each stream to specific conductance of a uniform mixture of the two would be the same as the proportionality of discharge. For the Rio Negro-Rio Solimões, the proportions based on conductivity would be $9N + 52S = 40(N+S)$ or 72 percent Solimões water and 28 percent Negro water. Discharge measurements showed that the actual proportions were 3.0 and 2.4 to 5.3, or 57 percent Solimões and 43 percent Negro water. This lack of agreement substantiates the visual evidence of some reaction between the two waters.

Some reaction is expectable in view of the differences in pH. The pH of the Solimões water was about 6.6, of the Negro about 5.0, and of the mixture about 6.4. The higher acidity of the Negro water is buffered to some extent by the Solimões water and also causes some desorption, or possibly some solution, of the sediment in the Solimões.

The Rio Madeira was passed in the night on both the upriver and downriver trip, making it impossible to observe comparative color or turbidity. However, specific conductance and pH were somewhat higher in the Rio Madeira just above its mouth than in the Amazon River above and below (52 and 6.9 compared with 40 and 6.4). Differences in specific conductance of the Amazon above and below the Madeira were no greater than the general range of variation from point to point, making it impossible to evaluate probable flow of the Madeira.

Observations in and below the Rio Tapajós may indicate an appreciable flow in that stream. The Rio Tapajós was virtually clear; the color was the characteristic deep blue of clear fresh water. A secki disc was visible to a depth of 20 feet. A zone of clear water was visible along the south side of the Amazon for 5 or 6 miles below the mouth of the Tapajós, and incomplete mixing was evident for several more miles. Temperature of the Rio Tapajós on the afternoon of July 13 was about 4°F higher than that of the Amazon; the difference was due to solar heating on the large lake above the mouth.

The pH (7.15) of the Tapajós water was slightly above neutral and the pH (about 6.5) of the Amazon water from both above and below the Tapajos was slightly below neutral. On the basis of this evidence, little reaction would be expected between the two waters. The specific conductance of the Tapajós water was 15.0; that of the Amazon water from above and below the Tapajós was 40.5 and 39.5. This difference is too small to permit placing much reliance on a computation of discharge in the Tapajós, but taken at face value it indicates a discharge equal to 4 or 5 percent of the Amazon, or 0.3 or 0.4 million cfs on the basis of 7.6 million cfs

Table 3.—*Water-quality observations, Amazon River, Brazil*

| Day (July 1963) | Time | Location | | Water | | | | | Air | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Lat S. | Long W. | Temperature (°F) | Specific conductance (micromhos at 25°C | pH | Bicarbonate (ppm) | Dissolved oxygen (ppm) | Temperature (°F) Dry bulb | Temperature (°F) Wet bulb | Relative humidity (percent) | Altimeter reading [1] (ft) |
| | | | | **Baia de Guajara** | | | | | | | | |
| 10 | 1000 | 1°24' | 48°30' | 84.0 | 33 | ---- | ---- | ---- | 81 | ---- | ---- | 1,010 |
| | 1145 | 1°09' | 48°30' | 85.5 | ---- | ---- | ---- | ---- | 83 | ---- | ---- | 1,020 |
| | | | | **Rio Para** | | | | | | | | |
| 10 | 1220 | 1°09' | 48°34' | 86.0 | ---- | ---- | ---- | ---- | 84 | ---- | ---- | 1,022 |
| | 1320 | 1°23' | 48°43' | 85.0 | 38 | ---- | ---- | ---- | 84 | 76 | 70 | 1,045 |
| | 1450 | 1°36' | 49°07' | 86.0 | 37 | 7.0 | ---- | ---- | 85 | 76 | 66 | 1,070 |
| | 1630 | 1°46' | 49°36' | 85.5 | 35.0 | ---- | ---- | ---- | 86.5 | 76.5 | 64 | 1,090 |
| | 1930 | 1°50' | 50°09' | 85.0 | 35.0 | 6.7 | ---- | ---- | ---- | ---- | ---- | 1,070 |
| 11 | 0600 | 1°50' | 50°09' | 83.0 | 35.0 | ---- | ---- | ---- | 78.0 | 77.5 | 98 | 1,020 |
| | | | | **Estraito de Boiucu** | | | | | | | | |
| 11 | 0800 | 1°47' | 50°28' | 83.0 | 37.0 | 6.65 | ---- | ---- | 78.0 | 75.5 | 89 | 1,020 |
| | | | | **Furo do Tajapuru** | | | | | | | | |
| 11 | 1100 | 1°21' | 50°49' | 83.0 | 38.0 | 6.70 | ---- | ---- | 84.0 | 75.0 | 66 | 1,000 |
| | 1140 | 1°11' | 50°51' | 83.0 | 37.5 | ---- | ---- | ---- | ---- | ---- | ---- | 1,000 |
| | | | | **Furo do Ituquara** | | | | | | | | |
| 11 | 1300 | 1°02' | 51°03' | 83.5 | 37.8 | 6.55 | ---- | ---- | ---- | ---- | ---- | 1,020 |
| | | | | **Amazon River (south channel)** | | | | | | | | |
| 11 | 1430 | 1°10' | 51°14' | 83.0 | 37.0 | 6.60 | ---- | ---- | ---- | ---- | ---- | 1,045 |
| | 1600 | 1°19' | 51°27' | 84.0 | 37.2 | 6.60 | ---- | ---- | 87 | 75 | 58 | 1,070 |
| | 2200 | 1°29' | 51°55' | 82.5 | 39.0 | ---- | ---- | ---- | ---- | ---- | ---- | ---- |
| 12 | 0600 | 1°29' | 51°55' | 82.5 | 39.0 | ---- | ---- | ---- | 76.0 | 75.0 | 95 | ---- |
| | | | | **Amazon River** | | | | | | | | |
| 12 | 0800 | 1°26' | 52°06' | 82.5 | 39.0 | 6.40 | ---- | ---- | 77.0 | 75.5 | 93 | 1,000 |
| | 1000 | 1°34' | 52°24' | 82.8 | 39.5 | ---- | ---- | ---- | 80.5 | 76.0 | 82 | 970 |
| | 1200 | 1°35' | 52°42' | 83.0 | 39.5 | 6.45 | ---- | ---- | 82.0 | 76.0 | 76 | 982 |
| | 1700 | 1°49' | 53°27' | 83.0 | 39.5 | 6.50 | ---- | ---- | 84 | 76.5 | 71 | 1,060 |
| 13 | 0600 | 1°59' | [2]53°55' | 82.0 | 39.8 | ---- | ---- | ---- | 77.0 | 75.0 | 91 | ---- |
| | 0800 | 2°15' | 54°03' | 82.2 | 39.8 | 6.50 | ---- | ---- | ---- | ---- | ---- | 1,005 |
| | 1000 | 2°25' | 54°18' | 82.5 | 39.5 | 6.55 | ---- | ---- | 82.0 | 74.0 | 68 | 990 |
| | 1200 | 2°28' | 54°38' | 83.0 | 35.5 | 6.50 | ---- | ---- | 84 | 76 | 69 | 1,008 |
| | 1230 | 2°25' | 54°42' | ---- | 28.5 | 6.55 | ---- | ---- | ---- | ---- | ---- | ---- |

Table 3.—*Water-quality observations, Amazon River, Brazil*—Continued

| Day (July 1963) | Time | Location | | Water | | | | | Air | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Lat S. | Long W. | Temperature (°F) | Specific conductance (micromhos at 25°C | pH | Bicarbonate (ppm) | Dissolved oxygen (ppm) | Temperature (°F) Dry bulb | Temperature (°F) Wet bulb | Relative humidity (percent) | Altimeter reading[1] (ft) |
| | | | | | | | **Rio Tapajós** | | | | | |
| 13-- | 1300 | 2°25' | [3]54°45' | 86.0 | 15.0 | 6.90 | ------ | ------ | ---- | ---- | -------- | 1,020 |
| | 1300 | 2°25' | [4]54°45' | 86.0 | 17.0 | 7.10 | ------ | ------ | ---- | ---- | -------- | 1,020 |
| | 2000 | 2°25' | 54°43' | 86.0 | 15.0 | 7.15 | ------ | 7.7 | 81.0 | 73.0 | 68 | 1,050 |
| 14-- | 0600 | 2°25' | 54°43' | 85.0 | 15.0 | 7.15 | ------ | ------ | ---- | ---- | -------- | 1,045 |
| | | | | | | | **Amazon River** | | | | | |
| 14-- | 0800 | 2°21' | 54°44' | 82.0 | 40.5 | 6.45 | ------ | 7.0 | 79 | 75 | 82 | 1,040 |
| | 1000 | 2°09' | 54°54' | 82.+ | 40.2 | 6.50 | 14.1 | 5.6 | ---- | ---- | -------- | 1,020 |
| | 1200 | 2°07' | 55°15' | 82.+ | 40.5 | 6.45 | ------ | ------ | 82 | 75 | 72 | 1,030 |
| | 1400 | 1°58' | 55°23' | 82.5 | [5]37.5 | 6.60 | 16.0 | 6.0 | 83.5 | 76.0 | 71 | 1,070 |
| 15-- | 0600 | 1°54' | [6]55°32' | 82.0 | 37.0 | 6.52 | ------ | 5.5 | 73.5 | 71.5 | 90 | 1,070 |
| | 1300 | 1°55' | 55°31' | | | | | | | | | |
| | | (Measurement cross section.) | | | | | | | | | | |
| | | Sta. 7,400 depth, 68 ft. | | | | | | | | | | |
| | | At 3-ft depth | | 83.0 | 37.5 | ---- | ------ | ------ | ---- | ---- | -------- | -------- |
| | | At 65-ft depth | | 83.0 | 39.5 | ---- | ------ | ------ | ---- | ---- | -------- | -------- |
| | | Sta. 4,000,depth, 175 ft. | | | | | | | | | | |
| | | At 10-ft depth | | 83.0 | 37.5 | 6.55 | 17.0 | 6.0 | ---- | ---- | -------- | -------- |
| | | At 50-ft depth | | 83.0 | 38.5 | 6.55 | 18.4 | 5.8 | ---- | ---- | -------- | -------- |
| | | Sta. 2,000,depth, 155 ft. | | | | | | | | | | |
| | | At 10-ft depth | | 83.0 | 37.5 | 6.55 | 17.3 | 5.8 | ---- | ---- | -------- | -------- |
| | 1700 | At 50-ft depth | | 83.0 | 39.0 | 6.55 | 18.2 | 5.8 | ---- | ---- | -------- | -------- |
| 17-- | 1330 | 2°35' | [2]57°17' | 82.0 | 42.5 | 6.4 | 15.6 | 6.0 | ---- | ---- | -------- | -------- |
| | 1930 | 2°50' | [2]58°00' | 82.0 | 45.0 | 6.34 | ------ | ------ | 82 | 76 | 76 | 1,060 |
| 18-- | 0600 | 3°21' | [2]58°48' | 82.0 | 35.5 | 6.40 | ------ | ------ | 77.2 | 73.8 | 85 | 1,070 |
| | 1200 | 3°04' | [7]59°45' | 82.5 | 13.5 | 5.60 | ------ | ------ | 81.5 | 76.0 | 78 | 1,060 |
| | 1215 | 3°04' | [8]59°46' | 82.0 | 51.5 | 6.37 | ------ | ------ | ---- | ---- | -------- | 1,060 |
| | | | | | | | **Rio Negro** | | | | | |
| 18-- | 1430 | 3°09' | [9]60°01' | 83.0 | 9.0 | 4.95 | ------ | ------ | ---- | ---- | -------- | 1,130 |
| 20-- | 1330 | 3°09' | 60°01' | 83.0 | 9.5 | 4.9 | ------ | 5.5 | ---- | ---- | -------- | -------- |
| | | | | | | | **Amazon River** | | | | | |
| 20-- | 1630 | 3°08' | 59°54' | | | | | | | | | |
| | | (Measurement cross section.) | | | | | | | | | | |
| | | Sta. 4,800,depth, 194 ft. | | | | | | | | | | |
| | | At 10-ft depth | | 83.5 | 52.5 | 6.55 | 24.0 | 5.3 | ---- | ---- | -------- | -------- |
| | | At 100-ft depth | | 83.0 | 52.5 | 6.60 | 24.7 | 5.8 | ---- | ---- | -------- | -------- |

Table 3.—*Water-quality observations, Amazon River, Brazil*—Continued

| Day (July 1963) | Time | Location: Lat S. | Location: Long W. | Water: Temperature (°F) | Water: Specific conductance (micromhos at 25°C) | Water: pH | Water: Bicarbonate (ppm) | Water: Dissolved oxygen (ppm) | Air: Temperature (°F) Dry bulb | Air: Temperature (°F) Wet bulb | Air: Relative humidity (percent) | Air: Altimeter reading[1] (ft) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **Amazon River—Continued** | | | | | | | | | | |
| 20-- | 1630 | Sta. 1,700, depth, 148 ft. | | | | | | | | | | |
| | 1700 | At 10-ft depth | | 83.5 | 10.0 | 5.10 | ------ | 5.2 | ---- | ---- | -------- | -------- |
| | | At 70-ft depth | | 83.0 | 9.0 | 5.12 | ------ | 5.8 | ---- | ---- | -------- | -------- |
| | | At 140-ft depth | | 83.0 | 9.0 | ---- | ------ | 6.2 | ---- | ---- | -------- | -------- |
| | | **Paraná do Careiro** | | | | | | | | | | |
| 22-- | 1200 | 3°13' | 59°50' | | | | | | | | | |
| | | (Measurement cross section; center of channel, depth, 80 ft.) | | | | | | | | | | |
| | | At 10-ft depth | | 83.0 | 50.2 | 6.65 | ------ | ------ | ---- | ---- | -------- | -------- |
| | | At 60-ft depth | | 84.0 | 50.2 | 6.65 | ------ | ------ | ---- | ---- | -------- | -------- |
| | | At 77-ft depth | | 84.0 | 50.2 | 6.65 | ------ | ------ | ---- | ---- | -------- | -------- |
| | | **Rio Solimões** | | | | | | | | | | |
| 23-- | 1630 | 3°11' | 59°54' | | | | | | | | | |
| | | (Measurement cross section.) Sta. 4,000, depth, 150 ft. | | | | | | | | | | |
| | | At 10-ft depth | | 83.0 | 52.8 | 6.70 | 26.5 | 6.0 | ---- | ---- | -------- | -------- |
| | | At 50-ft depth | | 83.2 | 52.8 | 6.65 | ------ | 6.0 | ---- | ---- | -------- | -------- |
| | | **Rio Negro** | | | | | | | | | | |
| 26-- | 1520 | 3°09' | [9]60°01' | 83.0 | 9.0 | 4.80 | ------ | 5.4 | ---- | ---- | -------- | -------- |
| | 1550 | 3°10' | 59°56' | 83.0 | 9.0 | 5.00 | ------ | 5.4 | ---- | ---- | -------- | -------- |
| | | **Amazon River** | | | | | | | | | | |
| 26-- | 1610 | 2°08' | [10]59°54' | 83.0 | 12.0 | 5.50 | ------ | ------ | ---- | ---- | -------- | -------- |
| | 1630 | 3°04' | [11]59°47' | 83 | 38.0 | 6.20 | ------ | ------ | ---- | ---- | -------- | -------- |
| | 1700 | 3°06' | 59°38' | 82.5 | 21.0 | [12]6.00 | ------ | ------ | ---- | ---- | -------- | -------- |
| | 1815 | 3°14' | 59°17' | 82.2 | 52.0 | 6.50 | ------ | ------ | ---- | ---- | -------- | -------- |
| | 1930 | 3°16' | 58°58' | 82.2 | 39.5 | 6.35 | ------ | ------ | ---- | ---- | -------- | -------- |
| | | **Rio Madeira** | | | | | | | | | | |
| 26-- | 2030 | 3°24' | 58°46' | 84.0 | 52.0 | 6.9 | 21.0 | 7.5 | ---- | ---- | -------- | -------- |

Table 3.—*Water-quality observations, Amazon River, Brazil*—Continued

| Day (July 1963) | Time | Location | | Water | | | | | Air | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Lat S. | Long W. | Temperature (°F) | Specific conductance (micromhos at 25°C | pH | Bicarbonate (ppm) | Dissolved oxygen (ppm) | Temperature (°F) Dry bulb | Temperature (°F) Wet bulb | Relative humidity (percent) | Altimeter reading[1] (ft) |
| | | | | | | Amazon River | | | | | | |
| 26-- | 2200 | 3°15' | 58°34' | 82.2 | 38.0 | ---- | ------ | ------ | ---- | ---- | -------- | --------- |
| 27-- | 0745 | 2°40' | 57°41' | 82.8 | 42.5 | ---- | ------ | ------ | 77.3 | 75.8 | 93 | 990 |
| | 0845 | 2°25' | 57°33' | 83.0 | 42.2 | 6.40 | 14.5 | 5.4 | 79.0 | ---- | -------- | 1,000 |
| | 0920 | 2°24' | 57°25' | 83.0 | 40.0 | 6.35 | 15.0 | 5.4 | ---- | ---- | -------- | --------- |
| | 1200 | 2°36' | 56°51' | 83.0 | 39.8 | 6.40 | 15.0 | 5.5 | 84.0 | ---- | -------- | 1,050 |
| | 1430 | 2°14' | 56°16' | 83.0 | 39.5 | ---- | ------ | ------ | 85.5 | 75.5 | 63 | 1,085 |
| | 1700 | 1°58' | 55°45' | 83.0 | 39.5 | 6.35 | ------ | 5.4 | 84.5 | 73.0 | 58 | 1,080 |
| | 1845 | 1°58 | 55°23' | 83.0 | 37.5 | 6.35 | 12.3 | 5.7 | 80.0 | 75.0 | 79 | 1,060 |
| 28-- | 0600 | 1°58' | 55°23' | 82.5 | 37.0 | 6.25 | ------ | 6.1 | 72 | 71 | 96 | --------- |
| | 1700 | 1°47' | 53°07' | 83.5 | 38.0 | ---- | ------ | ------ | 84.8 | 77.5 | 72 | --------- |
| 29-- | 0700 | 1°13' | 51°21' | 83.0 | 37.5 | ---- | ------ | ------ | ---- | ---- | -------- | --------- |
| | | | | | | Furo do Tajapuru | | | | | | |
| 29-- | 1200 | 1°39' | 58°37' | 84.5 | 39.0 | ---- | ------ | ------ | 86.0 | 73.5 | 55 | --------- |

[1] 1,000 ft = 0 at mean sea level at standard pressure.
[2] Approximate.
[3] Depth = 82 ft. Sampled at surface.
[4] Depth = 82 ft. Sampled at 10-ft depth.
[5] May be affected by flow from Rio Trombetas.
[6] At Obidos.
[7] Mostly Rio Negro water, black or Coca-Cola color.
[8] Mostly Rio Solimões water, turbid, yellow brown.
[9] At Manaus.
[10] At measurement cross section. Largely Rio Negro water.
[11] Large areas of Rio Negro and Rio Solimões water.
[12] Size of areas of unlike water much smaller. Turbid waters have "grainy" appearance, indicating flocculations.

measured in the Amazon near Obidos, 75 miles above the Tapajós.

Neither temperature nor chemical-quality gradients were indicated by temperature, specific-conductance, and pH measurements at various depths at the measuring sections near Obidos and near Manaus.

In the Rio Tapajos, about 3 miles above Santarém where water depth was about 80 feet, samples taken at the surface and at 10-foot depth had specific conductances of 15 and 17, and pH values of 6.0 and 7.1, respectively, at 1 p.m., July 13. However, these differences are considered too small to be meaningful. The temperature was 86.0°F at both the surface and the 10-foot depth. At 8 p.m., the pH was 7.15 at the surface, and temperature and conductivity were unchanged.

In the Amazon River at Obidos, the temperature and pH were identical at the surface and at 10- and 50-foot depths at three cross-section locations where the total depth ranged from 68 feet to 175 feet. Conductivity readings showed no change to 10-foot depth and values were only slightly higher at 50-foot depth. Titrations for dissolved oxygen showed virtually the same values for water from different depths and from the surface taken at different times of day.

At the measuring section in the Amazon River below the Rio Negro, there was no change of temperature, conductivity, or pH with depth, but the dissolved-oxygen content was appreciably higher at depth in both the Solimões water and the Negro water.

As mentioned earlier, the samples collected for laboratory analyses are not available at this writing. Consequently no data are available yet on sediment characteristics. Visual observation of sediment samples in the field indicated no suspended sediment in the Rio Negro and Rio Tapajós at the mouths, and only small concentrations in the Amazon itself. Field inspection of samples indicated no vertical gradient in the concentration of fine material. The concentration of sand grains decreased rapidly from bottom to top, but a few grains of very fine sand were evident in samples from 10-foot depth, where depth to riverbed was as much as 150 feet and velocities were as low as 4 feet per second. The largest particles in samples taken near both Obidos and Manaus appeared to be fine sand.

The occurrence of upwelling water in the form of mild but large-scale boils at the surface was evident in many places along the river. At first this manifestation seemed quite general, but later observation showed that it occurred only near the banks or in areas where shoals were indicated on the charts. Appreciable activity well out in the channel appeared to occur only in patches or in bands extending across the river. This in turn was thought to indicate quite shallow water, but inspection of the ship's echo-sounder chart at two or three of these locations indicated that the surface manifestation of turbulence occurred where depths were as great as 100 feet, downstream from deeper water. The boils probably result from upward vectors of velocity generated along the rising bed of the river in these reaches or from macroturbulent eddies generated by irregularities or bed configuration and velocity distribution (Sternberg, 1960).

## REFERENCES


Bittencourt, A., 1946, Uma Região Prospera: O Careiro; O Journal, Manaus (transcribed in Bol. Geog. 4), p. 1478–1480.

Durum, W.H., Heidel, S.G., and Tison, L.J., 1960, World-wide runoff of dissolved solids: Internat. Assoc. of Sci. Hydrology, pub. no. 51, p. 618–628.

Moraes, R., 1926, Na Planície Amazônica: Manaus, Livraria Clássica, 242 p. (6th ed., 1960, Rio de Janeiro, Conquista, 23 p.)

Parde, Maurice, 1956, Quelques aperçus relatifs à l'hydrologie brésilienne: Paris, 51 p., La Houille Blanche.

Soares, L. de C., 1956, Excursion guidebook no. 8, Amazonia: Internat. Geog. Union, p. 55.

Sternberg, H. O'R., 1956, A Agua e o Homen na Várzea do Careiro: Rio de Janeiro, 229 p. and portfolio of maps.

______ 1960, Radiocarbon dating as applied to a problem of Amazonian morphology: Cong. Internat. de Geographie, XVIII$^{e}$, Rio de Janeiro, 1956, Comptes rendus, p. 399–424 and insert map.


★ U.S. GOVERNMENT PRINTING OFFICE : 1967 O—276-030