# STREAMFLOW CHARACTERISTICS OF THE LOWER PASCAGOULA RIVER, MISSISSIPPI

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## INTRODUCTION

Fresh surface-water discharge is an abundant and important natural resource in the lower Pascagoula River Basin in Jackson County, Mississippi, but much is unknown of the real-time flow conditions (dynamic channel geometry, velocity distribution and direction, and other hydraulic characteristics) in complex estuarine and tide-affected riverine systems. The appropriate design of hydrodynamic flow models requires adequate understanding of the physical attributes of these complex flow phenomena. In November 1993, the U.S. Geological Survey (USGS) constructed a continuous-recording stage and velocity streamgage at the Pascagoula River at Graham Ferry to gain a better understanding of the effect tides from the Gulf of Mexico have on freshwater discharge in the lower Pascagoula River Basin.

The Mississippi Department of Environmental Quality, Office of Land and Water Resources (OLWR), currently (1995) is involved in intensive environmental studies of the lower Pascagoula River Basin in cooperation with the USGS, the Mississippi Department of Wildlife and Fisheries, the Mississippi Department of Marine Resources, and other State and county agencies. In accordance with the goals of these studies, the USGS surveyed channel-bed cross sections, thalweg (lowest point of flow) profiles, water-surface profiles, and geographic positions on the lower Pascagoula River Basin in April and May 1994. Using state-of-the-science signal processing technology known as pulse-to-pulse coherent sonar (RD Instruments 1993), the USGS, in cooperation with the OLWR, profiled three-dimensional velocities using an Acoustic Doppler Current Profiler (ADCP) [the use of trade or product names in this report is for identification purposes only and does not constitute endorsement by the USGS] at five locations in about an 18-mi (mile) reach of the lower Pascagoula River in October 1994. Pulse-to-pulse coherent sonar technology greatly enhances the calibration, performance, evaluation, and design of hydrodynamic flow models used to simulate the complex flow in riverine and estuarine systems. Velocity measurements made using this technology were also simultaneously compared to measurements obtained using standard USGS methods of measuring velocity (Rantz and others 1982).

### Purpose and Scope

This report describes and presents streamflow data collected by the USGS in 1993-94 for the lower Pascagoula River. These data are correlated with data collected using conventional streamgaging methods, an ADCP to measure three-dimensional velocity profiles, and a continuous-recording acoustic velocity meter (AVM). Examples of continuous stage, velocity, and discharge relations computed for data obtained from the USGS continuous recording stage and acoustic velocity streamgage at the Pascagoula River at Graham Ferry are presented.

### Description of the Study Area

The study area encompasses the lower 35 mi of the Pascagoula River in Jackson County, Mississippi (Figure 1). The drainage area at river mile 0.0 (second pier upstream from the Mississippi Sound and 0.8 mi upstream of the mouth on the left (east) bank) of the Pascagoula River is 9,498 mi2 (square miles). The drainage area at the USGS continuous recording stage and velocity gage at the Pascagoula River at Graham Ferry (station no. 02479310) at river mile 34.6 is 8,204 mi2. The length of the channel from the gage to the basin divide is about 230 mi, and the average slope of the channel between points located at 10 and 85 percent of the length upstream of the gage is about 1.6 ft/mi (feet per mile). Average channel and valley slopes in the vicinity of the gage are about 0.6 ft/mi. The drainage area of the Escatawpa River at its confluence with the East Pascagoula River at river mile 6.8 is 1,037 mi2.

## DATA COLLECTION

Data describing streamflow characteristics were collected on the lower Pascagoula River during short-term studies in April and October 1994 and collected continuously since November 1993 at the USGS streamgage at the Pascagoula River at Graham Ferry. These data were used by the USGS, other government agencies, and private interests to describe and document flow in the lower Pascagoula River during this period. The data-collection phase of this study is documented to detail not only what types of data were collected, but when and how these data were gathered, thereby providing details that help document and better define the methodology used in the analysis phase of the study. This phase also established baseline information for future studies in the area.

### November 1993 to Present (1995)

Since November 1993, the USGS has recorded stage, velocity, and other parameters at 30-minute intervals through a Data Collection Platform (DCP) at the Pascagoula River at Graham Ferry. These data are transmitted by satellite to the USGS at 4-hour intervals. Stage is measured using a submersible transducer attached to the right (west) main pier of the bridge. The transducer measures water pressure in pounds per square inch and then converts the pressure to feet of water and transmits this value to the DCP where it is recorded. Velocity is measured and transmitted to the DCP using an AVM which receives data from two transducers; one is mounted on the third main pier east of the right (west) abutment, and the second is mounted on a pile cluster near the right (west) bank about 220 ft downstream of the bridge. Discharge measurements are made at the site at 6-week intervals with either a standard current meter attached to a sounding weight from the downstream side of the bridge or with an ADCP mounted to a boat.

### April 1994

On April 19-23, 1994, the USGS surveyed the lower 35 miles of the Pascagoula River to collect channel geometry data that included channel-bed cross sections, thalweg elevations, and water-surface elevations. Cross sections were surveyed from a boat with a graphical fathometer and georeferenced with a mapping-grade global positioning system (GPS). These data were then digitized for later use in a geographic information system (GIS). Forty-seven cross sections were surveyed including: 8 cross sections in the main channel of the Pascagoula River; 18 cross sections in the East Pascagoula River; 18 cross sections in the West Pascagoula River; and 3 cross sections in the Escatawpa River. Thalweg points were fathomed at near quarter-mile intervals along the Pascagoula River, the East and West Pascagoula Rivers, and the Escatawpa River. A total of 185 thalweg points were surveyed and georeferenced with mapping-grade GPS equipment.

During the period the channel geometry was surveyed from April 19-23, 1994, the river at Graham Ferry (river mile 34.6) increased in stage from 15.0 ft (1000 hrs (hours) central daylight time, April 19) to a peak of 15.4 ft (1400 hrs, April 21) and decreased to 15.1 ft (1200 hrs, April 23). Relative changes in stage were similar during this period to changes in stage at Cumbest Bluff (river mile 25.4) and to changes at the divergence of the river into an east and west channel (river mile 17.3).

### May 1994

On May 11-13, 1994, the USGS surveyed temporary benchmarks established during the April study using survey-grade GPS equipment. This survey established accurate elevations (within 2-cm (centimeter) accuracy) as well as horizontal coordinates georeferenced to the Universal Transverse Mercator coordinate system for all temporary benchmarks used in the April study. The surveyed channel geometry and water-surface slopes were measured in the following river reaches: (1) the mouth of the East Pascagoula River at river mile -0.8 to the divergence at river mile 17.3; (2) the mouth of the West Pascagoula River at river mile 0.7 to the divergence at river mile 17.3; (3) the divergence of the East and West Pascagoula River at river mile 17.3 to the USGS continuous recording stage and velocity streamgage at river mile 34.6; and (4) the mouth of the Escatawpa River at its confluence with the East Pascagoula River at river mile 6.8 to river mile 2.8 on the Escatawpa River.

### October 1994

On October 10-11, 1994, the USGS measured discharge using an ADCP at five locations and a Price AA standard current meter at one location in about an 18-mi reach of the Pascagoula River. Water-surfaces elevations in the reach were also monitored during this period. Discharge and water-surface elevations were measured at the following river locations: (1) the East Pascagoula River at river mile 17.0; (2) the West Pascagoula River at river mile 17.0; (3) the divergence of the Pascagoula River at river mile 17.5; (4) the Pascagoula River about 0.4 mi downstream of Cumbest Bluff at river mile 25.0; and (5) the Pascagoula River at the USGS continuous recording stage and velocity streamgage at Graham Ferry at river mile 34.6.

A total of 18 discharge measurements were made within the 18-mi reach during the period October 10-11, 1994. The river at Graham Ferry (river mile 34.6) was in a tide-affected low-water flow condition, but runoff from rainfall in the upper parts of basin on October 8 negated the tidal effect beginning early on October 11. The stage increased steadily from 2.3 ft (1800 hrs, October 10) at the beginning of the data-collection period to a stage of 3.6 ft (0830 hrs, October 11) at the end of the data-collection period. Records at site indicate the stage peaked at 6.5 ft (1700 hrs, October 12).

## METHODOLOGY

The procedure used to process and analyze the data collected for this report was accomplished in three steps: (1) Channel geometry computations; (2) Unsteady flow computations; (3) Steady flow computations. All three steps required the use of both conventional and unique computational processes to analyze the data.

### CHANNEL GEOMETRY COMPUTATION

Channel depths from channel cross sections and thalweg elevations measured on April 19-23, 1994, were digitized from the graphical fathometer strip-charts and entered into a data base. Vertical controls of water surfaces at the various temporary gages used in the April 1994 study were compiled and stage hydrographs at each gage were constructed for the period. Water-surface slopes were computed from near simultaneous readings of water-surface elevations along the lower 35 mi study reach of the river. Water-surface elevations at each channel cross section and thalweg point were computed by linear interpolation of water-surface elevations between appropriate temporary gages upstream and downstream of each cross section and thalweg point. Channel-bed elevations were then obtained by subtracting depths from water-surface elevations at all channel cross sections and thalweg locations.

Channel-bed cross sections were computed at the Pascagoula River at the Roy O. Cumbest bridge at Graham Ferry from a Mississippi Department of Transportation (MDOT) survey and discharge measurements made at the site between 1958 and 1994 (Figure 2). A comparison of these cross sections indicates significant scour has occurred since construction of the bridge in about 1961. Thalweg elevations in 1958, 1971, 1979, and 1994 are -11.7, -24.6, -28.4, and -26.1 ft, respectively. These elevations indicate that the channel bed has lowered a maximum of 16. 7 ft, although scour near the right (west) pier appears to be approaching about 25 ft.

### UNSTEADY FLOW COMPUTATION

According to Harvey and others (1965), during periods of low flow the Pascagoula River is affected by normal tides in the Mississippi Sound to at least river mile 42, but not upstream of river mile 53. Data collected at the Pascagoula River at Graham Ferry (river mile 34.6) indicated a maximum tidal fluctuation of 0.67 ft for the 1994 water year occurred during a tidal period from August 31 to September 1, 1994.

Chow (1959) documented that discharge (Q) in cubic feet per second for steady or unsteady flow at a given channel section can be expressed as:

$$Q = VA \tag{1}$$

where, for the purposes of this report, V is the mean velocity in feet per second, and A is the cross-sectional flow area in square feet normal to the direction of the flow. The law of continuity for unsteady flow requires consideration of time.

To gage velocity and compute continuous discharge at the Pascagoula River at Graham Ferry during periods of low flow in which unsteady flow conditions exist as a result of tidal influence on stage and velocity, two relations were developed. First, acoustic transmitting and receiving transducers were placed at an elevation of about -4 ft on the downstream side of the third main pier left (east) of the right (west) bridge seat and on a pile cluster near the right (west) bank about 220 ft downstream of the bridge and skewed about 47 degrees from normal to the flow (Figure 3). Transducers are devices which convert electrical signals to sound and vice versa. The AVM measures travel time of sound through water using a differential travel time. The differential travel time is determined by making two successive travel time measurements on a given path in each direction. The forward direction measurement is made by measuring the travel time of sound from the upstream transducer to the downstream transducer, whereas the reverse direction measurement is the travel time of the sound from the downstream transducer to the upstream transducer. Therefore, the arrival time of the sound signal from the forward direction measurement will be shortened in proportion to the water velocity. When the velocity is zero, the forward and reverse travel times are equal. The AVM in use at this gage supports both positive and negative directions of flow. The relation can be best defined as:

$$TF = L/(C + v\cos A) \tag{2}$$

$$TR = L/(C - v\cos A) \tag{3}$$

where:

- TF is travel time in the forward (downstream) direction, in seconds;
- TR is travel time in the reverse (upstream) direction, in seconds;
- L is the path length between the two transducers, in feet;
- C is the speed of sound, in feet per second;
- v is the velocity of the water along the path, in feet per second; and
- cos A is the cosine of the path angle from the direction of flow.

Solving both equations for the speed of sound results in the following equation:

$$L/(TF - v\cos A) = L/(TR + v\cos A) \qquad (4)$$

The equation is further simplified by solving for v:

$$v = L/2\cos A\ (1/TF - 1/TR) \qquad (5)$$

Because the speed of sound can be altered by temperature, pressure, and salinity, the elimination of the speed of sound both simplifies the computation of an instantaneous point velocity and negates the need to measure other variables to account for changes in the speed of sound. Compensation was also made for signal delays due to cable length, the two transducers, and electronic hardware with the AVM. The transducers measure instantaneous point velocity and transmit this value to the AVM which then transmits the data to a data logger on 30-minute intervals.

Secondly, discharge measurements by conventional methods (Rantz et al. 1982) and from an ADCP, which transmits acoustic pulses from a transducer assembly along four beams, were used to develop a relation between the instantaneous point velocity measured by the AVM and average velocity computed from these discharge measurements. The ADCP has four transducers which transmit pulses of sound into the water. The transducers then measure the return sound as it is echoed from small particles floating ambiently with the water currents. Using the Doppler principle, the ADCP converts the returned sound into components of water-current velocity. The ADCP measures both the speed and direction of the water currents at multiple locations in the water column. It is beyond the scope of this report to detail all the vector mechanics involved in how the ADCP computes its position through time. Comparison of near simultaneous discharge measurements by personnel of the USGS have shown the ADCP to measure discharge within acceptable limits (within 5 percent) of the measurement obtained using a standard current meter. Comparison of the typical curves of equal velocity in a natural, irregular channel cross section from Chow (1959) and a cross section showing similar velocity curves generated from the ADCP data at the Pascagoula River at Graham Ferry, on October 11, 1994, show good correlation (Figure 4).

A relation was developed between average velocity computed by dividing the measured discharge by the area and instantaneous point velocity measured by the AVM (Figure 5). Discharge measurements made at 6-week intervals, as well as those measurements made during the October 1994 study, were used to develop this relation between average velocity across the measured channel-bed cross section and the instantaneous point velocity measured at an elevation of about -4 ft by the AVM transducers. This equation may be expressed as

$$V = 0.01 + 0.747v \qquad (6)$$

where V is the average velocity for the cross section, 0.01 is the y-offset, in feet, 0.747 is a dimensionless slope coefficient and v is instantaneous point velocity, in feet per second. For the purposes of this report, it was assumed that when instantaneous point velocity was 0 ft/s, average velocity was 0 ft/s, so the 0.01 ft offset was ignored. Because average velocity is inversely proportional to the area for a given constant discharge, if area changes, then velocity also changes. Given this and the unsteady nature of tidal fluctuations at the gage, slope and offset may change over time. For the purposes of this report, this equation to define average velocity is assumed valid for the period of the study.

To complete the first relation, a stage/area relation was developed using a fathomed cross section surveyed on April 20, 1994. Area was computed at 1-ft elevation intervals to develop a stage/area curve for stages influenced by tidal fluctuation (Figure 5). Therefore, to compute discharge during periods of tidal fluctuation, the velocity relation was used to compute mean velocity from instantaneous point velocity which was then multiplied by the area determined from the stage/area curve. The product of these two variables produced an instantaneous discharge.

## STEADY FLOW COMPUTATION

Upon observations of both the shape of the stage hydrograph and relative change of instantaneous point velocity to stage, a standard stage/discharge rating curve was determined effective above a stage of about 7 ft, although the exact stage at which tidal fluctuation becomes insignificant depends on the effect of the tide at the gage and the flow characteristics approaching from upstream. Discharge measurements made from 1958 to 1994 were used to develop a stage/discharge rating for periods of stage above 7 ft. Because the effect of tide on stage and velocity at the site depends upon flow characteristics near the gage, a 1-ft range of overlap was developed to provide a correlation between the standard stage/discharge rating and the tide-affected discharges. Between 7 and 8 ft of stage, instantaneous discharge was computed using both methods to insure a smooth transition in discharge hydrographs computed by the AVM and the standard stage/discharge rating.

## RESULTS

Continuous streamflow data as well as data for other channel characteristics have been collected, processed, and computed since November 1993 at the USGS continuous recording streamgage at the Pascagoula River at Graham Ferry, Mississippi. Analyses of the data provide stage/discharge information through time at the gage, as well as a variety of other characteristics of the lower river reaches of the Pascagoula River Basin (Figure 5). Analyses of the data also provide streamflow characteristics at the gage during periods of tidal fluctuation as well as during periods of high flow in which tidal influence is insignificant. Channel geometry data (that is, channel cross sections, water-surface elevations, thalweg profiles, and water-surface profiles) were compiled and processed for the lower 35 miles of the Pascagoula River from data collected during April and May 1994. Channel-bed cross sections were surveyed using a graphical fathometer. Each cross section was georeferenced for entry into a GIS. The channel-bed cross section near river mile 34.6 was used to develop a stage/area relation for use in computing discharge at the Pascagoula River at Graham Ferry, Mississippi, during periods of tidal fluctuation. These data were provided to the OLWR. Markers were placed at these cross sections for use in later studies.

Discharge was measured for unsteady and steady flow conditions at the gage using conventional velocity measuring instruments and an ADCP. Two ratings were used to compute discharge. The product of an average velocity for the entire channel cross section (derived from an average velocity to instantaneous point velocity relation) and an area for a given range in gage height from 1 to 8 ft was used to compute discharge during low flow periods that were affected by tidal fluctuation (Figure 5). The maximum change in stage during a tidal cycle at the gage since November 1993 was about 0.7 ft. For periods of flow above a gage height of 7 ft, a standard stage/discharge rating was developed from discharge measurements made from 1958 through 1994 (Figure 5). Because some uncertainty exists as to at what stage tidal fluctuation significantly affects discharge, a 1-ft overlap from a gage height of 7 to 8 ft was created between the two ratings. Discharges computed by the two ratings at these stages correlated very well.

A flood-frequency relation (Table 1) for the USGS gage at the Pascagoula River at Graham Ferry was developed using procedures outlined by Landers and Wilson (1991). The USGS has intermittently collected stage and discharge data at the site since 1958. A stage/discharge rating for stages above 7.0 ft was developed using discharge measurements made from 1959 through 1994. This rating represents non-tidal affected discharge.

## REFERENCES

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Harvey, E.J., H.G. Golden, and H.G. Jeffrey. 1965. Water resources of the Pascagoula area, Mississippi. U.S. Geological Survey Water-Supply Paper 1763.

Landers, M.L., and K.V. Wilson, Jr. 1991. Flood characteristics of Mississippi streams. U.S. Geological Survey Water-Resources Investigations Report 91-4037.

RD Instruments. 1993. Direct-reading broadband acoustic Doppler current profiler technical manual. RD Instruments, San Diego.

Rantz, S.E., et al. 1982. Measurement and computation of streamflow: Volume 1. Measurement of stage and discharge and Volume 2. Computation of discharge. U.S. Geological Survey Water-Supply Paper 2175.

Telis, P.A. 1991. Techniques for estimating 7-day, 10-year low-flow characteristics for ungaged sites on streams in Mississippi. U.S. Geological Survey Water-Resources Investigations Report 91-4130.

Table 1.--Elevation, peak discharge, and recurrence interval of annual floods at the Pascagoula River at Graham Ferry, Mississippi

| Elevations (feet above sea level) | Peak discharge (cubic feet per second) | Recurrence interval (years) |
|---|---|---|
| 16.4 | 71,300 | 2 |
| 17.7 | 109,000 | 5 |
| 18.4 | 138,000 | 10 |
| 19.2 | 174,000 | 25 |
| 19.8 | 206,000 | 50 |
| 20.4 | 242,000 | 100 |

Low-flow data were computed using procedures outlined by Telis (1991). The 7-day, 10-year low-flow discharge (7Q10) for the Pascagoula River at Graham Ferry is 1,140 cubic feet per second. This 7Q10 neglects any tidal influence at the bridge.

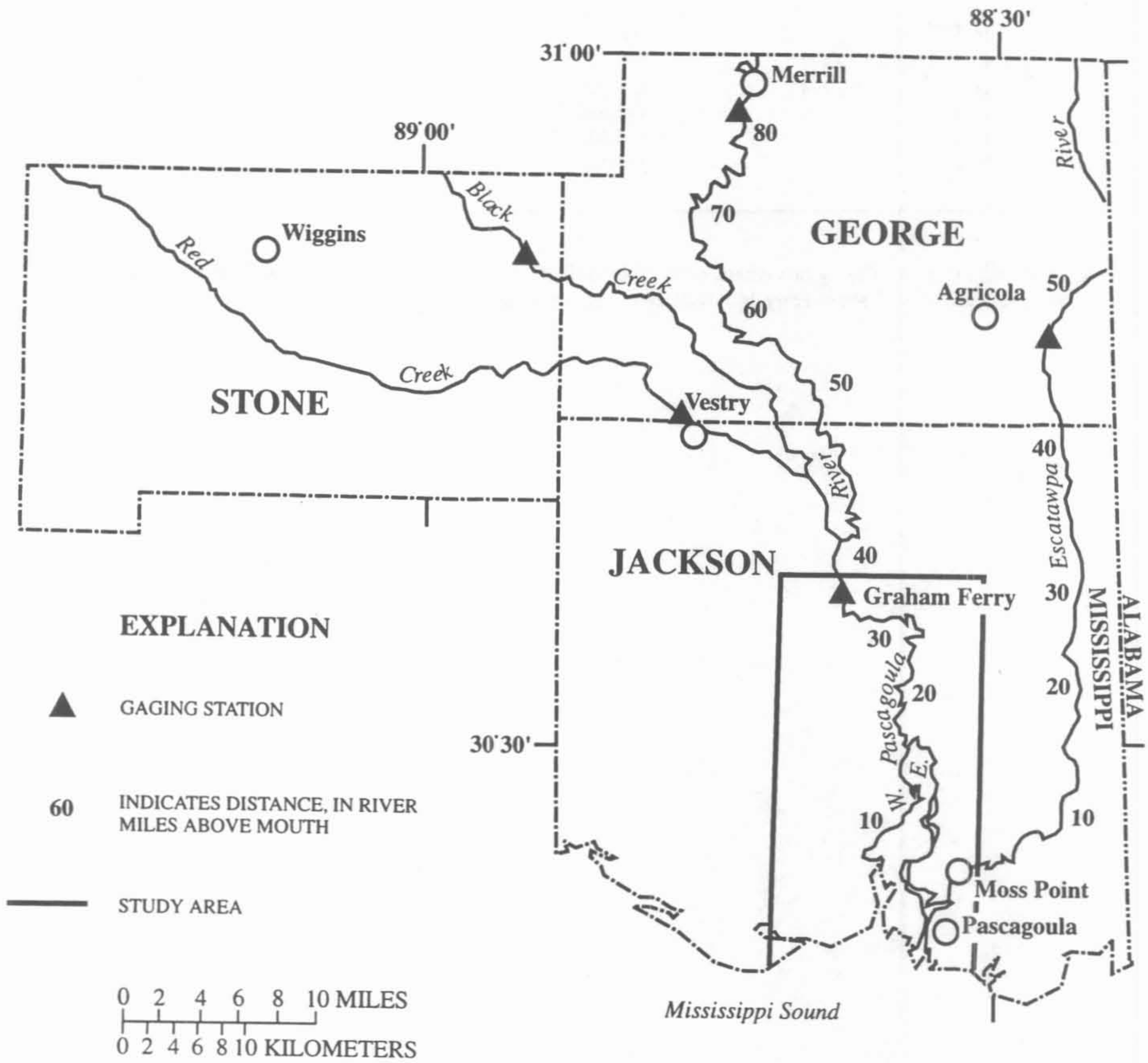


**Figure 1.** Study area location on the lower Pascagoula River.

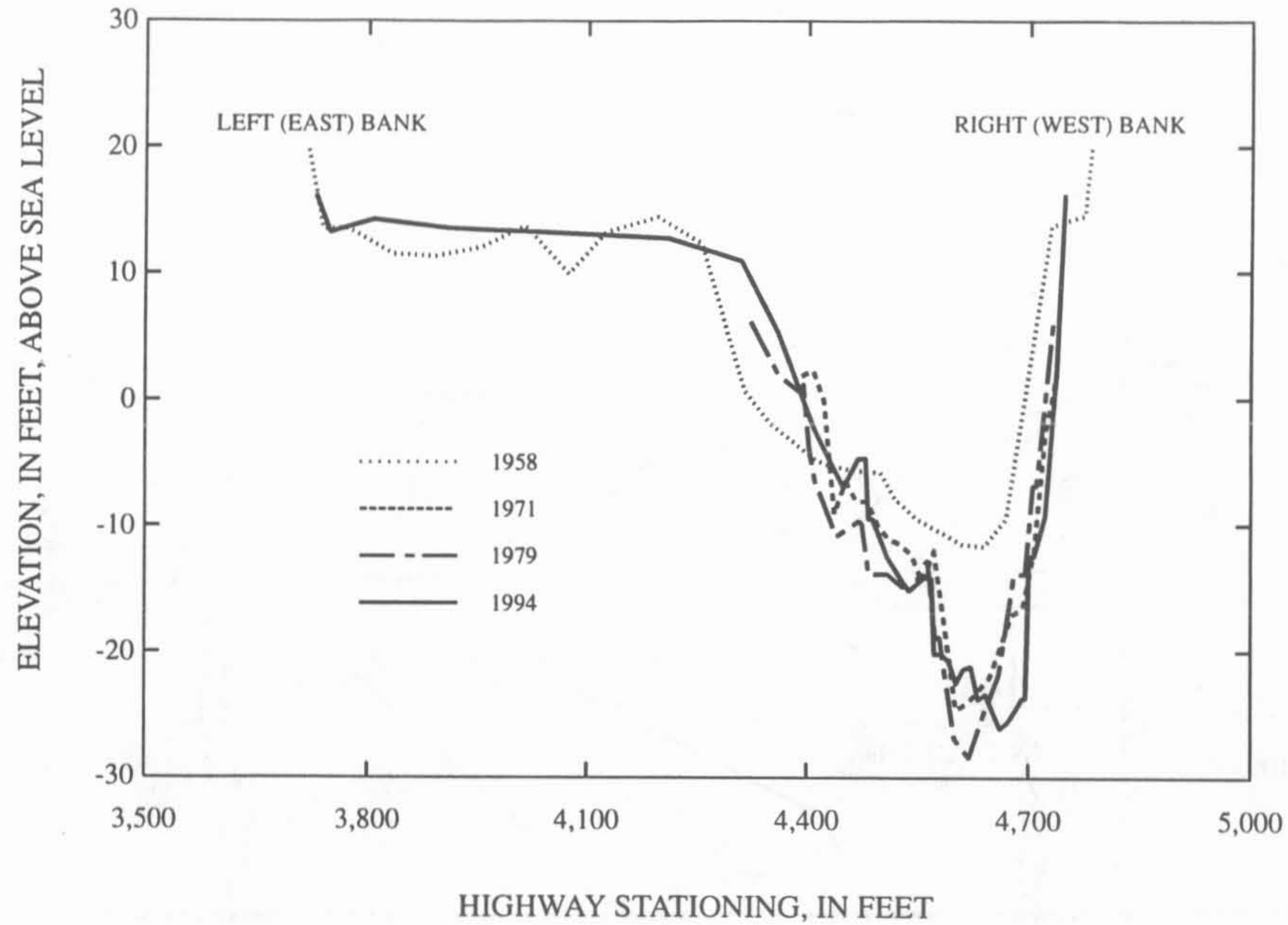


**Figure 2.** Cross sections from soundings make during historical and recent discharge measurements at the Pascagoula River at Graham Ferry, Mississippi.

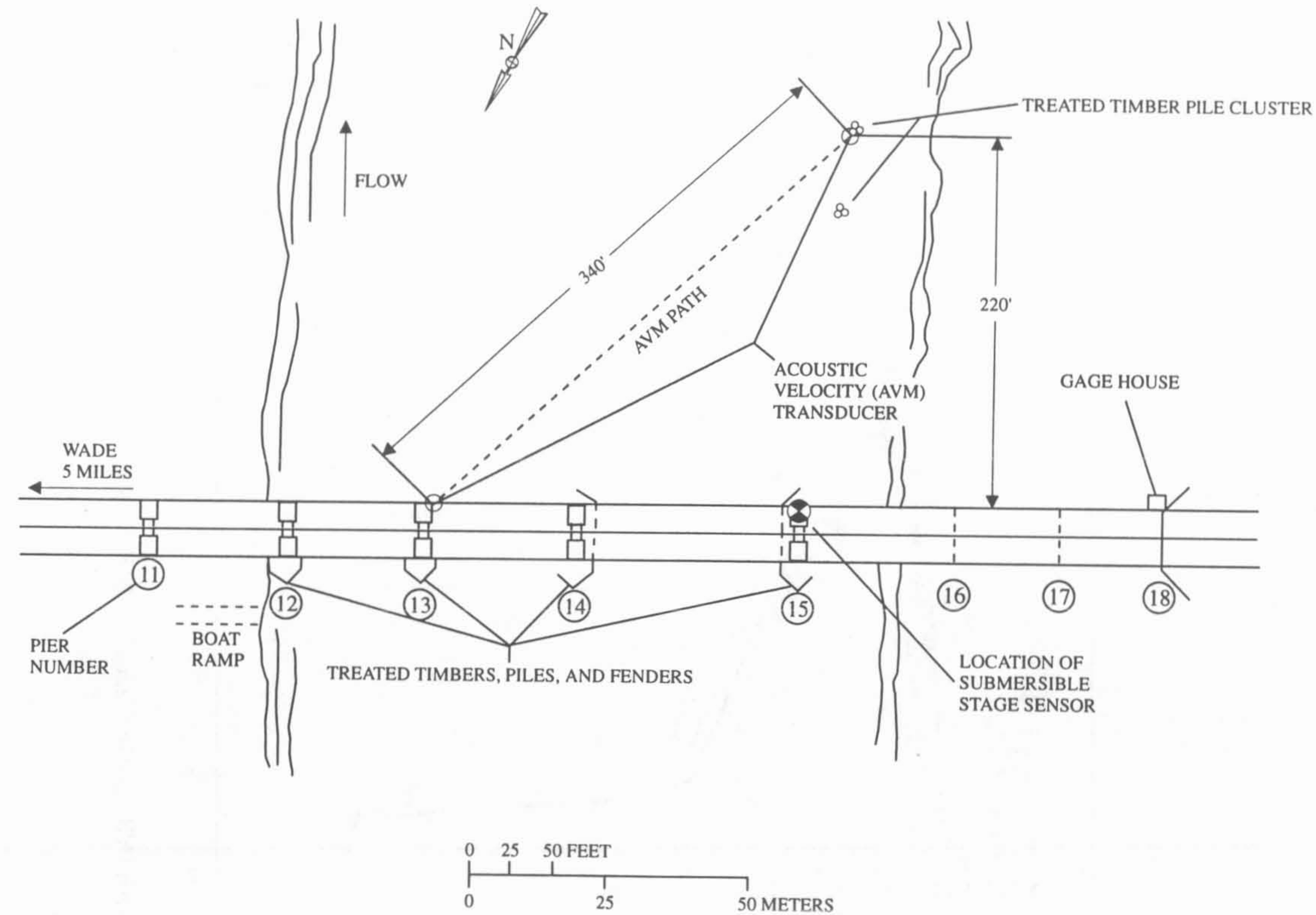


**Figure 3.** Plan view of U.S. Geological Survey continuous recording stage and velocity streamgage at the Pascagoula River at Graham Ferry, Mississippi, showing locations of submerged transducers.

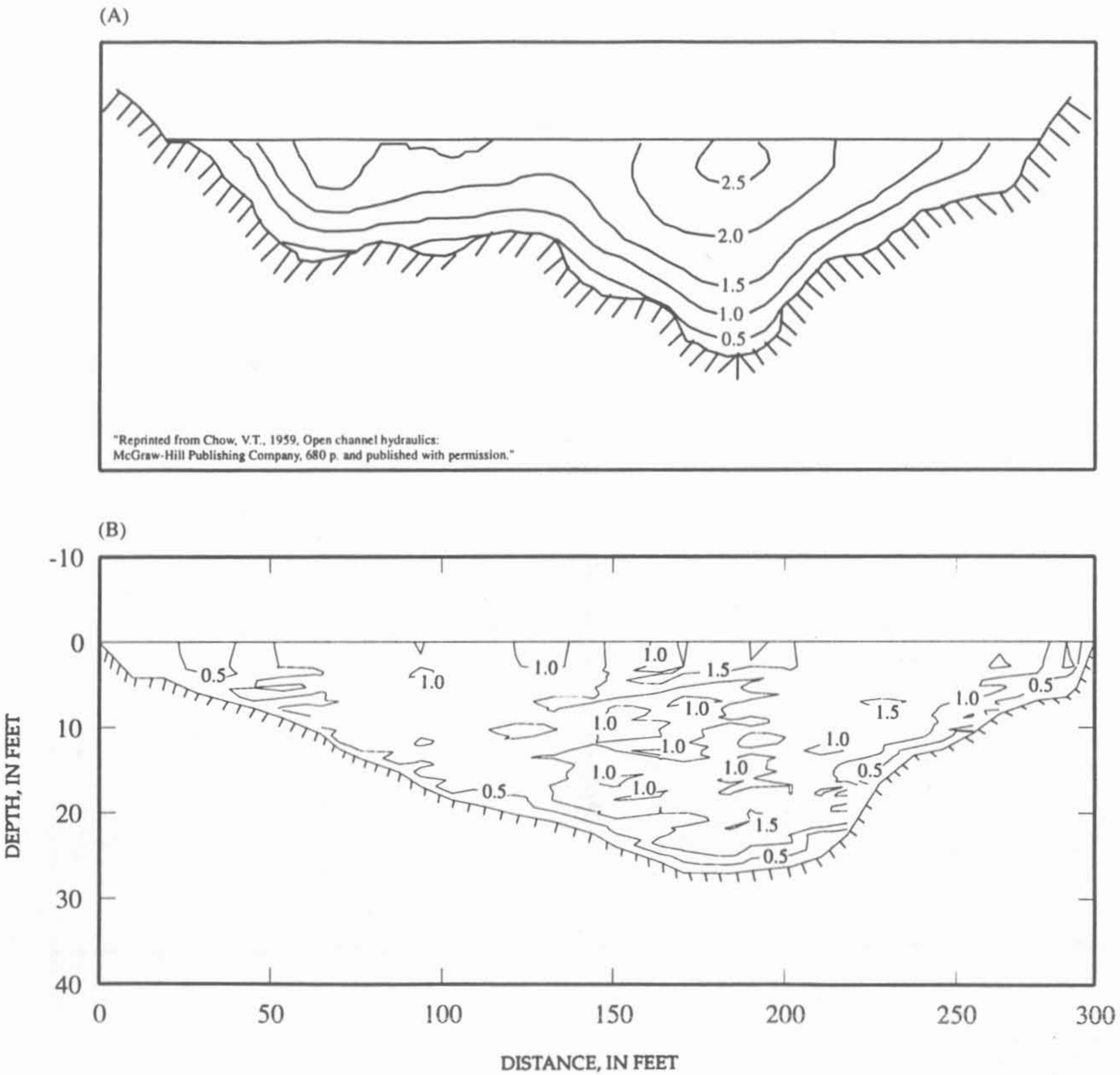


**Figure 4.** Typical curves of equal velocity in feet per second in a natural irregular channel as (A) documented by Chow (1959) and (B) measured by an Acoustic Doppler Current Profiler (ADCP) on October 11, 1994, at the Pascagoula River at Graham Ferry, Mississippi.

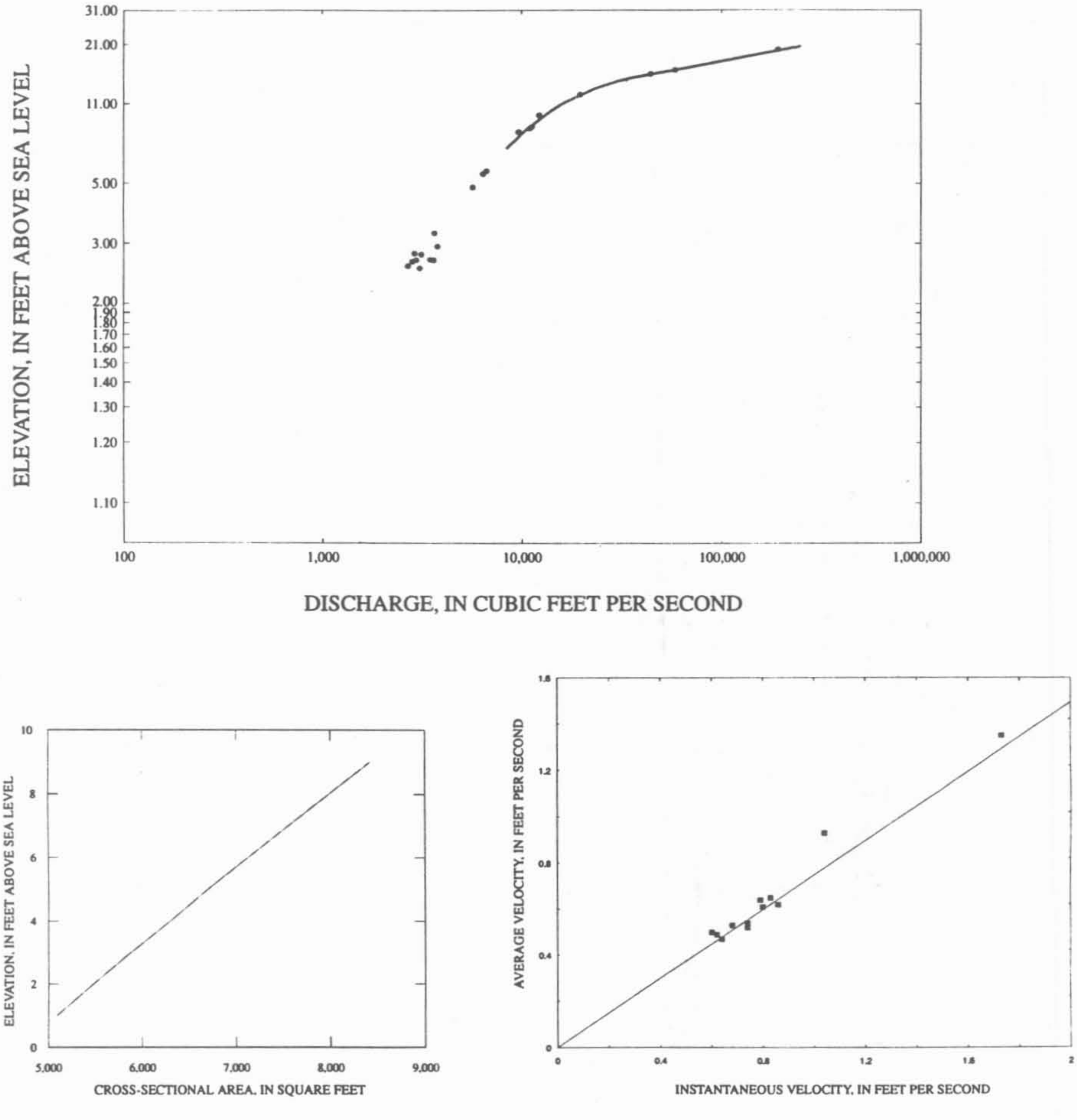


**Figure 5.** Stage/discharge relation, stage/area relation, instantaneous point/average velocity relation used to compute discharge at Graham Ferry, Mississippi.