Special Sediment Investigations Mississippi River at St. Louis, Missouri, 1961-63

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1819-J

Prepared in cooperation with the U.S. Army Corps of Engineers, St. Louis District

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By CLOYD H. SCOTT *and* HOWARD D. STEPHENS

CONTRIBUTIONS TO THE HYDROLOGY OF THE UNITED STATES

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Four sets of comprehensive hydraulic and sediment data are presented and briefly analyzed

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CONTENTS

ILLUSTRATIONS

[Plates are in pocket]

TABLES

CONTRIBUTIONS TO THE HYDROLOGY OF THE UNITED STATES

SPECIAL SEDIMENT INVESTIGATIONS MISSISSIPPI RIVER AT ST. LOUIS, MISSOURI, 1961–63

By CLOYD H. SCOTT and HOWARD D. STEPHENS

ABSTRACT

Four sets of comprehensive hydraulic and sediment data were obtained during 1961–63 for the Mississippi River at St. Louis at ranges of mean velocity from 3.3 to 5.6 feet per second, of mean depth from 22 to 37 feet, of width from 1,570 to 1,670 feet, of mean water-surface slope from 0.000054 to 0.000109, and of suspended-sediment concentration from 314 to 928 parts per million. The suspended sediment consisted of 9–46 percent sand, 30–46 percent silt, and 20–56 percent clay. The median size of bed material was about 0.42 millimeter for three sets of measurements and about 0.18 millimeter for the other set. A dune bed form was present during all four data-collection periods. Data obtained on consecutive days indicate that the turbulence constant can be computed from either streamflow-measurement notes or from vertical-velocity profiles. Constants computed from streamflow-measurement notes averaged 0.34, and those from vertical-velocity profiles averaged 0.35. The coefficients of vertical distribution of concentration for selected size ranges of suspended sands (expressed as z_1, the slope of the line relating the logarithms of concentration and a depth parameter) plotted against corresponding fall velocities indicate that on the average, the z_1's are proportional to about the 0.7 power of the fall velocity. The data also indicate that the relation of z_1 to fall velocity may vary with the mean velocity of flow.

INTRODUCTION

Comprehensive data for computation of hydraulic and sediment parameters of the deep flow of large rivers are obtained only rarely. A small amount of such data was obtained for the Mississippi River at St. Louis during 1948–60 and was used by Jordan (1965) as the basis for his discussion of flow resistance, vertical distribution of velocity and suspended sediment, and bed-material discharge of the river at that site. The purpose of the present study was to obtain additional data from which selected hydraulic and sediment parameters could be computed for the deep flows of the Mississippi River at St. Louis. Four sets of data—each including water-surface slopes, computed energy gradients, vertical-velocity profiles, streamflow measurements, water temperatures, distribution of sediment in the vertical, and size distributions of suspended sediment and bed material—were obtained in April 1961, April and October 1962, and April 1963. From these data, selected hydraulic and sediment parameters were computed. A detailed explanation of data-collection procedures and computation of the parameters are presented in this report; the data should help solve some problems relating to sediment transport by deep flows.

All the measurements were made in the river reach between mile 176.8 and mile 181.0 upstream from the mouth of the Ohio River (fig. 1). This reach is slightly curved and, except for being slightly wider between miles 177 and 179 than between miles 179 and 181, is of fairly uniform width. MacArthur Bridge, at mile 178.9, was the site of all velocity and water-temperature measurements and of all sampling of suspended sediment and bed material. Measurements of water-surface width and elevation were made at both ends of the reach and at selected intermediate cross sections. The St. Louis District of the U.S. Army Corps of Engineers cooperated in the study by establishing temporary bench marks at several places along the river edge and by operating a depth sounder to determine transverse and longitudinal profiles of the riverbed. During no set of measurements did the river stage fluctuate more than 3 feet; during the last set the range of fluctuation was slightly less than 0.5 foot.

HYDRAULIC DATA

Hydraulic data include streamflow measurements and point velocities obtained at mile 178.9, water-surface slopes, longitudinal and transverse profiles of the riverbed, and cross-section areas at miles 181.0, 178.9, and 176.8 or 177.1. Energy gradients were determined from water-surface elevations and computed velocity heads; turbulence constants were computed from streamflow measurement notes or from vertical velocity profiles.

STREAMFLOW MEASUREMENTS AND CROSS-SECTION AREAS

Streamflow was measured on 3 days during the first data-collection period, on 2 days during each of the second and third periods, and on 3 days during the fourth period (table 1). Additional determinations of streamflow were made from observations of gage height and from stage-discharge relations for the river at Eads Bridge. The determination of shift adjustments to the rating curve was based on streamflow measurements and an assumed straight-line change of shift with time. Cross-section

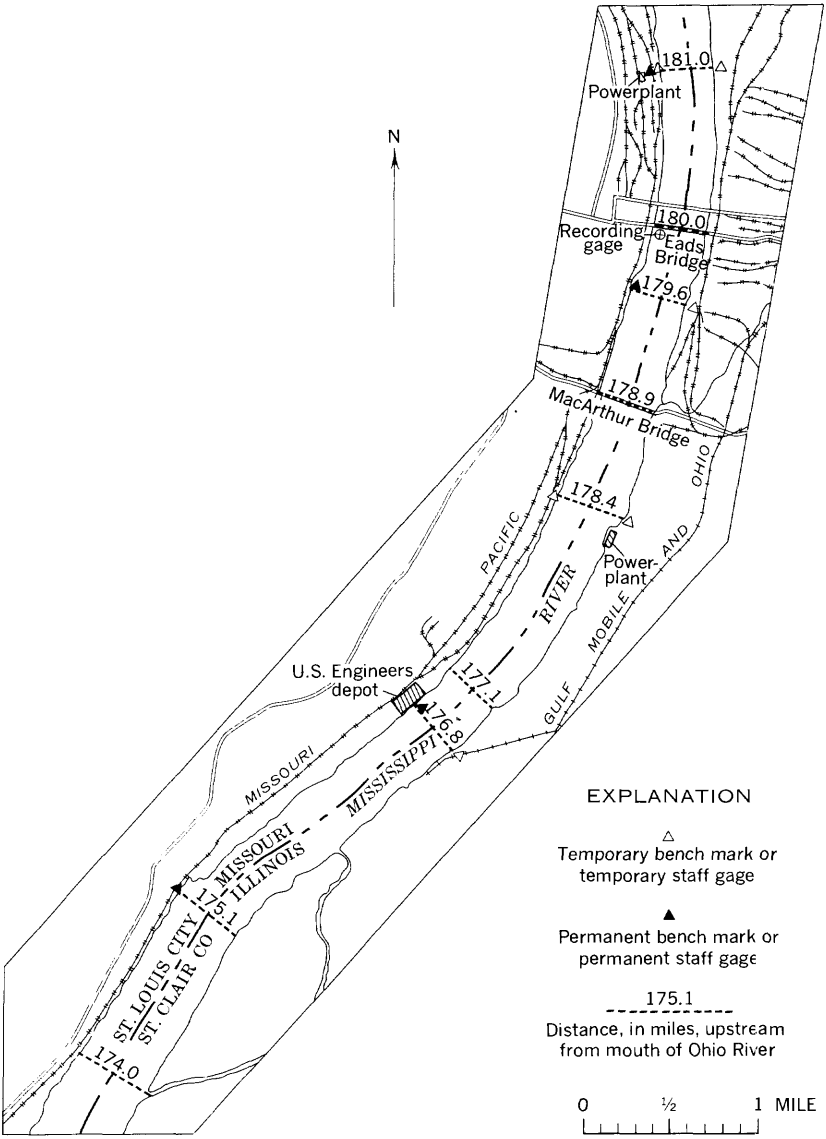


FIGURE 1.—Study reach of Mississippi River at St. Louis, Mo.

areas for intermediate times were determined by plotting areas from streamflow measurements against stage; areas determined from soundings obtained in connection with vertical-velocity measurements were used to aid in interpolating the area-stage relation when only two streamflow measurements were available for a data-collection period.

TABLE 1.—*Streamflow measurements from MacArthur Bridge, mile 178.9*

Date	Mean time	Gage height (feet)	Distance from reference point		Width of water surface [1] (feet)	Mean depth of water (feet)	Cross-section area (sq ft)	Mean velocity (fps)	Streamflow (cfs)
			Right edge of water (feet)	Left edge of water (feet)					
1961									
Apr. 18	1210	17.18	189	1,879	1,636	33.2	54,300	4.79	260,000
19	1325	16.16	195	1,873	1,624	32.4	52,600	4.64	244,000
21	1110	14.28	181	1,875	1,640	31.5	51,600	4.28	221,000
1962									
Apr. 19	1155	22.14	180	1,903	1,669	37.3	62,300	5.62	350,000
24	0945	19.72	175	1,895	1,666	34.9	58,100	5.18	301,000
Oct. 9	0810	6.14	213	1,862	1,595	24.5	39,100	3.27	128,000
12	0950	7.16	211	1,855	1,590	25.3	40,300	3.37	136,000
1963									
Apr. 17	1040	6.89	225	1,851	1,572	22.3	35,000	3.80	133,000
18	1045	6.88	225	1,851	1,572	22.6	35,500	3.75	133,000
19	1125	6.60	225	1,851	1,572	21.6	34,000	3.71	126,000

[1] Difference between right and left edge of water minus width of bridge piers (54 ft).

Cross-section areas at other than mile 178.9 were obtained by means of a depth sounder mounted in a boat. A correctly oriented large-scale map affixed to a planetable was used for determining the positions of the boat, and on signal from the sounder operator, the sounder chart and map were marked simultaneously at about 10 points along each section traversed by the boat. Profiles of the riverbed, as determined from the soundings, are shown in figure 2. Cross-section areas determined from the sounded profiles were corrected to the common time of the water-surface-slope determinations by adding or subtracting the net change of gage height multiplied by the average water-surface width of the sounded sections (table 2).

WATER-SURFACE SLOPES

Water-surface elevations used in slope observations were obtained from staff gages set near the water edge (fig. 1). Staff gages were established for each data-collection period, and levels were run from temporary bench marks to establish the elevation of the top of each staff. The water-surface elevation was determined by measuring from the top of the staff to the water surface. When wind, especially if moving generally in an upstream or downstream direction, caused waves that made determination of the water-surface elevation difficult, two independent readings were

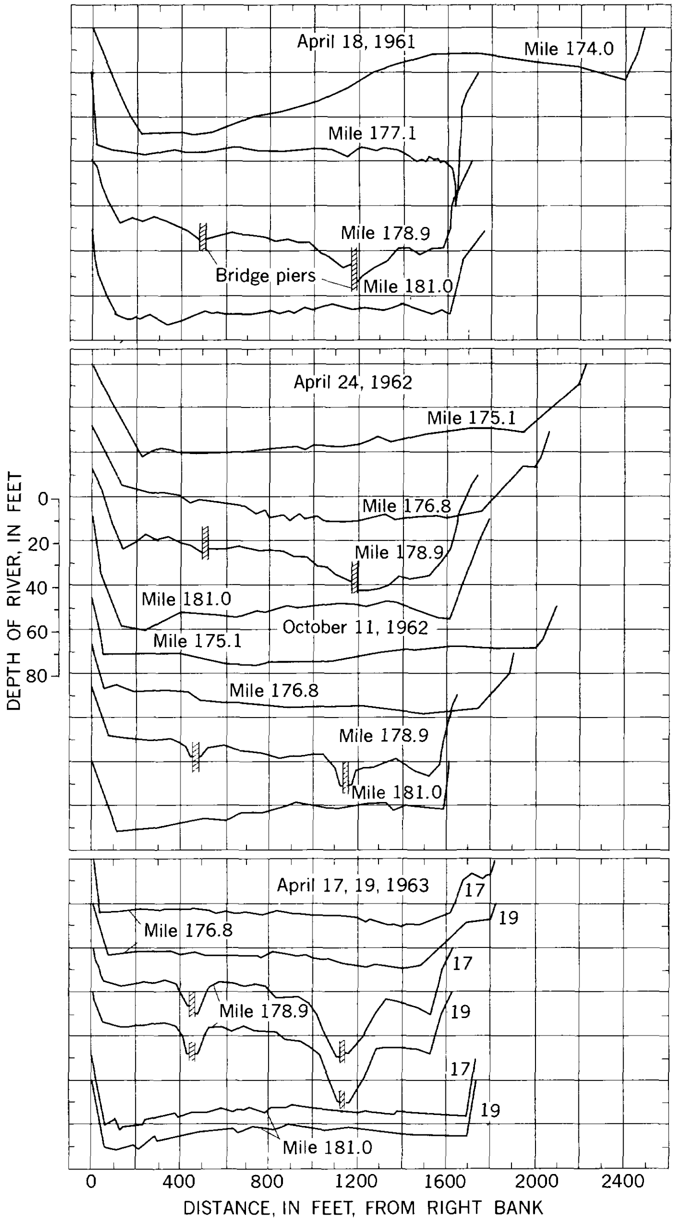


FIGURE 2.—Transverse profiles of riverbed.

TABLE 2.—*Cross-section data obtained with a depth sounder*

Date	Location (miles upstream from Ohio River)	Width (feet)	Mean depth (feet)	Cross-section area (sq ft)	Mean velocity (fps)
1961					
Apr. 18	181.0	1,760	34.2	60,220	4.37
	177.1	1,730	35.1	60,670	4.33
1962					
Apr. 24	181.0	1,780	39.1	69,700	4.30
	176.8	2,050	32.3	66,400	4.54
Oct. 11	181.0	1,610	22.4	36,100	3.79
	176.8	1,900	22.1	42,000	3.26
1963					
Apr. 17	181.0	1,730	23.9	41,400	3.22
	176.8	1,820	22.8	41,400	3.21
19	181.0	1,730	23.0	39,850	3.18
	176.8	1,820	21.6	39,200	3.22

obtained and averaged; the difference between the independent readings was commonly less than 0.05 foot. The water-surface elevations were plotted in the field as a check for errors; where apparently valid elevations seemed to be incorrect compared with other elevations, the staff on the opposite bank was reread as a check. Elevations of staff gages were redetermined whenever it seemed that the staff might have settled.

The water-surface elevation was generally slightly higher on the left side of the river than on the right. Curvature of the channel through most of the study reach may have caused the slight increase in water-surface elevation from right to left. At times, particularly in April 1963, the water-surface elevation on the right bank at mile 181.0 was somewhat inconsistent with the elevation on the left bank; apparently the elevation on the right bank is influenced by a large eddy created by release of powerplant cooling water returned to the river a short distance upstream.

Because the reading of the water-surface elevation at all the staff gages required 3–4 hours, the readings had to be corrected to a common time so they could be used for determining instantaneous slopes of the water surface. The elevations were corrected to a common time from the change of stage per hour at the recording gage located at mile 180.0. To determine whether the changes in stage at the recording gage were representative of the entire reach during each data-collection period, hourly stage readings were obtained from a staff gage at the Corps of Engineers depot at mile 176.8. These readings indicated that the rate of change of stage at the recording gage was satisfactory for use along the entire reach for all the sets of data.

ENERGY GRADIENTS

The energy gradient was computed by adding a velocity head to the corrected water-surface elevations at miles 181.0, 178.9, and either 177.1 or 176.8. The velocity head was computed from the equation

$$\text{velocity head} = \alpha_1 \frac{\bar{u}^2}{2g},$$

where

$\bar{u}$ is the mean velocity at the cross section,
g is the acceleration of gravity, and
α_1 is a correction factor.

The correction factor is approximated by the equation

$$\alpha_1 = \frac{\left(\frac{K_a^3}{A_a^2} + \frac{K_b^3}{A_b^2} + \dots + \frac{K_n^3}{A_n^2}\right)}{\frac{(\Sigma K)^3}{(\Sigma A)^2}},$$

where the subscripts denote subsections in the cross section and

A is the area of the subsection, and

K is equal to $\frac{1.49}{n} AR^{2/3}$, where

R is the hydraulic radius for which mean depth is substituted in these computations, and

n is Manning's coefficient of roughness (Kindsvater and others, 1953).

However, as n for the subsections is unknown, n for the section is assumed to be constant and α is approximated by the equation

$$\alpha_1 = \frac{(\Sigma A)^2 (A_aR_a^2 + A_bR_b^2 + \dots + A_nR_n^2)}{(A_aR_a^{2/3} + A_bR_b^{2/3} + \dots + A_nR_n^{2/3})^3}.$$

The water-surface slopes and the computed energy gradients (fig. 3) upstream from mile 178.9 (MacArthur Bridge) may be either higher or lower than the slopes downstream from mile 178.9. The relation between the slopes upstream from the bridge and the slopes downstream from the bridge does not depend on a single variable such as streamflow; instead, it depends on several variables, of which streamflow and scour and fill in the reach are probably the most important. Jordan (1965, p. 29) computed water-surface slopes from gages 4.4 miles upstream and 2.1 miles downstream from mile 178.9 and reported as follows: "During 1950–53, the slopes changed widely from time to time, but the

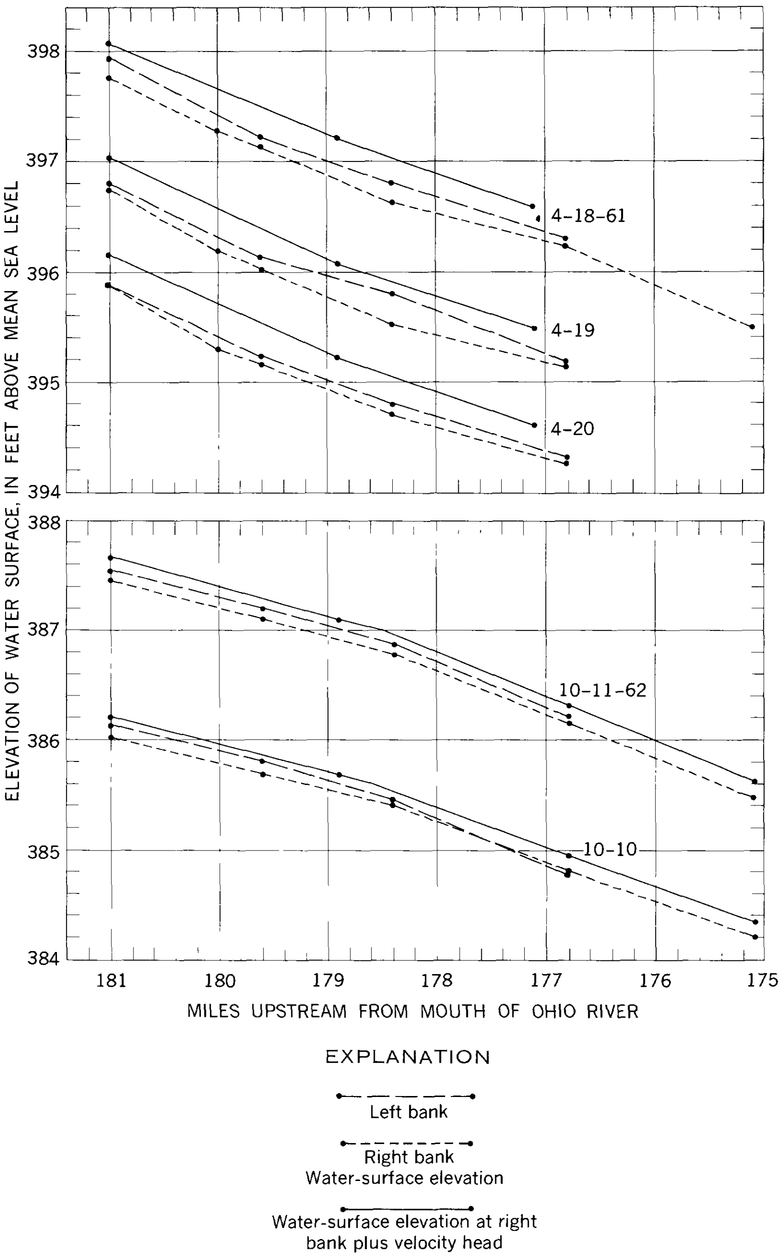


FIGURE 3.—Longitudinal water-surface and energy profiles.

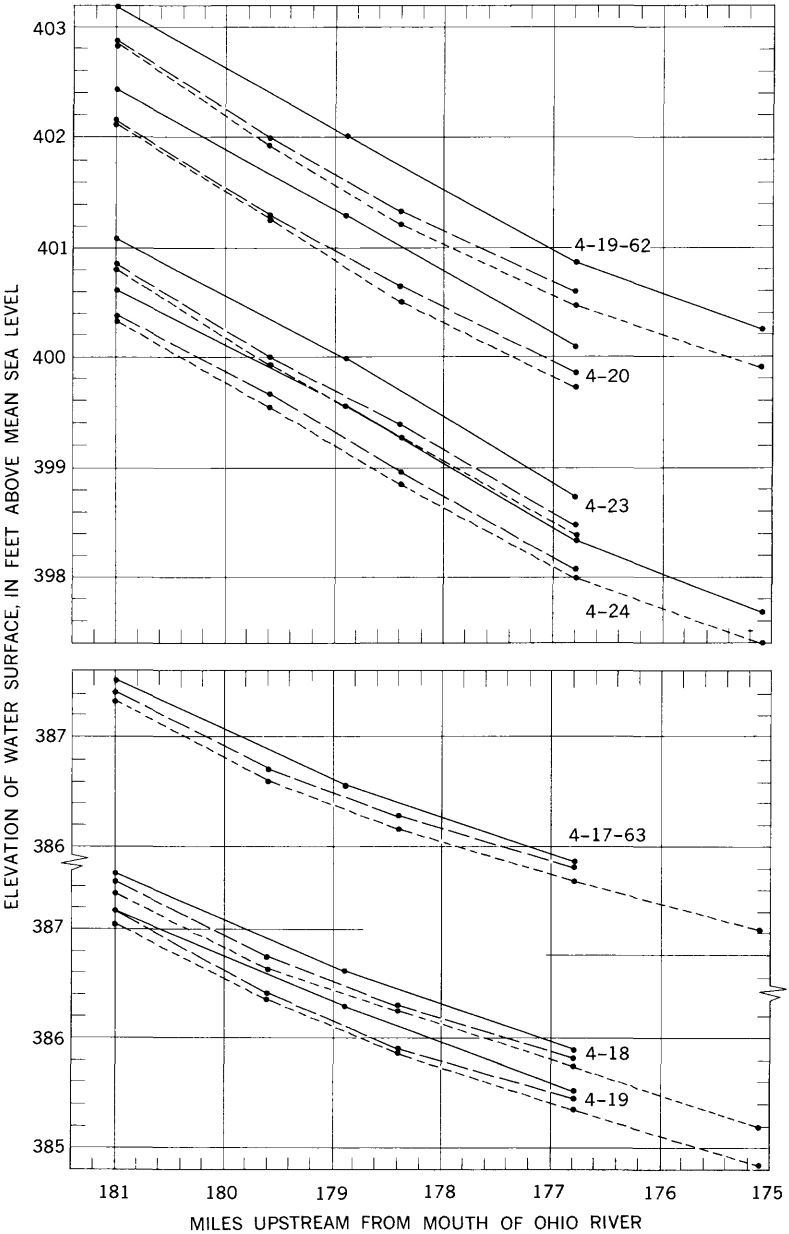


FIGURE 3.—Continued.

slopes upstream and downstream from the bridge were generally about the same at any given time. The slopes in the upstream reach tended to be slightly steeper than the slopes in the downstream reach. During 1954–59, the slopes were fairly constant, but those in the upstream reach were consistently steeper than those in the downstream reach; in 1956–57, the slopes upstream were about twice as steep as those downstream."

LONGITUDINAL BED PROFILES

Using a depth sounder, the Corps of Engineers, St. Louis District, determined the longitudinal bed profile at about quarter points of width for each set of data. (See figs. 4 and 5.) The range lines shown on the charts are not necessarily the same range lines for the different sets of data, but the approximate locations of the mile markers are shown to aid comparison of the profiles; streamflow is in the direction of decreasing mileage. These profiles were obtained to provide data to aid in studies of the relations between bed forms and roughness and in studies of depth effect on bed forms. Also, the profiles were obtained to determine changes in bed configuration that might be related to the breaks in water-surface slopes (fig. 3) and to determine possible causes for the breaks in slope. The left pier of MacArthur Bridge (mile 178.9) causes a definite scour hole and an area of deposition downstream from the bridge on the left side of the channel; the causes for changes in bed elevation and changes in size and shape of dunes at other places in the reach are obscure.

The longitudinal profiles do not show any changes in the bed that might be related, either as to cause or effect, to the breaks in water-surface slopes. The major breaks in water-surface slopes, when they occur, are in the vicinity of miles 179 and 177. There are two bridges in the study reach upstream from mile 179, but there is no bridge in the vicinity of mile 177; however, water-surface width (fig. 1) is somewhat greater between miles 179 and 177 than either upstream or downstream from that reach. A map of a detailed survey of the Mississippi River in the vicinity of St. Louis made by the Corps of Engineers in 1956 showed the reach between miles 179 and 177 to be about 200 feet wider than the reaches upstream and downstream. The location of the breaks in slope seems more likely to be related to changes in channel width and cross-sectional area than to location of bridges.

VERTICAL DISTRIBUTION OF VELOCITY

Point velocities for definition of vertical-velocity profiles (pl. 1) were obtained at about 15 verticals on 1 or 2 days of each data-

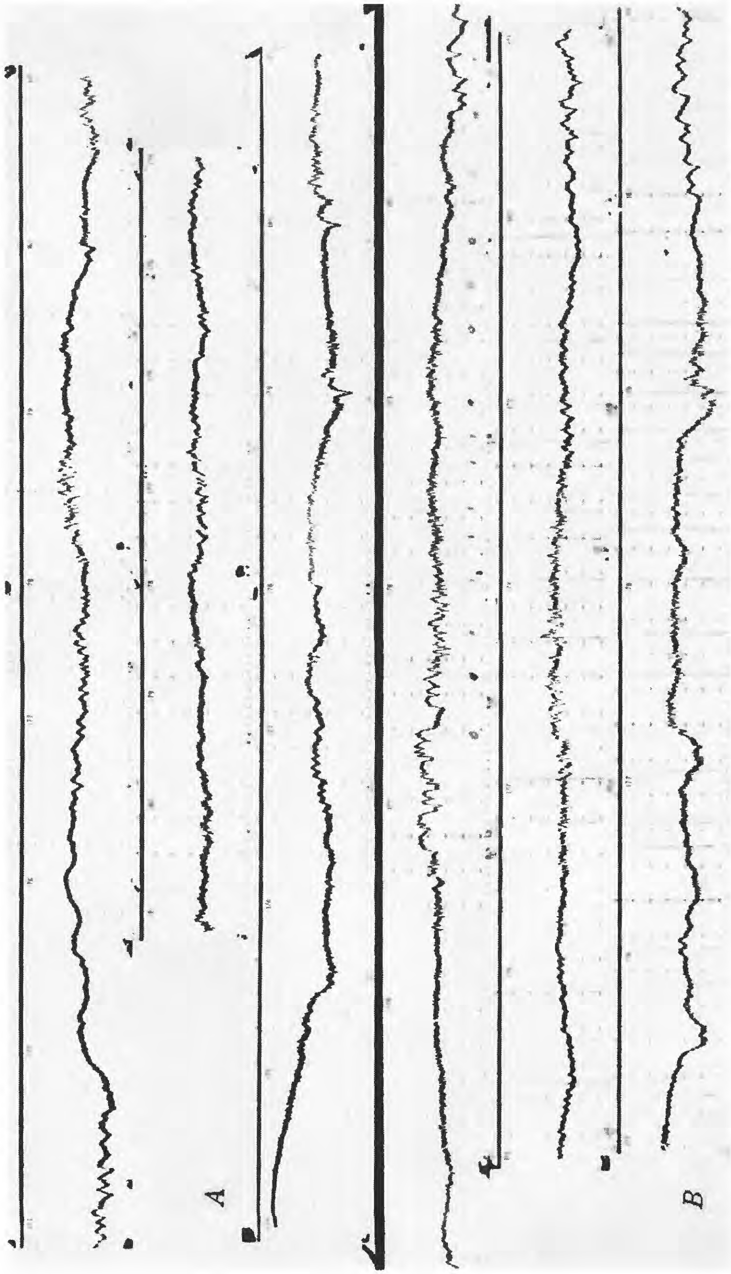
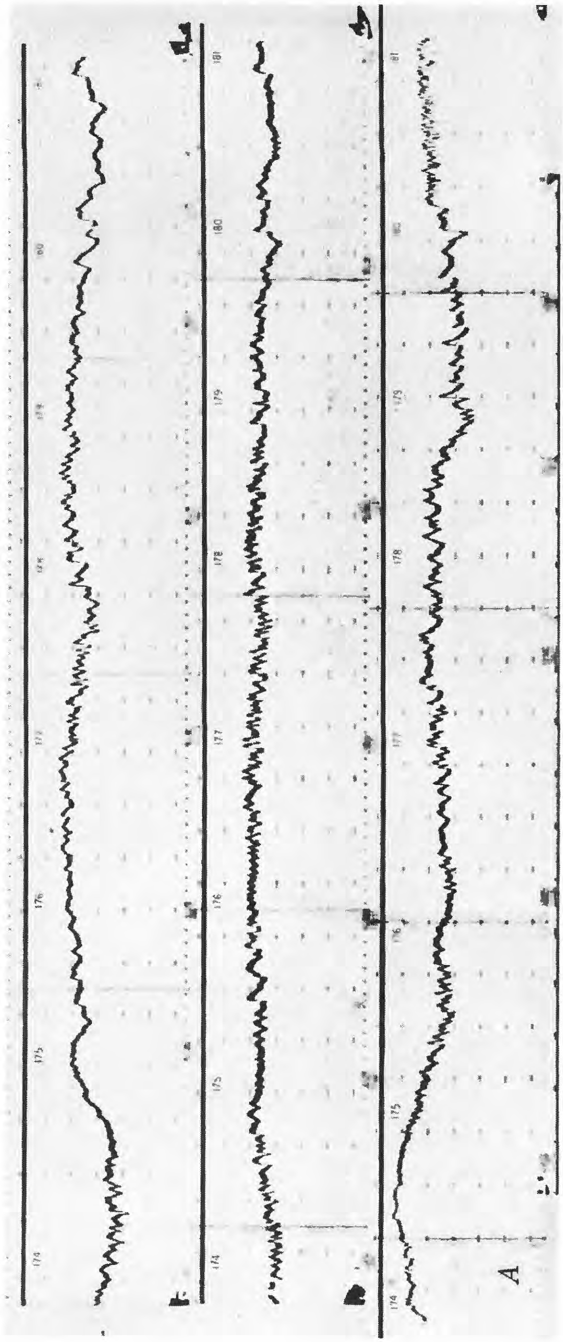


FIGURE 4.—Longitudinal profiles of riverbed through quarter points of river width: *A*, Apr. 19, 1961; *B*, Apr. 23, 1962. In both *A* and *B* the bottom profile is through the left quarter points and the top profile is through the right quarter points. Miles increase upstream; major divisions of vertical scale represent 10 feet. Originals on file, U.S. Geological Survey, Lincoln, Nebr.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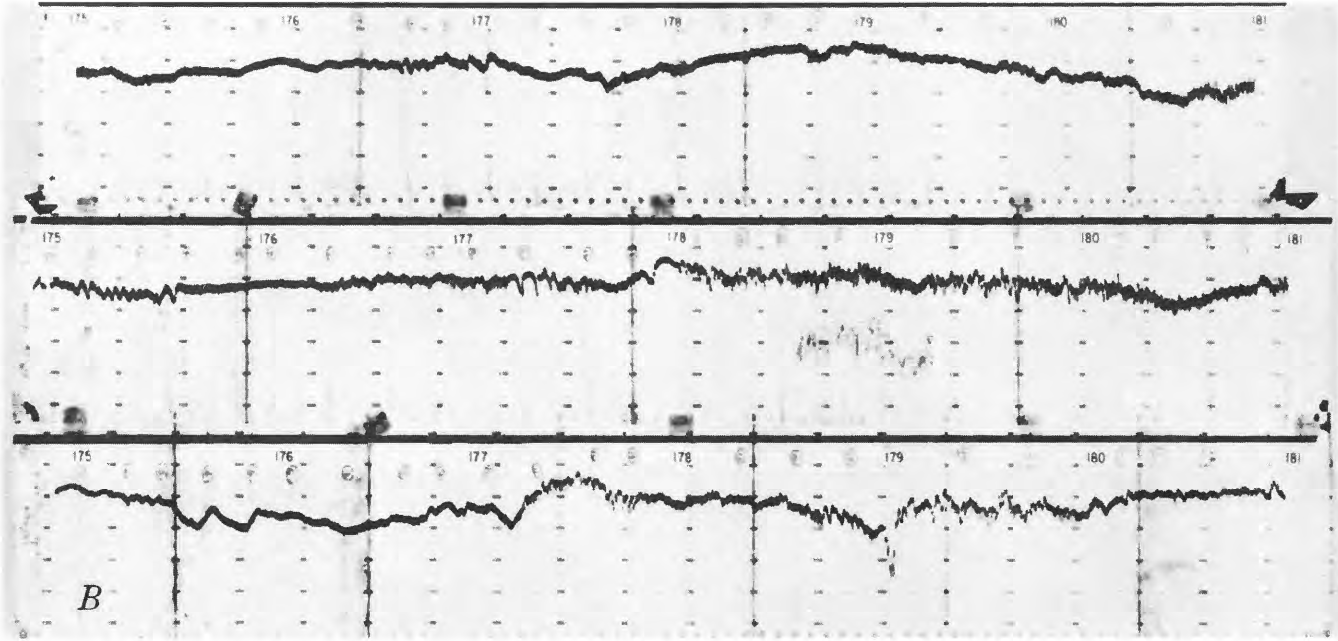

FIGURE 5.—Longitudinal profiles of riverbed through quarter points of river width: *A*, Oct. 11, 1962; *B*, Apr. 18, 1963. In both *A* and *B* the bottom profile is through the left quarter points and the top profile is through the right quarter points. Miles increase upstream; major divisions of vertical scale represent 10 feet. Originals on file, U. S. Geological Survey, Lincoln, Nebr.

collection period except in April 1963, during which vertical-velocity profiles were obtained only at the 6 verticals used for point sampling. The point-velocity measurements used in preparing the vertical-velocity profiles are presented in table 3. All point velocities were plotted against the logarithm of distance above the bed at the time they were obtained, and any velocities that appeared to be in error (except those obtained to determine short- and long-term changes in the vertical velocity on April 18 and 19) were rerun immediately. On April 18, three velocity profiles were obtained in succession at about 15-minute intervals at station 825, and the three profiles were repeated about 3 hours later. A barge had just passed near the station when the first set of velocity profiles was begun, and it definitely affected the profile at 0905 and probably affected the profile at 0920. The three profiles of the set that was started at 1200 show some variations, as do the profiles of the sets at station 1250 on April 19 beginning at 0935 and 1235. The average slope of the first set of three profiles at station 1250 was considerably different from the slope of the second set of three profiles at the same station. The differences between the average slopes of the sets are caused by shifting of the bed as dunes move through the section.

TABLE 3.—*Measured velocity, in feet per second, at selected points above riverbed, April 1961, April and October 1962, and April 1963*

Height of point above bed (ft)	*Measured velocity*
1961	
Station 300	
Apr. 20; total depth, 24.3 ft; mean time, 1715; gage height, 14.96 ft	
1.5	2.89
2.8	3.00
4.4	3.14
8.3	3.58
15.1	4.11
Station 465	
Apr. 20; total depth, 24.5 ft; mean time, 1700; gage height, 14.99 ft	
1.5	0.86
2	.93
2.8	2.16
3.4	3.07
4.4	3.27
6.1	3.76
8.3	4.14
11.3	4.47
15.2	4.90
	4.36
20.8	4.88
Station 625	
Apr. 20; total depth, 31.4 ft	
1.5	1.80
2.9	2.62
5.3	3.04
11.2	3.16
	2.91
19.1	4.43
Station 800	
Apr. 20; total depth, 30.8 ft	
1.5	2.80
	3.27
2.1	2.94
2.9	3.37
3.7	3.79
5.2	4.08
7.1	4.11
	3.72
9.9	4.43
13.5	4.44
18.8	4.58
	4.24
26.2	5.13

TABLE 3.—*Measured velocity, in feet per second, at selected points above riverbed, April 1961, April and October 1962, and April 1963*—Continued

Station 875

Apr. 20 ; total depth, 30.7 ft

Height of point above bed (ft)	*Measured velocity*
1.5	2.76
2.9	3.25
5.2	3.96
9.8	4.06
	4.19
18.7	5.22

Station 975

Apr. 20 ; total depth, 33.1 ft

Height of point above bed (ft)	*Measured velocity*
1.5	2.19
2.9	3.28
5.6	3.76
10.6	4.08
	3.86
20.1	4.94

Station 1050

Apr. 20 ; total depth, 35.4 ft

Height of point above bed (ft)	*Measured velocity*
1.5	3.27
2.1	2.73
	3.29
3	3.63
3.9	3.85
5.3	3.90
7.8	4.10
11	4.14
15.2	4.90
21.2	5.14
30.2	5.27

Station 1160

Apr. 20 ; total depth, 37.3 ft

Height of point above bed (ft)	*Measured velocity*
1.5	2.88
3	2.99
5.6	3.76
11.6	4.82
22.4	5.08
	4.87

Station 1250

Apr. 20 ; total depth, 38.9 ft

Height of point above bed (ft)	*Measured velocity*
1.5	2.35
2.1	2.91
3	2.28
	2.78
4.3	3.72
5.8	4.90
8.6	2.68
	4.86
12	4.64
16.7	5.00
23.4	5.35
33.1	5.72

Station 1300

Apr. 20 ; total depth, 45.5 ft

Height of point above bed (ft)	*Measured velocity*
1.5	2.86
3.2	3.47
5.5	3.40
	3.76
11.8	4.54
25.2	5.30

Station 1400

Apr. 20 ; total depth, 47.4 ft

Height of point above bed (ft)	*Measured velocity*
1.5	3.02
3.1	3.37
6.2	3.35
13.3	3.64
27	4.96
	5.62
	5.58

Station 1440

Apr. 19 ; total depth, 48.7 ft

Height of point above bed (ft)	*Measured velocity*
1.5	2.71
2.2	3.07
3.1	3.2[illegible]
4.6	3.70
	3.10
6.3	3.33
	3.33
9.2	3.8[illegible]
13.6	4.19
19.5	5.13
	5.40
27.8	5.45
39.9	6.3[illegible]

Apr. 20 ; total depth, 47.2 ft

Height of point above bed (ft)	*Measured velocity*
1.5	3.2[illegible]
2.2	3.70
	3.34
3.1	3.19
	3.27
4.4	3.70
6.1	4.0[illegible]
8.9	3.75
13.2	4.8[illegible]
18.9	5.04
26.9	5.6[illegible]
38.7	5.45
	5.7[illegible]

Station 1515

Apr. 18; total depth, 41.7 ft

Height of point above bed (ft)	*Measured velocity*
1.5	3.07
3	3.30
5.8	3.7[illegible]
12.1	4.72
24.2	5.53

TABLE 3.—*Measured velocity, in feet per second, at selected points above riverbed, April 1961, April and October 1962, and April 1963*—Continued

Station 1525

Apr. 20; total depth, 40.3 ft; mean time, 1300; gage height, 15.20 ft

Height of point above bed (ft)	*Measured velocity*
1.5	1.46
3	3.27
5.6	4.50
11.7	4.96
23.4	5.44

Station 1565

Apr. 18; total depth, 39.0 ft; mean time, 1700; gage height, 16.90 ft

Height of point above bed (ft)	*Measured velocity*
1.5	4.12
3	4.29
5.8	4.64
	4.29
12.1	5.26
23.2	5.76

Station 1590

Apr. 18; total depth, 38.3 ft; mean time, 1600; gage height, 16.95 ft

Height of point above bed (ft)	*Measured velocity*
1.5	4.29
	4.32
2.1	4.27
3	4.68
4.2	4.18
	4.35
5.8	5.04
8.4	4.99
11.9	5.40
16.5	5.67
23	5.99
32.6	5.90

Apr. 19; total depth, 41.0 ft; mean time, 1600; gage height, 16.08 ft

Height of point above bed (ft)	*Measured velocity*
1.5	2.87
2.1	3.09
3	3.07
	3.89
4.1	3.96
	3.37
5.7	3.91
8.2	4.50
11.9	5.04
16.8	5.36
23.8	5.72
33.6	5.99

Apr. 20; total depth, 38.8 ft

Height of point above bed (ft)	*Measured velocity*
1.5	4.07
2.1	4.07
3	4.54
	3.75
4.3	4.39
	4.18
5.8	4.39
	4.51
8.5	4.91
12	4.91

Station 1590—Continued

Height of point above bed (ft)	*Measured velocity*
12	5.09
16.7	5.40
23.3	5.53
33	5.71

Station 1670

Apr. 20; total depth, 37.3 ft

Height of point above bed (ft)	*Measured velocity*
1.5	3.20
3	3.76
5.6	4.00
11.6	4.14
22.4	4.86

Station 1750

Apr. 20; total depth, 35.9 ft; mean time, 1200; gage height, 15.25 ft

Height of point above bed (ft)	*Measured velocity*
1.5	1.89
3	2.40
5.4	2.33
	2.15
11.1	2.93
21.6	3.34

Station 1770

Apr. 18; total depth, 30.9 ft; mean time, 1530; gage height, 16.96 ft

Height of point above bed (ft)	*Measured velocity*
1.5	1.63
2.9	1.93
5.3	2.24
9.9	2.39
18.8	2.62

1962

Station 300

Apr. 20; total depth, 35.1 ft; mean time, 1620; gage height, 21.31 ft

Height of point above bed (ft)	*Measured velocity*
1.5	3.47
2.5	3.12
4.1	4.03
6.7	4.32
11	4.70
18	5.23
30	5.44

Apr. 23; total depth, 33.7 ft; mean time, 1300; gage height, 20.13 ft

Height of point above bed (ft)	*Measured velocity*
1.5	2.82
2.4	3.40
3.9	3.38
6.2	3.78
10	4.14
16	4.91
26	5.44

Station 400

Apr. 20; total depth, 28.7 ft

Height of point above bed (ft)	*Measured velocity*
1.5	3.66
2.4	4.21
3.9	4.47
6.2	4.85
10	5.66
16	6.10
26	6.10

TABLE 3.—*Measured velocity, in feet per second, at selected points above riverbed, April 1961, April and October 1962, and April 1963*—Continued

Station 400—Continued

Apr. 23; total depth, 27.7 ft

Height of point above bed (ft)	*Measured velocity*
1.5	2.89
2.4	3.76
3.9	4.21
6.2	4.43
	3.57
10	5.34
16	5.55
26	6.10

Station 535

Apr. 20; total depth, 32.2 ft

Height of point above bed (ft)	*Measured velocity*
1.5	4.72
2.4	4.36
3.9	4.21
6.2	5.12
10	5.98
16	5.88
26	6.31

Apr. 23; total depth, 30.1 ft

Height of point above bed (ft)	*Measured velocity*
1.5	3.80
2.4	4.02
3.9	4.47
	3.82
6.2	4.21
10	4.79
16	5.66
26	6.10

Station 625

Apr. 20; total depth, 36.4 ft

Height of point above bed (ft)	*Measured velocity*
1.5	3.14
2.5	2.75
4.1	3.64
6.7	4.25
11	4.06
18	5.23
30	6.10

Apr. 23; total depth, 33.8 ft

Height of point above bed (ft)	*Measured velocity*
1.5	3.78
2.5	3.97
4.1	4.79
6.7	4.69
11	5.01
18	5.34
30	6.31

Station 725

Apr. 20; total depth, 35.2 ft

Height of point above bed (ft)	*Measured velocity*
1.5	3.09
2.5	3.04
4.1	3.60
6.7	3.85
11	4.27
18	4.49
30	6.10

Station 725—Continued

Apr. 23; total depth, 34.2 ft

Height of point above bed (ft)	*Measured velocity*
1.5	2.93
2.5	3.78
4.1	3.83
6.7	4.53
11	5.13
18	6.10
30	6.31

Station 900

Apr. 20; total depth, 36.0 ft

Height of point above bed (ft)	*Measured velocity*
1.5	3.33
2.5	3.61
4.2	3.71
7	4.33
12	4.91
20	5.44
33	5.83

Apr. 23; total depth, 35.1 ft

Height of point above bed (ft)	*Measured velocity*
1.5	2.79
2.5	3.33
4.1	4.17
6.7	5.07
11	5.13
18	6.10
30	6.40

Station 985

Apr. 20; total depth, 36.5 ft

Height of point above bed (ft)	*Measured velocity*
1.5	3.02
2.5	3.23
4.2	3.57
7	3.71
12	4.79
20	5.88
33	5.88

Apr. 23; total depth, 35.8 ft

Height of point above bed (ft)	*Measured velocity*
1.5	3.76
2.5	3.67
4.1	4.03
6.7	4.85
11	4.79
18	5.44
30	6.19

Station 1100

Apr. 20; total depth, 38.8 ft

Height of point above bed (ft)	*Measured velocity*
1.5	2.89
2.5	2.91
4.1	3.58
6.7	4.58
11	5.23
18	5.76
30	6.53

TABLE 3.—*Measured velocity, in feet per second, at selected points above riverbed, April 1961, April and October 1962, and April 1963*—Continued

Height of point above bed (ft)	*Measured velocity*
Station 1100—Continued	
Apr. 23; total depth, 37.2 ft	
1.5	3.42
2.5	3.06
4.1	4.47
6.7	4.85
11	4.91
18	6.19
30	6.31
Station 1220	
Apr. 20; total depth, 42.6 ft	
1.5	3.49
2.5	3.78
4.2	4.58
7	4.64
12	5.34
20	5.44
33	6.75
Apr. 23; total depth, 41.6 ft	
1.5	3.61
2.6	3.25
4.4	3.82
	4.68
7.4	4.79
13	5.23
22	5.88
37	6.40
Station 1290	
Apr. 20; total depth, 49.5 ft	
1.5	3.97
2.6	3.73
4.4	4.75
7.4	4.42
13	5.34
22	5.76
37	6.75
Apr. 23; total depth, 45.6 ft	
1.5	3.71
2.6	3.71
4.4	3.49
7.4	4.06
13	3.69
22	5.23
37	6.53
Station 1390	
Apr. 20; total depth, 54.3 ft	
1.5	3.20
2.6	3.64
4.5	4.79
7.9	4.90
14	5.01
24	5.88
42	7.25
Station 1390—Continued	
Apr. 23; total depth, 51.5 ft	
1.5	3.25
2.6	4.07
4.5	4.10
7.9	4.96
14	5.66
	4.36
24	6.53
42	6.75
Station 1450	
Apr. 20; total depth, 52.5 ft	
1.5	4.14
2.6	4.72
4.5	4.14
7.9	5.77
14	5.23
24	6.53
42	6.75
Apr. 23; total depth, 51.2 ft	
1.5	3.59
2.6	4.62
4.5	4.14
7.9	5.18
14	5.44
24	5.76
42	6.31
Station 1585	
Apr. 20; total depth, 49.5 ft	
1.5	3.49
2.6	4.19
4.4	3.93
7.4	5.37
13	5.34
22	6.19
37	6.75
Apr. 23; total depth, 47.5 ft	
1.5	2.32
2.6	3.78
4.4	3.93
7.4	4.69
13	4.70
22	5.88
37	6.40
Station 1675	
Apr. 20; total depth, 49.4 ft	
1.5	3.90
2.6	3.95
4.4	4.06
7.4	4.68
13	3.93
22	5.66
37	4.79

TABLE 3.—*Measured velocity, in feet per second, at selected points above riverbed, April 1961, April and October 1962, and April 1963*—Continued

Height of point above bed (ft)	*Measured velocity*
Station 1675—Continued	
Apr. 23; total depth, 45.9 ft	
1.5	3.80
	3.78
2.6	3.69
4.5	4.47
7.9	4.21
14	4.58
24	5.55
42	5.76
Station 1725	
Apr. 20; total depth, 44.0 ft; mean time, 0930; gage height, 21.48 ft	
1.5	2.21
2.5	2.91
4.2	3.21
7	3.64
12	3.71
20	4.79
33	4.36
Apr. 23; total depth, 40.8 ft; mean time, 0900; gage height, 20.19 ft	
1.5	2.23
2.6	2.70
4.4	3.89
7.4	3.60
13	4.36
22	4.23
	3.98
37	4.40
Station 375	
Oct. 10; total depth, 18.3 ft; mean time, 0940; gage height, 5.80 ft	
1.5	1.59
2.2	1.89
3.3	2.05
4.9	2.16
7.2	2.35
10.8	2.46
16	2.21
Oct. 11; total depth, 20.1 ft; mean time, 0925; gage height, 7.11 ft	
1.5	1.77
2.3	2.01
3.4	2.16
5.1	2.87
7.6	3.00
11.5	3.33
17.4	3.51
Station 525	
Oct. 10; total depth, 18.9 ft	
1.5	2.38
2.2	2.55
3.3	2.75
	3.12
5	3.30
7.4	3.57
Station 525—Continued	
11	3.75
16.4	2.89
	3.66
Oct. 11; total depth, 20.0 ft	
1.5	2.11
2.3	2.40
3.4	3.00
5.1	3.10
7.6	3.51
11.5	3.66
17.4	3.70
Station 600	
Oct. 10; total depth, 19.0 ft	
1.5	2.74
2.2	2.79
3.3	3.00
5	3.21
7.4	3.46
11	3.49
16.5	3.76
Oct. 11; total depth, 19.4 ft	
1.5	2.69
2.3	2.82
3.4	3.08
5	3.25
7.4	3.60
11.1	3.58
16.6	3.66
	3.90
Station 775	
Oct. 10; total depth, 20.9 ft	
1.5	2.56
2.3	2.75
3.4	2.56
	3.07
5.2	3.0[illegible]
7.8	3.14
12	3.15
18	3.7[illegible]
Oct. 11; total depth, 22.9 ft	
1.5	2.8[illegible]
2.3	2.56
3.5	3.10
5.3	2.9[illegible]
8.2	3.3[illegible]
12.8	3.73
19.8	3.90
Station 900	
Oct. 10; total depth, 23.6 ft	
1.5	2.56
2.3	2.69
3.5	3.14
5.5	3.30
8.4	3.45
13.2	3.3[illegible]
	3.25
20.3	3.73

TABLE 3.—*Measured velocity, in feet per second, at selected points above riverbed, April 1961, April and October 1962, and April 1963*—Continued

Height of point above bed (ft)	*Measured velocity*
Station 900—Continued	
Oct. 11; total depth, 25.2 ft	
1.5	2.35
2.3	3.07
3.6	2.93
5.5	3.14
8.6	3.10
13.6	3.51
21.3	3.81
Station 1000	
Oct. 10; total depth, 25.2 ft	
1.5	2.56
2.3	2.69
3.6	2.75
5.7	3.14
8.8	3.30
13.9	3.44
21.5	3.81
Oct. 11; total depth, 26.9 ft	
1.5	3.04
2.3	3.00
	3.07
3.6	2.75
5.7	3.03
9	3.20
14.4	3.66
22.9	3.99
Station 1100	
Oct. 10; total depth, 25.9 ft	
1.5	2.56
2.4	2.62
3.7	2.78
	3.30
5.8	3.14
	3.46
9	3.78
14.2	4.05
22.1	4.14
Oct. 11; total depth, 27.6 ft	
1.5	3.00
2.4	3.00
	3.07
3.8	3.58
	2.93
6	3.30
9.5	3.30
	3.58
15.2	3.90
24	4.17
Station 1160	
Oct. 10; total depth, 27.1 ft	
1.5	2.94
2.3	3.05
3.6	3.02
5.7	3.54
9	3.65
Station 1160—Continued	
14.4	3.84
22.9	4.11
Oct. 11; total depth, 28.4 ft	
1.5	2.86
2.4	3.08
3.8	3.45
6	3.51
9.5	4.06
	3.66
15.2	4.06
24	4.29
Station 1260	
Oct. 10; total depth, 24.5 ft	
1.5	2.62
2.3	3.07
3.6	3.73
5.5	3.86
8.5	4.27
13.4	4.30
	4.27
20.9	4.27
	4.38
Oct. 11; total depth, 27.2 ft	
1.5	2.87
2.3	3.51
	3.58
3.6	3.51
5.7	4.08
	4.17
9	4.27
14.4	4.38
22.9	4.76
Station 1300	
Oct. 10; total depth, 32.4 ft	
1.5	1.92
2.5	2.06
4.1	2.62
6.9	3.07
11.3	3.82
	3.73
19	3.81
31.7	4.17
Oct. 11; total depth, 33.7 ft	
1.5	2.69
2.6	2.56
4.3	3.07
7.3	3.81
12.2	4.08
20.9	4.56
28.4	4.76
Station 1410	
Oct. 10; total depth, 33.6 ft	
1.5	1.39
2.6	1.45

TABLE 3.—*Measured velocity, in feet per second, at selected points above riverbed, April 1961, April and October 1962, and April 1963*—Continued

Height of point above bed (ft)	*Measured velocity*
Station 1410—Continued	
4.3	1.29
7.3	2.06
	1.39
12	2.59
16.6	3.22
31.4	4.56
Oct. 11; total depth, 34.3 ft	
1.5	2.56
2.5	2.87
4	3.00
6.5	2.87
10.5	3.73
17.8	4.38
29.4	4.47
Station 1475	
Oct. 10; total depth, 31.0 ft	
1.5	2.62
2.4	2.75
3.9	2.93
6.5	3.44
10.5	3.99
27.2	4.38
28	4.47
Oct. 11; total depth, 32.5 ft	
1.5	3.00
	2.51
2.4	3.00
	2.69
3.8	2.93
6.3	2.75
	3.22
10.2	3.81
16.7	4.38
	3.90
27.3	4.66
Station 1550 [1]	
Oct. 10; total depth, 27.9 ft	
1.5	3.17
2.4	3.06
3.8	3.84
6	4.03
Oct. 11; total depth, 29.7 ft	
1.5	2.93
2.4	2.95
3.8	3.14
	3.58
6.2	4.21
9.9	3.66
	3.32
16	4.69
25.6	4.76
Station 1625	
Oct. 11; total depth, 32.5 ft	
1.5	2.56
2.4	2.81
Station 1625—Continued	
3.8	3.07
9.3	3.66
	3.81
13.2	3.73
19.7	3.90
30.2	4.38
Station 1700	
Oct. 11; total depth, 37.1 ft; mean time, 1405; gage height, 7.25 ft	
1.5	2.01
	1.62
2.5	1.92
4.1	2.16
6.7	2.62
11.1	2.69
18.6	3.14
31.3	3.38
1963	
Station 475	
Apr. 19; total depth, 15.0 ft; mean time, 1125; gage height, 6.46 ft	
1.5	2.33
2.2	2.85
	2.91
3.1	3.20
4.5	3.27
	3.20
6.6	3.42
9.4	3.63
13.5	3.71
Station 825	
Apr. 18; total depth, 16.3 ft; mean time, 0905; gage height, 6.89 ft	
1.5	3.27
2.2	2.98
3.2	3.20
4.7	3.71
6.9	4.05
10.1	3.96
14.5	3.87
Apr. 18; mean time, 0920; gage height, 6.89 ft	
1.5	2.73
2.2	3.27
3.2	2.85
4.7	2.91
6.9	3.63
10.1	3.96
14.5	4.15
Apr. 18; mean time, 0935; gage height, 6.88 ft	
1.5	3.12
2.2	3.20
3.2	3.20
4.7	3.36
6.9	3.63
10.1	3.63
14.5	4.05

[1] Station 1550 not completed owing to equipment breakdown.

TABLE 3.—*Measured velocity, in feet per second, at selected points above riverbed, April 1961, April and October 1962, and April 1963*—Continued

Station 825—Continued

Apr. 18; mean time, 1200; gage height, 6.89 ft

Height of point above bed (ft)	*Measured velocity*
1.5	2.61
2.2	2.85
3.2	3.49
4.7	3.36
6.9	3.49
10.1	3.63
14.5	4.15

Apr. 18; mean time, 1215; gage height, 6.89 ft

Height of point above bed (ft)	*Measured velocity*
1.5	2.53
2.2	2.79
3.2	2.98
4.7	3.12
6.9	3.12
10.1	3.96
14.5	4.15

Apr. 18; mean time, 1230; gage height, 6.90 ft

Height of point above bed (ft)	*Measured velocity*
1.5	2.61
2.2	2.63
3.2	2.91
4.7	3.12
6.9	3.27
10.1	3.71
14.5	3.63

Station 1100

Apr. 17; total depth, 21.8 ft

Height of point above bed (ft)	*Measured velocity*
1.5	3.64
2.3	3.71
3.5	4.15
5.4	4.25
8.4	4.36
13	4.74
19.6	5.31

Station 1250

Apr. 19; total depth, 28.5 ft; mean time, 0935; gage height, 6.58 ft

Height of point above bed (ft)	*Measured velocity*
1.5	3.27
2.4	3.49
3.9	3.42
6.2	3.79
10	3.96
16	4.53
	4.63
25.8	4.73

Apr. 19; mean time, 0950; gage height, 6.59 ft

Height of point above bed (ft)	*Measured velocity*
1.5	2.98
2.4	3.27
3.9	3.20

Station 1250—Continued

Height of point above bed (ft)	*Measured velocity*
6.2	3.56
	3.87
10	3.87
	4.25
16	4.53
	4.83
25.8	4.83

Apr. 19; mean time, 1005; gage height, 6.60 ft

Height of point above bed (ft)	*Measured velocity*
1.5	3.05
2.4	3.27
3.9	3.49
	3.05
6.2	3.49
10	3.96
16	4.63
25.8	4.83

Apr. 19; mean time, 1235; gage height, 6.64 ft

Height of point above bed (ft)	*Measured velocity*
1.5	2.91
2.4	3.20
3.9	2.67
	2.73
6.2	3.56
	3.96
10	3.79
	3.49
16	4.63
25.8	5.06

Apr. 19; mean time, 1250; gage height, 6.64 ft

Height of point above bed (ft)	*Measured velocity*
1.5	2.67
2.4	2.85
3.9	2.98
6.2	2.98
10	3.63
	3.87
16	4.25
	4.44
25.8	4.83

Apr. 19; mean time, 1305; gage height, 6.64 ft

Height of point above bed (ft)	*Measured velocity*
1.5	2.61
2.4	2.61
3.9	3.36
	3.49
6.2	3.42
10	3.71
16	4.44
	4.63
25.8	4.83

TABLE 3.—*Measured velocity, in feet per second, at selected points above riverbed, April 1961, April and October 1962, and April 1963*—Continued

Station 1450

Apr. 18; total depth, 36.2 ft

Height of point above bed (ft)	*Measured velocity*
1.5	3.49
2.5	3.49
4.2	3.63
7	3.49
11.8	4.25
19.8	4.44
36.6	4.73

Station 1650

Apr. 17; total depth, 25.5 ft

Height of point above bed (ft)	*Measured velocity*
1.5	3.97
2.3	4.36
	4.74
3.7	4.36
5.8	4.64
9.3	4.54
14.8	4.64
23	5.19

COMPUTATION OF AVERAGE TURBULENCE CONSTANT

The turbulence, or Karman, constant, k, can be computed from the equation

$$k=\frac{2.30u_*}{(V_{10y}-V_y)},$$

where

u_* is the shear velocity equal to $\sqrt{gDS_e}$, where
 g is the acceleration of gravity,
 D is the depth, and
 S_e is the energy gradient,
V is the velocity, and
y is the distance above the river bed.

The velocities at distances $10y$ and y above the riverbed are taken from the line of best fit of the vertical-velocity profiles. The average turbulence constant for a cross section can be obtained in two ways: it can be computed from an average u_* and the average velocity differences, or it can be computed for each vertical and the individual k's averaged. According to Colby (in Jordan, 1965, p. 54), the turbulence constant can also be computed as

$$k=\frac{1.39u_*}{(V_{4y}-V_y)},$$

where u_* is computed from the mean of depths at the measuring verticals and the velocity differences at distances $4y$ and y from the bed are from the 0.2 and 0.8 depth velocities obtained for the streamflow measurement. The average u_* and average velocity differences are used in computing k from the streamflow measurement data; therefore, the averaging procedure corresponds to the first method described above. Depths and velocity differences for verticals near the banks, where bank resistance has an appreciable effect on the vertical-velocity profile, are not included in the computations of average constants.

Turbulence constants computed from data obtained on consecutive days (table 4) indicate that data from either streamflow-measurement notes or from vertical-velocity profiles are satisfactory for computing k for flows at St. Louis; Colby (in Jordan, 1965, p. 42–56) also found that the turbulence constants could be computed from either type of data. All turbulence constants for the set of data obtained April 16–20, 1963, were computed from streamflow-measurement notes. The averages of all k's computed from streamflow-measurement notes and from average velocity difference and average depth at each vertical are 0.34 and 0.35, respectively. Colby (in Jordan, 1965, p. 54) found the averages of k's computed by the same procedures to be 0.33 and 0.35, respectively. The average (0.38) of all k's in the last column of table 4 is somewhat higher than the average from either of the other computations because of the difference in the procedures used in computing the individual k's.

In the computation of shear velocity (u_*), the energy gradient, S_e, appears under the square-root sign. If a 5 percent error in k due to incorrect energy gradient is acceptable, then the energy gradient may differ as much as ±10 percent from the true energy gradient. As energy gradients are likely to range from 0.3 to 0.8

TABLE 4.—*Summary of turbulence constants*

Date	Turbulence constant, k, computed from—		
	Streamflow-measurement data	Average velocity difference and average depth at each vertical	Average of k's at each vertical
1961			
Apr. 19	0.31		
20		0.32	0.34
21	.30		
1962			
Apr. 19	.35		
20		.40	.43
23		.37	.40
24	.40		
Oct. 9	.30		
10		.30	.36
11		.34	.36
12	.35		
1963			
Apr. 17	.32		
18	.35		
19	.35		

foot per mile for most flows at St. Louis, the assumed energy gradient could differ from the true energy gradient by 0.03 foot per mile for the least steep slope to 0.08 foot per mile for the steepest slope; the difference for 4 miles could range from 0.12 to 0.32 foot.

The *k*'s were computed from the energy gradients determined for the reach from mile 181.0 to mile 177.1 or from mile 181.0 to mile 176.8; the break that generally occurs in the energy gradient in the vicinity of mile 178.9 was ignored. Although the errors caused by inaccurate measurement of the water-surface slopes over the entire reach probably are well within the 5 percent assumed as a reasonable limit, the break in the energy gradient that generally occurs at mile 178.9 could cause appreciable differences in the computed *k* if the energy gradient upstream or downstream from mile 178.9 is used in the computation of u_* rather than the gradient for the reach from mile 181.0 to 176.8 or 177.1. In April 1962, the slopes (table 5) upstream and downstream from mile 178.9 were within ±10 percent of the slope over the entire reach, but in April 1961, October 1962, and April 1963, the highest and lowest slopes differed more than 10 percent from the slope over the entire reach. The maximum difference between the computed energy gradient over the entire reach and the computed energy gradient upstream or downstream from mile 178.9 occurred in the April 1961 data; it was about 17 percent.

SEDIMENT DATA

Each set of sediment data consists of point samples, cross-section samples, bed-material samples, and water temperatures. The size distribution of material 2.0 millimeters and larger was determined by sieving, and that of material smaller than 2.0 mm by fall-diameter methods. The visual-accumulation-tube method was used for material between 1.0 mm and 0.062 mm, and the pipet method for material less than 0.062 mm.

VERTICAL DISTRIBUTION OF SUSPENDED SEDIMENT

Point-integrated samples were obtained on the 2d, 3d, and 4th days of each data-collection period except in the April 1962 period when they were obtained on 4 days. Each vertical was sampled at three to six depths, and the depths at which the samples were taken were selected so that the differences in the logarithms of $(D-y)/y$ (where D is depth and y is distance above the bed) were about equal. In April 1961, April 1962, and April 1963, the samples were obtained with a U.S. P–46 sampler having an addi-

TABLE 5.—*Summary of energy gradients*

[Water-surface elevation is corrected to common time of 1000 for 1961 and 1100 for 1962–63]

Date	Water-surface elevation at right bank (feet)			Velocity head (feet)			Energy gradient		
	Mile 181.0	Mile 178.9	Mile 177.1	Mile 181.0	Mile 178.9	Mile 177.1	Miles 181.0–177.1	Miles 181.0–178.9	Miles 178.9–177.1
1961									
Apr. 18	397.78	396.84	396.30	0.31	0.38	0.30	0.000072	0.000078	0.000065
19	396.76	395.72	395.20	.29	.36	.28	.000076	.000088	.000063
20	395.88	394.89	394.33	.27	.33	.26	.000076	.000084	.000066
			Mile 176.8			Mile 176.8	Miles 181.0–176.8		Miles 178.9–176.8
1962									
Apr. 19	402.85	401.54	400.47	.35	.50	0.40	0.000105	.000105	0.000106
20	402.14	400.84	399.73	.33	.48	.37	.000106	.000101	.000110
23	400.78	399.57	398.40	.30	.43	.34	.000108	.000098	.000114
24	400.33	399.14	398.00	.30	.43	.34	.000103	.000096	.000111
Oct. 10	386.01	385.52	384 80	.20	.16	.15	.000057	.000048	.000066
11	387.45	386.92	386.15	.23	.18	.17	.000061	.000052	.000070
1963									
Apr. 17	387.36	386.35	385.70	.16	.23	.16	.000075	.000085	.000065
18	387.35	386.39	385.74	.16	.23	.16	.000072	.000080	.000065
19	387.04	386.08	385.37	.16	.22	.16	.000075	.000081	.000069

tional sounding weight suspended below. The lowest sampling point was about 1.8 feet above the bed because the additional weight prevented sampling closer. In October 1962, no sounding weight was used and the lowest sampling point was 1.5 feet above the bed. The number of verticals that could be sampled in a day depended on the concentration of sand. If the concentration of sand was relatively high, three verticals could be sampled per day; however, if the concentration was relatively low, only one or two could be sampled because a larger sample had to be obtained at each point to insure that enough material was available for a reliable analysis of particle-size distribution. The verticals at which point samples were obtained were selected to represent subsections of about equal flow.

The sample from each point in the vertical was analyzed for concentration of suspended sediment and particle-size distribution (table 6). The concentration for various size ranges was computed as the product of the sample concentration and the decimal portion of the sample in the size range, as determined from the size analysis. The slope, called z_1, of the relation of the logarithm of the concentration of various size ranges (C_y) plotted against the logarithm of $(D-y)/y$ defines the vertical distribution of sediment concentration for the various size ranges of sand (pl. 2). The vertical distribution of sediment for various size ranges can be computed from the theoretical equation

$$z=\frac{V_s}{ku_*},$$

where

V_s is the fall velocity of the geometric mean size of the size range in question,

k is the turbulence, or Karman, constant, and

u_* is the shear velocity equal to $\sqrt{gDS_e}$.

The energy gradient enters the computation of u_* to the one-half power; therefore, the computed z varies inversely with the one-half power of the energy gradient. The energy gradient upstream and downstream from mile 178.9 can vary considerably from the average gradient over the entire reach, but the percentage variation in the computed z's will be less than the percentage variation of the gradient upstream and downstream from the average gradient. The fall velocity enters to the first power in the computation of z, but the relation of the measured z_1 to fall velocity indicated that the power of the fall velocity should be less than one (pl. 3). The fall velocities are from a report of the U.S. Inter-Agency Committee on Water Resources (1957, table 2). The

TABLE 6.—*Size distribution of suspended sediment and velocity at selected points above riverbed, April 1961, April and October 1962, and April 1963*

[Velocity computed from sample volume, filling time, and nozzle size]

Mean time	Gage height (feet)	Water temperature (°F)	Height of point above bed (feet)	Velocity (fps)	Suspended sediment					
					Concentration (ppm)	Percent finer than indicated size (mm)				
						0.062	0.125	0.250	0.500	1.000
1961										
Station 465 Apr. 20; total depth, 25.8 ft										
1357	---------	52	1.8	2.49	1,200	81	87	99	100	------
1424	---------	52	6.4	3.37	1,150	85	91	100	-----	------
1452	---------	52	14.2	4.16	1,050	90	96	100	-----	------
1603	---------	52	21.9	4.57	987	94	98	100	-----	------
Station 800 Apr. 19; total depth, 31.8 ft										
1432	---------	49	1.8	3.05	1,360	78	84	96	100	------
1452	---------	49	4.0	3.29	1,310	82	87	98	100	------
1520	---------	50	9.5	4.62	1,210	87	92	99	100	------
1553	---------	50	17.5	4.63	1,150	90	94	100	-----	------
1621	---------	50	24.8	4.83	1,100	95	98	100	-----	------
1759	---------	50	28.9	5.06	1,050	96	98	100	-----	------
Station 1050 Apr. 20; total depth, 36.2 ft										
1102	---------	50	1.8	1.59	1,070	74	81	92	100	------
1118	---------	50	4.7	3.45	986	79	86	97	100	------
1132	---------	50	10.9	4.16	902	85	92	100	-----	------
1152	---------	50	19.9	4.21	876	88	94	100	-----	------
1216	---------	50	28.2	5.08	788	93	97	100	-----	------
1250	---------	50	32.9	5.21	766	94	98	100	-----	------
Station 1250 Apr. 18; total depth, 41.2 ft										
1532	---------	48	1.8	1.99	1,560	61	66	79	98	100
1550	---------	48	4.5	4.64	1,170	80	86	98	100	------
1604	---------	48	11.1	4.30	1,120	83	88	99	100	------
Station 1250 Apr. 20; total depth, 39.5 ft										
0840	---------	49	1.8	3.99	1,000	59	67	83	100	------
0856	---------	49	5.2	4.44	808	70	78	96	100	------
0911	---------	49	11.9	5.41	711	81	89	100	-----	------
0933	---------	49	21.7	5.21	640	84	90	100	-----	------
0954	---------	49	30.8	5.34	634	87	94	100	-----	------
1018	---------	49	35.9	5.47	578	90	96	100	-----	------
Station 1440 Apr. 19; total depth, 48.2 ft										
1012	---------	48	1.8	2.87	862	56	61	99	100	------
1034	---------	48	5.3	3.53	1,060	52	59	93	100	------
1052	---------	48	13.0	4.28	720	69	77	99	100	------
1117	---------	46	25.4	5.74	547	80	88	100	-----	------
1145	---------	46	37.1	6.17	420	89	93	100	-----	------
1210	---------	46	43.8	5.89	418	92	96	100	-----	------

TABLE 6.—*Size distribution of suspended sediment and velocity at selected points above riverbed, April 1961, April and October 1962, and April 1963*—Continued

Mean time	Gage height (feet)	Water temperature (°F)	Height of point above bed (feet)	Velocity (fps)	Suspended sediment					
					Concentration (ppm)	Percent finer than indicated size (mm)				
						0.062	0.125	0.250	0.500	1.000
Station 1580 **Apr. 18; total depth, 41.8 ft**										
1111	---------	45	1.8	2.61	1,210	33	38	99	100	------
1136	---------	45	4.6	2.56	956	40	47	98	100	------
1155	---------	45	11.3	4.05	655	60	66	99	100	------
1222	---------	45	22.2	4.59	462	70	77	100	-----	------
1255	---------	46	32.2	4.96	350	87	92	100	-----	------
1325	---------	46	38.0	5.21	312	93	96	100	-----	------
1962										
Station 400 **Apr. 23; total depth, 33.3 ft**										
1340	20.11	------------	1.8	2.52	2,000	19	24	51	97	100
1357	---------	52	5.7	3.69	789	47	57	76	98	100
1428	---------	------------	14.0	4.46	603	63	71	88	100	------
1440	---------	55	23.3	4.46	478	73	84	96	100	------
1501	---------	------------	30.3	5.48	406	86	92	100	-----	------
Station 725 **Apr. 19; total depth, 38.7 ft**										
1454	22.06	51	1.8	4.25	964	36	42	52	87	99
1516	---------	------------	6.4	3.70	734	49	59	72	96	100
1530	---------	------------	16.2	3.96	553	62	75	88	98	100
1545	---------	51	28.3	6.12	452	72	84	96	98	100
1600	---------	51	35.2	6.57	390	81	91	99	100	------
Station 725 **Apr. 24; total depth, 35.3 ft**										
1438	19.64	57	1.8	3.30	541	51	64	83	98	100
1454	---------	55	6.0	4.66	540	55	67	86	100	------
1508	---------	55	14.8	5.24	536	70	82	96	100	------
1538	---------	55	26.0	5.74	307	78	89	99	100	------
1615	---------	55	32.1	6.75	319	84	92	99	100	------
Station 985 **Apr. 20; total depth, 41.6 ft**										
1356	21.34	50	1.8	3.00	844	34	42	58	95	100
1414	---------	50	5.8	3.83	520	50	65	82	99	100
1432	---------	50	16.2	4.38	436	63	75	90	100	------
1452	---------	50	30.0	5.46	333	75	87	98	100	------
1718	---------	------------	37.9	5.76	317	80	89	99	100	------
Station 985 **Apr. 23; total depth, 36.3 ft**										
1616	20.06	55	1.8	4.14	447	44	55	87	100	------
1633	---------	------------	6.2	4.55	421	56	67	84	100	------
1713	---------	56	15.2	4.91	364	64	78	92	100	------
1756	---------	------------	26.4	5.20	322	71	84	97	100	------
1818	---------	------------	33.0	5.44	270	84	91	99	100	------

TABLE 6.—*Size distribution of suspended sediment and velocity at selected points above riverbed, April 1961, April and October 1962, and April 1963*—Continued

Mean time	Gage height (feet)	Water temperature (°F)	Height of point above bed (feet)	Velocity (fps)	Suspended sediment: Concentration (ppm)	Percent finer than indicated size (mm): 0.062	0.125	0.250	0.500	1.000
Station 1220 — Apr. 19; total depth, 43.2 ft										
1632	22.00	50	1.8	3.42	648	34	40	50	100	
1646		50	6.0	3.94	518	41	48	61	100	
1702		50	16.9	5.94	291	73	80	93	100	
1717		50	31.1	7.02	241	84	87	97	100	
1743		50	39.3	6.99	225	87	92	98	100	
Station 1220 — Apr. 24; total depth, 41.6 ft										
1210	19.67	54	1.8	3.84	422	48	55	67	99	100
1229		54	5.8	4.15	368	57	64	75	98	100
1248		54	16.2	4.95	282	72	80	91	100	
1308		54	30.0	6.02	235	85	91	98	100	
1334		54	37.9	6.46	219	90	95	100		
Station 1450 — Apr. 20; total depth, 53.6 ft										
1020	21.45	50	1.8	3.55	1,020	19	20	32	100	
1036		50	6.4	4.63	458	41	44	58	98	100
1056		50	19.8	5.24	320	57	62	74	100	
1126		50	38.1	6.50	237	77	82	90	100	
1154		50	48.8	6.71	214	86	90	96	100	
Station 1450 — Apr. 23; total depth, 49.8 ft										
1028	20.14	53	1.8	4.17	561	34	38	48	99	100
1118		53	7.0	4.60	343	55	57	69	100	
1136		53	19.4	5.02	262	73	79	86	100	
1222		53	35.9	5.24	226	84	88	95	100	
1245		53	45.3	5.86	210	88	92	97	100	
Station 1670 — Apr. 19; total depth, 49.4 ft										
1257	22.10	51	1.8	4.75	418	43	46	75	100	
1312		51	6.9	4.72	283	69	73	87	100	
1326		51	19.3	5.99	222	83	85	94	100	
1346		51	35.6	5.37	207	84	87	94	98	100
1401		51	45.0	5.77	199	91	95	98	100	
Station 1685 — Apr. 24; total depth, 45.1 ft										
0928	19.72	55	1.8	3.72	374	53	55	95	100	
0944		54	6.3	4.00	235	78	80	94	100	
1002		54	17.6	4.55	208	90	92	98	100	
1028		54	32.5	5.23	198	92	94	99	100	
1056		54	41.0	5.35	187	94	96	99	100	

TABLE 6.—*Size distribution of suspended sediment and velocity at selected points above riverbed, April 1961, April and October 1962, and April 1963*—Continued

Mean time	Gage height (feet)	Water temperature (°F)	Height of point above bed (feet)	Velocity (fps)	Suspended sediment: Concentration (ppm)	Percent finer than indicated size (mm): 0.062	0.125	0.250	0.500	1.000
Station 600 Oct. 11; total depth, 20.3 ft										
0825	7.05	67	1.5	2.58	513	86	90	99	100	------
0850	7.08	------------	4.7	3.24	450	95	98	100	-----	------
0921	7.11	67	10.0	3.55	430	97	98	100	-----	------
1008	7.15	------------	15.6	3.83	418	98	99	100	-----	------
1137	7.20	68	18.3	3.94	403	98	100	-----	-----	------
Station 1160 Oct. 10; total depth, 26.9 ft										
0902	5.81	66	1.5	2.65	497	53	65	96	99	100
0928	5.81	------------	5.2	3.46	323	80	87	100	-----	------
1004	5.78	66	12.3	3.70	283	88	94	100	-----	------
1117	5.76	------------	21.0	4.07	264	93	96	100	-----	------
1241	5.76	68	24.8	4.11	252	96	99	100	-----	------
Station 1550 Oct. 9; total depth, 29.3 ft										
0939	6.14	65	1.5	2.39	238	48	57	91	98	100
1016	6.13	------------	5.4	3.74	166	64	75	98	100	------
1205	6.11	67	13.0	3.92	145	75	84	100	-----	------
1312	6.09	------------	22.5	4.48	122	85	91	100	-----	------
1429	6.07	68	26.5	4.53	124	86	91	100	-----	------
1963										
Station 475 Apr. 19 ; total depth 15.2 ft										
1244	6.64	64	1.8	3.11	593	68	73	98	100	------
1258	6.64	64	4.4	3.17	501	79	83	99	100	------
1318	6.65	64	8.2	3.46	480	86	90	100	-----	------
1400	6.67	64	12.2	4.03	405	98	96	100	-----	------
Station 825 Apr. 18; total depth, 16.5 ft										
1225	6.90	63	1.8	2.49	1,380	52	57	96	100	------
1323	6.90	63	11.5	4.01	358	83	86	100	-----	------
1406	6.90	------------	14.0	4.18	327	89	93	100	-----	------
Station 1100 Apr. 17; total depth, 23.5 ft										
1258	6.87	61	1.8	2.80	1,360	16	19	87	99	100
1323	6.87	------------	5.1	4.31	441	47	55	100	-----	------
1340	6.88	------------	11.2	4.47	285	71	79	100	-----	------
1402	6.89	------------	17.5	5.23	256	78	84	100	-----	------
1440	6.93	------------	21.4	5.54	204	88	92	100	-----	------

TABLE 6.—*Size distribution of suspended sediment and velocity at selected points above riverbed, April 1961, April and October 1962, and April 1963*—Continued

Mean time	Gage height (feet)	Water temperature (°F)	Height of point above bed (feet)	Velocity (fps)	Suspended sediment: Concentration (ppm)	Percent finer than indicated size (mm): 0.062	0.125	0.250	0.500	1.000
Station 1250 Apr. 19; total depth, 28.5 ft										
1006	6.59	61	1.8	3.57	494	43	49	100	-----	-----
1105	6.61	62	21.0	4.86	214	75	80	100	-----	-----
1146	6.63	-----	25.0	5.10	179	85	89	100	-----	-----
Station 1450 Apr. 18; total depth, 39.0 ft										
0908	6.89	61	1.8	2.91	542	19	22	100	-----	-----
1010	6.89	60	28.2	4.66	99	82	85	100	-----	-----
1100	6.89	-----	35.5	4.81	92	89	91	100	-----	-----
Station 1650 Apr. 17; total depth, 27.5 ft										
1004	6.91	61	1.8	3.83	295	28	33	98	100	-----
1024	6.91	-----	5.4	4.24	203	40	43	100	-----	-----
1041	6.90	-----	12.5	4.40	145	56	60	100	-----	-----
1113	6.90	-----	20.3	4.94	102	79	83	100	-----	-----
1146	6.90	61	25.0	5.16	88	91	95	100	-----	-----

value of the power varies widely for individual verticals, but the average is about 0.69 for all measurements obtained for the comprehensive sets of data.

Other investigators (Anderson, 1942; Colby and Hembree, 1955) have presented data which show that z_1's for sand sizes vary with about the 0.7 power of the fall velocity. The relation of z_1 to fall velocity, however, seems to vary with streamflow for the deep flows at St. Louis. In April 1962, the streamflow was more than 300,000 cubic feet per second and z_1 varied, on the average, with about the 0.8 power of the fall velocity; in April 1961, the streamflow was near 250,000 cfs and z_1 varied with about the 0.7 power of the fall velocity. In October 1962 and April 1963, the streamflow was about 130,000 cfs and the z_1's varied with about the 0.69 and 0.54 powers of the fall velocities, respectively. Streamflow and mean velocity are rather closely related for the Mississippi River at St. Louis, and the average z_1 may, therefore, correlate with mean velocity and, possibly to some extent, with temperature; there are too few comprehensive sets of data available for a check.

CROSS-SECTION SUSPENDED-SEDIMENT SAMPLES

A U.S. P–46 sampler was used to obtain cross-section suspended-sediment samples at the beginning and end of each sampling period except April 1961, when samples were obtained on only 1 day. All samples were collected by the equal-transit-rate method using 10 verticals in the cross section. The cross-section samples were collected in duplicate; one was analyzed for concentration and the other for size distribution (table 7).

TABLE 7.—*Size distribution of suspended sediment in cross-section samples*

Date	Mean time	Water temperature (°F)	Streamflow (cfs)	Suspended sediment											
				Mean concentration (ppm)	Discharge (tons per day)	Percent finer than indicated size (mm)									
						0.002	0.004	0.008	0.016	0.031	0.062	0.125	0.250	0.500	1.000
1961															
Apr. 21	1040	52	221,000	645	385,000	36	41	47	57	71	85	90	98	100	----
1962															
Apr. 17	1230	48	363,000	455	446,000	29	32	39	48	60	69	76	85	99	100
25	1220	56	297,000	314	252,000	33	35	39	48	62	74	84	95	100	----
Oct. 8	1020	65	131,000	318	112,000	56	56	60	63	82	91	95	100	---	----
12	1300	68	136,000	328	120,000	43	45	53	63	79	91	95	100	----	----
1963															
Apr. 16	1235	58	137,000	318	118,000	25	28	---	36	50	58	64	100	---	---
20	0950	62	124,000	415	139,000	19	20	---	31	---	54	57	99	100	----

The concentration of sand is generally very low for the deep flows of the Mississippi River at St. Louis. The measured concentrations of sand for samples obtained for this study ranged from about 29 parts per million on October 8, 1962, to about 190 ppm on April 20, 1963. The extremes of the variation occurred during the two periods when the streamflows and measured total concentrations were nearly the same. In October 1962, only 9 percent of the suspended sediment was sand, whereas in April 1963 about 44 percent of the suspended sediment was sand; however, the average velocity and average depth (table 1) were about 3.30 feet per second and 25 feet in October 1962 and 3.80 feet per second and 22 feet in April 1963.

BED-MATERIAL SAMPLES

A BM–54 sampler was used to collect bed-material samples 1 or 2 days before and again 1–4 days after the suspended-sediment data were obtained. Samples of bed material were generally collected at about 30 equally spaced points in the cross section and were analyzed to determine particle-size distribution (table 8).

The size distribution of bed material varied somewhat; generally about 50–60 percent of the sediment was in the size range of 0.062–0.500 mm, and the median size was about 0.42 mm for the samples obtained in 1961 and in 1962. In April 1963, however, the amount of finer sediment had increased; about 95 percent of the sediment was in the size range of 0.062–0.500 mm, and the median size was about 0.18 mm. The increase of fine sediment in the bed is reflected in the increase in percentage of sand in suspension. The size distribution of bed material at individual verticals in the cross section was quite variable; however, in 1961 and 1962, the size of bed material in the right half of the channel was larger than that in the left half. In April 1963, when the mean size of bed material in the cross section was only about 0.18 mm, the mean sizes in the right and left half of the channel also were about 0.18 mm.

TABLE 8.—*Size distribution of bed material*

Date	Number of sampling points	Streamflow (cfs)	Percent finer than indicated size (mm)									
			0.062	0.125	0.250	0.500	1.000	2.000	4.000	8.000	16.00	32.00
1961												
Apr. 17	28	290,000	3	5	33	64	87	93	97	99	100	-----
21	19	220,000	0	1	32	55	83	92	97	99	100	-----
1962												
Apr. 18	29	354,000	6	6	16	63	85	90	94	96	99	100
26	29	296,000	3	5	10	52	80	88	93	96	99	100
Oct. 8	30	130,000	4	9	24	60	82	87	93	97	99	100
15	29	131,000	3	7	22	54	77	84	90	95	99	100
1963												
Apr. 15	30	145,000	0	2	80	95	99	100	-----	-----	-----	-----
20	30	123,000	0	2	84	95	98	99	99	100	-----	-----

SUMMARY

Four sets of comprehensive hydraulic and sediment data for deep flows are presented with explanations of field and computational procedures. These data cover a range of mean velocity from 3.3 to 5.6 feet per second, mean depth from 22 to 37 feet, and suspended-sediment concentration from 314 to 928 ppm, of which 9–46 percent was sand. The median size of bed material was about 0.42 mm for three of the sets of measurements but only about 0.18 mm for the other set.

Hydraulic data included streamflow measurements, water-surface slopes, cross-sectional areas, and point velocities. Energy gradients were computed by adding a velocity head to the water-surface elevations. Water-surface slopes and computed energy gradients generally break in the vicinity of mile 179. Longitudinal profiles did not show any bed-configuration changes that might be related to breaks in slope, and the breaks in slope seem likely to have been related to changes in channel width and cross-sectional area in the study reach. The maximum difference between the computed energy gradient over the entire study reach and the computed energy gradient upstream or downstream from the break was about 17 percent. The average turbulence, or Karman, constant was computed by three methods, but two of the methods were similar because both were computed from average shear velocities and average velocity differences. Measurements obtained on consecutive days indicated that data from either streamflow-measurement notes or from vertical-velocity profiles were satisfactory for computation of the turbulence constant. The turbulence constants computed from streamflow-measurement data ranged from 0.31 to 0.40 and averaged 0.34; the constants computed from vertical-velocity profiles ranged from 0.32 to 0.40 and averaged 0.35.

The sets of sediment data consisted of point samples, cross-section samples, bed-material samples, and water temperatures. Vertical distributions of concentration of various size ranges of sand were used to define z_1's. The z_1's for various size ranges plotted against corresponding fall velocities indicated that the average power of the fall velocity in the relation $z = V_s/ku_*$ should be about 0.7. The data also indicated that the relation of z_1's to fall velocity may vary with the mean stream velocity.

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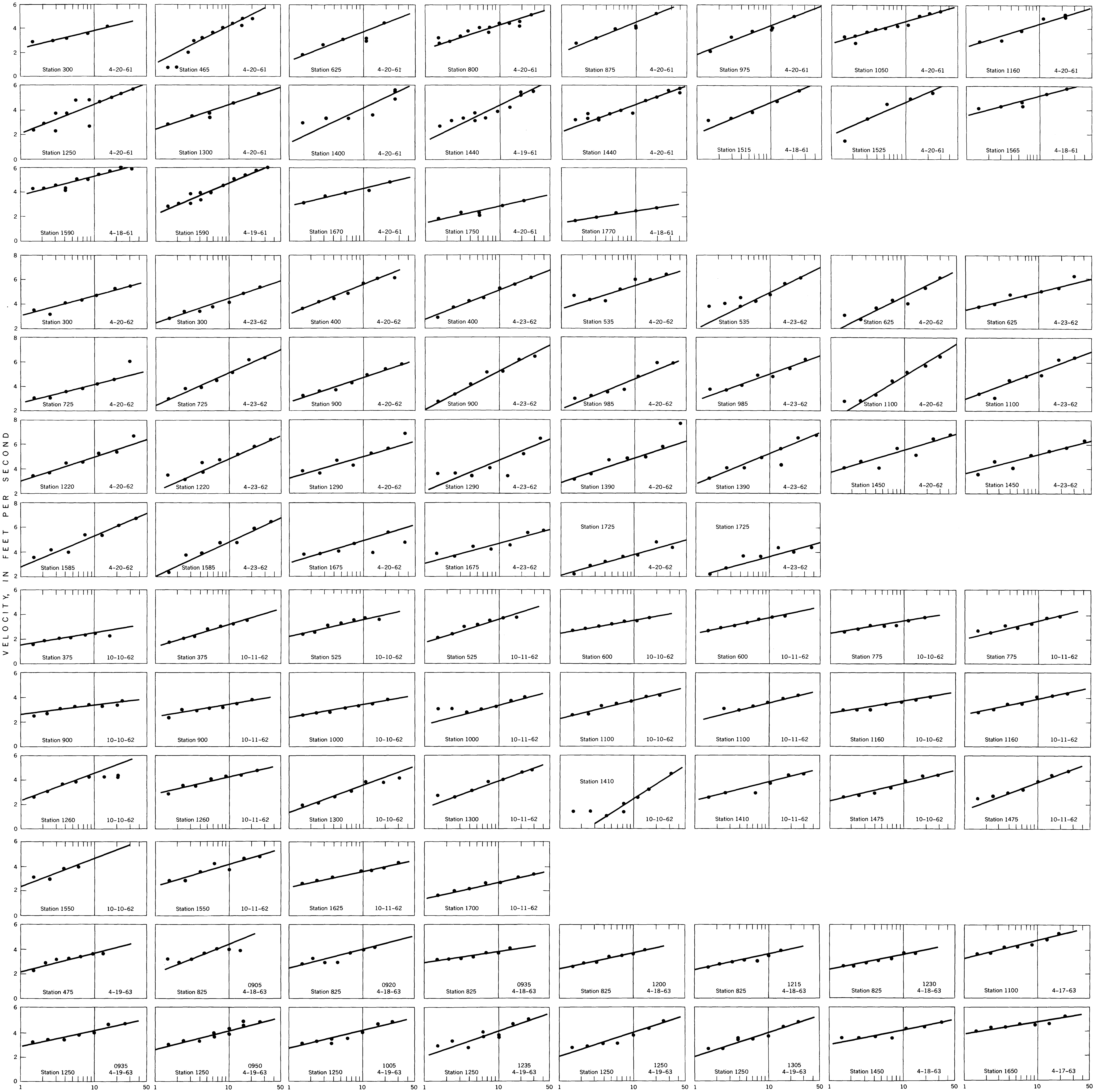
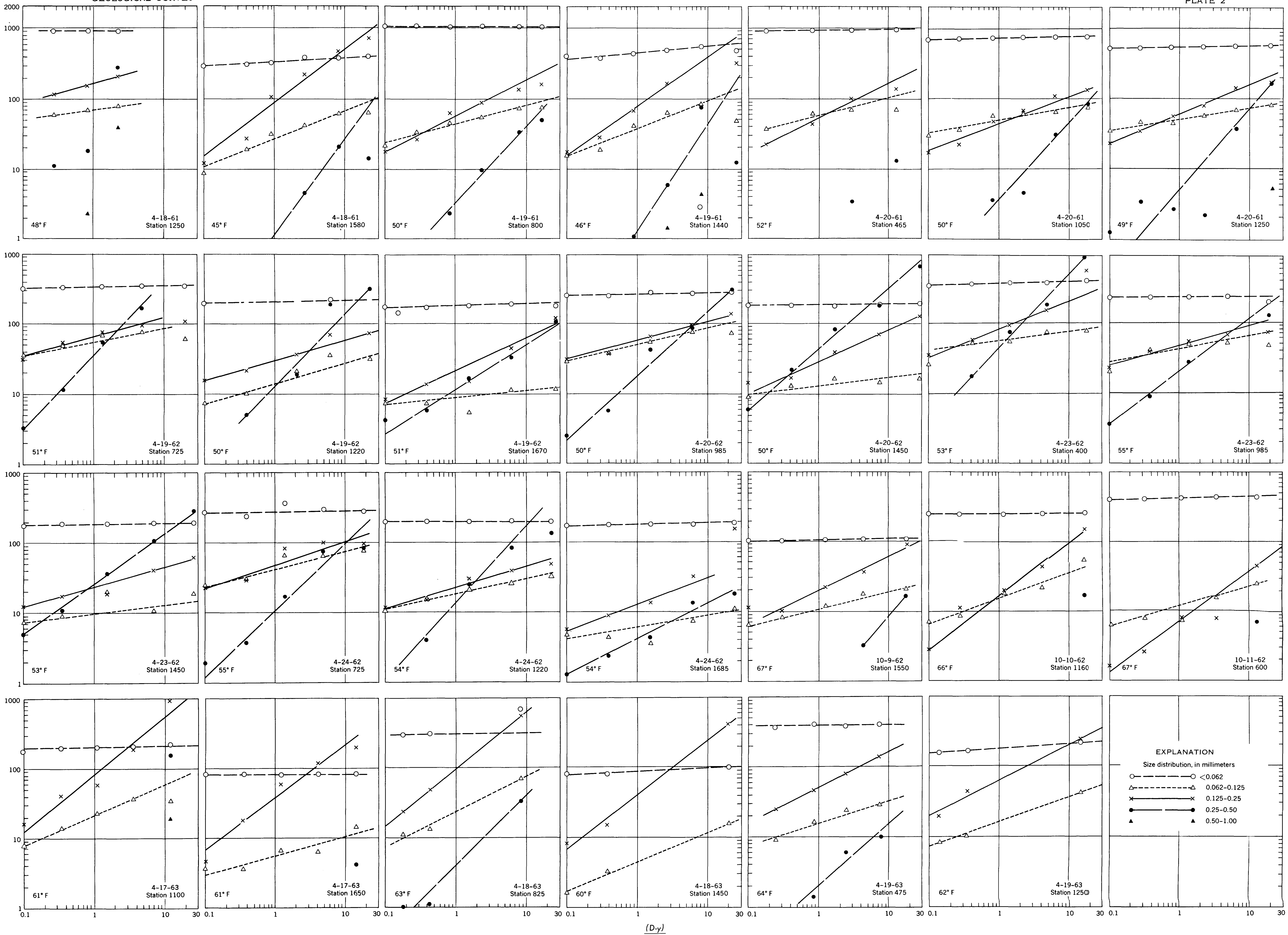


GRAPHS SHOWING VERTICAL DISTRIBUTION OF VELOCITY IN THE MISSISSIPPI RIVER AT ST. LOUIS, MISSOURI



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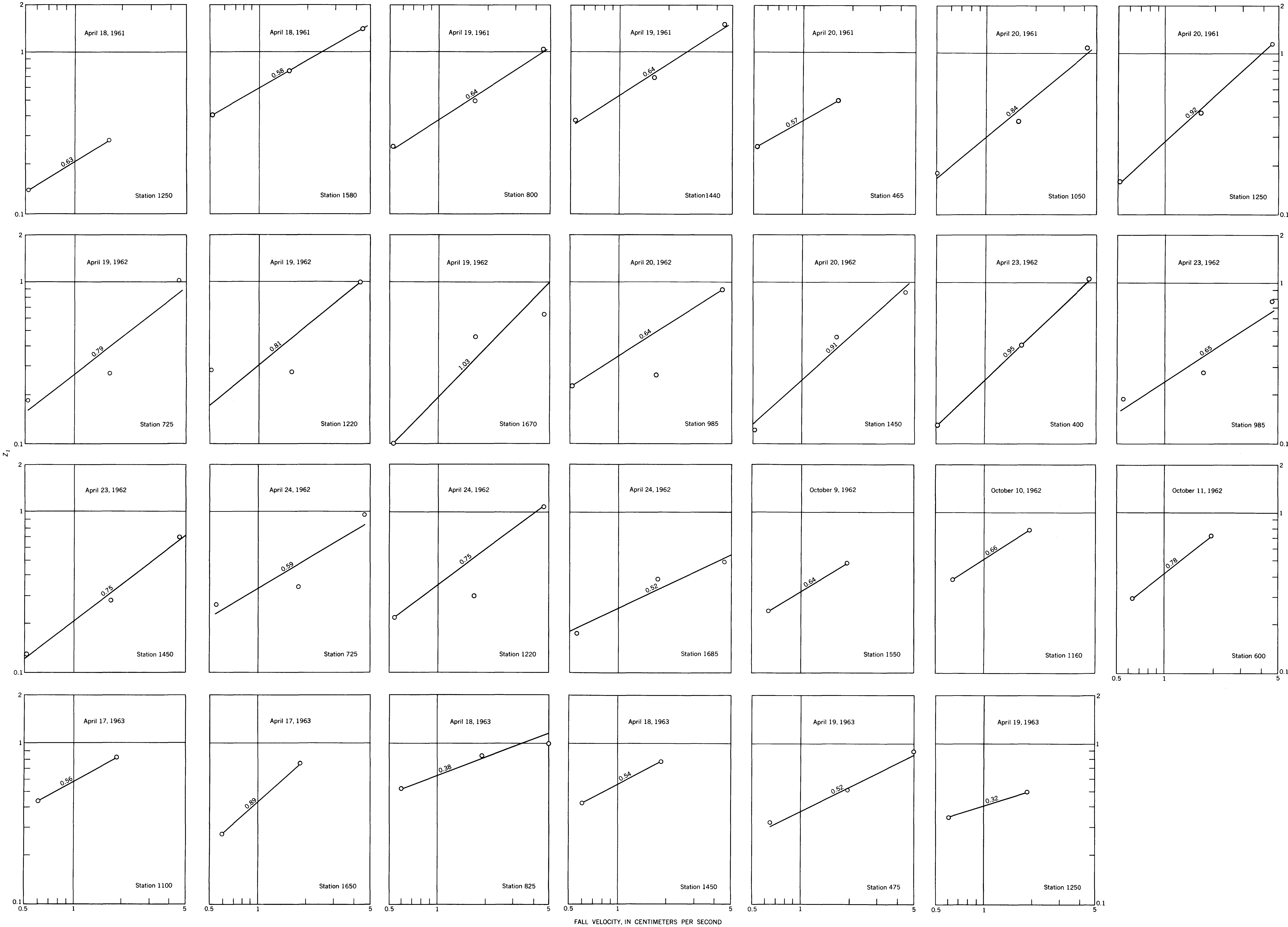

GRAPHS SHOWING RELATION OF z_1 TO FALL VELOCITY IN THE MISSISSIPPI RIVER AT ST. LOUIS, MISSOURI