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US Army Corps of Engineers
Lower Mississippi Valley Division

DOWNWARD TREND IN MISSISSIPPI RIVER SUSPENDED-SEDIMENT LOADS

Potamology Program (P-1)

Report 5

Prepared by

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This investigation was Phase III of a three-phase study of the sediment regime of the Mississippi River Basin. Phase I, conducted under the earlier Lower Mississippi Valley Division (LMVD) Potamology Program (T-1), resulted in the publication of US Army Engineer Waterways Experiment Station Technical Report M-77-1, "Inventory of Sediment Sample Collection Stations in the Mississippi River Basin." The end product of Phase II was LMVD Potamology Program (P-1) Report 1, "Characterization of the Suspended-Sediment Regime and Bed-Material Gradation of the Mississippi River Basin," published in August 1981. The Phase II study identified a downward trend in Mississippi River suspended-sediment loads that apparently began around the middle of the 20th century. The current study deals with suspended-sediment sampling, analysis, and load-computation procedures used at key stations on major streams in the Mississippi River Basin and the possible influence of these procedures on the downward trend.

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Mississippi River Basin	Sediment samplers	Sediment transport
Sediment analysis procedures		Suspended-sediment load

PREFACE

The study reported herein was conducted under the auspices of the Potamology Program (P-1) of the Lower Mississippi Valley Division (LMVD). The Potamology Program is conducted under the direction of the Commander, LMVD, and is a comprehensive study of physical forces that influence the flood-carrying capacity and navigability of the lower Mississippi River. The purpose of the Potamology Program is to define cause-and-effect relationships that result in short- and long-term changes in the stage-discharge relationships of the lower Mississippi River and to develop improved design concepts and criteria for construction of channel stabilization works that will improve flood control and navigation along this river.

The Potamology Program has two major components: Sedimentation, Mississippi River Basin; and Aggradation and Degradation, Mississippi River. This study is part of the Sedimentation component. Future studies will be directed toward development and utilization of a flow sediment model capable of detailed investigations of short- and long-term sedimentation trends locally and throughout the main stem Mississippi River.

The study reported herein was the responsibility of the US Army Engineer District, New Orleans (LMN), New Orleans, LA. The LMN contracted with the US Army Engineer Waterways Experiment Station (WES), Vicksburg, MS, for conduct of the study and preparation of the report. The study was conducted by the WES from 1 February 1981 to 30 September 1982.

This investigation was Phase III of a three-phase study of the sediment regime of the Mississippi River Basin. Phase I, conducted under the earlier LMVD Potamology Program (T-1), resulted in the publication of WES Technical Report M-77-1, "Inventory of Sediment Sample Collection Stations in the Mississippi River Basin." The end product of Phase II was LMVD Potamology Program (P-1) Report 1, "Characterization of the Suspended-Sediment Regime and Bed-Material Gradation of the Mississippi River Basin," published in August 1981. The Phase II study identified a downward trend in Mississippi River suspended-sediment loads that apparently began around the middle of the 20th century. The current study deals with suspended-sediment sampling, analysis, and load-computation procedures used at key stations on major streams in the Mississippi River Basin and the possible influence of these procedures on the downward trend.

Publication had been delayed, with the intention of later including the findings of this study with those of follow-on efforts. However, the anticipated funding required to conduct the follow-on efforts did not become available, and, as a result, this report has remained unpublished until now.

ACKNOWLEDGMENTS

Mr. Elba A. Dardeau, Jr., serving as principal investigator, planned and conducted the tasks necessary to meet project objectives. Mr. Dardeau and Ms. Etta M. Causey prepared this report. Mr. Robert M. Russell, Jr., prepared the figures.

Acknowledgment is also made to Messrs. Billy J. Garrett, LMN; Malcolm P. Keown, WES; W. J. Mathes, Jr., US Geological Survey, Iowa City, IA; and John V. Skinner, Federal Inter-Agency Sedimentation Project, Minneapolis, MN, for their helpful guidance and suggestions during the study.

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CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
acre-feet	1,233.489	cubic metres
cubic feet	0.02831685	cubic metres
cubic yards	0.7645549	cubic metres
feet	0.3048	metres
grains	0.06479891	grams
inches	25.4	millimetres
miles (US statute)	1.609347	kilometres
ounces (mass)	28.34952	grams
ounces (US fluid)	29.57353	cubic centimetres
pints (US liquid)	0.4731765	cubic decimetres
pounds (mass)	0.4535924	kilograms
pounds (mass) per cubic foot	16.01846	kilograms per cubic metre
quarts (US liquid)	0.9463529	cubic decimetres
square miles	2.589998	square kilometres
tons (2,000 pounds, mass)	907.1847	kilograms

DOWNWARD TREND IN MISSISSIPPI RIVER SUSPENDED-SEDIMENT LOADS

PART I: INTRODUCTION

Background

1. Historic records of ancient civilizations, such as China, Egypt, and Mesopotamia, show that man has always been subjected to both the beneficial and harmful influences of fluvial sediment.* Seasonal floods provided the moisture and soil nutrients necessary for sustained agricultural productivity. On the other hand, excessive streamflows with their accompanying peak sediment loads sometimes impacted severely on floodplain farming and other riparian pursuits. Even though fluvial sediment has always significantly affected the development of civilizations, the processes of sediment transport and deposition have not been investigated until relatively recent times (Graf 1971).

2. The earliest recorded study of suspended sediments was conducted by two Frenchmen, Gorsse and Subuors, who analyzed Rhône River samples collected approximately 35 miles** upstream from the mouth at Arles, France, in 1808 and 1809 (Humphreys and Abbot 1876). American studies began in 1838 when CPT A. Talcott sampled the lower Mississippi River main stem in Southeast and Southwest Passes near the mouth.† Since Talcott's time, many individuals and Government agencies have measured suspended-sediment concentrations and calculated loads of major streams in the Mississippi River Basin.

3. CPT Andrew Atkinson Humphreys and LT Henry Larcom Abbot made the first comprehensive attempt to understand the hydraulic and sedimentary characteristics of the Mississippi River Basin. In addition to making numerous hydraulic and geometric measurements in the Mississippi, they examined the collection and analytical techniques and the results of earlier studies. After spending several years in Europe studying the work on streams of that

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* Appendix A is a glossary of sediment-related terms.

** A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 4.

† The term "lower Mississippi River" refers to that reach of the main stem of the Mississippi River downstream from the confluence of the Mississippi and Ohio Rivers at Cairo, IL. The upper Mississippi River is that reach of the main stem upstream from Cairo.

continent, Humphreys realized that none of the European river systems were comparable to the Mississippi and none of the existing hydraulic theories were appropriate. Thus, Humphreys and Abbot had to develop their own theories to describe the complex Mississippi. Their report (Humphreys and Abbot 1876) is considered a classic in hydraulic engineering literature.

4. In 1930, the US Army Engineer Waterways Experiment Station (USAEWES) published Paper H (USAEWES 1930), a summary of sediment investigations in the Mississippi River Basin prior to that time. Paper H described sampling and analysis procedures and the available data resulting from these early investigations. The following year, the USAEWES published Paper U (USAEWES 1931) as an update to Paper H.

5. Several Federal agencies, including the US Army Corps of Engineers (CE), formed a committee in 1939 to study sediment data collection problems and to standardize the methods and equipment used for sampling and analysis. This organization (now known as the Federal Inter-Agency Sedimentation Project (FISP)) was a subcommittee of the Federal Inter-Agency Committee on Water Resources. The subcommittee published a report in 1940 on field practices and equipment used for sampling suspended sediment throughout the world (FISP 1940). The following year, the FISP documented methods used to analyze sediment samples (FISP 1941b).

6. The Water Resources Planning Act of 1965 and other legislative acts have authorized special interagency groups to conduct a number of comprehensive basin studies for major component watersheds of the Mississippi River Basin. Most of these studies have addressed the subject of fluvial sediment, reviewing the results of prior sediment investigations and covering such topics as sediment yield and reservoir deposition.

7. Under the Lower Mississippi Valley Division (LMVD) Potamology Program (T-1), USAEWES published an "Inventory of Sediment Sample Collection Stations in the Mississippi River Basin" (Keown, Dardeau, and Kennedy 1977) in an effort to update Papers H and U (paragraph 4). Besides a comprehensive inventory of sediment sample collection stations pertinent to the CE mission in the basin and narrative summaries for key stations selected from the inventory, the report also included a general discussion of physiographic and cultural impacts on sediment flow through basin streams.

8. More recently, under the LMVD Potamology Program (P-1), Keown, Dardeau, and Causey (1981) characterized the suspended-sediment regime and bed-material gradation of the Mississippi River Basin using data from sediment

sample collection stations and information relevant to the natural environmental characteristics and cultural history of the basin. Their analysis showed a significant downward trend in the average annual suspended-sediment loads transported by the Mississippi River and many of its tributaries. The trend identified by Keown, Dardeau, and Causey (1981) apparently began around the middle of the 20th century and has continued through the present time.

Purpose and Approach

9. The purpose of this study was to evaluate the sampling, analysis, and load-computation procedures used to obtain the values of reported suspended-sediment loads in the Mississippi River Basin and to assess the influence of these procedures on the identified downward trend in Mississippi River suspended-sediment loads. This task was approached by (a) reconstructing a history of the development of these procedures and (b) determining if the sampling, analysis, and load-computation procedures themselves had any influence on the downward trend.

PART II: SUSPENDED-SEDIMENT STUDIES IN THE MISSISSIPPI RIVER BASIN

10. Since 1838, a number of suspended-sediment studies have been conducted in the Mississippi River Basin. Part II provides a historic overview of these studies, showing how sampling, analysis, and load-computation procedures first evolved independently and later became standardized with the formation of the FISP in 1939. This history begins with CPT Talcott's 1838 study and concludes with the findings of the LMVD Potamology Programs, (T-1) and (P-1). The individual sediment investigations are presented chronologically until the establishment of the FISP in 1939, after which the major comprehensive programs and pertinent legislative acts are covered.

Nineteenth-Century Studies

11. Suspended-sediment studies began in the United States with CPT Talcott's 1838 investigation on the main stem of the lower Mississippi. The following paragraphs provide a history of the various 19th century suspended-sediment investigations beginning with Talcott's and ending with that of the Mississippi River Commission (MRC) from 1879-1881.

Talcott: 1838

12. CPT Talcott, CE, directed observations "to determine the amount of earthy matter in the mouths of the Mississippi" (USAEWES 1930) in conjunction with a hydrographi survey of the lower main stem in 1838. He collected samples in both Southeast and Southwest Passes and reported his results as grains of sediment per 100 grains of water. The ratio of sediment to water (concentration ratio)* was 1:1,724 for Southeast Pass. Talcott determined both surface and below-surface ratios for Southwest Pass as 1:1,580 and 1:1,043, respectively, and he adopted a combined ratio for Southwest Pass of 1:1,256. Extracts from the report by CPT Talcott and the full reports of his two assistants, Messrs. W. H. Slidell and George G. Meade, are presented in Appendix A of Humphreys and Abbot (1876).

* In some of these early studies, concentration ratios (based on weight) were used; in others, only proportional volumes were reported. If available or feasibly derivable, sediment load estimates are presented.

Riddell: 1843 and 1846

13. In July 1843, Professor J. L. Riddell determined that the average concentration ratio of s··pended sediment to Mississippi River water was 1:1,245, based on the a· ·ysis results of lower Mississipp· River sediment samples taken at Randolph, TN (Mile 183*); Carthage Landing, MS (Mile 709); and New Orleans, LA (Mile 969) (USAEWES 1930). In a letter to Sir Charles Lyell, Professor Riddell described his 1843 laboratory procedure:

> The sediment was allowed near ten days for natural subsidence; it was then carefully collected, allowed to dry spontaneously, and when effectually dry was carefully weighed (Humphreys and Abbot 1876).

Between 21 May and 13 August 1846, Riddell made a second set of 18 surface observations in the lower Mississippi River at New Orleans at 3-day intervals. He collected his samples in a pail, agitated the pail, and then measured two 1-pt samples. After the samples settled for 2 days, Riddell then decanted approximately two-thirds of the clear water and poured the remaining water containing the sediment through double filters. After the filters were dry, he weighed the contents and used these weights to compute an average concentration ratio of 1:1,158 (USAEWES 1930).

Brown: 1846-1848

14. Mr. Andrew Brown analyzed the contents of 484 surface samples (of known volume) collected between 1 July 1846 and 30 July 1848 at Natchez, MS (lower Mississippi River Mile 706). These samples represented "the different conditions and stages for the river's height and velocity" (USAEWES 1930). After each sample had been collected, Brown poured it into a 48-in.-long cylindrical tin vessel. Water in the tin column dripped slowly through a small brass cock into a glass vessel while the sediment settled in the column. In 1848, Brown reported that he had collected a total of 46.5 in. of sediment out of a total water column height of 22,232 in. represented by the 484 samples. Based on an assumed final settlement of 44 in., he concluded that the mean proportional volume of sediment to water was 1:528 (USAEWES 1930).

Marr: 1849 and 1851

15. LT R. A. Marr, US Navy, conducted a series of daily surface observations beginning in April and continuing through part of July 1849 at

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* Lower Mississippi River mileages given in Part II of this report were measured downstream from Cairo, instead of upstream from Head of Passes, as they are today.

Memphis (lower Mississippi River Mile 226). He placed a known quantity of river water in a box, removed the water as it became clear, and weighed the dry sediment. The average concentration ratio was 1:596. He conducted a second series of measurements at the same location between 1 March 1850 and 1 March 1851. Humphreys and Abbot (1876) provide an extract from LT Marr's second series of observations.

> A quantity of water has been daily obtained from the middle of the surface of the river, and two quarts of it placed in a barrel to settle. In bulk, the sediment thus obtained has been found to be in proportion to the water by which it was deposited as 1 to 2950.

Existing documentation on LT Marr's two experiments is insufficient to determine if the reported changes in concentrations between 1849 and 1851 could have been attributable to changes in the river itself or to differences in methods he used (USAEWES 1930).

Mississippi Delta
Survey: 1851-1853, 1858

16. The Mississippi Delta Survey consisted of studies conducted from 1851 through 1853 by Professor C. G. Forshey at Carrollton, LA, and during 1858 by Messrs. Henry E. Fillebrown, W. E. Webster, and C. L. Jones at Columbus, KY.

17. Forshey: 1851-1853. For a 1-year period that began on 17 February 1851, Professor Forshey collected samples 6 days each week (except Sundays) from three verticals in a cross section at Carrollton, LA (Mile 960). These verticals were positioned: (a) "about 300 ft from the east (left) bank," (b) "in the middle of the river," and (c) "about 400 ft from the west (right) bank" (Humphreys and Abbot 1876). Forshey's sampling device was a small weighted keg. A large valve was attached to each end of the keg. The valves permitted free passage of the water through the body of the sampler during descent to either middepth or near bottom, but they were closed when the keg was being pulled back to the surface. Three samples were taken from the left-bank and center verticals ("high-water" depths of 100 ft), while only surface and near-bottom samples were collected from the right-bank vertical ("high-water" depth of 40 ft) (Humphreys and Abbot 1876). In the laboratory,

> One hundred grammes of water were accurately measured from each of the eight samples, and each parcel was separately preserved in a precipitating bottle. After receiving six days' contributions, these bottles were set aside for two weeks to settle. The greater part of the water, then perfectly clear, was removed by a

> syphon. The remainder, after thorough shaking, was poured upon a double filter composed of two pieces of filtering paper of exactly equal weight. The bottle was then rinsed with clear water and again emptied upon the filter, so as to secure all the sediment. After becoming quite dry, the two papers were separated and placed--one containing all the sediment of the 600 grammes of river water, and the other perfectly pure--in opposite sides of a very delicate balance (correct to a milligramme). The difference of weight, which was, of course, the exact weight of the sediment, was then accurately ascertained (Humphreys and Abbot 1876).

18. In 1852, Forshey collected only surface samples and used a coefficient of 1.2 to obtain an average suspended-sediment concentration for the Carrollton cross section (FISP 1940, Hooker 1896, Humphreys and Abbot 1876, USAEWES 1930). Forshey's concentration ratios were as follows (Humphreys and Abbot 1876):

	Concentration Ratio		
Period	Maximum	Mean	Minimum
1851-1852	1:681	1:1,808	1:6,383
1852-1853	1:572	1:1,499	1:8,584

The estimated annual suspended-sediment load at Carrollton for 1851-1852 was 379 million tons computed by using concentration and discharge data (USAEWES 1930). No estimate was made for 1852-1853. Commenting on Forshey's data, Humphreys and Abbot (1876) stated that "the Mississippi water is not charged to its maximum capacity with sediment."

19. Fillebrown, Webster, and Jones: 1858. From 15 March to 15 November 1858, Fillebrown, Webster, and Jones made intermittent measurements of suspended-sediment concentrations at the surface of the lower Mississippi River, 20 miles downstream from the Ohio River confluence at Columbus, KY. Both "Ohio River" (near the left or east bank) and Mississippi River water (near the right or west bank) were sampled at the surface and analyzed separately. Based on Forshey's work at Carrollton (paragraphs 17-18), they multiplied the numerical mean of the results of the surface observations by a coefficient of 1.2 (USAEWES 1930). These observations

> . . . demonstrate that the Mississippi and the Ohio waters do not mingle until after passing Columbus. . . . Where the waters do become completely blended is not known, but they are very distinct at Columbus. . . (Humphreys and Abbot 1876).

Generally, the results showed that the average concentration ratio was 34 percent greater in Mississippi than in "Ohio" waters; however, the results indicated considerable variation (USAEWES 1930). Humphreys and Abbot (1876) concluded from the study at Columbus, like that at Carrollton, that the Mississippi water was not "charged" to its maximum capacity with sediment.

Humphreys and Abbot: 1861 and 1876

20. In the spring of 1850, the Louisiana Legislature asked Congress to task the CE with finding a way to curb the floods that periodically devastated the Mississippi alluvial valley. A special Army Engineer Board was established in November 1850 to plan a way for "taming" the lower Mississippi. Before such a plan could be formulated and implemented, the Board needed data on flows under varying conditions; on how currents attacked the bed and banks; on probable elevation, frequency, and duration of future floods; and on the sediment loads. Not only were such data unavailable, but the Board also had to develop techniques for measuring them. The job of finding the answer to these and many other scientific and engineering questions was given to CPT Humphreys, whose initial assignment was to make a complete topographic and hydrographic survey of the river from Cape Giradeau, MO, to the Gulf of Mexico. The magnitude and complexity of Humphreys' undertaking were scarcely appreciated.

21. In early 1851, field parties began collecting information on old flood marks and existing levees, including the size, frequency, nature, and cause of breaks in the levees. They selected various points along the river to measure stream velocity, examine the transport of suspended sediment and bed material, and evaluate the effects of wind on water movement. Humphreys became ill in the summer of 1851 and had to discontinue the field survey. During his illness, he received permission to visit the delta rivers in Europe and examine existing data to determine what engineers had done to control floods over the centuries. Humphreys' research included many streams, such as the Danube, Rhine, and Po, and extended as far back in history as the Roman Empire. None of the European engineers had ever studied a river with discharges and sediment loads comparable to the Mississippi; therefore, little of the European work had specific application to the Mississippi.

22. After his return from Europe in 1854, Humphreys was placed in charge of the Pacific Railroad Survey, thus delaying the resumption of the Mississippi River Survey until 1857, at which time LT Abbot was assigned to assist him. The field personnel under these two engineers measured flow

velocities at various depths and made observations of water surface slope and sediment movement in various reaches of the lower Mississippi, Ohio, Hatchie, St. Francis, White, Arkansas, Yazoo, Red, Black, Atchafalaya, and Old Rivers. After studying their own data and those collected during previous studies, Humphreys and Abbot (1876) concluded that:

> If the mean annual discharge of the Mississippi be correctly assumed at 19,500,000,000,000 cubic feet, it follows that 812,500,000,000 pounds (406.2 million tons) of sedimentary matter, constituting one square mile of deposit, 241 feet in depth, are yearly transported in a state of suspension to the Gulf.

Commenting on the quantity of bed material transported by the Mississippi River, Humphreys and Abbot (1876) stated that:

> Besides the amount held in suspension, the Mississippi pushed along to the Gulf large quantities of earthy matter. . . . No exact measurement of the amount of the annual contributions to the Gulf from this source can be made, but from the yearly rate of progress of the bars into the Gulf, it appears to be about 750,000,000 cubic feet, which would cover a square mile about 27 feet deep.

23. The Humphreys and Abbot report, initially published in 1861, was the first extensive hydrographic survey of a major river basin that also provided a critical review of previous hydraulic and sediment studies. Their study concluded that a system of levees should be built from Cape Giradeau, MO, to the mouth of the river. Implementation of the Humphreys and Abbot plan was delayed by the Civil War (1861-1865). A revised version of the report was published in 1876 and translated into the principal European languages (Humphreys and Abbot 1876; US Army Corps of Engineers 1961).

Henry Flad, CE: 1867

24. Under the direction of Mr. Henry Flad, CE, the St. Louis Board of Water Commissioners performed experiments in 1867 "to determine the quantity of mud carried in the Mississippi water" (USAEWES 1930). Flad analyzed samples collected from a pump cylinder at the city waterworks (upper Mississippi Mile 190) and reported that the concentration ratios ranged from 1:680 to 1:219. He compared water from the Missouri side (right bank), visibly identifiable as "Missouri River" water, with that from the Illinois side (left bank) by filtering and weighing equal quantities obtained from near both banks at the same time. The proportion of sediment in the water taken from the Missouri side to that in the water taken from the Illinois side was approximately 2.5:1 (USAEWES 1930).

The CE in South Pass: 1877-1898

25. For a 1-year period beginning 26 March 1877, the CE made suspended-sediment measurements with a trap bucket in South Pass. CPT M. R. Brown, CE, computed the total suspended-sediment load through South Pass upstream from Grand Bayou during this initial observation as 23.4 million cu yd (37.3 million tons*). He estimated that South Pass carried 10 percent of the suspended load of the Mississippi (based on the proportion of the total Mississippi River discharge carried by South Pass), making the 1877-1878 annual estimate for all passes of the river approximately 234 million cu yd (373 million tons). Between 1879 and 1898, the CE collected 1-qt samples twice each week in South Pass near Port Eads. Concentration ratios for 1879-1898 ranged from 1:2,191 to 1:910, with the mean being 1:1,453. Annual suspended-sediment loads for South Pass for this period ranged from 18.5 to 53.2 million tons. The discharge and suspended-sediment load through South Pass was reported as 10 percent of the river's total for 1877-1881 but only 8 percent for 1894. Paper H (USAEWES 1930) stated that if a constant decrease in the percentage of discharge carried by South Pass during 1881-1894 time-frame were assumed, then the estimated mean annual suspended-sediment load through all passes of the Mississippi River for the period 1879-1893 would have been 314.5 million tons.

Low Water Board: 1878-1879

26. On 8 July 1878, the Low Water Board was organized to improve low-water navigation of the Mississippi and Missouri Rivers. The Board directed suspended-sediment observations at locations on the upper Mississippi River at Burlington, IA (Mile 428) and St. Louis (Mile 197); the lower Mississippi River at Columbus (Mile 21), Hampton Landing, AR (Mile 242), Helena, AR (Mile 306), and Kings Point, MS (Mile 595); the Missouri River at St. Charles, MO (Mile 29); the Ohio River at Paducah, KY (Mile 45**); the White River at Clarendon, AR (Mile 134); the Arkansas River at Pine Bluff, AR (Mile 110); and the Red River at Alexandria, LA (Mile 111). These measurements by the Low Water Board provided much valuable data on the concentration and gradation of suspended sediment in the major streams of the Mississippi River Basin. Little detailed documentation remains on the kinds of sampling equipment or the

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* CPT Brown used a density of 118 lb/cu ft.

** Ohio River mileage was measured upstream from the Mississippi-Ohio confluence at Cairo instead of downstream from the Ohio-Allegheny-Monongahela confluence, as it is currently measured.

methods of analysis used by the Low Water Board. On 28 June 1879, Congress created the MRC to continue the work that the Board had begun. Concentration and sediment load data resulting from the miscellaneous Low Water Board observations were published in Paper H (USAEWES 1930).

The MRC: 1879-1881

27. Between November 1879 and November 1880, the MRC collected surface, middepth, and near-bottom samples in eight verticals evenly spaced across sections of the lower Mississippi River at Fulton, TN (Mile 175); Lake Providence, LA (Mile 542); and Carrollton, LA (Mile 960). The MRC also sampled a number of cross sections on the upper Mississippi River from 1 October 1880 through 1 October 1881, including Prescott, WI (Mile 847); Winona, MN (Mile 760); Clayton, IA (Mile 647); Hannibal, MO (Mile 329); Grafton, IL (Mile 234); and St. Louis, MO (Mile 195). Surface samples were collected with a pail. Middepth and near-bottom samples were obtained with a slip bottle, a hollow iron cylinder (6 in. long with an 8-in. external diameter closed at its upper end) that moved on a vertical axis. At the appropriate depth, an observer in a boat released a string-activated catch to fill the slip bottle. Samples were halved, and each half was combined both horizontally and vertically, with the horizontal combinations consisting of 2 oz from the same horizontal level in all eight verticals and the vertical combination being 2 oz from each of the three depths in a single vertical. An MRC laboratory filtered and furnace dried the samples for 3 hr at 120° C and then weighed them to the nearest milligram. Extant data resulting from these MRC observations were published in Paper H (USAEWES 1930).

Early 20th-Century Studies

28. Mississippi River Basin sediment sample collection activities continued into the early part of the 20th century as newer devices were developed to collect samples. The work by Humphreys and Abbot (1876) and the establishment of the MRC in 1879 had set the stage for more extensive studies in the basin by a number of agencies. These early 20th-century studies are presented chronologically, ending with the establishment of the FISP in 1939.

Board of Water Commissioners of St. Louis: 1905-1922

29. Between 1 April 1905 and 1 April 1922, the Board of Water Commissioners of St. Louis analyzed suspended-sediment samples collected at its

waterworks (upper Mississippi River Mile 190) in much the same manner as Flad had done in 1867 (paragraph 24). Concentration ratios determined during the course of these observations ranged from a minimum annual mean value of 1:943 to a maximum of 1:436. The overall annual mean during the 17-year period was 1:659. Because the intakes used in this study were located near the right (west or Missouri) bank, the samples contained a disproportionate amount of Missouri River water. Thus, the concentration values cannot be treated as representative of the entire cross section at St. Louis. No sediment loads were determined in conjunction with these observations (USAEWES 1930).

US Geological Survey (USGS): 1906-1907

30. The USGS made a number of sediment investigations in the Mississippi River Basin during 1906 and 1907 in conjunction with water quality studies of surface waters of the United States. Four-ounce samples were collected daily either from waterworks intakes, from the surface, or from below the surface using a weighted bottle. Samples were taken from a number of locations on the upper Mississippi, lower Mississippi, Minnesota, Rock, Iowa, Des Moines, Illinois, Missouri, Cumberland, and Tennessee Rivers. In the laboratory, the contents of the 4-oz bottles collected at the same location on the same day were combined, filtered through an asbestos mat in a porcelain crucible with a perforated bottom, dried for 1 hr at 180° C, and then weighed. Paper H (USAEWES 1930) shows the ranges of concentrations of suspended sediment for each location sampled by the USGS and contains some estimates of upper Mississippi suspended-sediment loads based on these 1906 and 1907 concentrations and on discharge measurements obtained by the MRC in 1881.

The MRC at Pointe-à-la-Hache, LA: 1927

31. Between 16 January and 24 June 1927, the MRC conducted investigations on the lower Mississippi River from Mile 1,019.3 to Mile 1,029.9 to determine the effect that the operation of the (then existing) Pointe-à-la-Hache, LA, spillway had on a number of parameters that influence the lower Mississippi River flow regime. These elements included high-water slope, scour and fill of the riverbed, volume of discharge, and suspended-sediment load. The MRC collected sediment samples with a specially designed sediment trap (Figure 1). This device was a 2-in.-diam, 11-in-long iron pipe connected at both ends to crane brass swinging check valves. These valves remained open during descent and closed when the sampler was stationary or pulled upward. Both surface and middepth samples were collected in eight verticals, equally

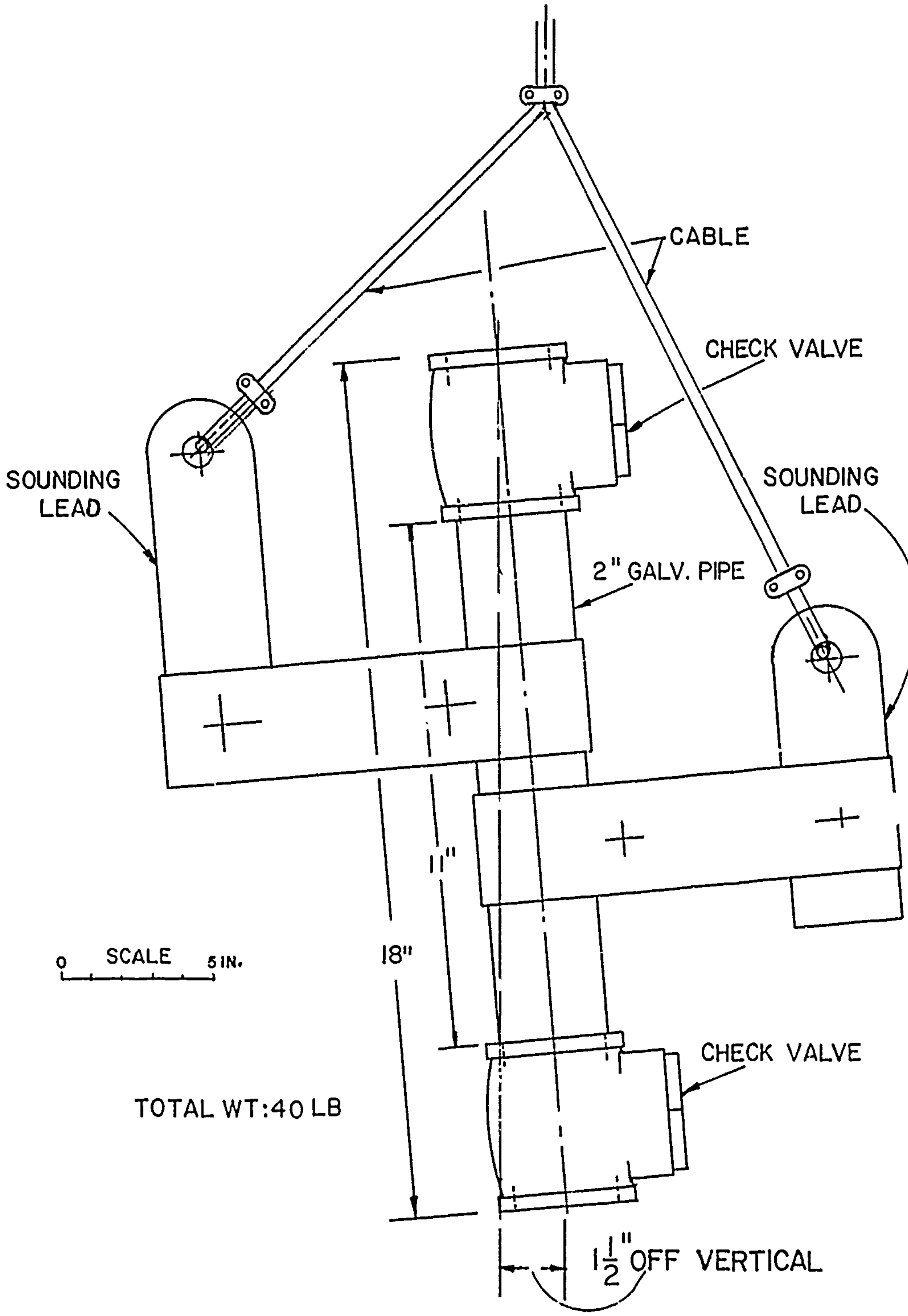

Figure 1. The MRC sediment trap (after USAEWES 1931)

spaced across the sediment ranges upstream and downstream from the spillway. The St. Louis Waterworks laboratory analyzed the samples. The 100-cu cm sediment samples were placed in platinum crucibles of known tare weights, evaporated, oven dried at 104° C, and then weighed. Originally, reported as cubic yards per day, the following results for the period of observation have been converted to tons per day (USAEWES 1930):

Location from Spillway	Daily Suspended-Sediment Loads tons × 10^6*		
	Maximum	Mean	Minimum
Upstream	4.0	1.8	1.1
Downstream	1.9	1.5	0.8

* Using a density of 118 lb/cu ft.

US Army Engineer (USAE)
Division, Missouri River: 1929-1930

32. The USAE Division, Missouri River, under the direction of Dr. L. G. Straub, collected samples from the Missouri River and tributaries during 1929 and 1930. Straub had developed the Straub (or USAE District, Kansas City*) sampler (Figure 2), which used a 1-pt milk bottle that was secured in the sampler frame. The bottle was closed by a valve prior to sampling and then opened at the desired depth by a messenger weight. When the bottle filled, the sampler closed by a cork float within the bottle. At the Missouri River stations, samples were taken at 0.2 and 0.8 depth, with coefficients of 5 and 3, respectively, applied to the sediment concentration observed at those depths to obtain the mean of the vertical. The spacing between verticals ranged from 40 to 150 ft. On tributary stations, only single surface samples were collected at midstream, and coefficients ranging from 1.1 to 1.2 were applied to obtain the mean of the cross section. Straub's choices of points in a vertical and coefficients were based on rational derivation verified by experimentation. The reports by Straub (1935) and the FISP (1940) provide details on the Straub method.

The MRC: 1929-1931

33. Beginning in 1929 and continuing through 1931, the MRC collected suspended-sediment samples in major streams in the Mississippi River Basin.

* Personal Communication, June 1982, Paul C. Benedict, USGS, Menlo Park, CA.

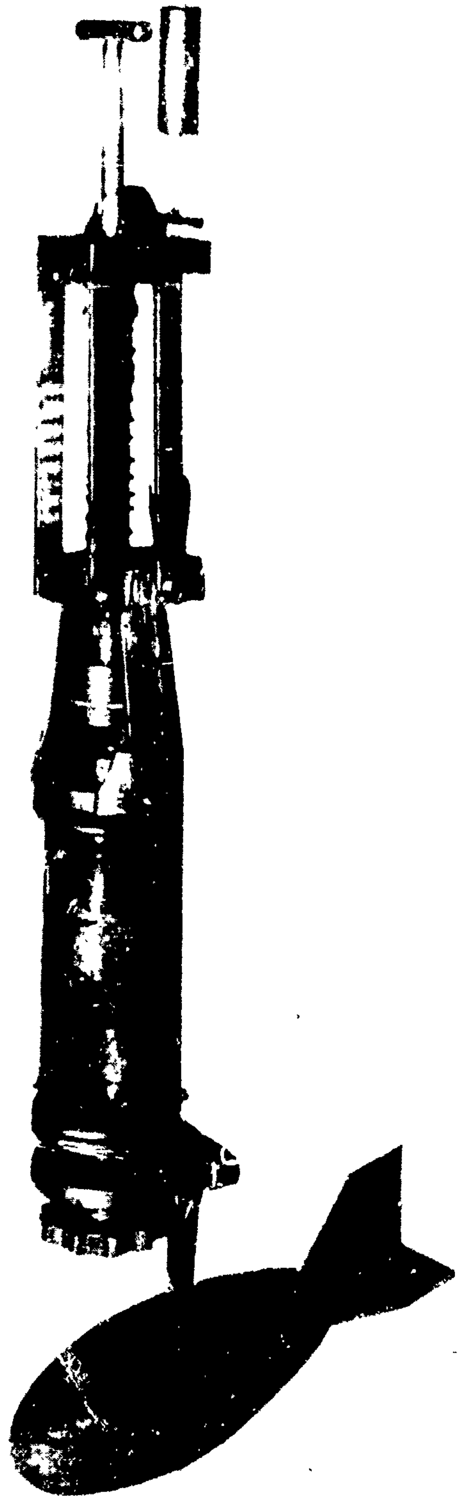

Figure 2. The Straub (or USAE District, Kansas City) sampler (USAE Division, Missouri River, undated)

This agency took surface samples with a pail and below-surface samples with the MRC sediment trap (Figure 1). Samples were shipped to the USAEWES laboratory for analysis. In the laboratory, the volume of the sample was measured to the nearest cubic centimetre, recorded, and returned to the sample bottles. After the sediment samples had settled, the clear water was siphoned to within about 0.5 in. of the deposit. Colloids held in suspension were flocculated and settled by the addition of two or three drops of concentrated hydrochloric acid. The sediment and remaining water were then shaken and poured into evaporating dishes, which were placed on a hot plate. After the residue became thick and soupy, the evaporating dishes were then transferred to an oven and thoroughly dried at a temperature of 110° C. After drying, the samples were placed in a desiccator, allowed to cool for about 2 hr, and then weighed to the nearest 0.10 mg. The resulting data from these studies were published in USAEWES Papers H and U (USAEWES 1930, 1931).

US Department of Agriculture: 1930

34. Between 1924 and 1930, the US Department of Agriculture (USDA) collected suspended-sediment samples in Texas streams, including the Red River. The Red River was sampled in 1930 with a grab sampler that has been referred to in various publications as a Texas, USDA, or Faris sampler (Figure 3).* The collected samples were placed in glass tubes to settle for 7 days before being filtered, dried in an automatic electric oven at 110° C for 1-1/2 hr, cooled in a desiccator, and then weighed on an analytical balance to the nearest 0.005 g (Faris 1933; FISP 1957a; Welborn 1969). The resulting data collected with the Texas sampler were published in USDA Technical Bulletin 382 (Faris 1933).

The USAEWES: 1930-1931

35. In 1930, the USAEWES, then as a part of the MRC, compiled data from prior sediment investigations on the Mississippi River and its tributaries. Both published and unpublished studies were included. The end product of this study was the first USAEWES technical publication, Paper H (USAEWES 1930). Paper H contained all available data on suspended-sediment concentrations and loads for Mississippi River main stem and other important basin streams. The report also presented arguments concerning the influence of the Missouri River on sediment concentrations in the Mississippi main stem. In December 1931,

* The Texas sampler is discussed in more detail in Appendix B, paragraph 5.

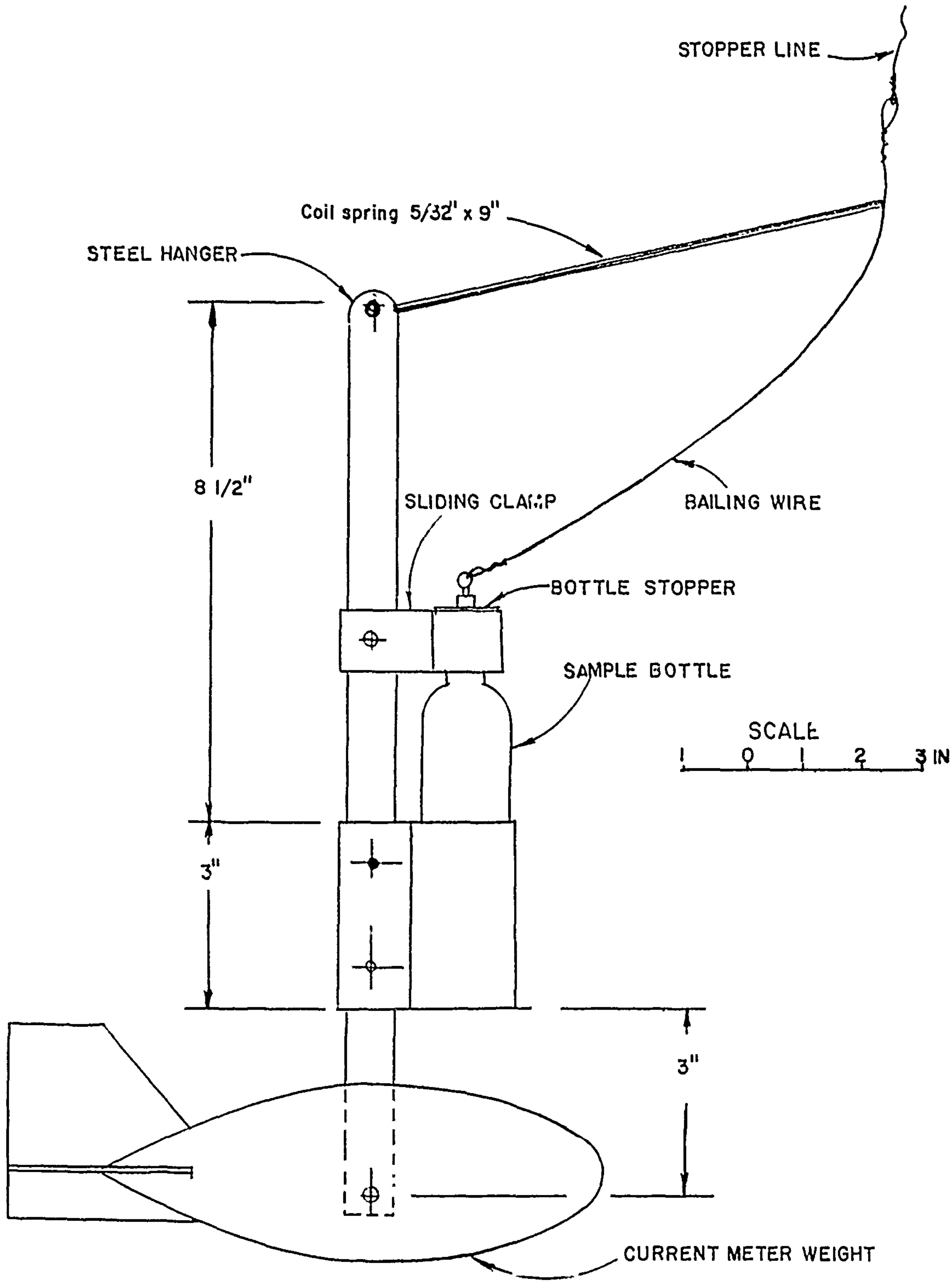

Figure 3. The Texas (also USDA or Faris) sampler (after Faris 1933)

the USAEWES published Paper U (USAEWES 1931), which summarized and presented the resulting data from MRC suspended-sediment investigations in the Mississippi River and other basin streams from September 1930 through September 1931. This report also discussed sediment collection, analysis, and load-computation methods.

USAE District
St. Paul, 1930-1933 and 1937

36. The USAE District, St. Paul, collected daily suspended-sediment samples in the upper Mississippi River and tributaries (upstream from upper Mississippi Mile 625) during 1930-1933. At most locations, only single surface samples were taken, and their observed concentrations were multiplied by coefficients to obtain the mean concentrations for the cross section. These coefficients were established by the Straub method (paragraph 32) or by "precise measurements" at depths of 1 ft below the surface and 1 ft above the streambed and at 0.2, 0.6, and 0.8 depth. The precise method involved the construction of curves relating depth to velocity and sediment concentration. Corresponding concentration and velocity values for each depth increment were then multiplied to obtain a sediment concentration-velocity curve, with the area under the curve representing the sediment discharge in that vertical. The St. Paul District used the following coefficients (FISP 1940):

Stream	Coefficient
Chippewa River	5.0
Black and Wisconsin Rivers	1.4
All other streams	1.15

No information is available on the type of sampling equipment used; however, the St. Paul District did publish the resulting data (USAE District, St. Paul 1935).

37. In 1937, the St. Paul District used a sampling method developed by Mr. J. P. Luby. The samples were taken at points spaced vertically in such a manner that each sample represented a proportional part of the total discharge in the vertical. Luby's method involved the sampling of five points in each vertical at 8.7, 26, 44, 63, and 87 percent of the total depth. Usually, three to nine verticals were sampled at each location (FISP 1940). Data resulting from the 1937 investigation were also published (US Engineer Laboratory, Fountain City 1937).

The MRC Low-Water Investigations: 1936 and 1939

38. In 1936 and again in 1939, the MRC conducted low-water investigations to determine the quantity and particle-size distribution of suspended sediment and the chemical composition of the dissolved solids in samples collected in the lower Mississippi, Atchafalaya, and Old Rivers. The MRC sampled several verticals in each cross section; however, no information is available on the type of sampling equipment used in these two surveys. The USAEWES analyzed the samples and published two technical memoranda (USAEWES 1937, 1940) that contained the resulting data. These data included plots of stage, total suspended matter, and total dissolved matter versus time.

The USAEWES at Mayersville, MS: 1937-1938

39. In 1937 and 1938, the USAEWES conducted a sediment investigation on the Mayersville, MS, Discharge Range No. 2 (lower Mississippi River Mile 533.8). The study involved the collection of samples in verticals spaced over the cross section. Two different samplers, the vertical-type trap (Figure 4) and the horizontal-type trap (Figure 5), were used. The vertical-type trap, which was very similar to the MRC sediment trap (Figure 1), took samples between the surface and about 4 ft from the riverbed. This device consisted of a 1-ft length of 1-1/4-in. pipe with standard check valves attached to the ends. A babbitt was cast around the sampler in the shape of two cones, base to base (100 lb total weight). When suspended, the sampler was inclined with the valves opened, and these valves remained open during descent. At the desired depth, the trap was halted, and the valves snapped shut to trap a sample. The horizontal-type trap, developed in 1934 by the USAE District, Vicksburg, was used to collect samples within 4 ft of the bottom. This device consisted of a 2-ft length of 1-in. pipe with sliding gate valves inserted 4 in. from each end. Like its vertical counterpart, the horizontal-type trap was also cast with a babbitt for added weight (300 lb total). The gate valves remained open until the sampler reached the streambed and activated a contact bar. The USAEWES published data resulting from the Mayersville study in Technical Memorandum 122-1 (USAEWES 1939).

The CE: 1938

40. In 1938, the CE collected suspended-sediment samples simultaneously with velocity measurements at 0.1, 0.3, 0.5, 0.7, and 0.9 of the depth in seven verticals on the upper Mississippi at Chester, IL, and in six to eight

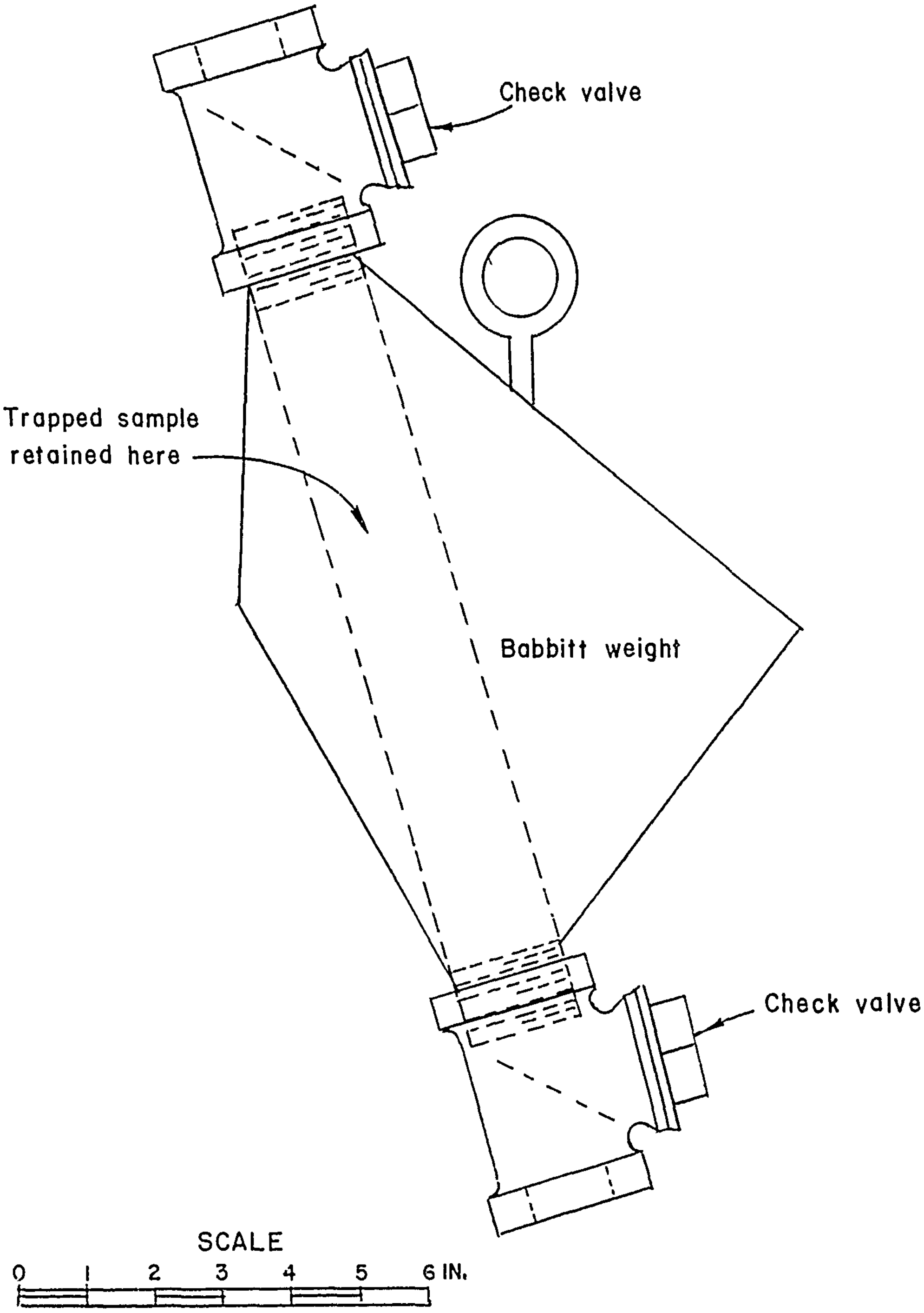

Figure 4. Vertical-type trap used by the USAEWES at Mayersville Discharge Range No. 2 in 1937 and 1938 (after USAEWES 1939)

verticals of 8 to 12 points each. They used the precise method (paragraph 36) in this study (FISP 1940).

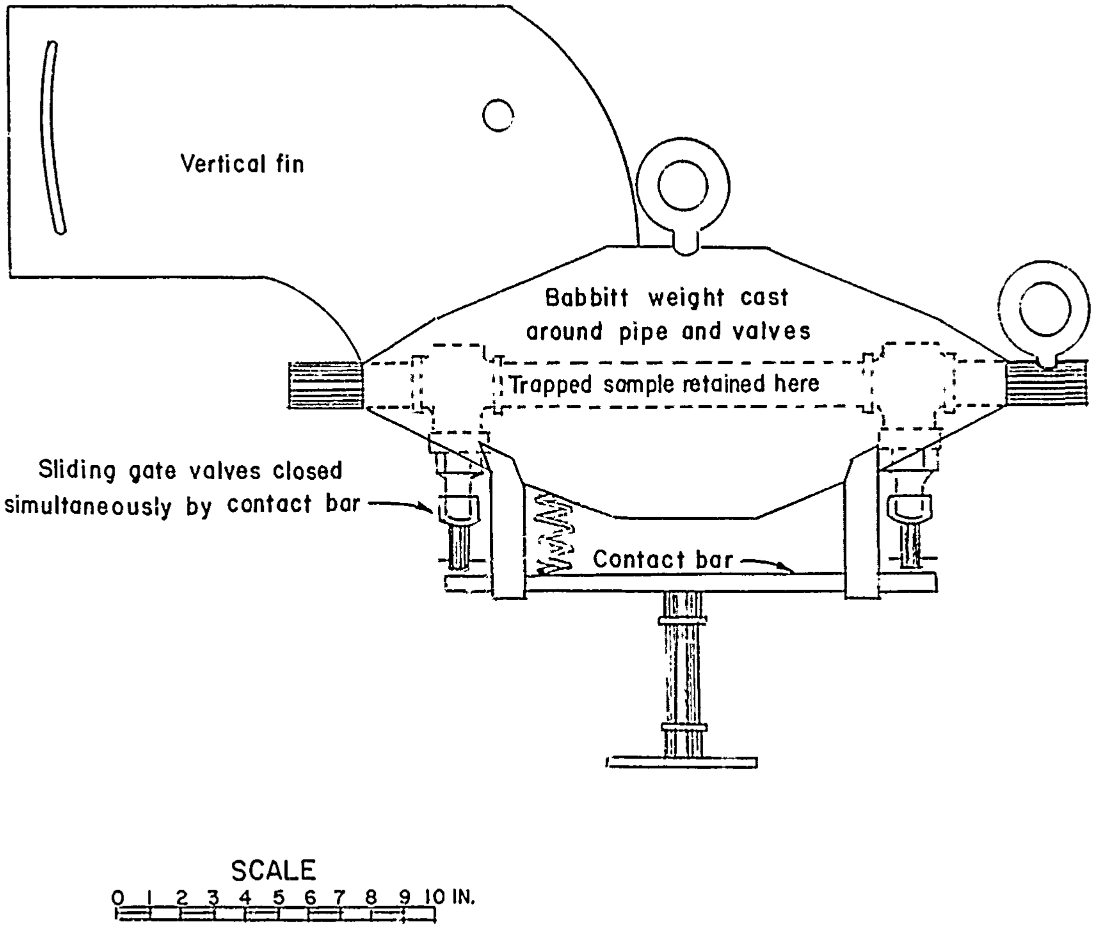

Figure 5. Horizontal-type trap developed by USAE District, Vicksburg, and used at Mayersville Discharge Range No. 2 in 1937 and 1938 (after USAEWES 1939)

Other early 20th-century studies

41. By the late 1930's, a number of agencies were collecting suspended-sediment samples in various parts of the Mississippi River Basin. Among these agencies were the Tennessee Valley Authority (TVA) in the Tennessee River Basin; the USGS in various parts of the Mississippi River Basin (Collins 1939); the US Forest Service in streams in Tennessee and North Carolina; the USDA Soil Conservation Service and the USGS in the Tarkio River in Missouri, the USAE District, Little Rock, in various Oklahoma, Kansas, Colorado, Arkansas, Missouri, and northern Texas streams; the USAE District, Fort Peck, using the Luby method (paragraph 37) in the upper Missouri and its tributaries; the USAE District, Omaha, on the upper Missouri River and its tributaries; the USAE District, Rock Island, in the upper Mississippi River

and its tributaries; and the MRC on tributaries of the lower Mississippi. Most of these agencies, who had developed their own methods of sampling, laboratory analysis, and load computation, organized the FISP in 1939 to standardize their diverse techniques.

FISP

42. In 1939, a group of Federal agencies organized "an informal interdepartmental committee to sponsor an exhaustive study of all problems encountered in collecting sediment data and, eventually, to standardize accepted methods and equipment" (Nelson and Benedict 1951). The agencies involved included the CE, USDA, USGS, Bureau of Reclamation, Indian Service, and TVA. The initial project was under the general supervision of Professor E. W. Lane of the Iowa Institute of Hydraulic Research (formerly the University of Iowa, Hydraulic Laboratory), Iowa City, IA. The Subcommittee on Sedimentation of the Federal Inter-Agency River Basin Committee assumed the duties of the interdepartmental committee in 1946, although investigations were still conducted at the Iowa facility. In June 1948, the project was transferred to the St. Anthony Falls Hydraulic Laboratory of the University of Minnesota at Minneapolis, MN. By 1956, the Subcommittee on Sedimentation had adopted a guidance memorandum that outlined the program and organization of the present FISP, with the principal purpose of the FISP being to find solutions to sedimentation problems common to all agencies (FISP 1963a). Current participants in the FISP include the CE, USGS, US Forest Service, Bureau of Reclamation, Office of Surface Mining, Science and Education Administration (USDA), and Federal Highway Administration (FISP 1981).

43. Member agencies of the FISP have prepared reports that discuss basic fluvial sediment concepts including rock weathering and soil formation; erosion, transport, and deposition; geomorphic considerations; economic aspects; data requirements; and program objectives (Guy 1970). Since its inception, the FISP has sought to standardize the samplers used, as well as the methods of sampling, laboratory analysis, and load computation. Each of these topics is covered briefly.

Samplers

44. During the past four decades, the FISP has developed and made improvements on a number of suspended-sediment samplers. In the process of developing the United States (US) Series of depth- (D) and point-integrating

(P) samplers,* the FISP has evaluated most of its own samplers, as well as many of the early agency samplers. These evaluations have dealt mainly with determining intake characteristics and concentration ratios (when compared with that obtained with other samplers).**

Methods of sampling

45. Sampling methods used for FISP members have been documented in various publications. Guy and Norman (1970) probably best express the philosophy of sediment sampling:

> The purpose of the suspended-sediment sampler is to obtain a sample that is representative of the water-sediment mixture moving in the stream in the vicinity of the sampler. . . . When a suspended-sediment sampler is submerged with the nozzle pointed directly into the flow, a part of the streamflow enters the sampler container through the nozzle as air is exhausted under the combined effect of three forces:
>
> 1. The dynamic positive head of the flow at the nozzle entrance.
> 2. A negative head at the end of the air-outlet tube.
> 3. A hydrostatic pressure because of the difference in elevation between the nozzle entrance and the air-outlet tube.

At most active sediment sampling stations, samples are taken on a routine basis (e.g., daily, twice weekly, weekly, etc.). In smaller streams, a single sample (usually depth-integrating) is generally adequate to measure suspended-sediment concentrations, which in turn are used to determine numerical values for the passing loads. On larger streams, several samples are required to correctly estimate the passing loads.

46. Calibration measurements are periodically made to determine whether or not the routine samples are yielding representative concentrations. Two calibration techniques were developed. Samples could be taken either (a) in centroids-of-equal-discharge increments (EDI) or (b) at an equal-transit rate (ETR) in verticals equally spaced across the stream cross section. The EDI method is usually limited "to streams with stable channels where discharge

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* Point-integrating samplers can also be used for depth integration. Examples of such usage will be discussed in Part III of this report.

** Descriptions and evaluations of samplers used at key stations in the Mississippi River Basin (see Part III) are presented in Appendix B of this report.

ratings change very little during a year" (Guy and Norman 1970). The ETR method, first used by Mr. B. C. Colby in 1946, is "most often used in shallow and/or sandbed streams where the distribution of water discharge in the cross section is not stable" (Guy and Norman 1970). Calibration methods are used to determine whether or not correction coefficients should be applied to the routine concentration values. As a general rule, correction coefficients are not applied unless the gap between routine values and the calibrated values is 10 percent or larger. The correction coefficient simply adjusts a routine value to make it representative of the entire cross section. The EDI and ETR methods are discussed in more detail in the reports by the FISP (1941a and 1963b) and by Guy and Norman (1970).

Laboratory analysis

47. Prior to 1939, there were widespread variations in the laboratory procedures used to determine suspended-sediment concentrations. The FISP documented procedures for analyzing samples (FISP 1941b). Other reports that followed this initial effort (FISP 1943, 1953, 1957b, 1957c, 1958) standardized laboratory procedures and provided guidance for the calibration and use of laboratory equipment. The report by Guy (1969) is probably the most complete publication currently available on laboratory theory and analysis; it outlines procedures; provides definitions, equations, and graphs; and discusses equipment.

Load computation

48. The computation of a suspended-sediment load requires input of concentration and discharge to solve the following equation (Porterfield 1972):*

$$Q_s = Q_w \times C_s \times k \tag{1}$$

where

Q_s = sediment load (sediment discharge), tons/day

Q_w = water discharge, cfs

C_s = concentration of suspended sediment, mg/ℓ (Note: the factor used to convert parts per million to milligrams per litre increases with increased concentration.)

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* Porterfield (1972) provides information on typical computation procedures used by FISP member agencies.

k = coefficient based on the unit of measurement of water discharge that assumes a specific weight of 2.65 for sediment (In the above relation, k is 0.0027.)

The FISP published Report 8, "Measurement of Sediment Discharge of Streams" (FISP 1948), which was superseded by Report 14, "Determination of Fluvial Sediment Discharge" (FISP 1963b).

Comprehensive Basin Studies

Specific legislation

49. Since the beginning of the 20th century, Congress has authorized comprehensive basin studies to address the needs of major drainage basins and to initiate m. jor watershed planning. The subject of "fluvial sediment," which includes examination of earlier sediment investigations, sediment yields, reservoir deposition surveys, and erosion, has been an important element of these comprehensive studies. Among the component watersheds within the Mississippi River Basin that have been the subject of such special legislation are:

a. Mississippi River and Tributaries (US House of Representatives 1964). A six-volume, in-depth study of the lower Mississippi and its tributaries downstream from Cairo.

b. Missouri River (US House of Representatives 1911, 1940, 1944; US Senate 1944). Documents pertaining to all or part of the Missouri River and its basin.

c. Kansas River (US House of Representatives 1914, 1935, 1950; US Senate 1962). Kansas River and tributaries.

d. Arkansas-White-Red Rivers (Arkansas-White-Red Basins Inter-Agency Committee 1955, US House of Representatives 1957, US Senate 1966). Basin development and water quality investigations of the Arkansas-White-Red Rivers Basin.

e. White River (US House of Representatives 1933). Comprehensive study of the White River Basin.

Water Resources Planning Act

50. In 1965, President Lyndon B. Johnson signed into law the Water Resources Planning Act (WRPA) (Public Law 89-90), which created the Water Resources Council. The Council instituted a program for comprehensive planning that called for the development of framework studies for all major river basins of the contiguous United States. Studies were intiated to develop programs that could be used to guide citizens and Government agencies in dealing with common problems and make the best use or combination of uses

of water and related land resources. Participants included representatives of the states that comprised the subject watershed plus a number of Federal agencies. Like the specific legislation (paragraph 49), these studies provided some data on suspended-sediment concentrations in basin streams; on sediment yields, reservoir deposition, erosion; and the relations between sediment and basin development. Among the more significant comprehensive basin studies authorized by the WRPA for watersheds within the Mississippi River Basin were:

a. Upper Mississippi River Comprehensive Basin Study (USAE Division, North Central 1970-1972). Main report and 17 appendixes. Covered the drainage basin of the upper Mississippi River, with the exception of the watershed of the Missouri River. Additionally, the Great River Environmental Action Team (1980-1983) has conducted studies on the development of a river system management plan that incorporates total resource requirements of the upper Mississippi.

b. Lower Mississippi Region Comprehensive Study (Lower Mississippi Region Comprehensive Study Coordinating Committee 1974). Main report and 21 appendixes covering the entire watershed of the lower Mississippi (with the exception of the upper reaches of the Arkansas and White Rivers), the Atchafalaya River drainage (including the lower Red River), and the watersheds of coastal Louisiana streams entering the Gulf of Mexico between the Atchafalaya and Sabine Rivers.

c. Missouri River Basin Comprehensive Framework Study (Missouri River Basin Inter-Agency Committee 1971). Main report and nine appendixes. Later, "The Missouri River Basin Water Resources Plan" (Missouri River Basin Commission 1977) was published.

d. Ohio River Basin Comprehensive Survey (USAE Division, Ohio River 1964-1969). Main report and 13 appendixes on the Ohio River Basin, with the exception of the Tennessee River drainage.

e. Comprehensive Basin Study, White River Basin, Arkansas and Missouri (White River Basin Coordinating Committee 1968). Main report and 16 appendixes.

f. Comprehensive Basin Study, Red River Below Denison Dam (Red River Basin Coordinating Committee 1968). Main report and 15 appendixes on the Red River Basin downstream from Denison Dam (excluding the Ouachita-Black drainage).

The LMVD Potamology Programs

51. Between 1932 and 1935, the MRC conducted its first major potamology studies at the USAEWES. These initial studies attempted to determine the most favorable alignment in which to stabilize the Mississippi River in connection

with the program of channel cutoffs that had been initiated (Moore 1972). Results of the many investigations that followed this original effort were documented in various potamology investigations reports. Beginning in 1974, the LMVD initiated the first of its two most recent potamology programs, (T-1) and (P-1). The purpose of the LMVD Potamology Programs was

> . . . to achieve through field, office, and laboratory investigations, a better understanding of the mechanisms and relationships that give rise to the large-scale changes in the regime of alluvial rivers, and specifically the Lower Mississippi River and its tributaries within the alluvial valley from the standpoint of both natural phenomena and manmade modifications (USAE Division, Lower Mississippi Valley 1974).

Both the (T-1) and (P-1) Programs consisted of a number of individual efforts designed to continue ongoing studies, initiate new studies, and establish a base for future long-range investigations.

Potamology Program (T-1)

52. In 1974, the LMVD prepared documentation for 10 work packages that provided the framework of its Potamology Program (T-1) (USAE Division, Lower Mississippi Valley 1974). Work Package No. 9 (Sedimentation) was assigned to the USAEWES. The principal objective of this work package was to update Papers H and U (USAEWES 1930, 1931) (see paragraph 35). Included in the scope of the USAEWES investigation was a generalized study of the effects of physiographic and cultural conditions on sediment flow in the Mississippi River Basin, a comprehensive inventory of sediment sample collection stations in the Mississippi River Basin, and the preparation of narrative summaries for key stations selected from the inventory. The end product of the USAEWES (T-1) investigation was USAEWES Technical Report M-77-1, "Inventory of Sediment Sample Collection Stations in the Mississippi River Basin" (Keown, Dardeau, and Kennedy 1977).

53. Another report prepared under the (T-1) Program was entitled, "LMVD Potamology Study (T-1)" (Munger et al. 1976). This study was conducted by a team of specialists whose primary purpose was

> . . . to collect data pertaining to hydrologic, hydraulic, geologic, and morphologic factors that relate to the Mississippi River downstream from Alton, Ill. (to Head of Passes), and to present them in a format that would be amenable to detailed analysis at a future time (Munger et al. 1976).

The report by Munger et al. (1976) consisted of a main text and a number of companion appendixes.

Potamology Program (P-1)

54. The LMVD Potamology Program (P-1) (USAE Division, Lower Mississippi Valley 1976) was developed in 1976 after the (T-1) work packages had been completed. The (P-1) Program was designed to achieve the level of knowledge and understanding of Mississippi River behavior needed to develop the most efficient and economic flood-control and navigation channel possible. The program was structured around seven study areas. The USAEWES, under the sponsorship of the USAE District, New Orleans, began its work on Study Area IV (Sedimentation, Mississippi River Basin) in 1977 and continued through 1980, with the final product being LMVD Potamology Program (P-1) Report 1, "Characterization of the Suspended Sediment Regime and Bed-Material Gradation of the Mississippi River Basin" (Keown, Dardeau, and Causey 1981).

PART III: INFLUENCE OF SAMPLING, ANALYSIS, AND LOAD-COMPUTATION PROCEDURES ON THE DOWNWARD TREND

55. Several cultural impacts over the past two centuries have shaped the current character of the Mississippi main-stem suspended-sediment regime. Initially, sediment loads were accelerated when much of the basin land that had once been primarily forest and grasslands was cleared for agricultural activities, urban and industrial sites, and transportation arteries. During this century, however, a number of other measures have resulted in the reduction of sediment loads.

- a. The Old River Control Structures became operational in 1963, preventing unregulated flow from the Mississippi to the Red-Atchafalaya system.
- b. Sediment-retention structures were built (1953-1967), and channel improvement features were constructed on the Missouri River and its tributaries.
- c. Sediment-retention structures were built (1963-1970), and channel improvement features were built on the Arkansas River and its tributaries.

In addition, improved land-use management practices and channel stabilization on the major Mississippi River Basin streams have undoubtedly reduced main-stem suspended-sediment loads, although these impacts are difficult to assess quantitatively. The major finding of Report 1 of the (P-1) Program (Keown, Dardeau, and Causey 1981) was the identification of downward trend in the annual suspended-sediment loads carried by the Mississippi River. This trend apparently began around the middle of the 20th century.

56. The USAE District, New Orleans, uses the suspended-sediment sample collection station at Tarbert Landing, MS (lower Mississippi River Mile 306.3), to monitor the load of the Mississippi main stem that is available for transport to the Gulf of Mexico. The station at Simmesport, LA (Atchafalaya River Mile 8.2), reflects the current best estimate of the suspended-sediment load that enters the gulf through the Atchafalaya River. Thus, the sum of the suspended-sediment loads at these two stations (Tarbert Landing and Simmesport) can provide an approximate value for the sediment yield of the entire Mississippi River Basin, although not accounting for the bed load. Prior to 1963, the sum of the suspended loads measured at Tarbert Landing and Simmesport was 434 million tons per year (Figure 6); however, this combined load has currently declined to 255 million tons per year (Figure 7),

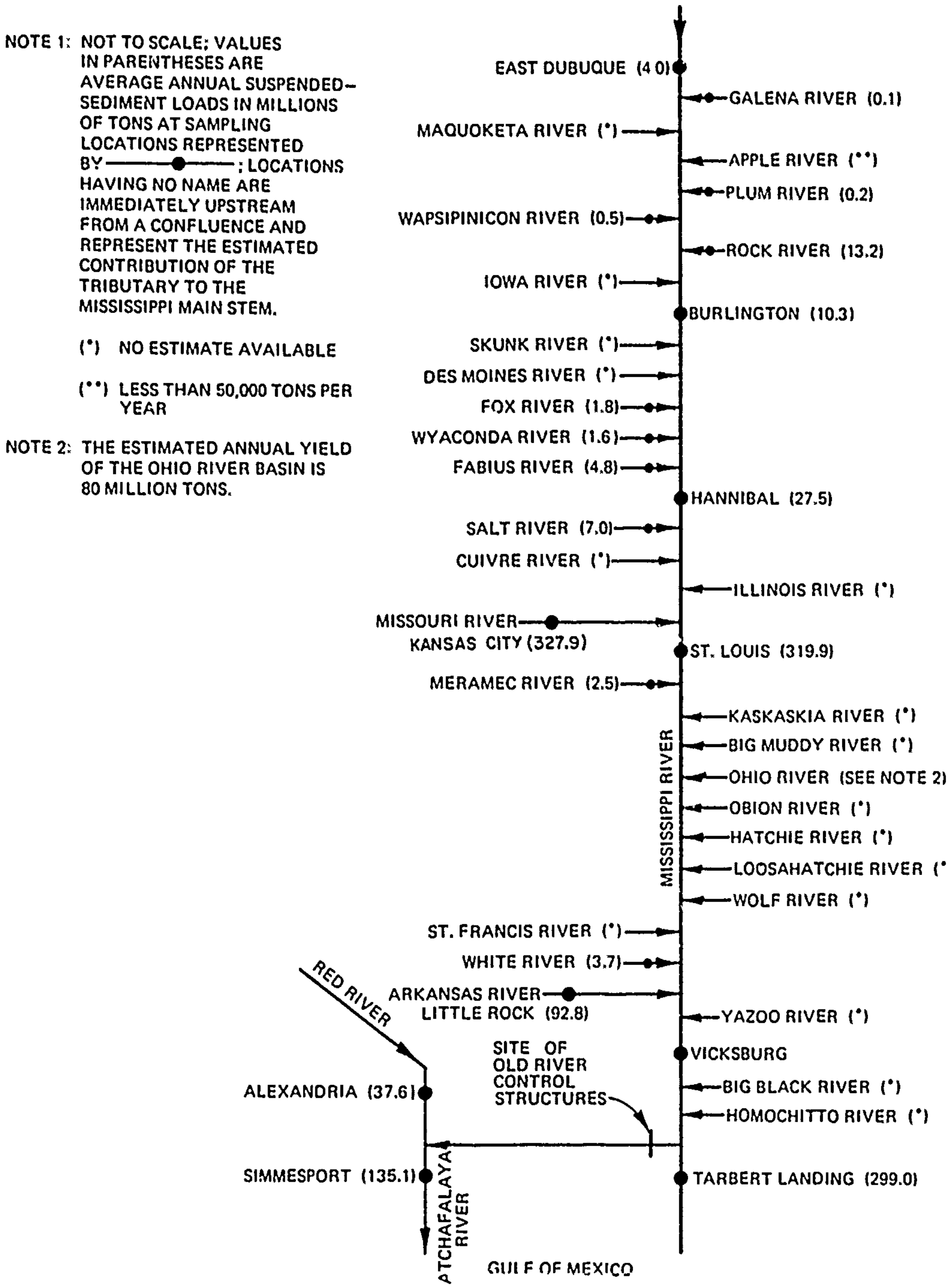


Figure 6. Mississippi River suspended-sediment flow regime prior to the operation of the Old River Control Structures (1963) and closure of several major multipurpose dams in the Missouri River Basin (1953-1967) and in the Arkansas River Basin (1953 1970) (see Note 1) (adapted from Keown, Dardeau, and Causey 1981). The estimated annual yield of the Ohio River Basin (Note 2) is discussed in Appendix F of the referenced report

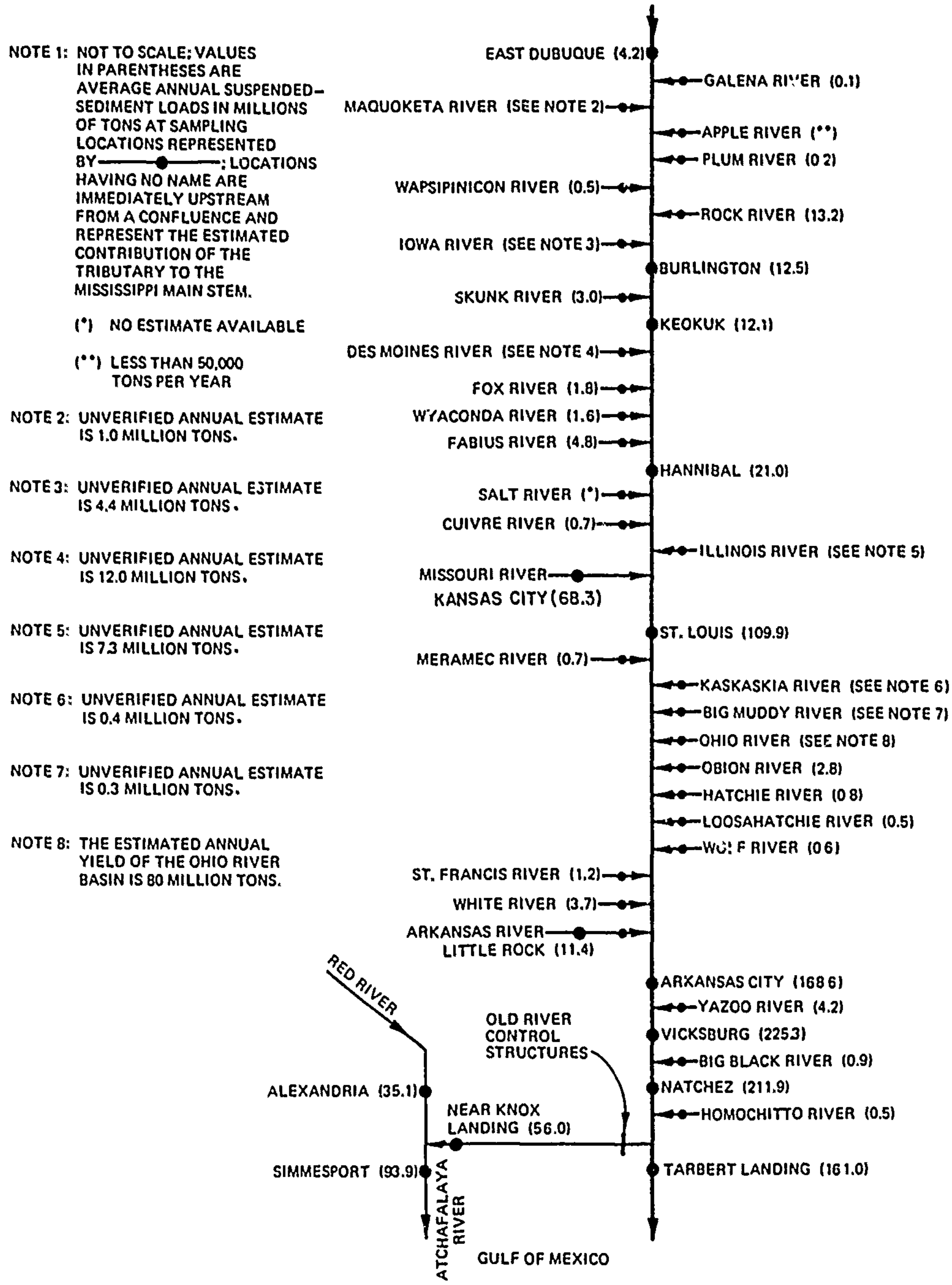


Figure 7. The 1970-1978 Mississippi River suspended-sediment flow regime (see Note 1) (adapted from Keown, Dardeau, and Causey 1981). The unverified annual estimates for Notes 2-7 are discussed in Appendix C of the referenced report; the estimated annual yield for the Ohio River Basin is discussed in Appendix F of the referenced report

reflecting the downward trend in the Mississippi River sediment loads. Although this trend has been primarily attributed to sediment-retention structures, river-training works, streambank-protection revetments, and improved land-use practices, the possibility also exists that suspended-sediment sampling, analysis, and load-computation procedures could have influenced this trend.

Key Stations

57. Long-term suspended-sediment data are not available for many reaches of streams in the Mississippi River Basin. However, data are available for key stations on the main stem and its major tributaries and distributaries, such that an assessment of the influence of the sampling, analysis, and load-computation procedures on this downward trend can be made. The key stations (see also Table 1) selected for this study include:

Stream	Station (River Mile)	Used to Monitor
Upper Mississippi River	East Dubuque, IL (Mile 579.9)	Main-stem loads on the upper reaches of the upper Mississippi River
	St. Louis (Mile 179.1)	Main-stem loads downstream from the Missouri River confluence
Missouri River	Kansas City, MO (Mile 365.5)*	Contribution of the Missouri River to the main stem
Ohio River	None**	
Arkansas River	Little Rock (Miles 141.5 and 148.0)	Contribution of the Arkansas River to the main stem

(Continued)

* Kansas City was selected as the key station on the Missouri River, used to monitor the contribution of the Missouri River to the main stem. (No major tributaries enter the Missouri River between Kansas City and the mouth.) There is a station at Hermann, MO (Mile 97.9); however, it was eliminated from consideration because of the lack of comparative data to evaluate the suspended-sediment samplers used at that station.

** There is no long-term suspended-sediment sample station near the mouth of the Ohio River that can be used to monitor the contribution of this stream to the Mississippi. Preliminary estimates indicate that the annual contribution is approximately 80 million tons. A study of the suspended-sediment regime of the Ohio River Basin did not indicate that the contribution of the Ohio River to the Mississippi River main stem had significantly changed since the beginning of the 20th century (Keown, Dardeau, and Causey 1981).

Stream	Station (River Mile)	Used to Monitor
Lower Mississippi River	Vicksburg (Mile 435.41)	Main-stem loads between the Arkansas River confluence and Old River Outflow Channel
	Tarbert Landing (Mile 306.3)	Contribution of the main stem to the Gulf of Mexico
Red River	Alexandria (Mile 104.9)	Contribution of the Red River to the Atchafalaya River
Atchafalaya River	Simmesport (Mile 8.2)	Contribution of the Atchafalaya River to the Gulf of Mexico

Table 1 shows the periods of record of the various suspended-sediment samplers used at these key stations.*

Determining Impacts of Procedures Used at Key Stations

58. The impact of suspended-sediment sample collection, analysis, and load-computation procedures on reported loads at each key station was assessed by following the series of steps outlined below:

- a. Step A. Were suspended-sediment samples taken with more than one sampler at the key station? If the answer is yes, go to Step B. If the answer is no, the sampling, analysis, and load-computation procedures used with the sampler should be examined to determine if any information related to these procedures would place the integrity of the suspended-sediment data for that key station in question. Further, any laboratory or field tests conducted to evaluate the performance of the sampler should also be examined. Following the sequence in this step will indicate whether or not the sampling, analysis, and load-computation procedures have influenced the numerical values reported for suspended-sediment loads measured at this key station.
- b. Step B. Have there been any upstream regime changes that would have affected suspended-sediment loads reported for the key station? If the answer is yes, go to Step C. If the answer is no, then plots of annual discharge and suspended-sediment load versus time should be examined to determine if changes in loads generally follow changes in discharge or if the changes in loads seem to be influenced by changes in samplers. Further, the sampling, analysis, and load-computation procedures used

* Appendix B provides descriptions and evaluations of the samplers discussed in Part III.

Table 1

Suspended-Sediment Samplers Used at Key Stations in the Mississippi River Basin

Stream	Station river mile	Period of Record	Sampler(s) Used
Upper Mississippi River	East Dubuque, IL (Mile 579.9)	1 October 1942-30 September 1949	Rock Island
		1 October 1949-present	US D-49
	St. Louis, MO (Mile 179.1)	1 October 1948-30 September 1968	US P-46
		1 October 1968-present	US P-61 (50%) US P-63 (50%)
Missouri River	Kansas City, MO (Mile 365.5)	14 August 1948-30 October 1963	US P-46
		31 October 1963-present	US P-61
Arkansas River	Little Rock, AR (Miles 141.5 and 148.0)	1 October 1940-22 October 1946	Texas
		23 October 1946-30 September 1949	Depth-integrating sampler
		1 October 1949-30 September 1968	US D-49
		1 October 1968-present	US P-61
Lower Mississippi River	Vicksburg, MS (Mile 435.41)	1968-present	US P-61
	Tarbert Landing, MS (Mile 306.3)	1 October 1949-12 April 1974	US P-46
		13 April 1974-present	US P-61
Red River	Alexandria, LA (Mile 104.9)	1 October 1952-present	US P-46
Atchafalaya River	Simmesport, LA (Mile 8.2)	1 October 1951-14 April 1974	US P-46
		15 April 1974-present	US P-61

with the samplers should also be examined to determine if any information related to these procedures would place the integrity of the suspended-sediment data for that key station in question. In addition, any laboratory or field tests conducted to evaluate the performance of the samplers should also be examined. Following the sequence in this step will indicate whether or not a change in samplers or the collection, analysis, and load-computation procedures have influenced the numerical values reported for suspended-sediment loads measured at this key station.

c. Step C. If regime changes have affected the resulting suspended-sediment load data at the key station, then are data available for the same samplers at other stations (whether or not on the same stream*) not influenced by upstream regime changes? If the answer is no, go to Step D. If the answer is yes, return to Step B and evaluate the suspended-sediment load data from the other stations in the same manner as used for the key station. In addition, the sampling, analysis, and load-computation procedures used at the key station itself should be examined.

d. Step D. If suspended-sediment load data for other stations unaffected by upstream regime changes cannot be obtained, then are laboratory or field test data for the key station samplers available? If the answer is no, then the influences of changing samplers and of upstream regime changes cannot be distinguished. If, however, laboratory or field test data are available, then perhaps any influence of the change in samplers can be evaluated. In addition, the sampling, analysis, and load-computation procedures used at the key station itself should be examined.

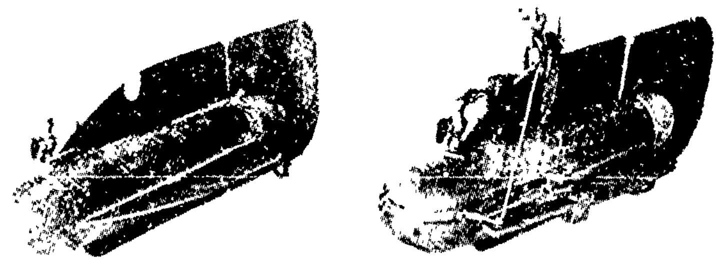
East Dubuque

Station history

59. The USAE District, Rock Island, has operated its upper Mississippi River suspended-sediment sample collection at East Dubuque, IL (Mile 579.9), continuously since 1 October 1942. Between the beginning of the period of record and 30 September 1949 (2,555 days), the District used the Rock Island sampler (Figure 8). From 1 October 1949 through the present, the US D-49 sampler (Figure 9) has been used.** A single depth-integrating vertical has

* In this study, records of sediment stations outside the Mississippi River Basin were also examined; however, sufficient comparison data for key station samplers at stations unaffected by regime changes could not be found. Comparisons presented in this report, therefore, are based on sediment stations within the basin.

** Records available through 30 September 1977. The US D-49 sampler was used at East Dubuque 10,585 days between 1 October 1949 and 30 September 1977.



a. Original sampler b. Sampler with alterations

Figure 8. The Rock Island suspended-sediment sampler (FISP 1941b)

been sampled daily throughout the period of record. Prior to 1967, the Rock Island District analyzed sediment samples in its own laboratory; however, since 1967, the USGS laboratory in Iowa City, IA, has provided this service. The standard procedures employed by both laboratories, which are described by Guy (1969), have remained unchanged during the period of record of this station. When the Rock Island sampler was used, 10 percent was added to the concentration values. The Rock Island District has been responsible for computing suspended-sediment loads throughout the entire period of record. Prior to 1968, these computations were performed manually using Equation 1, and no attempt was made to interpolate missing sediment concentrations values. Since 1968, the suspended-sediment concentration data and daily average discharges have been punched into computer cards and used as input to a program that computes daily suspended-sediment loads (USAE District, Rock Island 1971). This program is capable of handling interpolation of up to 29 consecutive days of missing suspended-sediment concentration record, provided that discharges are obtained on those days (Keown, Dardeau, and Kennedy 1977). Both the manual and the automated methods of computing suspended-sediment loads at East Dubuque are standard procedures (Porterfield 1972) that utilize Equation 1, the only difference being that the program provides an additional interpolative capability.

Change of samplers

60. Suspended-sediment samples were collected with two different samplers at East Dubuque; however, the loads reported for this station have never been affected by any upstream regime change. Therefore, Step B (paragraph 58)

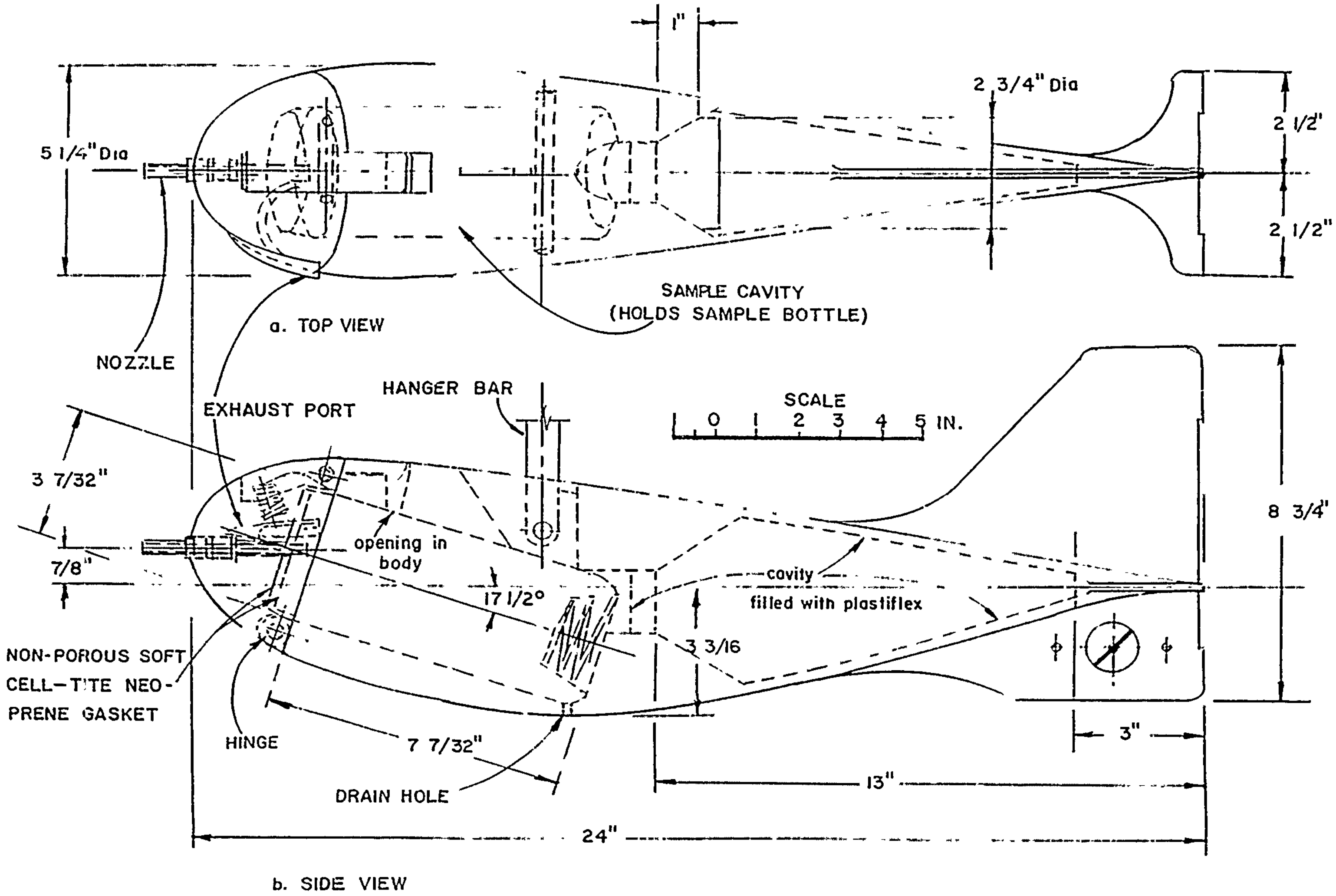


Figure 9. The US D-49 suspended-sediment sampler (after FISP 1963b)

will be followed to examine the sampling, analysis, and load-computation procedures used at East Dubuque.

61. Figure C28 of the report by Keown, Dardeau, and Causey (1981) shows plots of the annual discharge and suspended-sediment load data for East Dubuque. If these annual discharge and suspended-sediment load values are averaged over equal (7-year) portions of the period of record immediately before and after the change in samplers, the following results are obtained:

Sampler Used	Period of Record water years	Average Annual Discharge acre-ft $\times 10^6$	Average Annual Suspended-Sediment Load, tons $\times 10^6$
Rock Island	1943-1949	35.8	5.5*
US D-49	1950-1956	35.2	4.7

* Annual suspended-sediment loads for East Dubuque during the time the Rock Island sampler was used reflect a 10-percent addition to the suspended-sediment concentration values (paragraph 59). If this adjustment were eliminated, the average load would then be 5.0 million tons.

As the above tabulation shows, a slight decrease in the average annual discharge measured at East Dubuque was accompanied by a slight decrease in the average annual suspended-sediment load, which is to be expected. Results of laboratory and field tests of the Rock Island and US D-49 samples (Appendix B, Table B1) indicate that these devices properly measure the suspended-sediment concentration of the passing streamflow.

Influence of procedures on the suspended-sediment data

62. The following observations can be made regarding the validity of the suspended-sediment loads reported for East Dubuque, the key station used to monitor main-stem loads on the upper reaches of the upper Mississippi River:

- a. There is no reason to question the validity of the sampling, analysis, or load-computation procedures used at East Dubuque (paragraph 59).
- b. The change of samplers from the Rock Island to the US D-49 at East Dubuque has apparently had no impact on suspended-sediment loads reported for that station (paragraph 61).
- c. Results of laboratory and field tests of the Rock Island and US D-49 samplers indicate that these devices properly measure the suspended-sediment concentration of the passing streamflow (paragraph 61).

Therefore, the sampling, analysis, and load-computation procedures used at East Dubuque have apparently had no influence on suspended-sediment loads reported for this key station.

St. Louis

Station history

63. The USGS has operated the upper Mississippi River sediment sample collection station at St. Louis since 1 October 1948. Samples have been collected once weekly, except during high flows when daily samples are taken. From the beginning of the period of record through 30 September 1968, the agency used the US P-46 sampler (Figure 10); since 1 October 1968, the US P-61 (Figure 11) and the US P-63 (Figure 12) have each been used 50 percent of the time. The P-63 is used during high flows. From the beginning of the period of record through 30 September 1968, the samplers were raised and lowered by means of a mobile crane at River Mile 178.9. Since 1 October 1968, samples have been collected at Mile 179.1 from a trolley mounted on a monorail beneath the Poplar Street Highway Bridge. Prior to October 1974, two depth-integrating EDI verticals were sampled; since that time, five EDI verticals have been collected, with the second and the fourth of each series being used for sediment analysis and the remaining three verticals for chemical and biological analyses. Samples have been analyzed by the USGS laboratory at Rolla, MO, throughout the period of record. The standard procedures used by the Rolla laboratory are described by Guy (1969). Laboratory personnel enter concentration and associated discharge values at a remote terminal so that they can be processed by the USGS mainframe computer in Reston, VA. A program computes suspended-sediment loads (using Equation 1) and then interpolates daily values. These standard load-computation procedures (Porterfield 1972) have been the same throughout the period of record. Plots of the annual suspended-sediment loads and discharges for the St. Louis station are shown in Figure C27 of the report by Keown, Dardeau, and Causey (1981).

Change of samplers

64. Three different samplers, the US P-46, the US P-61, and the US P-63, have been used at St. Louis. Loads measured at this station have been influenced by upstream regime changes in the Missouri River Basin (paragraph 55). The record can be divided into three phases, as follows:

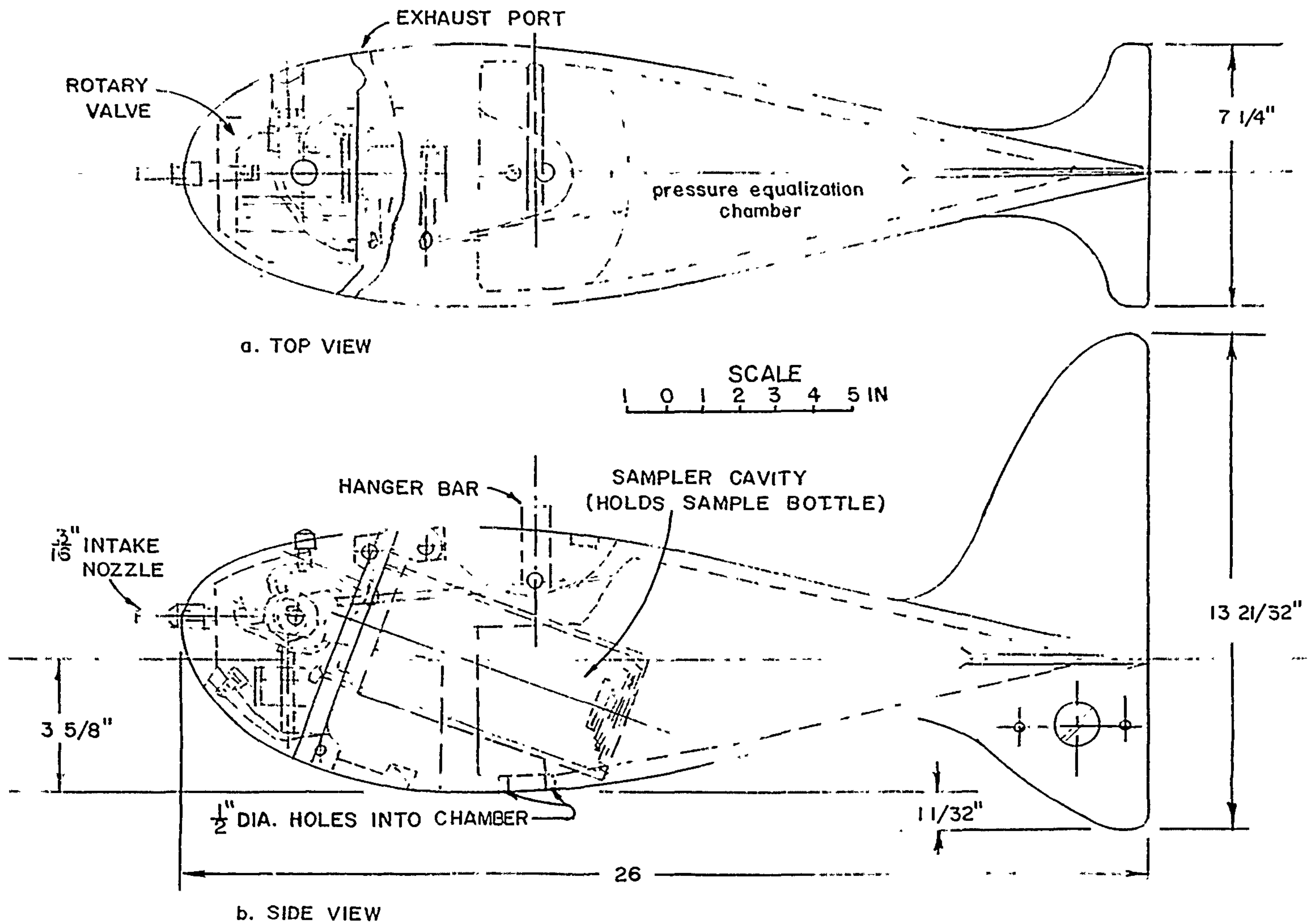


Figure 10. The US P-46 suspended-sediment sampler (after FISP 1952, 1963b)

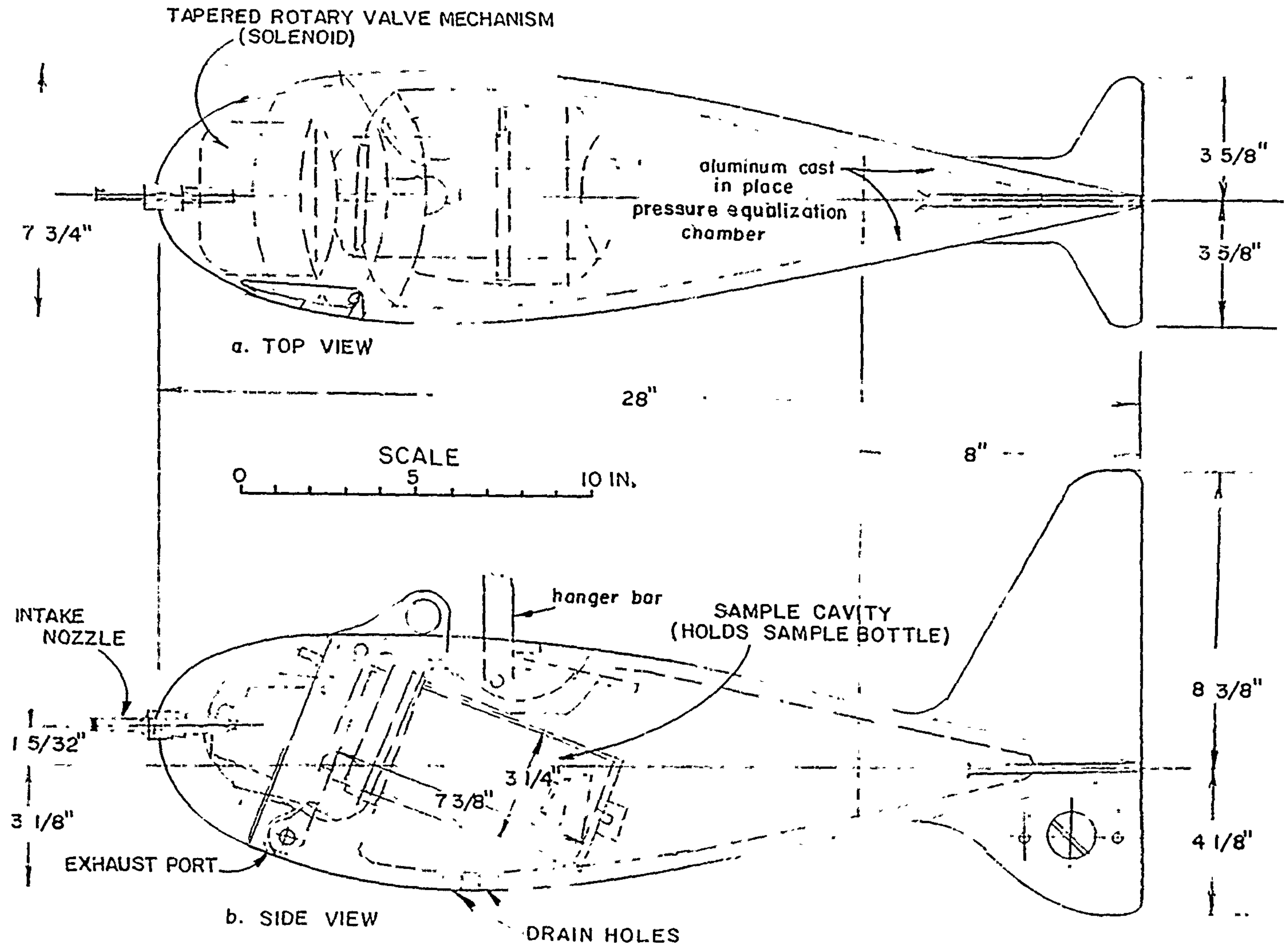


Figure 11. The US P-61 suspended-sediment sampler (after FISP 1981)

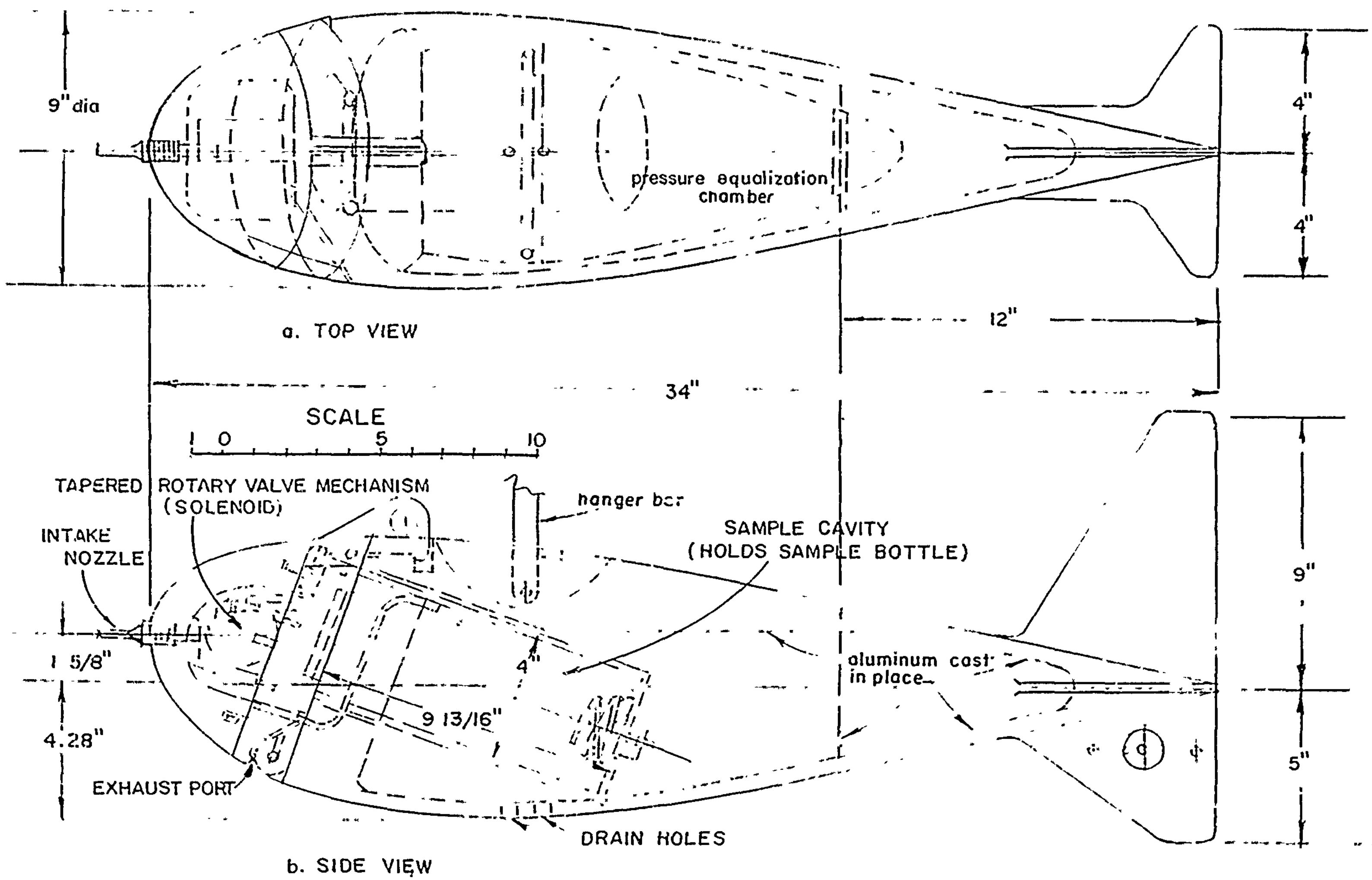


Figure 12. The US P-63 suspended-sediment sampler (after FISP 1981)

Phase	Period
Preconstruction (before regime changes took place)	Before 1953
Transition (phase influenced by regime changes)	1953-1967
Postconstruction (since regime changes have taken place)	After 1967

Therefore, Step C (paragraph 58) will have to be followed to examine the suspended-sediment sample collection, analysis, and load-computation procedures used at St. Louis. Suspended-sediment load data for Tarbert Landing and Simmesport (two key stations), where samples have been collected with both the US P-46 and the US P-61 samplers during a phase not influenced by regime changes, will be used.*

65. Figures F11 and F12 of the report by Keown, Dardeau, and Causey (1981) show plots of the annual (by water year) discharge and suspended-sediment load data for Tarbert Landing and Simmesport, respectively. The periods of record of these two sediment stations, operated by the USAE District, New Orleans, can be divided into three phases, based on the effect of upstream regime changes, as follows:

Phase	Period
Preconstruction	Before 1963
Transition	1963-1969
Postconstruction	After 1969

At Tarbert Landing, the US P-46 was used from 1 October 1949, the beginning of the period of record, through 12 April 1974 (8,954 days); the US P-61 has been used continuously since 13 April 1974.** The US P-46 was used from the time of establishment of the Simmesport station, 1 October 1951 through 14 April

* No records of stations not influenced by regime changes are available to compare the US P-63 with either the US P-46 or the US P-61 samplers. The US P-63 is very similar to the US P-61 sampler, except that the US P-63 is larger, heavier, and better adapted for use at greater depths and higher velocities (FISP 1981) Therefore, because the two devices have similar sampling characteristics, they will be treated as such in this report. Appendix B, Paragraph 5, contains descriptions of both the US P-61 and the US P-63 samplers.

** Records available through 30 September 1978. The US P-61 sampler was used at Tarbert Landing 1,630 days between 13 April 1974 and 30 September 1978.

1974 (8,226 days), while the US P-61 has been used from 15 April 1974 through the present time.* Therefore, the portion of the periods of record of the two stations that will be examined is the postconstruction phase when both samplers were used.

66. Each week, New Orleans District personnel collect five point-integrating suspended-sediment samples in eight verticals at Tarbert Landing. At Simmesport, the weekly sampling includes the collection of five point-integrating suspended-sediment samples in three verticals. Until June 1973, the Testing Section, Foundations and Materials Branch, New Orleans District, analyzed the sediment samples; since June 1973, the USGS, Louisiana District, has performed this function at its Baton Rouge laboratory. The standard procedures (Guy 1969) used by both agencies are identical (Keown, Dardeau, and Kennedy 1977; USAE District, New Orleans, undated). Until the late 1960's, suspended-sediment loads were determined manually from the concentrations obtained from the laboratory analyses, along with discharge measurements; since that time, the input data have been processed remotely by the USAEWES mainframe computer to determine daily suspended-sediment loads. Both the manual and the automated methods of computing suspended-sediment loads at Tarbert Landing and Simmesport are standard procedures (Porterfield 1972) that utilize Equation 1.

67. If the annual discharge and suspended-sediment load data for Tarbert Landing and Simmesport (Figures F11 and F12 of the report by Keown, Dardeau, and Causey (1981)) are averaged over equal (4-year) portions of the available periods of postconstruction record of Tarbert Landing and Simmesport, during which both the US P-46 and the US P-61 samplers were used, the following results are obtained:**

* Records available through 30 September 1978. The US P-61 sampler was used at Simmesport 1,629 days between 15 April 1974 and 30 September 1978.

** Water Year 1974 data have been eliminated because both samplers were used.

Sampler Used	Period of Record water years	Average Annual Discharge acre-ft × 10^6**	Average Annual Suspended-Sediment Load, tons × 10^6
		Tarbert Landing	
US P-46	1970-1973	355.1	177.6
US P-61	1975-1978	321.0	155.4
		Simmesport	
US P-46	1970-1973	179.2	90.4
US P-61	1975-1978	154.0	85.1

** The 1970-1973 annual averages for both stations reflect the influence of the 1973 peak discharge values (the discharges of record since the sediment stations became operational) and their associated suspended-sediment loads.

As the above tabulation shows, decreases in the average annual discharges measured at Tarbert Landing and Simmesport were accompanied by decreases in the average annual suspended-sediment loads, which is to be expected. Results of laboratory and field tests of the US P-46 sampler (Appendix B, Table B1) indicate that this device properly measures the suspended-sediment concentration of the passing streamflow. Neither the US P-61 nor the US P-63 has been evaluated in the laboratory or the field.

Influence of procedures on the suspended-sediment data

68. The following observations can be made regarding the validity of the suspended-sediment loads reported for St. Louis, the key station used to monitor main-stem loads downstream from the Missouri River confluence:

- a. There is no reason to question the validity of the sampling, analysis, or load-computation procedures used at St. Louis (paragraph 63).
- b. There is also no reason to question the validity of the sampling, analysis, and load-computation procedures used at Tarbert Landing and Simmesport (paragraphs 65-66).
- c. The change of samplers from the US P-46 to the US P-61 at Tarbert Landing and at Simmesport has apparently had no impact on suspended-sediment loads reported for those two stations (paragraph 67).
- d. Results of laboratory and field tests of the US P-46 sampler indicate that this device properly measures the suspended-sediment concentration of the passing streamflow (paragraph 67).

Therefore, the sampling, analysis, and load-computation procedures used at St. Louis have apparently had no influence on loads reported for this key station.

Kansas City

Station history

69. The USAE District, Kansas City, has operated the suspended-sediment sample collection station on the Missouri River at Kansas City since 14 May 1948. Between the beginning of the period of record and 30 October 1963, this District used a US P-46 sampler (Figure 10) (5,674 days). From 31 October 1963 through the present, the US P-61 sampler (Figure 11) has been used.* Sample collection was handled by the Kansas City District prior to 1968; since that time, the USGS, Missouri District, has had this responsibility. Both agencies have taken five depth-integrating EDI verticals at least once a week (two or three times per week during high flows). The spacings between verticals are computed from discharge measurements taken prior to sampling. Before May 1973, the Kansas City District laboratory analyzed the suspended-sediment samples collected at Kansas City; since May 1973, the Missouri River Division Soils Laboratory in Omaha has had this responsibility. The two laboratories have followed standard procedures (Guy 1969; USAE Division, Missouri River 1968, 1969, 1970).

70. Computations of daily suspended-sediment loads were performed manually prior to 1966, using Equation 1. From 1966-1969, a computer program requiring a large number of input parameters, including seasonal and terrain conditions as well as concentrations and discharges, was used. Although this program worked satisfactorily when used with all of the correct input parameters, it was discontinued because the amount of input data required was not amenable to rapid computations of sediment loads for a large number of sediment stations. No documentation is available on this program. In 1969, the "Suspended-Sediment Load Computer Program" (also known as the "Kansas City Load Program") was written. This latter program, a simplified version of the one in use from 1966-1969, uses Equation 1 to make suspended-sediment load

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* Records available through 30 September 1976. The US P-61 was used at Kansas City 4,718 days between 31 October 1963 and 30 September 1976.

computations based on concentrations and discharges. These data are entered via a remote terminal in Kansas City to a mainframe computer in Berkeley, CA. The "Kansas City Load Program" (Sullivan 1970) is capable of interpolating up to 59 days of missing concentration record, provided that discharge values are available; accuracy, of course, decreases as the width of the data gap increases. The manual and the two automated methods of computing suspended-sediment loads at Kansas City are standard procedures (Porterfield 1972); however, the 1966-1969 program considered the influence of input parameters other than concentration and discharge, while the "Kansas City Load Program" provides a broad interpolative capability. Plots of the annual suspended-sediment load and discharge data for the Kansas City station are shown in Figure B17 of the report by Keown, Dardeau, and Causey (1981).

Change of samplers

71. Two different samplers, the US P-46 and the US P-61, have been used at Kansas City. Loads measured at this station have been influenced by upstream regime changes (paragraph 55). The period of record can be divided into three phases, as follows:

Phase	Period
Preconstruction	Before 1963
Transition	1953-1967
Postconstruction	After 1967

Therefore, Step C (paragraph 58) will have to be followed to examine the suspended-sediment sample collection, analysis, and load-computation procedures used at Kansas City. Suspended-sediment load data for Tarbert Landing and Simmesport can be used in the evaluation of the Kansas City station records. Paragraphs 65-67 provide station histories, as well as a discussion and comparison of the US P-46 and US P-61 samplers at Tarbert Landing and Simmesport. Results of laboratory and field tests of the US P-46 sampler (Appendix B, Table B1) indicate that this device properly measures the suspended-sediment concentration of the passing streamflow. The US P-61 has not been evaluated in the laboratory or the field.

Influence of procedures on
the suspended-sediment data

72. The following observations can be made regarding the validity of the suspended-sediment loads reported for Kansas City, the key station used to monitor the contribution of the Missouri River to the main stem:

a. There is no reason to question the validity of the sampling, analysis, or load-computation procedures used at Kansas City (paragraphs 69-70).

b. There is also no reason to question the validity of the sampling, analysis, and load-computation procedures used at Tarbert Landing and Simmesport (paragraphs 65-66).

c. The change of samplers from the US P-46 to the US P-61 at Tarbert Landing and Simmesport apparently had no impact on suspended-sediment loads reported for these two stations (paragraph 67).

d. Results of laboratory and field tests of the US P-46 sampler indicate that this device properly measures the suspended-sediment concentration of the passing streamflow (paragraph 71).

Therefore, the sampling, analysis, and load-computation procedures used at Kansas City have apparently had no influence on suspended-sediment loads reported for this key station.

Little Rock

Station history

73. The USAE District, Little Rock, has operated a suspended-sediment sample collection station on the Arkansas River at Little Rock since 1 October 1940. Between the beginning of the period of record and 22 October 1946, the Little Rock District used the Texas sampler (Figure 3). From 23 October 1946 through 30 September 1949, field personnel collected depth-integrating samples with a locally designed and fabricated depth-integrating device. This sampler had a brass body that permitted flow through either of two different sizes of nozzles into a 1-qt mason jar.* From 1 October 1949 through 30 September 1968, the Little Rock District used the US D-49 sampler (Figure 9) (6,935 days), and after 1 October 1968, the US P-61 sampler (Figure 11).**

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* Personal Communications, 19 April 1982, James Baker, and 21 September 1982, Luck Wilson, USAE District, Little Rock.

** Records available through 30 September 1978. The US P-61 sampler was used at Little Rock 3,285 days between 1 October 1969 and 30 September 1978.

Sample collection was the responsibility of the Little Rock District prior to October 1969; since that time, the Little Rock District and the USGS, Arkansas District, have cooperated in this effort by collecting suspended-sediment samples whenever discharge readings were made (usually once weekly). Prior to the 1969 closure of Murray Lock and Dam, samples were taken at the Main Street Bridge (Mile 141.5). Since 1969, the usual sampling location has been downstream from Murray Dam (Mile 148.0); however, during times of high stream velocity, the samples are collected from the Main Street Bridge.

74. Before Water Year 1949, the Little Rock District soils laboratory analyzed the suspended-sediment samples; samples have been analyzed since Water Year 1949 by the USAE Division, Southwestern, laboratory in Dallas, TX (Keown, Dardeau, and Kennedy 1977). Both laboratories have followed standard procedures in analyzing these samples (Guy 1969). Additionally, the two laboratories have employed standard load-computation procedures (Porterfield 1972), using suspended-sediment concentrations and discharges to compute sediment loads (Equation 1). From these computations, a suspended-sediment rating curve showing the relation between suspended-sediment concentration and measured discharge is constructed. Sediment loads are interpolated for the days on which only discharge but not concentration data are obtained (Keown, Dardeau, and Kennedy 1977). Plots of the annual suspended-sediment load and discharge data for the Little Rock station are shown in Figure E10 of the report by Keown, Dardeau, and Causey (1981).

Change of samplers

75. Little Rock District personnel used four different samplers, the Texas, the local depth-integrating sampler, the US D-49, and the US P-61. Loads measured at this station have been influenced by regime changes on the Arkansas River (paragraph 55). The period of record can be divided into three phases, as follows:

Phase	Period
Preconstruction	Before 1963
Transition	1963-1970
Postconstruction	After 1970

The Texas sampler, which was subject to contamination resulting from both initial inrush and from inflow during ascent (Appendix B, paragraph 5), and the local depth-integrating device, whose sampling characteristics are not known, were both used before Water Year 1950. Because the period influenced by regime changes (the transition phase) on the Arkansas River did not begin until 1963, the suspended-sediment loads obtained at Little Rock with these two earlier samplers will not be considered in the analysis of the downward trend in the Mississippi main-stem loads. Instead, the examination of sampling, analysis, and load-computation procedures used at Little Rock will be limited to the US D-49 and US P-61 samplers, the two devices that have been used since Water Year 1950.

76. Preconstruction (1950-1962) annual suspended-sediment loads measured with the US D-49 sampler at Little Rock averaged 63.6 million tons, while the average annual discharge during the same time was 29.3 million acre-ft. The postconstruction (1971-1978) loads (using the US P-61) have averaged 11.0 million tons, with the average annual discharge during the same period being 34.1 million acre-ft. Therefore, the average annual postconstruction suspended-sediment loads reported for Little Rock have been reduced to 17 percent of what they were during the preconstruction phase; the average annual postconstruction discharges are 16 percent higher.

77. No records from stations not influenced by regime changes are available to directly compare the US D-49 and the US P-61 samplers. Thus, no definite statement can be made as to whether this decline in sediment loads is attributable to regime changes or to changes in samplers. However, because both the US D-49 and the US P-61 have been used with other key station samplers at sediment stations not influenced by regime changes* and because both devices have demonstrated the nearly identical sampling characteristics as the other samplers with which they were compared, a similarity of sampling characteristics can be inferred.

78. Step D (paragraph 58) will have to be followed to evaluate the influence of the sample collection analysis and load-computation procedures used at Little Rock on suspended-sediment loads reported for that station. Results of field tests of the US D-49 sampler (Appendix B, Table B1) indicate that this device properly measures the suspended-sediment concentration of the passing streamflow. The US P-61 has not been evaluated in the laboratory or in the field.

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* Comparison of the US D-49 and the Rock Island sampler is discussed in paragraph 61 (East Dubuque). The US P-61 is compared with the US P-46 in paragraph 67 (Tarbert Landing and Simmesport).

Influence of procedures on
the suspended-sediment data

79. The following observation can be made regarding the validity of the suspended-sediment loads reported for Little Rock, the key station used to monitor the contribution of the Arkansas River to the main stem:

a. There is no reason to question the validity of the sampling, analysis, or load-computation procedures used at Little Rock since Water Year 1950 (paragraphs 73-74).

b. A similarity of sampling characteristics between the US D-49 and US P-61 samplers can be inferred because both of these samplers have performed in a manner nearly identical to the other devices with which they were compared at East Dubuque, Tarbert Landing, and Simmesport (paragraph 77).

c. Results of field tests of the US D-49 sampler indicate that this device properly measures the suspended-sediment concentration of the passing streamflow (paragraph 78).

Therefore, sampling, analysis, and load-computation procedures used at Little Rock since Water Year 1950 have apparently had no influence on suspended-sediment loads reported for that key station.

Vicksburg

Station history

80. The USAE District, Vicksburg, has used a US P-61 sampler (Figure 11) since 1968 to collect suspended-sediment samples from the lower Mississippi River at Vicksburg (Mile 425.41). Point-integrating samples are taken weekly (monthly before May 1972) in six verticals, with six EDI centroids located at 10.7, 32.3, 57.0, and 84.0 percent of the total depth. The sampler is operated from a boat and is suspended by cable, reel, and crane. Samples have been analyzed by Vicksburg District laboratory using standard procedures (Guy 1969) throughout the period of record (Keown, Dardeau, and Kennedy 1977). Suspended-sediment loads are calculated using standard procedures discussed by Porterfield (1972) and Equation 1. A computer program provides printed output (Keown, Dardeau, and Kennedy 1977).

US P-61 sampler

81. Only one sampler, the US P-61, has been used at the Vicksburg station.* Therefore, Step A (paragraph 58) was followed to determine whether or not collection, analysis, and load-computation procedures have influenced the numerical values reported for suspended-sediment loads measured at Vicksburg. These procedures have not changed during the entire period of record. No laboratory or field tests have been conducted to evaluate the sampling characteristics of the US P-61.

Influence of procedures on the suspended-sediment data

82. The following observation can be made regarding the validity of the suspended-sediment loads reported for Vicksburg, the key station used to monitor main-stem loads between the Arkansas River confluence and Old River Outflow Channel:

> There is no reason to question the validity of the sampling, analysis, or load-computation procedures used at Vicksburg (paragraph 80).

Therefore, sampling, analysis, and load-computation procedures used at Vicksburg have apparently had no influence on suspended-sediment loads reported for this key station.

Tarbert Landing

Station history

83. The station history for Tarbert Landing is presented in paragraphs 65 and 66.

Change of samplers

84. Two different samplers, the US P-46 and the US P-61, have been used to collect suspended-sediment samples at Tarbert Landing. Although the suspended-sediment loads reported for the Tarbert Landing station have been influenced by regime changes, both samplers have been used for at least 4 years each during the postconstruction phase; therefore, Step B

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* Suspended-sediment loads passing the Vicksburg station were influenced by upstream regime changes that occurred during the period 1963-1970 (paragraph 55); however, because only one sampler, the US P-61, was used, regime changes do not have to be considered.

(paragraph 58) will be followed to examine the suspended-sediment sampling, analysis, and load-computation procedures used at Tarbert Landing.

85. A summary of the annual discharge and suspended-sediment loads for each of the two samplers used at Tarbert Landing (paragraph 67) indicated that a decrease in the average annual discharge was accompanied by a decrease in the average annual suspended-sediment load, which is to be expected. Results of laboratory and field tests of the US P-46 sampler (Appendix B, Table B1) indicate that this device properly measures the suspended-sediment concentration of the passing streamflow. The US P-61 has not been evaluated in the laboratory or the field.

Influence of procedures on
the suspended-sediment data

86. The following observations can be made regarding the validity of the suspended-sediment loads reported for Tarbert Landing, the key station used to monitor the contribution of the main stem to the Gulf of Mexico:

a. There is no reason to question the validity of the sampling, analysis, or load-computation procedures used at Tarbert Landing (paragraphs 65-66).

b. The change of samplers from the US P-46 to the US P-61 at Tarbert Landing has apparently had no impact on suspended-sediment loads reported for that station (paragraph 67).

c. Results of laboratory and field tests of the US P-46 sampler indicate that this device properly measures the streamflow (paragraph 85).

Therefore, the sampling, analysis, and load-computation procedures used at Tarbert Landing have apparently had no influence on suspended-sediment loads reported for this key station.

Alexandria

Station history

87. Only one suspended-sediment sampler, the US P-46 (Figure 10), has been used by the New Orleans District at its Alexandria station on the Red River (Mile 104.9) since the beginning of the period of record (1 October 1952).* Twice each month, four or five point-integrated suspended-sediment

* Records available through 30 September 1978. The US P-46 sampler was used at Alexandria 9,490 days between 1 October 1952 and 30 September 1978.

samples are taken on three to five verticals equally spaced across the stream. The number of points on each vertical and the number of verticals are based on the gage reading (Keown, Dardeau, and Kennedy 1977). The point-integrated samples are taken for 2-min. intervals. Throughout the period of record, analysis and load-computation procedures have been standard and in accordance with those used at Tarbert Landing and Simmesport (paragraph 66).

Change of samplers

88. Only one sampler, the US P-46, was used at the Alexandria station.* Therefore, Step A (paragraph 58) will be followed to determine whether or not sampling, analysis, and load-computation procedures have influenced the numerical values reported for suspended-sediment loads measured at Alexandria. These procedures have not changed during the entire period of record. Results of laboratory and field tests of the US P-46 sampler (Appendix B, Table B1) indicate that this device properly measures the suspended-sediment concentration of the passing streamflow.

Influence of procedures on the suspended-sediment data

89. The following observations can be made regarding the validity of the suspended-sediment loads reported for Alexandria, the key station used to monitor the contribution of the Red River to the Atchafalaya River:

a. There is no reason to question the validity of the sampling, analysis, or load-computation procedures used at Alexandria (paragraph 87).

b. Results of laboratory and field tests of the US P-46 sampler indicate that this device properly measures the suspended-sediment concentration of the passing streamflow (paragraph 88).

Therefore, the sampling, analysis, and load-computation procedures used at Alexandria have apparently had no influence on suspended-sediment loads reported for the key station.

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* The farthest downstream dam on the Red River, Denison (Mile 725.5), was closed in 1944, while records of the suspended-sediment sample collection station at Alexandria (Mile 104.9) did not begin until 1 October 1952. Therefore, the impact of upstream regime changes (if any) on loads passing Alexandria cannot be assessed. However, because only one sampler, the US P-46, was used, regime changes do not have to be considered.

Simmesport

Station history

90. The station history for Simmesport is presented in paragraphs 65 and 66.

Change of samplers

91. Two different samplers, the US P-46 (Figure 10) and the US P-61 (Figure 11), were used to collect suspended-sediment samples at Simmesport. Although the suspended-sediment loads reported for the Simmesport station have been influenced by regime changes, both samplers have been used for at least 4 years each during the postconstruction phase (paragraph 65); therefore, Step B (paragraph 58) will be followed to examine the suspended-sediment sampling, analysis, and load-computation procedures used at Simmesport.

92. A summary of the annual discharge and suspended-sediment loads for each of the two samplers used at Simmesport (paragraph 67) indicated that a decrease in the average annual discharge was accompanied by a decrease in the average annual suspended-sediment loads, which is to be expected. Results of laboratory and field tests of the US P-46 sampler (Appendix B, Table B1) indicate that this device properly measures the suspended-sediment concentration of the passing streamflow. The US P-61 has not been evaluated in the laboratory or the field.

Influence of procedures on the suspended-sediment data

93. The following observations can be made regarding the validity of the suspended-sediment loads reported for Simmesport, the key station used to monitor the contribution of the Atchafalaya River to the Gulf of Mexico:

a. There is no reason to question the validity of the sampling, analysis, or load-computation procedures used at Simmesport (paragraphs 65-66).

b. The change of samplers from the US P-46 to the US P-61 at Simmesport has apparently had no impact on suspended-sediment loads reported for that station (paragraph 67).

c. Results of laboratory and field tests of the US P-46 sampler indicate that this device properly measures the suspended-sediment concentration of the passing streamflow (paragraph 92).

Therefore, the sampling, analysis, and load-computation procedures used at Simmesport have apparently had no influence on suspended-sediment loads reported for this key station.

PART IV: SUMMARY AND CONCLUSION

Summary

94. This study was conducted to determine the influence of sample collection, analysis, and load-computation procedures on the downward trend in Mississippi River suspended-sediment loads that apparently began around the middle of the 20th century. First, the scientific and engineering literature was examined to reconstruct a history of the development of these procedures in the Mississippi River Basin beginning with the first investigation by CPT Talcott in 1838 and continuing through the present time.

95. Next, key station histories were reconstructed, documenting the sampling, analysis, and load-computation procedures used throughout their periods of record. These procedures were then examined to determine if any information related to the procedures themselves would place the integrity of the suspended-sediment data for that key station in question. Further, data from any laboratory or field tests conducted to evaluate the performance of the samplers were also examined. The effects of using more than one sampler and of any upstream regime changes were considered by following a series of analytical steps.

Conclusion

96. Based on the examination of the sampling, analysis, and load-computation procedures used at key stations on the Mississippi River main stem and its major tributaries and distributaries, there is no reason to suspect that these procedures had a direct impact on the observed downward trend in suspended-sediment loads on the main stem of the Mississippi River that apparently began around the middle of the 20th century.

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APPENDIX A: GLOSSARY

Ambient--Surrounding, such as the ambient stream velocity at a sampling point.

Basin (or waterst ɔd)--An area confined by drainage divides, usually having only one streamflow outlet.

Bed (or streambed)--The bottom of a watercourse.

Bed load--That portion of the total sediment load that moves in essentially continuous contact with the streambed. The bed load and the suspended-sediment load together comprise the total load.

Composite sediment sample--A single sample formed by combining all the individual samples of a single sampling unit (e.g., a cross section of a stream). Concentration--See suspended-sediment concentration.

Concentration ratio--See suspended-sediment concentration ratio.

Depth-integrating sampler--A device capable of collecting a water-sediment mixture isokinetically, as its intake traverses the flow vertically.

Depth integration--A method of sediment sampling to obtain a representative sample of the water-sediment discharge from any (or every) part of a stream vertical, except in a small unsampled zone near the streambed.

Discharge--The volume of water that passes through a stream cross section during a specific time interval.

Fluvial sediment--See sediment.

Gage height (or river stage or stage)--A water-surface elevation referenced to some arbitrary datum.

Grab sample--A single sample taken from a stream cross section, usually to determine suspended-sediment concentration. Estimation of suspended-sediment discharge using data derived from a grab sample is often in error except at those locations where thorough mixing is known to occur (e.g., outflow channel of a dam).

Grab sampler--A suspended-sediment sampler designed to collect a specimen of the water-sediment mixture in a portion of a stream cross section during a relatively rapid period of time. Grab samplers, which have often been as unsophisticated as open jars or buckets, collect samples at an intake rate that usually exceeds that of the ambient stream velocity.

Initial inrush--The immediate and rapid flow of a water-sediment mixture into a sampler. The volume entering the sampler is directly portional to the depth of submergence. Initial inrush represents the volume decrease of the air within the sampler. During this action, no air escapes from the sampler.

Isokinetic--Condition in which the intake velocity of a suspended-sediment sampler equals the ambient stream velocity.

Key station--In this report, a sediment station located on the main stem of the Mississippi River, usually upstream or downstream from a major trib a y or distributary, or on a major tributary or distributary near the c luence with the main stem. Key stations serve to monitor sediment loads at various points within the Mississippi River Basin.

Main stem--The principal stream of a basin (or watershed). In this report, the Mississippi River.

Normal filling--The flow of a sediment-water mixture into a sampler after initial inrush. Normal filling rate is essentially a constant for a given sampler and can be either uniform and smooth if a separate air exhaust is provided or intermittent if a single opening serves for both sample intake and air exhaust.

Particle-size distribution--The proportion of material of each particle-size range (e.g., clay, silt, sand, and gravel) present in a given sample.

Point-integrating sample--A water-sediment mixture accumulated continuously in a sampler held at a relatively fixed point in a stream. The point-integrating sample represents the mean concentration of suspended sediment in the stream discharge passing a point during the sampling interval.

Point-integrating sampler--A device capable of collecting a water-sediment mixture isokinetically for a specified time interval by opening and closing while under water.

Point-integration--A sampling method that represents the mean concentration of suspended sediment in the discharge passing a point in a stream during the sampling interval.

Reach--A length of stream channel.

River mile--Distance along a stream (in US statute miles) as measured from a reference point, usually the confluence of one stream with another or at a selected point within a delta or estuary of a stream.

River stage--See gage height.

Sampling vertical (or vertical)--An approximately vertical path from the water surface to the streambed along which samples are taken to determine the sediment concentration.

Sediment (or fluvial sediment)--The solid material that originates mostly from disintegrated rocks and is transported by, suspended in, or deposited from water. Sediment includes chemical and biochemical precipitates and decomposed organic material, such as humus. The quantity, characteristics, and cause of the occurrence of sediment in streams are influenced by environmental factors. Some major factors are slope, length of slope, soil characteristics, land use, and duration and intensity of precipitation.

Sedimentation--That portion of the metamorphic cycle from the separation of particles from parent rock to (and including) their consolidation into another rock.

Sediment-rating curve--A curve fit to a plot of known values of sediment load versus discharge or stage, from which unknown values of sediment load can be estimated for a known discharge or stage.

Sediment range--A cross-sectional plane of a stream, usually normal to mean direction of flow, in which two or more verticals are taken to determine the concentration, particle-size distribution, or other characteristics of the sediment load.

Sediment station--A location on a stream where sediment samples are collected.

Sediment yield--The total sediment outflow from a drainage basin at a point of reference for a specified time interval.

Stage--See gage height.

Streambed--See bed.

Streambed material--See bed material.

Stream-gaging station--A location on a stream, canal, lake, or reservoir at which observations are made of discharge or gage height.

Suspended-sediment concentration (or concentration)--The weight of suspended sediment per unit volume of solution, usually expressed as milligrams of dry sediment per litre of water-sediment mixture.

Suspended-sediment concentration ratio (or concentration ratio)--The weight of suspended sediment per weight of sample solution, expressed as a ratio.

Suspended-sediment load--Refers to those sediment particles that are transported entirely within the body of the fluid and that have very little contact with the bed. The suspended-sediment load, together with the bed load, comprise the total load.

Total load--The sum of the bed load and the suspended-sediment load.

Trend--A statistical term referring to the direction or rate of increase or decrease in magnitude of the individual members of a time series of data when random fluctuations of individuals are disregarded.

Unsampled zone--The vertical distance between the intake of a suspended-sediment sampler and the streambed measured when the sampler is resting on the streambed.

Vertical--See sampling vertical.

Watershed--See basin.

Water year--The period from 1 October through the following 30 September.

APPENDIX B: DESCRIPTIONS AND EVALUATIONS OF SUSPENDED-SEDIMENT SAMPLERS USED AT KEY STATIONS IN THE MISSISSIPPI RIVER BASIN

1. A total of six different devices have been used to collect the majority of the suspended-sediment* samples at the key stations in the Mississippi River Basin. These samplers include:

a. Texas.

b. Rock Island.

c. US P-46.

d. US D-49.

e. US P-61.

f. US P-63.

The Texas sampler (also referred to as the US Department of Agriculture (USDA) or Faris sampler) was a grab sampler first developed by the USDA in the 1920's for use in Texas streams, while the Rock Island sampler was a local sampler used by the US Army Engineer (USAE) District, Rock Island. The other four samplers are part of the United States (US) Standard Series developed by the Federal Inter-Agency Sedimentation Project (FISP), with the designations, D and P, identifying a particular sampler as depth-integrating or point-integrating, respectively. The last two digits indicate the 20th-century year that the sampler became available for general use.

2. Depth-integrating samplers operate at a constant vertical transit rate between the stream surface and a point slightly above the streambed. For an accurate measure of suspended-sediment load, a sufficient number of these vertical samples should be taken in a stream cross section. The sampler should admit the water-sediment mixture at a rate equal to that of the ambient stream velocity. Depth-integrating samples can be integrated in one (either ascending or descending trips) or both directions (round trip). There is always an unsampled zone just above the streambed.**

3. Point-integrating samplers are usually held at fixed points in the stream cross section. They admit the water-sediment mixture of the stream at

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* Appendix A is a glossary of terms that relate to sediment sampling.

** See paragraphs 45 and 46, main text, for details on the FISP procedures used to measure fluvial sediment in a stream. See also Guy and Norman (1970). References cited in this appendix are included in the references following the main text of this report.

a rate equal to that of the instantaneous stream velocity at the point. The point-integrating sample represents the mean concentration of sediment in the stream discharge passing a point during the sampling time. These devices can also b used to collect multiple depth-integrating samples in each vertical in streams too deep to sample in a single round-trip integration.*

4. This appendix contains descriptions of samplers used at key stations and a discussion of sampler evaluations that have been reported in the literature.

Descriptions of Samplers

5. Below are brief descriptions of each of the seven suspended-sediment samplers used at key stations in the Mississippi River Basin:

a. Texas. The Texas sampler (Figure 3, main text), a grap sampler, consisted of a 1/2-pt wide-mouth stoppered bottle attached to a 1/8- by 3/4- by 15-in. steel hanger by means of a sheet metal bottle container. At the bottom of the hanger was a 15-lb current meter weight. This sampler was raised and lowered by hand-held sash cord. Until the sampler was lowered to the appropriate depth (usually 0.6 of the vertical distance from the water surface to the streambed), the bottle was kept sealed and held in place by a sliding clamp attached to a loop that had a diameter slightly larger than that of the lip on the neck of the bottle. At the desired depth, the operator removed the bottle stopper by pulling on the stopper line that was attached to a stiff piece of bailing wire connected to the bottle stopper. As a precaution designed to prevent premature removal by tension produced in the stopper line by the current, a 5/32- by 9-in. coil spring was attached to the top of the hanger and to the stopper wire in such a manner that the spring absorbed the tension (Faris 1933, Welborn 1969). The sampler was left at the sampling point to permit the container to fill and was then raised to the surface without replacing the stopper. Samples were contaminated by extensive initial inrush. Because the sample bottle remained open, additional contamination occurred during sampler ascent (FISP 1957a).

b. Rock Island. The original Rock Island sampler (Figure 8a, main text) consisted of a horizontal sampler container, 18 in. long, with an intake tube, a controlled air exhaust, and brass vertical fins attached to a lead-covered body. The 1/4-in.-diam opening of the intake orifice was flush with the front end of the streamlined sample container that was oriented directly into

* Examples of point-integrating samplers used for depth integrations are presented in Part III of the main text of this report.

the streamflow. A 3/16-in. inside diameter (ID) air exhaust tube extended upward and was inclined downstream to provide for the evacuation of air from the sampler. The exhaust tube contained an adjustable stop cock that regulated the rate of air escape to control the filling rate. This device was later altered by the addition of rubber pad stoppers that were held in place over the water intake and air exhaust openings by springs (Figure 8b, main text). An operator opened the sampler orifice by maintaining tension on an auxiliary line and holding these springs away from the openings. When the pull was released, the stoppers were forced back over the openings by the springs, thus closing the sampler (FISP 1940, Péwé 1946, and unpublished data).

c. US P-46. The US P-46 sampler (Figure 10, main text) is 26 in. long and weighs 100 lb. This device has a streamlined cast bronze shell with tailvanes to orient the 3/16-in. intake nozzle of the sampler so that it points directly into the streamflow. Other features of the US P-46 include an inner recess to hold the round 1-pt milk bottle sample container, a pressure-equalizing chamber with a volume about five times that of the sample bottle, and a tapered rotary valve that controls the sample-intake and air-exhaust passages. When these passages are closed prior to lowering the sampler into a stream, two permanent openings in the bottom of the shell equalize the air pressure in the chamber and in the sample container. The valve, controlled by a solenoid, has three positions: (1) intake and air exhaust closed with pressure-equalizing passage open, (2) intake and air exhaust open with equalizing passage closed, and (3) all passages closed. The sampler can be used to depths of 100 ft. There is a 5-in. unsampled zone (FISP 1948, 1952, 1962, 1963b).

d. US D-49. The US D-49 sampler (Figure 9, main text) weighs 62 lb and is relatively stable in high velocity or turbulent flows. The sampler has a 24-in.-long cast bronze streamlined body that encloses a round or square 1-pt milk sample bottle. The head of the sampler is hinged to permit access to the sample container. Tailvanes orient the sampler into the streamflow. The head of the sampler is drilled and tapped to receive a 1/4-, 3/16-, or 1/8-in. intake nozzle, which projects directly into the streamflow for collecting the sample. The device is suspended on a hanger bar attached to a 1/8-in. steel cable that is lowered and raised by means of a reel mounted on a crane. There is an unsampled zone of about 4 in. (FISP 1963b, 1965; Guy and Norman 1970).

e. US P-61. The US P-61 (Figure 11, main text) is a 28-in.-long electrically operated cast bronze sampler that weighs 107 lb. It can be used with a 3/16-in. intake nozzle and either 1-pt or 1-qt sample containers for point-integration or for depth-integration to stream depths of up to 180 ft. Its size, shape, construction materials, use of pressure-equalization chamber, sample container, tapered rotary valve, two-conductor suspension cable, and power supply are very similar to that of the US P-46. The valve-operating switch, located at the observer's station (usually on a bridge or cableway), has two positions (instead of three, as in the US P-46 sampler): (1) solenoid not energized--the intake and air exhaust passages are closed and the valve is in the equalizing position or (2) solenoid energized--the intake and air exhaust passages are open and the valve is in the sampling position. The unsampled zone is approximately 4 in. (FISP 1963b, 1981; Guy and Norman 1970).

f. US P-63. The US P-63 (Figure 12, main text) is a cast bronze sampler, 34-in. long and weighing 202 lb. Its valve and intake nozzle size are identical to that of the US P-61. The sample container is either a 1-pt or 1-qt round bottle. Because it is larger and heavier than the US P-61, the US P-63 sampler is better adapted for use at greater depths and at higher stream velocities. The unsampled zone is approximately 6 in. (FISP 1981, Guy and Norman 1970).

Evaluation of Samplers

6. Nelson and Benedict (1951) stated that an ideal suspended-sediment sampler should be designed to:

a. Permit sampling close to the streambed.

b. Be streamlined and have sufficient weight to remain stable in the streamflow.

c. Be rugged and simply constructed to minimize field repair. Sample containers should be removable and suitable for transportation to the laboratory without loss or contamination of the contents.

d. Have the intake orifice oriented into the approaching flow and protruding upstream from the zone of disturbance caused by the presence of the sampler.

The velocity of the intake should be equal to that of the stream in which the sediment sample is collected, and the nozzle should permit intake without initial inrush (Nelson and Benedict 1951). Beverage (1979) stated that

> The fundamental assumption of all US Series samplers is that of isokineticity. That is, a sampler whose intake velocity equals the ambient stream velocity will collect a truly representative sample of the stream at that point.

7. A "truly representative" sample is, therefore, one whose concentration is equal to that portion of the stream cross section that it represents. The literature shows that a number of the suspended-sediment samplers used on the Mississippi River main stem and its major tributaries and distributaries have been evaluated, with the greatest majority of the research having been conducted by the FISP. Table B1 shows the testing and evaluation of suspended-sediment samplers that have been reported in the literature. These

studies were conducted to determine sampler intake characteristics (i.e., whether or not the sampling velocity was isokinetic with respect to that of the ambient streamflow) and comparative concentration ratios (side-by-side comparisons with other samplers).

8. Some concentration comparisons of key station samplers (paragraph 5, this appendix) have also been made with other sediment samplers, including the Omaha, the Colorado River, the US P-43, the US D-43, and the US DH-59. These other samplers are described below:

a. Omaha. The Omaha sampler (Figure B1) was a smooth-filling, point-integrating sampler designed by the USAE District, Omaha. The 1-pt, wide-mouth glass jar sample container was completely enclosed in a recess in a weighted, streamlined sampler. A brass screw cover for the sample container had a 1/4-in.-diam orifice for the water intake and a 1/4-in.-diam tube for the air exhaust. This tube extended vertically about 1-1/2 in. above the cover and had the top cut obliquely so that the opening for air escape faced downstream only. A large cork float suspended beneath the lid closed both the intake and air exhaust tube when the bottle was full; however, no provision had been made to prevent the sampler from filling during its descent to the desired depth (FISP 1940).

b. Colorado River. The original Colorado River sampler (Figure B2a), which was developed and used by the US Geological Survey (USGS), consisted of a 1-pt milk bottle enclosed and suspended in a simple metal frame. The bottle was capped by a rubber insert having a hole of sufficient diameter to obtain the desired rate of filling. Prior to sampling, the hole was closed with a rubber stopper. The stopper could be removed at the desired sampling point by a simple lever system actuated by the impact of a messenger weight. No provision was made for closing the bottle after the sample was taken. An altered version of the Colorado River sampler (Figure B2b) had the lever system reversed so that when the weight was dropped down the suspension line, the sampler was closed by forcing the rubber stopper over the bottle opening. A pull on an auxiliary line opened the sampler. At shallow depths a rod, instead of the drop weight, could be used to close the sampler (FISP 1941c).

c. US P-43. The US P-43 (Figure B3) was a point-integrating sampler that weighed 33 lb and had a 3/16-in.-diam intake nozzle and a cast bronze streamlined body with both horizontal and vertical tailvanes. On top of the sampler was a manually operated valve mechanism, tripped by a messenger weight that was dropped down a current meter cable. The sampler container was a 1-pt mason jar that was secured in place by a coil spring and sealed with sponge rubber. The sampler saw very little usage in the field; however, it was evaluated in the laboratory against a number of other samples that were used at key stations in the Mississippi River Basin (Table B1). Limitations of this sampler included its light weight, its manually operated tripping

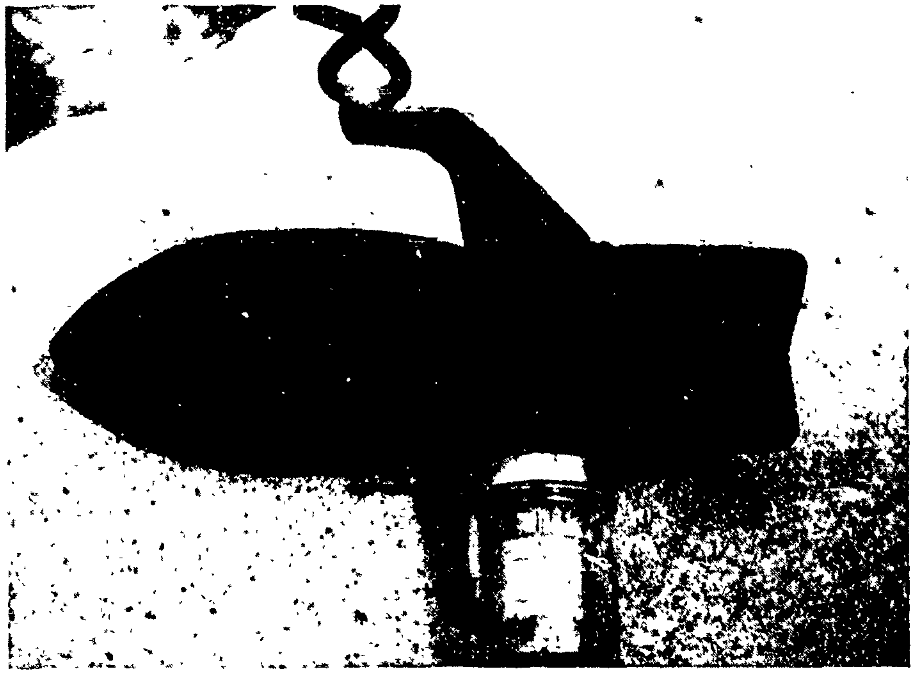
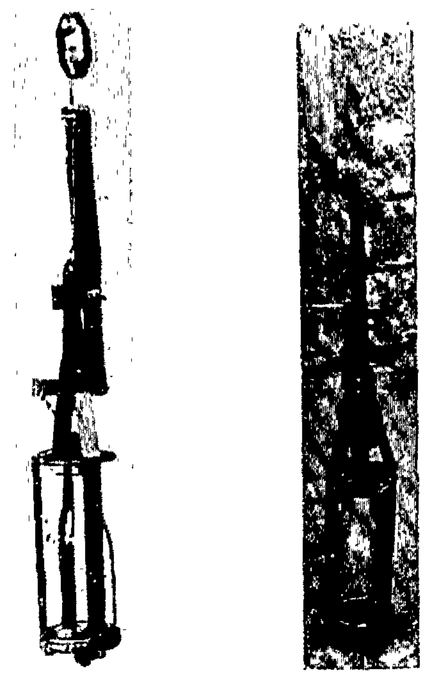


Figure B1. The Omaha suspended-sediment sampler (courtesy of USAE District, Omaha)



a. Original sampler

b. Sampler with alterations

Figure B2. The Colorado River suspended-sediment sampler (FISP 1941b)

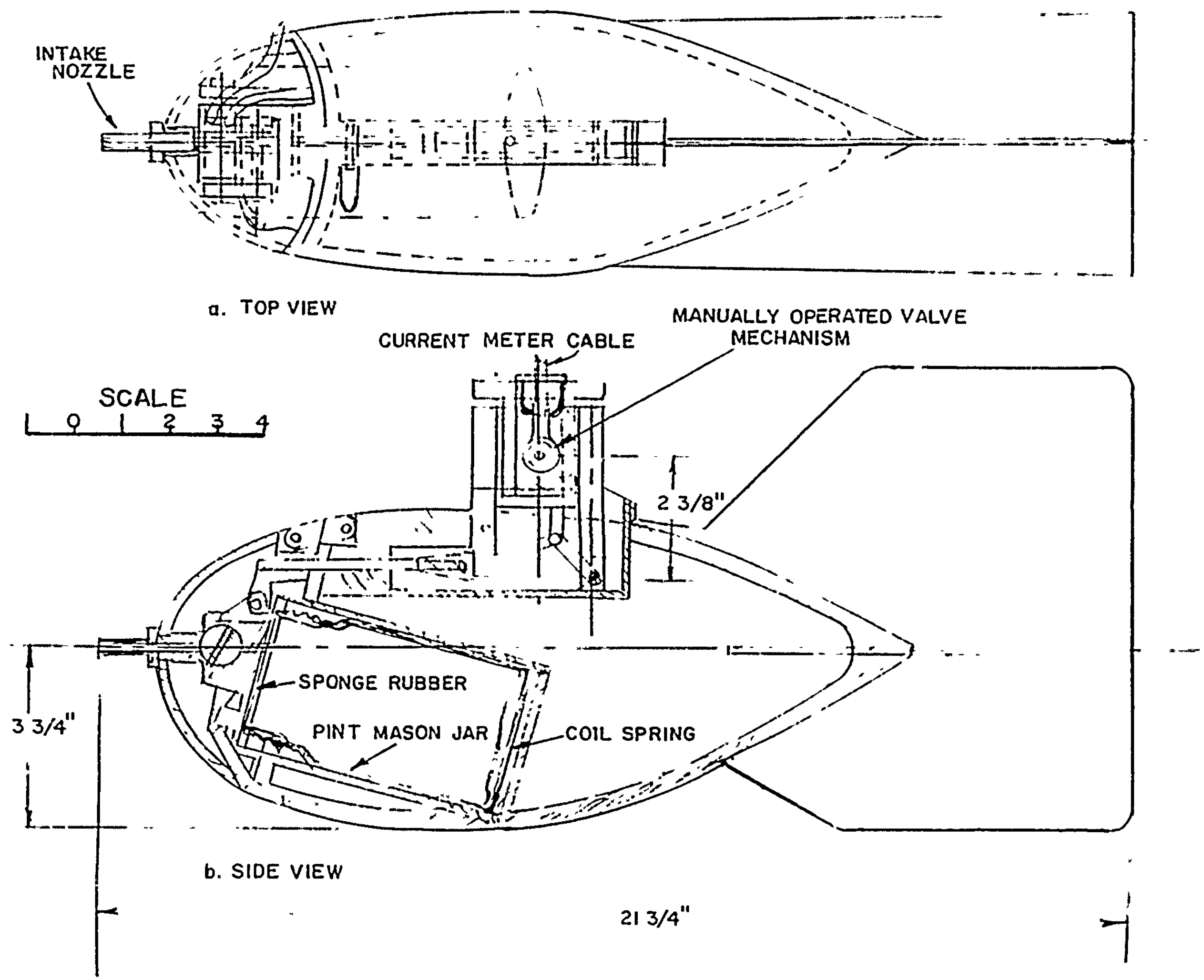


Figure B3. The US P-43 suspended-sediment sampler (after Benedict and Nelson 1944)

Table B1

Testing and Evaluation of Suspended-Sediment Samplers Used at Key Stations in the Mississippi River Basin

Sampler Designation	Evaluation				
	Type of Test	Date	Location	Agency	Reference(s)
Texas	Concentration ratio	May 1943 (compared with Omaha, Rock Island, Colorado River, and US D-43 samplers)	Various field locations	FISP	Nelson and Benedict 1946, 1951
		1943-1944 (compared with Omaha, Rock Island, Colorado River, US P-43, and US D-43 samplers)	Various field locations	FISP	Benedict and Nelson 1944
		1943-1944 (compared with Omaha, Rock Island, Colorado River, and US D-43 samplers)	Various field locations	FISP	Nelson 1944
		1943-1946 (compared with Omaha, Colorado River, and US D-43 samplers)	Various field locations	FISP	FISP 1957a

(Continued)

Note: FISP = Federal Inter-Agency Sedimentation Project; USAED = US Army Engineer District, TWDB = Texas Water Development Board; UIHL = University of Iowa, Hydraulic Laboratory.

(Sheet 1 of 4)

Table B1 (Continued)

Sampler Designation	Evaluation				
	Type of Test	Date	Location	Agency	Reference(s)
Texas	Concentration	1946-1948 (compared with US D-43 sampler)	Various field locations, USAED, Tulsa	USAED, Tulsa	USAED, Tulsa 1949
		1961-1963 (compared with US D-43, US P-46, and US DH-59 samplers)	Various Texas streams	TWDB	Welborn 1967, 1969
Rock Island	Intake Characteristics	1941	UIHL	FISP	FISP 1941c
		19[illegible]-1944	Various field locations, USAED, Rock Island	FISP	unpublished data
		1943-1946	UIHL	FISP	Nelson and Benedict 1946, 1951
	Concentration ratio	1940-1944 (compared with and without fins and with US D-43 sampler)	Various field locations, USAED, Rock Island	FISP	Péwé 1946 and unpublished data
		1943 (compared with US D-43 sampler)	Various field locations, USAED, Rock Island	FISP	Nelson and Benedict 1946, 1951

(Continued)

(Sheet 2 of 4)

Table B1 (Continued)

Sampler Designation	Evaluation				
	Type of Test	Date	Location	Agency	Reference(s)
Rock Island	Concentration ratio	1943-1944 (compared with US D-43 sampler)	Various field locations, USAED, Rock Island	FISP	Benedict and Nelson 1944
		1943-1944 (compared with US D-43 sampler)	Various field locations, USAED, Rock Island	FISP	Nelson 1944
US P-46	Intake characteristics	1946	UIHL	FISP	FISP 1952
		1947	Colorado River near Grand Canyon, AZ	FISP	FISP 1951
		1948	David Taylor Model Basin Carderock, MD	FISP	FISP 1954
	Concentration ratio	1947 (based on stream and FISP (1941c) values)	Colorado River near Grand Canyon, AZ	FISP	FISP 1951
		1961-1963 (compared with Texas sampler)	Various Texas streams	TWDB	Welborn 1967, 1969
US D-49	Concentration ratio	1961-1963 (compared with Texas sampler)	Various Texas streams	TWDB	Welborn 1967, 1969

(Continued)

Table B1 (Concluded)

Sampler Designation	Evaluation				
	Type of Test	Date	Location	Agency	Reference(s)
US P-61	Never evaluated				
US P-63	Never evaluated				

(Sheet 4 of 4)

mechanism, and its tendency to accumulate sediment in the nozzle while the intake was closed (Benedict and Nelson 1944, Nelson 1944).

d. US D-43. The US D-43 sediment sampler (Figure B4) was 20-1/2 in. long and had a cast bronze streamlined body with horizontal and vertical tailvanes. The forward section of the sampler had a double hinge to provide access to the 1-pt sample container and was adapted to receive 1/4- or 1/8-in.-diam nozzles. A spring latch on the underside of the sampler held the head securely in the closed position and permitted it to be opened readily. The sampler weighed about 50 lb* and was suspended by a steel cable from a reel and crane. The US D-43 sampler was suitable for depth integration in streams less than 27 ft deep in which the velocities did not exceed 7 fps. It could sample within 5 in. of the streambed (FISP 1952, Guy and Norman 1970, Nelson 1944).

e. US DH-59. Th US DH-59 sampler (Figure B5) was designed for use with a flexib handline suspension, primarily in streams that cannot be wa but that have velocities of 5 fps or less. This device, which weighs 22 lb, consists of a 15-in.-long streamlined bronze casting that partially enclosed a round 1-pt milk bottle. A tailvane assembly orients the intake nozzle of the US DH-59 into the approaching flow as the sampler enters the stream. As shown in Figure B5, the sample bottle is sealed against a gasket in the head cavity of the casting by pressure applied to the base of the bottle by a hand-operated, spring-tensioned, pull-rod assembly. The sampler is calibrated and supplied with nozzles having 1/4-, 3/16-, or 1/8-in. bores. The appropriate nozzle is selected and seated in the threaded recess of the sampler head, and the sampler is lowered and raised at a uniform rate between the water surface and the bottom of the stream. Upon contact with the streambed, the direction of travel is reversed instantly, and the sampler is raised at the same or some other uniform rate. The US DH-59 continues to sample throughout the period of submergence and must be removed from the stream before the bottle has completely filled. Because of the inclination of the sampling bottle, any point bottle more than 90 to 95 percent filled after sampling could be in error due to circulation of the water-sediment mixture. There is an unsampled zone of about 4-1/2 in. (FISP 1963b, 1965, 1981). The US DH-59 has been subjected to concentration comparisons with the Texas sampler (Welborn 1967, 1969).

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* An early experimental version of the US D-43 weighed 38 lb.

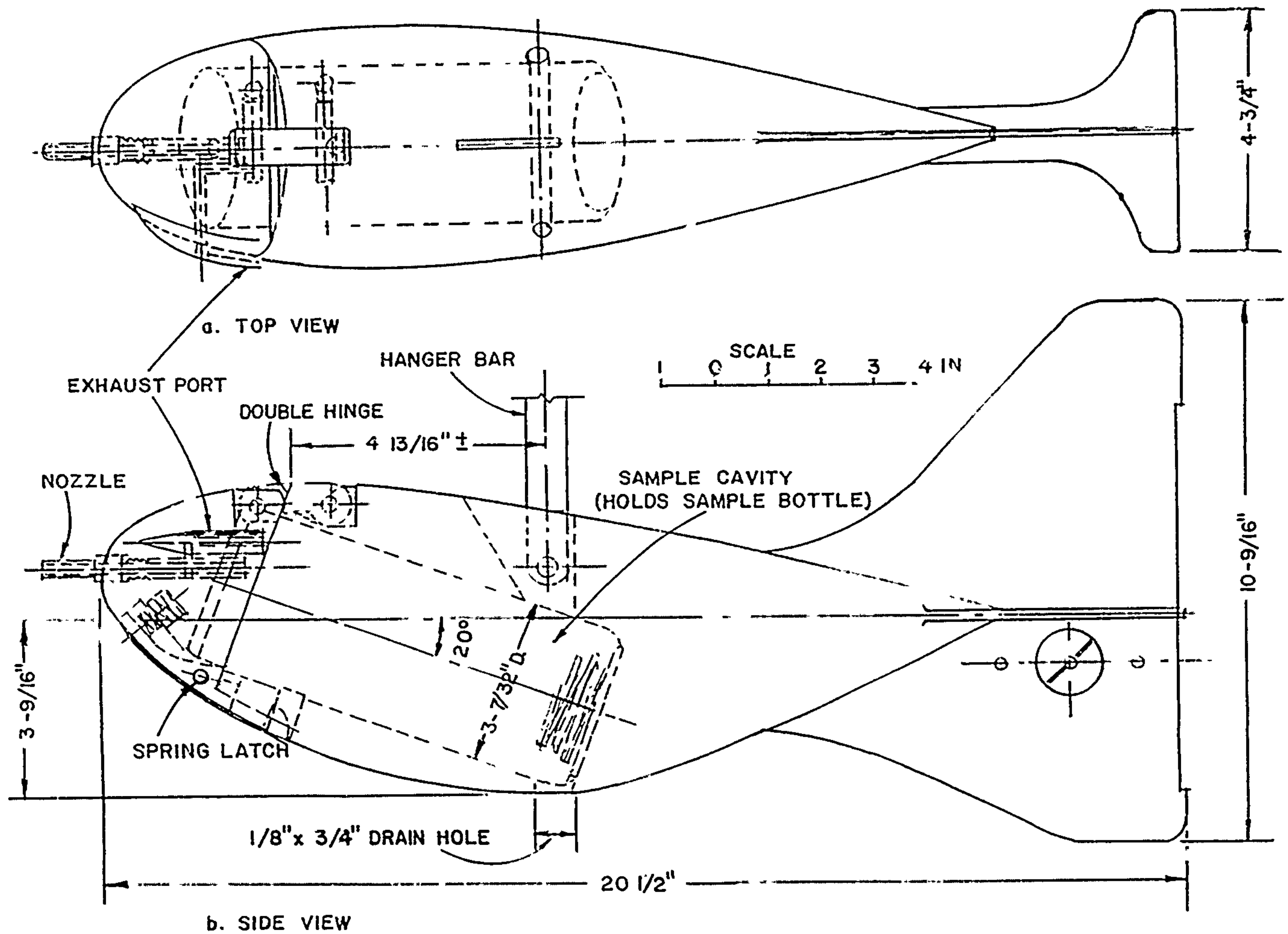

Figure B4. The US D-43 suspended-sediment sampler (after FISP 1952)

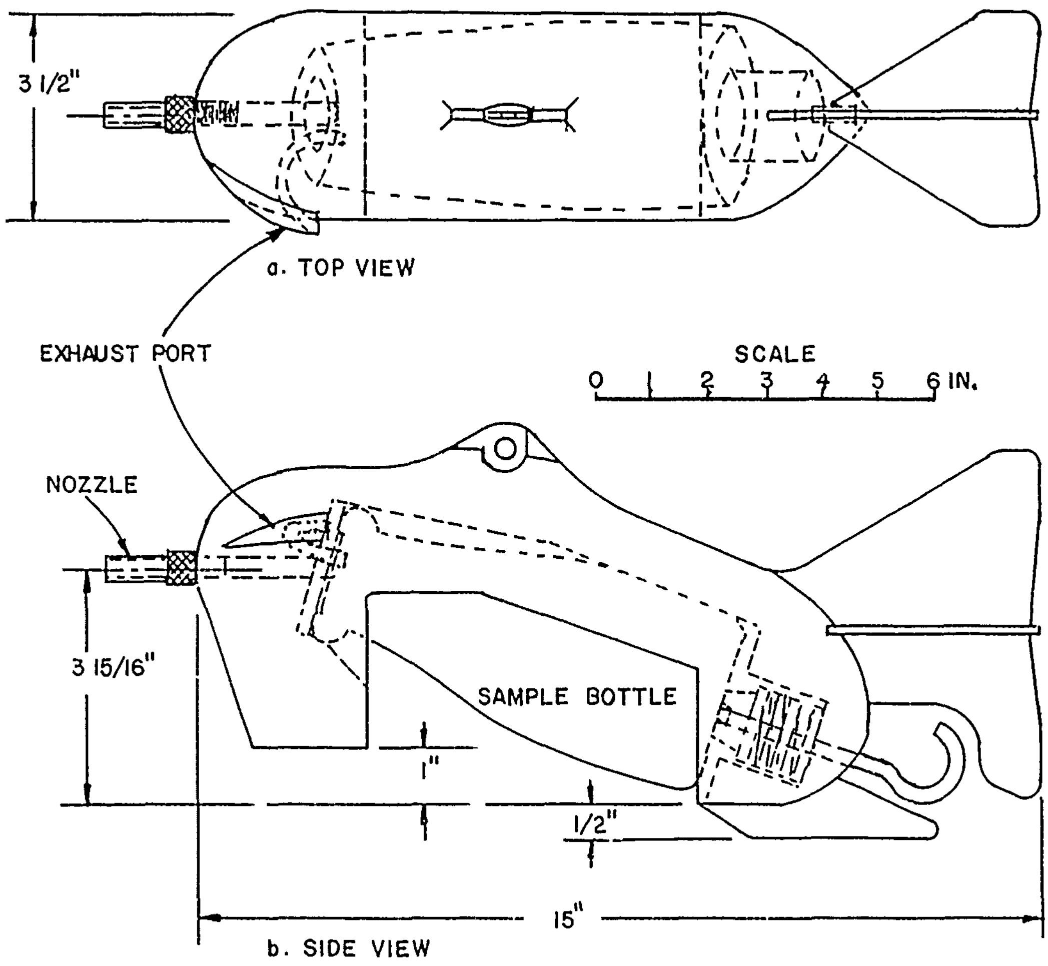

Figure B5. The US DH-59 handline suspended-sediment sampler (after FISP 1981)