U.S. DEPARTMENT OF THE INTERIOR
March 3, 1849

Techniques of Water-Resources Investigations of the United States Geological Survey

Chapter C3

COMPUTATION OF FLUVIAL-SEDIMENT DISCHARGE

By George Porterfield

Book 3

APPLICATIONS OF HYDRAULICS

UNITED STATES DEPARTMENT OF THE INTERIOR
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PREFACE

The series of manuals on techniques describes procedures for planning and executing specialized work in water-resources investigations. The material is grouped under major subject headings called books and further subdivided into sections and chapters; Section C of Book 3 is on sediment and erosion techniques.

The unit of publication, the chapter, is limited to a narrow field of subject matter. This format permits flexibility in revision and publication as the need arises.

Provisional drafts of chapters are distributed to field offices of the U.S. Geological Survey for their use. These drafts are subject to revision because of experience in use or because of advancement in knowledge, techniques, or equipment. After the technique described in a chapter is sufficiently developed, the chapter is published and is sold by the U.S. Geological Survey, 1200 South Eads Street, Arlington, VA 22202 (authorized agent of Superintendent of Documents, Government Printing Office).

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COMPUTATION OF FLUVIAL-SEDIMENT DISCHARGE

George Porterfield

Abstract

This report is one of a series concerning the concepts, measurement, laboratory procedures, and computation of fluvial-sediment discharge. Material in this report includes procedures and forms used to compile and evaluate particle-size and concentration data, to compute fluvial-sediment discharge, and to prepare sediment records for publication.

Introduction

Collection, computation, and publication of fluvial-sediment and related environmental data are part of a national program to evaluate effects of sedimentation on the life and economics of projects related to navigation, flood control, transportation, reclamation, water supply, recreation, pollution, and fisheries. Fluvial-sediment investigations may include determination of the sediment discharge of rivers, surveys of reservoirs, studies of channel morphology, research in basic processes, and interpretation of sediment data.

The purpose of this chapter is to combine into a single handbook the necessary information to evaluate sediment data, compute sediment discharge, and tabulate the data for publication. The content is based not only on the author's experience but includes information from the voluminous literature accumulated during the past two or three decades as well as the ideas of many experienced coworkers.

Although this chapter is limited to methods of compilation, computation, and editorial format, it also includes reference to sampling techniques, laboratory procedures, principles of sediment transport, and quality control, because knowledge of these is fundamental to computation of sediment records. The entire operation, from the collection of the sample in the field to the laboratory analysis and the computation and publication of the records, requires a high degree of coordination. Minor duplication of material in other chapters of the manual is necessary and intentional to allow use of the chapter as separate entities.

This manual was prepared by the California district, Water Resources Division, U.S. Geological Survey, Menlo Park, Calif., under the general supervision of R. Stanley Lord, District Chief. Technical advice and assistance were given by Geological Survey personnel in California, Texas, New Mexico, and Pennsylvania districts and by F. C. Ames, H. P. Guy, and J. K. Culbertson.

Types of Records

Two basic types of sediment records—daily and periodic—are published by the Geological Survey.

Daily records are prepared for sites where sufficient determinations of sediment concentration and water discharge are obtained to justify computation of daily sediment discharge. The end product is a tabulation of daily mean concentration, suspended-sediment discharge, and periodic determinations of particle-size distribution of suspended sediment and bed material. These are combined with other quality-of-water data and released, usually by water year (October through following September) and on an annual basis, by the Geological Survey in basic-data reports covering a specific State or in the water-supply-paper series "Quality of Surface Waters of the United States."

Periodic records are prepared for sites where determinations of concentration and water discharge are not sufficient to justify computation of daily sediment discharges or where only miscellaneous samples are obtained. In addition to publication of the records, the data and computations are maintained on file in the district offices of the Water Resources Division and are available for examination or for use in interpretative reports or research.

Checklist for Daily Records

Steps in the procedure for the computation of daily records of fluvial-sediment discharge are given in the following checklist. A checklist for periodic and mixed records is given in the section "Periodic Observation" of this report. Data on stream stage and discharge needed in the daily sediment computation may be obtained from an A-35-analog-recorder chart or a plot of bihourly gage heights or discharge and from data forms 9-192, 9-210, and 9-207. The checklist items are as follows:

- Particle-size analyses:
  - Compute from laboratory analyses
  - Tabulate
  - Apply instantaneous water discharge
- Tabulate water temperature
- Sediment concentration:
  - Compute from laboratory analyses
  - List sediment measurements
  - Copy size-concentration values on concentration notes
  - Compute coefficients
- Chart computations:
  - Plot concentration
  - Draw concentration graph
  - Review concentration graph
  - Compute concentration
  - Apply concentration coefficient
  - Compute subdivided days
  - Check subdivided days
- Sediment-discharge worksheet:
  - Copy water discharge
  - Copy concentration
  - Compute sediment discharge
  - Compute totals
  - Check totals
- Sediment-discharge worksheet—Continued
  - Compute maximum and minimum
  - Insert footnotes
- Plot sediment-transport curve
- Plot hydrograph
- Write or update station description
- Write station analysis
- Review entire record
- Prepare copies for records-processing center

Particle-Size Analysis

Samples of suspended sediment from each sampling site taken at specific or selected times of the year are analyzed for particle-size distribution. These samples indicate the average particle-size distribution of the material transported and should be obtained at various seasons of the year and at sufficient increments of discharge to cover the complete range in seasonal flow. Samples of bed material also are obtained to define the size distribution of bed material at various increments of flow and to define the physical properties of the material available for transport. The type and purpose of the sample dictates to some degree the sampling procedure, the methods used to analyze the sample, and the methods and forms used to present the data. Sampling procedures are discussed in detail in the manual on field methods for fluvial-sediment measurements (Guy and Norman, 1970) and by the U.S. Inter-Agency Committee on Water Resources (1963). Laboratory procedures and methods of analyses are discussed in detail in the manual on laboratory theory and methods for sediment analyses (Guy, 1969).

Evaluation of size data

Particle-size analyses should be evaluated during the review and tabulation process for—

1. Correct method of analysis,
2. Total number of analyses,
3. Range of water discharge,
4. Agreement of concentration and water discharge on the particle-size tabulation with those on the sediment-discharge sheet and published records, of water discharge, and

5. Validity of percentage-finer values.

The number of samples analyzed, methods of sample collection, and method of analysis depend partly on the purpose and scope of the sediment project or data program; results of analyses should be reviewed to determine if the number of samples and method used for analysis fulfills the goals of the sampling program.

Accuracy of the analysis is dependent, among other factors, on the quantity and physical characteristics of the sediment analyzed; an inspection of the data sheet will indicate if a sufficient quantity of material was collected for analysis. Analysis made on samples containing insufficient material may be in error. Particle-size distribution of these samples should be carefully evaluated for accuracy, and if suspect they should not be published. In general, the quantity of sediment needed for analysis is as follows:

Method	*Quantity of sediment, in grams*	
	Minimum	*Optimum*
Dry sieve	50	100
Wet sieve	.05	0.5-1.0
VA tube	.05	1.0-7.0
Pipet	.8	3.0-5.0
BW tube	.5	0.7-1.3

The minimum number of bottles of sample required to provide sufficient sediment for size analysis may be determined from the curves in figure 1. The range of concentration values and percentage finer than 62 microns needed to use figure 1 are available in the station records for the preceding year.

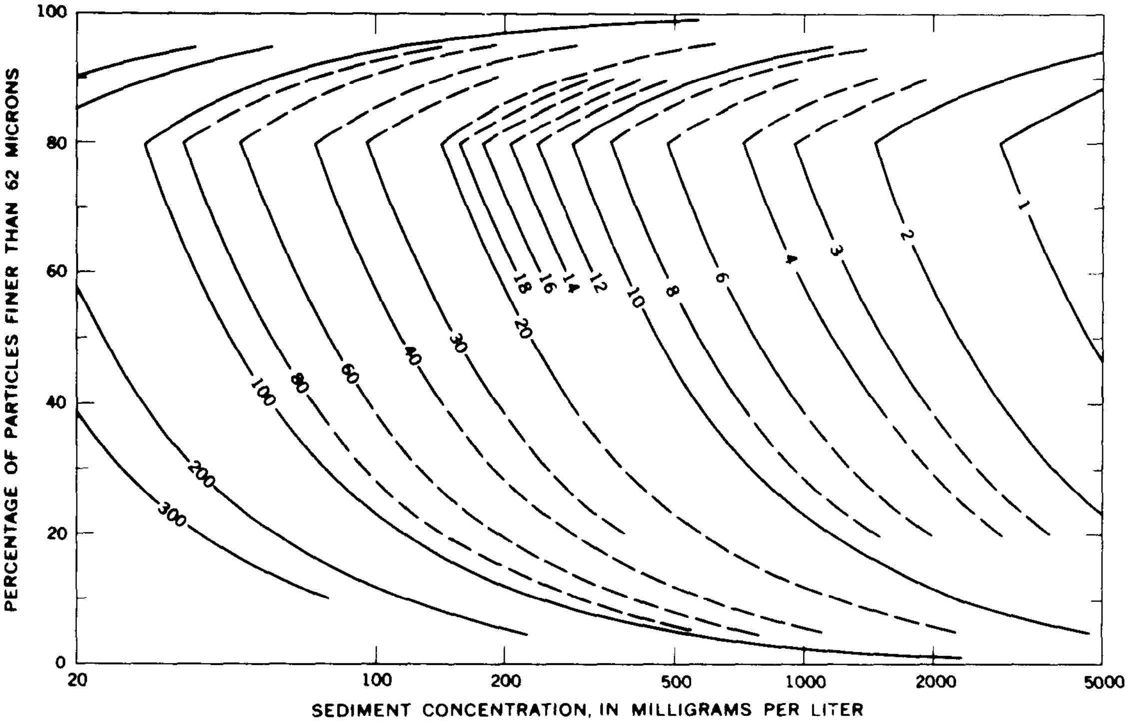


Figure 1.—Minimum number of bottles of sample required to yield sufficient sediment for size analysis. Explanation: Estimate sediment concentration and percentage finer than 62 microns by referring to analysis of samples obtained previously or by visual examination of the sediment sample. The number of bottles required is the value indicated by the line to the left of the intersection of the ordinate and abscissa. Interpolation of number of bottles is made along the abscissa. Values of the number of bottles required were computed on the assumption that each sample bottle contains 350 grams of water-sediment mixture and that a minimum of 0.2 gram of sand for a sieve or visual-accumulation-tube analysis and 0.8 gram of silt and clay for a pipet analysis in 400-milliliter suspension are needed for analysis. The number of bottles required to yield sufficient silt and clay for a bottom-withdrawal-tube analysis is five-eighths of the number indicated.

Tabulation of size data

Particle-size analyses of suspended sediment are tabulated on form 9–1539D, shown in figure 2. This form is also used to tabulate periodic or miscellaneous concentration and particle-size data. Particle-size analyses of bed material are tabulated on form 9–1539E (not illustrated). Examples of offset copy furnished by computer for publication are illustrated in the section on "Format of Sediment Tables."

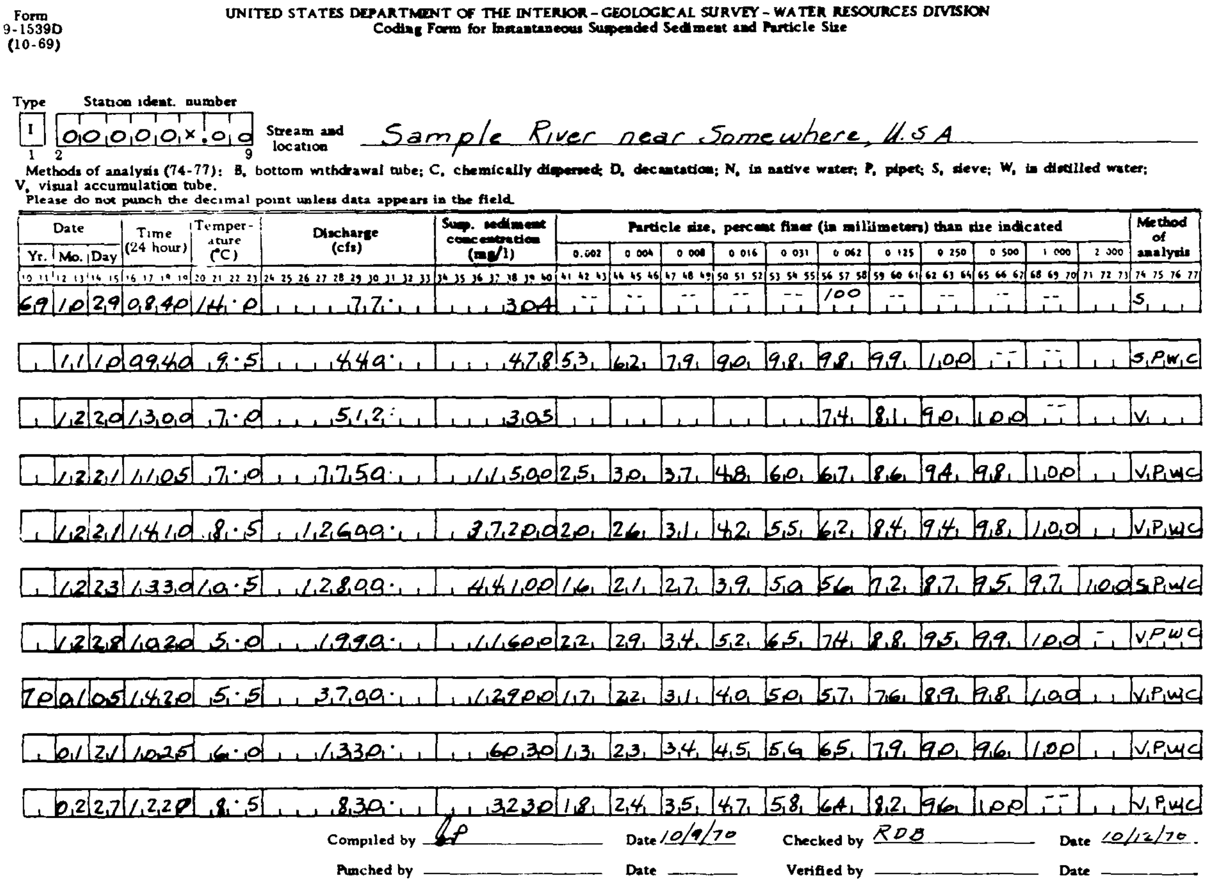
Instantaneous water discharge at the time of sampling and concentration of the sample analyzed for particle-size distribution are determined and tabulated for each sample. These values must be compared for validity with the daily values published for water discharge in the surface-water records and on the sediment-discharge sheet. Water-discharge values may be computed and listed in the space provided on the particle-size forms or may be listed on the multiple-purpose form described in the section on "Analysis of Cross-Section Concentration Data."

Data from the particle-size analyses should be transcribed neatly on the form shown in figure 2. The data are arranged on the form as follows:

Date of collection.—Tabulate year, month, and day. January 1, 1970, for example, is 700101.

Time (24 hour).—Time is reported in 24-hour local standard time. The hours and minutes are always written to four places and without punctuation. Do not use a.m. or p.m. For example: 0001 hours is 1 minute after midnight; 0100 hours is 1 a.m.; 1048 hours is 10:48 a.m.; 1200 hours is 12 m. (noon); 1430 hours is 2:30 p.m.; and 2400 hours is 12 p.m. (midnight).

Water temperature (°C).—Water-temper-



Form
9-1539D
(10-69)

UNITED STATES DEPARTMENT OF THE INTERIOR - GEOLOGICAL SURVEY - WATER RESOURCES DIVISION
Coding Form for Instantaneous Suspended Sediment and Particle Size

Type: 1
Station ident. number: 00000x00
Stream and location: Sample River near Somewhere, U.S.A

Methods of analysis (74-77): B, bottom withdrawal tube; C, chemically dispersed; D, decantation; N, in native water; P, pipet; S, sieve; W, in distilled water; V, visual accumulation tube.
Please do not punch the decimal point unless data appears in the field.

Date			Time (24 hour)	Temperature (°C)	Discharge (cfs)	Susp. sediment concentration (mg/l)	Particle size, percent finer (in millimeters) than size indicated											Method of analysis
Yr.	Mo.	Day					0.002	0.004	0.008	0.016	0.031	0.062	0.125	0.250	0.500	1.000	2.000	
10 11	12 13	14 15	16 17 18 19	20 21 22 23	24 25 26 27 28 29 30 31 32 33	34 35 36 37 38 39 40	41 42 43	44 45 46	47 48 49	50 51 52	53 54 55	56 57 58	59 60 61	62 63 64	65 66 67	68 69 70	71 72 73	74 75 76 77
69	10	29	0840	14.0	77.	304	--	--	--	--	--	100	--	--	--	--		S
	11	10	0940	9.5	449.	478	53	62	79	90	98	98	99	100	--	--		SPWC
	12	20	1300	7.0	512.	305						74	81	90	100	--		V
	12	21	1105	7.0	7750.	11500	25	30	37	48	60	67	86	94	98	100		VPWC
	12	21	1410	8.5	12600.	37200	20	26	31	42	55	62	84	94	98	100		VPWC
	12	23	1330	10.5	12800.	44100	16	21	27	39	50	56	72	87	95	97	100	SPWC
	12	28	1020	5.0	1990.	11600	22	29	34	52	65	74	88	95	99	100	-	VPWC
70	01	05	1420	5.5	3700.	12900	17	22	31	40	50	57	76	89	98	100		VPWC
	01	21	1025	6.0	1330.	6030	13	23	34	45	56	65	79	90	96	100		VPWC
	02	27	1220	8.5	830.	3230	18	24	35	47	58	64	82	96	100	--		VPWC

Compiled by Lp Date 10/9/70 Checked by RDB Date 10/12/70.
Punched by ______ Date ______ Verified by ______ Date ______

Figure 2.—Annual tabulation of particle-size analyses of suspended sediment.

ature data are reported to the nearest 0.5 degree Celsius.

Number of sampling points.—Use when reporting bed-material analyses. This is the number of samples obtained in the stream cross section.

The laboratory may report individual analysis for each sample to show variation of bed-material size distribution in the cross section and to provide necessary data for computation of total sediment discharge by the procedure described by Colby and Hembree (1955). Generally the average size distribution in the cross section is published; however, individual analysis may be published if there is a large variation of median diameter among verticals or if there is a need for more detailed information.

Discharge (cfs).—The discharge is usually reported for the time of sampling; however, if no measurment is made or the rating does not justify reporting the instantaneous discharge, the daily mean discharge is reported. If mean discharge is used, change heading to "Mean discharge (cfs)" or use footnote "D" as explained in the section on "Footnotes."

Concentration (mg/l).—All sediment concentrations will be reported in milligrams per liter although they will be determined in the laboratory as parts per million. The supervisor must determine that all concentrations have been properly converted prior to tabulating concentrations or computing sediment discharge.

Sediment discharge (tons per day).—Values for tons per day should be determined as discussed in the section on "Computation of Sediment Discharge." Records tabulated for computer processing do not require computation of sediment discharge because values in this column are computed and listed by computer.

Particle sizes, percent finer than size (in millimeters) indicated.—The sizes for suspended sediment are 0.002, 0.004, 0.008, 0.016, 0.031, 0.062, 0.125, 0.250, 0.500, 1.00, 2.00 mm. The sizes for bed-material analyses are 0.004, 0.062, 0.125, 0.250, 0.500, 1.00, 2.00, 4.00, 8.00, 16.00, and 32.00 mm.

Method of analysis.—In the method of analysis column, the symbols should be recorded in the same order that the methods were used for the analysis. For example:

SBWC
VPWC
SPWC
VPN
SV

The symbols are explained in the headnotes and are standard.

Water Temperature

Temperature is an important physical characteristic of water, and information on water temperature is a necessary part of any study of water quality. It is also an important parameter needed to compute total-sediment discharge. A temperature observation should be obtained with each chemical-quality or sediment sample.

A temperature record may consist of a tabulation of maximum and minimum observations, once-daily observations, or observations obtained during periodic visits to a station. A continuous temperature record may be obtained from one of the many devices that sense and record fluctuations of water temperature on a continuous chart. Maximum and minimum temperatures for each day are computed from the chart and listed as illustrated in figure 3. A tabulation of once-daily temperature observations obtained by field personnel or contract observers is illustrated in figure 4. The form shown in figure 4 is a modified 9-211C.

Those observations taken daily or more frequently will be included in the tables of annual reports; observations obtained at infrequent visits to the station will be published in conjunction with other data, such as the tabulation of particle-size data on form 9-265b (fig. 2) or periodic sediment data (fig. 45). The completed tabulations (fig. 3 or 4) including maximum and minimum values are sent to the records-processing center where they are prepared for publication. The tabular data must be complete, that is with an entry in each space. If no

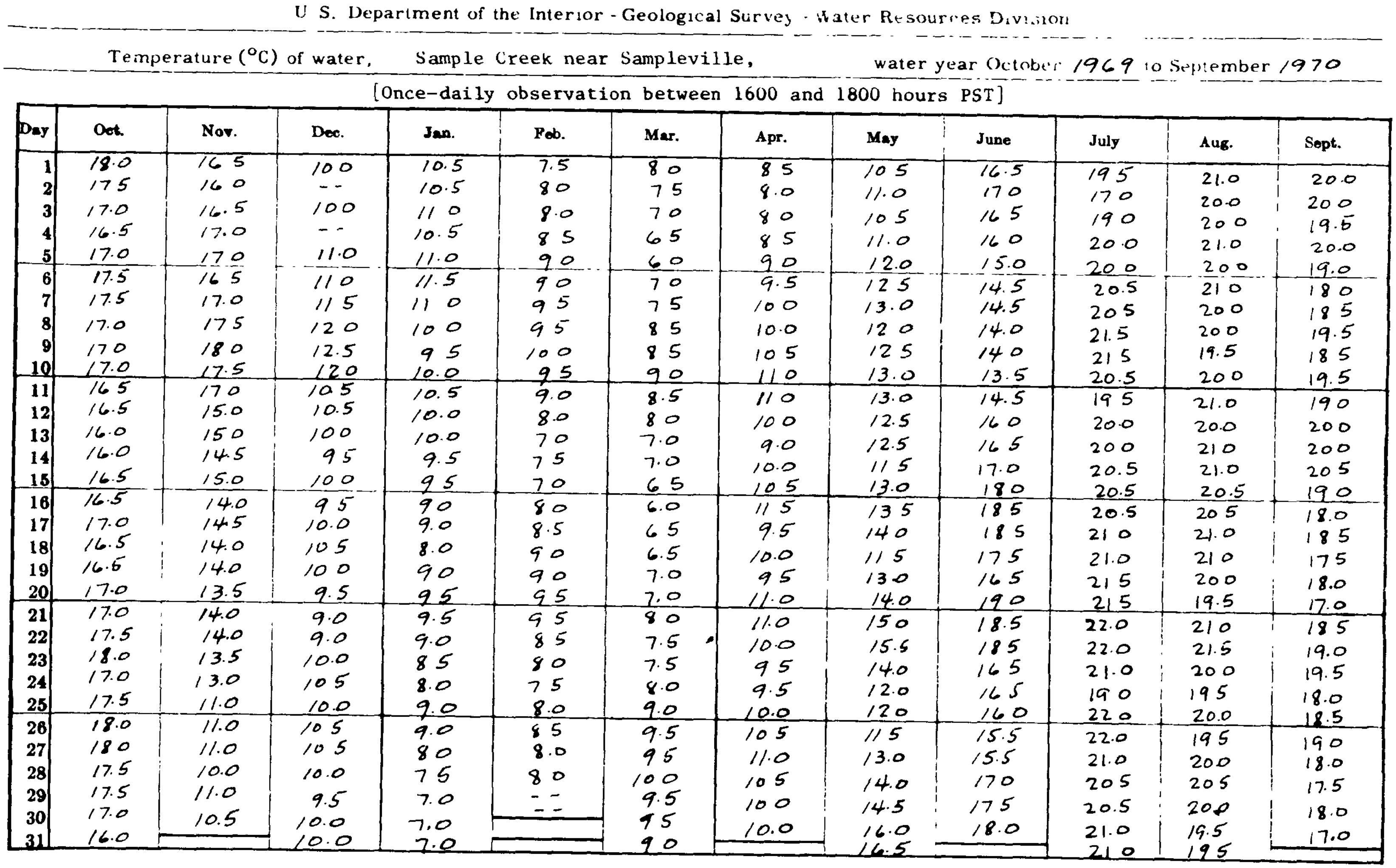
9-267d

U S. Department of the Interior - Geological Survey - Water Resources Division

Temperature (°C) of water, Sample River at Sampleville, water year October 1969 to September 1970

Day	October		November		December		January		February		March		April		May		June		July		August		September	
	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min
1	21.0	16.0	12.5	10.5	6.5	5.0	6.5	5.5	4.5	2.5	6.0	4.0	9.5	6.0	12.5	8.5	23.0	16.5	19.5	17.0	24.0	17.0	24.5	16.0
2	20.5	14.0	13.5	11.0	6.0	5.0	7.0	6.0	5.0	3.0	5.5	4.0	8.0	5.5	13.0	8.0	23.5	16.5	22.5	17.0	24.0	17.5	23.0	17.5
3	20.0	14.5	12.5	11.0	6.0	5.0	6.5	6.5	5.5	3.5	5.0	3.5	7.0	4.5	10.5	8.0	24.0	17.0	23.0	17.5	24.5	17.5	22.5	17.0
4	15.5	15.0	12.0	11.0	7.0	5.0	7.0	6.5	4.0	3.5	6.0	3.5	8.0	6.0	13.0	7.5	23.5	17.5	23.0	17.5	24.5	17.5	22.0	14.5
5	18.5	15.0	13.0	11.5	8.5	7.5	7.5	6.5	5.5	4.0	6.0	4.5	8.0	6.0	16.0	10.0	20.5	17.0	23.5	18.0	24.0	17.0	23.0	14.0
6	18.0	13.5	11.5	10.0	7.5	6.0	7.5	6.5	5.5	3.5	6.5	4.5	8.5	6.5	18.0	12.5	19.5	16.0	23.5	17.5	24.0	17.0	24.0	15.5
7	18.0	13.5	14.0	11.0	7.0	6.5	7.0	5.5	6.0	4.0	7.5	5.0	10.0	6.5	17.5	14.0	17.0	15.5	25.0	17.5	23.5	17.5	24.5	17.0
8	18.0	12.0	14.5	12.5	9.0	7.0	5.5	4.0	6.5	5.0	7.5	4.5	12.0	9.0	18.0	15.0	17.0	15.0	25.5	18.0	24.0	17.0	25.0	17.5
9	18.0	11.0	16.0	13.0	10.0	9.0	4.0	2.0	6.5	4.5	6.5	5.0	10.5	9.0	16.5	14.0	17.0	15.0	25.5	18.5	20.0	17.0	24.5	17.0
10	19.0	14.5	16.0	13.5	11.5	8.0	5.0	4.0	7.0	6.0	7.0	4.5	12.0	8.5	17.0	14.5	17.5	15.5	23.5	18.0	23.0	17.5	23.5	16.0
11	16.5	15.0	14.0	12.5	8.0	6.0	5.5	5.0	7.5	5.5	6.0	3.5	12.5	10.0	20.0	15.0	18.0	15.5	22.0	18.0	23.0	17.5	22.0	16.0
12	16.0	13.5	12.5	9.0	6.5	5.0	7.0	5.5	6.0	5.0	8.0	4.0	11.5	9.0	18.5	15.5	20.0	15.5	25.0	17.5	23.5	17.5	22.0	17.0
13	15.5	12.0	9.0	8.0	7.0	6.0	7.5	6.0	5.5	4.0	8.5	4.5	9.5	7.5	15.5	13.5	20.5	16.0	25.0	17.5	25.0	16.5	20.5	17.5
14	14.5	11.0	8.0	7.0	7.5	6.5	6.0	5.5	5.5	5.0	7.5	4.0	9.0	8.0	18.0	13.0	18.5	16.0	25.0	17.0	24.5	17.0	22.0	16.0
15	16.0	12.0	8.0	7.5	7.5	6.5	5.5	5.0	6.0	5.0	9.0	5.0	11.0	8.5	18.0	14.5	18.5	16.5	24.0	18.0	24.5	17.0	21.5	14.5
16	17.0	12.5	9.0	7.5	6.5	6.0	5.0	4.0	6.0	4.5	7.0	6.0	12.0	9.0	20.0	14.5	24.0	17.0	25.0	17.5	24.5	17.0	21.0	14.0
17	18.5	13.5	10.0	9.0	6.0	6.0	4.5	3.0	6.0	5.0	7.5	6.5	10.0	9.0	21.0	14.5	24.5	17.5	25.5	16.5	24.0	15.0	22.0	15.0
18	17.5	12.5	10.5	9.0	6.0	6.0	5.0	4.5	6.5	5.5	7.5	5.5	12.0	9.5	18.5	14.0	22.5	18.0	26.0	17.0	24.0	17.5	22.5	18.0
19	17.5	13.0	11.0	10.0	6.0	5.0	7.0	5.0	7.5	6.5	7.0	4.5	12.5	9.5	18.0	12.5	21.5	17.5	26.5	16.5	23.0	18.0	20.0	17.5
20	18.0	13.0	10.0	9.5	5.0	3.5	8.0	6.0	6.5	5.0	7.0	6.0	13.0	10.0	19.5	13.0	20.5	17.0	26.5	18.0	25.0	18.5	20.0	16.5
21	17.5	12.5	10.5	9.0	3.5	3.0	8.5	6.5	6.5	5.0	9.0	6.5	13.5	12.0	21.0	14.0	21.0	17.0	26.5	18.5	26.0	18.0	21.0	17.0
22	17.0	11.5	11.0	10.0	4.0	3.0	6.5	5.0	5.5	4.0	10.0	7.0	13.0	11.5	21.5	15.5	23.0	17.5	27.0	18.5	25.5	17.5	22.0	16.5
23	18.0	13.0	10.5	9.0	5.0	4.5	5.5	3.0	4.5	4.5	9.5	7.0	11.5	7.0	21.5	16.0	23.0	17.5	26.5	19.0	24.5	17.5	22.5	17.0
24	19.0	13.5	9.0	8.5	7.0	5.0	5.0	4.0	5.5	4.5	10.0	7.5	9.5	6.5	18.0	15.5	23.5	17.5	24.5	19.0	24.0	17.0	22.5	18.0
25	17.5	13.0	8.5	8.0	6.5	5.5	8.0	5.0	4.5	3.0	10.0	6.0	11.0	6.0	20.0	15.0	20.5	17.5	26.0	19.5	24.0	17.0	22.0	15.5
26	18.0	12.5	8.0	7.0	5.5	4.5	8.5	4.0	6.0	3.0	10.0	6.5	12.0	8.0	17.5	14.0	21.0	15.5	26.5	17.5	24.0	17.0	22.0	17.0
27	18.0	12.0	8.0	7.0	5.5	5.0	4.5	3.0	5.5	5.0	10.5	7.0	13.0	10.0	18.0	13.5	19.5	15.0	20.0	17.0	24.0	17.0	21.5	16.5
28	17.0	11.5	8.0	7.0	5.0	5.0	3.5	3.0	5.0	4.0	10.5	7.5	13.5	11.0	20.0	13.0	23.0	14.5	25.0	17.0	23.5	16.5	21.0	15.5
29	16.5	13.0	8.0	6.0	5.0	4.5	3.5	2.0	—	—	10.5	7.5	12.5	9.5	21.0	14.5	24.0	16.0	25.5	17.5	23.0	17.0	20.5	16.0
30	13.5	12.0	7.5	5.0	5.0	4.0	3.0	1.0	—	—	11.0	8.0	12.0	9.0	21.5	16.0	24.5	17.0	24.5	17.0	23.0	16.5	21.0	16.5
31	14.0	11.0	—	—	5.0	4.0	3.0	2.0	—	—	11.5	8.0	—	—	22.0	16.5	—	—	21.0	17.0	25.0	15.5	—	—

Figure 3.—Maximum and minimum daily water-temperature tabulation.



U S. Department of the Interior - Geological Survey - Water Resources Division

Temperature (°C) of water, Sample Creek near Sampleville, water year October 1969 to September 1970

[Once-daily observation between 1600 and 1800 hours PST]

Day	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
1	18.0	16 5	10 0	10.5	7.5	8 0	8 5	10 5	16.5	19 5	21.0	20.0
2	17 5	16 0	--	10.5	8 0	7 5	8.0	11.0	17 0	17 0	20.0	20 0
3	17.0	16.5	100	11 0	8.0	7 0	8 0	10 5	16 5	19 0	20 0	19.5
4	16.5	17.0	--	10.5	8 5	6 5	8 5	11.0	16 0	20.0	21.0	20.0
5	17.0	17 0	11.0	11.0	9 0	6 0	9 0	12.0	15.0	20 0	20 0	19.0
6	17.5	16 5	11 0	11.5	9 0	7 0	9.5	12 5	14.5	20.5	21 0	18 0
7	17.5	17.0	11 5	11 0	9 5	7 5	10 0	13.0	14.5	20 5	20 0	18 5
8	17.0	17 5	12 0	10 0	9 5	8 5	10.0	12 0	14.0	21.5	20 0	19.5
9	17 0	18 0	12.5	9 5	10 0	8 5	10 5	12 5	14 0	21 5	19.5	18 5
10	17.0	17.5	12 0	10.0	9 5	9 0	11 0	13.0	13.5	20.5	20 0	19.5
11	16 5	17 0	10 5	10.5	9.0	8.5	11 0	13.0	14.5	19 5	21.0	19 0
12	16.5	15.0	10.5	10.0	8.0	8 0	10 0	12.5	16 0	20.0	20.0	20 0
13	16.0	15 0	10 0	10.0	7 0	7.0	9.0	12.5	16 5	20 0	21 0	20 0
14	16.0	14.5	9 5	9.5	7 5	7.0	10.0	11 5	17.0	20.5	21.0	20 5
15	16.5	15.0	10 0	9 5	7 0	6 5	10 5	13.0	18 0	20.5	20.5	19 0
16	16.5	14.0	9 5	9 0	8 0	6.0	11 5	13 5	18 5	20.5	20 5	18.0
17	17.0	14 5	10.0	9.0	8.5	6 5	9.5	14 0	18 5	21 0	21.0	18 5
18	16.5	14.0	10 5	8.0	9 0	6.5	10.0	11 5	17 5	21.0	21 0	17 5
19	16.6	14.0	10 0	9 0	9 0	7.0	9 5	13.0	16 5	21 5	20 0	18.0
20	17.0	13.5	9.5	9 5	9 5	7.0	11.0	14.0	19 0	21 5	19.5	17.0
21	17.0	14.0	9.0	9.5	9 5	8 0	11.0	15 0	18.5	22.0	21 0	18 5
22	17.5	14.0	9.0	9.0	8 5	7.5	10.0	15.6	18 5	22.0	21.5	19.0
23	18.0	13.5	10.0	8 5	8 0	7.5	9 5	14.0	16 5	21.0	20 0	19.5
24	17.0	13.0	10 5	8.0	7 5	8.0	9.5	12.0	16 5	19 0	19 5	18.0
25	17.5	11.0	10.0	9.0	8.0	9.0	10.0	12 0	16 0	22 0	20.0	18.5
26	18.0	11.0	10 5	9.0	8 5	9.5	10 5	11 5	15.5	22.0	19 5	19 0
27	18 0	11.0	10 5	8 0	8.0	9 5	11.0	13.0	15.5	21.0	20 0	18.0
28	17.5	10.0	10.0	7 5	8 0	10 0	10 5	14.0	17 0	20 5	20 5	17.5
29	17.5	11.0	9.5	7.0	--	9.5	10 0	14.5	17 5	20.5	20 0	18.0
30	17.0	10.5	10.0	7.0	--	9 5	10.0	16.0	18.0	21.0	19.5	17.0
31	16.0		10.0	7.0		9 0		16.5		21 0	19 5	

Figure 4.—Tabulation of once-daily water temperatures.

value is available, a leader (..) should be placed in the blank space.

Although temperature data have been published by the Geological Survey in degrees Celsius since October 1967, many temperature measurements are made with a Fahrenheit thermometer and converted to Celsius when recorded on the permanent laboratory and field sheets. Thermograph records may be converted directly to Celsius by template, or the values may be tabulated in Fahrenheit (figs. 3, 4) and the conversion to Celsius made by digital computer. Values recorded on digital tape by temperature monitors also may be converted by computer. All other temperature values, including the "extremes" values for the period of record, should be converted to Celsius (table 1) in

Table 1.—Temperature conversion table to nearest 0.5 degree

[The numbers in the center columns refer to temperatures, either in Celsius or Fahrenheit, which are to be converted to the other scale. If converting Fahrenheit to Celsius, the equivalent temperature will be found in the left columns. If converting Celsius to Fahrenheit, the equivalent temperature will be found in the right columns]

	0 to 24.5			25.0 to 49.5			50.0 to 74.5			75.0 to 100.0	
—18.0	0	32.0	—4.0	25.0	77.0	10.0	50.0	122.0	24.0	75.0	167.0
—17.5	.5	33.0	—3.5	25.5	78.0	10.5	50.5	123.0	24.0	75.5	168.0
—17.0	1.0	34.0	—3.5	26.0	79.0	10.5	51.0	124.0	24.5	76.0	169.0
—17.0	1.5	34.5	—3.0	26.5	80.0	11.0	51.5	124.5	25.0	76.5	170.0
—16.5	2.0	35.5	—3.0	27.0	80.5	11.0	52.0	125.5	25.0	77.0	170.5
—16.5	2.5	36.5	—2.5	27.5	81.5	11.5	52.5	126.5	25.0	77.5	171.5
—16.0	3.0	37.5	—2.0	28.0	82.5	11.5	53.0	127.5	25.5	78.0	172.5
—16.0	3.5	38.5	—2.0	28.5	83.5	12.0	53.5	128.5	26.0	78.5	173.0
—15.5	4.0	39.0	—1.5	29.0	84.0	12.0	54.0	129.0	26.0	79.0	174.0
—15.5	4.5	40.0	—1.5	29.5	85.0	12.5	54.5	130.0	26.5	79.5	175.0
—15.0	5.0	41.0	—1.0	30.0	86.0	13.0	55.0	131.0	26.5	80.0	176.0
—14.5	5.5	42.0	—1.0	30.5	87.0	13.0	55.5	132.0	27.0	80.5	177.0
—14.5	6.0	43.0	— .5	31.0	88.0	13.5	56.0	133.0	27.0	81.0	178.0
—14.0	6.5	43.5	— .5	31.5	88.5	13.5	56.5	134.0	27.5	81.5	179.0
—14.0	7.0	44.5	0	32.0	89.5	14.0	57.0	134.5	28.0	82.0	179.5
—13.5	7.5	45.5	.5	32.5	90.5	14.0	57.5	135.5	28.0	82.5	180.5
—13.5	8.0	46.5	.5	33.0	91.5	14.5	58.0	136.5	28.5	83.0	181.5
—13.0	8.5	47.5	1.0	33.5	92.5	14.5	58.5	137.0	28.5	83.5	182.0
—13.0	9.0	48.0	1.0	34.0	93.0	15.0	59.0	138.0	29.0	84.0	183.0
—12.5	9.5	49.0	1.5	34.5	94.0	15.5	59.5	139.0	29.0	84.5	184.0
—12.0	10.0	50.0	1.5	35.0	95.0	15.5	60.0	140.0	29.5	85.0	185.0
—12.0	10.5	51.0	2.0	35.5	96.0	16.0	60.5	141.0	29.5	85.5	186.0
—11.5	11.0	52.0	2.0	36.0	97.0	16.0	61.0	142.0	30.0	86.0	187.0
—11.5	11.5	52.5	2.5	36.5	98.0	16.5	61.5	143.0	30.0	86.5	188.0
—11.0	12.0	53.5	3.0	37.0	98.5	16.5	62.0	143.5	30.5	87.0	188.5
—11.0	12.5	54.5	3.0	37.5	99.5	17.0	62.5	144.5	31.0	87.5	189.5
—10.5	13.0	55.5	3.5	38.0	100.5	17.0	63.0	145.5	31.0	88.0	190.5
—10.5	13.5	56.0	3.5	38.5	101.5	17.5	63.5	146.5	31.5	88.5	191.0
—10.0	14.0	57.0	4.0	39.0	102.0	18.0	64.0	147.0	31.5	89.0	192.0
— 9.5	14.5	58.0	4.0	39.5	103.0	18.0	64.5	148.0	32.0	89.5	193.0
— 9.5	15.0	59.0	4.5	40.0	104.0	18.5	65.0	149.0	32.0	90.0	194.0
— 9.0	15.5	60.0	4.5	40.5	105.0	18.5	65.5	150.0	32.5	90.5	195.0
— 9.0	16.0	61.0	5.0	41.0	106.0	19.0	66.0	151.0	33.0	91.0	196.0
— 8.5	16.5	62.0	5.5	41.5	107.0	19.0	66.5	152.0	33.0	91.5	197.0
— 8.5	17.0	62.5	5.5	42.0	107.5	19.5	67.0	152.5	33.5	92.0	197.5
— 8.0	17.5	63.5	6.0	42.5	108.5	19.5	67.5	153.5	33.5	92.5	198.5
— 8.0	18.0	64.5	6.0	43.0	109.5	20.0	68.0	154.0	34.0	93.0	199.5
— 7.5	18.5	65.5	6.5	43.5	110.5	20.5	68.5	155.0	34.0	93.5	200.5
— 7.0	19.0	66.0	6.5	44.0	111.0	20.5	69.0	156.0	34.5	94.0	201.0
— 7.0	19.5	67.0	7.0	44.5	112.0	21.0	69.5	157.0	34.5	94.5	202.0
— 6.5	20.0	68.0	7.0	45.0	113.0	21.0	70.0	158.0	35.0	95.0	203.0
— 6.5	20.5	69.0	7.5	45.5	114.0	21.5	70.5	159.0	35.0	95.5	204.0
— 6.0	21.0	70.0	8.0	46.0	115.0	21.5	71.0	160.0	35.5	96.0	205.0
— 6.0	21.5	71.0	8.0	46.5	115.5	22.0	71.5	161.0	36.0	96.5	206.0
— 5.5	22.0	71.5	8.5	47.0	116.5	22.0	72.0	162.0	36.0	97.0	206.5
— 5.5	22.5	72.5	8.5	47.5	117.5	22.5	72.5	162.5	36.5	97.5	207.5
— 5.0	23.0	73.5	9.0	48.0	118.5	23.0	73.0	163.5	36.5	98.0	208.5
— 4.5	23.5	74.5	9.0	48.5	119.5	23.0	73.5	164.0	37.0	98.5	209.5
— 4.5	24.0	75.0	9.5	49.0	120.0	23.5	74.0	165.0	37.0	99.0	210.0
— 4.0	24.5	76.0	9.5	49.5	121.0	23.5	74.5	166.0	37.5	99.5	211.0
									38.0	100.0	212.0

the field. Temperature data are to be observed, reported, and published to the nearest 0.5 degree Celsius.

Suspended-Sediment Concentration

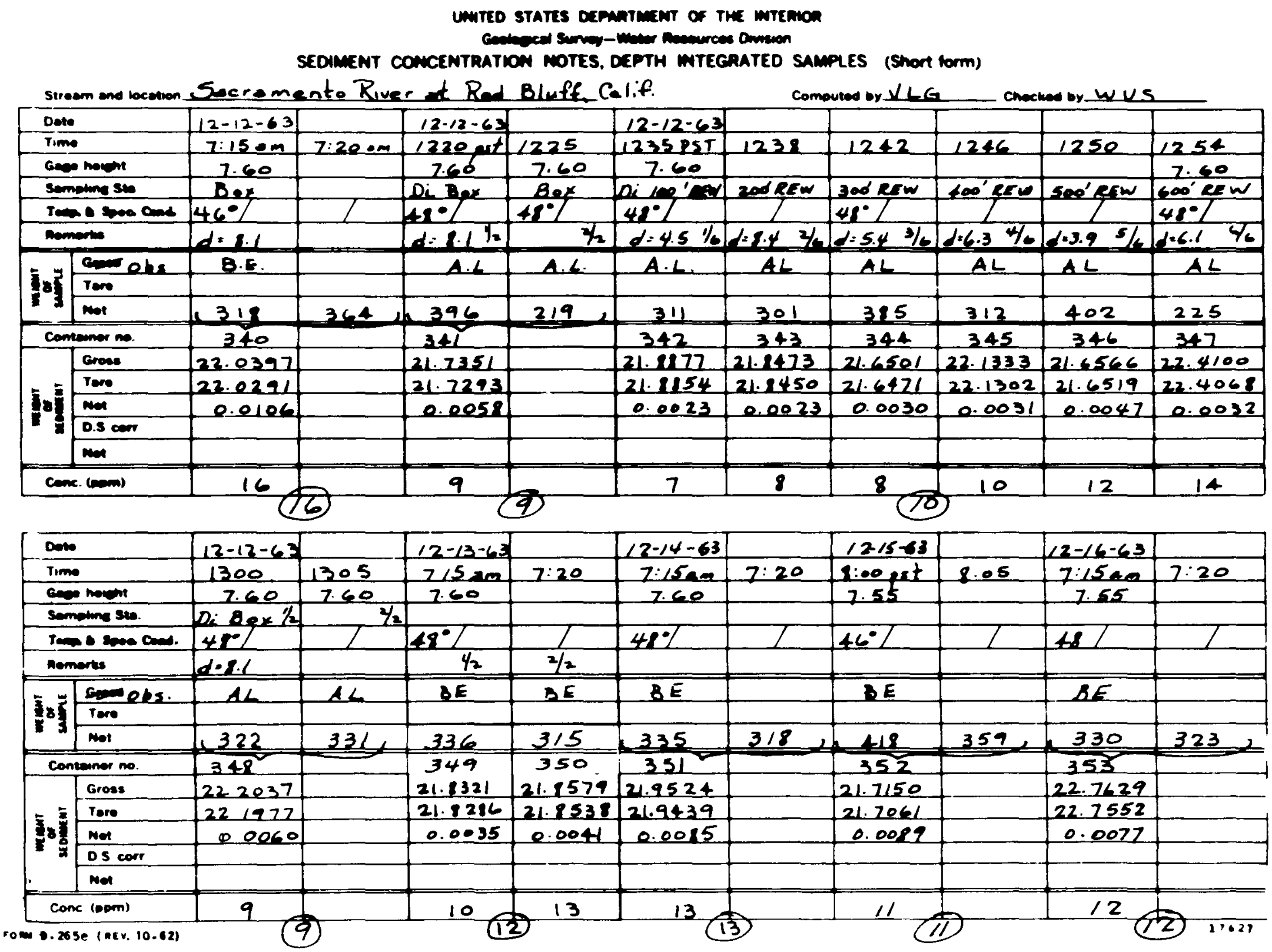
Sediment concentration may be determined as the ratio of the weight of the sediment to the (1) weight of the water-sediment sample, (2) weight of the water in the water-sediment sample, or (3) weight of the pure water equal in volume to the volume of the sample. Discharge-weighted concentration is usually determined by the first method and is the concentration determined by the laboratory and referred to in this manual. Because of convenience in the laboratory, it is determined in parts per million and is defined as the dry weight of sediment divided by the weight of the water-sediment mixture multiplied by 1 million. As the concentration is published in miligrams per liter, however, the values determined in the laboratory must be converted to milligrams per liter prior to computation of sediment discharge or publication.

The discharge-weighted mean concentration in the vertical generally is obtained from depth-integrated samples obtained with standard velocity-weighting samplers. The mean concentration in the vertical also may be obtained from point samples, which represent equal units of depth by (1) weighting each sample by the velocity at each sampling depth or (2) recording the sampling time for each sample and using the weight of the sample collected per second in lieu of point velocity to weight each sample. A discharge-weighted mean in the vertical also may be obtained from a composite of point samples if all samples in the vertical are taken for an equal period of sampling time (U.S. Inter-Agency Committee on Water Resources, 1963, p. 46–50).

The discharge-weighted mean concentration in the cross section may be computed from the mean concentrations of the several sampled verticals. If the sampled verticals represent centroids of equal discharge (EDI method) (Guy, 1970), the mean concentration is the average of the several verticals or is the mean of the composited samples, provided all samples are of the same volume. Thus, samples obtained by the EDI method that are to be composited for particle-size analysis must be the same volume. Samples collected at centroids to define lateral distribution of sediment in the cross section should be analyzed individually and, therefore, do not require an equal volume of water in each sample. If the sampled verticals are uniformly spaced and the same transit rate is used for all verticals (ETR method) (U.S. Inter-Agency Committee on Resources, 1963, p. 41), the mean concentration is the ratio of the total weight of sediment to the total weight of the water-sediment mixture in all samples. Hence, samples collected by the ETR method must be composited either in the laboratory or arithmetically, because the concentration of any individual sample is relatively meaningless.

Concentration data obtained to compute sediment discharge should define the vertical and lateral distribution of concentration in the cross section and the variation of the mean concentration with time. Each sample obtained at daily and periodic stations is analyzed for concentration, and the results are listed in the concentration notes (fig. 5). Concentration notes also include the date and time and identify the sampling and laboratory procedures. Samples may be composited for analysis or analyzed individually.

Compositing, as used here, is the practice of combining the water-sediment mixture of all samples into one container to determine the concentration or particle-size distribution. The mean concentration of a composite sample is the ratio of the total weight of the sediment to the total weight of water-sediment mixture. Samples usually composited are those collected only to define the average concentration in the cross section, those collected for analysis of particle-size distribution, and those collected by the ETR method. Samples analyzed individually are those collected to define the vertical or lateral distribution of concentration in the stream



UNITED STATES DEPARTMENT OF THE INTERIOR
Geological Survey—Water Resources Division
SEDIMENT CONCENTRATION NOTES, DEPTH INTEGRATED SAMPLES (Short form)

Stream and location Sacramento River at Red Bluff, Calif.
Computed by VLG
Checked by WUS

Date		12-12-63		12-12-63		12-12-63					
Time		7:15am	7:20am	1220 pst	1225	1235 PST	1238	1242	1246	1250	1254
Gage height		7.60		7.60	7.60	7.60					7.60
Sampling Sta		Box		Di Box	Box	Di 100' REW	200 REW	300 REW	400' REW	500' REW	600' REW
Temp. & Spec. Cond.		46°/	/	48°/	48°/	48°/	/	48°/	/	/	48°/
Remarks		d: 8.1		d: 8.1 1/2	2/2	d: 4.5 1/6	d: 8.4 2/6	d: 5.4 3/6	d: 6.3 4/6	d: 3.9 5/6	d: 6.1 6/6
WEIGHT OF SAMPLE	~~Gross~~ Obs	B.E.		A.L.	A.L.	A.L.	AL	AL	AL	AL	AL
	Tare										
	Net	318	364	396	219	311	301	385	312	402	225
Container no.		340		341		342	343	344	345	346	347
WEIGHT OF SEDIMENT	Gross	22.0397		21.7351		21.8877	21.8473	21.6501	22.1333	21.6566	22.4100
	Tare	22.0291		21.7293		21.8854	21.8450	21.6471	22.1302	21.6519	22.4068
	Net	0.0106		0.0058		0.0023	0.0023	0.0030	0.0031	0.0047	0.0032
	D.S corr										
	Net										
Conc. (ppm)		16		9		7	8	8	10	12	14
		⑯		⑨				(70)			

Date		12-12-63		12-13-63		12-14-63		12-15-63		12-16-63	
Time		1300	1305	7:15am	7:20	7:15am	7:20	8:00 pst	8.05	7:15am	7:20
Gage height		7.60	7.60	7.60		7.60		7.55		7.55	
Sampling Sta.		Di Box 1/2	2/2								
Temp. & Spec. Cond.		48°/	/	48°/	/	48°/	/	46°/	/	48 /	/
Remarks		d: 8.1		1/2	2/2						
WEIGHT OF SAMPLE	~~Gross~~ Obs.	AL	AL	BE	BE	BE		BE		BE	
	Tare										
	Net	322	331	336	315	335	318	418	359	330	323
Container no.		348		349	350	351		352		353	
WEIGHT OF SEDIMENT	Gross	22.2037		21.8321	21.8579	21.9524		21.7150		22.7629	
	Tare	22.1977		21.8286	21.8538	21.9439		21.7061		22.7552	
	Net	0.0060		0.0035	0.0041	0.0085		0.0089		0.0077	
	D S corr										
	Net										
Conc (ppm)		9		10	13	13		11		12	
		⑨		⑫		⑬		⑪		⑫	

FORM 9-265e (REV. 10-62)

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Figure 5.—Short form for sediment-concentration notes.

cross section. Mean concentration in the cross section, or vertical, is computed by weighting the concentration of each sample by the increment of discharge it represents.

Examples of concentration notes are shown in figure 5. Samples individually analyzed are the six-bottle sample of December 12 and the two-bottle sample of December 13. All other samples collected December 12–16 were composited.

The samples collected from 1220 to 1305 hours December 12 were obtained to determine the relation between the mean concentration in the cross section and the mean concentration at the fixed sampling stations. The average concentrations for the fixed sampling station at 1220 to 1225 hours and 1300 to 1355 hours and for six verticals in the cross section at 1235 to 1250 hours are circled.

Adequacy of data

A continuous evaluation of concentration data must be maintained to insure that sufficient samples are obtained and that the samples are of acceptable quality. The step-by-step preparation of records offers a continuing base for cross consultation among personnel responsible for records, laboratory, and fieldwork to evaluate the overall efficiency of the sampling program and to determine if the quantity and quality of the basic data meet desired standards.

Errors in concentration values usually occur because of simple mistakes in sampling procedure or because too few samples were obtained to cover the natural random variation in concentration and size gradation of transported sediment. A description of the sampling procedure is given by Colby (1963, p. 40), by the U.S. Inter-Agency Committee on Water Resources (1963), and by Guy and Norman (1970). Factors that should be evaluated regularly are (1) the number of samples collected in each vertical, (2) the number of verticals sampled in each cross section, (3) the number of samples with respect to time, and (4) the relation of the concentration in the single sampling vertical to average concentration in the cross section.

The number of samples required in each vertical and the number of verticals which must be sampled to determine the mean concentration within acceptable limits may vary with location and time. A study of the variation of concentration in sand-bed streams is given by Hubbell (1960), and a statistical method for determining the number of samples required is described by Guy (1968). Additional information is available in Guy and Norman (1970).

Relation between single-vertical and cross-sectional concentrations

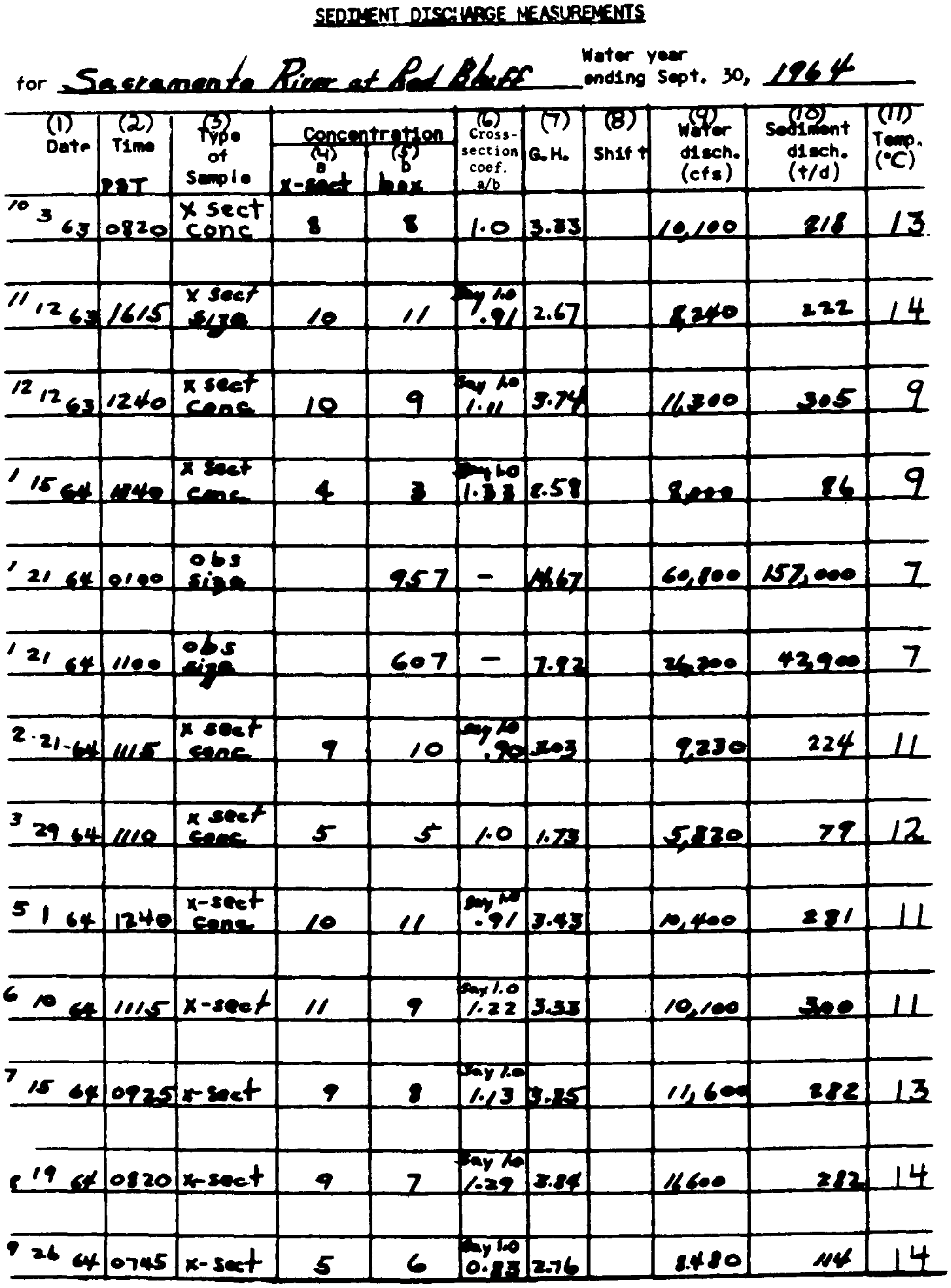
If sediment samples are obtained routinely at a single vertical in a cross section, the relation of the concentration of the single-vertical sample to the mean concentration in the cross section must be determined prior to computation of sediment discharge. This relation, in the form of a coefficient, is determined by an analysis of cross-section concentration data.

Ideally, sufficient samples should be obtained routinely in the cross section to define the mean concentration both in time and space, and if cost were of no concern this procedure might be selected for all operations. In practice, however, we obtain a computation of routine daily samples at from one to three verticals plus less frequent but more comprehensive samples at sufficient verticals in the cross section to define mean concentration in the cross section. This mean concentration is used to determine the departure of the concentration observed at the single vertical, or fixed-sampling vertical, from the mean concentration in the cross section.

This information should be used (1) to relocate the fixed-sampling station at a vertical that is more representative of the average stream concentration or (2) to determine a coefficient to convert the concentration of the fixed-vertical sample to the mean value for the stream cross section. The adequacy of the sample at the fixed vertical may be determined by an inspection and analysis of the data for stations with uniform concentrations in the cross section and by statistical analysis at stations where variation in sediment concentrations exceed the desired accuracy (Hubbell, 1960).

Cross-section coefficient

The ratio of the average sediment concentration in the cross section to the concentration determined by daily samples at a fixed station (box) is computed on the forms shown in figures 6 and 7. This ratio is referred to as the cross-section coefficient.

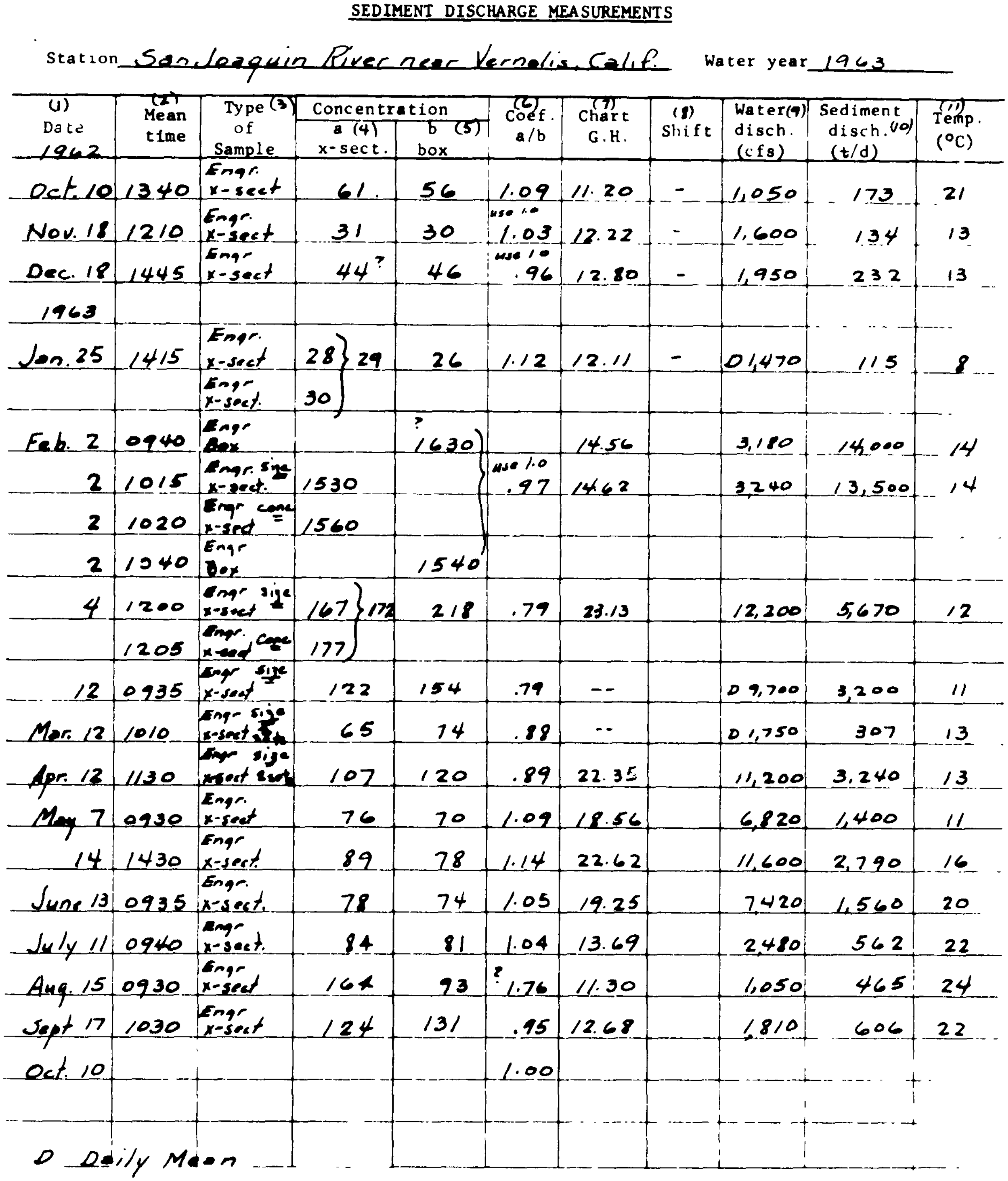


SEDIMENT DISCHARGE MEASUREMENTS

for Sacramento River at Red Bluff Water year ending Sept. 30, 1964

(1) Date	(2) Time PST	(3) Type of Sample	Concentration (4) a x-sect	(5) b box	(6) Cross-section coef. a/b	(7) G.H.	(8) Shift	(9) Water disch. (cfs)	(10) Sediment disch. (t/d)	(11) Temp. (°C)
10 3 63	0820	X Sect Conc	8	8	1.0	3.33		10,100	218	13
11 12 63	1615	X Sect size	10	11	Say 1.0 .91	2.67		8,240	222	14
12 12 63	1240	X sect conc	10	9	Say 1.0 1.11	3.74		11,300	305	9
1 15 64	1140	X Sect Conc	4	3	Say 1.0 1.33	2.58		8,000	86	9
1 21 64	0100	obs size		957	–	16.67		60,800	157,000	7
1 21 64	1100	obs size		607	–	7.92		26,200	42,900	7
2-21-64	1115	X sect conc	9	10	Say 1.0 .90	3.03		9,230	224	11
3 29 64	1110	X sect conc	5	5	1.0	1.73		5,820	79	12
5 1 64	1240	x-sect conc	10	11	Say 1.0 .91	3.43		10,400	281	11
6 10 64	1115	X-sect	11	9	Say 1.0 1.22	3.33		10,100	300	11
7 15 64	0925	x-sect	9	8	Say 1.0 1.13	3.85		11,600	282	13
8 19 64	0820	x-sect	9	7	Say 1.0 1.29	3.84		11600	282	14
9 26 64	0745	x-sect	5	6	Say 1.0 0.83	2.76		8480	114	14

Figure 6.—Tabulation of sediment data in the cross section.



SEDIMENT DISCHARGE MEASUREMENTS

Station San Joaquin River near Vernalis, Calif. Water year 1963

(1) Date 1962	(2) Mean time	(3) Type of Sample	Concentration (4) a x-sect.	Concentration (5) b box	(6) Coef. a/b	(7) Chart G.H.	(8) Shift	(9) Water disch. (cfs)	(10) Sediment disch. (t/d)	(11) Temp. (°C)
Oct. 10	1340	Engr. x-sect	61.	56	1.09	11.20	-	1,050	173	21
Nov. 18	1210	Engr. x-sect	31	30	use 1.0 1.03	12.22	-	1,600	134	13
Dec. 18	1445	Engr x-sect	44?	46	use 1.0 .96	12.80	-	1,950	232	13
1963										
Jan. 25	1415	Engr. x-sect	28 } 29	26	1.12	12.11	-	D 1,470	115	8
		Engr x-sect.	30							
Feb. 2	0940	Engr Box		? 1630		14.56		3,180	14,000	14
2	1015	Engr. size = x-sect.	1530		use 1.0 .97	14.62		3,240	13,500	14
2	1020	Engr conc = x-sect	1560							
2	1040	Engr Box		1540						
4	1200	Engr size = x-sect	167 } 172	218	.79	23.13		12,200	5,670	12
	1205	Engr. conc = x-sect	177							
12	0935	Engr size = x-sect	122	154	.79	--		D 9,700	3,200	11
Mar. 12	1010	Engr size x-sect	65	74	.88	--		D 1,750	307	13
Apr. 12	1130	Engr size x-sect	107	120	.89	22.35		11,200	3,240	13
May 7	0930	Engr. x-sect	76	70	1.09	18.56		6,820	1,400	11
14	1430	Engr x-sect.	89	78	1.14	22.62		11,600	2,790	16
June 13	0935	Engr. x-sect.	78	74	1.05	19.25		7,420	1,560	20
July 11	0940	Engr x-sect.	84	81	1.04	13.69		2,480	562	22
Aug. 15	0930	Engr x-sect	164	93	? 1.76	11.30		1,050	465	24
Sept 17	1030	Engr x-sect	124	131	.95	12.68		1,810	606	22
Oct. 10					1.00					

D Daily Mean

Figure 7.—Tabulation of sediment data in the cross section.

The manner in which the coefficient is applied depends on the cause of the lateral variation in the distribution of sediment concentration. This variation may be caused, among other reasons, by proximity and quantity of tributary inflow, bed form, channel alinement, source and type of sediment, season, and discharge. Based on these conditions, each record should be analyzed in detail to determine the most efficient and accurate manner for application of the coefficient.

In addition to using the data to adjust the current concentration values, coefficient analysis also may be used to reevaluate the sampling methods and the location of the sampling vertical at the station. This may make it possible to adjust the sampling locations so that a coefficient that is nearly equal to 1.0 will exist for all conditions of flow.

Common methods for determining daily coefficients involve the correlation of the cross-section coefficient with season and gage height or discharge. As an example, coefficient values for the San Joaquin River near Vernalis, Calif., for the 1963 water year (fig. 7) are plotted against discharge and season (fig. 8). The correlation of coefficient with discharge is poor; however, the correlation with season indicates a possible trend. This trend was investigated by plotting the values of the coefficient on the annual hydrograph of discharge and concentration (fig. 9). The seasonal effect indicated on the hydrograph indicates a coefficient of about 1.0 during the late summer and autum, less than 1.0 during the first few months of the storm season (February, March, and April), and more than 1.0 during the sustained high discharge during the irrigation season; this effect is verified by the repetition of this trend during successive years.

Sometimes coefficients show a reasonable correlation with stage, as indicated in figure 10. The values of the coefficient were determined for 2-percent increments or less for the corresponding range in stage (gage height) and tabulated in the figure. These

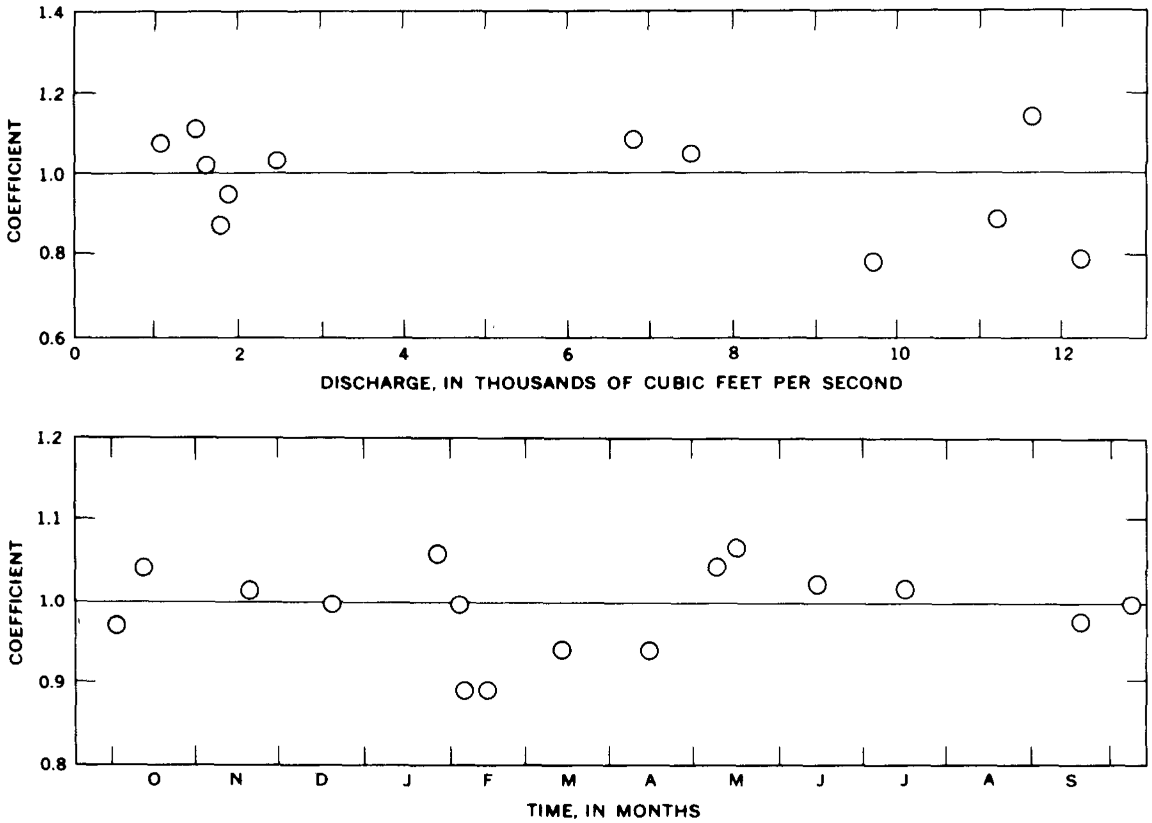


Figure 8.—Relation of cross-section coefficient to discharge and season for San Joaquin River near Vernalis, Calif.

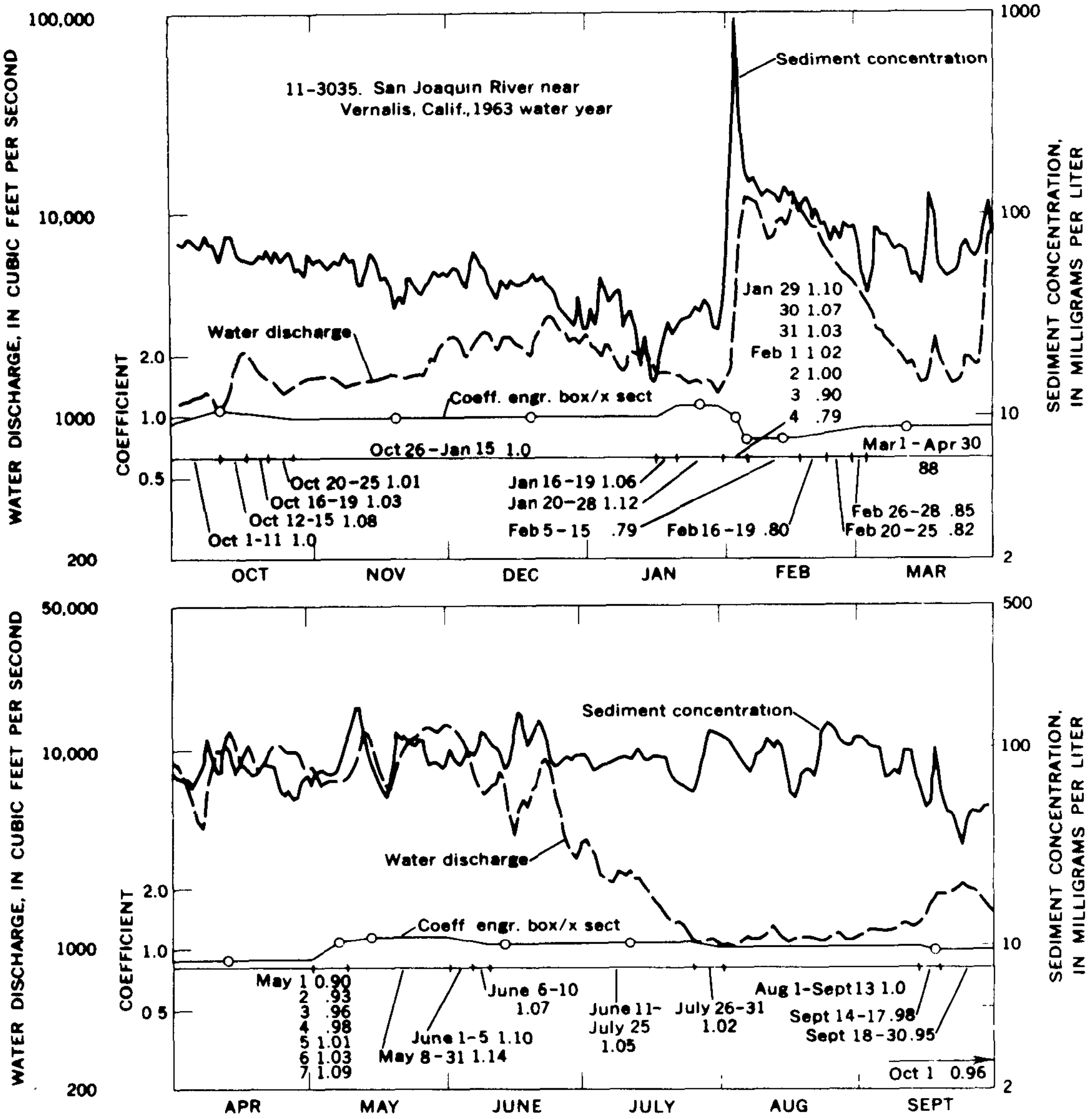
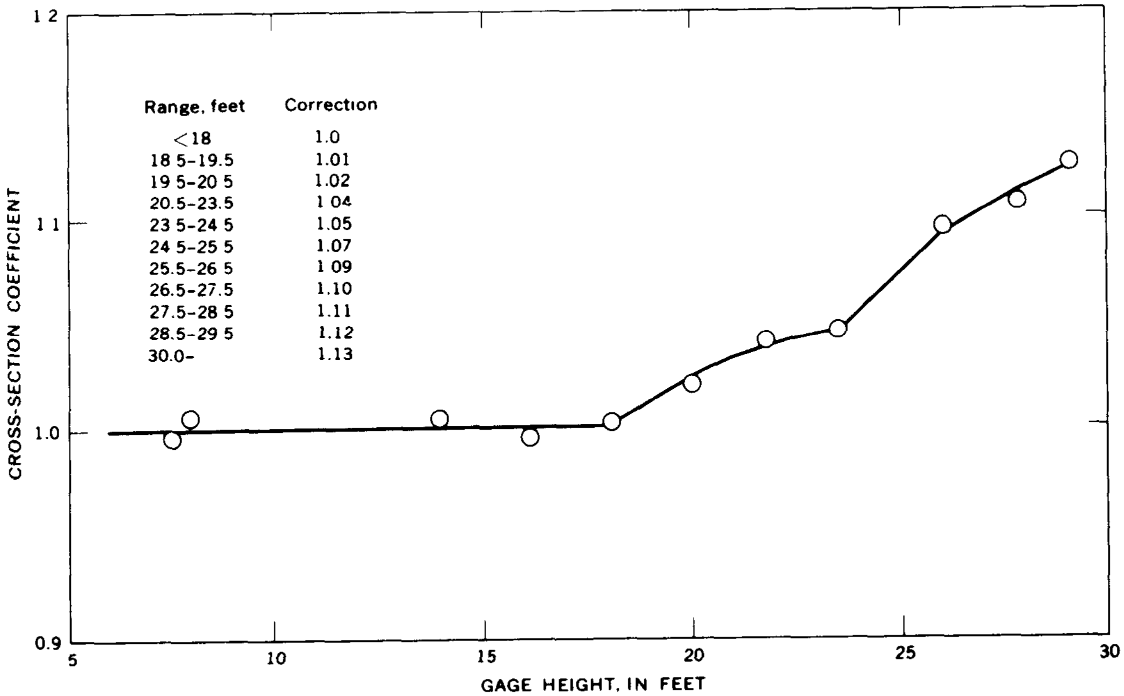


Figure 9.—Water discharge, sediment concentration, and coefficients for correcting observer's single-vertical samples to cross section.

values may be used to correct daily concentration values or concentration values for intervals of a subdivided day.

The average coefficient for the Sacramento River at Red Bluff (fig. 6) was assumed to be 1.0, and no correction was made to the daily concentration values, even though the ratios of individual measurements ranged from 0.83 to 1.33. This example illustrates that the application of a coefficient, as in applying a rating shift to a gage-height value, is a matter of judgment based on the data available. The ratio of 10/9 = 1.11 indicates a 10-percent (plus) error, and a correction ordinarily would be made. However, the difference of 1 mg/l (milligram per liter) between the cross section and the box sample may be the result of error in laboratory procedures and the result of rounding numbers; therefore, for all practical purposes, such coefficients are ignored. A variation of a few milligrams per liter above 50 mg/l also is considered negligible, and a coefficient is not applied if the indicated corrections



Range, feet	Correction
<18	1.0
18.5-19.5	1.01
19.5-20.5	1.02
20.5-23.5	1.04
23.5-24.5	1.05
24.5-25.5	1.07
25.5-26.5	1.09
26.5-27.5	1.10
27.5-28.5	1.11
28.5-29.5	1.12
30.0-	1.13

Figure 10.—Relation of cross-section coefficient to gage height.

are random. Coefficients should be applied, however, if all corrections are in the same direction and if the trend persists seasonally and is evident in the record for preceding years.

Variation with time

The number of samples required to define the variation of concentration with time may be difficult to determine from visual inspection of the concentration notes. The effectiveness of the sampling schedule should be evaluated after each storm event. An efficient way to evaluate the adequacy of sampling is to plot the concentration values on the gage-height record as soon as possible after the data are available. Plotting and evaluating the concentrtion data with respect to time are described in the section "Development of a Temporal Concentration Graph."

Analysis of cross-section concentration data

Concentration values obtained from cross-section samples are listed on the multiple-purpose form shown in figures 6 and 7, which may also be used to (1) list particle-size analyses and compute the instantaneous discharge required to complete tabulation of size analyses (fig. 2) and (2) list samples obtained at periodic stations or miscellaneous sites.

The tabulation of cross-section samples is used to compute the coefficient needed to adjust the concentration of samples obtained at a single, or fixed, vertical to the average concentration determined by cross-section sampling. The average concentration of the cross section determined from multiple-vertical sampling is recorded in column 4 (fig. 6), and the concentration for the corresponding date and time of the observer's fixed-sampling vertical or three-vertical set is recorded in column 5. The coefficient used to adjust the observer's samples is the ratio of a/b and is recorded in column 6.

The gage height at the time of sampling is obtained from the corrected gage-height record and recorded in column 7. Any gage height recorded on the bottle, particularly by the observer, should be considered as uncorrected data and generally used only to fix the sample in time, to aid in making necessary corrections to the pen record, or to estimate missing gage-height records. The gage height forms the base for computation of the instantaneous water discharge and the sediment discharge.

An evaluation of the quality of the coefficient for a given sampling design may be made by the method developed by Guy (1968).

Samples collected by the EDI method must have nearly equal volumes for each sampling vertical if they are composited; otherwise the bottles must be analyzed individually, and the concentrations for each cross-sectional set of samples averaged. If this procedure is not followed, the quality of the data obviously is affected. Experience has shown that suspended samples from sand-bed streams occasionally will be contaminated with varying quantities of bed material. Considerable judgment must be exercised in the field and laboratory to insure that these samples are eliminated from the composite.

The determination of sediment discharge requires the use of water discharge; therefore, the accuracy of the computed value for sediment discharge is dependent on the accuracy of measurements of both water discharge and sediment concentration. In many locations, the water discharge can be determined to a high degree of accuracy from the relation of discharge to stage. If, however, the relation of discharge to stage is not stable, as for most sand-bed streams, or an accurate relation is not available, as for a new station, a measurement of water discharge is necessary at the time sediment concentration is sampled in the cross section. Discharge measurements and discharge ratings at gaging stations are discussed by Buchanan and Somers (1965, 1968) and Carter and Davidian (1965, 1968). An earlier detailed description of stream-gaging procedures is found in U.S. Geological Survey Water-Supply Paper 888 (Corbett and others, 1943).

The evaluation and application of daily values of the cross-section coefficient are discussed in the section "Cross-Section Coefficient."

Development of a Temporal Concentration Graph

The next step in the computation procedure for sediment discharge is to translate individual values of concentration into a continuous temporal concentration curve. This step may be reasonably simple if values for water discharge or sediment concentration do not vary greatly and (or) if sufficient samples are obtained to define adequately the changes in concentration with time. Accurate results are obtained from a concentration curve defined adequately by samples because a large number of samples successfully integrate the many complex interrelations among variables affecting the availability and movement of sediment in streams (Guy, 1970).

Development of a temporal concentration graph may be difficult if too few samples were obtained. Preparation of the concentration graph will require application of theoretical and practical principals of sedimentation. Inadequate sampling results in a less accurate graph, and much more time is required to prepare the graph. Because of the extra time, in addition to loss in accuracy, it is usually less expensive to collect additional samples than to estimate the concentration graph.

A sampling program for each station should be designed to obtain optimum results when the desired accuracy of record is balanced against the many physical and economic conditions. A few samples properly spaced with time may adequately define the concentration of a flood event at certain stations, providing that the personnel computing sediment discharge have detailed knowledge of seasonal sediment trends for the complete range of flow conditions experienced. Lack of knowledge of these trends, such as at a new station or a station with a large number of variable conditions affecting sediment erosion and transport, requires an intensive sampling program. Successful station operation requires continuous modification of the sampling program to obtain the best accuracy possible with a reasonable expenditure of time and effort.

Concentration data should be interpreted and the graph drawn by personnel with a knowledge of the sampling program, the physical and cultural environments affecting the stream regimen and sediment sources, and the fundamentals of sediment transport. After the graph is drawn, it should be reviewed and modified as required prior to computation of daily mean concentration values and sediment discharges. Changes in the graph are made easily at this point and may eliminate possible future recomputation.

Difficulties may be encountered while drawing the continuous graph because of paucity of samples, unusual storm events, or periods of missing records. Valuable guidance may be available from past records of sediment discharge at the site and at nearby sites. A study of these records before plotting the data and drawing the graph should be a required part of the computation procedure. Some of the factors that should be considered prior to drawing the concentration graph and examples of concentration graphs are included in the following section.

Plotting symbols and scales

Concentration values are plotted on a gage-height chart or a copy of the chart. If an analog record of stream stage is not available because of the use of digital recorders, a plot of gage height or discharges from the digital record must be made for the important periods of changing stage and concentration, such as during rapid snowmelt or storm runoff.

The symbols and scales used for plotting should be chosen carefully and, if possible, be consistent with those used in preceding years. Suggestions relating to the plotting of concentration values and the choosing of scales are summarized as follows:

1. Adjust concentration values from parts per million to milligrams per liter prior to plotting.
2. If necessary, adjust the plotting times for chart-time corrections and travel time between sampling site and gage.
3. Plot the average value for each set of samples. Individual values of each bottle should be plotted if poor agreement exists among bottles.
4. Use plotting symbols such as the following:
   - ⊙ Observer samples—mean value.
   - ◌ Observer samples—individual samples.
   - △ Technician sample at observer's fixed station (box).
   - ⊡ Technician cross-section sample—mean value.
   - ⦾ Particle-size sample. Use above symbols and circle if sample analyzed for particle-size gradation.
5. Use of a proper plotting scale facilitates computation and checking, increases accuracy of daily mean concentration values picked from the graph, and provides a visual method for comparison and study of various flood events; therefore,
   - (a) Use simple scales such as 1 to 1, 1 to 2, 1 to 5, or multiples of 10 thereof, with zero at the base line.
   - (b) Use as few scales as possible, but do not hesitate to change scale as needed.
   - (c) Plainly mark each change in scale. Use previous year's record as guide to scales. Use the same scale for all events of similar magnitude; such a scale provides a visual means for comparing and evaluating graphs and assists in development of characteristic curves that are extremely helpful in shaping the graph when incomplete sampling data are available.
6. Use a maximum height of the graph 5-8 inches above the base line (0 mg/l) on the gage-height chart. As the concen-

tration decreases after a storm, change the scale when the concentration graph approaches to within 1 or 2 inches of the base line. Experience indicates that personnel drawing a graph near the base line tend to be influenced by the limiting 0-mg/l base line, and therefore values determined from a graph approaching the base line usually are high.

7. Choose a scale, if possible, so that concentration values can be plotted to three significant figures. For example, if a stream has concentrations that range from 300,000 to 400,000 mg/l, a scale of 1 inch=50,000 mg/l allows a maximum height for the graph of 6-8 inches, and concentrations above 100,000 mg/l (2 inches) may easily be plotted to three significant figures. Below 100,000 mg/l the scale can be read only to two significant figures and should be changed.

Theoretical considerations

Considerable information is available on theory of sediment transport and the factors affecting the availability of sediment for transport. Colby (1964a, p. A3) states that

> Relationships of sediment discharge to characteristics of sediment, drainage basin, and streamflow are complex because of the large number of variables involved, the problems of expressing some variables simply, and the complicated relationships among the variables. At a cross section of a stream, the sediment discharge may be considered to depend: on depth, width, velocity, energy gradient, temperature, and turbulence of the flowing water; on size, density, shape, and cohesiveness of particles in the banks and bed at the cross section and in upstream channels; and on the geology, meterology, topography, soils, subsoils and vegetal cover of the drainage area. Obviously, simple and satisfactory mathematical expressions for such factors as turbulence, size and shape of the sediment particles in the streambed, topography of the drainage basin, and rate, amount, and distribution of precipitation are very difficult, if not impossible, to obtain.

References that will aid in understanding the interrelation of some of the above-listed variables and sediment discharge are cited in pertinent text sections and are listed at the end of this manual. This list is by no means complete, but will serve as a starting point for those interested in furthering their understanding of sediment transport.

Study of past records

A study of the variation and range of suspended-sediment concentration with time at a given point, or sampling station, reveals many similarities among different flood events. A plot of concentration values with time and with flood stage will define graphs that can be used to estimate concentration graphs for missing periods or for inadequately sampled periods. The absolute values and duration of these values may vary considerably from event to event; however, the shape of the temporal graph may be similar among the several events. Thus, the first step in drawing the concentration graph is to study the plotted points for trends, sketch in the parts of the graph well defined by samples, and study those parts defined previously—for the entire historical record if necessary.

A file of historical concentration graphs that are characteristic of the variation and range of suspended-sediment concentration should be assembled to facilitate the use of these graphs during development of the temporal concentration graph and to reduce the number of past records stored in current files. Characteristic graphs may be different for different basins, and many characteristic graphs may exist for each station.

Relation of water discharge to concentration

The relation of water discharge to concentration is an important aspect to consider when developing the temporal concentration graph. The variation of water discharge, as depicted by the continuous graph of stage on an analog chart or a plot of bihourly discharges from a digital record, provides a valuable clue to the time and magnitude of changes in the sediment concentration of the stream. The relation between water discharge and sediment concentration is not fixed. It is affected by many variables, and the variation and range of concentration during one storm period or during one low or medium streamflow period may differ from the concentrations during other periods, even though the streamflow may be identical or similar. Therefore, interpretation of concentration data and the drawing of the temporal concentration graph always requires consideration of the variables that affect the relation between water discharge and concentration.

Availability of sediment is a major variable affecting sediment concentration. Factors affecting availability are discussed in detail by Guy (1970) and in many texts. The availability for a short period may be considered relatively constant, and curves characteristic of the relation of water discharge to concentration for diverse storm periods, tributary inflow, and seasonal effect may be assembled for ready reference. (See previous section and the section on "Examples of the Sediment-Concentration Graph.") Changes in natural availability of sediment may be caused by such events as forest fires or channel changes, landslides, and mass wasting associated with or accelerated by catastrophic floods. These changes should be noted and considered during development of the concentration graph.

Availability of sediment also is influenced by the activities of man. Activities which may cause rapid and large changes in sediment availability include road construction, dam construction, diversions, land-use changes, logging, urbanization, and gravel mining.

Basin size may affect the correlation of concentration and water discharge and the shape of the concentration graph. In general, the smaller basin has a more predictable relation between water discharge and concentration than the large basin, which is often affected by a larger number of variables. The Colorado River at Grand Canyon, for example, has tributaries affected by many variables. These tributaries include rivers with large flows and very low concentrations as well as streams with small flows and large concentrations. All these water and sediment conditions, plus regulation by upstream dams, imposed on one downstream station cause a large range in concentration for a given water discharge.

Other factors affecting the relation between sediment discharge and streamflow are listed in the section on "Theoretical Considerations."

Estimates for periods of missing data

The shape and magnitude of the temporal concentration graph for individual rises have characteristics based on the principles previously discussed. A knowledge of the typical patterns from past records is helpful when interpreting the concentration data and constructing the concentration graph for periods of inadequate concentration data.

Concentration data are considered inadequate when a significant part of a record cannot be defined within probable limits of 5 or 10 percent. The efficient and reasonably accurate development of a continuous concentration graph or determination of sediment discharge during the period of missing data requires careful study, in which experience and ability to make sound estimates based on concentration data collected during other periods are most helpful. The length of the inadequately defined period may range from 20 minutes to several days. The short period usually occurs on streams having rapid changes of water discharge and concentration and very frequently occurs at the beginning of a rise resulting from intense rainfall. This situation is particularly critical on streams in arid regions and on streams with small drainage areas. Long periods of missing data may occur because the sampling site is inaccessable during floods or because of loss of equipment or samples.

An estimated concentration graph is preferable to direct estimates of sediment discharge. During short periods of missing data, a continuous concentration graph may be estimated accurately and used to compute daily mean concentration and sediment discharge. During long periods of missing data, an accurate estimate of concentration may not be possible, and daily values of sediment discharge must be estimated directly from the historical relation between water and sediment discharge by interstation correlation or by comparison with records obtained at an upstream or downstream station. A complete record of daily values facilitates interpretation or statistical evaluation of the data by computer techniques; therefore, if possible, estimates of both sediment concentration and discharge should be made. During periods that sediment discharge was estimated directly, daily concentration values must be estimated independently of sediment discharge if the period includes rapid or large changes in concentration or water discharge. An independent estimate of daily mean concentration is necessary because published values of concentration are time weighted, and daily time-weighted values of concentration cannot be computed from daily values of water and sediment discharge that represent periods of changing streamflow and concentration. If an acceptable estimate of concentration is impossible, no daily concentration will be published, and a leader (..) will be placed in the concentration column.

The methods or combination of methods used to estimate missing data may vary from station to station and seasonally for the same station. Each period of missing data, therefore, must be studied, and the best estimate made on the basis of existing data and circumstances; regardless of the method chosen the estimate should be verified by a second method. A partial list of methods commonly used to estimate sediment data follows.

Visual comparison with adequately defined concentration graphs

The visual procedure, when supplemented by the two succeeding methods, probably is the most common and accurate method used to construct concentration graphs for periods when data are insufficient. The principles involved are discussed in more detail elsewhere in the manual and especially in the sections on "Study of past records" and "Examples of the sediment-concentration graph." Each station should be sampled in detail during sufficient runoff events to provide a catalog of the shape and magnitude of the sediment curves pertinent to the station.

The shape of the concentration graph with respect to the gage-height graph should be carefully considered as to the time the rapid increase starts, the time of peak concentration, and the slope of the recession curve. Typical concentration graphs of the various types, such as advanced, simultaneous, and lagging, are illustrated in figures 11, 12, and 13.

Hydrographic comparison with records of upstream and downstream stations

Hydrographic comparison is an excellent tool to check the accuracy of the concentration record and sampling program, as well as to estimate periods of missing records. Each record should routinely be compared with adjacent station records wherever possible, and consideration should be given to significant natural and manmade differences that would account for discrepancies in the computations.

Short periods of missing concentration data can be estimated on the basis of the concentration curve for an adjacent station. Longer periods of missing sediment data can be estimated by comparing values of daily sediment discharge plotted on hydrograph form 9-284 (fig. 25).

Water-sediment relation curves

The relation between water discharge and sediment discharge may be expressed by an average curve. This curve is called a sediment-transport curve and is used frequently to estimate periods of missing data or to extend records.

The types of sediment-transport curves are numerous, and the selection of the correct type for each use is important. According to

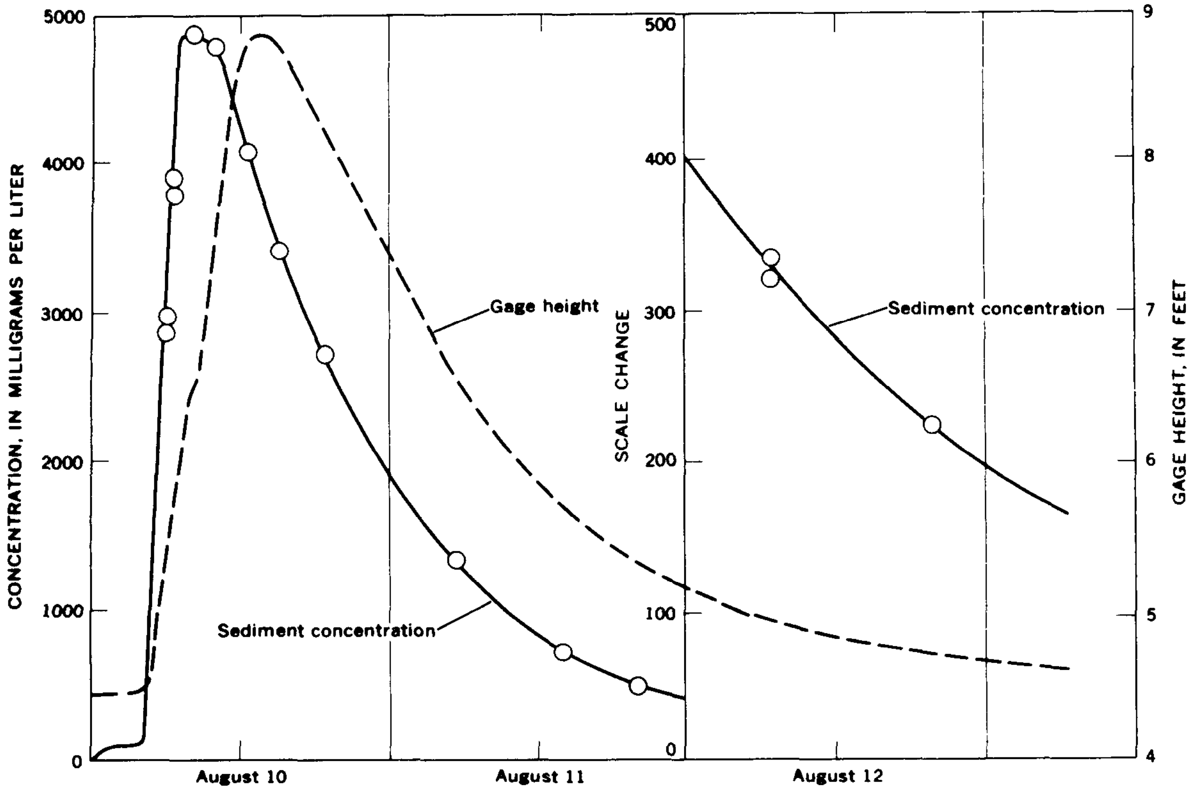


Figure 11.—Advanced concentration during excess runoff periods.

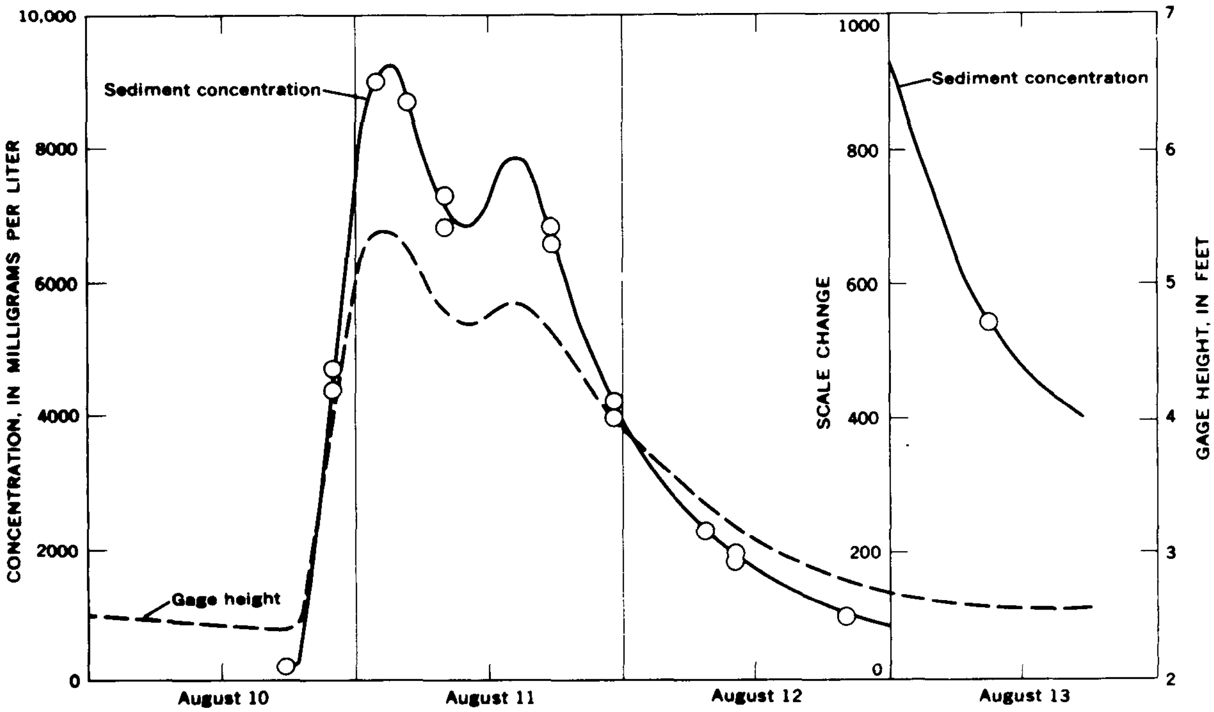


Figure 12.—Simultaneous concentration during excess runoff periods.

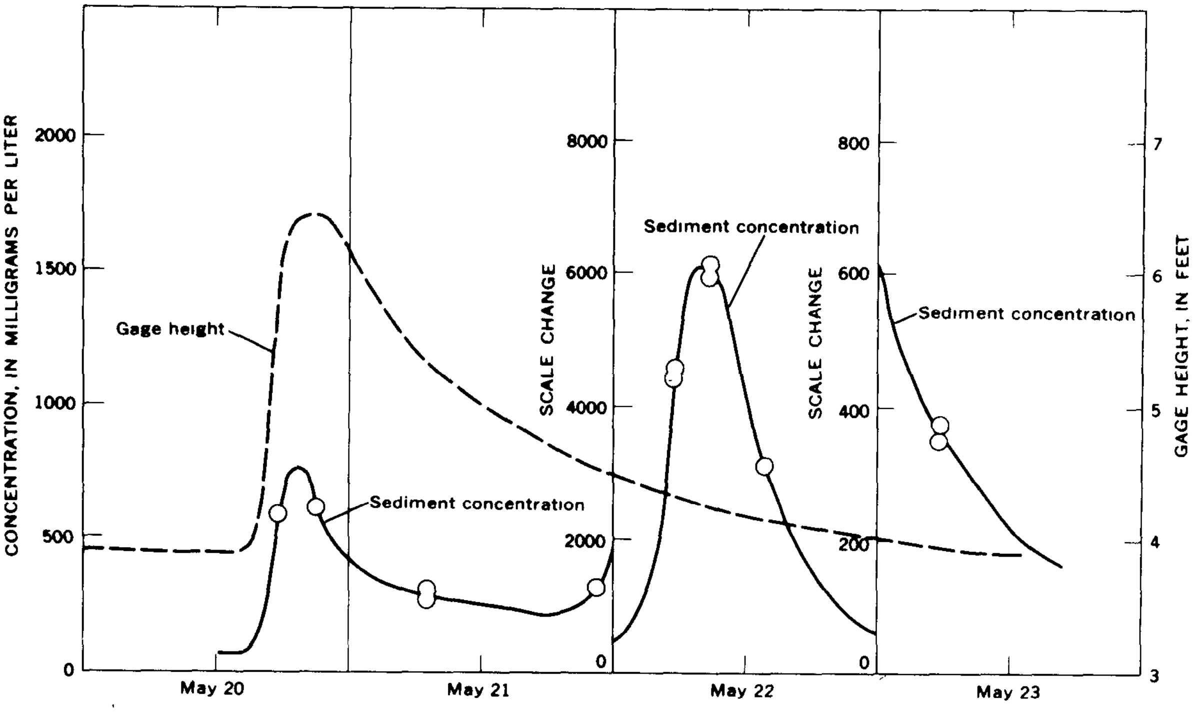


Figure 13.—Lagging concentration during excess runoff periods.

Colby (1956a), sediment-transport curves may be classified according to either the period of the basic data that define a curve or the kind of sediment discharge that a curve represents. Thus sediment-transport curves may be classified as instantaneous, daily, monthly, annual, or flood-period curves. The instantaneous sediment-transport curves are defined by concurrent measurements of sediment discharge and water discharge for periods too short to be materially affected by changes in flow or concentration during the measurements. Daily, monthly, annual, and flood-period sediment-transport curves usually are defined by and expressed as average sediment and water discharges for periods of days, months, years, or flood periods, respectively. They can be defined by and expressed as total quantities of sediment and water discharges during the respective lengths of time. On the basis of the kind of sediment that they represent, sediment-rating curves may be classified as suspended-sediment rating curves, unmeasured sediment-rating curves, and total-sediment rating curves. These sediment-rating curves may be further divided according to size of particles for which the defining sediment discharges were computed.

The simplest relation between sediment discharge and water discharge is represented by an instantaneous sediment-transport curve. Such a curve is not affected by the extent or pattern of changes in concentration or flow. It is likely to be the most suitable curve from which to determine the effect of different factors on the basic relation between sediment discharge and water discharge and on departures from this relation. On the other hand, an instantaneous sediment-transport curve is not theoretically applicable to the direct computation of daily sediment discharges from daily water discharges except for days on which the rate of water discharge was about constant throughout the day. In practice, however, an instantaneous curve may agree with a daily curve within limits of accuracy of their definition.

Daily or instantaneous sediment-transport curves adjusted for factors that account for some of the scatter from an average curve may be used to compute approximate daily, monthly, and annual sediment discharge. Colby (1956a) describes in detail the selection of the proper type transport curve and the use, preparation, and adjustment of transport curves.

Methods to improve water-sediment relation curves are discussed also by Guy (1964). Two methods using water-sediment relation curves to estimate concentration or discharge are: (1) a plot of the total water discharge versus total sediment discharge or concentration for each storm event or flood period (fig. 14) and (2) a cumulative unit graph relating total water discharge and total sediment discharge for individual storms (fig. 15).

These plots generally are most applicable to small streams with a uniform source of sediment and a low base flow. For many streams the correlations may be greatly improved if the base flow is subtracted from the water discharge. Data must be available for a number of adequately defined hydrographs representing a range of flow and seasons to insure reasonable success with these methods.

The procedures for using these methods are apparent from the illustrations. The limitations of their use will depend on the

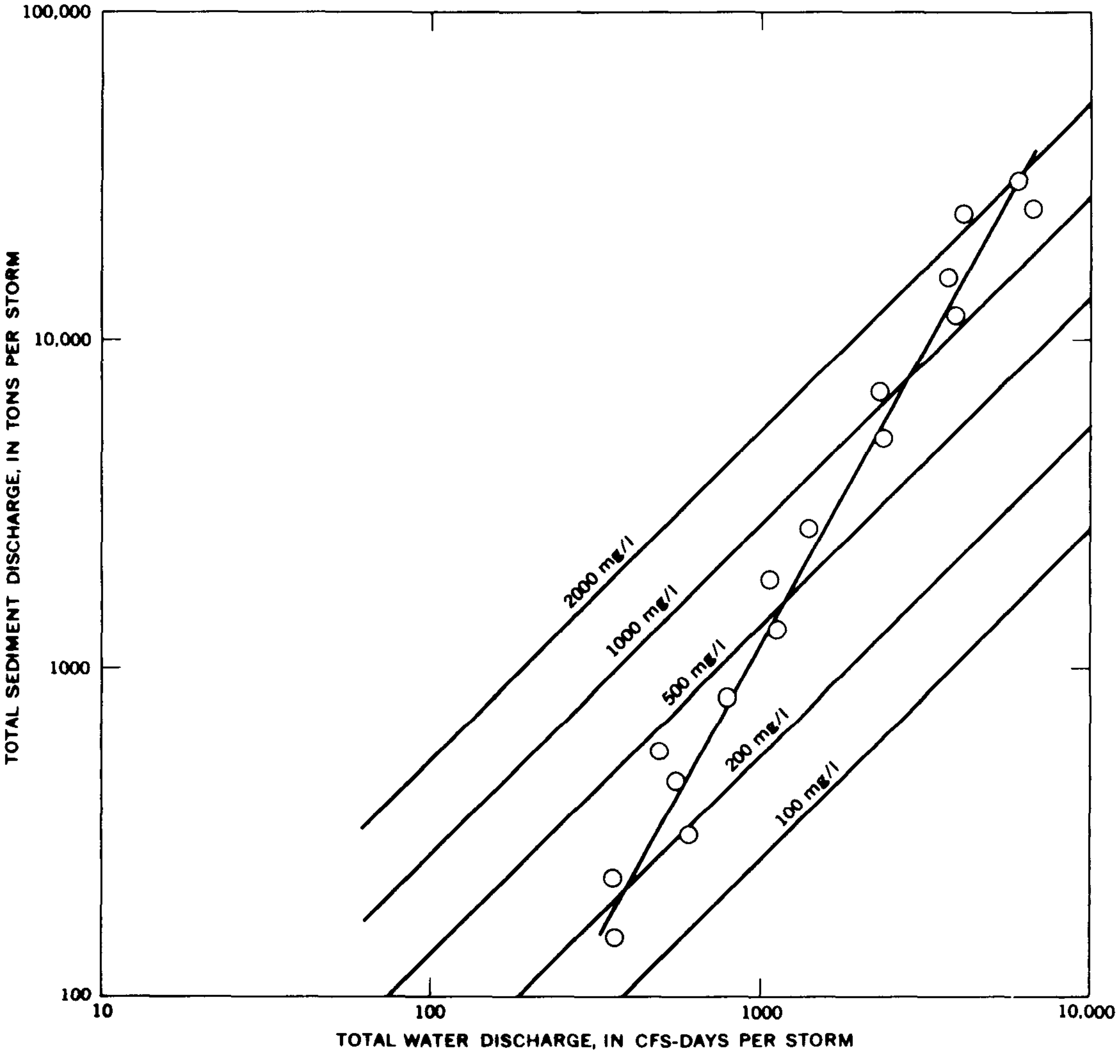


Figure 14.—Sediment-transport curve on a storm basis with indicated mean concentration.

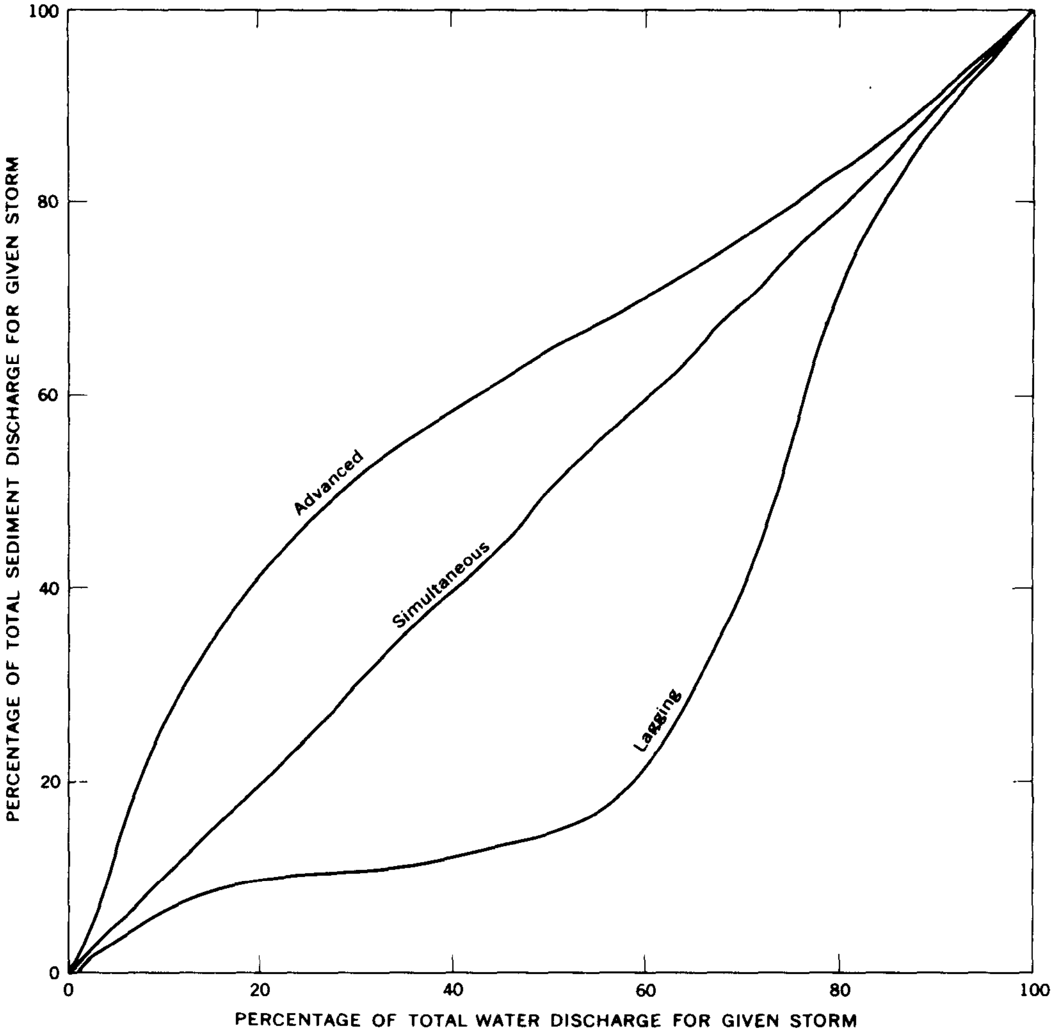


Figure 15.—Cumulative unit relation of total water discharge and total sediment discharge for typical advanced, simultaneous, and lagging types of concentration graphs.

circumstances encountered with the individual record; consequently, as in other interpretive studies, judgment is required. For example, the sediment-transport curve plotted on a storm basis (fig. 11) may be biased (1) if several years of record were used in its preparation and the sediment yield from the basin was changing significantly with time as a result of changing land use or (2) if an unusual number of off-season storms occurred. The change in the sediment yield of a basin was illustrated by a study of 9 years of data of Brandywine Creek, Pa. (Guy, 1957). The cumulative unit graph (fig. 12) is used in conjunction with the total sediment-discharge method to provide estimates for subdividing the storm hydrograph into smaller increments. These methods may or may not be useful in the development of a continuous concentration graph for extended periods of insufficient data, but they are useful for estimating sediment discharge.

Instantaneous values of concentration from advanced and lagging graphs (figs. 11, 13) plot as "loops" on the sediment-transport curves, and this loop effect should be considered if values from the transport curve are used to estimate the shape and magnitude of the continuous-concentration graph for periods of missing records. Daily values also may plot as a loop on the transport curve because of the variation with time of the factors affecting sediment transport and of the subdivision effect.

Suspended-sediment discharges computed from any sediment-transport curves, except curves for some streams that transport mostly sands, will be less accurate than sediment discharges computed from frequent samples. The difference in accuracy may or may not be worth the difference in cost of operation. This decision will depend on the particular sampling station and the use to be made of the sediment records.

Flow-duration curves have been widely used with instantaneous or daily sediment-rating curves to compute the average sediment discharge for long periods of time when no samples were collected. In principle, and within the limits of averaging and multiplying averages, the method is equivalent to computing average sediment discharge from a daily sediment-transport curve and daily water discharges. The flow-duration curve is used only as a convenient method for abbreviating the distribution of daily water discharges and thereby shortening the computations.

Examples of the sediment-concentration graph

The preceding sections discuss many reasons for the variation of sediment concentration with time and discharge. This section presents examples of (1) the relation between concentration and discharge (or gage height) for basins of various size, climatic conditions, geology, and land use and (2) variations of this relation that may occur in a large basin.

Figure 16 is an example of the typical, sharp discharge peak and concentration graph produced when high-intensity rainfall of short duration occurs over a small basin and the stream channel is dry or has only low flow prior to the storm. The typical concentration graph will rise rapidly and peak at or slightly before the discharge peak, after which it decreases rapidly, generally at a faster rate than the recession in water discharge. The shape of the recession curve usually is parabolic. At the discharge peak, the concentration may fluctuate rapidly for a short period before starting to recede. The duration of the concentration peak is seldom greater than that of the water-discharge peak. Note that the concentration did not start to increase prior to the increase in water discharge.

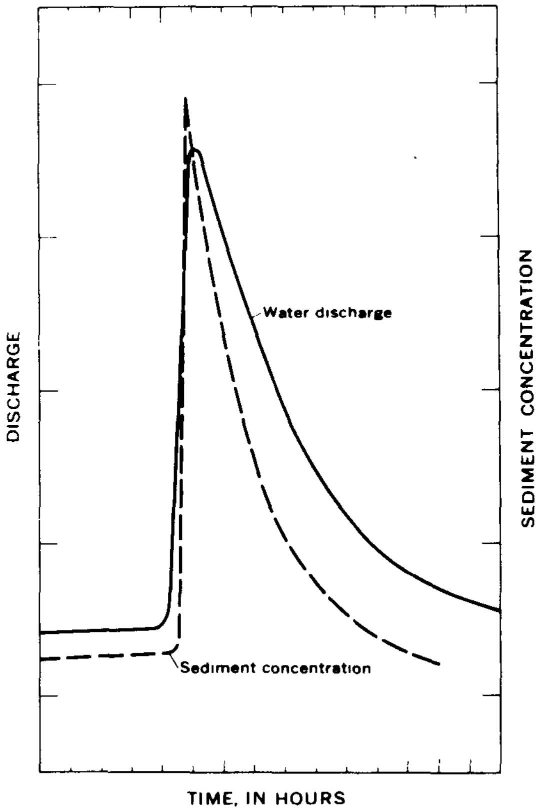


Figure 16—*Typical effect of high-intensity short-duration rainfall on discharge and concentration for a small-drainage-basin stream having a very small amount of base flow or none.*

An example of a concentration graph of a stream in a small basin, Corey Creek near Mainesburg, Pa., (12.2 sq mi) when the runoff increased at a slower rate is shown in figure 17. This basin generally has better vegetal cover, less intense precipitation, a more humid climate, and a higher base flow than the basin illustrated in figure 16.

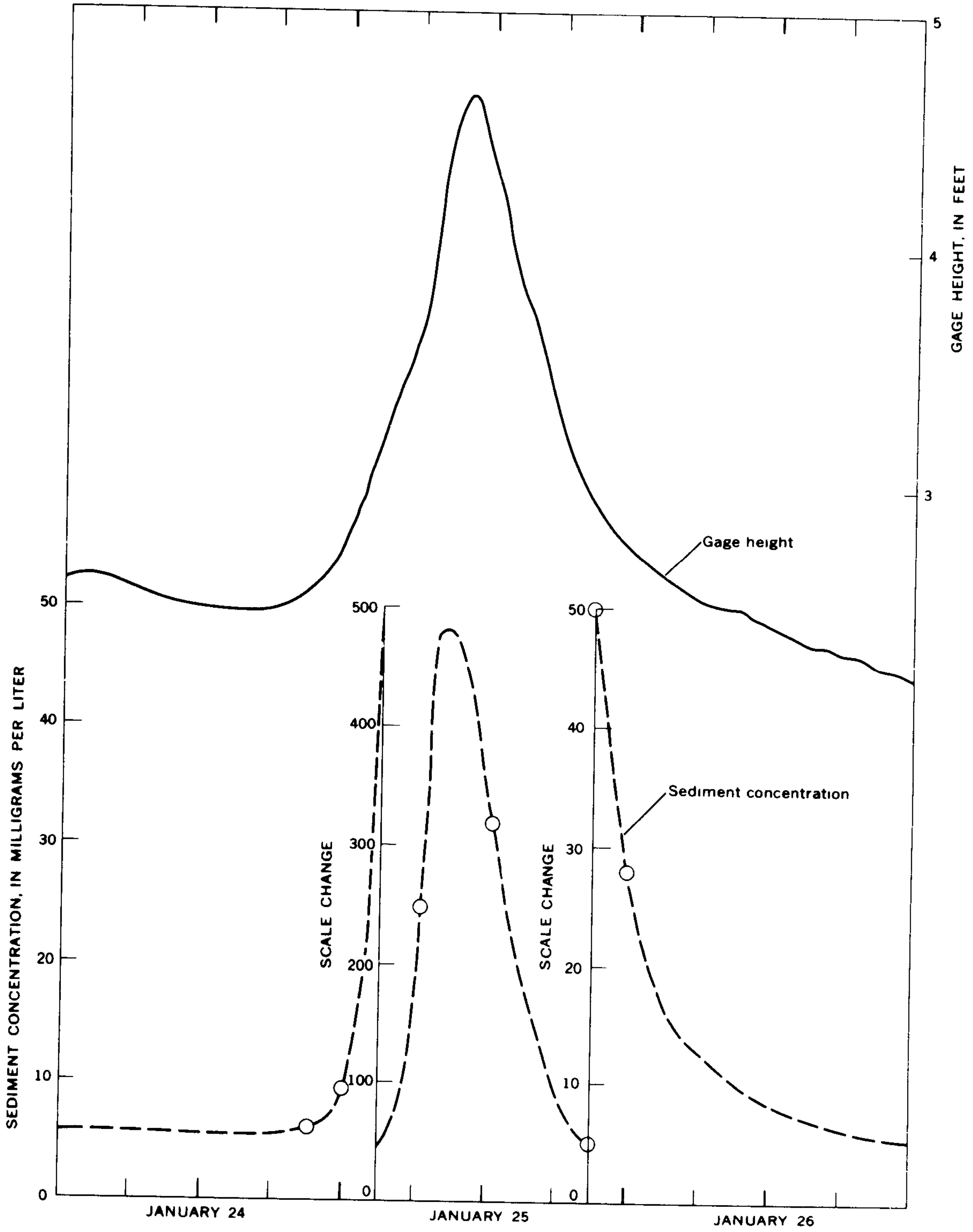


Figure 17.—Gage height and sediment concentration, Corey Creek near Mainesburg, Pa.

Figure 18 shows the effect on sediment concentration in the Rio Grande near Bernalillo, N. Mex., of two separate releases of water from a tributary reservoir over 100 miles upstream. In both instances, the release is at the same rate of discharge; the major difference is in the quantity of water in the stream at the time of release (the initial flow). The shape of the hydrograph is similar in both cases, but there is a marked difference in the sediment-concentration graph owing to the initial flow conditions. Figure 18*A* illustrates low initial flow conditions. The released water erodes sediment from the bed and the banks of the stream and causes an initial sediment peak, followed by the usual recession, similar to that illustrated in figure 16. After the initial recession another rise in concentration occurs which represents the suspended material contained in, or picked up by, the released water. Figure 18*B* illustrates the effect of initial channel storage on concentration. Because of high initial flow, the change in stage and velocity is less, and there is little or no additional erosion of sediment from the bed and banks of the stream by the initial increase in flow. The concentration pattern for the released water, however, is the same as that for figure 18*A*. The interface between the water initially in the river and the released water is defined not only by the changes in suspended sediment but also by a change in temperature and conductivity. In other words, the water represented by the hydrograph peak preceding the sediment-concentration graph is water that was in the channel prior to the release and moved downstream ahead of the release.

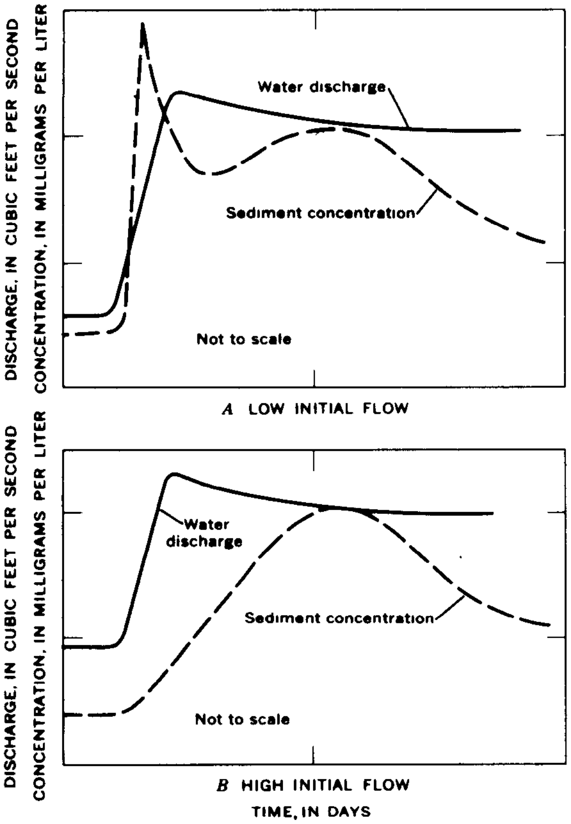


Figure 18.—Effect of two different flow conditions on discharge and concentration for the Rio Grande near Bernalillo, N. Mex.

The examples shown in figures 19-22 illustrate for the Colorado River near San Saba, Tex., the range of concentration peaks and the variation of concentration with time which can occur in a river that drains a large basin of diverse geologic, topographic, climatic, and land-use characteristics.

The graphs for the period May 1-6, 1952 (fig. 19), illustrate a typical water-discharge peak and sediment-concentration graph for a large stream when the flow was caused by thunderstorm activity in a small area of the basin. The graphs differ from those shown for a small basin (fig. 16) in that (1) the increase in discharge from 0400 and 1700 hours May 1 is water previously in the channel and (2) the rate of increase of discharge was attenuated by the distance from the source to the station. These two differences cause the significant rise in concentration to be delayed.

Several general conclusions regarding the sediment characteristics of this station can be inferred from figure 19 and illustrate the type of analysis that should be applied to each station record. First, the concentration from 0400 to 1700 hours on May 1 is only slightly larger than the concentration on the preceding day and illustrates a general rule that the concentration graph seldom will show a large increase before the actual storm

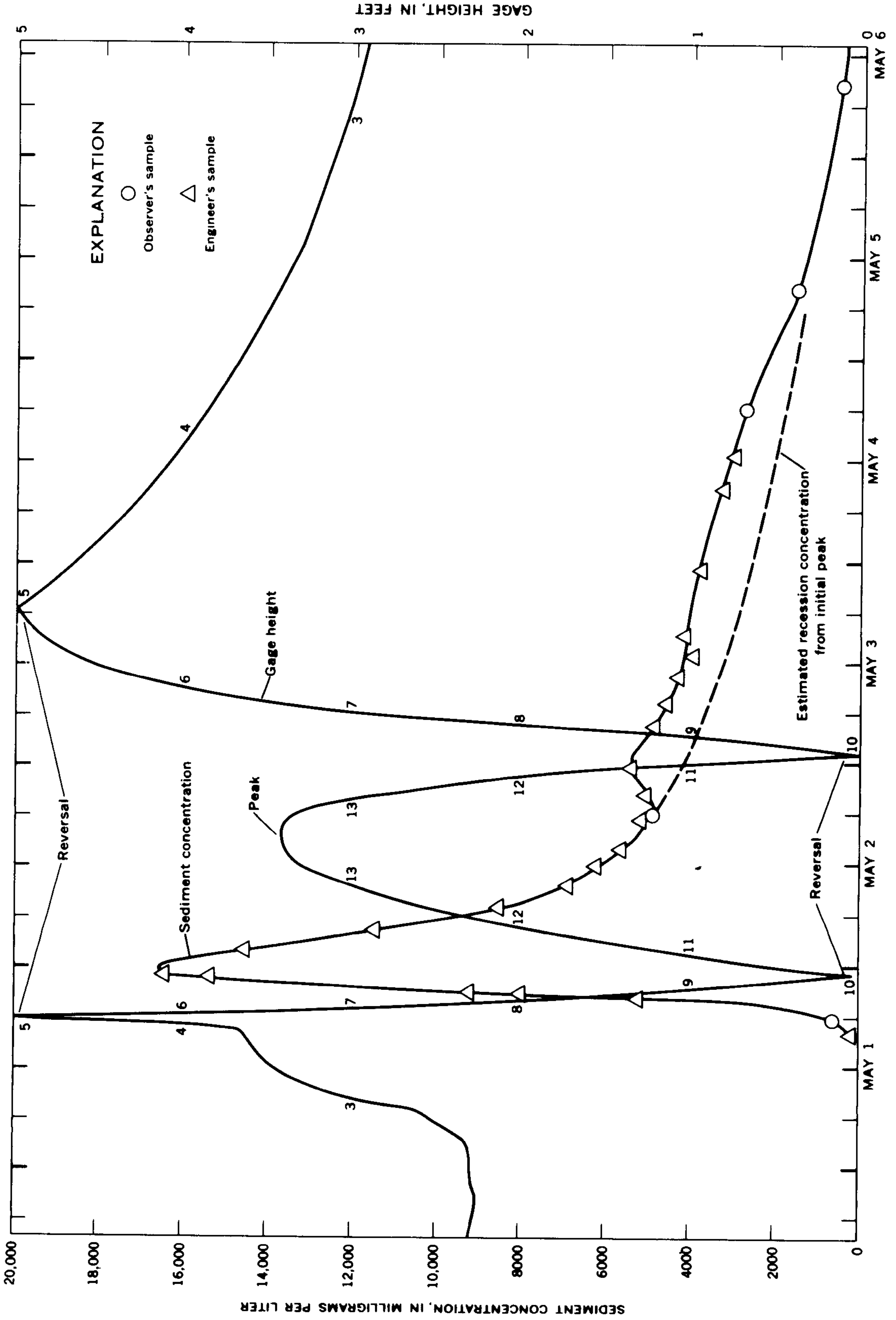


Figure 19.—Gage height and sediment concentration, Colorado River near San Saba, Tex., May 1-6, 1952.

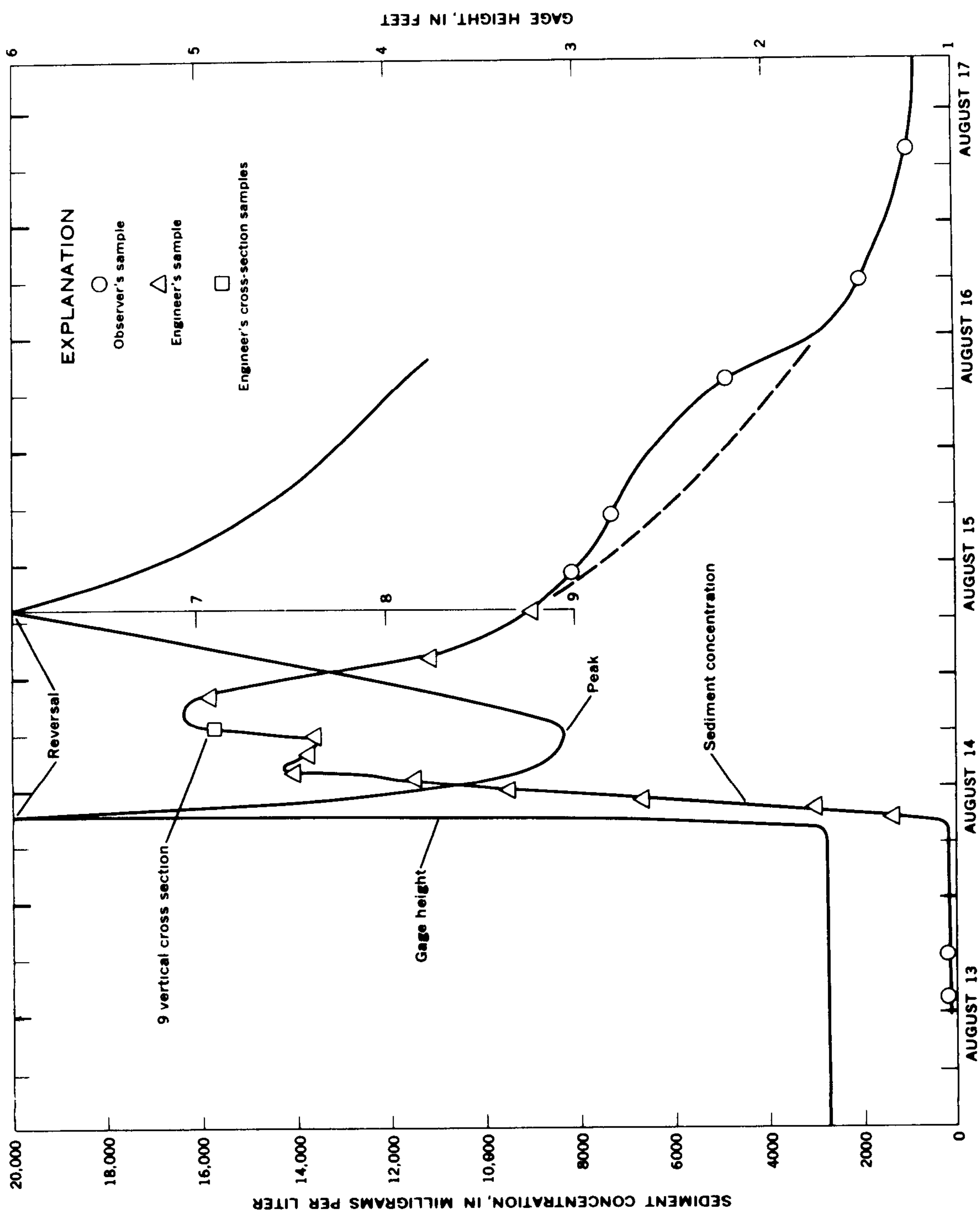


Figure 20.—Gage height and sediment concentration, Colorado River near San Saba, Tex., August 13-17, 1951.

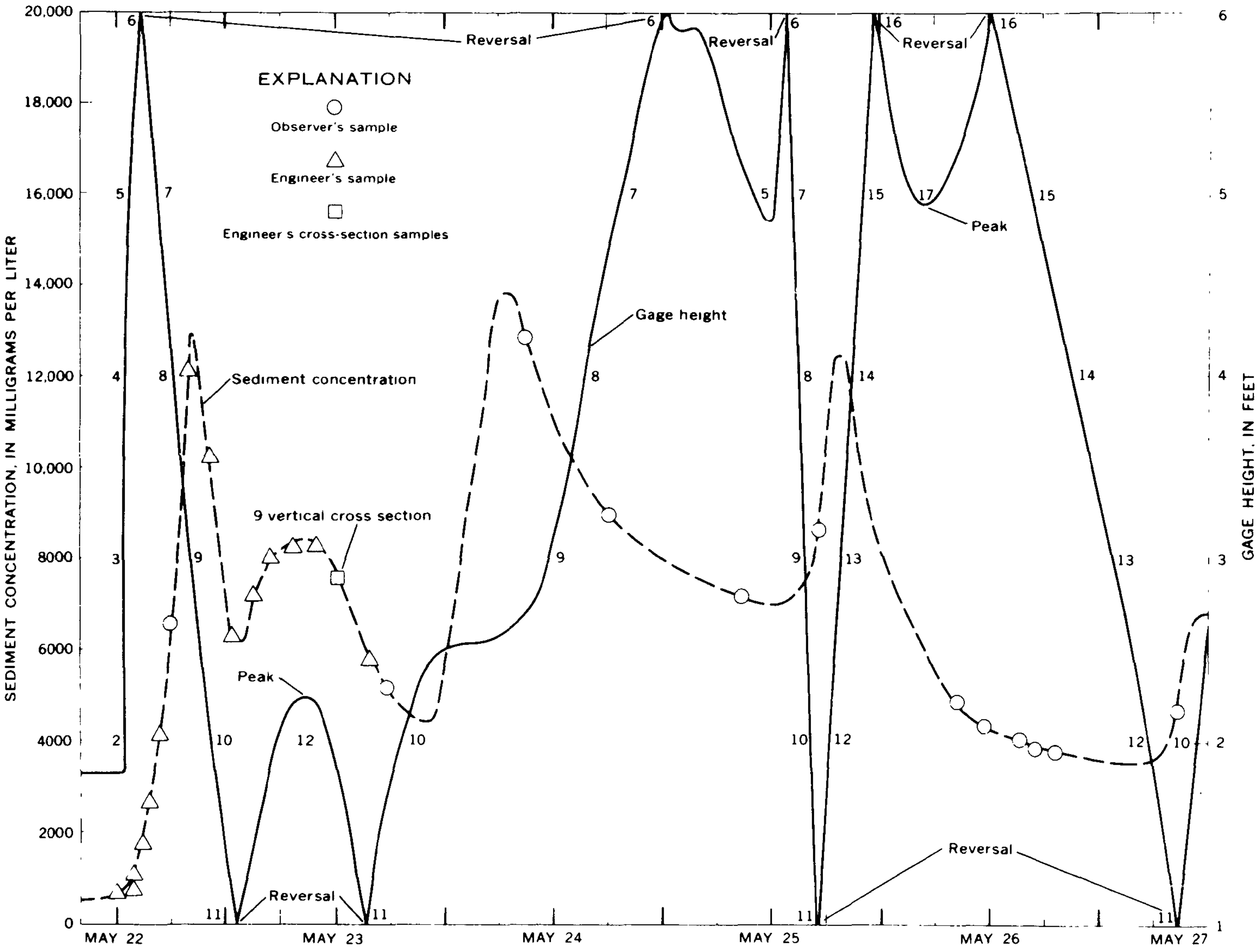


Figure 21.—Gage height and sediment concentration, Colorado River near San Saba, Tex., May 22-27, 1951.

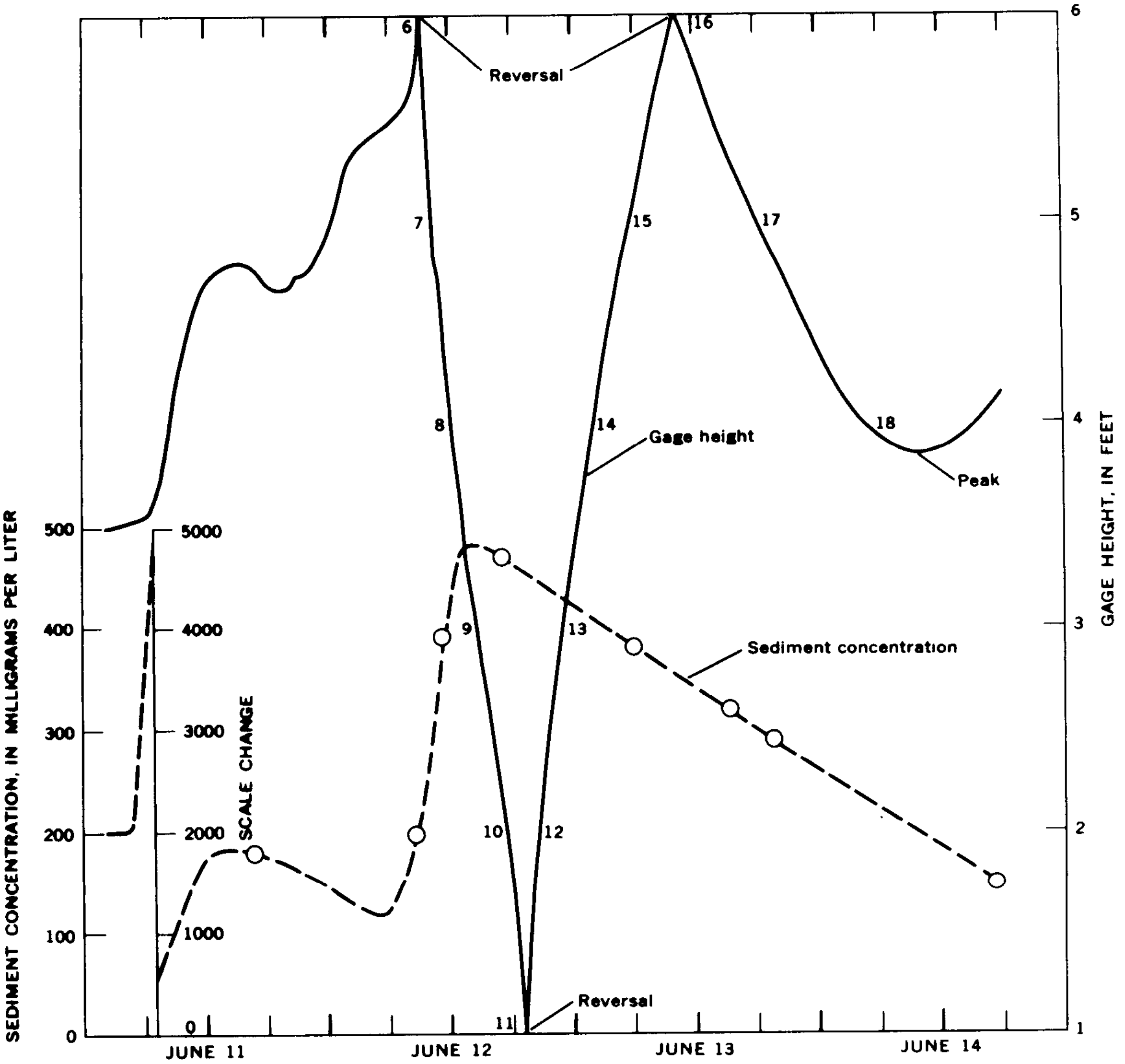


Figure 22.—Gage height and sediment concentration, Colorado River near San Saba, Tex., June 11-14, 1951.

water reaches the station—in this instance, at about 1630 hours. Second, the water peak occurred about 24 hours after the first storm water reached the station, although the concentration peak occurred about 7 hours after the first storm water reached the station.

These graphs illustrate that, for this station, the concentration peak usually precedes the water peak and indicate that, by a comparison of the initial peaks in figures 19-22, the longer the time period between the first arrival of storm water and the storm peak, the longer the time interval between the concentration peak and water peak. Or, conversely, the concentration peak occurred about 7 hours after the initial storm water reached the station, even though the time interval between the initial storm water reaching the station and the water peak increases. Although this time interval (7 hours) should not be considered a firm rule at this station, it could be used in conjunction with the general shape of the concentration curve shown in figure 19 to describe adequately the curves in figures 19-22 even though only two samples had been collected each day.

The May 1-6 rise (fig. 19) has a near

classic hydrograph recession; however, the concentration graph fails to follow the classic pattern. The sediment recession seems normal until 1800 hours May 2, after which the concentration increases and is somewhat above the normal recession curve until about 1200 hours May 5. For purposes of illustration, a normal concentration recession line was estimated for May 2-5 and is represented by a dashed line. The sediment represented by the difference in the estimated graph and the graph based on samples probably was introduced into the main stem by inflow from a small storm on one or more tributaries in the lower part of the basin. The tributary flow contained a higher concentration of suspended sediment than the river, but the water discharge was insufficient to be noticed on the stage record. The effect of various sediment sources superimposed on one hydrograph is more pronounced in the examples to follow.

The period August 13-17, 1951 (fig. 20), has a hydrograph similar to that previously discussed (fig. 19), and runoff apparently came from one source. Correspondingly, the sediment-concentration graph would be expected to have a single rise and characteristic recession. The sediment samples indicate, however, that possibly three major sources of water and suspended material combined to form the single water peak. The initial concentration peak occurred about 4 hours prior to the water peak. Then a tributary flow of higher concentration combined with the initial flow and caused a secondary, and higher, concentration peak. Evidence of a third source of material is indicated by the change in recession rate of concentration about 0300-0800 hours August 16. Finally, on August 16 the sediment concentration dropped abruptly to a level that may have occurred August 15 had the flood peak contained water and sediment from only one source.

The graphs for May 22-27, 1951 (fig. 21), indicate the effect of several peaks produced from several rainstorms or from drainage of several subbasins, or from both. The first increase in discharge was rapid, and the initial concentration peak was conventional, although the peak concentration was not as high as that previously experienced (fig. 20). The difference between this graph and those in the previous examples may be the result of different antecedent conditions in the basin or sediment from a different subbasin. The second concentration peak superimposed on the original sediment recession could not be predicted from the gage-height trace. The third concentration peak may be anticipated because of the abrupt decrease in rate of recession about 2200 hours May 23. The fourth concentration peak, that of May 25, apparently follows the characteristic pattern. The fifth peak (May 27) could not be anticipated from study of the hydrograph and may have been caused by small downstream tributary flow or more likely by bank sloughing which followed the extensive period of high flow.

The period June 11-14 (fig. 22) has a higher water discharge than the preceding examples and a longer delay time between arrival of the first floodwater and the peak discharge, as usually characterized by long periods of general low-intensity rainfall. The sediment concentrations are lower than in the preceding examples. The low concentration may be attributed to antecedent conditions caused by the May storms or, more likely, to the less intense rainfall but longer duration of the June storms.

The examples discussed previously demonstrate some of the variations in concentration graphs that may be expected in a large basin when the runoff events are produced in upstream tributaries of diverse characteristics by isolated rainfall of short duration and high intensity. Figure 23 illustrates a storm event on a large stream, Susquehanna River at Harrisburg, Pa. (drainage area, 24,100 square miles), that drains a basin consisting of three major physiographic provinces with generally good vegetal cover. The March 3-14 flood was caused by intermittent rainfall that occurred March 2-10 throughout the State. The sediment concentration started to increase with the increase in water discharge, unlike the example in

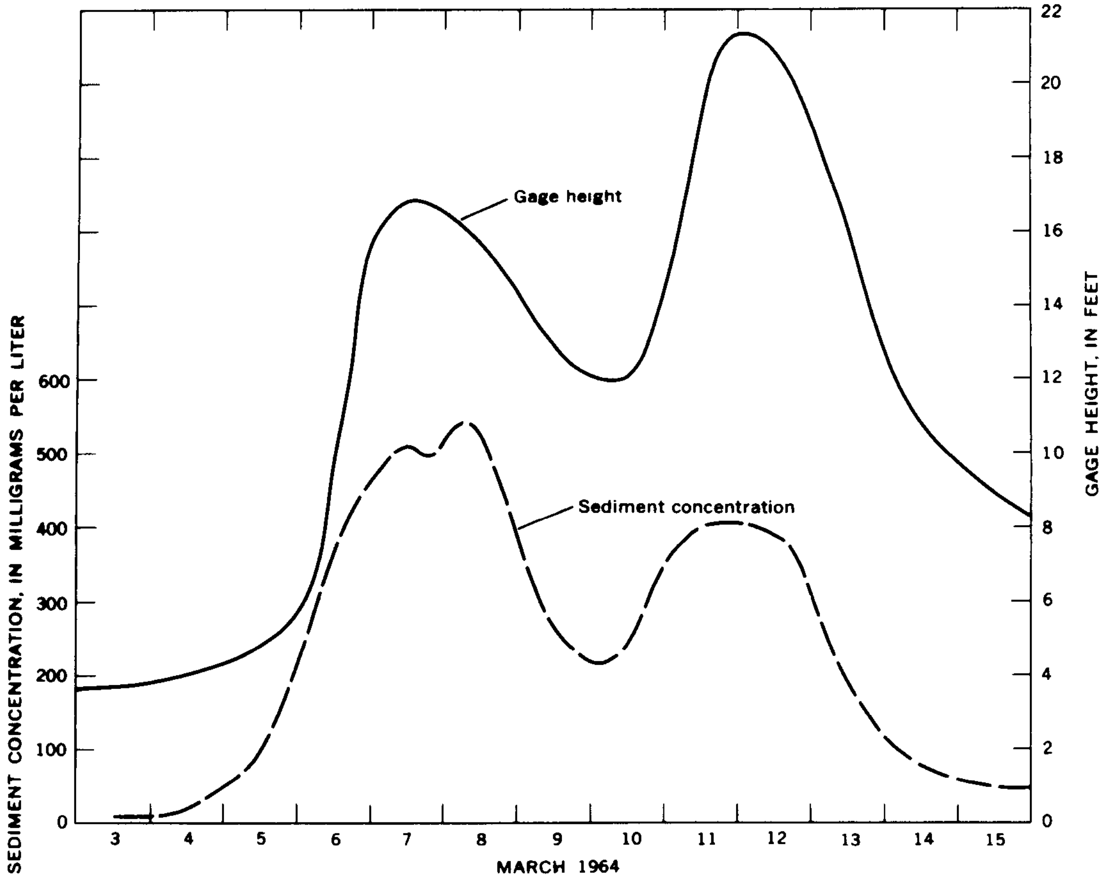


Figure 23.—Gage height and sediment concentration, Susquehanna River at Harrisburg, Pa.

figure 19, because the source area of the water and sediment was local as well as upstream and the concentration continued to increase until the discharge started to decrease. Even so, there was a small secondary concentration peak March 8. The second water-discharge peak on March 11-12, although higher than the first peak, had a lower concentration because less soil was readily available for erosion after the first few days of rain.

The hydrograph of the discharge and suspended-sediment concentrations of the Willamette River at Portland, Ore., during the recordbreaking floods of December 1964 (fig. 24) is a good example of the relation between discharge and concentration for a large flood on a large river. The discharge continued to increase for 4 days until it reached a peak. Sediment concentration, however, reached the maximum value the second day following the beginning of the rise and decreased over 50 percent by the time the water discharge reached a maximum value. Several common characteristic trends may be noted here: (1) The large increase in discharge at the outset caused a minor increase in concentration, (2) the discharge increased slowly for several days to reach a maximum value whereas the concentration increased rapidly and reached a maximum value, in less time, and (3) the water discharge receded slowly, being sustained by additional rainfall and contributions from bank and channel storage, whereas the concentration receded rapidly after reaching the maximum value.

Snowmelt discharge and sediment concentration

The relation between water discharge and