GEOLOGICAL SURVEY CIRCULAR 67

May 1950

PROGRESS REPORT

INVESTIGATIONS OF FLUVIAL SEDIMENTS OF THE NIOBRARA RIVER NEAR CODY, NEBRASKA

By

Eugene F. Serr III

Compiled as part of Interior Department program
for development of Missouri River Basin

UNITED STATES DEPARTMENT OF THE INTERIOR
Oscar L. Chapman, Secretary

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WASHINGTON, D. C.

Free on application to the Director, Geological Survey, Washington 25, D. C.

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ABSTRACT

Comparison of sediment concentrations at a naturally contracted section on the Niobrara River near Cody, Nebraska, with those measured at the regular gaging station one quarter mile upstream, indicates that approximately 50 percent of the sediment is transported as bed load at the regular gaging station. The bed load percentage varied from 24 to 68 for the 34 determinations available, without significant correlation with water or sediment discharge. The investigation indicates that practically the total sediment load is transported in suspension at the contracted section. The normal sediment load is essentially bed material, averaging about 0.20 millimeters in diameter.

INTRODUCTION

The investigation of fluvial sediments in the Niobrara River Basin is a part of the Geological Survey's Water Resources program in the Missouri River Basin. An important phase of the Niobrara Basin investigation is the determination of the general relation between the suspended sediment load and the total sediment load for the streams of this region. The percentage of the total load moving as bed load for these streams draining the sand hill region is known to be high compared to that of most streams. Since field data on sediment transportation as bed load are scarce, and generally difficult to obtain, effort is being made in this investigation to obtain information of general value to hydrologists concerned with fluvial sediment problems.

The measurement of the sediment discharge of streams is generally limited to the material moving as suspended load. The problem of obtaining information on the quantity of material moving as bed load has long confronted engineers designing hydraulic structures. Development of bed-load sampler that is reliable under general field conditions has not been successful. The Geological Survey is approaching the problem in the Missouri Basin by measuring the suspended load both at a normal stream cross section and at a cross section where increased turbulence forces the bed load into suspension. If the turbulence is sufficient to momentarily suspend the total load at the sampling section, the difference between the loads measured will represent the bed load.

A suitable turbulent section may be introduced artifically, as is being done by the Geological Survey on the Middle Loup River near Dunning, Nebraska. An installation of this type on a large stream generally presents difficult construction problems, with attendant expense. On the Niobrara River near Cody, Nebraska, a natural flume is available for this investigation. This report concerns the data available from the investigation near Cody, which is being continued and expanded to include water surface slopes, water temperatures, and stream channel surveys.

ACKNOWLEDGMENTS

The investigation in the Niobrara River Basin is conducted by the Water Resources Division of the Geological Survey. C. G. Paulsen, Chief Hydraulic Engineer, and S. K. Love, Chief of the Quality of Water Branch, Washington, D. C. It is under the immediate supervision of Paul C. Benedict, District Engineer, and Ray B. Vice, hydraulic engineer, Lincoln, Nebraska.

Acknowledgment is made to the following personnel of the Lincoln Office of the Quality of Water Branch who assisted in the laboratory work under the supervision of John E. Adams, soil scientist: P. R. Nyquist, W. M. Barr, D. C. Sloan, and M. R. Jones. Final preparation of the figures was done by Lynn E. Hull.

Records of water discharge were furnished by D. D. Lewis, District Engineer, Surface Water Branch, Geological Survey, Lincoln, Nebraska. Mr. M. G. Zellars, resident engineer stationed at Valentine, Nebraska, assisted with the special field work. The daily samples were collected by Bessie V. Mogle, local observer.

NOTATION

Definition of Terms

Bed load............The difference between the total sediment load transported and the measured suspended load.

Bed material.........The sedimentary material of which the stream bed is composed.

Concentration........The ratio of the weight of dried sediment to the total weight of sample, expressed in parts per million.

Depth-integration....The continuous accumulation of a sample at a uniform transit rate throughout the depth such that each increment is received at the stream velocity of each point.

Fluvial sediment.....Sediment transported by, suspended in, or deposited by streams.

Point-integration....The continuous accumulation of a sample at a point over a period of time such that each increment is received at the instantaneous stream velocity at the point.

Sediment.............Fragmental material transported by, suspended in, or deposited by water or air, or accumulated in beds by other natural agents. This does not include ice or organic material floating on the surface.

Sediment discharge...The rate of sediment transportation expressed as a weight per unit time, usually tons per day.

Suspended load.......(1) The material moving in suspension in the fluid, being kept up by the upward component of the turbulent currents or by colloidal suspension, or (2) the material collected with a suspended load sampler.

Total sediment load..The total weight of sediment transported over a given period.

List of Symbols

C_{ds} Mean suspended sediment concentration in the daily sampling vertical.

C_{cs} Mean suspended sediment concentration in the contracted measuring section.

C_{ns} Mean suspended sediment concentration in the normal cross section.

P_{bm} Percentage by weight of the bed material finer than a certain particle size.

P_{cs} Percentage by weight of the sediment in suspension at the contracted section finer than a certain particle size.

P_{ns} Percentage by weight of sediment in suspension at the normal section finer than a certain particle size.

DESCRIPTION OF THE MEASURING SECTIONS

The daily sediment sampling station on the Niobrara River near Cody is located on the county bridge 10 miles south of Cody. A sketch of the river plan at the site of the investigation is shown in figure 1. The county bridge spans a narrow chute, or natural flume, in the channel, where the stream is cutting through argillaceous siltstone containing limestone concretions, in the basal or "Valentine" member of the Ogallala formation. The stream first enters this contracted channel about 50 feet above the bridge, where the water surface is about 2 feet wide, and gradually widens to about 12 feet at the bridge. The photographs of figure 2 show this reach of the channel. Since it was desired to install the sampler where the susperded sediment concentration was greatest, several sections nearer the head of the reach were investigated before installation was made. The suspended concentration was found to be greatest at the contracted section at the bridge. The 50-foot reach is apparently required for diffusion of the sediment in accordance with the increased turbulence.

The stilling well and water stage recorder are located about a quarter of a mile upstream at a section with a sand bed from bank to bank, typical of the stream. This channel section is shown in the photographs of figure 3. Ordinarily the stream-gaging and sampling of this cross section is done by wading about 30 feet downstream from the gage well. About 100 yards upstream from the gage well is a wide, shallow section, part of which has a shale bottom, known locally as the "ford". Formerly this shallow section was waded for gaging and sampling during moderately high stages. Cross-section plots of the three sections described are shown in figure 4. With the completion of a cableway over the section just below the gage on February 24, 1949, all high-stage gaging and sampling is now done from the cableway.

DAILY WATER AND SEDIMENT DISCHARGE RECORDS

Sediment samples are taken one to three times daily at one vertical by the local observer with the permanently installed US D-43 sampler at the county bridge. A continuous concentration graph is prepared from the analysis of these samples, and daily mean concentrations are calculated from this graph. These concentrations were adjusted to represent the cross section by applying a mean ratio of the concentration in the cross section to that at the vertical sampled daily, as will be discussed later. The sediment discharges in tons per day are calculated by multiplying the product of the daily mean water discharges and the daily mean concentrations by the constant 0.00270. (See table 1). These data are most readily visualized when both water and sediment discharge are plotted on one hydrograph form (fig. 5).

The relations between water and sediment discharge at the normal and contracted sections are shown in figure 6. The solid curve averages the daily discharges at the contracted section (table 1), while the dotted curve averages the data from the periodic measurements at the normal section near the gage well (table 2).

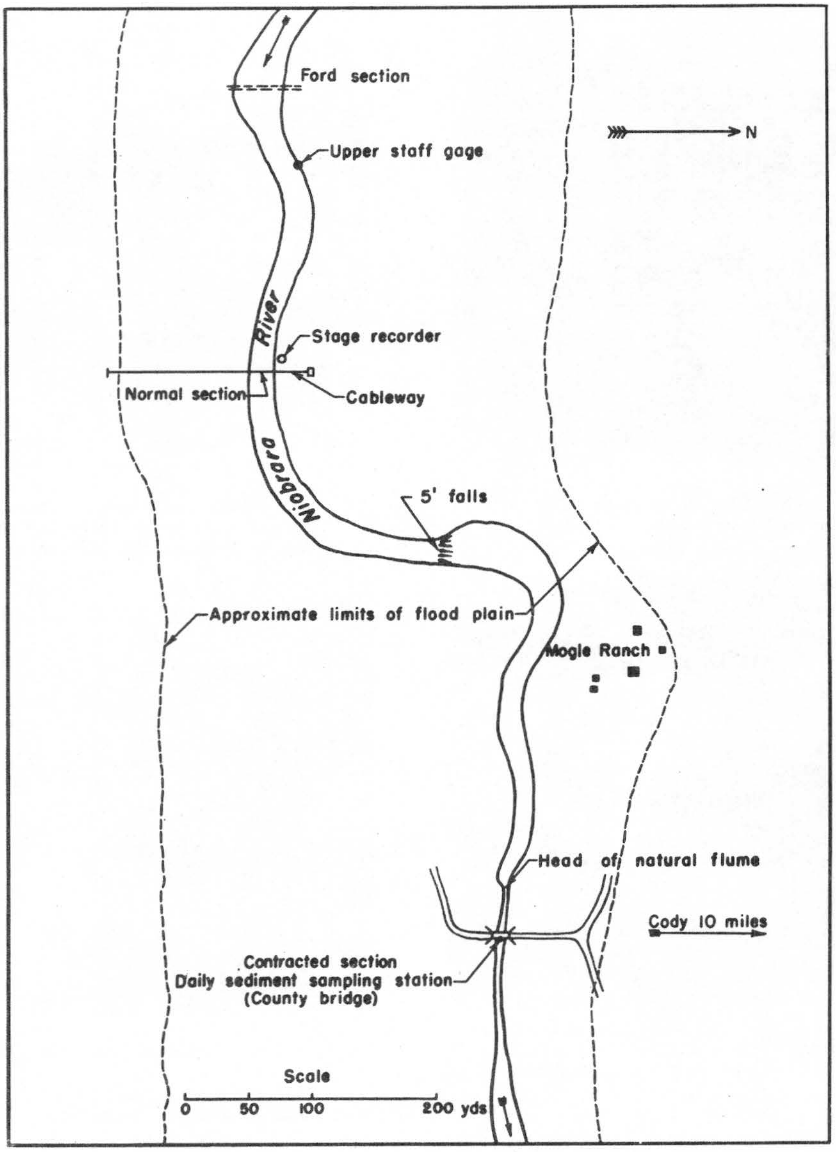


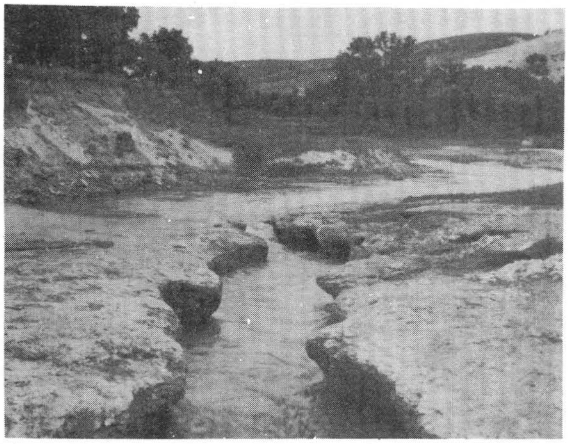
Figure 1.--Niobrara River near Cody, Nebraska.

THE RELATION BETWEEN THE SUSPENDED SEDIMENT CONCENTRATION AT THE NORMAL AND CONTRACTED SECTIONS

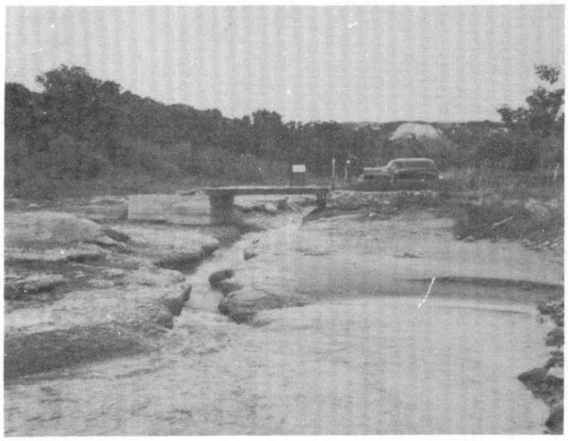
Thirty-four measurements of the suspended sediment concentration at each of the two sections are available for comparison for the period December 17, 1947, to November 3, 1948 (table 2). A few of the earlier determinations were made at the ford section, but investigation indicated that the difference in measured concentration is small in comparison with the accuracy of measurement.

The concentration C_{ns} (table 2) at the normal section is the mean of determinations of samples from three to five verticals spaced so as to represent areas of equal discharge. The concentration C_{ds} at the daily sampling vertical located in the center (station 10) of the contracted section was adjusted to obtain the average concentration in the contracted section C_{cs}.

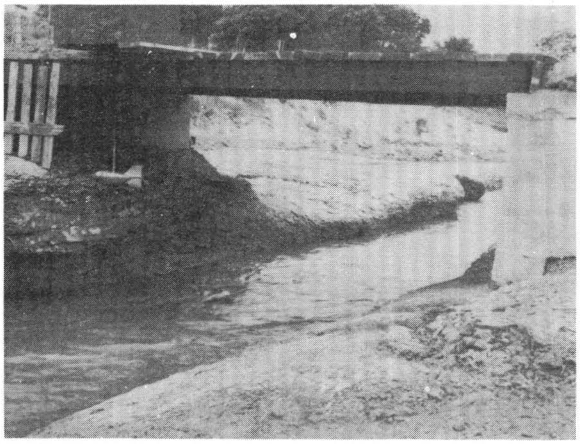
The ratio of the suspended concentration at the normal section C_{ns} to that at the contracted section C_{cs}, varies from 0.32 to 0.76, with a mean of 0.51. Weighting the determinations of C_{ns}/C_{cs} with sediment discharge at the contracted section results in a mean of 0.53, not significantly different from the non-weighted mean. To further examine the correlation of this ratio with the corresponding water discharge, the quantities were plotted against each other (fig. 7). The available data indicate a low degree of corre-



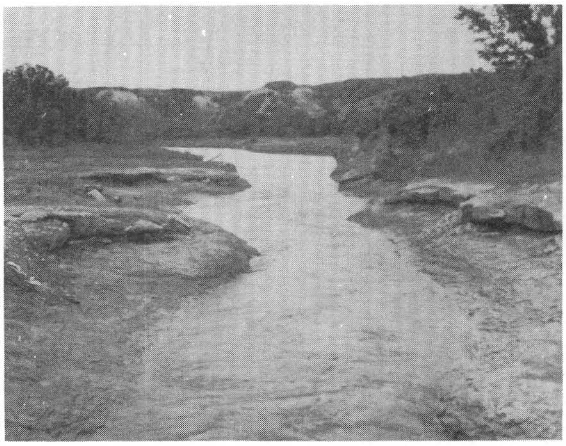
A. View upstream from bridge showing entrance to contracted channel.



B. View downstream showing contracted channel and county highway bridge. The shelter housing the US D-43 sampler is visible on the bridge.



C. View upstream showing contracted section at daily sampling point. US D-43 sampler shown at left.



D. View downstream from county highway bridge.

Figure 2.—Natural flume on the Niobrara River near Cody, Nebr.

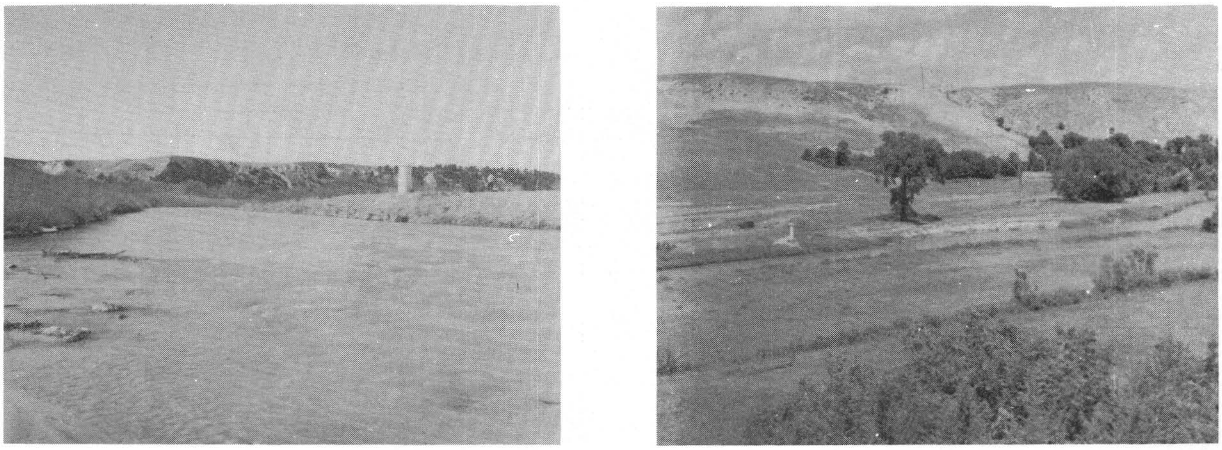
lation of this ratio with water discharge. However, the curves of figure 6 indicate that a general relation will be developed when a large number of comparisons are available over the entire discharge range of the stream regimen.

The data are necessarily treated as though the sampling at the two sections was simultaneous. This was not practicable, and possibly not desirable because of the time of travel between the sections. The time difference between the measurements at the two sections varied from 1 to 5 hours. Any single comparison may thus be affected by changes in water, suspended-load, or bed-load discharge during the time required for the sampling.

THE DISTRIBUTION OF THE SUSPENDED SEDIMENT IN THE CONTRACTED SECTION

Information on the distribution of the sediment through the contracted section, with respect to both concentration and particle size, is necessary in determining the nature of the sediment movement at this section. The more nearly uniform the concentration and particle size throughout the depth, the greater the indicated turbulence and the less the sediment movement as bed load at this section. If the coarsest material found in suspension in the flume is as large as the coarsest material found on the bed at the normal section, then the turbulence apparently would be sufficient to suspend the total load through the flume.

The sediment concentrations at the contracted section shown in table 1 were computed by adjusting the concentrations at the



A. View upstream showing normal sampling section and gage well.

B. View downstream Niobrara River and valley at gaging station.

Figure 3.--Gaging station on the Niobrara River near Cody, Nebr.

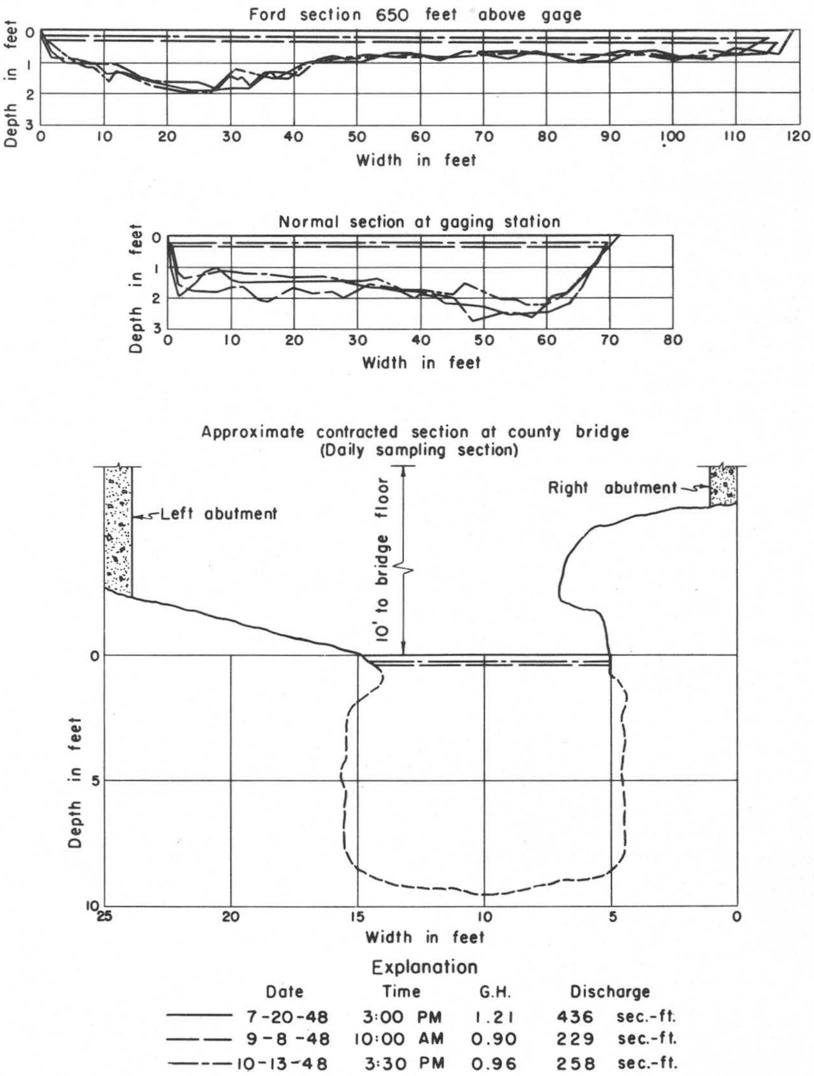


Figure 4.--Cross-section plots of the sampling sections.

Table 1.--Daily mean water discharge, suspended sediment concentration, and suspended sediment discharge at the contracted section on the Niobrara River near Cody, Nebr., for April through September 1948

Day	April			May			June			July			August			September		
	Mean discharge (sec.-ft.)	Suspended sediment: Mean concentration (p.p.m.)	Suspended sediment: Tons per day	Mean discharge (sec.-ft.)	Suspended sediment: Mean concentration (p.p.m.)	Suspended sediment: Tons per day	Mean discharge (sec.-ft.)	Suspended sediment: Mean concentration (p.p.m.)	Suspended sediment: Tons per day	Mean discharge (sec.-ft.)	Suspended sediment: Mean concentration (p.p.m.)	Suspended sediment: Tons per day	Mean discharge (sec.-ft.)	Suspended sediment: Mean concentration (p.p.m.)	Suspended sediment: Tons per day	Mean discharge (sec.-ft.)	Suspended sediment: Mean concentration (p.p.m.)	Suspended sediment: Tons per day
1	---	---	---	403	2,120	2,310	283	1,140	871	334	1,220	1,100	243	750	492	229	720	445
2	---	---	---	398	1,820	1,960	288	1,120	871	334	1,180	1,060	273	860	634	229	660	408
3	---	---	---	387	2,140	2,240	288	1,080	840	314	1,130	958	433	2,030	2,580	234	620	392
4	---	---	---	376	1,590	1,610	278	800	600	314	1,060	899	345	1,650	1,540	232	620	388
5	---	---	---	371	1,550	1,550	283	990	757	288	980	762	382	1,480	1,530	229	620	383
6	---	---	---	340	1,650	1,510	293	960	760	258	900	627	345	1,440	1,340	234	640	404
7	---	---	---	334	1,540	1,390	263	870	618	263	820	582	329	1,320	1,170	234	760	480
8	---	---	---	324	1,670	1,460	253	850	580	248	750	502	324	1,230	1,080	243	880	577
9	376	1,750	1,780	392	1,770	1,870	253	860	588	248	700	469	319	1,140	982	273	960	708
10	366	1,970	1,950	430	2,090	2,430	238	760	488	229	---	440	314	1,050	890	268	980	709
11	366	1,880	1,860	436	2,400	2,820	263	850	604	253	---	510	329	1,310	1,270	248	920	616
12	361	1,800	1,750	420	1,900	2,150	288	860	669	268	---	560	314	2,860	2,420	234	850	537
13	366	2,150	2,120	398	1,810	1,940	288	980	762	258	790	550	314	1,290	1,090	234	800	505
14	350	1,850	1,750	376	1,210	1,230	298	1,130	909	329	1,030	1,150	314	---	890	224	720	436
15	345	1,760	1,640	340	1,410	1,290	314	1,410	1,200	469	2,310	2,920	314	---	840	210	660	374
16	340	1,750	1,610	314	1,490	1,260	308	1,150	956	436	1,860	2,190	303	---	780	205	690	382
17	329	1,640	1,460	303	1,450	1,190	324	1,060	927	425	1,640	1,880	293	---	700	219	720	426
18	329	1,670	1,480	293	1,400	1,110	1,850	---	58,000	420	1,420	1,610	248	800	536	229	720	445
19	345	1,510	1,410	283	1,310	1,000	809	4,720	10,300	572	4,880	8,200	234	700	442	234	690	436
20	355	1,530	1,470	268	890	644	555	4,020	6,020	436	2,770	3,260	224	660	399	234	690	436
21	345	1,550	1,440	273	890	656	464	2,710	3,390	403	2,340	2,550	229	610	377	238	730	469
22	361	1,570	1,530	273	880	649	497	2,210	2,960	366	1,560	1,540	219	590	349	263	710	504
23	361	1,580	1,540	314	1,180	1,000	475	2,540	3,260	345	1,330	1,240	224	560	339	308	900	748
24	382	1,950	2,010	283	1,010	772	425	1,980	2,270	314	1,020	865	219	550	325	387	1,380	1,440
25	537	2,600	3,770	293	840	664	387	1,460	1,530	293	930	736	219	540	319	324	1,330	1,160
26	566	1,810	2,760	345	1,180	1,100	408	1,480	1,630	278	840	630	229	550	340	293	1,320	1,040
27	549	2,430	3,600	334	1,290	1,160	392	1,630	1,730	268	730	528	234	590	373	283	1,120	856
28	469	3,470	4,390	324	1,500	1,310	387	1,420	1,480	268	700	507	248	840	562	273	1,110	818
29	436	3,180	3,740	329	1,500	1,330	376	1,470	1,490	268	990	716	243	770	505	273	1,250	921
30	408	2,690	2,960	319	1,580	1,360	361	1,450	1,410	238	980	630	243	670	440	258	960	669
31	---	---	---	308	1,240	1,030	---	---	---	243	770	505	238	580	373	---	---	---
Total	8,642	---	48,020	10,581	---	44,000	12,189	---	108,500	9,980	---	40,680	8,739	---	25,910	7,576	---	18,110
Mean	393	1/2,060	2,180	341	1/1,540	1,420	406	1/3,300	3,620	322	1/1,510	1,310	282	1/1,100	836	2,525	1/885	604
Maximum	566	3,470	4,390	436	2,400	2,820	1,850	---	58,000	572	4,880	8,200	433	2,860	2,580	387	1,380	1,440
Minimum	329	1,510	1,410	268	840	644	238	760	488	229	---	445	219	540	319	205	620	374

Total load for period Apr. 9 to Sept. 30 (tons) - 285,200

1/ Mean weighted with water discharge.

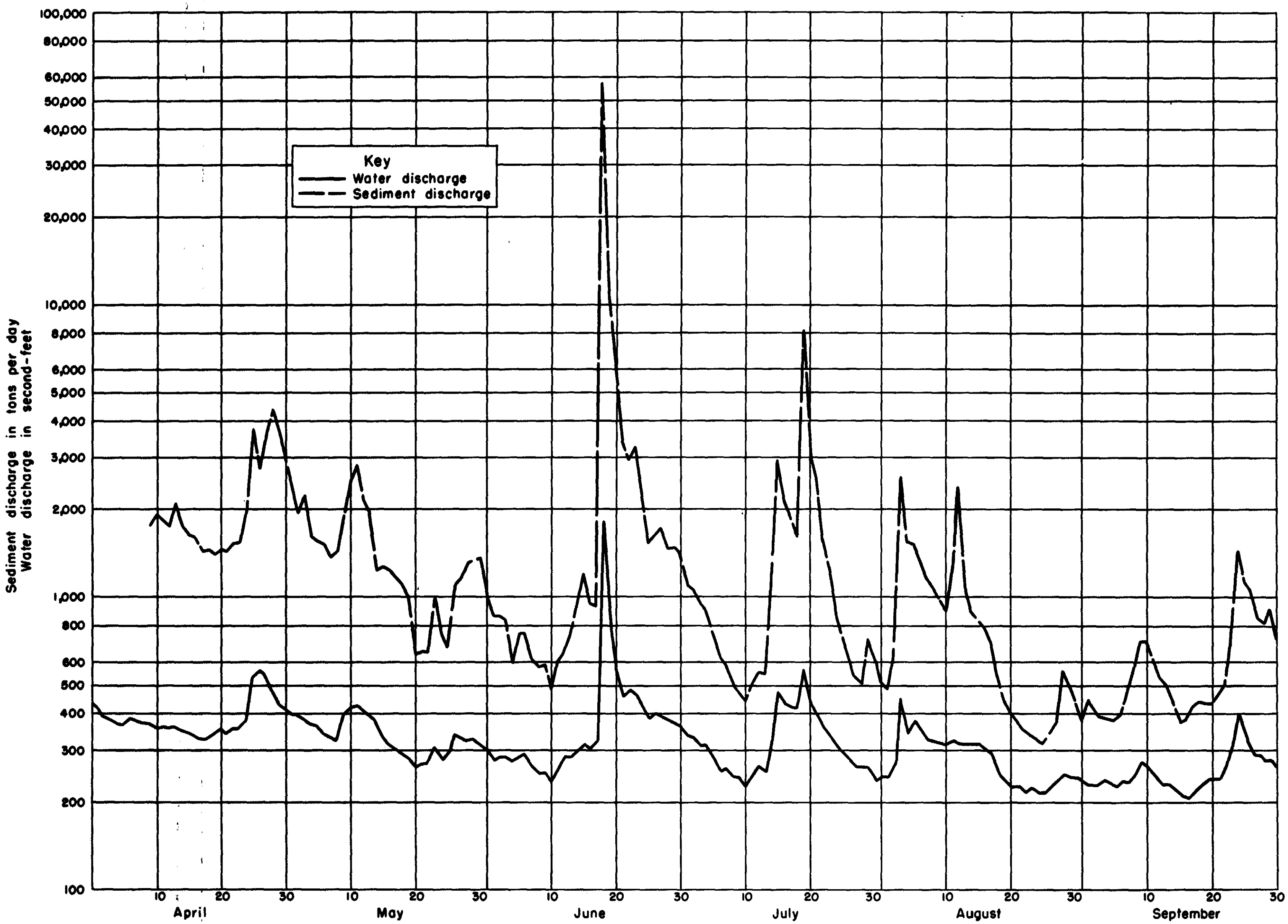


Figure 5.--Hydrograph of water and sediment discharge of the Niobrara River near Cody, Nebraska, for April through September 1948.

Table 2.—Measurements of the increase of sediment in suspension through the natural flume on the Niobrara River near Cody, Nebr.

Date	Mean time	Mean gage height	Water discharge (sec.-ft.)	Suspended sediment concentration in p.p.m.			Ratio $\frac{C_{ns}}{C_{cs}}$	Suspended sediment discharge in tons per day	
				Normal section	Contracted section			Normal section	Contracted section
				C_{ns}	C_{ds}	C_{cs}			
1947									
Dec. 17	10:20 a.m.	- -	- -	842	1,400	1,580	0.53	- - -	- - -
Dec. 18	3:10 p.m.	0.90	248	794	1,710	1,930	.41	532	1,290
Dec. 27	1:50 p.m.	1.11	355	951	1,680	1,900	.50	912	1,820
1948									
Jan. 5	2:45 p.m.	1.13	366	1,110	1,780	2,010	.55	1,100	1,990
Jan. 21	12:05 p.m.	1.05	334	737	2,060	2,330	.32	665	2,100
Jan. 29	12:30 p.m.	0.84	238	656	1,180	1,330	.49	421	855
Feb. 4	12:40 p.m.	0.90	268	773	1,760	1,990	.39	559	1,440
Feb. 21	12:40 p.m.	1.06	350	1,180	1,680	1,900	.62	1,120	1,800
Mar. 4	1:10 p.m.	1.02	329	946	2,180	2,460	.38	840	2,190
Mar. 13	12:35 p.m.	1.07	371	1,330	1,890	2,140	.62	1,330	2,140
Mar. 16	3:50 p.m.	2.41	1,160	3,470	4,640	5,240	.66	10,900	16,400
Mar. 19	12:55 p.m.	1.36	492	1,280	2,480	2,800	.46	1,700	3,720
Ma[illegible] 29	1:10 p.m.	1.35	486	1,070	2,050	2,320	.46	1,400	3,050
[illegible] 9	1:50 p.m.	1.16	382	844	1,530	1,730	.49	870	1,780
[illegible]pr. 27	1:00 p.m.	1.58	620	1,460	2,290	2,590	.56	2,440	4,340
May 7	9:30 a.m.	1.16	382	894	1,330	1,500	.60	922	1,550
May 13	10:10 a.m.	1.23	420	648	1,760	1,990	.33	735	2,260
May 27	2:00 p.m.	1.02	308	720	1,080	1,220	.59	599	1,010
June 1	1:45 p.m.	0.94	268	534	846	956	.56	386	692
June 12	12:20 p.m.	0.95	273	427	844	954	.45	315	703
June 15	12:20 p.m.	0.97	283	406	1,090	1,230	.33	310	940
[illegible] 23	12:20 p.m.	1.44	537	1,280	1,560	1,760	.73	1,860	2,550
[illegible] 30	9:30 a.m.	1.15	376	721	1,450	1,640	.44	732	1,660
[illegible]y 13	12:00 m.	0.96	258	328	715	808	.41	228	563
[illegible] 20	11:20 a.m.	1.24	452	1,370	1,950	1/ 1,800	.76	1,670	2,200
Au[illegible] 2	10:30 a.m.	1.00	278	475	761	860	.55	356	646
Aug. 18	9:50 a.m.	0.92	238	634	741	837	.76	407	538
Aug. 25	11:35 a.m.	0.88	219	394	486	549	.72	233	325
Sept. 8	2:30 p.m.	0.90	229	389	653	1/ 776	.50	241	480
Sept. 25	2:45 p.m.	1.06	308	518	1,150	1,300	.40	431	1,080
Oct. 5	12:35 p.m.	0.97	263	362	693	783	.46	257	556
Oct. 13	4:20 p.m.	0.96	258	483	1,100	1/ 1,180	.41	336	822
Oct. 25	1:40 p.m.	1.07	314	535	1,060	1,200	.45	454	1,020
Nov. 3	2:50 p.m.	1.06	308	564	1,260	1/ 1,610	.35	469	1,340
						Mean	.51		

1/ Based on samples from three verticals in the cross section. Other values based on the mean C_{cs}/C_{ds} ratio of 1.13.

daily sampling vertical by the mean ratio of the concentration in the cross section to that at the daily sampling vertical, C_{cs}/C_{ds}. The available determinations of the ratio C_{cs}/C_{ds} are shown in table 3. Since these seven determinations vary from 0.93 to 1.28 without significant correlation with water or sediment discharge, the mean (1.13) was used.

Concentration Variation in the Vertical at the Contracted Section

Three sets of point-integrated samples were taken (September 8, October 13, and November 11) with the US P-46 sampler from the bridge over the contracted section. Each set consisted of samples from four points in each of three verticals. The profiles of concentration determined from these point samples are shown in figures 8, 9, and 10. In figure 8 each point represents the composited con-

Table 3.—Sediment concentrations in parts per million across the contracted section

Date	Time	Station 7	Station 10 Cds	Station 14	Ccs mean	$\frac{C_{cs}}{C_{ds}}$
1948						
July 20	5:00 p.m.	1,820	1,950	1,640	1,800	0.93
Sept. 8	11:00 a.m.	829	653	845	776	1.19
Sept. 8	3:00 p.m.	733	623	875	744	1.19
Oct. 13	4:00 p.m.	1,480	1,100	963	1,180	1.07
Oct. 13	12:45 p.m.	1,900	1,229	1,144	1,424	1.16
Nov. 3	2:20 p.m.	2,000	1,260	1,580	1,610	1.28
Nov. 3	12:15 p.m.	1,780	1,450	1,560	1,596	1.10
					Mean	1.13

Table 4.—Sediment concentrations and mean particle sizes of point-integrated samples from the contracted section

Station	Depth	Sept. 8, 1948 229 sec.-ft.		Oct. 13, 1948 258 sec.-ft.		Nov. 3, 1948 308 sec.-ft.	
		Concentration (p.p.m.)	Size (mm.)	Concentration (p.p.m.)	Size (mm.)	Concentration (p.p.m.)	Size (mm.)
7	1.0	513	0.168				
	2.0			1,220	0.208	1,090	0.192
	3.0	739	.187				
	4.5					2,320	.287
	5.0	924	.283	2,000	.233		
	7.0	920	.283	3,810	.322	3,740	.351
	8.4			4,370	.384	3,230	.402
11 (daily)	2.0	485	.188	858	.196	1,050	.213
	4.0	556	.154				
	5.0			1,220	.218	1,490	.270
	6.0	709	.168				
	8.0			1,960	.242	2,250	.281
	8.6	1,240	.248				
	9.2			3,210	.226	3,300	.329
15	2.0	759	.187	977	.198	1,410	.228
	4.0	871	.224	1,270	.208	1,660	.242
	6.0	931	.220	1,440	.204		
	6.5					2,230	.258
	7.6			2,070	.247	2,080	.286
	8.2	1,430	.300				

centration of three samples taken in succession; in figures 9 and 10 each point represents the composited concentration of two samples taken in succession. Each point-integrated cross section required about 4 hours sampling time.

These concentration profiles, increasing 1½ to 5 times from surface to bed, indicate the possibility of considerable movement of sediment as bed load at the contracted section. They are not interpreted to indicate definitely an appreciable bed load at the contracted section. It is not known whether the gradient of these profiles is less or greater than that required for equilibrium between suspension by turbulence and settling by gravity for the size range of the total load.

The velocity profiles at these sampling verticals (fig. 11) were determined by using the sample volumes and the filling times recorded for each sample. The principle assumption in this procedure is that the intake velocity of the sampler nozzle is equal to the actual stream velocity at each point. The considerable variation between these three sets of velocity profiles is probably due to the effect of the irregular side walls. The comparison shows a gradual velocity pattern change for the three discharges.

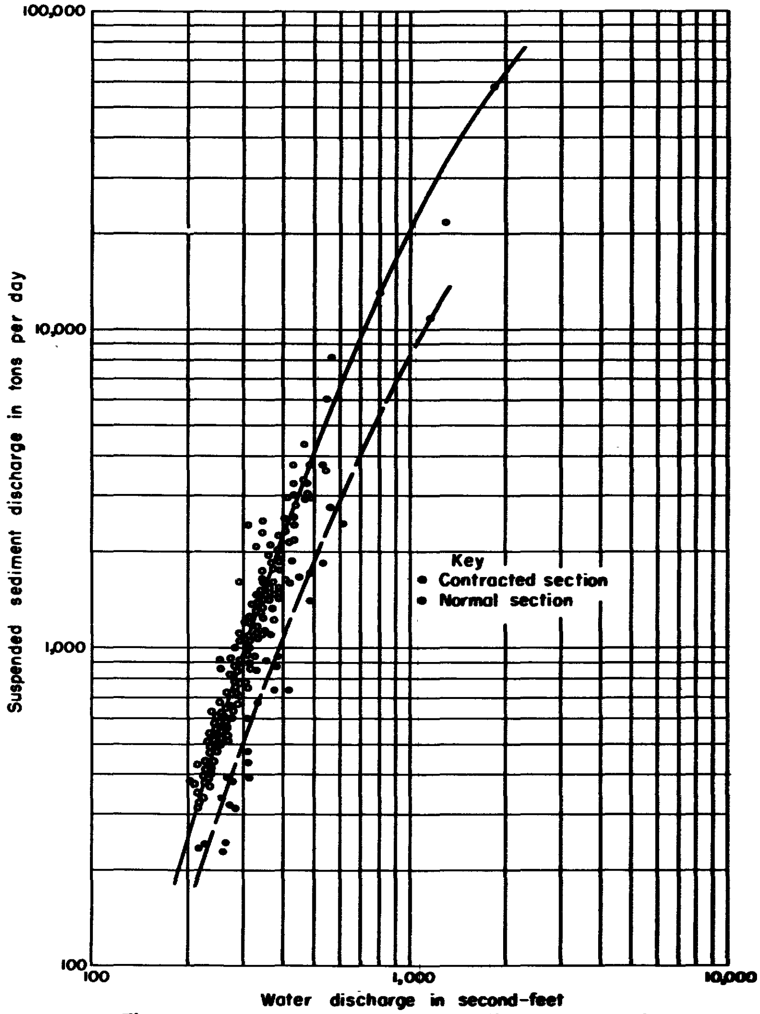


Figure 6.--Water and sediment discharge relation at normal and contracted sections.

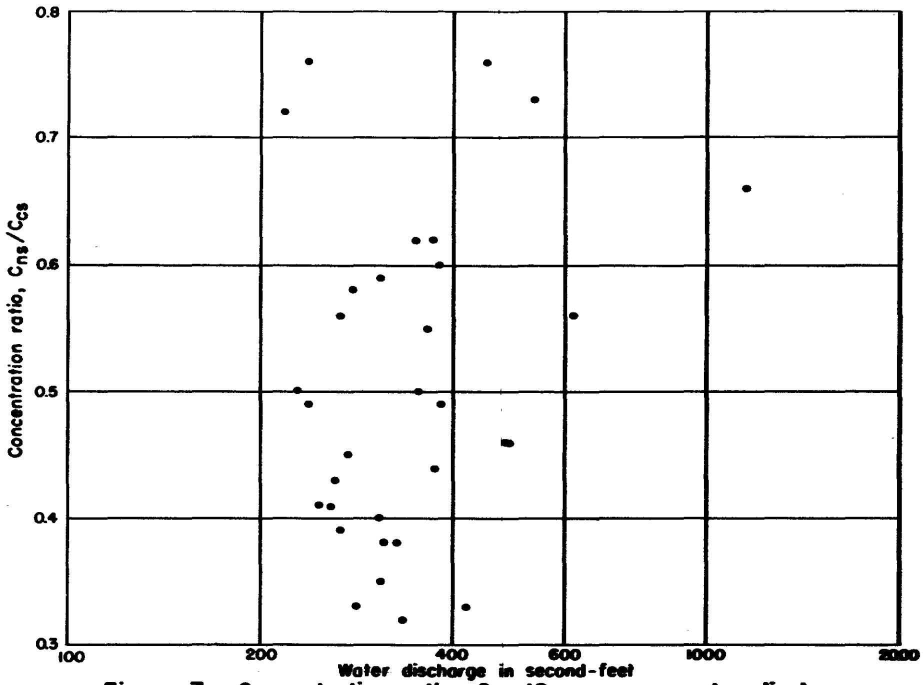


Figure 7.--Concentration ratio, C_{ns}/C_{cs}, versus water discharge.

Depth-integrated samples were taken for comparison as soon as possible after the point-sampling was completed in the section. Mean values of concentration and velocity were taken from the profiles of the point samples for each of five equal depth intervals. A weighted mean concentration for each vertical was then computed from the point samples for comparison with the concentrations of the depth-integrated samples. The ratio of the weighted mean concentration as determined from the point samples to the concentration of the depth-integrated samples averaged 0.98, and varied from 0.88 to 1.15 for the nine comparisons available for September 8 and November 3. Considering the time interval between the point-sampling and the depth-integration, and the difficulty of holding the 100-pound P-46 sampler steady in the flume, this comparison is considered satisfactory. On October 13, the ratios for the three verticals were 1.19, 1.12, and 1.28, indicating a general increase in the sediment concentration during the time interval between the two samplings.

Particle Size Variation in the Vertical at the Contracted Section

Size analyses were run on all point samples taken in the contracted section. The bottom-withdrawal tube method of analysis was used, with the native water of the samples as the settling medium. The range in stream concentration for all point samples were 485 to 4,370 parts per million. The concentration at which the analyses were run in the bottom-withdrawal tubes averaged 40 percent higher than the stream concentrations.

Typical size-analyses curves for each point in each vertical are shown in figures 12 to 17. Examination of these curves shows that in general the size distribution (shape of curve) is similar within each vertical, and that the mean size (position of curve) increases gradually toward the bed. These conditions are required for equilibrium between the turbulent diffusion and the force of gravity. Table 4 was prepared to show that the mean particle size generally increased throughout the depth for the increasing discharges.

Typical size analyses of the depth-integrated samples taken with the point samples are shown in figures 25 and 28. The fact that the depth-integrated curves fall within the group of corresponding point-integrated curves affords a check on the reliability of the samples and analyses.

It is important to note that the effective mean particle diameters of the point samples nearest the bottom varied from 0.23 to 0.40 millimeter and averaged 0.30 millimeter. This size is to be compared with the size of the bed material at the normal section upstream.

THE PARTICLE SIZE RELATIONSHIPS

Suspended Material

Four comparisons of the suspended particle sizes at the two sections are shown in figures 18 to 21. Each of these curves is the mean representing 3 to 5 verticals, typical samples of which are shown in figures 22 to 29. The mean particle size at the normal section varies from 0.02 to 0.18 millimeter, averaging 0.14 millimeter. At the contracted section the mean size varies from 0.13 to 0.26 millimeter, averaging 0.20 millimeter for the four comparisons.

Bed Material at the Normal Section

The bed material of the river was sampled on October 13, at four points in the cross section about 100 yards above the contracted section. This section is about 50 feet wide and averages 2½ feet in depth. The sampling was accomplished by wading out and forcing a pint ice-cream container quickly into the sand bed. Visual examination of small cores from these containers yielded no evidence of sorting or layering in the 4 inches of depth sampled.

The bed material samples were analyzed for particle size both by the bottom-withdrawal tube method and by sieve analysis (figs. 30 and 31). For the settling rate analysis, duplicate portions of 0.5 gram were split out of each sample and run in distilled water. A tube concentration of about 1,000 parts per million was obtained, which was near the average for all the analyses of the investigation. Distilled water was used in the analysis only because insufficient native water was available. This factor probably would not lead to any significant differences in results with such coarse material. The sieve analyses were run on duplicate 50 gram portions split from each sample. A Ro-Tap shaker was used with a 15 minute shaking period.

The mean particle size of the bed samples obtained is about 0.25 millimeter for both settling rate and sieve analysis (figs. 30 and 31). The high degree of rounding, or sphericity, of the particles, clearly evident from visual examination, supports the conclusion that the two analyses are very similar. It is significant to note that this mean size is smaller than the 0.30 millimeter mean size found in suspension near the bottom of the contracted section. Further examination of the data shows that while the bed material averages about 10 percent coarser than 0.50 millimeter, the suspended material near the bottom of the contracted section averages about 20 percent coarser than 0.50 millimeter. The implication is that the turbulence in the contracted section for this normal flow is sufficient to suspend all particle sizes in the bed.

The conclusion that the material in suspension near the bottom of the contracted section is coarser than the bed material at the normal sections upstream merits further discussion. The turbulence in the natural flume has a sorting influence on the bed load that is forced into suspension. Only the very coarsest material of the bed load will continue to move near the bottom exclusively. Thus it is possible to obtain point-integrated suspended-load samples near the bottom of the contracted section that show a coarser size distribution than the bed material at the normal section.

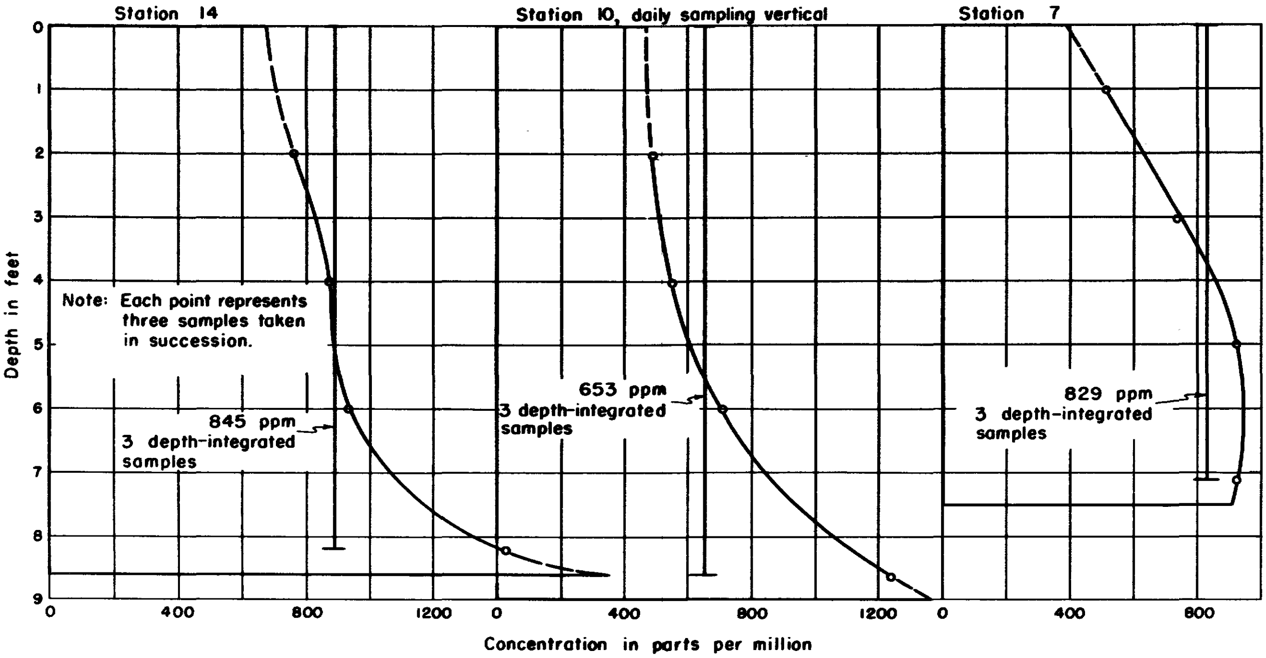


Figure 8.--Sediment concentration profiles at the contracted section on September 8, 1948. Water discharge 229 second-feet.

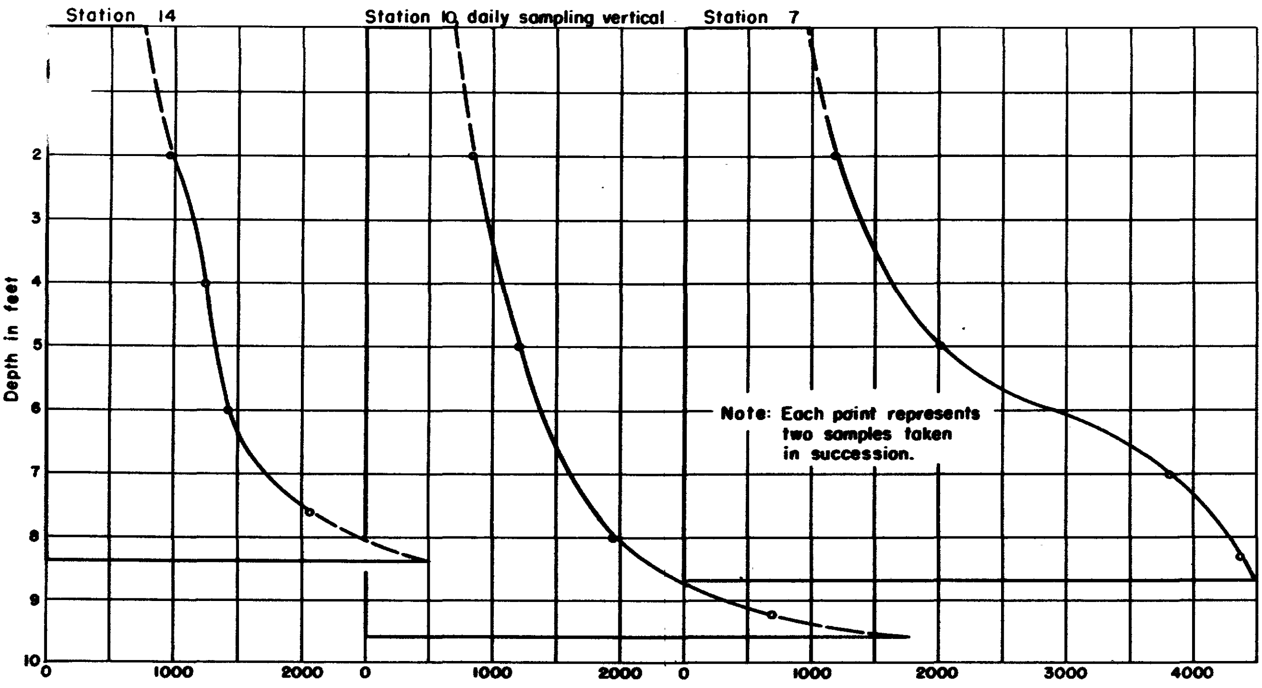


Figure 9.--Sediment concentration profiles at the contracted section on October 13, 1948. Water discharge 258 second-feet.

Comparison and Analysis

The mean size curve of the bed-material analyses was compared with the mean curves for the suspended material sampled at the same time (fig. 20). The ratio of suspended concentration at the normal section to that at the contracted section on October 13 was 0.41 (table 2). Assuming the bed material samples analyzed represent the bed-load size, the size distribution for the material in the contracted section should be obtained by combining the size percentages as follows:

$$P_{cs} = 0.41\ P_{ns} + 0.59\ P_{bm}$$

where P_{cs} = Percentage finer than a certain size at the contracted section.

P_{ns} = Same at the normal section.

P_{bm} = Same for the bed material.

The general agreement of the points thus determined (fig. 20) with the actual mean size in the contracted section indicates that the bed material samples taken actually represent the bed-load size.

Since the bed material samples were taken to a depth of about 4 inches, this bed-load size should be essentially constant for this flow. The size curve for the bed load should combine with other suspended-load size curves to yield the corresponding size distribution in the contracted section. For September 8, the combining ratio (table 2) should be:

$$P_{cs} = 0.50\ P_{ns} + 0.50\ P_{bm}$$

an similarly for the other determinations. Figures 19 to 21 show a general agreement of the computed size distribution with the actual size analyses.

In figure 18 the actual size analysis was considerably coarser than the computed size distribution. On this date, however, the stream discharge was 452 second-feet as compared with 229, 258, and 308 second-feet for the other three comprehensive measurements. At 308 second-feet (fig. 21) the coarser half of the actual size analysis was also considerably coarser than the computed size distribution. It has already been shown (table 4) that the mean particle size in the contracted section increased generally throughout the depth for the increasing discharges. This indicates that at higher discharges the bed scours to some depth, in some places, where coarser material is entrained. Bed material samples will be taken at various discharges to establish this relation.

BED LOAD AT THE NORMAL AND CONTRACTED SECTIONS

In this report the bed load is defined as the difference between the total load transported and the suspended load measured at the normal section. The depth-integrating samplers used (D-43 and DH-48) sample no closer to the bed than about 0.3 foot. The nozzle of the P-46 point-integrating sampler approaches no closer to the bed than about 0.4 foot. More exact determinations of these figures are not justified since the samplers generally penetrate soft beds several hundreths of a foot.

Before the bed load can be discussed in this report, the question of possible sediment movement as bed load through the contracted section must be considered. The following evidence may indicate considerable bed load in the flume:

1. Both sediment concentration (figs. 8-10) and particle size (figs. 12-17) increase considerably toward the bed.

2. Resident observers at this station report that deposition takes place in the contracted section during extreme low flows.

Neither of these points is conclusive. As pointed out before, the concentration and particle size gradient in the vertical may still be greater than that required for turbulence-settling equilibrium for the size range of the total load. Deposition at extreme low flows is probably irrelevant to the question of normal bed load.

Considerable evidence indicates that the bed load in the contracted section is very small. First, since the material in suspension near the bottom of the contracted section was found to be coarser than the bed material at the normal section upstream, the turbulence in the contracted section for this flow must be sufficient to suspend all particle sizes in the bed. Second, the attempt to compute the size distribution in the contracted section by combining the bed-material size curve and suspended load size curve in the ratio of the mean concentrations at the two sections was generally successful (figs. 19 to 21). The major discrepancies (figs. 18 and 21) were on the fine side of the actual analyses, not the coarse side as would follow if the total load were not being sampled in the contracted section.

Since available data indicate a negligible bed load in the contracted section, the assumption of essentially no bed load at this section appears justified. Thus the mean ratio of the sediment concentration at the normal section to that at the contracted section, C_{ns}/C_{cs}, represents the mean ratio of suspended sediment load to total sediment load, assuming no appreciable increase in water discharge in the quarter-mile reach. The mean ratio of normal section concentration to contracted section concentration, C_{ns}/C_{cs}, is 0.51 for 34 determinations. Thus approximately 50 percent of the total sediment load is transported in suspension at the normal section, or, conversely, 50 percent is transported as bed load.

CONCLUSIONS

1. The plot of suspended sediment discharge against water discharge (fig. 6) reveals a general correlation at both normal and contracted sections.

2. The suspended sediment concentration profiles in the contracted section show that the concentration at the bottom is from 1½ to 5 times the concentration at the surface.

3. The mean particle size in suspension at the normal section was 0.14 millimeter; in the bed, 0.25 millimeter; and in suspension at the contracted section, 0.20 millimeter.

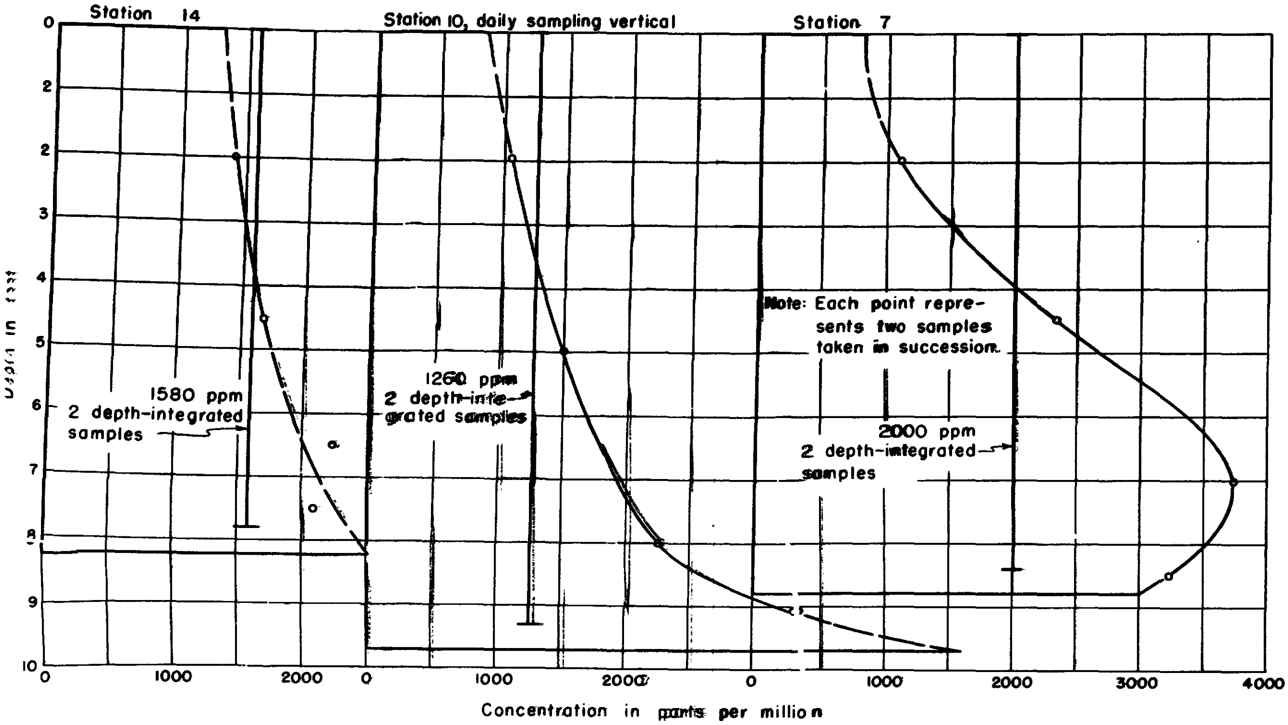


Figure 10.--Sediment concentration profiles at the contracted section on November 3, 1948. Water discharge 308 second-feet.

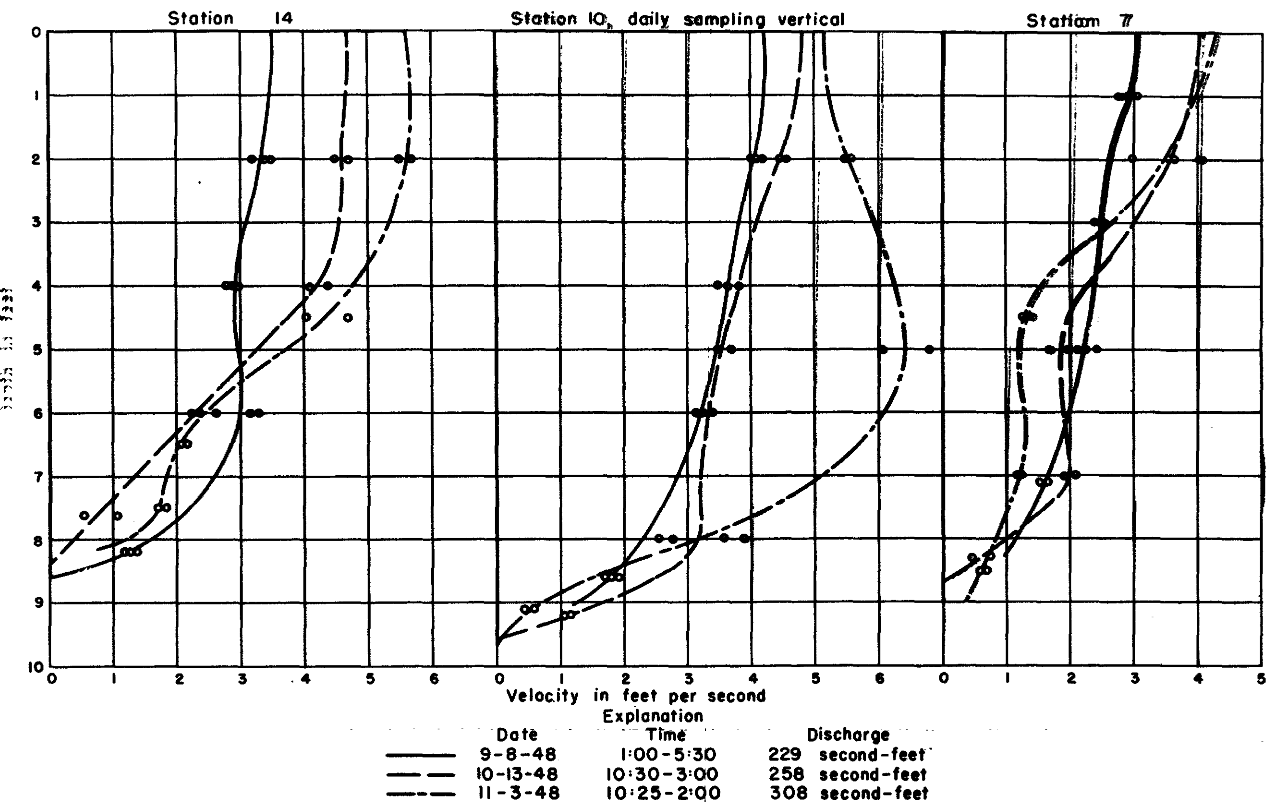


Figure 11.--Velocity profiles at the contracted section.

4. The material in suspension near the bottom of the natural contracted section was found to be coarser than the bed material at the normal section upstream, indicating that the turbulence in the contracted section was sufficient to suspend all particle sizes in the bed.

5. A combination of the bed and suspended material particle size curves at the normal section in the ratio of the suspended concentrations at the two sections yielded a particle size curve which closely approximated the actual size distribution of the suspended material in the contracted section, in three of four comparisons.

6. In view of these data it is reasonable to assume that practically all of the sediment load passes through the contracted section in suspension.

7. Approximately 50 percent of the sediment discharge of the Niobrara River near Cody, Nebraska, as determined from daily suspended sediment samples taken in the natural contracted section, is transported as bed load at the normal cross section one-quarter mile upstream. This percentage varied from 24 to 68 for the 34 determinations available, without significant correlation with water or sediment discharge.

8. The normal sediment load in this reach is essentially bed material. All particle sizes found in suspension are present in the bed material. The mean particle size of the suspended load increases with water discharge.

9. The results of this preliminary study indicate that the investigation on the Niobrara River near Cody, Nebraska, should be expanded to include the collection of all data necessary to check existing equations and analytical procedures applied to the transportation of fluvial sediments. The additional data should include water surface slopes, water temperatures, and surveys of the stream channel.

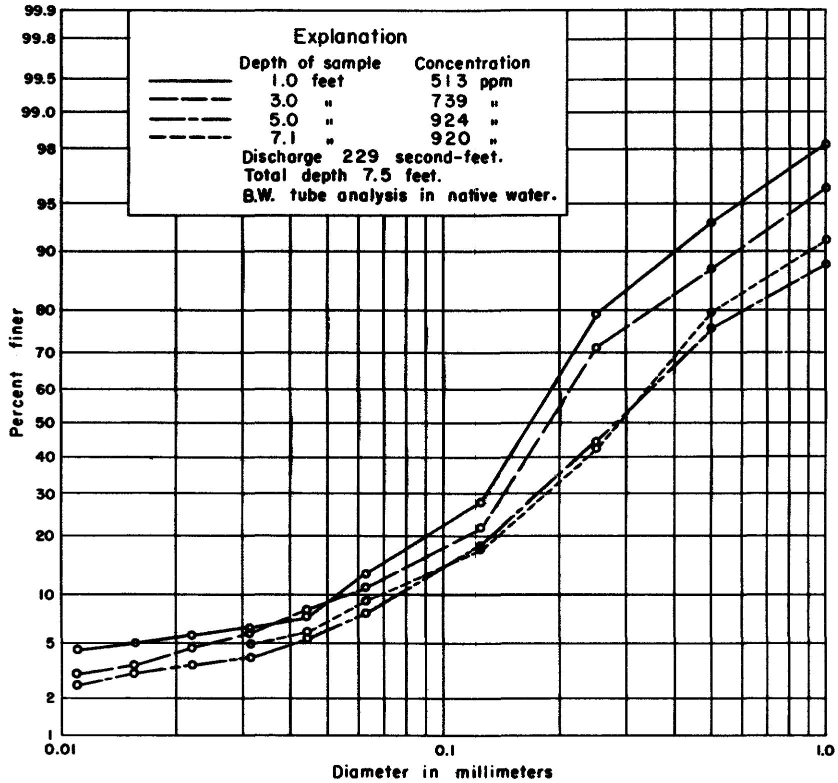


Figure 12.--Particle size analyses of point-integrated samples from station 7 in the contracted section on September 8, 1948.

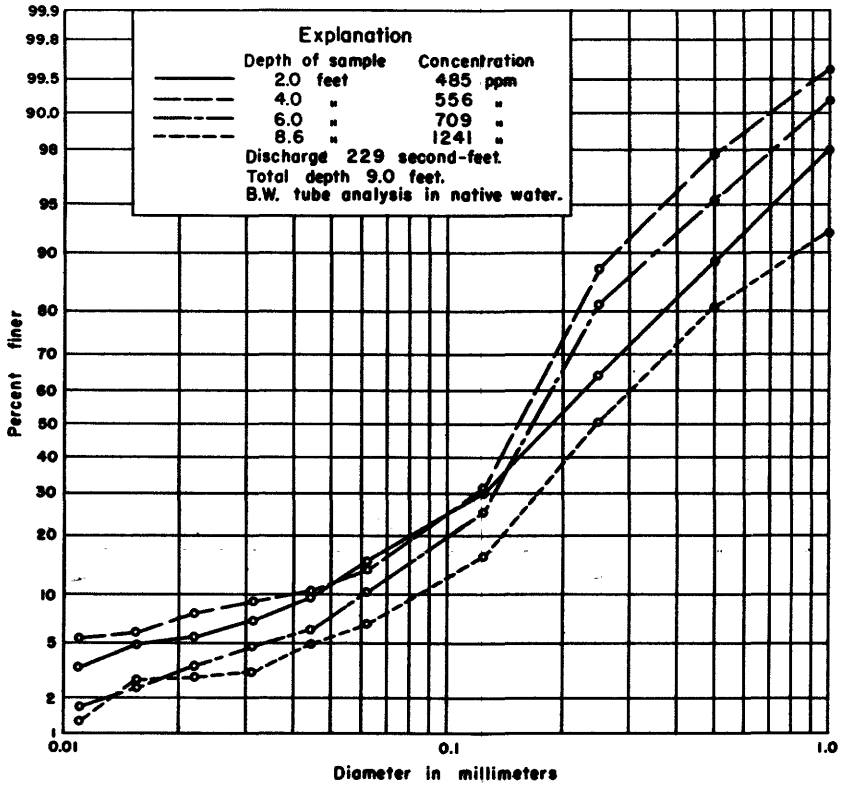


Figure 13.--Particle size analyses of point-integrated samples from station 10 in the contracted section on September 8, 1948.

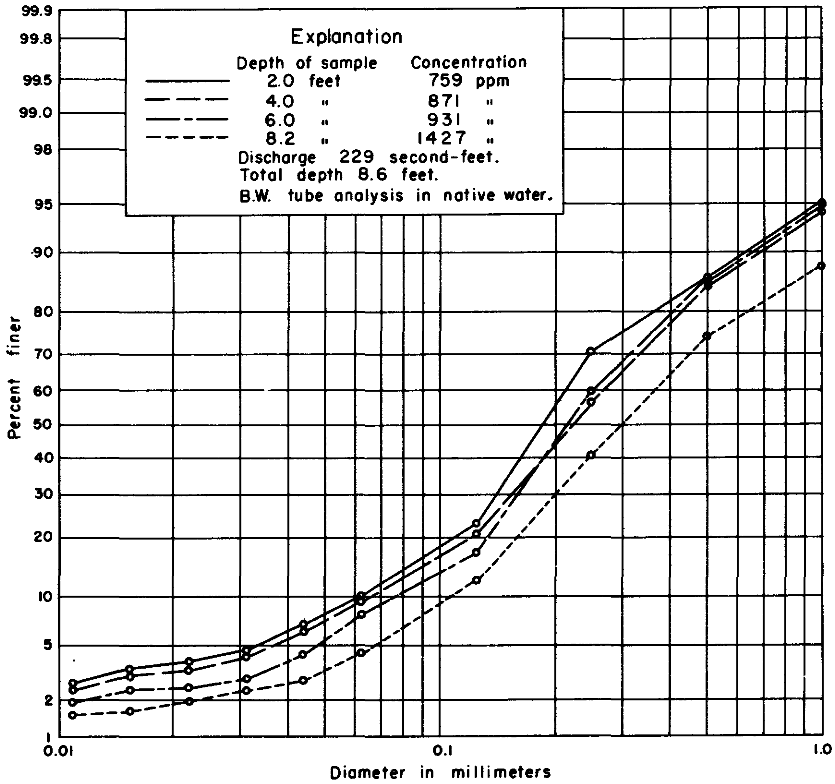


Figure 14.--Particle size analyses of point-integrated samples from station 14 in the contracted section on September 8, 1948.

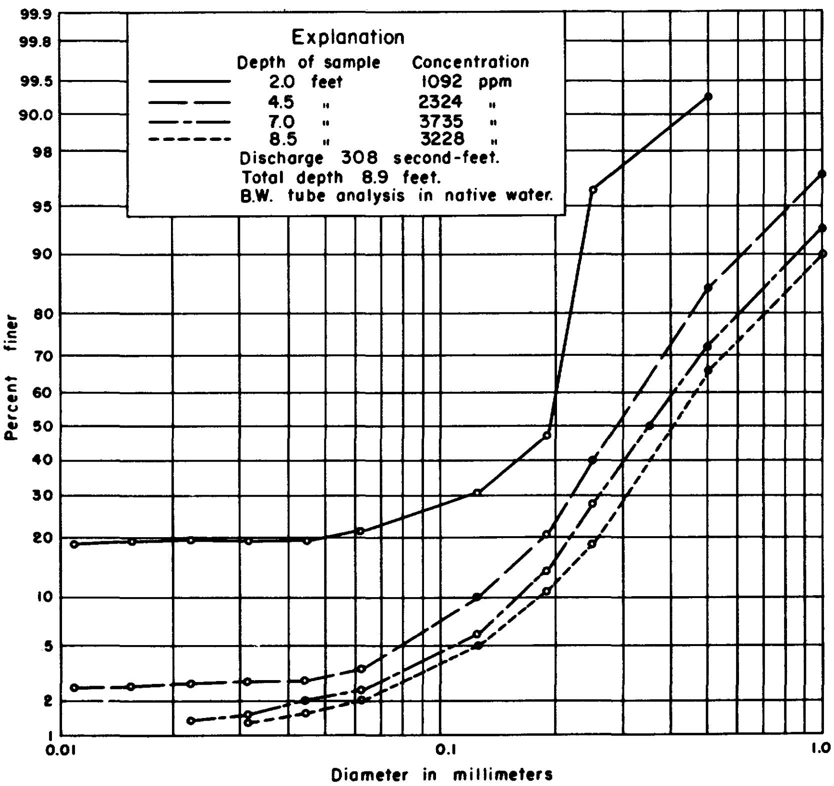


Figure 15.--Particle size analyses of point-integrated samples from station 7 in the contracted section on November 3, 1948.

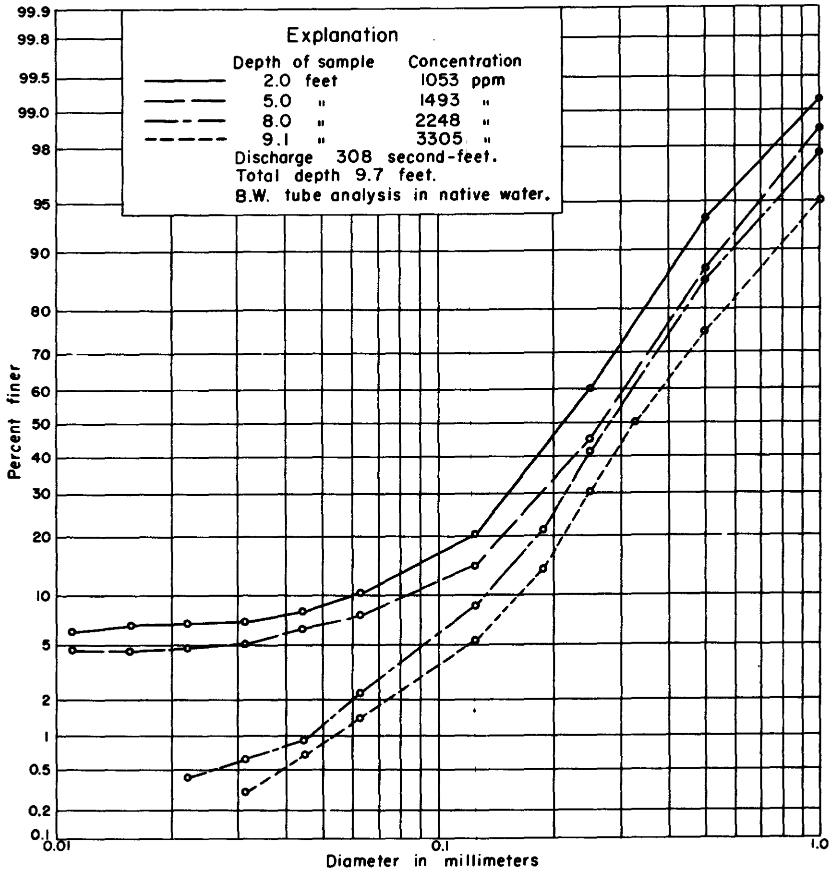


Figure 16.--Particle size analyses of point-integrated samples from station 10 in the contracted section on November 3, 1948.

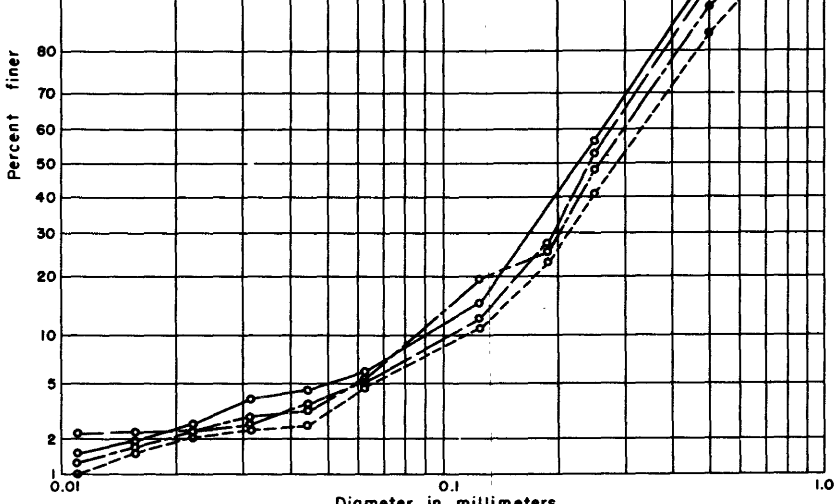


Figure 17.-- Particle size analyses of point-integrated samples from station 14 in the contracted section on November 3, 1948.

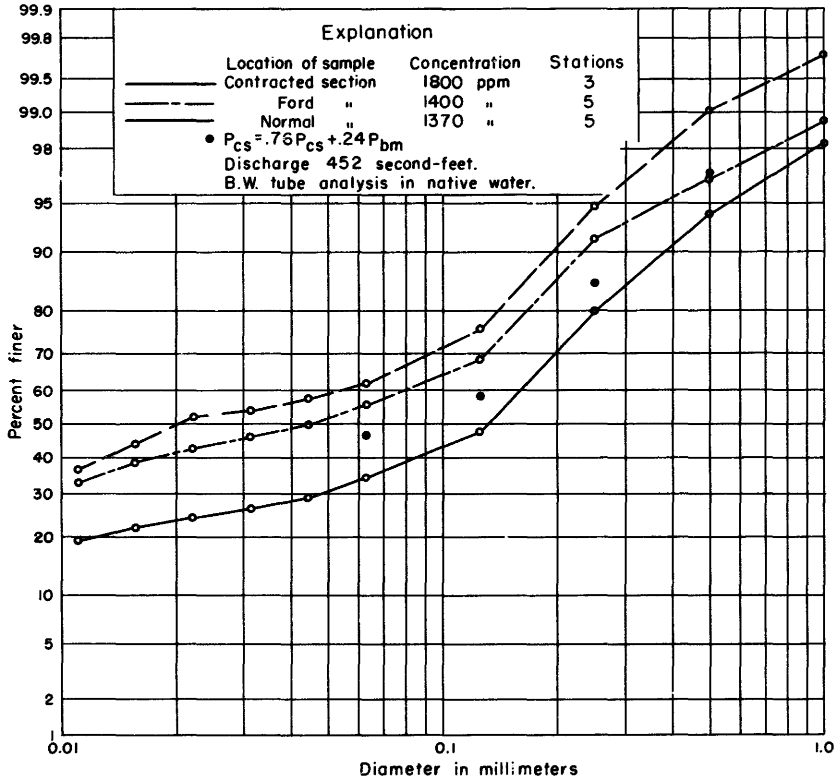


Figure 18.--Mean particle size analyses of depth-integrated samples from the normal, contracted, and ford sections on July 20, 1948.

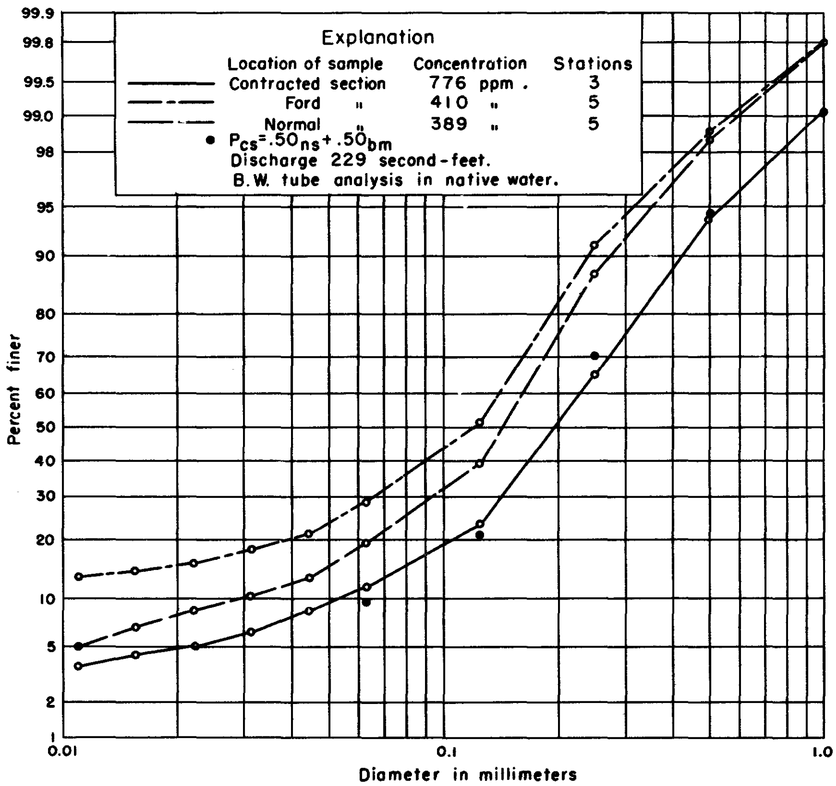


Figure 19.-- Mean particle size analyses of depth-integrated samples from the normal, contracted, and ford sections on November 8, 1948.

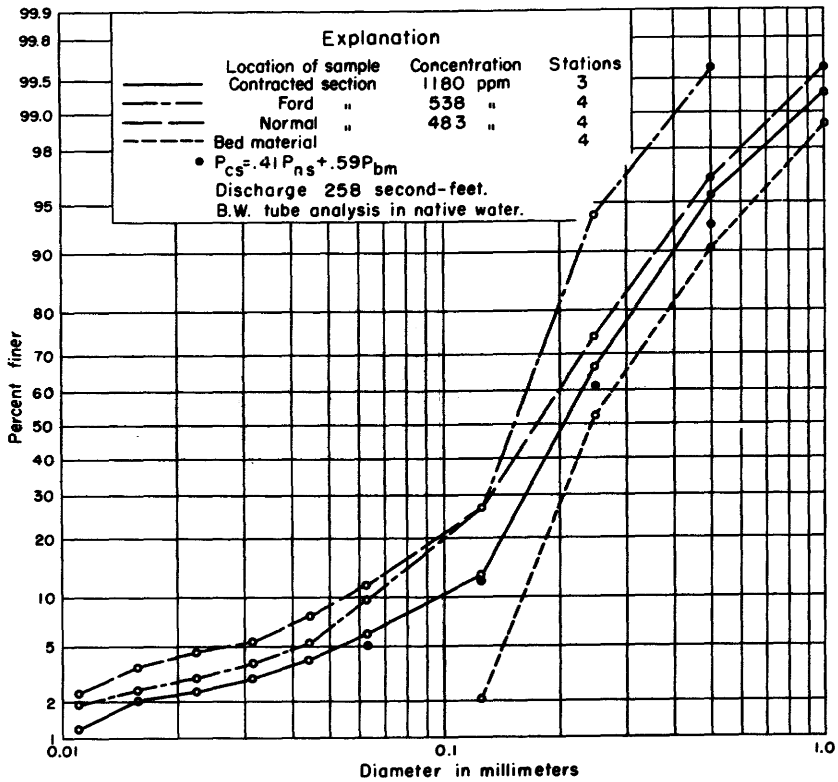


Figure 20.--Mean particle size analyses of depth-integrated samples from the normal, contracted, and ford sections on October 13, 1948, and of the stream bed material.

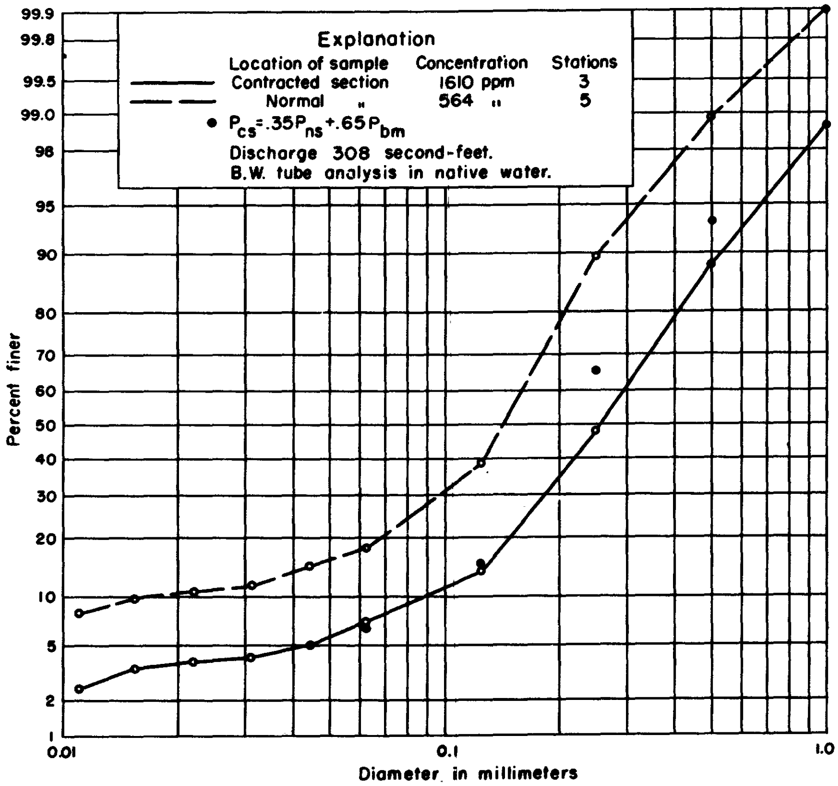


Figure 21.--Mean particle size analyses of depth-integrated samples from the normal and contracted sections on November 3, 1948.

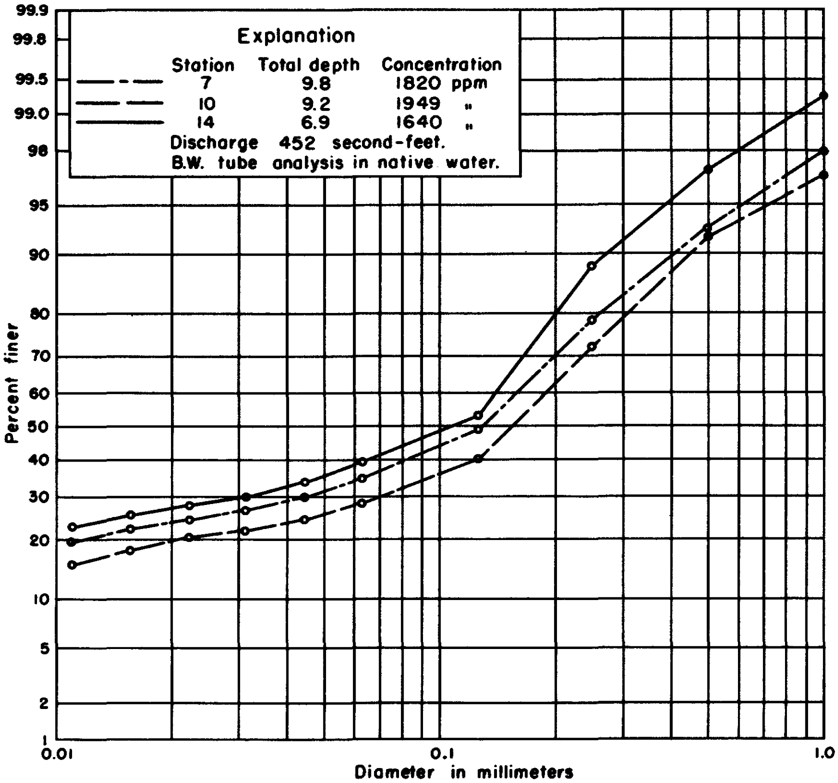


Figure 22.--Particle size analyses of depth-integrated samples from the contracted section on July 20, 1948.

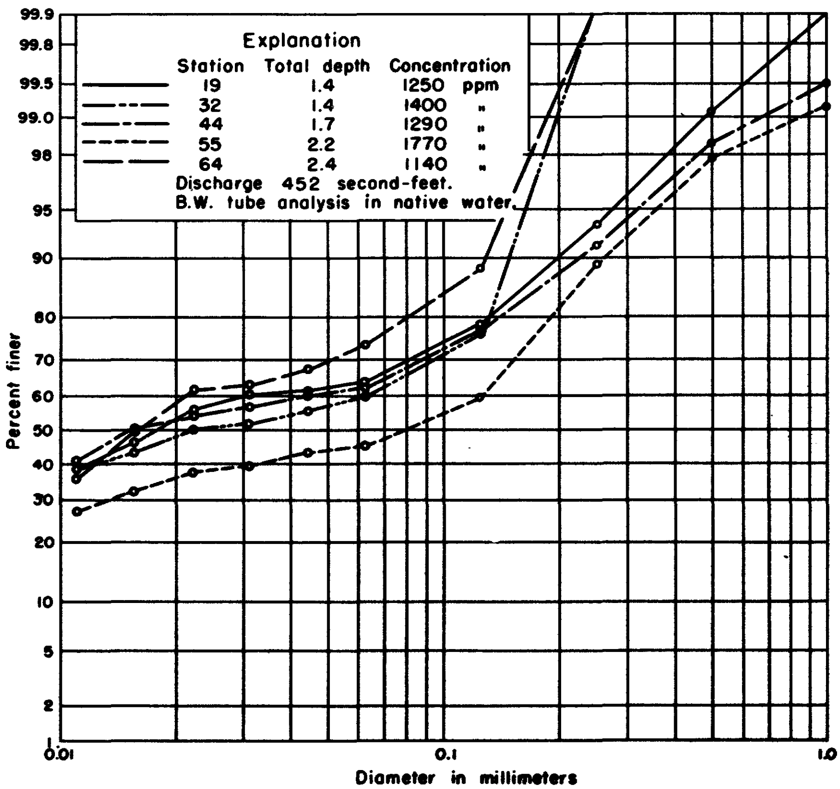


Figure 23.--Particle size analyses of depth-integrated samples from the normal section on July 20, 1948.

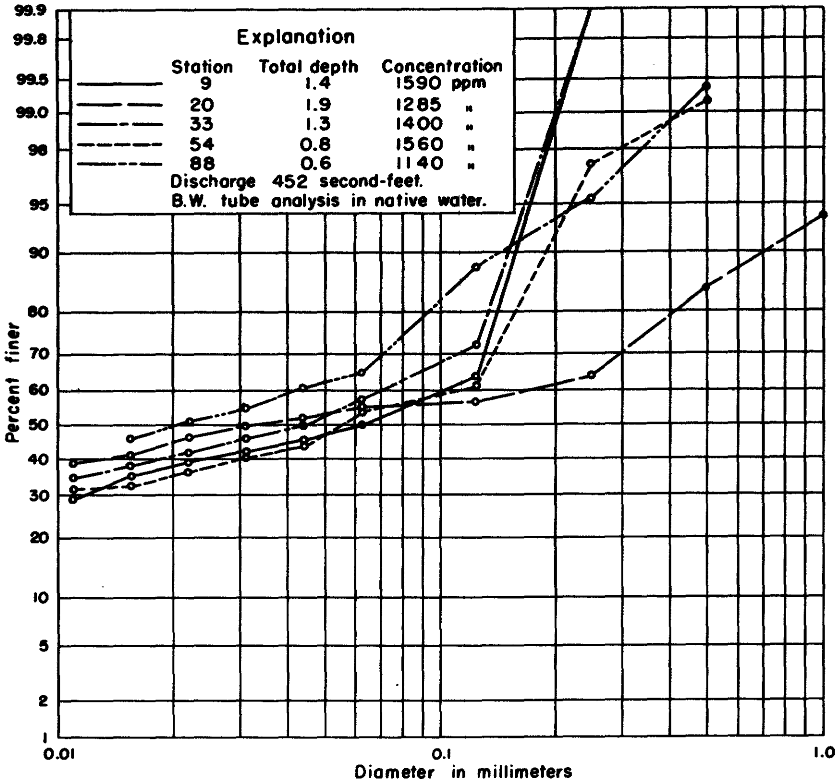


Figure 24.--Particle size analyses of depth-integrated samples from the ford section on July 20, 1948.

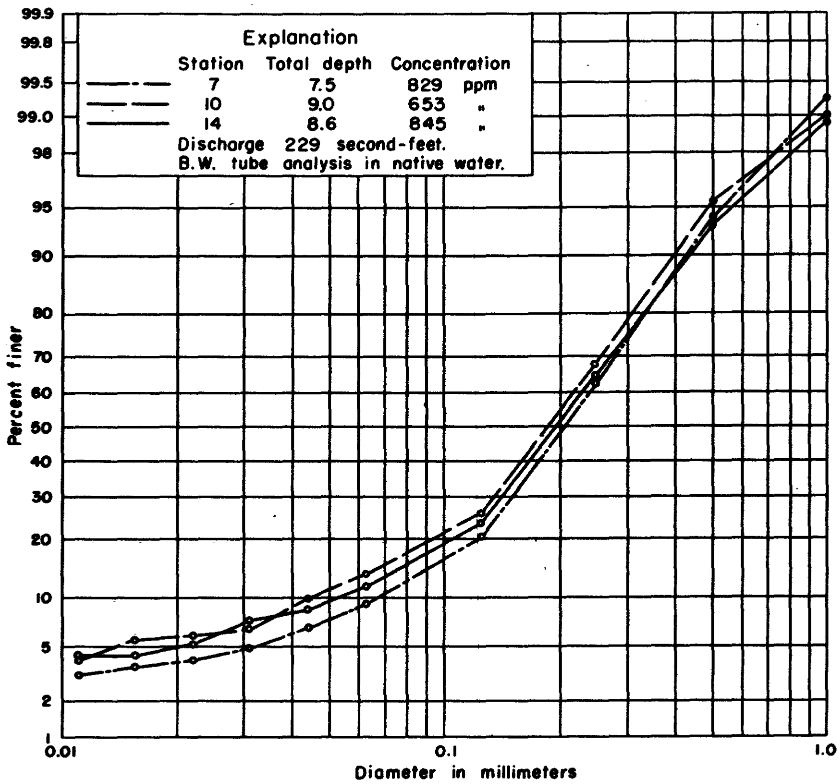


Figure 25.--Particle size analyses of depth-integrated samples from the contracted section on September 8, 1948.

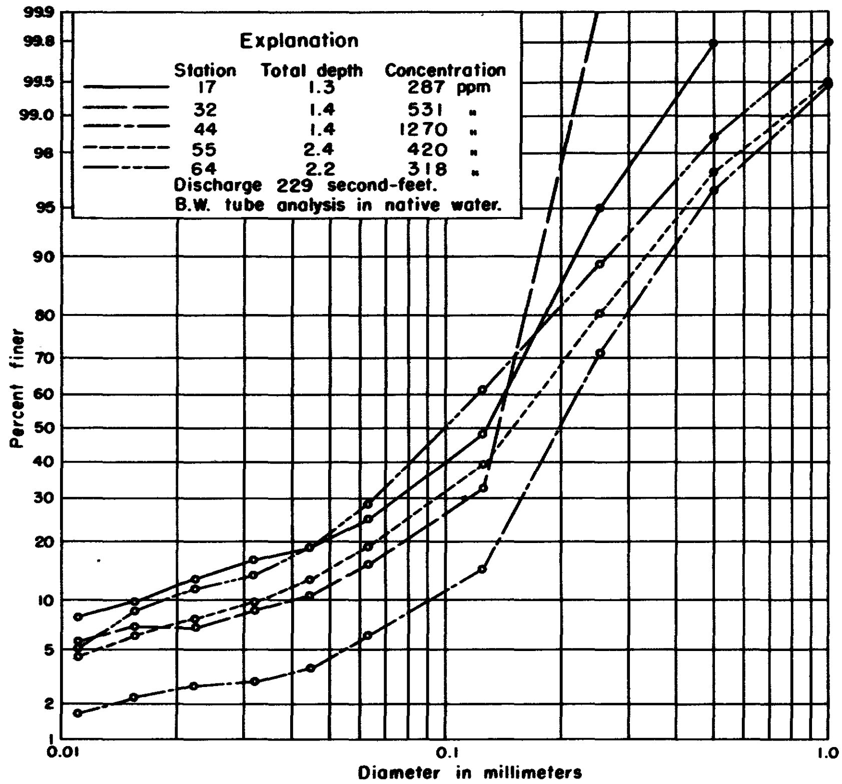


Figure 26.--Particle size analyses of depth-integrated samples from the normal section on September 8, 1948.

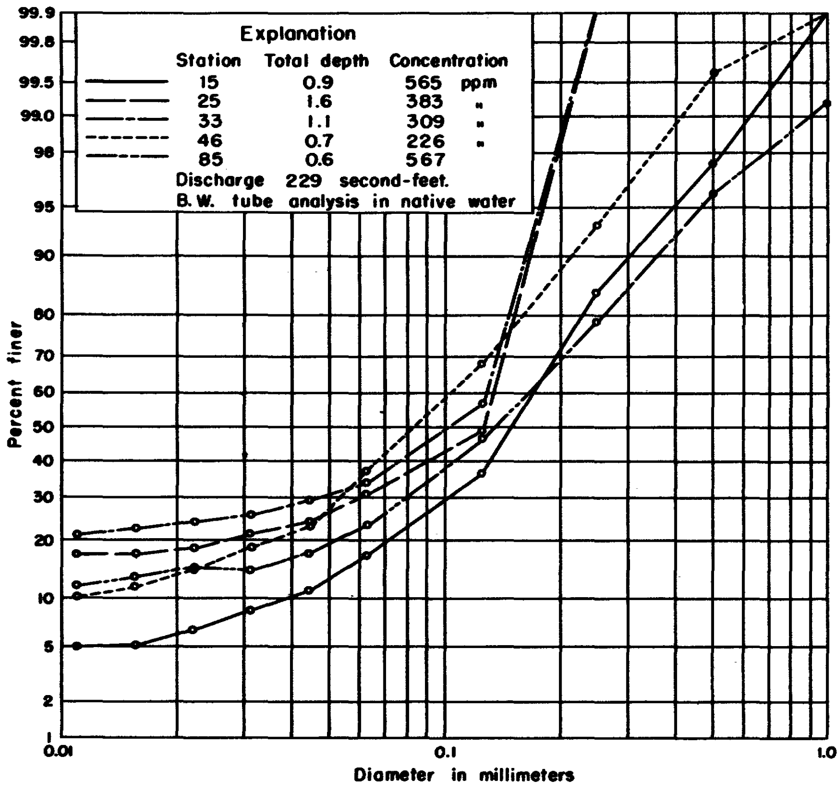


Figure 27.--Particle size analyses of depth-integrated samples from the ford section on September 8, 1948.

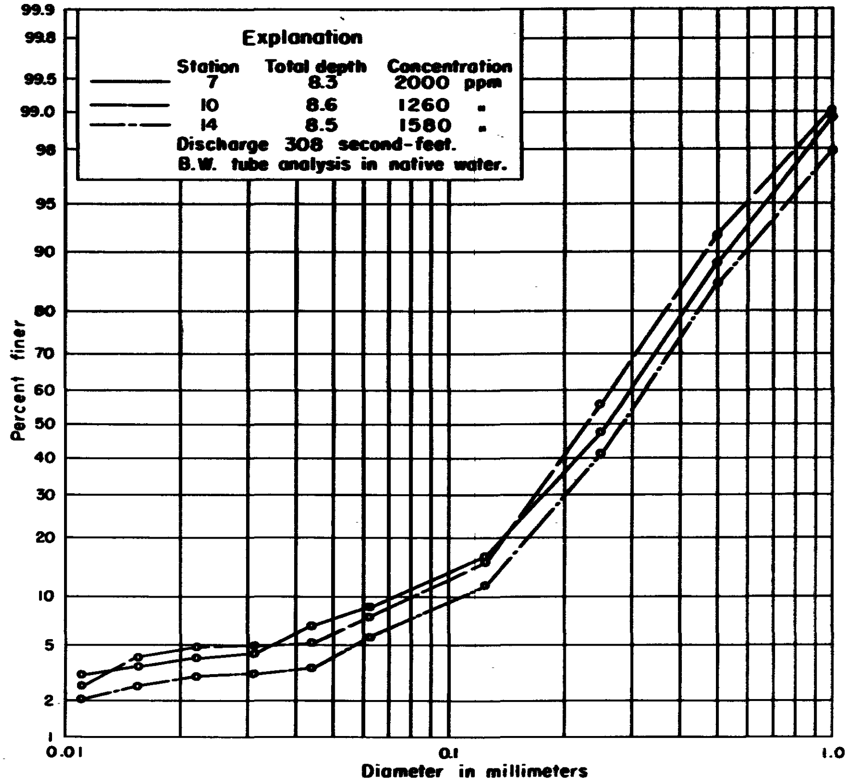


Figure 28.--Particle size analyses of depth-integrated samples from the contracted section on November 3, 1948.

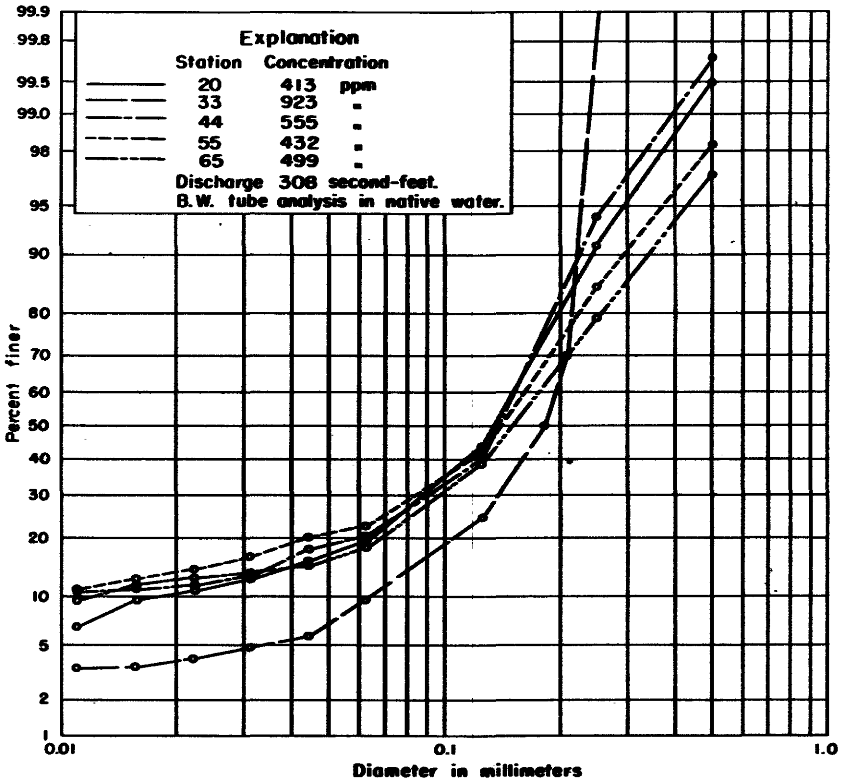


Figure 29.--Particle size analyses of depth-integrated samples from the normal section on November 3, 1948.

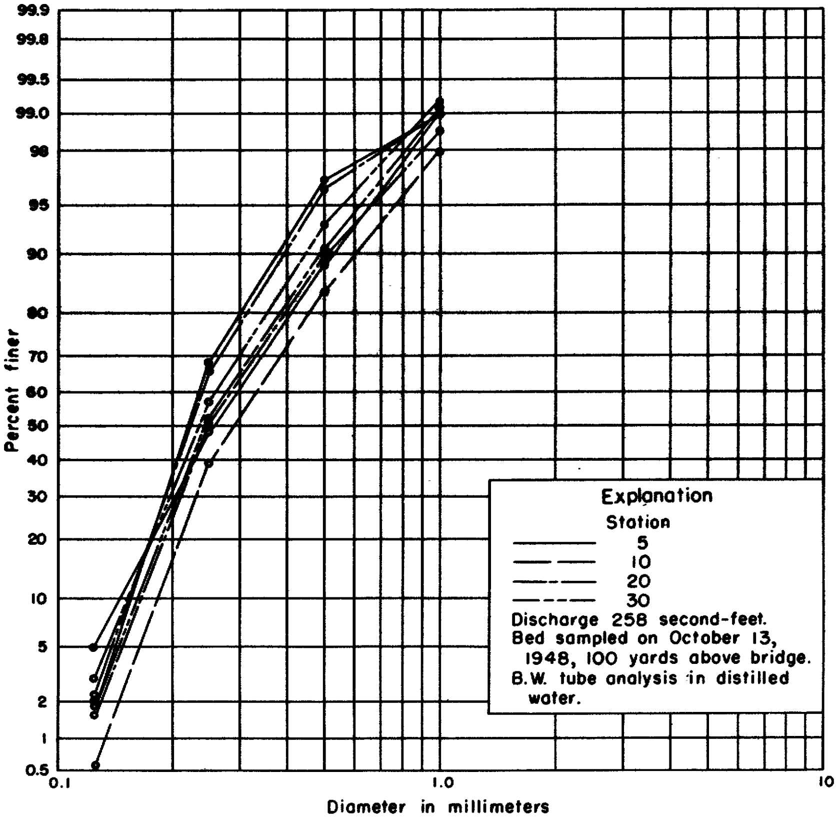


Figure 30.--Bottom-withdrawal tube analyses of bed material samples.

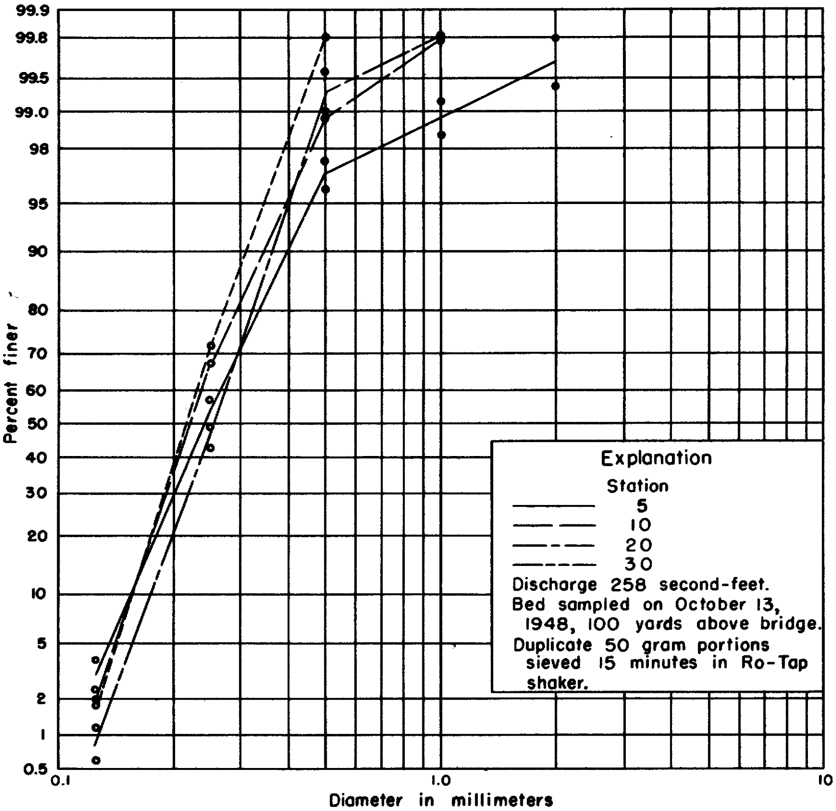


Figure 31.--Sieve analyses of bed material samples.