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The 1963-64 Lake Mead Survey

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Bureau of Reclamation

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THE 1963-64 LAKE MEAD SURVEY

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and
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Region 3
Bureau of Reclamation

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16. ABSTRACT

The 1963-64 Lake Mead survey was run to compute the reservoir capacity. Results of the geodetic and hydrographic surveys and sediment sampling equipment are described. The geodetic survey showed Hoover Dam subsided an average of 118 mm since 1935. Sonic sounding, photogrammetry, and cross-sectional profiling methods were used to run the hydrographic survey. Reservoir area and capacity tables were generated using an electronic computer. The present lake capacity is 29,755,000 acre-ft and the reservoir surface area is 162,700 acres at elevation 1229 ft. 2,720,000 acre-ft of sediments accumulated in the lake since 1935. A unit weight of 60 lb/cu ft was determined representative of the deposited sediments. Samples were collected from the major basins with a piston core sampler. A gamma probe was used to measure in situ wet bulk densities. Special sampling with a drill rig was conducted in Pierce Basin representing the sediment accumulation in the delta area. The reservoir trap efficiency is judged to be 100%.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS-- / *reservoir surveys/ *reservoir silting/ aggradation/ core drilling/ *geodetic surveys/ first order surveys/ land subsidence/ *gamma rays/ rebound/ *hydrographic surveys/ sounding/ photogrammetry/ thalweg/ topographic mapping/ *sedimentation/ fluvial hydraulics/ unit weight/ sediment transport/ sediment sampling/ *physical properties/ watersheds (basins)/ trap efficiency

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THE 1963-64 LAKE MEAD STUDY

by

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August 1970

Division of Project Investigations
Office of Chief Engineer
Denver, Colorado

and

Division of Water and Land Operations
Region 3 Office
Boulder City, Nevada

UNITED STATES DEPARTMENT OF THE INTERIOR * BUREAU OF RECLAMATION
Ellis L. Armstrong
Commissioner

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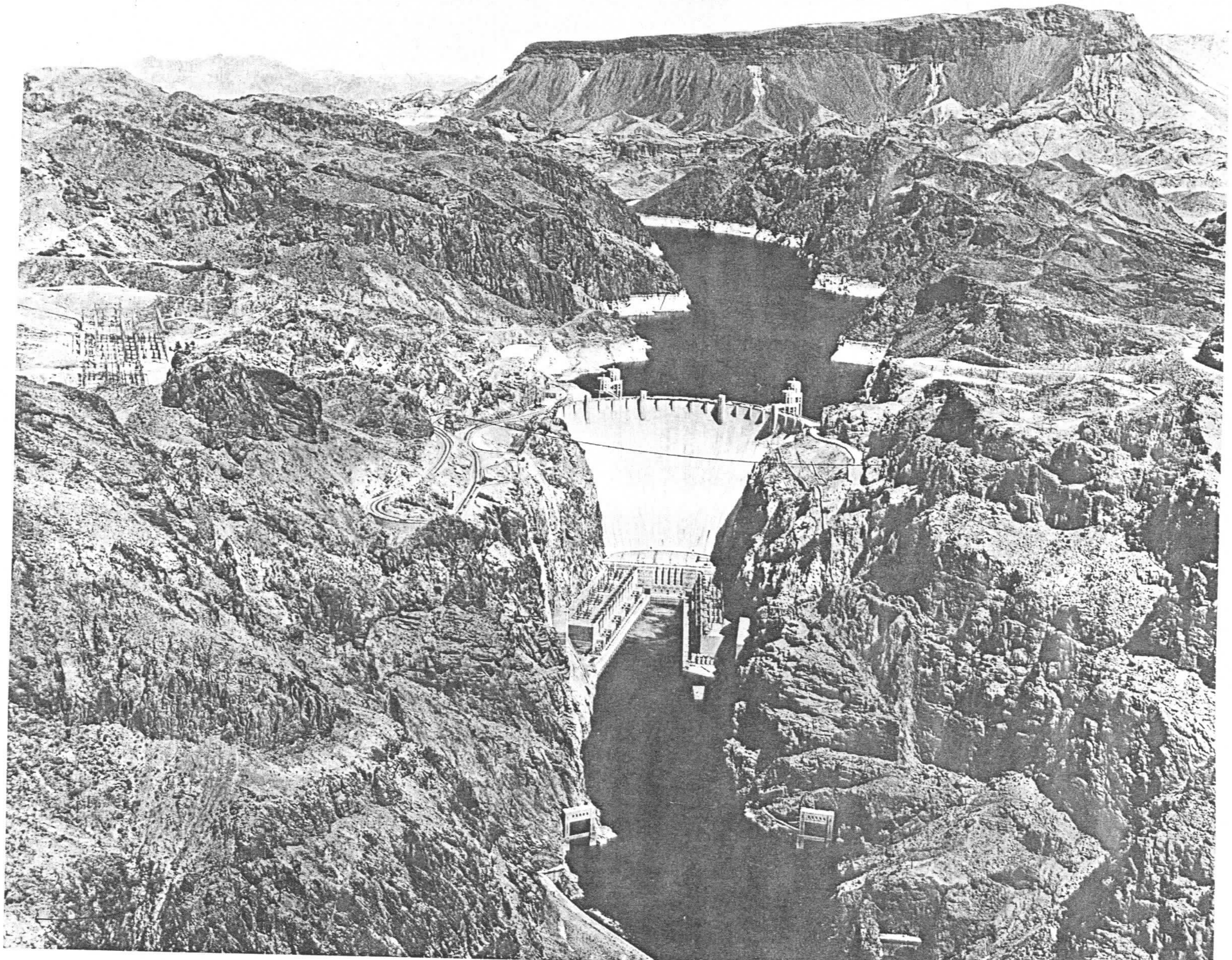


PART 1—FOREWORD

Lake Mead is a reservoir that was formed by the construction of Hoover Dam in 1935. The dam is located 30 miles east of Las Vegas, Nevada, in Black Canyon of the Colorado River. The original capacity of Lake Mead was 32,471,000 acre-feet at elevation 1229 feet. The 1948-49 survey of Lake Mead was prompted by the need to know the reduction in capacity because of sediment accumulation. In 1963, Glen Canyon Dam on the Colorado River, 370 miles upstream from Hoover Dam, was closed. The 1963-64 survey of Lake Mead was made to update the capacity of the reservoir at the time of the closure of Glen Canyon Dam.

Results of the 1963-64 survey are analyzed in this report to investigate environmental factors and to study the sedimentation features. The geodetic and hydrographic surveys are described. A discussion is included on the physical characteristics of the deposited reservoir sediments and on the instruments and field techniques used.

Graphs, maps, tables, and photographs are extensively used to document the information and analyses made of the field measurements and field data collected during the survey.

Standard land surveying methods combined with the photogrammetric and special hydrographic surveys were used to map the reservoir topography.

Lake level areas delineated at 10-foot vertical intervals from the topography were planimetered and used to compute the reservoir capacity. First order levels were rerun over an established geodetic base network totaling 340 miles. Funds were not available for field crews to complete all the original network lines.

Special instruments and apparatus were used to sample or obtain physical samples of the sediments deposited at various locations in the reservoir. Drilling equipment was needed for a special test site located in the delta area of Pierce Basin. Personnel and equipment had to be transported by helicopter to this test site.

The Colorado River Basin and the location of Hoover Dam and Lake Mead are shown on the map in Figure 1-1. The renown of Hoover Dam was highlighted in 1955 when it was selected as one of the seven engineering wonders in the United States by the American Society of Civil Engineers.[1-1] The Lake Mead area was originally mapped in 1935 by the Soil Conservation Service before the dam was completed. Topographic maps of the area were prepared with a 1:12,000 scale for each 5-minute quadrangle of latitude and longitude (Figure 3-1).

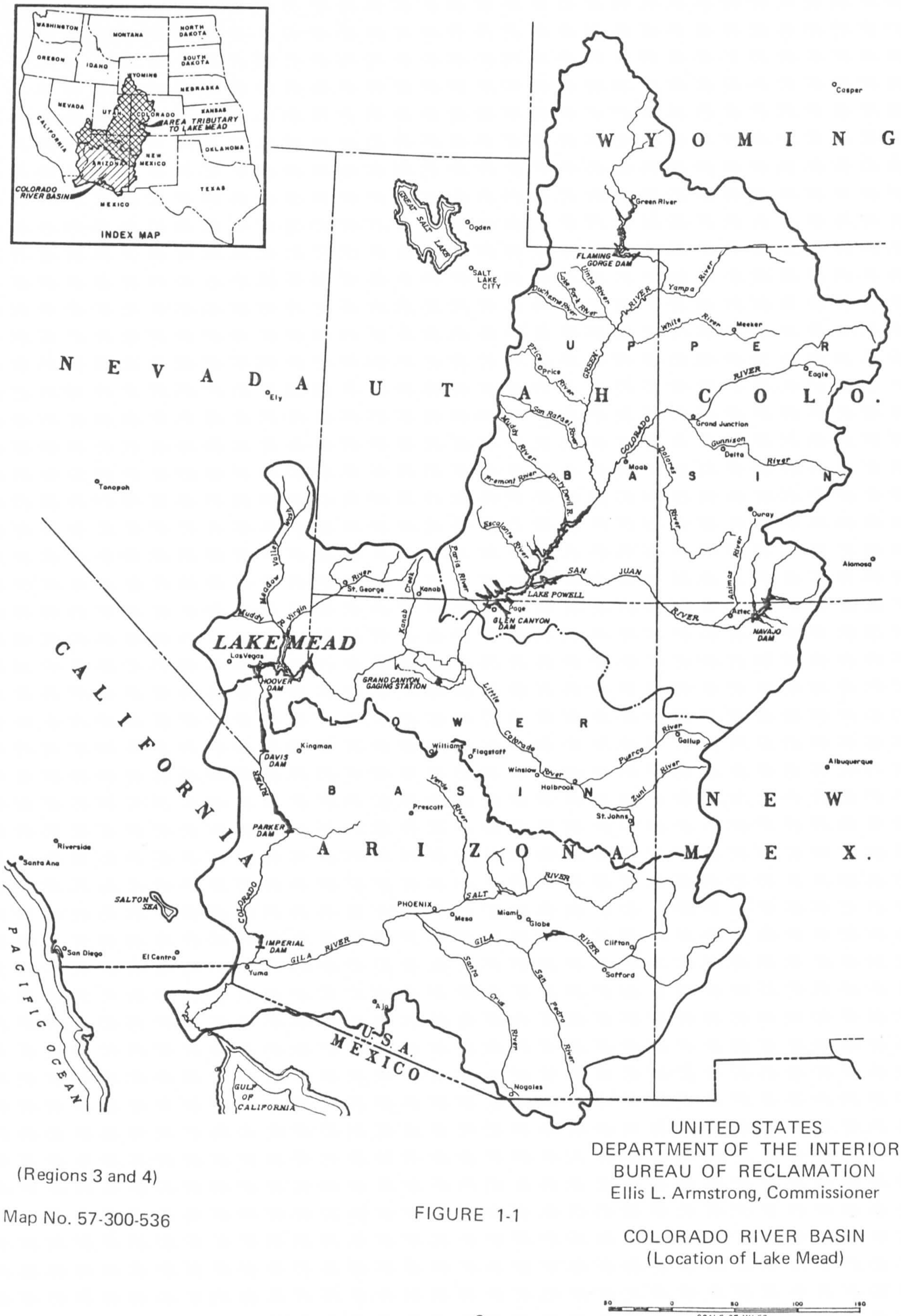
When Hoover Dam was closed in 1936, about 3,223,000 acre-feet of dead storage was available in the space below elevation 895 feet. Although the U.S. Geological Survey had measured the suspended sediment loads of the Colorado River near Grand Canyon above Lake Mead since 1926, the actual amount of the sediment accumulation in the lake was unknown. The quantity and distribution of these sediments became a major concern related to the reservoir operation and storage loss; consequently, a project was organized after the second world war to resurvey the lake to determine the reservoir capacity at that time. The 1948-49 sediment survey resulted from these efforts and two reports on Lake Mead, comprehensively describing the lake and its environs, were published to document this survey. The first was issued in three volumes[1-2] and the other was published as a single report[1-3].

Subsequent to the 1948-49 survey, Bureau of Reclamation engineers concluded that Lake Mead should be resurveyed to coincide, in time, approximately with the closure of Glen Canyon Dam located about 370 miles above Hoover Dam. A comparison could then be made of the rate, composition, and location of sediment accumulations in Lake Mead before and after the Glen Canyon Dam closure. After considering several proposals from hydrographic firms, a cooperative agreement was reached in June 1963, between the Departments of the Interior and Commerce to have the Coast and Geodetic Survey run the survey of Lake Mead. Requirements of the survey were established in the agreement which included that it would be run similar to the one in 1948-49. The main requirement was to obtain sufficiently detailed and accurate data for the reservoir below elevation 1229 feet, from which computations of the current lake area and capacity could be made at 10-foot vertical intervals throughout its depth. The 1963-64 survey was run to accomplish this purpose.

[1-1] Finch, J. Kip, "Seven Modern Civil Engineering Wonders in U.S. Named," *Civil Engineering,* Vol. 25, No. 11, pp 33-45, Nov. 1955.

[1-2] U.S. Department of the Interior, "Lake Mead Comprehensive Survey of 1948-49," Report, Vols. I, II, and III, Feb. 1954.

[1-3] Geological Survey, "Comprehensive Survey of Sedimentation in Lake Mead, 1948-49," Professional Paper 295, 254 p, 1960.



(Regions 3 and 4)

Map No. 57-300-536

FIGURE 1-1

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
Ellis L. Armstrong, Commissioner

COLORADO RIVER BASIN
(Location of Lake Mead)

ACKNOWLEDGEMENTS

Arrangements for the survey and coordination with the Office of Chief Engineer, Denver, Colorado, were made by John S. McEwan, Chief, Channel Control Branch under the supervision of Paul A. Oliver, River Control Engineer, Lower Colorado River Control Office, Boulder City, Nevada.

Preparation of this report was under the joint supervision of Joe M. Lara, Hydraulic Engineer, Division of Project Investigations, Office of Chief Engineer, Denver, Colorado, and John I. Sanders, Supervisory Hydraulic Engineer, Water Scheduling Branch, Division of Water and Land Operations, Boulder City, Nevada, under the supervision of B. P. Bellport, Chief Engineer, and A. B. West, Regional Director.

Mr. Alan C. Doyle, Geologist, Water Scheduling Branch, Division of Water and Land Operations, Boulder City, Nevada, prepared the portion of the report on "Analysis of Releveling Data" and gave detailed assistance on all portions of the report prepared by the Boulder City, Nevada Office.

Mr. Dale P. Weskamp, Geologist, Geology Branch, Division of Project Development, Boulder City, Nevada, wrote the section on "Review of Structural Geology" and made helpful suggestions on other portions of the report concerning geology.

Personnel of the U.S. Coast and Geodetic Survey ran the hydrographic survey. The Chiefs of Party were:

- Mr. Clarence Symns, Chief, Geodetic Level Party
- Mr. P. A. Stark, Comdr., and Mr. H. E. McCall, Lt., Chiefs, Hydrographic Field Party 219
- Mr. James H. Blumer, Lt., Chief, Photographic Party 6423

Parts of the "Descriptive Reports" (mentioned on page 44) prepared by the field parties of the U.S. Coast and Geodetic Survey were quoted verbatim in the report because it was not practical to contact personnel who prepared the original reports for more detailed descriptions.

Mrs. Hortense G. Bagni, Engineering Technician, under the supervision of C. O. Wamstad, Chief, Design Branch, Boulder City, Nevada, was responsible for the detailed planimetering of the reservoir sheets, provided by the U.S. Coast and Geodetic Survey and the Soil Conservation Service 5-minute quadrangle sheets requiring planimetric work.

Messrs. Whitney M. Borland and Ernest L. Pemberton, Chief and Assistant Chief, Sedimentation Branch, respectively, Office of Chief Engineer reviewed this report in great depth. Both offered helpful advice and suggestions in preparing it for final publication.

Mr. Thomas D. Murphy, Hydraulic Engineer, formerly of Division of Project Investigations, Office of Chief Engineer, Denver, Colorado, was responsible for the collection of the sediment samples. He was also responsible for drafting a preliminary outline guide and partial writeup of the report.

Personnel of the various laboratories in the Division of Research, Office of Chief Engineer, Denver, Colorado, ran the sediment, mineralogical, and chemical tests of the collected sediment samples.

Personnel of the Division of Data Processing, Office of Chief Engineer, Denver, Colorado, ran the computations and generated the area and capacity tables using the electronic computer.

Many others of both the Office of Chief Engineer, Denver, Colorado, and the Regional Office, Boulder City, Nevada, gave valuable assistance and advice in completing the survey and during the preparation of this report.

PART 2—GEODETIC SURVEY

Objective

The first geodetic level net for the Lake Mead area was established in March and April 1935. This level net, referred to as the Hoover Dam level net, has served as a reference from which periodic measurements are made of any vertical movement subsequently occurring in the immediate and surrounding areas because of the loading by impounded reservoir waters. Because this reference was established when the reservoir was beginning to fill, the elevations of established bench marks represented the conditions before there was any appreciable loading by the impounded waters. A precise level resurvey of the established bench marks was rerun in the October 1940 through April 1941 period and again between December 1949 and July 1950.

A portion of the Hoover Dam level net was again resurveyed by the Coast and Geodetic Survey from April through June 1963. This survey established vertical control for the 1963-64 Lake Mead survey and provided information useful in estimating the expected vertical deformation of the earth's crust believed caused largely by the varying load brought about by the change in amount of impounded reservoir waters. The pattern of the basic level net is shown in Figure 2-1. Table 2-1 lists the elevations in meters for the respective bench marks obtained during each run of the level surveys in 1935, 1940-41, 1949-50, and 1963.

Field Procedure

Precise Releveling

In April, May, and June 1963, a Coast and Geodetic Survey field party ran first-order releveling over all or portions of the following basic level-net lines shown in Figure 2-1: (III) Las Vegas to 15 miles south of Las Vegas, Nevada; (IV) Las Vegas to Corn Springs, Nevada; (V) Las Vegas to Cane Springs, Nevada; (IX) 4 miles west of Boulder City, Nevada, to 35 miles north of Chloride, Arizona; and spur line from 4 miles west of Hoover Dam to Saddle Island, Nevada; (X) Las Vegas to Searchlight, Nevada; (XI) 10 miles north of Las Vegas, Nevada, to 35 miles north of Chloride, Arizona. Not all of the original basic lines shown in Figure 2-1 were rerun in 1963 because funds were curtailed. Bench mark numbers are shown only for lines which were releveled in 1963.

The level lines rerun in the 1963-64 survey totaled 340 miles. The average adjustment distribution rate was 0.35 mm per kilometer and the maximum on a line of appreciable size was 0.85 mm per kilometer. Requirements for the 1963 level net set a maximum tolerance of 3.0 mm $\sqrt{K}$ between the forward and backward runs, the same as set for previous level nets. The term, K, is the length of run in kilometers. Table 2-1 shows the millimeter changes in elevations during the two periods 1935 to 1963, and 1949 to 1963, for the respective bench marks over which levels were rerun, and for which a "special" adjustment was made based on Bench Mark R1 at Cane Springs.

Adjustment of Levels

The basic level network of 1935 was adjusted to sea level datum of 1929 by holding fixed the elevations resulting from previous adjustments for a ring of junctions on the perimeter of the net. This "supplementary" adjustment was made to obtain elevations consistent with the surrounding control and the same elevations were published for general public use. Similar "supplementary" adjustments were made for each of the reruns since 1935.

Considering future geodetic studies of the reservoir area, it was believed advisable to make a "special" adjustment in which the elevations would be free from the effects of warping due to fitting to the older net. Accordingly, a second adjustment was made for each of these level runs, in which only one bench mark elevation (R1 at Cane Springs) from the first adjustment, was held fixed. The elevations resulting from this "special" adjustment were used as a network for comparing subsequent basin subsidence and rebound. The elevations and changes in elevations of each bench mark listed in Table 2-1 are based on this "special" adjustment.

Interpretation of Releveling Results

Review of Structural Geology

A brief review of the structural geology of the Lake Mead area is desirable for a better understanding of the vertical earth crustal movements. Lake Mead is located in southeastern Nevada and northern Arizona, a portion of the Basin and Range Physiographic Province. The area surrounding and including the reservoir is characterized by broad valleys bordered by north-south trending mountain ranges of rugged relief. The region is bordered on the east by the Grand Wash Cliffs; on the north by the Virgin, Muddy, and Frenchman Mountain ranges; on the west by the Spring Mountain range; and on the south by the Black,

Table 2-1

HOOVER DAM LEVEL NET ELEVATIONS AND CHANGES IN ELEVATIONS

Elevations resulting from the Special Adjustments
of the Surveys of 1935, 1940-41, 1949-50, and 1963-64.

Line I: Hackberry to Kingman, Arizona

BM	Elevation (meters)				Change in elevation (millimeters)	
	1935	1940-41	1949-50	1963	1935-63	1949-63
K 1	1080.1844	1080.0983				
148+80	1079.2574	1079.1729				
A 124	1081.9889	1081.9035				
B 124	1085.4086	1085.3245				
C 124	1088.6374	1088.5535				
D 124	1095.2701	1095.1885				
3608	1099.9290	1099.8494				
E 124	1098.1447	1098.0642				
F 124	1099.5595	1099.4789				
3591	1094.6037	1094.5248				
G 124	1090.0121	1089.9342				
3542	1079.6903	1079.6140				
H 124	1074.7749	1074.6962				
J 124	1055.2318	1055.1520				
H 1	1042.3114	1042.2336				
K 124	1021.4238	1021.3491				
L 124	1009.8357	1009.7615				
M 124	1000.9188	1000.8439				
N 124	995.1055	995.0339				
P 124	997.7024	997.6309				
Q 124	999.7564	999.6858				
R 124	1003.0579	1002.9930				
S 124	1004.6518	1004.5883				
T 124	1008.6684	1008.6058				
U 124	1017.8350	1017.7720				
V 124	1029.0919	1029.0328				
W 124	1037.7705	1037.7147				
124	1050.9463	1050.8849				
124	1061.5729	1061.5155				
Z 124	1067.3301	1067.2784				
Z 126	1048.8751	1048.8263				
B 1	1014.8973	1014.8433				
A 1	1018.1959	1018.1423				

Table 2-1—Continued

Line [illegible]ston, California, to Kingman, Arizona

BM	Elevation (meters)				Change in elevation (millimeters)	
	1935	1940-41	1949-50	1963	1935-63	1949-63
E 6	922.0181	921.9880	921.8840			
A 328	981.8800	981.8511	981.7437			
J 122	1039.6527	1039.6303	1039.5201			
A 148	1111.0309	1111.0114	11110.8974			
K 110	1180.8758	1180.8643	1180.8269			
B 148	1258.6884	1258.6842	1268.5571			
L 110	1308.6676	1308.6670	1308.5424			
C 148	1376.5210	1376.5209	1376.3925			
M 110	1422.5215	1422.5265	1422.4150			
D 148	1492.5816	1492.5880	1492.4531			
N 110	1443.8649	1443.8717	1443.7377			
E 148	1390.6723	1390.6776	1390.5401			
P 110	1357.1747	1357.1810	1357.0389			
F 148	1307.1002	1307.1052	1306.9652			
Q 110	1260.7922	1260.7867	1260.6450			
G 148	1213.0199	1213.0143	1212.8831			
R 110	1178.5418	1178.5308	1178.4012			
H 148	1142.7019	1142.6879	1142.5586			
S 110	1114.8889	1114.8718	1114.7480			
J 148	1087.5184	1087.4986	1087.3725			
T 110	1070.5452	1070.5205	1070.3971			
K 148	1048.2519	1058.2296	1058.1077			
V 109	1051.4412	1071.4217	1071.3028			
W 109	1079.9647	1079.9457				
L 148	1085.1156	1085.0996	1084.9799			
U 110	1053.0739	1053.0571	1052.9391			
M 148	990.6139	990.5919	990.4806			
V 110	926.7303	926.7203	926.6080			
N 148	855.1567	855.1423	855.0375			
W 110	763.0853	763.0695	762.9772			
Ferry	736.7976	736.7817	736.6922			
R.M. 2	736.3956	736.3813	736.2906			
R.M. 1	735.9222	735.9085	735.8173			
P 148	690.8752	690.8588	690.7728			
X 110	622.3783	622.3573	622.2812			
Q 148	554.3132	554.2874	554.2226			
Y 110	482.9640	482.9307	482.8737			
R 148	418.8478	418.8113	418.7593			
Z 110	350.8653	350.8327	350.7802			
S 148	300.8739	300.8405	300.7898			

Table 2-1—Continued

Line II: Nipton, California, to Kingman, Arizona—Continued

BM	Elevation (meters)				Change in elevation (millimeters)	
	1935	1940-41	1949-50	1963	1935-63	1949-63
[illegible] 111	265.6824	265.6508	265.6017			
[illegible]	193.3719	193.3343	193.2947			
[illegible] A	188.5515	188.5135	188.4824			
398.1 B	186.6282	186.5868	186.5494			
A 116	175.8931	175.8414	175.8051			
P 52	175.0226	174.9699	174.9361			
B 116	175.4384	175.3839	175.3563			
Q 52	182.0895	182.0354	182.0126			
C 116	228.5885	228.5354	228.5098			
[illegible]	290.9689	290.9166	290.8914			
R 52	293.0490	292.9977	292.9728			
D 116	374.2008	374.1481	174.1239			
S 52	461.7001	461.6446	461.6206			
E 116	563.1241	563.0765	563.0421			
T 52	633.3543	633.3069	633.2728			
P 53	690.3992	690.3437				
U 52	871.1694	871.1038	871.0730			
116A	925.6027	925.5330	925.4991			
G 116	1024.8128	1024.7529	1024.7064			
V 52	1161.9087	1161.8415	1161.7943			
H 116	1117.0309	1116.9625	1116.9133			
W 52	1065.8133	1065.7472	1065.6987			
J 116	1023.8798	1023.8118	1023.7622			
X 52	990.8453	990.7766	990.7306			
K 116	969.9569	969.8895	969.8486			
Y 52	941.1790	941.1025	941.0632			
L 116	916.5657	916.5004	916.4564			
Z 52	903.8929	903.8234	903.7831			
M 116	913.1827	913.1192	913.0795			
A 60	932.8847	932.8224	932.7794			
N 116	974.1947	974.1341	974.0871			
C 60	988.0418	987.9738				
P 116	1006.4387	1006.3747				
D 60	1041.0819	1041.0232				
Q 116	1061.7499	1061.6922				
E 60	1085.6583	1085.6009				
R 116	1100.9290	1100.8710				
F 60	1148.6222	1148.5685				
S 116	1180.4595	1180.4017				
G 60	1205.4144	1205.3583				

Table 2-1—Continued

Line II: Nipton, California, to Kingman, Arizona—Continued

BM	Elevation (meters)				Change in elevation (millimeters)	
	1935	1940-41	1949-50	1963	1935-63	1949-63
H 60	1222.0551	1221.9987				
T 116	1179.9541	1179.8915				
J 60	1140.9635	1140.9044				
U 116	1108.0690	1108.0035				
K 60	1089.5409	1089.4730				
V 116	1086.2288	1086.1590				
L 60	1068.3982	1068.3215				
W 116	1052.0556	1051.9830				
M 60	1065.8344	1065.7519				
X 116	1050.1027	1050.0243				
N 60	1032.9147	1032.8371				
Y 116	1003.3494	1003.2722				
P 60	986.6049	986.5269				
Z 116	957.4494	957.3770				
Q 60	949.6790	949.6077				
X 119	1000.3891	1000.3271				
R 60	1055.1837	1055.1151				
S 60	1106.1798	1106.1258				
Z 119	1054.0523	1053.9949				
Line III: Nipton, California, To Las Vegas, Nevada						
H 328	917.0277	916.9971	916.8957			
G 328	904.2849	904.2538	904.1493			
F 6	888.7312	888.6975	888.5926			
F 328	868.1503	868.1206	868.0160			
G 6	854.6171	854.5910	854.4805			
E 328	845.5023	845.4817	845.3700			
D 328	843.6213	843.6028	843.4896			
C 328	846.4611	846.4453	846.3310			
B 328	838.6682	838.6474	838.5317			
H 6	836.7741	836.7545	836.6406			
Q 150	832.9007	832.8858	832.7706			
P 150	828.2186	828.2002	828.0841			
Roach	815.0074	814.9874	814.8695			
Roach	798.5678	798.5482	798.4224			
A	796.3413	796.3209				
N 150	795.1718	795.1533	795.0328			
M 150	795.2918	795.2701	795.0636			
L 150	795.7124	795.6876	795.5712			
K 150	807.9107	807.8874	807.7662			
B	823.9988	823.9808	823.8621			

Table 2-1—Continued

Line III: Nipton, California, to Las Vegas, Nevada—Continued

BM	Elevation (meters)				Change in elevation (millimeters)	
	1935	1940-41	1949-50	1963	1935-63	1949-63
J 150	826.8858	826.8703	826.7500			
H 150	835.9910	835.9871	835.8619			
G 150	848.1404	848.1362	848.0149			
F 150	859.8331	859.8279	859.7100			
E 150	874.6329	874.6282	874.5131			
D 150	873.3249	873.3194	873.2012			
C 150	892.2436	892.2354	892.1238			
B 150	909.8779	909.8635	909.7589			
P 170	931.6454	931.6361	931.5274			
N 170	936.6007	936.5917	936.4862			
F	942.2379	942.2320	942.1255			
G	951.6242	951.6140	951.5107			
T 170	937.6776	937.6683				
S 170	924.8486	924.8399	924.7359			
R 170	906.6933	906.6798	906.5848			
[illegible] 170	894.8490	894.8365	894.7451			
[illegible] 170	876.7450	876.7335	876.6435			
I	862.2277	862.2099				
L 170	847.6273	847.6029	847.5195			
J	828.3198	828.3015	828.2218			
K 170	814.3689	814.3480	814.2672			
J 170	799.4161	799.3928	799.3116			
K	784.8209	784.7933	784.7167			
[illegible]	772.9112	772.8820	772.8077			
[illegible]	760.8740	760.8469				
F 170	753.9836	753.9511	753.8786	753.967	−17	+88
E 170	742.4761	742.4470	742.3776	742.462	−14	+84
M	732.0351	732.0052	731.9356	732.020	−15	+84
2336	711.6289	711.5977	711.5211	711.610	−19	+89
D 170	696.9291	696.9006	696.8260	696.909	−20	+83
[illegible]	679.9266	679.8966	679.8130	679.875	−52	+62
[illegible]	663.6361	663.6110	663.5239	663.521	−115	−3
[illegible]	660.6774	660.6518				
2136	650.5808	650.5544				
A 170	640.3877	640.3563	640.2610	640.225	−163	−36
Z 169	627.9321	627.9008	627.7922			
Y 169	620.9336	620.8967				
2024	616.3714	616.3073	616.1700			
2033	619.1184	619.0645	618.9313			

Table 2-1—Continued

Line IV: Las Vegas to Corn Springs, Nevada

BM	Elevation (meters)				Change in elevation (millimeters)	
	1935	1940-41	1949-50	1963	1935-63	1949-63
F 18	615.9320	615.8693	615.7354			
K 169	614.4879	614.3879	614.2133	613.914	–574	–299
L 169	614.5946	614.5018	614.2447	613.886	–709	–359
M 169	626.5636	626.5269	626.4284			
N 169	637.9769	637.9500	637.8571	637.812	–165	–45
E 18	651.5393	651.5228		*651.126		
P 169	668.2565	668.2405	668.1489	668.123	–133	–26
Q 169	688.2855	688.2722	688.1793	688.176	–110	–3
C 18	698.8717	698.8601		698.861	–11	
R 169	708.0353	708.0282	707.9229	707.932	–103	+9
S 169	718.6936	718.6935	718.5942	718.632	–62	+38
T 169	734.6913	734.6929	734.5981	734.645	–46	+47
B 18	747.6091	747.6160	747.5222	747.574	–35	+52
U 169	764.0221	764.0245	763.9407	763.995	–27	+54
A 18	775.3420	775.3386	775.2602	775.318	–24	+58
V 169	790.5902	790.5924	790.5141	790.580	–10	+66
Z 17	806.0056	806.0074	805.9334	806.007	+1	+74

Line V: Las Vegas to Cane Springs, Nevada

BM	1935	1940-41	1949-50	1963	1935-63	1949-63
V 170	592.4419	592.3850	592.2212	591.853	–589	–368
W 170	583.5067	583.4649	583.3676	583.209	–298	–159
X 170	581.3484	581.3104	581.2303	581.184	–164	–46
Y 170	581.1051	581.0675	581.0011	581.018	–87	+17
Z 170	588.2399	588.1974	588.1339	588.169	–71	+35
A 171	592.4729	592.4286	592.3723	592.402	–71	+30
S	612.3152	612.2747	612.2179	612.250	–65	+32
B 171	617.5763	617.5359	617.4801			
C 171	634.4268	634.3907	634.3263	634.363	–64	+37
P 166	644.7350	644.6967	644.6294	644.666	–69	+37
T	650.8084	650.7708	650.7057	650.738	–70	+32
D 171	664.6117	664.5742	664.5108	664.548	–64	+37
U	685.7054	685.6685	685.6045	685.644	–61	+40
E 171	699.0871	699.0533	698.9868	699.026	–61	+39
F 171	713.0530	713.0193	712.9583	712.996	–57	+38
V	735.5757	735.5408	735.4779	735.517	–59	+39
G 171	731.8667	731.8302	731.7666	731.804	–63	+37
H 171	742.3380	742.3039	742.2380	742.275	–63	+37
P 171	748.7812	748.7491	748.6852	748.721	–60	+36
J 171	733.9843	733.9560	733.8899	733.929	–55	+39

*Bench mark reset

Table 2-1—Continued

Line V: Las Vegas to Cane Springs, Nevada—Continued

BM	Elevation (meters)				Change in elevation (millimeters)	
	1935	1940-41	1949-50	1963	1935-63	1949-63
K 171	717.6004	717.5724				
X	709.3395	709.3116	709.2471	709.281	−59	+34
L 171	701.4764	701.4483	701.3864	701.417	−59	+31
W 160	969.9089	696.8824	696.8198			
M 171	690.1895	690.1634	690.1070	690.134	−56	+27
X 160	689.6961	689.6707	689.6154	689.641	−55	+26
N 171	689.9125	689.8845	689.8316	689.855	−57	+23
Y	683.4715	683.4481	683.3896	683.416	−56	+26
Z	681.9690	681.9459	681.8866			
Y 160	666.1381	666.1168	666.0627	666.087	−51	+24
Z 160	655.9948	655.9604	655.9094	655.928	−67	+19
A 1	651.6778	651.6458	651.5925	651.614	−64	+22
A 161	645.6414	645.6080	645.5572	645.579	−62	+22
B 161	641.0298	640.9970	640.9513	640.972	−58	+21
C 161	639.3150	639.2796	639.2425	639.259	−56	+17
D 161	638.1775	638.1512	638.1461	638.013	−165	−133
E 161	637.4817	637.4476				
F 161	636.4197	636.4192	636.4589	636.489	+69	+30
D 1	639.8093	639.7792	639.7642	639.761	−48	−3
G 161	634.2167	634.1917	634.1750	634.172	−45	−3
H 161	631.5357	631.5107	631.5028	631.460	−76	−43
J 161	619.4155	619.3336	619.3597	619.357	−59	−3
E 1	619.8636	619.8345				
K 161	614.0776	614.0475	614.0353	614.051	−27	+16
L 161	605.9734	605.9470	605.9219	605.936	−37	+14
M 161	602.4560	602.4317	602.4112	602.421	−35	+10
N 161	594.8283	594.8048	594.7977	594.813	−15	+15
P 161	586.7787	586.7527	586.7539	586.764	−15	+10
F 1	589.0488	589.0272	589.0102	589.030	−19	+20
Q 161	586.4773	586.4559	586.4454	586.474	−3	+29
R 161	576.5718	576.5486	576.5272	576.550	−22	+23
S 161	562.2231	562.1988	562.1828	562.199	−24	+16
T 161	545.2194	545.2146	545.2016			
G 1	544.2067	544.2107				
U 161	530.4982	530.4938	530.4783	530.480	−18	+2
V 161	519.6524	519.6564	519.6350	519.626	−26	−9
W 161	503.1407	503.1391				
H 1	484.3751	484.3707	484.3487	484.332	−43	−17
X 161	488.8772	488.8750	488.8626	*489.900		
Moapa La-Place	507.5787	507.5792	507.5625	507.559	−20	−3

*Bench mark reset

Table 2-1—Continued

Line V: Las Vegas to Cane Springs, Nevada—Continued

BM	Elevation (meters)				Change in elevation (millimeters)	
	1935	1940-41	1949-50	1963	1935-63	1949-63
I 1 Reset	508.2275	508.2274	508.2113	*508.209		
J 1	508.1132	508.1120	508.0974	508.097	−16	0
K 1	510.9748	510.9679	510.9538	510.965	−10	+11
L 1	514.1282	514.1164				
Y 161	522.3020	522.3008	522.2925	522.285	−17	−7
Z 161	520.7514	520.7471	520.7405	520.738	−13	−2
A 162	519.3154	519.3089	519.3103	519.317	+2	+7
B 162	524.8091	524.8013				
C 162	531.4374	531.4311	531.4119			
D 162	530.8237	530.8181	530.8091	530.817	−7	+8
E 162	526.2410	526.2339	526.2283	526.234	−7	+6
F 162	526.5212	526.5352	526.5533	526.581	+60	+28
G 162	527.6390	527.6382	527.6442	527.656	+17	+12
H 162	526.6973	526.6924	526.6791	526.682	−15	+3
N 1	531.8613	531.8612	531.8505	531.853	−8	+3
J 162	536.2008	536.2023	536.2007	536.210	+9	+9
K 162	542.4236	542.4250	542.4194	542.420	−4	+1
L 162	553.0505	553.0540				
M 162	561.6788	561.6829	561.6744	561.676	−3	+2
Rivet	570.8389	570.8402	570.8395			
N 162	571.5654	571.5660	571.5639	571.558	−7	−6
P 162	582.0190	582.0211	582.0218	582.015	−4	−7
Q 162	589.6361	589.6275	589.6260	589.549	−87	−77
R 162	601.0142	601.0092	601.0075	600.985	−29	−23
S 162	609.8053	609.7961	609.7989	609.795	−10	−4
T 162	612.6530	612.6347	612.6342	*613.815		
R 1	617.9456	617.9456	617.9456	617.946	0	0

Line VI: Moapa, Nevada, to Beaver Dam Creek, Arizona

BM	1935	1940-41	1949-50	1963	1935-63	1949-63
U 50	468.0901	468.0961				
W 50	463.8735	463.8719	463.8623			
A 160	480.4906	480.4919	480.4738			
X 50	509.0801	509.0770	509.0635			
B 160	563.8805	563.8822				
Y 50	628.2211	628.2327				
C 160	627.3292	627.3439				
Z 50	631.0647	631.0795				
D 160	630.7846	630.8026				
A 51	627.5886	627.6038				

*Bench mark reset

Table 2-1—Continued

Line VI: Moapa, Nevada, to Beaver Dam Creek, Arizona—Continued

BM	Elevation (meters)				Change in elevation (millimeters)	
	1935	1940-41	1949-50	1963	1935-63	1949-63
E 160	616.7940	616.8030				
B 51	613.9541	613.9626				
F 160	617.7027	617.7115				
C 51	621.5532	621.5612				
G 160	626.4022	626.4039				
D 51	632.3829	632.3820				
H 160	640.9838	640.9777				
E 51	641.8334	641.8291				
J 160	639.5692	639.5638				
F 51	633.9648	633.9604				
K 160	629.2808	629.2767				
G 51	634.7141	634.7097				
L 160	598.0783	598.0759				
H 51	533.9812	533.9721				
M 160	501.7822	501.7863				
N 160	487.8930	487.8811				
J 51	437.9480	437.9360				
P 160	483.0318	483.0229				
K 51	464.5973	464.5857				
Q 160	478.8535	478.8399				
L 51	485.8216	485.8099				
R 160	476.7454	476.7375				
M 51	466.3354	466.3295				
S 160	473.1548	473.1419				
N 51	480.1006	480.0909				
T 160	475.9028	475.8989				
P 51	480.8922	480.8819				
U 160	484.5833	484.5754				
Q 51	486.8128	486.8065				
R 51	490.1284	490.1127				
V 160	496.5020	496.4947				
0+00	540.9453	540.9387				
31+40.0	517.9033	517.8954				
E 111	522.0585	522.0521				
E 55	536.8544	536.8504				
F 111	561.4935	561.4891				
G 111	526.4270	526.4223				
G 55	525.2395	525.2331				
H 111	586.0457	586.0398				
H 55	595.2214	595.2137				

Table 2-1—Continued

Line VI: Moapa, Nevada, to Beaver Dam Creek, Arizona—Continued

BM	Elevation (meters)				Change in elevation (millimeters)	
	1935	1940-41	1949-50	1963	1935-63	1949-63
J 111	590.2345	590.2251				
508+50.0	557.1392	557.1352				
K 111	559.8073	559.8008				
K 55	614.9709	614.9677				

Line VII: Hackberry, Arizona, to Moapa, Nevada

BM	1935	1940-41	1949-50	1963	1935-63	1949-63
B 53	1044.5758	1044.4895				
B 125	1033.1282	1033.0342				
3371	1027.3976	1027.3104				
C 53	1026.2804	1026.1926				
C 125	1013.5035	1013.4186				
D 53	1002.0574	1001.9715				
D 125	989.1887	989.1091				
E 53	976.8167	976.7433				
E 125	966.9072	966.8389				
3130	955.6578	955.5959				
F 125	945.9433	945.8808				
F 53	934.6039	934.5408				
G 125	926.7680	926.7017				
3015	918.9394	918.8657				
H 125	911.9974	911.9250				
G 53	911.2727	911.1994				
J 125	904.8909	904.8179				
2968	905.2807	905.2043				
K 125	901.7404	901.6688				
H 53	903.6678	903.5979				
L 125	907.1793	907.1067				
2971	906.0155	905.9394				
M 125	896.6208	896.5516				
N 125	885.2128	885.1414				
2879	877.9277	877.8532				
P 125	876.0183	875.9462				
J 53	862.9324	862.8588				
Q 125	854.3795	854.3103				
2886	849.7900	849.7235				
R 125	843.8636	843.7977				
K 53	842.0149	841.9472				
S 125	840.6315	840.5673				
L 53	840.1994	840.2125				
T 125	840.2402	840.1919				
M 53	842.0033	841.9519				

Table 2-1—Continued

Line VII: Hackberry, Arizona, to Moapa, Nevada—Continued

BM	Elevation (meters)				Change in elevation (millimeters)	
	1935	1940-41	1949-50	1963	1935-63	1949-63
[illegible] 125	848.0522	848.9067				
[illegible] 53	858.5970	858.5520				
[illegible] 125	862.0703	862.0261				
P 53	865.8584	865.8103				
W 125	868.9818	868.9350	868.9000			
X 125	871.3362	871.2781	871.2398			
2860	871.9543	871.8861	871.8406			
Y 125	894.7302	894.6738	894.6392			
Q 53	931.7418	931.6859	931.6481			
[illegible] 125	993.7496	993.6940	993.6514			
R 53	1055.3384	1055.2825	1055.2403			
A 126	1117.1713	1117.1125	1117.0692			
S 53	1189.9439	1189.8817	1189.8363			
B 126	1238.8428	1238.7769	1238.7314			
T 53	1209.7249	1209.6584	1209.6110			
C 126	1206.7136	1206.6470	1206.6118			
U 53	1173.9951	1173.9215	1173.8953			
D 126	1157.3735	1157.2987	1157.2738			
V 53	1149.0989	1149.0196	1148.9985			
E 126	1134.1572	1134.0797	1134.0598			
W 53	1094.8840	1094.8037	1094.7896			
F 126	1069.0707	1068.9972	1068.9823			
X 53	1053.5859	1053.5168	1053.4983			
G 126	1025.1597	1025.0885	1025.0701			
H 126	998.5941	998.5256	998.5037			
Y 53	987.8306	987.7580	987.7418			
J 126	960.6528	960.5794	960.5657			
K 126	940.8457	940.7727	940.7603			
Z 53	924.5651	924.4884	924.4802			
L 126	951.5492	951.4706	951.4617			
M 126	934.0025	933.9293	933.9152			
A 54	926.7102	926.6379	926.6232			
N 126	914.1867	914.1148	914.0995			
P 126	890.9268	890.8526	890.8419			
B 54	869.8756	869.8059	869.7924			
Q 126	851.2786	851.2043	851.1947			
R 126	837.6002	837.5235	837.5152			
S 126	832.1673	832.0931	832.0833			
C 54	843.4041	843.3353				
T 126	805.3659	805.2972	805.2859			

Table 2-1—Continued

Line VII: Hackberry, Arizona, to Moapa, Nevada—Continued

BM	Elevation (meters)				Change in elevation (millimeters)	
	1935	1940-41	1949-50	1963	1935-63	1949-63
U 126	785.3507	785.2813	785.2729			
V 126	769.3156	769.2469	769.2405			
D 54	783.1508	783.0769	783.0710			
W 126	789.4613	789.3893	789.3811			
X 126	789.4699	789.3961	789.3885			
Y 126	747.9177	747.8442	747.8386			
M 129	732.5711	732.4990	732.4948			
E 54	715.2201	715.1523	715.1450			
A 127	678.1258	678.0575	678.0553			
B 127	654.3778	654.3105	654.3071			
C 127	618.8328	618.7624	618.7655			
D 127	594.3490	594.2804	594.2839			
F 54	575.5368	575.4668	575.4722			
E 127	543.9801	543.9130	543.9181			
F 127	523.7244	523.6552	523.6675			
G 127	496.3698	496.3036	496.3140			
G 54	487.8288	487.7630	487.7748			
H 127	445.1462	445.0822	445.0994			
J 127	417.6781	417.6138	417.6310			
K 127	389.1241	389.0595				
L 127	373.3758	373.3129	373.3358			
M 127	379.2887	379.2371	379.2507			
N 127	401.9111	401.8505	401.8605			
P 127	406.8019	406.7391	406.7450			
Q 127	412.2134	412.1529	412.1565			
K 54	425.3930	425.3311	425.3347			
R 127	433.0160	432.9560	432.9581			
S 127	411.4468	411.3830	411.3838			
T 127	386.0118	385.9505	385.9492			
U 127	400.3334	400.2832	400.2804			
V 127	410.5392	410.4844	410.4806			
L 54	421.1277	421.0730	421.0654			
W 127	431.9795	431.9210	431.9119			
X 127	444.3123	444.2516	444.2421			
Y 127	458.7561	458.6968	458.6836			
Z 127	473.8422	473.7821	473.7686			
N 129	491.1179	491.0619	491.0460			
M 54	495.9036	495.8741	495.8604			
P 129	512.1801	512.1268	512.1102			
Q 129	521.6859	521.6346	521.6168			

Table 2-1—Continued

Line VII: Hackberry, Arizona, to Moapa, Nevada—Continued

BM	Elevation (meters)				Change in elevation (millimeters)	
	1935	1940-41	1949-50	1963	1935-63	1949-63
[illegible]29	540.1408	540.1035	540.0627			
[illegible]9	552.9010	552.8567	552.8447			
[illegible] 54	577.9009	577.8496	577.8347			
T 129	609.8734	609.8213	609.8045			
U 129	638.4526	638.4021	638.3821			
V 129	656.2884	656.2378	656.2162			
P 54	663.1099	663.0599	663.0371			
W 129	701.8534	701.8073	701.7838			
X 129	732.1964	732.1521	732.1205			
[illegible]29	736.9187	736.8730	736.8446			
Q 54	719.7435	719.6987	719.6696			
Z 129	686.0295	685.9861	685.9598			
A 130	656.1732	656.1329	656.1082			
B 130	630.8648	630.8286	630.8045			
R 54	626.6026	626.5672	626.5415			
C 130	611.4157	611.3823	611.3560			
D 130	576.2883	576.2559	576.2317			
[illegible] 54	566.0954	566.0647	566.0395			
E 130	563.2080	563.1802	563.1524			
T 54	585.1687	585.1378	585.1075			
F 130	584.3111	584.2949	584.2584			
U 54	592.4627	592.4408	592.4119			
G 130	612.9289	612.9136	612.8781			
V 54	631.4579	631.4415	631.4076			
H 130	646.2515	646.2396	646.2084			
W 54	659.4976	659.4878	659.4570			
J 130	638.8046	638.7940	638.7605			
X 54	611.2334	611.2217	611.1916			
K 130	539.4799	539.4739	539.4451			
Y 54	532.3950	532.3922	532.3647			
L 130	514.2756	514.2710	514.2421			
Z 54	490.5450	490.5450	490.5106			
M 130	500.3563	500.3628	500.3301			
[illegible] 55	511.5651	511.5740	511.5427			
N 130	542.8774	542.8972	542.8644			
B 55	564.9350	564.9303	564.8820			
P 130	605.3502	605.3518	605.3222			
C 55	613.4258	613.4253	613.3964			
Q 130	634.2979	634.2979	634.2663			
D 55	669.0994	669.0924	669.0608			

Table 2-1 Continued

[illegible] Nevada—Continued

[illegible]	Elevation (meters)				Change in elevation (millimeters)	
	[illegible]	1940-41	1949-50	1963	1935-63	1949-63
[illegible]	[illegible]	[illegible]	[illegible]			
[illegible]	[illegible]	[illegible]	[illegible]			
[illegible]	[illegible]	[illegible]	[illegible]			
[illegible]	[illegible]	[illegible]	[illegible]			
[illegible]	[illegible]	[illegible]	[illegible]			
[illegible]	[illegible]	[illegible]	[illegible]			
[illegible]	[illegible]	[illegible]	[illegible]			
[illegible]	[illegible]	580.4055	[illegible]			
[illegible]	[illegible]	[illegible]	[illegible]			
[illegible]	[illegible]	[illegible]	[illegible]			
[illegible]	[illegible]	526.3185	[illegible]			
[illegible]	[illegible]	509.1535	[illegible]			
[illegible]	[illegible]	505.1425	[illegible]			
[illegible]	[illegible]	586.2145	[illegible]			
[illegible]	[illegible]	576.2070	[illegible]			
[illegible]	[illegible]	581.4886	[illegible]			
[illegible]	[illegible]	552.1628	[illegible]			
[illegible]	[illegible]	552.5854	[illegible]			
[illegible]	541.1594	541.1466	[illegible]			
[illegible]	[illegible]	526.2882	[illegible]			
[illegible]	513.8044	513.7807	[illegible]			
[illegible]	[illegible]	496.8615	[illegible]			
[illegible]	[illegible]	477.1646	[illegible]			
[illegible]	[illegible]	479.1496	[illegible]			
[illegible]	502.4945	502.4768	[illegible]			
[illegible]	493.1724	493.1669	[illegible]			
[illegible]	478.1098	478.1147	[illegible]			
[illegible]	468.8491	468.8621	[illegible]			
[illegible]	460.0335	460.0521	[illegible]			
[illegible]	452.2097	452.2303	[illegible]			
[illegible]	[illegible]	456.0916	[illegible]			
[illegible]	441.2091	441.2302	[illegible]			
[illegible]	435.3823	435.4055	[illegible]			
[illegible]	[illegible]	431.2281	[illegible]			
[illegible]	425.6930	425.7165	[illegible]			
[illegible]	393.6370	393.6610	[illegible]			
[illegible]	383.2591	383.2857	[illegible]			
[illegible]	381.5655	381.5925	[illegible]			
[illegible]	378.4809	378.5080	[illegible]			
[illegible]	366.5867	366.6090	[illegible]			

Table 2-1—Continued

Line VII: Hackberry, Arizona, to Moapa, Nevada—Continued

BM	Elevation (meters)				Change in elevation (millimeters)	
	1935	1940-41	1949-50	1963	1935-63	1949-63
[illegible] 163	369.1488	369.1730	369.1789			
[illegible] 163	430.9566	430.9859	430.9931			
U 163	454.4896	454.5144	454.5223			
V 163	476.7401	476.7506	476.7545			
W 163	494.2097	494.2088	494.2090			
X 163	447.6748	447.6666	447.6636			
Y 163	432.4297	432.4173	432.3974			
Z 163	435.4432	435.4363	435.4313			
A 164	574.2664	574.2586	574.2571			
[illegible] 164	573.8871	573.8782	573.8776			
C 164	576.6373	576.6235	576.6264			
D 164	577.3872	577.3727	577.3774			
E 164	575.9048	575.8917	575.8949			
F 164	572.0472	572.0337	572.0379			
G 164	568.4704	568.4587	568.4627			
H 164	565.7350	565.7200	565.7231			
I 164	568.0405	568.0279	568.0344			
K 164	565.9203	565.9095	565.9164			
L 174	564.6241	564.6125	564.6217			
M 164	567.7731	567.7613	567.7716			
N 164	567.6669	567.6569	567.6646			
P 164	569.0957	569.0828	569.0950			
Q 164	570.4987	570.4882	570.4982			
R 164	572.6276	572.6189	572.6290			
S 164	527.8059	527.7995	527.8016			
T 164	487.3650	487.3592	487.3550			
U 164	472.2958	472.2906	472.2850			
V 164	461.9338	461.9300	461.9218			
W 164	450.4154	450.4114	450.4014			
X 164	438.9921	438.9862	438.9745			
Y 164	422.2125	422.2062	422.1955			
Z 164	411.3175	411.3123	411.2999			
A 165	408.1869	408.1809	408.1673			
B 165	389.1005	389.0944	389.0802			
C 165	387.2599	387.2520	387.2376			
D 165	385.6955	385.6848	385.6660			
E 165	384.4702	384.4514	384.4286			
F 165	385.2877	385.2616				
G 165	389.6355	389.6135	389.5837			
H 165	390.9407	390.9220	390.8979			

Table 2-1—Continued

Line VII: Hackberry, Arizona, to Moapa, Nevada—Continued

BM	Elevation (meters)				Change in elevation (millimeters)	
	1935	1940-41	1949-50	1963	1935-63	1949-63
34 B	1043.3872	1043.4415	1043.3312			
S 175	1004.0715	1004.1167				
R 175	967.2289	967.2709	967.1640			
P 175	888.7678	888.7931	888.7002			
N 175	892.7265	892.7547	892.6649			
M 175	901.2260	901.2619	901.1643			
L 175	942.2421	942.2774	942.1901			
K 175	901.8772	901.9116	901.8191			
35 B	942.4596	942.4859	942.4031			
J 175	947.1608	947.1883	947.1037			
H 175	879.1667	879.1914	879.1109			
G 175	982.0767	982.1135	982.0276			
36 B	1034.8658	1034.9192	1034.8203			
F 175	1060.4367	1060.4917	1060.3945			
E 175	1133.6050	1133.6609	1133.5703			
37 B	1131.4962	1131.5544	1131.4657			
D 175	1049.7486	1049.7904	1049.7193			
C 175	992.8933	992.9228	992,8674			
B 175	946.9397	946.9594	946.9080			
38 B	945.2747	945.2878	945.2393			
A 175	977.5579	977.5806	977.5288			
Z 174	920.4330	920.4461	920.3948			
Y 174	885.0971	885.1017	885.0548			
39 B	851.8736	851.8750	851.8299			
X 174	791.0687	791.0670	791.0207			
W 174	764.8496	764.8477	764.8059			
V 174	773.8962	733.8954	733.8535			
U 174	706.4007	706.3975	706.3598			
T 174	678.9212	678.9195	678.8793			
40 B	648.2311	648.2477				
S 174	617.2401	617.2291	617.2016			
R 174	587.0604	587.0424	587.0239			
Line IX: 4 miles west of Boulder City, Nevada, to 10 miles north of Chloride, Arizona						
E 167	707.8742	707.8610		*705.968		
F 167	714.9842	714.9688		*713.310		
G 167	724.3519	724.3321	724.2359	724.347	−5	+111
H 167	731.5412	731.5236	731.4285	731.542	+1	+114
J 167	740.8730	740.8507		*739.787		

*Bench mark reset

Table 2-1—Continued

IX: 4 miles west of Boulder City, Nevada, to 10 miles north of Chloride, Arizona—Continued

BM	Elevation (meters)				Change in elevation (millimeters)	
	1935	1940-41	1949-50	1963	1935-63	1949-63
L 167	755.4180	755.3905	755.3084	755.428	+10	+120
M 167	766.3665	766.3366	766.2428	766.360	−6	+117
B 169	764.2284	764.2006	764.1093	764.228	0	+119
C 169	776.3039	776.2722	776.1846	776.303	−1	+118
N 167	740.1006	740.0661	739.9832	740.098	−3	+115
P 167	683.3375	683.3041	683.2266	683.324	−14	+97
Q 167	676.4023	676.3717	676.2964			
R 167	647.2255	647.1912	647.1198	647.206	−20	+86
S 167	624.2652	624.2332	624.1609	624.240	−25	+79
T 167	606.5918	606.5597	606.4887	606.561	−31	+72
U 167	578.3922	578.3642	578.2931	578.358	−34	+65
V 167	558.4837	558.4532	558.3827	558.443	−41	+60
W 167	545.8486	545.8176	545.7496	545.809	−40	+59
X 167	525.1424	525.1122	525.0430	525.098	−44	+55
Y 167	510.9409	510.9100	510.8453	510.902	−39	+57
Z 167	509.8795	509.8466	509.7816	509.832	−48	+50
1665.78	507.8987	507.8652	507.8010	507.851	−48	+50
A 168	522.8645	522.8312	522.7651			
B 168	526.8796	526.8437	526.7711	526.820	−60	+49
[illegible]8	533.0572	533.0216	532.9460	532.994	−63	+48
D 168	546.3782	546.3347	546.2551	546.298	−80	+43
E 168	519.7271	519.6840	519.6008	519.639	−88	+38
F 168	494.2293	494.1818	494.0933	494.121	−108	+28
D 169	479.8378	479.7976	479.7090	479.727	−111	+18
E 169	434.4310	434.3880	434.3062			
F 169	393.3532	393.3114				
G 169	337.1442	337.1088	337.0408	337.055	−89	+14
H 169	281.3563	281.3150	281.2541	281.272	−84	+18
J 169	235.2160	235.1788				
N 16	215.3956	215.3627				
L 174	205.8249	205.7696	205.6993	205.697	−128	−2
M 174	205.8367	205.7713	205.7009	205.701	−136	0
Q 174	214.8902	214.8243	214.7470	214.749	−141	+2
C 136	214.8942	214.8257	214.7554	214.758	−136	+3
Z 135	205.8365	205.7687	205.7015	205.702	−134	0
Y 135	205.8264	205.7685	205.7036	205.705	−121	+1
A 134	222.4716	222.4191				
B 134	282.8890	282.8401	282.7739	282.792	−97	+18
C 134	327.8787	327.8308	327.7646	327.783	−96	+18
D 134	310.5059	310.4557	310.3926	310.411	−95	+18

Table 2-1—Continued

Line IX: 4 miles west of Boulder City, Nevada, to 10 miles north of Chloride, Arizona—Continued

BM	Elevation (meters)				Change in elevation (millimeters)	
	1935	1940-41	1949-50	1963	1935-63	1949-63
E 134	297.0055	296.9576	296.9000	296.913	−93	+13
F 134	322.2753	322.2284	322.1683	322.179	−96	+11
G 134	373.9699	373.9315	373.8671	373.880	−90	+13
U 173	474.3783	474.3311	474.2378	474.240	−138	+2
V 173	456.6559	456.6097	456.5217	456.525	−131	+3
W 173	440.2458	440.1974	440.1092	440.118	−128	+9
X 173	424.7247	424.6724	424.5854	424.595	−130	+10
Y 173	408.5563	408.5094	408.4323	408.440	−116	+8
Z 173	397.7309	397.6910	397.6159	397.621	−110	+5
A 174	389.1720	389.1253	389.0508	389.054	−118	+3
D 174	385.7668	385.7135	385.6364	385.641	−126	+5
C 174	379.5752	379.5172	379.4440	379.449	−126	+5
E 174	375.8266	375.7698	375.6992	375.705	−122	+6
K 174	377.0976	377.0299	376.9676	376.974	−124	+6
F 174	375.8028	375.7423	375.6735	375.683	−120	+9
J 174	375.8240	375.7695	375.7163	375.733	−91	+17
G 174	375.7931	375.7355	375.6700	375.682	−111	+12
H 174	375.8119	375.7467	375.6808	375.693	−119	+12
Q 135	375.8013	375.7373	375.6720	375.686	−115	+14
R 135	375.7964	375.7413	375.6776	375.692	−104	+14
U 135	375.8412	375.7871	375.7362	375.756	−85	+20
S 135	375.8022	375.7428	375.6796	375.692	−110	+12
T 135	375.8292	375.7738	375.7122	375.723	−106	+11
V 135	377.1544	377.0996	377.0342	377.044	−110	+10
W 135	377.1318	377.0764	377.0060	377.013	−119	+7
X 135	391.1660	391.1034	391.0301	391.039	−127	+9
H 134	441.2318	441.1837	441.1099	441.125	−107	+15
J 134	442.1861	442.1421	442.0694	442.087	−99	+18
K 134	396.2704	396.2283	396.1606	396.164	−106	+3
L 134	401.4428	401.4059	401.3381	401.351	−92	+13
C 256		396.3603	396.2933	396.308		+15
M 134	417.3278	417.2963	417.2328	417.259	−69	+26
N 134	446.3865	446.3521	446.2899	446.325	−61	+35
P 134	465.2856	465.2510	465.1887	465.225	−61	+36
Q 134	489.2536	489.2194	489.1587	489.195	−59	+36
R 134	480.3080	480.2736	480.2113	480.249	−59	+38
S 134	470.9512	470.9135	470.8529	470.889	−62	+36
T 134	471.0910	471.0539	470.9949	471.032	−59	+37
U 134	503.6753	503.6398	503.5794	503.624	−51	+45
V 134	529.7834	529.7478	529.6881	529.735	−48	+47

Table 2-1—Continued

Line IX: 4 miles west of Boulder City, Nevada, to 10 miles north of Chloride, Arizona—Continued

BM	Elevation (meters)				Change in elevation (millimeters)	
	1935	1940-41	1949-50	1963	1935-63	1949-63
[illegible]	558.1310	558.0943	558.0327	558.087	–44	+54
[illegible]	557.7915	557.7550	557.6923	557.745	–47	+53
X 134	578.4971	578.4607	578.3974	578.454	–43	+57
1934.35	588.9416	588.9046	588.8409	588.898	–44	+57
2043.88	622.3271	622.2877	622.2191	622.284	–43	+65
Y 134	654.4611	654.4220	654.3526	654.423	–38	+70
Z 134	665.5479	665.5081	665.4371	665.510	–38	+73
A 135	673.0838	673.0428	672.9726	673.048	–36	+75
B 135	665.7847	665.7439	665.6745	665.746	–39	+72
[illegible]	665.5784	665.5393	665.4710	665.542	–36	+71
D 135	661.9428	661.9084	661.8374	661.905	–38	+68
E 135	647.3983	647.3669	647.2968	647.359	–39	+62
F 135	639.5849	639.5486	639.4811	639.543	–42	+62
2165.03	659.3009	659.2585	659.1941	659.258	–43	+64
G 135	673.1301	673.0833	673.0222	673.092	–38	+70
H 135	685.9887	685.9457	685.8779	685.950	–39	+72
[illegible]3.05	675.4719	675.4318	675.3620	675.431	–41	+69
[illegible]5	628.1500	628.1092	628.0435	628.106	–44	+62
[illegible]92.29	606.6259	606.5808	606.5198	606.576	–50	+56
[illegible] 135	583.0371	582.9938	582.9320	582.983	–54	+51
1919.15	584.3809	584.3350	584.2753	584.324	–57	+49
2118.75	645.3096	645.2620	645.1988	645.258	–52	+59
K 135	690.6351	690.5832	690.5239	690.587	–48	+63
Builder 1935	688.4759	688.4230	688.3720	688.450	–26	+78
R.M. 1	688.1203	688.0670	688.0098	688.070	–50	+60
R.M. 2	688.5067	688.4543	688.4083			
2258.32	687.8259	687.7889	687.7787	687.851	+25	+72
R.M. 3	691.0127	690.9600	690.9378	691.007	–6	+69
2288.55	697.0380	696.9829	696.9512	697.011	–27	+60
L 135	711.1432	711.0797	711.0310	711.083	–60	+52
M 135	704.7676	704.7054	704.6516			
F 121	714.7370	714.6674	714.6268			
[illegible] 121	733.3441	733.2737	733.2293			
[illegible] 121	729.9892	729.9163	729.8795			
[illegible] 121	732.7414	732.6648	732.6343			
K 121	735.8984	735.8180	735.7910			
L 121	738.2562	738.1780	738.1472			
M 121	746.0991	746.0276	745.9884			
P 121	765.1204	765.0542	765.0125			
Q 121	776.5499	776.4856	776.4450			

Table 2-1—Continued

Line IX: 4 miles west of Boulder City, Nevada, to 10 miles north of Chloride, Arizona—Continued

BM	Elevation (meters)				Change in elevation (millimeters)	
	1935	1940-41	1949-50	1963	1935-63	1949-63
R 121	788.1402	788.0772	788.0372			
S 121	800.4565	800.3975	800.3549			
T 121	813.4114	813.3541	813.3104			
U 121	819.0010	818.9508	818.9064			
980+73	826.6792	826.6283	826.5838			
954+01.25	831.5126	831.4605	831.4128			
933+55	836.7323	836.6793	836.6287			
V 121	844.3755	844.3166	844.2735			
873+31.66	851.3101	851.2546	851.2143			
848+51.66	857.8905	857.8414	857.8018			
825+00	862.9715	862.9274	862.8903			
W 121	870.1578	870.1070	870.0654			
770+00	879.6244	879.5837	879.5466			
743+01.25	887.8383	887.7938	887.7587			
713+01.25	897.5371	897.4893	897.4534			
X 121	904.0177	903.9653	903.9307			
664+10	911.5983	911.5487	911.5077			
Y 121	918.0234	917.9694	917.9267			
614+00	925.7264	925.6712	925.6287			
Z 121	937.4167	937.3569	937.3142			
567+45	941.9395	941.8837	941.8401			
541+20	950.8947	950.8328	950.7892			
Line X: Las Vegas to Searchlight, Nevada						
A 166	596.4059	596.3160	596.1170			
S 51	565.5255	565.4816				
B 166	556.4184	556.3646		*555.546		
T 51	551.8639	551.8277	551.7483			
C 166	540.9927	540.9608				
U 51	519.7438	519.7105	519.6214			
D 166	510.6398	510.5971				
V 51	504.4641	504.4220		*504.088		
E 166	501.1667	501.1188	501.0465			
W 51	504.2330	504.1841	504.1128	504.155	−78	
F 166	517.5240	517.4783				
X 51	546.5950	546.5536				
G 166	589.1780	589.1423	589.0567	589.123	−55	
Y 51	621.0475	621.0121	620.9288			
H 166	645.5509	645.5191	645.4323	645.514	−37	

*Bench mark reset

Table 2-1—Continued

[illegible]ne X: Las Vegas to Searchlight, Nevada—Continued

BM	Elevation (meters)				Change in elevation (millimeters)	
	1935	1940-41	1949-50	1963	1935-63	1949-63
Z 51	660.7085	660.6844	660.5958	660.682	−26	+86
J 166	692.1899	692.1713	692.0744	692.171	−19	+97
A 109	721.5448	721.5326	721.4316	721.540	−5	+108
A 169	705.7972	705.7833		708.162	*+2,365	
B 109	685.8298	685.8182	685.7195	685.823	−7	+103
K 166	628.2995	628.2862	628.1897	628.284	−16	+94
C 109	574.1625	574.1452	574.0563	574.149	−13	+93
[illegible]66	537.9377	537.9172	537.8324	537.920	−18	+88
[illegible]09	531.0581	531.0410	530.9516	531.042	−16	+90
M 166	521.4701	521.4499	521.3598	521.448	−22	+88
1712	521.2341	521.2124	521.1260	521.216	−18	+90
U 148	521.8422	521.8191	521.7280	521.819	−23	+91
V 148	521.5301	521.5129	521.4203	521.510	−20	+90
W 148	524.3348	524.3182	524.2252	524.315	−20	+90
X 148	525.3969	525.3770	525.2807	525.379	−18	+98
Y [illegible]	526.0683	526.0460	525.9477	526.049	−19	+101
Z 148	528.4737	528.4484	528.3533	528.453	−21	+100
A 149	540.4899	540.4626	540.3662	540.468	−22	+102
[illegible]09	568.5543	568.5320	568.4305	568.537	−17	+107
[illegible]9	596.1745	596.1546	596.0494	596.164	−10	+115
J 109	620.4705	620.4534	620.3381	620.462	−8	+124
C 149	642.2699	642.2603	642.1336	642.266	−4	+132
K 109	662.7123	662.7103	662.5761	662.712	0	+136
D 149	689.7818	689.7835	689.6445	689.786	4	142
L 109	723.4815	723.4813	723.3412	723.489	+7	+148
E 149	766.5220	766.5290	766.3892	766.542	+20	+153
M 109	803.7414	803.7439	803.6051	803.756	+15	+151
[illegible] 149	836.3213	836.3193	836.1838	836.329	+8	+145
[illegible] 149	892.7438	892.7405	892.6073	892.751	+7	+144
[illegible]109	914.3253	914.3244	914.1889	914.333	+8	+144
[illegible]149	935.9159	935.9083	935.7745	935.924	+8	+150
[illegible]109	955.4355	955.4847	955.3470	955.498	+62	+151
[illegible]	965.5637	965.5561	965.4211	965.571	+7	+150
[illegible]	982.4149	982.4083	982.2715	982.424	+9	+152
[illegible]	1004.4790	1004.4819	1004.3421	1004.495	+16	+153
[illegible]	1027.2303	1027.2302	1027.0940	1027.245	+15	+151
[illegible]	1035.9446	1035.9469	1035.8105	1035.960	+15	+150
[illegible]	1046.9935	1046.9970	1046.8609	1047.014	+20	+153
[illegible]	1077.4600	1077.4425	1077.3187	1077.473	+13	+154
[illegible]	1[illegible]5.3994	1095.3792	1095.2617	1095.430	+31	+168

*[illegible]rk reset

Table 2-1—Continued

XI: 10 miles north of Las Vegas, Nevada, to 35 miles north of Chloride, Arizona—Continued

BM	Elevation (meters)				Change in elevation (millimeters)	
	1935	1940-41	1949-50	1963	1935-63	1949-63
[illegible]72	595.2820	595.1735	595.1196	595.170	−112	+50
[illegible]2	623.7124	623.6059	623.5475	623.608	−104	+60
S [illegible]72	661.0292	660.9181	660.8598	660.927	−102	+67
N 173	679.9593	679.8432	679.7918	679.860	−99	+68
R 172	696.4189	696.3002	696.2498	696.320	−99	+70
P 173	714.2253	714.1094	714.0575	714.131	−94	+73
Q 172	736.6823	736.5666	736.5141	736.592	−90	+78
Q 173	708.2675	708.1564	708.1234	708.241	−27	+118
P 172	691.0658	690.9566	690.9087	690.985	−81	+76
[illegible]72	637.1047	636.9945	636.9410	637.007	−98	+66
S 173	618.2547	618.1452	618.0865	618.147	−108	+61
M 172	597.9426	597.8321	597.7748	597.828	−115	+53
T 173	580.9883	580.8780	580.8227	580.872	−116	+49
L 172	567.8658	567.7570	567.7047			
K 172	545.8283	545.7160	545.6617	545.708	−120	+46
J 172	530.7755	530.6608	530.6092	530.651	−125	+42
[illegible] 172	508.2401	508.1281				
[illegible]8 B	493.3775	493.2640	493.2144	493.252	−126	+38
[illegible] 172	492.6757	492.5609	492.5114	492.550	−126	+39
[illegible]2	476.6946	476.5791	476.5318	476.570	−125	+38
E 172	462.0646	461.9500	461.8989	461.934	−131	+35
D 172	443.1696	443.0526	442.9992	443.036	−134	+37
C 172	420.5034	420.3842	420.3302	420.366	−137	+36
B 172	397.4192	397.3002	397.2466	397.276	−143	+29
B 173	401.0312	400.9126	400.8572	400.888	−143	+31
[illegible]73	399.0861	398.9666	398.9126	398.943	−143	+30
A 172	378.3464	378.2249	378.1722	378.199	−147	+27
Line continues at Detrital Wash Gage						
U 120	372.9261	372.8298	372.7085	372.726	−200	+18
T 120	381.6922	381.5968	381.5606	381.576	−116	+15
S 120	386.8406	386.7474	386.7024	386.721	−120	+19
[illegible] 120	392.4618	392.3650	392.3204	392.339	−123	+19
[illegible]20	396.7546	396.6577	396.6123	396.631	−124	+19
P 120	404.6594	404.5659	404.5173	404.537	−122	+20
N 120	406.8016	406.7066	406.6591	406.680	−122	+21
M 120	414.1629	414.0677	414.0188	414.042	−121	+23
K 120	425.3583	425.2608	425.2163	425.242	−116	+26
J 120	430.5282	430.4310	430.3857	430.412	−116	+26

Table 2-1—Continued

Line continues at Detrital Wash Gage—Continued

BM	Elevation (meters)				Change in elevation (millimeters)	
	1935	1940-41	1949-50	1963	1935-63	1949-63
H 120	437.2917	437.1937	437.1483	437.177	−115	+29
F 120	446.8332	446.7363	446.6907	446.718	−115	+27
B 120	474.3705	474.2753	474.2321	474.263	−107	+31
A 120	491.4185	491.3267	491.2813	491.310	−108	+29
W 119	501.0701	500.9792	500.9328	500.963	−107	+30
V 119	491.0919	491.0019	490.9603	490.987	−105	+27
S 119	520.5318	520.4429	520.3987	520.430	−102	+31
R 119	544.0001	543.9180	543.8669	543.905	−95	+38
Q 119	556.3500	556.2715	556.2193	556.255	−95	+36
P 119	575.7561	575.6772	575.6226	575.664	−92	+41
N 119	586.8172	586.7378	586.6809	586.724	−93	+43
M 119	600.7776	600.7058	600.6486	600.693	−85	+44
L 119	611.5263	611.4544	611.3992	611.445	−81	+46
K 119	620.2487	620.1730	620.1232	620.169	−80	+46
J 119	626.4799	626.4060	626.3575	626.403	−77	+45
H 119	658.3606	658.2970	658.2393	658.288	−73	+49
G 119	678.6425	678.5812	678.5170	678.572	−70	+55
F 119	689.4392	689.3790	689.3172	689.374	−65	+57
E 119	698.7463	698.6917	698.6300	698.689	−57	+59
D 119	670.3047	670.2366	670.1858	670.238	−67	+52
C 119	667.3118	667.2426	667.1962	667.248	−64	+52
B 119	685.0971	685.0323	684.9830	685.037	−60	+54
A 119	710.4912	710.4269	710.3751	710.429	−62	+54

. cCullough and Eldorado Mountain Ranges. Regional tectonics are shown in Figures 2-2 and 2-3.

~~uctural basins containing sedimentary deposits form intermountain valleys. Mountains and valleys were formed by the mechanics of block faulting, a seismological process where large blocks of the earth's crust were uplifted or lowered along major faults. The ults have substantial displacement ranging from a few et to several thousand feet. The upfaulted blocks ave been eroded to the present mountain forms. Diverse fluvial and lacustrial sediments of Tertiary to Quaternary age are deposited on the down-faulted blocks. The Grand Wash Cliffs, formed by the Grand Wash fault, separate the Basin and Range Physiographic Province from the Colorado Plateau Physiographic Province at the head of Lake Mead. The Grand Wash fault has been traced for more than 110 miles. The area est of the fault is believed to have dropped, relative the area east of the fault, about 16,000 feet. Lake Mead is surrounded by a large number of gravity faults in the underlying rock formations. The presence of the vast weight of water in Lake Mead has caused minor earth tremors, but there has been no evidence of violent earth crustal movements. These gravity faults are known to be relatively inactive in the Quaternary period.

alysis of Releveling Data

eveling data of 1963 and the Coast and Geodetic urvey elevations, based on their "special" adjustment, generally indicate the reservoir area of Lake Mead made a rebound since the 1948-49 survey.

Lines were drawn connecting points of equal change in elevation for the periods 1935-63 (Figure 2-2) and 19-63 (Figure 2-3) using the 1963 level data. bound or subsidence in areas between the releveled lines were interpolated to indicate the pattern of vertical movement. The areas of vertical movement were delineated by contours of increasing or decreasing elevations determined from relevel data. Broken lines were drawn to indicate areas where releveling was not run in 1963 and where releveled lines were relatively far apart. In these areas, 1964 "supplemental" Coast a ! Geodetic Survey data were used to estimate the d of movement.

Areas of subsidence and rebound are evident in the 1935-63 change in elevation map (Figure 2-2). Rebound areas are indicated in the upper Colorado River and upper Virgin River arms of Lake Mead and subsidence indicated in the other areas. Most of the subsidence occurred between 1935 and 1963 in the Las Vegas area. The land surface of Las Vegas Valley has subsided from Henderson northeasterly through Las Vegas to Nellis Air Force Base. A maximum subsidence of 709 millimeters (mm) appears at the intersection of Level Lines IV and V at Las Vegas. A large area of subsidence enclosing both Boulder and Virgin Basins, with pronounced depressions near the center of each basin, is indicated for the period between 1935 and 1963. The Boulder Basin depression has a depth of 40 mm and is separated from the Las Vegas depression by the more stable Frenchman Mountain ridge composed of quartzite, limestone, and conglomerate formations. A strong fault zone on the western edge of a Pre-Cambrian granite in Boulder Canyon bordering Boulder Basin on the east and other existing gravity faults (vertical breakage planes) south of Hoover Dam and north and west of Boulder Basin possibly have some effect on the Boulder Basin depression. The depression could have been influenced by the more easily compressible and flexible mid-Cenozoic to recent formations comprising the floor of this basin. The Virgin Basin shows a maximum subsidence of 200 mm. Gravity faults in rock formations surrounding Boulder Wash have possibly influenced the shape of this depression.

For the 1949-63 period, the area between Hoover Dam and the mouth of Detrital Wash has remained relatively stable (see Figure 2-3). The rebound in Boulder Basin and Virgin Basin since 1949, varies between 0 and 40 mm. The relevel data have again disclosed an enlarged depression in Las Vegas Valley which correlates strongly with changes in ground-water levels during the same time period and further substantiates the theory that subsidence in Las Vegas Valley is due to removal of ground water. It is generally concluded that subsidence in the Lake Mead area since 1949 has ceased and the formations underlying the reservoir are in a state of rebound.

Three reasons were suggested[2-1] for subsidence: (1) elasticity of the underlying rocks, (2) movement along existing faults, and (3) compaction of alluvial deposits and loosely consolidated formations on the reservoir bottom. The 1949 relevel data support the second and third reasons. The first is supported by the 1963 relevel data.

Earthquake epicenters have been located by seismographic methods at 1.5 miles east-northeast, 4 miles west and about 10 miles northwest of Hoover Dam. An earthquake, that occurred in this locality shortly before the 1963 releveling, could have influenced the rebound in Boulder Basin as determined by the 1963 relevel data.

2- eological Survey, "Comprehensive Survey of Sedimentation in Lake Mead, 1948-49," Professional Paper 295, 2 , 1960.

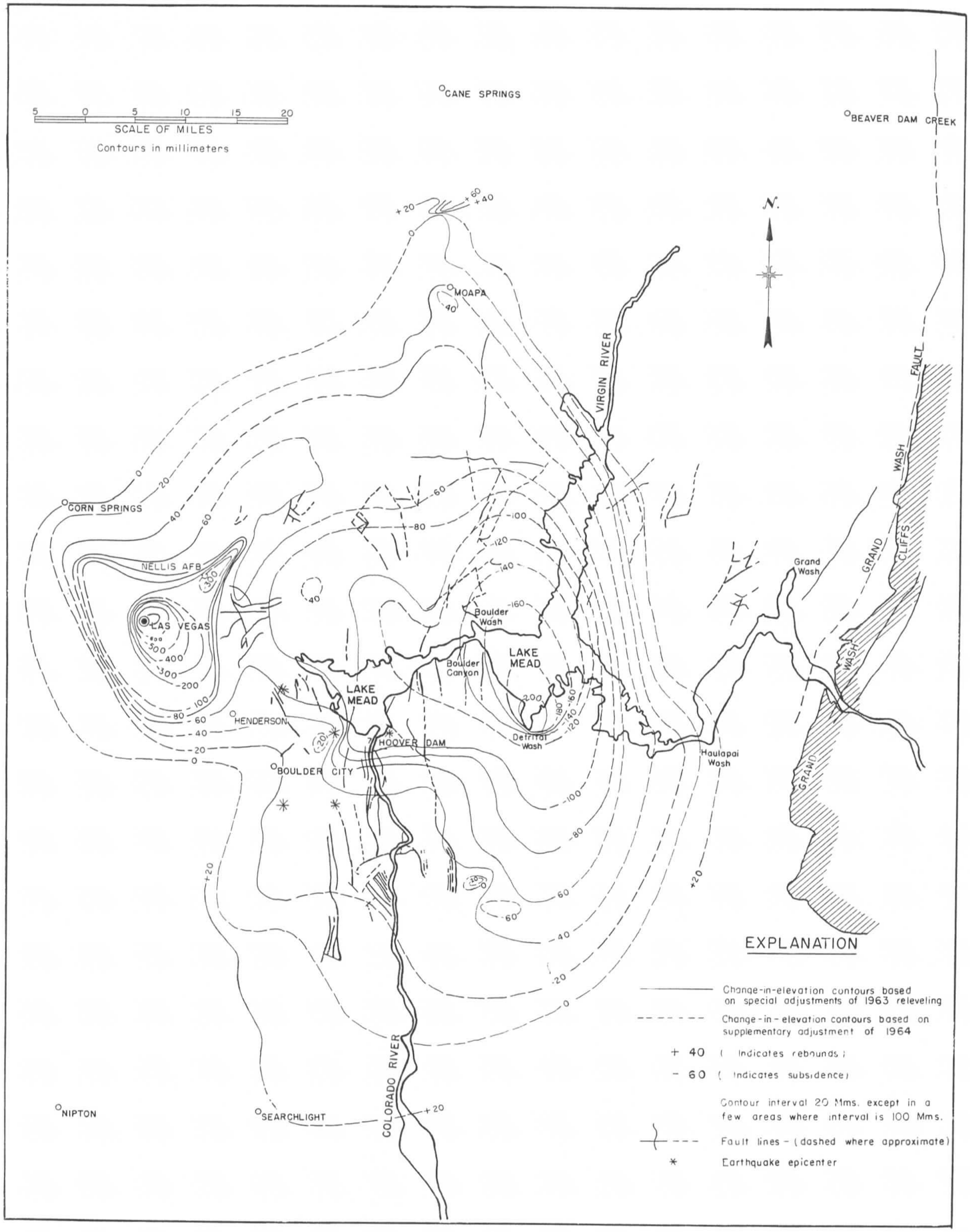


Figure 2-2. Contours showing changes in elevation, 1935 to 1963.

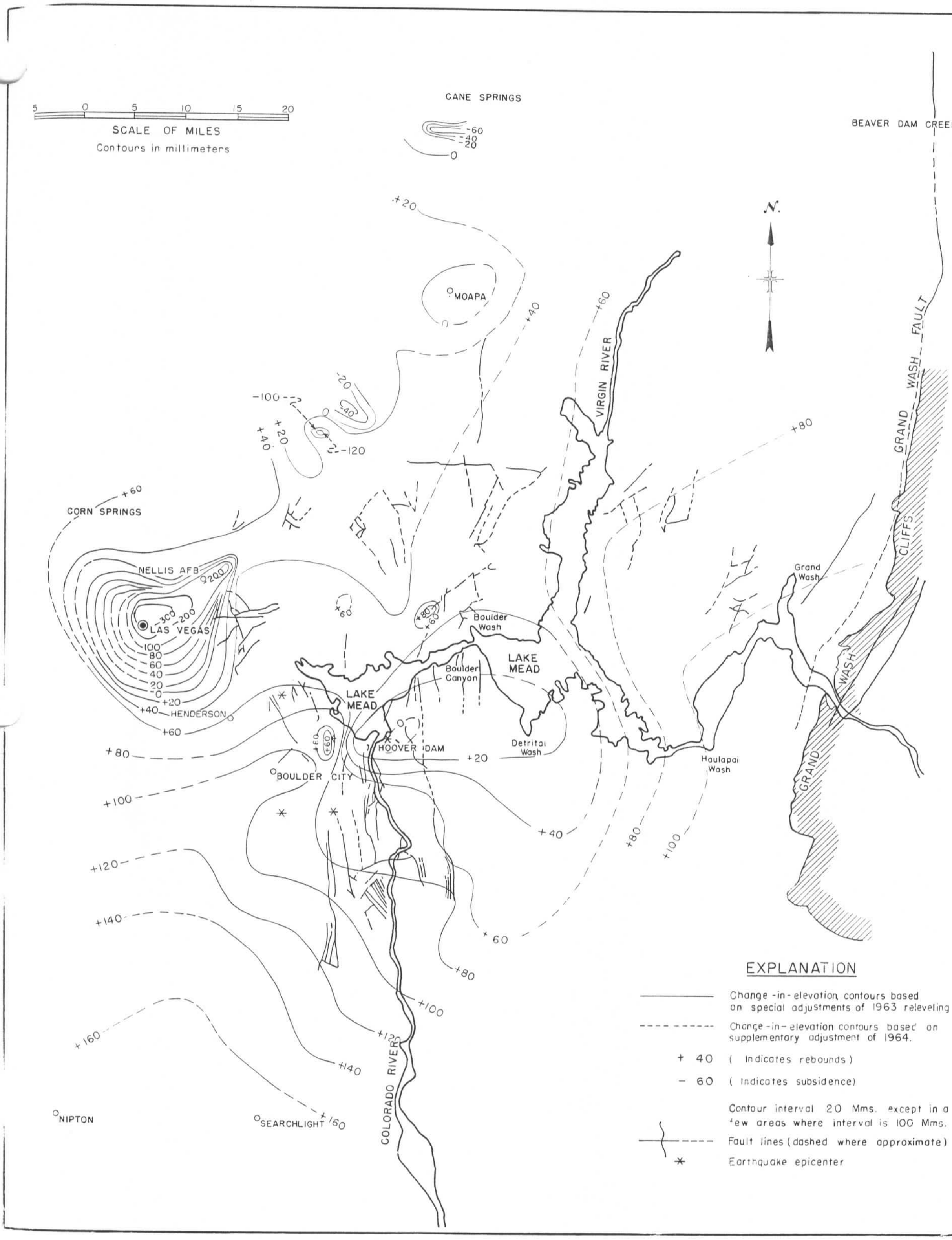


Figure 2-3. Contours showing changes in elevation, 1949 to 1963.

Effect of Subsidence or Rebound Upon Reservoir Capacity

The precise leveling of 1935 known as Hoover Dam net "Powerhouse Datum" has been used as a base for all topographic and hydrographic surveys of the reservoir area and for tabulations of reservoir area and capacity in 1940-41, 1948-49, and 1963-64. The computations of area and capacity do not include adjustments for any changes in elevations of the basic reference marks as documented by any of the releveled lines since 1935.

Table 2-2 shows the changes that have occurred at 17 of the Hoover Dam bench marks. Subsidence averaged 118 mm since 1935 at the dam as contrasted to a subsidence range of 60 to 200 mm in the Boulder Basin, Boulder Canyon and Virgin Basin portions of the reservoir indicated in Figure 2-2. More than 80 percent of the reservoir capacity at elevation 1150 feet is contained in Boulder Basin, Boulder Canyon, and Virgin Basin. This percentage increases with declining lake levels. An average rebound of 8 mm was noted for the 17 bench marks at the dam since 1949 as compared to the 20- to 80-mm range of rebound indicated in Figure 2-3 for this portion of the reservoir.

The change in reservoir capacity since 1935, that occurred owing to subsidence or rebound of the reservoir basin, is considered insignificant because the changes in elevation representing most of the reservoir bottom have been relatively small and in the same direction as the Hoover Dam change in elevation. Furthermore, a 200-mm change in elevation (0.66 foot), which is about the maximum divergence indicated by the 1963 relevel data, is within the accuracy limits of the survey methods used to determine the 10-foot reservoir contours.

Table 2-2

HOOVER DAM

AVERAGE SUBSIDENCE IN MILLIMETERS
(Special Adjustment)

1935-63; 1949-63

Bench marks at Hoover Dam	1935 elevation meters	1949 elevation meters	1963 elevation meters	1935-63 difference millimeters	1949-63 difference millimeters
E 174	375.8266	375.6992	375.705	−122	+6
K 174	377.0976	376.9676	376.974	−124	+6
F 174	375.8028	375.6735	375.683	−120	+9
J 174	375.8240	375.7163	375.733	−91	+17
G 174	375.7931	375.6700	375.682	−111	+12
H 174	375.8119	375.6808	375.693	−119	+12
Q 135	375.8013	375.6720	375.686	−115	+14
R 135	375.7964	375.6776	375.692	−104	+14
U 135	375.8412	375.7362	375.756	−85	+20
S 135	375.8022	375.6796	375.692	−110	+12
T 135	375.8292	375.7122	375.723	−106	+11
Z 135	205.8365	205.7015	205.702	−134	0
L 174	205.8249	205.6993	205.697	−128	−2
M 174	205.8367	205.7009	205.701	−136	0
Y 135	205.8264	205.7036	205.705	−121	+1
Q 174	214.8902	214.7470	214.749	−141	+2
C 136	214.8942	214.7554	214.758	−136	+3

1935-63 average subsidence = 118 mm.
1949-63 average rebound = 8 mm.

PART 3–HYDROGRAPHIC SURVEY

Objective

The objective of the hydrographic survey was to obtain the latest data on the reservoir contour areas at 10-foot vertical intervals below water surface elevation of 1229 feet. These data were used to determine the new area and capacity of the reservoir. They also provided information on the volume and distribution of the sediment deposits and the extent of other reservoir changes determined by comparing with data from previous surveys (see Part 5).

Field work for the Lake Mead survey began on July 9, 1963, in the north Overton Arm area and was completed on October 14, 1964. The location and numbering system of the various basins are shown in Figure 3-1. Aerial photographs were taken during the fall of 1963 when the lake was at elevation 1150 feet. Sonar soundings were made from a launch to determine lake depths for the impounded reservoir area. Photogrammetric and standard surveying methods were used for the Overton Arm, Grand Bay, and Pierce Basin to determine the increased volume or the movement of sediment deposits that have occurred in the area above elevation 1150 feet since the 1948-49 survey. Lower Granite Gorge was surveyed by running the same cross-section locations used in the 1948-49 survey. The remaining areas above the 1150-foot level where no changes had taken place were not resurveyed.

Computations of the new Lake Mead areas and capacities were made and the results tabulated (Tables 3-5 and 3-6) using the 1963-64 data. These updated capacity tables are important to the efficient planning and scheduling operations of Lake Mead, the largest reservoir on the Lower Colorado River System.

The 1963-64 survey which determined the volume and distribution of sediments is a valuable supplement to the 1948-49 comprehensive survey of Lake Mead. The rate of sediment inflow to Lake Mead was substantially changed after Glen Canyon Dam was closed in March 1963. Much of the sediment that heretofore deposited in Lake Mead is now being captured by Lake Powell (formed by Glen Canyon Dam).

Vertical Control

The reservoir forebay elevation gage at Hoover Dam was the principal reference used in establishing vertical control for the hydrographic surveys. This gage, included in the relevel net, was found to check the graphic record at the dam within 0.0l foot.

Additional tidal and staff gages shown in Figure 3-2 were established on the perimeter of Lake Mead. These were used to determine the lake surface elevation and possible differences because of seiches, tides, wind, and slope during the hydrographic survey. The gages were located at Boulder Wash, Nevada; Hualapai Wash, Arizona; Center Point, Arizona; Overton Arm, Nevada; Echo Bay, Nevada; and Detrital Wash, Arizona.

Vertical control for each cross section in the Lower Granite Gorge area was established by a combination of differential and trigonometric levels that were used with the established elevations of recoverable bench marks listed in a supplemental base data report.[3-1]

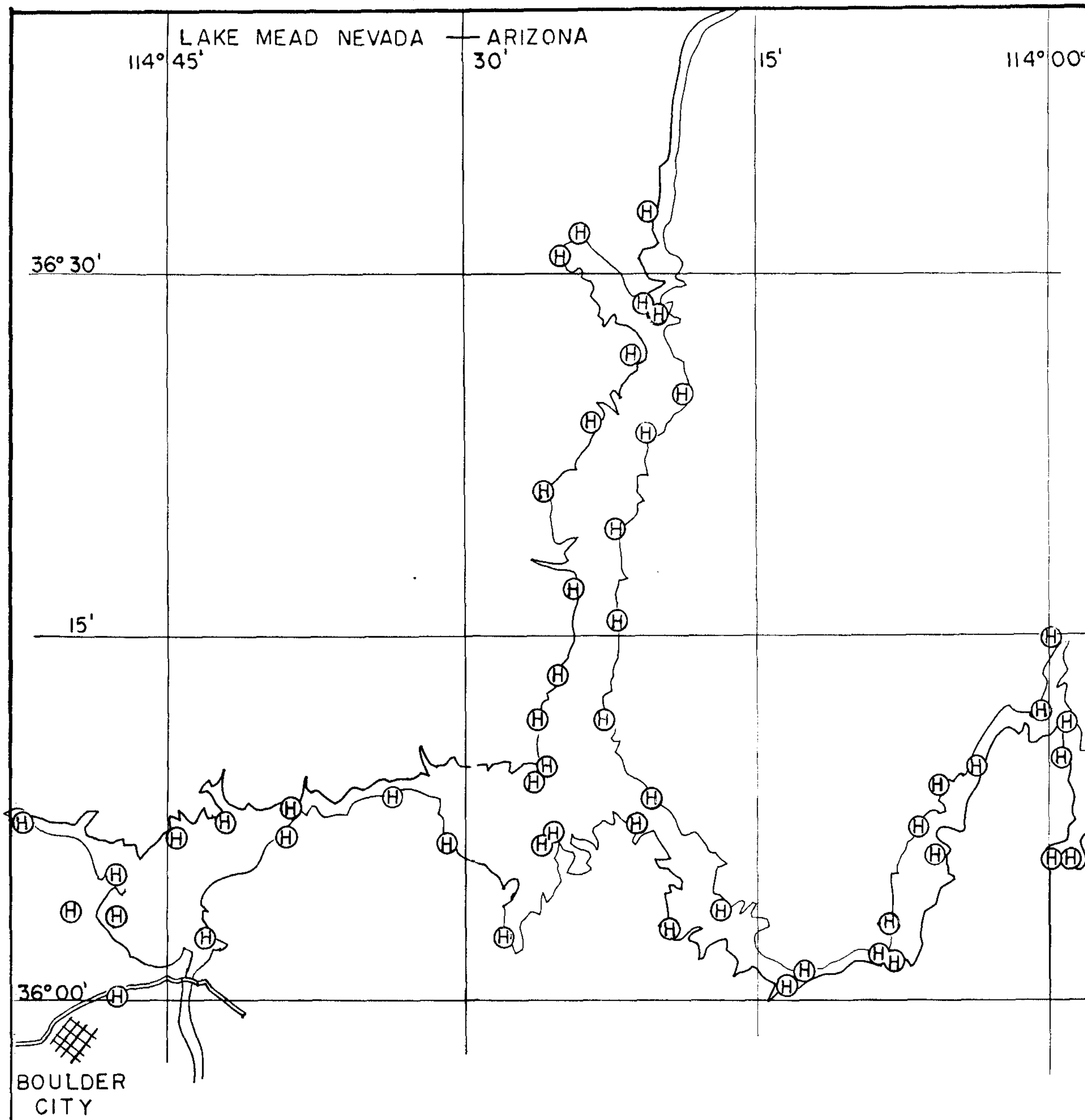
Horizontal Control

After reviewing the results of previous survey work, it was decided to use, wherever practicable, the same triangulation stations established during the 1948-49 survey for the horizontal control in the 1963-64 Lake Mead survey. Most stations were located and the others recovered or reestablished by third order triangulation. The station locations were plotted on boat sheets to control boat lines and to sight fixes (positions) as needed. The triangulation nets established during the 1948-49 survey for the various basins in Lake Mead are shown in the Geological Survey report.[3-2] Tables listing the geographic positions of the triangulation stations are given in a supplemental base data report.[3-3]

Triangulation Work

Fifty-two stations were premarked for aerial photography with 15-foot white crosses, most of which were centered over existing triangulation stations. The map (scale 1:500,000) in Figure 3-3 shows where these stations were located and Table 3-1 lists their coordinates in the East Zone, Nevada Grid. Ten of the stations were in areas where control was not available and were located by third order triangulation. Many of the triangulation station poles set up in the 1948-49 survey were still in place and served as sighting points for this later survey. Triangulation stations close to the shoreline were excellent targets for sighting by sextant. The boat sounding positions were plotted directly from the sextant sightings on the triangulation stations.

[3-1] U.S. Department of the Interior, "Supplemental Base Data for Lake Mead Comprehensive Survey of 1948-49," Report, 121 p, July 1954.
[3-2] Geological Survey, "Comprehensive Survey of Sedimentation in Lake Mead, 1948-49," Professional Paper 295, 254 p, 1960.
[3-3] Same as footnote 3-1.



CONTROL FOR AERIAL PHOTOGRAPHY

— 1963 —

JUNE 1 TO DEC. 31

SCALE — 1:500,000

LEGEND

Ⓗ PREMARKED HORIZONTAL CONTROL STATIONS FOR AERIAL PHOTOGRAPHY

═══ U.S. HIGHWAY 93 & 466

FIGURE 3-3

Table 3-1

HORIZONTAL CONTROL STATIONS USED FOR AERIAL PHOTOGRAPHY

Station	East Zone Nevada Grid	
	X Coordinate	Y Coordinate
N-2	731,260.56	474,664.10
N-3	732,454.40	485,044.56
N-5B	714,228.42	501,339.82
Vegas Wash No. 1	706,504.08	507,715.08
Vegas Wash No. 2	734,586.20	499,181.29
N-8A	744,704.57	499,778.49
N-10A	757,912.21	502,749.83
N-12	775,955.36	506,687.62
N-34	839,289.87	516,542.61
N-39	844,543.09	542,381.18
N-54	848,978.46	563,749.23
N-55A	843,936.26	567,099.26
N-63	843,858.40	586,968.45
N-68	850,426.05	600,773.93
N-75	860,543.75	618,203.44
N-91	841,961.25	641,162.24
N-92	845,423.92	648,000.85
Virgin Arm Substation	865,672.15	657,462.32
N-80D	864,000.98	630,643.38
N80C	866,439.32	628,557.93
N-70	869,426.68	601,888.48
N-67	863,467.56	595,413.55
N-62	856,316.10	577,446.93
N-45	856,887.43	550,873.34
N-38	851,542.34	530,298.91
N-107	867,488.88	505,790.78
N-112	880,561.47	484,340.30
N-126	907,263.19	464,749.42
N-135	925,715.51	475,335.72
N-143	936,213.05	510,484.84
A-89	963,672.84	531,288.41
Grand Wash No. 2	964,843.52	549,882.36
A-90	965,895.60	530,427.31
A-115	970,682.85	501,466.24
A-116	968,847.29	502,444.65
A-97	968,334.35	521,531.44
A-73	947,955.08	523,391.24
A-65	937,412.80	491,939.99
A-58	924,599.76	466,720.18
A-47	902,857.96	462,650.55
A-36	869,435.46	473,956.34
A-32	861,136.74	500,466.29
A-27A	844,936.62	497,891.43
A-26C	841.531.26	492,622.22
A-25DA	829,792.19	474,607.37
A-24	814,662.89	498,639.88
A-20	798,433.88	510,696.88
Indian Canyon	776,126.30	500,888.30
A-2	754,217.40	477,300.86
Rough Substation	741,350.80	460,835.52
Rich	734,719.55	458,875.62
Scanlon Hill	926,900.35	492,990.30

The Nevada State system of plane coordinates was extended a short distance into Arizona by computations for the stations in Grand Bay and Pierce Basin. These computations were made by the Coast and Geodetic Office, Washington, D.C. Some of the stations were used for control of aerial photography in the upper Overton Arm, Grand Bay, and Pierce Basin where such photography was the supplemental technique necessary to delineate the 10-foot contours between elevations of 1150 and 1230 feet.

River range sections established in the 1948-49 survey but not recoverable in Lower Granite Gorge were relocated by traverse using a theodolite and a subtense bar. Traverse angles were measured by closing the horizon with a 6-second rejection and the subtense bar intercept measured four times with a 4-second rejection limit. When only one end of an old section was recoverable, direction was based on the compass azimuth listed in the supplemental base data report.[3-4] Azimuth checks at the beginning and end of traverses were made using a solar attachment with the theodolite. Each traverse was adjusted to the 1948-49 stadia traverse.

Hydrographic Survey Procedures

The Lake Mead Reservoir area was divided into two areas each surveyed by different techniques. Longitude 113° 57′ was the dividing line of the area between the main part of the lake and lower Granite Gorge. This was the same delineation used in the 1948-49 survey.

The main part of the lake was surveyed using echo-sounding equipment. This part, identified as "Lake Mead area west of Longitude 113° 57′," extends from Pierce Ferry for about 65 miles to Hoover Dam and includes the Overton Arm. It is characterized by a series or chain of wide basins connected by short narrow canyon sections.

The Lower Granite Gorge area was surveyed by conventional procedures using a manually operated sounding machine to resurvey the submerged portion of the cross sections. The gorge in the upper section of the lake is a deep rugged canyon about 40 miles long. It extends upstream from a point just above Pierce Ferry to Bridge Canyon.

Lake Mead Area West of
Longitude 113° 57′

Eleven reservoir sheets were laid out for mapping the Lake Mead area below elevation 1150 feet. The geographic limits of each sheet are given in the descriptive reports of the Coast and Geodetic Survey and their latitudes and longitudes listed in Table 3-2. Two supplemental reservoir Sheets, 7 and 11, were laid out for mapping the Overton Arm, Grand Bay, and Pierce Basin above elevation 1150 feet, the only areas showing any significant change in sediment deposits. These sheets cover about the same areas in Sheets 7 and 11 below 1150 feet. Figure 3-4 shows a layout of the 1963-64 survey sheets superimposed on the layout of the Soil Conservation Service 5-minute quadrangle sheets for the 1935 survey.

The latitudes and longitudes in Table 3-2 are not, in every case, the same as the common or match lines used by the Bureau of Reclamation for planimetry of sheet and basin contour areas. Some basin areas included more than one smooth sheet. In some cases it was necessary to use the original 1935 Soil Conservation Survey contour areas above the 1150-foot elevation to complete the elevation-area relationship for the whole reservoir. In these cases it was necessary to planimeter the areas between the previously established basin boundaries and the 5-minute quadrangle limits of the original 1935 survey.

Water depths were found using sonar equipment and using some manual leadline soundings in the submerged portions. In the exposed portions of the reservoir, elevations were determined by standard land surveying procedures.

Two fathometers, one operating on 200 kc and the other on 20 kc, were installed in each vessel. The 200-kc fathometer operating in the foot mode was primarily used to obtain soundings for the entire survey. In areas having an irregular bottom both echo sounders were operated with the 20-kc instrument set in the fathom mode so the fathometer operator could determine the correct range of the 200-kc instrument. Both fathometers were operated in the foot mode on crosslines. Here the 200-kc fathometer would sound from the top of the sediments; however, the 20-kc echo sounder did not penetrate the silt as expected.

A variable frequency power supply unit was furnished for experimental purposes consisting of an inverter, driven by a variable 12-volt direct-current supply capable of delivering a 115-volt alternating current at a frequency range of 57 to 63 cps. The speed of the stylus drive motor could be controlled as desired by changing the input power frequency to the fathometer recorder. The operator was able to choose a power frequency which gave the least overall correction for

[3-4] Ibid.

Table 3-2

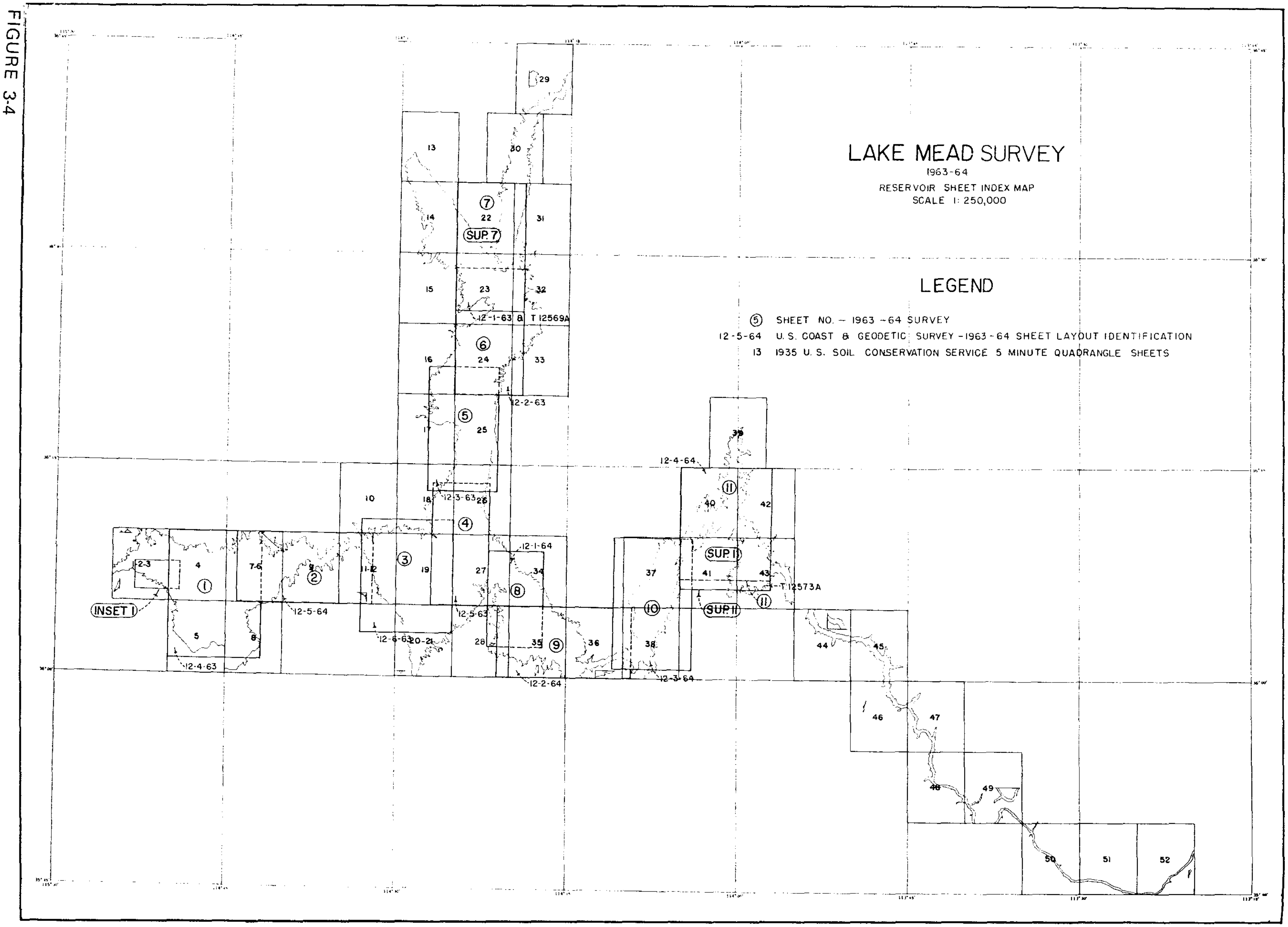
1963-64 LAKE MEAD SHEETS

S.B.R. Sheet	USC&GS Field No.	Geographic Description			
		Latitude		Longitude	
		From	To	From	To
nset 1	12-4-63	36°06'N	36°08'N	114°49'W	114°53'W
et 1	12-4-63	36°01'N	36°10'N	114°42'W	114°50'W
et 2	12-5-64	36°05'N	36°10'N	114°32'W	114°44'W
Inset 3	12-6-63	36°03'N	36°11'N	114°25'W	114°33'W
Inset 4	12-5-63	36°05'N	[1] 36°13'N	114°22'W	114°27'W
Inset 5	12-3-63	36°13'N	36°22'N	114°21'W	114°27'W
Inset 6	12-2-63	36°20'N	36°29'N	114°19'W	114°25'W
Inset 7	12-1-63	36°26'N	36°35'N	114°19'W	114°25'W
Supp. 7	*T-12569A	36°26'00"N	36°35'00"N	114°19'00"W	114°25'00"W
Supp. 8	12-1-64	36°02'N	36°09'N	114°17'W	114°22'W
pp. 9	12-2-64	36°00'N	36°05'N	114°09.15'W	114°21'W
p. 10	12-3-64	36°00.70'N	36°10'N	114°04'W	114°11'W
pp. 11	12-4-64	36°07'N	36°15'N	113°57'W	114°05'W
Supp. 11	*T-12573A	36°06'30"N	36°15'00"N	113°57'00"W	114°05'00"W

* Shoreline Manuscript number.

[1] U.S. Coast and Geodetic Survey Descriptive Report H-8776 states that the north limit of this sheet is at latitude 36°13'N. A Government memorandum dated 17 May 1965, for Contour Sheet C&GS HFP-12-5-63, states that the north limit of this sheet is at latitude 36°13'30"N.

FIGURE 3-4


LAKE MEAD SURVEY
1963-64
RESERVOIR SHEET INDEX MAP
SCALE 1: 250,000
LEGEND
⑤ SHEET NO. – 1963 –64 SURVEY
12-5-64 U. S. COAST & GEODETIC SURVEY –1963 – 64 SHEET LAYOUT IDENTIFICATION
13 1935 U. S. SOIL CONSERVATION SERVICE 5 MINUTE QUADRANGLE SHEETS
INSET I
SUP. 7
SUP. I
SUP. II
12-1-63 & T 12569A
12-2-63
12-3-63
12-4-63
12-5-63
12-6-63
12-1-64
12-2-64
12-3-64
12-4-64
12-5-64
T 12573A

ti ange to be sounded. The change in recorded soundings was proportional to any change made in the wer frequency. The largest change in the recorded undings occurred at the greater water depths. The effects of temperature were also considered during the experimental tests. The Lake Mead curve relating temperature and depth showed a sharp bend between 50 and 75 feet. Changing the power supply to consider erature effects would not reduce the corrections the entire range of soundings. After running se ral bar checks, 60 cps was the operating frequency found to yield the most accurate results; therefore, standard inverters were used.

In traversing areas of irregular bottom, the fathometer operator occasionally was unable to switch depth scales at a rate equal to the rate of substantial change in ttom conditions; therefore, soundings were made the 20-kc instrument set in fathom mode. For se situations, a notation was entered in the field books (sounding volumes) that the fathom scale was used in the soundings. Velocity corrections for these soundings were determined and also entered in the sounding volumes. Echo-sounding corrections applied to the fathometer soundings were determined from daily bar checks and temperature observations taken at 2-week intervals.

echo-sounding equipment provided continuous undings along designated lines or courses. Soundings re made along parallel lines spaced about 300 yards art. The divergence at the ends of lines in radial patterns was generally less than 400 yards. Boat lines were controlled by visual three-point fixes on the triangulation stations. Additional topographic signals were located by ground survey methods. In zones where hydrography was run with no available fixes, at sounding lines were controlled by transit sighting d stadia from shore.

Two sets of map sheets of the lake were prepared for the survey. One set, called boat sheets, was used for delineating the sounding lines to be run and for field plotting the boat courses actually traveled. The other set, called smooth sheets which conform to more rigid mapping standards, was used for the final smooth otting of the boat courses, entry of the bottom vations as computed from the echo-sounding corders, and the delineation of contour lines indicated by the sounding data. In some cases the normal procedure of locating positions on the boat sheet using prominent shoreline features was not followed although a position was given at the end of the lines and a reference, "see boat sheets," was noted in the sounding volumes. The lines were plotted on the boat sheets according to time and course; "see boat sheets" positions were not used for hydrographic contouring of smooth sheets. In all the coves in which hydrography was run with no available fixes, sounding lines were run by "dead reckoning." Dead reckoning is a procedure by which the position of a vessel at any instant is determined by applying the vessel's course from the last known position using the course heading in degrees, vessel speed in mph or knots, and the time traveled from the last known position.

When the survey of an area on one sheet was completed, the depths sounded along lines common to adjacent sheets were compared. Generally, agreement was good and the contours could be satisfactorily drawn at common lines.

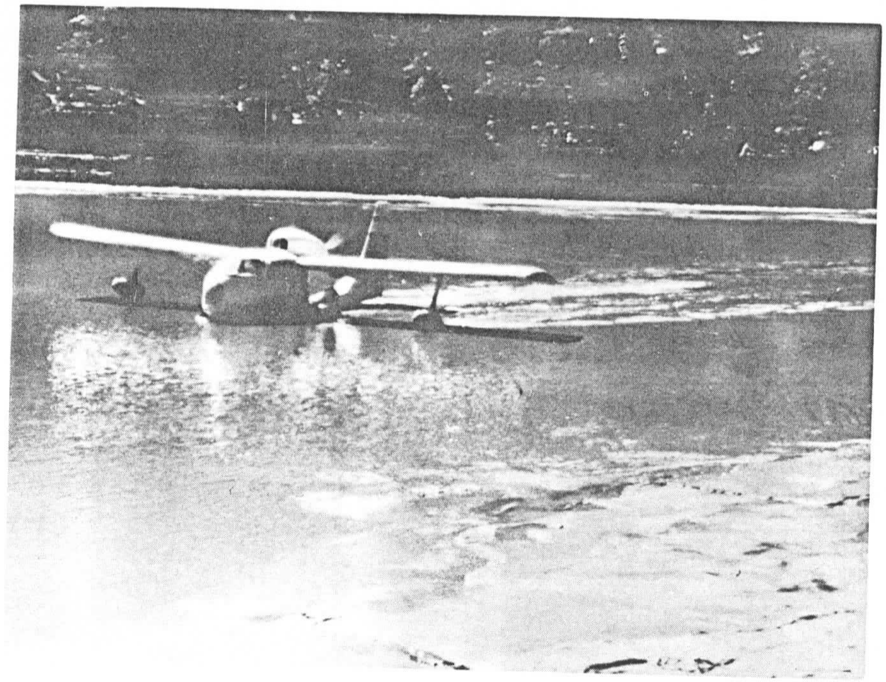
Comparison was also made with charts from the Coast and Geodetic Survey of 1955 revised in 1961. All reefs and rocks indicated on the charts were plotted on an overlay of the boat sheets with their respective elevations marked in red. For each rock or reef the charted position, charted elevations, new elevations found by this survey, and a recommendation of charting or changes were listed in the descriptive report written for each of the 11 respective area divisions. Fixed lights, reef markers, and other aids to navigation were investigated with regard to location, condition, elevation, and adequacy. The results and pertinent comments are given in the descriptive reports of the U.S. Coast and Geodetic Survey.

Lower Granite Gorge Area

To run the survey of the Lower Granite Gorge area, a six-man team was flown (Figure 3-5) into the gorge on September 23, 1963. A base Camp No. 1 was established in the gorge at River Mile 267 and later a Camp No. 2 was set up at River Mile 247.

The field work for the 1963-64 survey included reprofiling the same 174 river sections above the head of Pierce Basin used in the 1948-49 survey. Of these sections, however, 148 were recoverable and the other 26 had to be reestablished.

To reprofile the cross sections, three men were required, two aboard a 14-foot aluminum skiff equipped with a tag line and one ashore to keep the skiff on range. Horizontal distances between sounding points along each section were measured with a theodolite and stadia rod. Soundings were taken using a tag line that was run through a registering sheave calibrated in fathoms and attached to a standard Coast and Geodetic Survey hand-sounding machine mounted



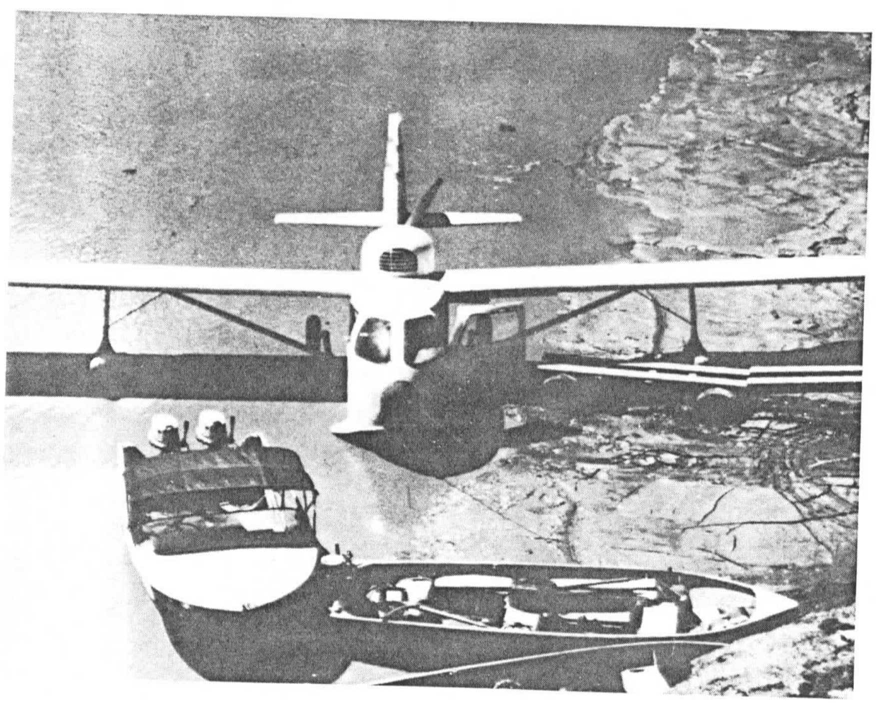


Figure 3-5. Because of the low lake levels prevailing in 1963, surface watercraft could not be used for traveling to the Pierce Ferry Basin delta area. Above are two views of the amphibian used to transport men and equipment to the inaccessible areas in Lower Granite Gorge of the Colorado River. Top Photo P45-D-68117, bottom Photo P45-D-68118

in th skiff. At the free end of the tag line a standard mud anchor was attached with a snap-type clip. The anchor was firmly seated on the beach on range and the skiff brought up to shore. The sheave was zeroed and the soundings were taken at 3-fathom (18-foot) intervals. Because of the strong currents prevailing, it was necessary to back the skiff across the river using the engines in reverse to control alinement and keep on range. Stadia methods (Figure 3-6) were used to establish the elevation of the water surface, locate water's edge, and check tag line distances.

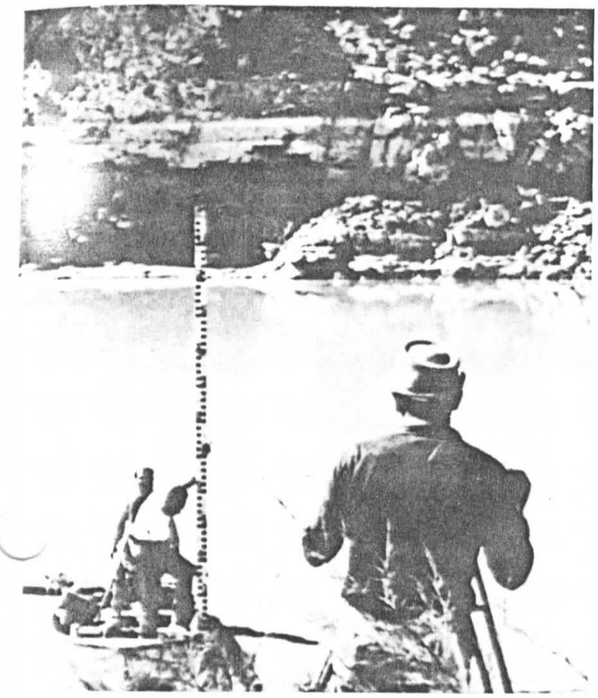


Figure 3-6. Example of using stadia to establish reservoir water's edge. Photo P45-D-68119

The crosses marking each relocated range were repainted white. White crosses were also painted at the ends of each range reestablished during the 1963-64 survey.

Determination of Contour Areas

Contour areas were determined by personnel from the Regional Office, Bureau of Reclamation, Boulder City, Nevada. The areas at 10-foot contours below elevation 1150 feet for the reservoir lake portion, excluding Lower Granite Gorge, were determined from the topographic sheets of the 1963-64 survey. Supplemental topographic sheets of this survey and portions of the 5-minute quandrangle sheets of the 1935 Soil Conservation Service survey were used to trace contour areas above elevation 1150 feet.

The subbasin boundary lines were at different latitudes and longitudes from the common or match lines of the 1963-64 topographic sheets. It became necessary, therefore, to divide the planimetering of certain topographic sheets at subbasin boundaries so the proper areas could be totaled for the individual subbasins. It was also necessary to do this on various portions of the 1935 5-minute quadrangle sheets.

Each 10-foot contour on the topographic sheets was planimetered a minimum of three runs. Averages were taken of the recorded differences between beginning and end readings for each run. These averages were multiplied by the acreage factor per planimeter unit to obtain the contour areas.

The percentage of difference between the runs for each contour was obtained and used as a guide in selecting contours to be replanimetered as a check. Using this guideline, a minimum of two 10-foot contours per topographic sheet having the greatest percentage of difference was selected.

All contours encompassing an area greater than 25 acres, with a maximum difference of 1 percent between runs, were replanimetered as a check. For contour areas of 25 acres or less, a 2 percent difference between runs was allowed before making a smiliar check. Examining the actual percentage of difference in a representative number of elevations showed an average of 0.6 of 1 percent variation between runs on the planimeter work for this survey. The replanimeter work was always done by a different planimeter operator.

The relation between elevation and area was plotted for each topographic sheet. When a marked deviation from the general trend of this relationship was noted, a planimeter check was made of the contour area at the elevation showing the divergence. In some instances, planimetric checks were also made of the contour areas at the 10-foot elevations above and below the one of maximum deviation.

From results of the two different types of planimeter checks described, necessary adjustments to the contour areas were made for the affected elevations.

Some topographic sheets had areas where the 10-foot contours were too closely spaced for accurate planimetering. Here, contour areas were determined by interpolating between the areas planimetered at elevations of greater contour intervals. This method was used for the area just upstream from Hoover Dam on Soil Conservation Service 5-minute quadrangle Sheet 8. Each 50-foot contour interval was planimetered and the intervening 10-foot contour areas determined by interpolation. The same method was used on that portion of Soil Conservation Service quadrangle Sheet 11-12 used for Boulder Canyon Basin X+Y, on which only the contours at elevations 1100, 1200, and 1300 feet were planimetered. In several instances this method was also used as a check on fully planimetered areas.

Contour areas by 5-minute quadrangle sheets as determined in the 1935 survey are given in Table 3-3. The full table is included for future reference. The 1935 data compiled by the Soil Conservation Service were used for areas above elevation 1150 feet except where areas were resurveyed in 1948-49. Certain corrections have been made and explanatory footnotes added to Table 3-3. The corrections apply to the 1935 survey results and include the addition of contour areas omitted and the correction of contour areas erroneously included. The Soil Conservation Service was consulted before corrections were made.

The Lower Granite Gorge portion of the reservoir was covered by 174 cross sections from the 1963-64 survey. Data from the 1948-49 survey were used to extend some of these sections to higher elevations.

Contour areas for the Lower Granite Gorge were computed using the average width times the length of the reach for each 10-foot vertical interval. This was done for each area between the 174 river sections covering the entire length of Lower Granite Gorge. Areas between reaches at the same 10-foot elevation were then added to arrive at the total 10-foot contour areas of the gorge. Side canyon areas along Lower Granite Gorge were determined by planimetering 100-foot contour areas and interpolating values for each 10-foot contour.

Comparative contour areas for the 1935, 1948-49, and 1963-64 surveys are listed in Table 3-4. The total contour areas at 10-foot elevation intervals for each basin are listed in Table 3-5 for the 1963-64 survey.

Computation of Reservoir Capacities

The capacities of the individual basins and of the total reservoir as listed in Table 3-6 were computed using the data of the areas planimetered. The computations were made by personnel of the Division of Data Processing, Office of Chief Engineer, Bureau of Reclamation, Denver, Colorado. Area and capacity curves are shown in Figure 3-7. Total individual basin capacities are listed in Table 3-7 for each of the surveys run in 1935, 1948-49, and 1963-64.

A computer program was written to interpolate the total and individual basin area values at 1-foot elevation intervals by the Lagrangian Method applied to the values in Table 3-5. Using these interpolated area values, total and individual basin capacities were, in turn, computed also at 1-foot elevation intervals by the average end-area method. A study of the computer output results shows that exact checks using a desk calculator cannot always be obtained of the capacity between 10-foot elevation intervals. These checks cannot be obtained because of the accumulative and rounding-off effects that occur in the computer processing of the values at the 1-foot elevation intervals.

The 1963-64 survey indicates that the total reservoir volume below elevation 1229 feet decreased 1,292,000 acre-feet since the 1948-49 survey. Changes in capacity of the individual subbasins below elevation 1229 feet are listed in acre-feet in table on following page.

Reasons for the changes listed in the table on following page are discussed in Part 5.

Miscellaneous Hydrologic Data

The monthly evaporation losses and end of the month surface areas are recorded in the graph of Figure 3-8. The recorded average monthly Hoover Dam releases and available contents since 1935 are plotted in Figure 3-9.

CHANGES IN CAPACITY OF INDIVIDUAL SUBBASINS IN ACRE-FEET

Basin	[1] 1935 to 1948-49	[2] 1948-49 to 1963-64	Totals
Boulder Basin	[3] −437,000 (Boulder Basin, Boulder Canyon, Virgin Basin)	−81,700	[3] 850,700 (Boulder Basin, Boulder Canyon, Virgin Basin)
Boulder Canyon		−54,000	
Virgin Basin		−278,000	
Temple Bar Area	[4] −59,000 (Temple Bar Area, Virgin Canyon)	−87,000	[4] 163,700 (Temple Bar Area, Virgin Canyon)
Virgin Canyon		−17,700	
Gregg Basin	−114,000	−206,100	320,100
Grand Bay	−97,000	−269,800	366,700
Pierce Basin	−144,000	−222,700	366,700
Lower Granite Gorge	−541,000	+15,800	525,200
Overton Arm	−33,900	−91,900	125,800
Total	−1,425,900	−1,293,100	2,718,900

[1] Taken from Table 6 of report, "Comprehensive Survey of Sedimentation in Lake Mead, 1948-49," Professional Paper 295, Geological Survey, 1960.

[2] See Table 5-1 of this report.

[3] Total in Boulder Basin, Boulder Canyon, and Virgin Basin.

[4] Total in Temple Bar Area and Virgin Canyon.

Table 3-3

SOIL CONSERVATION SERVICE
1935 LAKE MEAD SURVEY

10-foot Contour Areas in Acres

Sheet No.	Elevation (feet)				
	650	660	670	680	690
1, 2, 3					
4					
5				73.82	136.86
6, 7			128.00	190.16	423.44
8				365.79	663.69
9		227.62	734.97	913.19	1,178.06
10			3.98	23.47	134.02
11, 12					
14					
15					
16					
17					
18					
19					
20, 21					
22					
23					
24					
25					
26					
27					
28					
30					
31					
32					
33					
34					
35					
36					
37					
38					
39					
40					
41					
42					
43					
44					
45					
46					
47					
48					
49					
50					
51					
52					
Totals		227.62	866.95	1,566.43	2,536.07

Table 3-3—Continued

SOIL CONSERVATION SERVICE
1935 LAKE MEAD SURVEY

10-foot Contour Areas in Acres

Sheet No.	Elevation (feet) 700	710	720	730	740
1, 2, 3					
4	205.08	241.55	277.71	313.89	358.26
5	460.82	519.06	582.59	652.13	715.86
6, 7	1,106.57	1,388.97	1,643.85	1,813.78	1,990.57
8	1,326.15	1,400.32	1,466.88	1,525.43	1,578.10
9	386.26	457.04	520.57	582.76	640.55
10					
11	36.54	123.61	275.83	382.95	610.64
14					
15					
16					
17					
18					
19					288.62
20, 21					
22					
23					
[illegible]					
25					
[illegible]					
[illegible]					2.59
[illegible]					
30					
31					
32					
33					
[illegible]					
[illegible]					
36					
37					
38					
39					
40					
41					
42					
43					
[illegible]					
[illegible]					
46					
47					
48					
49					
50					
51					
52					
Totals	3,521.42	4,130.55	4,767.43	5,270.94	6,185.19

Table 3-3—Continued

SOIL CONSERVATION SERVICE
1935 LAKE MEAD SURVEY

10-foot Contour Areas in Acres

Sheet No.	Elevation (feet)				
	750	760	770	780	790
1, 2, 3					
4	400.65	464.69	511.99	552.07	589.10
5	769.55	813.95	858.84	913.62	998.06
6, 7	2,166.27	2,426.19	2,662.51	2,828.78	2,978.71
8	1,621.83	1,677.21	1,734.17	1,790.08	1,852.62
9	678.27	717.17	744.17	768.88	795.09
10					
11, 12	874.94	993.54	1,099.84	1,254.24	1,423.30
14					
15					
16					
17					
18					
19	1,209.54	1,448.00	1,874.06	2,245.40	2,598.30
20, 21					
22					
23					
24					
25					
26				100.12	264.28
27	345.01	542.03	707.01	839.14	937.80
28					
30					
31					
32					
33					
34	118.93	174.88	198.54	238.42	274.31
35		12.55	122.87	392.85	670.02
36					83.99
37					
38			1.35	13.72	33.29
39					
40					
41					
42					
43					
44					
45					
46					
47					
48					
49					
50					
51					
52					
Totals	8,184.99	9,270.21	10,515.35	11,937.32	13,498.87

Table 3-3—Continued

SOIL CONSERVATION SERVICE
1935 LAKE MEAD SURVEY

10-foot Contour Areas in Acres

Sheet No.	Elevation (feet)				
	800	810	820	830	840
1, 2, 3					
4	626.17	677.03	729.08	781.26	829.21
5	1,142.80	1,288.78	1,422.75	1,577.07	1,719.89
6, 7	3,123.76	3,273.92	3,407.43	3,541.45	3,698.77
8	1,907.14	1,965.81	2,031.74	2,089.03	2,147.32
9	824.35	870.59	918.26	956.16	993.69
10					
1[illegible]2	1,553.69	1,650.14	1,728.29	1,809.59	1,873.10
14					
15					
16					
17					
18	156.42	319.11	499.46	635.73	798.29
19	3,111.04	3,535.90	4,034.76	4,380.65	4,637.82
20, 21					
22					
23					
24					
25					
26	571.49	834.60	1,008.90	1,076.59	1,172.77
27	1,026.25	1,117.35	1,214.39	1,373.38	1,516.04
28					
30					
31					
32					
33					
	296.51	317.23	336.09	354.05	371.30
	849.63	974.35	1,103.07	1,226.74	1,351.58
36	242.09	266.41	303.01	327.31	350.83
37			6.23	76.07	227.26
38	98.91	179.55	303.03	570.55	783.64
39					
40					1.94
41					
42					
45					
46					
47					
48					
49					
50					
51					
52					
Totals	15,530.25	17,270.77	19,046.49	20,775.63	22,473.45

Table 3-3—Continued

SOIL CONSERVATION SERVICE
1935 LAKE MEAD SURVEY

10-foot Contour Areas in Acres

Sheet No.	Elevation (feet)				
	850	860	870	880	890
1, 2, 3					
4	881.54	940.89	1,018.71	1,112.06	1,208.88
5	1,862.11	2,006.37	2,197.14	2,318.83	2,503.16
6, 7	3,858.52	4,034.51	4,213.40	4,433.06	4,608.68
8	2,211.16	2,279.50	2,341.28	2,403.01	2,455.15
9	1,045.35	1,098.46	1,151.75	1,206.41	1,261.06
10					
11, 12	1,946.31	2,021.43	2,088.52	2,163.52	2,253.84
14					
15					
16					
17					
18	901.72	998.58	1,066.86	1,149.05	1,190.72
19	5,025.43	5,301.62	5,449.20	5,758.26	5,983.84
20, 21					
22					
23					
24					
25				2.32	72.52
26	1,275.23	1,429.11	1,622.95	1,771.95	1,912.45
27	1,804.83	1,998.98	2,159.17	2,327.55	2,517.89
28					
30					
31					
32					
33					
34	396.61	418.52	453.20	478.99	510.19
35	1,481.77	1,607.14	1,734.94	1,873.57	2,036.65
36	385.28	407.63	434.12	454.84	498.56
37	409.61	654.77	851.32	980.47	1,104.45
38	1,199.20	1,350.00	1,445.00	1,527.15	1,632.56
39					
40	26.87	109.48	202.70	295.91	419.78
41		16.89	60.72	89.90	102.14
42				*9.43	*76.34
43				3.42	41.96
44					
45					
46					
47					
48					
49					
50					
51					
52					
Totals	24,711.54	26,673.88	28,490.98	30,359.70	32,390.82

*Areas added to table in 1966.

Table 3-3—Continued

SOIL CONSERVATION SERVICE
1935 LAKE MEAD SURVEY

10-foot Contour Areas in Acres

Sheet	Elevation (feet)				
	900	910	920	930	940
1, 2, 3					
4	1,321.97	1,448.63	1,586.39	1,727.66	1,865.56
5	2,710.80	2,940.59	3,099.03	3,235.06	3,423.35
6, 7	4,727.52	4,918.80	5,094.28	5,276.14	5,485.66
8	2,512.82	2,587.73	2,643.16	2,690.08	2,757.98
9	1,318.28	1,385.41	1,455.04	1,520.45	1,578.76
10					
11, 12	2,338.08	2,456.98	2,533.51	2,620.56	2,689.11
13, 14					
15					
16					
17					
18	1,225.00	1,313.95	1,360.66	1,441.79	1,513.57
19	6,203.50	6,445.21	6,688.94	6,901.47	7,134.02
20, 21					
22					
23					
24					
25	149.19	223.52	358.91	503.04	720.49
26	2,057.28	2,228.68	2,381.62	2,528.41	2,672.27
27	2,695.22	2,938.69	3,319.14	3,727.00	3,998.30
28					
30					
31					
32					
33					
34	544.53	596.56	643.33	700.13	746.46
35	2,206.25	2,372.14	2,513.49	2,669.70	2,828.77
36	509.53	529.81	578.21	605.73	634.70
37	1,244.67	1,366.97	1,470.43	1,584.50	1,689.39
38	1,716.95	1,832.32	1,917.41	2,008.18	2,115.71
39					
40	543.63	595.62	647.58	697.13	746.68
41	110.32	118.64	124.23	132.94	138.77
42	*119.42	*148.00	*169.00	*185.40	*199.50
43	136.07	386.72	590.91	682.71	771.44
44	2.12	53.30	128.05	217.20	278.15
45					
46				0.23	0.57
47					
48					
49					
50					
51					
52					
Totals	34,393.15	36,888.27	39,303.32	41,655.51	43,989.21

*Areas added to table in 1966.

Table 3-3—Continued

SOIL CONSERVATION SERVICE
1935 LAKE MEAD SURVEY

10-foot Contour Areas in Acres

Sheet No.	Elevation (feet)				
	950	960	970	980	990
1, 2, 3					
4	1,996.06	2,148.18	2,303.37	2,479.31	2,671.47
5	3,636.03	3,828.17	4,014.64	4,168.55	4,343.44
6, 7	5,640.54	5,817.96	5,989.21	6,157.86	6,293.96
8	2,816.12	2,879.64	2,936.30	2,999.47	3,061.14
9	1,638.30	1,710.65	1,781.38	1,850.18	1,906.19
10					
11, 12	2,772.36	2,870.26	2,958.63	3,078.72	3,182.09
14					
15					
16					
17					
18	1,586.55	1,665.87	1,731.99	1,797.87	1,874.74
19	7,349.67	7,625.83	7,895.94	8,156.88	8,420.82
20, 21			1.45	25.40	49.88
22					
23					
24				276.33	791.23
25	1,061.88	1,494.60	1,809.28	2,157.99	2,349.73
26	2,835.28	2,995.05	3,156.53	3,320.02	3,489.59
27	4,218.70	4,417.29	4,602.62	4,786.35	4,979.05
28			2.42	4.42	6.93
30					
31					
32					
33					
34	808.94	872.27	937.68	987.36	1,045.85
35	3,004.62	3,199.49	3,368.07	3,564.56	3,789.87
36	665.20	714.66	729.93	760.99	816.67
37	1,813.68	1,923.24	2,030.17	2,149.46	2,281.05
38	2,231.71	2,320.91	2,410.33	2,491.38	2,590.77
39					
40	809.56	872.43	953.09	1,033.74	1,113.72
41	147.88	153.95	161.00	165.70	172.70
42	*211.34	*224.00	*238.00	*251.50	*266.30
43	841.88	914.47	992.95	1,063.50	1,140.59
44	339.63	390.31	436.34	470.50	505.56
45				185.10	221.25
46	1.10	7.53	36.05	55.10	79.66
47					25.99
48				0.45	1.66
49					
50					
51					
52					
Totals	46,427.03	49,046.76	51,477.37	54,438.69	57,471.90

*Areas added to table in 1966.

Table 3-3—Continued

SOIL CONSERVATION SERVICE
1935 LAKE MEAD SURVEY

10-foot Contour Areas in Acres

Sheet No.	Elevation (feet)				
	1,000	1,010	1,020	1,030	1,040
1, 2, 3			14.86	30.26	
4	2,876.36	3,078.50	3,299.77	3,519.95	3,739.29
5	4,484.45	4,714.97	4,876.11	5,014.37	5,148.99
6, 7	6,435.16	6,603.63	6,769.31	6,940.60	7,123.96
8	3,144.25	3,208.44	3,263.76	3,322.21	3,362.06
9	1,965.44	2,047.38	2,126.50	2,196.21	2,260.09
10					
12	3,278.30	3,379.79	3,470.00	3,565.06	3,667.21
14					
15					
16					
17					
18	1,946.04	2,040.84	2,114.78	2,202.87	2,283.71
19	8,734.72	9,095.69	9,449.17	9,803.25	10,155.49
20, 21	87.21	119.38	162.56	215.53	270.30
22					
23					
24	1,302.29	1,932.94	2,591.91	3,165.02	3,910.89
[illegible]	2,570.31	2,772.34	2,961.07	3,179.57	3,403.60
26	3,655.31	3,842.08	4,021.64	4,234.23	4,449.59
27	5,173.67	5,371.07	5,556.68	5,789.77	5,989.44
28	12.51	17.20	22.74	30.87	37.85
30					
31					
32					
33					
34	1,111.17	1,187.05	1,253.00	1,330.22	1,404.44
35	4,013.26	4,248.20	4,368.11	4,582.97	4,765.20
36	830.89	899.44	932.06	975.87	1,017.69
37	2,407.93	2,533.18	2,639.07	2,798.33	2,925.84
38	2,687.41	2,789.50	2,882.70	2,980.04	3,108.18
39					
40	1,196.08	1,278.97	1,373.34	1,448.75	1,551.85
41	177.40	184.10	188.61	195.47	200.07
42	*281.06	*296.00	*310.00	*325.00	*339.50
43	1,213.59	1,320.06	1,403.30	1,505.72	1,601.42
44	541.21	576.36	599.81	634.94	658.34
45	260.28	291.51	317.24	344.67	372.51
46	96.05	111.25	121.40	136.93	147.27
47	43.31	86.24	114.87	148.00	170.12
48	2.46	10.50	33.96	56.35	77.36
49					4.23
50					
51					
52					
Totals	60,528.12	64,036.61	67,223.47	70,657.63	74,176.75

*Areas added to table in 1966.

Table 3-3—Continued

SOIL CONSERVATION SERVICE
1935 LAKE MEAD SURVEY

10-foot Contour Areas in Acres

Sheet No.	Elevation (feet)				
	1,050	1,060	1,070	1,080	1,090
1, 2, 3	50.42	78.07	111.64	150.54	202.77
4	3,978.76	4,221.40	4,434.55	4,658.49	4,906.59
5	5,290.08	5,419.92	5,510.58	5,616.46	5,751.28
6, 7	7,286.93	7,476.59	7,659.63	7,838.72	8,041.90
8	3,416.20	3,483.80	3,550.74	3,613.71	3,689.97
9	2,331.74	2,410.99	2,488.68	2,565.88	2,633.59
10				1.45	3.55
11, 12	3,767.17	3,884.94	3,994.71	4,105.58	4,218.23
14					
15					
16			0.50	1.60	2.10
17				0.46	3.06
18	2,368.15	2,442.06	2,507.12	2,592.42	2,680.49
19	10,469.13	10,732.07	11,024.89	11,317.31	11,600.02
20, 21	352.61	429.72	502.59	584.19	662.61
22					
23		252.75	738.84	1,172.75	1,722.36
24	4,674.38	5,444.82	5,993.35	6,492.64	6,901.62
25	3,644.20	3,918.79	4,185.91	4,437.74	4,664.09
26	4,640.20	4,823.00	5,030.26	5,230.80	5,398.99
27	6,166.09	6,350.05	6,558.83	6,768.83	7,044.24
28	50.35	65.88	83.60	102.75	124.04
30					
31					
32			5.16	16.94	30.69
33					
34	1,484.37	1,578.60	1,666.37	1,756.10	1,866.13
35	4,985.08	5,208.41	5,456.20	5,672.51	5,904.95
36	1,060.91	1,104.03	1,137.98	1,177.03	1,192.57
37	3,087.23	3,231.03	3,388.31	3,529.17	3,694.68
38	3,223.87	3,373.38	3,484.70	3,560.73	3,705.63
39					
40	1,662.98	1,773.33	1,903.14	2,033.93	2,181.23
41	206.29	210.45	218.19	223.38	233.27
42	354.17	373.09	396.41	416.01	448.28
43	1,752.09	1,879.43	2,044.49	2,195.67	2,343.05
44	695.60	720.51	755.02	778.06	811.33
45	404.80	434.88	467.40	500.28	539.77
46	162.02	171.87	184.69	193.27	201.66
47	195.96	213.19	227.63	237.27	254.35
48	106.01	123.82	139.73	153.47	167.85
49	26.75	41.79	54.92	63.67	87.37
50					
51					
52					
Totals	77,894.54	81,872.66	85,906.76	89,759.81	93,914.31

Table 3-3—Continued

SOIL CONSERVATION SERVICE
1935 LAKE MEAD SURVEY

10-foot Contour Areas in Acres

Sheet	Elevation (feet)				
	1,100	1,110	1,120	1,130	1,140
1, 2, 3	282.61	376.42	464.77	548.47	643.40
4	5,187.61	5,505.20	5,834.84	6,154.83	6,352.18
5	5,901.89	6,021.44	6,153.35	6,295.57	6,428.69
6, 7	8,234.25	8,384.30	8,549.14	8,714.64	8,890.94
8	3,712.58	3,789.67	3,854.53	3,918.67	3,968.08
9	2,700.62	2,804.81	2,902.72	2,972.54	3,047.79
10	5.24	7.39	9.59	13.57	16.39
12	4,332.81	4,463.51	4,561.10	4,661.28	4,764.58
[illegible]					
15					
16	11.85	51.33	109.32	168.77	234.05
17	12.76	42.89	73.69	118.99	163.87
18	2,776.78	2,868.58	2,959.18	3,030.15	3,094.66
19	11,844.38	12,139.95	12,423.55	12,716.82	13,058.49
20, 21	748.19	811.45	877.79	951.29	1,046.21
22					
23	2,033.08	2,330.58	2,793.97	3,160.35	3,610.58
[illegible]	7,252.96	7,566.60	7,885.97	8,220.90	8,524.35
25	4,951.04	5,240.86	5,466.76	5,734.86	5,972.36
26	5,560.53	5,754.98	5,913.35	6,068.29	6,215.72
27	7,265.14	7,472.58	7,667.74	7,890.85	8,097.95
28	149.24	188.35	215.87	248.09	280.73
30					
31					
32	51.15	79.79	131.08	221.42	369.36
33	21.37	53.61	91.26	151.90	204.27
[illegible]	1,959.73	2,092.16	2,186.27	2,271.48	2,345.75
35	6,140.54	6,373.59	6,580.00	6,831.93	7,043.52
36	1,281.18	1,353.77	1,380.53	1,446.38	1,467.87
37	3,845.37	4,005.74	4,162.30	4,334.36	4,487.78
38	3,876.22	4,017.82	4,125.15	4,243.11	4,347.40
39					
40	2,323.58	2,461.66	2,604.56	2,775.95	2,948.70
41	239.83	248.89	254.91	263.48	269.21
42	471.14	515.77	555.80	611.16	660.19
43	2,492.81	2,692.78	2,854.33	3,039.15	3,215.77
[illegible]	833.76	863.79	883.80	918.00	940.82
45	578.16	616.69	645.76	682.46	721.62
46	207.26	219.17	228.40	238.21	244.79
47	265.70	290.96	307.79	326.10	338.28
48	178.93	198.87	212.12	234.95	251.29
49	103.15	138.01	161.27	201.68	228.62
50					13.14
51					
52					
Totals	97,833.44	102,043.96	106,082.56	110,380.65	114,509.40

Table 3-3—Continued

SOIL CONSERVATION SERVICE
1935 LAKE MEAD SURVEY

10-foot Contour Areas in Acres

Sheet No.	Elevation (feet)				
	1,150	1,160	1,170	1,180	1,190
1, 2, 3	738.41	842.71	949.69	1,064.19	1,175.46
4	6,656.44	6,866.41	7,255.04	7,536.44	7,794.41
5	6,572.55	6,724.99	6,879.33	7,046.18	7,227.96
6, 7	9,051.65	9,249.34	9,403.96	9,591.52	9,788.03
8	4,037.77	4,100.81	4,163.85	4,227.09	4,295.15
9	3,124.29	3,197.49	3,276.61	3,352.59	3,429.93
10	19.61	24.95	32.11	39.74	47.56
11, 12	4,863.69	4,976.20	5,060.50	5,174.32	5,302.95
14					
15					
16	283.29	373.42	447.96	536.40	630.08
17	210.45	281.44	378.74	503.18	626.53
18	3,161.92	3,255.87	3,321.25	3,402.83	3,471.79
19	13,453.99	13,873.64	14,220.79	14,592.83	14,908.13
20, 21	1,153.23	1,308.33	1,478.00	1,657.03	1,798.93
22	85.71	292.01	485.00	715.10	1,113.48
23	4,138.85	4,576.17	5,120.53	5,834.75	6,315.91
24	8,864.49	9,161.94	9,533.25	9,842.54	10,211.79
25	6,234.97	6,490.34	6,743.52	6,992.47	7,239.45
26	6,379.44	6,546.21	6,703.58	6,855.28	7,015.10
27	8,320.98	8,550.27	8,781.12	9,031.87	9,333.50
28	344.33	386.83	442.15	494.78	549.93
30				0.85	2.16
31	11.94	51.42	76.22	141.45	287.64
32	548.65	802.34	792.03	886.67	934.26
33	275.40	373.31	468.42	554.03	652.61
34	2,450.14	2,543.63	2,631.18	2,704.71	2,796.43
35	7,277.95	7,482.72	7,660.84	7,875.84	8,083.62
36	1,552.06	1,593.39	1,657.41	1,707.50	1,812.77
37	4,655.25	4,832.41	4,970.05	5,107.24	5,264.57
38	4,481.33	4,594.49	4,689.27	4,797.82	4,877.64
39					
40	3,121.77	3,302.32	3,470.68	3,627.55	3,787.59
41	278.76	285.17	297.12	305.10	326.60
42	726.39	803.05	829.91	887.61	920.07
43	3,432.04	3,635.23	3,851.84	4,054.35	4,281.07
44	985.40	1,015.15	1,054.25	1,080.28	1,118.29
45	769.00	815.00	863.07	895.13	942.09
46	255.08	261.96	273.40	281.18	293.82
47	360.06	374.55	397.11	412.14	35.63
48	268.88	280.62	301.33	315.15	335.48
49	273.12	302.82	337.28	360.29	383.11
50	28.81	41.51	60.35	79.13	94.22
51					
52					
Totals	119,447.99	124,470.46	129,358.74	134,565.16	139,505.74

Table 3-3—Continued

SOIL CONSERVATION SERVICE
1935 LAKE MEAD SURVEY

10-foot Contour Areas in Acres

Sheet No.	Elevation (feet)			
	1,200	1,210	1,220	1,230
1, 2, 3	1,336.17	1,510.52	1,662.74	1,839.37
4	8,072.43	8,404.44	8,712.67	8,971.24
5	7,403.83	7,617.46	7,809.37	7,997.67
6, 7	9,965.52	10,177.46	10,372.41	10,545.71
8	4,356.23	4,413.15	4,467.30	4,529.01
9	3,502.23	3,596.92	3,679.74	3,762.12
10	54.63	65.87	77.34	86.94
12	5,433.08	5,570.32	5,714.99	5,847.93
			4.93	328.31
15			17.26	34.38
16	738.54	860.08	1,042.89	1,088.43
17	783.76	903.83	1,010.69	1,130.44
18	3,557.72	3,645.39	3,720.54	3,792.36
19	15,231.37	15,578.01	15,847.51	16,097.32
20, 21	1,945.96	2,192.31	2,456.78	2,847.86
22	1,570.88	1,962.07	2,317.85	2,990.30
	6,723.40	7,114.30	7,460.01	7,806.97
	10,509.61	10,861.42	11,200.06	11,377.18
	7,470.78	7,735.76	7,990.28	8,252.33
	7,159.21	7,323.34	7,470.42	7,605.02
27	9,598.33	9,972.77	10,282.85	10,618.80
28	611.25	668.95	733.85	824.89
30	3.04	94.25	234.79	472.48
31	453.98	681.91	1,007.26	1,150.15
32	1,021.07	1,130.60	1,166.91	1,364.67
33	750.52	852.99	959.97	1,061.72
	2,884.72	2,992.32	3,064.80	3,156.03
35	8,305.19	8,505.38	8,636.93	8,852.11
36	1,866.68	1,993.61	2,039.23	2,169.10
37	5,424.23	5,594.30	5,735.24	5,886.26
38	4,991.33	5,104.99	5,175.53	5,285.58
39	13.45	38.71	68.57	99.04
40	3,939.46	4,101.59	4,233.45	4,382.74
41	340.99	375.86	408.91	451.55
42	989.07	1,057.42	1,104.30	1,170.77
	4,502.36	4,693.49	4,876.98	5,085.47
	1,143.65	1,180.99	1,205.91	1,238.72
45	973.37	1,013.55	1,040.38	1,076.52
46	302.82	320.75	331.55	345.47
47	451.29	480.41	499.79	524.97
48	350.03	374.27	390.47	412.84
49	398.30	431.49	453.61	481.98
50	109.31	127.90	146.54	180.75
51				
52				
tals	145,239.79	151,320.95	156,833.60	163,223.50

Table 3-4

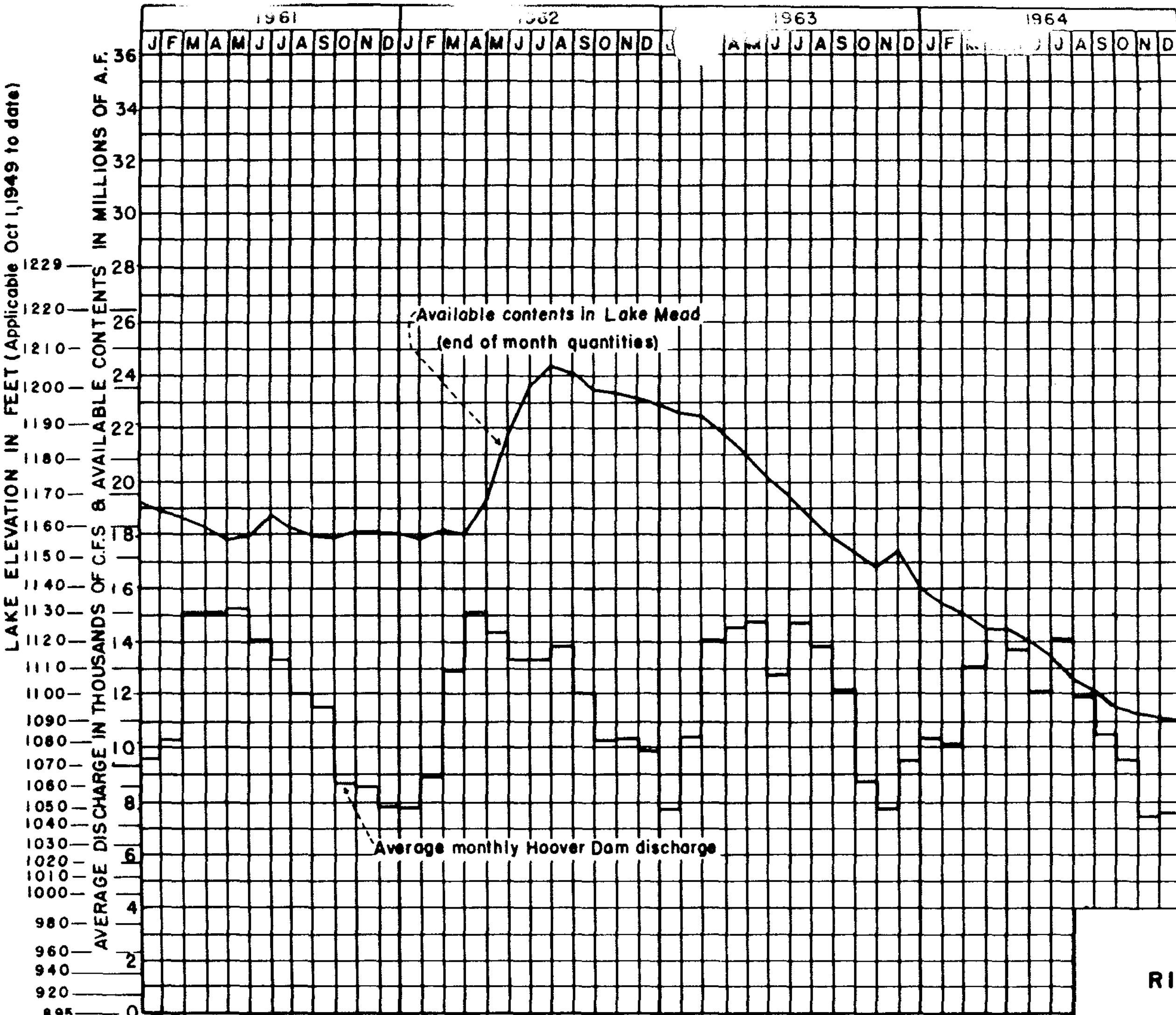
COMPARISON DATA SHOWING AREA, IN THOUSANDS OF ACRES, AS A FUNCTION OF ELEVATION

1 Elevation (FT.MSL)	2 Original 1935 contour areas	3 1948-49 contour areas	4 1963-64 contour areas	5 Column 2 minus Column 3	6 Column 3 minus Column 4	7 Column 2 minus Column 4
650	0.0	0.0	0.0	0.0	0.0	0.0
660	0.2	0.0	0.0	−0.2	0.0	−0.2
670	1.0	0.0	0.0	−1.0	0.0	−1.0
680	1.7	0.0	0.0	−1.7	0.0	−1.7
690	2.5	0.0	0.0	−2.5	0.0	−2.5
700	3.5	0.0	0.0	−3.5	0.0	−3.5
710	4.1	0.0	0.0	−4.1	0.0	−4.1
720	4.8	0.0	0.0	−4.8	0.0	−4.8
730	5.5	0.0	0.0	−5.5	0.0	−5.5
740	6.2	0.0	2.1	−6.2	+2.1	−4.1
750	8.1	4.3	4.2	−3.8	−0.1	−3.9
760	9.2	6.0	5.2	−3.2	−0.8	−4.0
770	10.5	7.1	6.2	−3.4	−0.9	−4.3
780	11.9	8.7	7.2	−3.2	−1.5	−4.7
790	13.5	11.8	8.7	−1.7	−3.1	−4.8
800	15.5	13.8	12.3	−1.7	−1.5	−3.2
810	17.2	15.8	14.5	−1.4	−1.3	−2.7
820	19.0	18.0	16.2	−1.0	−1.8	−2.8
830	20.7	19.8	17.7	−0.9	−2.1	−3.0
840	22.5	21.4	19.6	−1.1	−1.8	−2.9
850	24.7	23.1	21.5	−1.6	−1.6	−3.2
860	26.6	24.8	23.3	−1.8	−1.5	−3.3
870	28.5	26.6	24.9	−1.9	−1.7	−3.6
880	30.4	28.8	26.3	−1.6	−2.5	−4.1
890	32.4	30.8	27.9	−1.6	−2.9	−4.5
900	34.4	33.0	29.9	−1.4	−3.1	−4.5
910	36.9	35.2	32.4	−1.7	−2.8	−4.5
920	39.3	37.4	34.6	−1.9	−2.8	−4.7
930	41.7	39.6	36.9	−2.1	−2.7	−4.8
940	44.0	41.9	39.1	−2.1	−2.8	−4.9
950	46.4	44.2	41.6	−2.2	−2.6	−4.8
960	49.0	46.8	44.2	−2.2	−2.6	−4.8
970	51.5	49.1	46.7	−2.4	−2.4	−4.8
980	54.4	51.9	49.1	−2.5	−2.8	−5.3
990	57.5	55.0	51.6	−2.5	−3.4	−5.9
1000	60.5	58.1	54.8	−2.4	−3.3	−5.7
1010	64.0	61.5	58.1	−2.5	−3.4	−5.9
1020	67.2	64.6	61.2	−2.6	−3.4	−6.0
1030	70.7	68.0	64.3	−2.7	−3.7	−6.4
1040	74.2	71.6	67.5	−2.6	−4.1	−6.7

Table 3-4--Continued

COMPARISON DATA SHOWING AREA, IN THOUSANDS OF ACRES, AS A FUNCTION OF ELEVATION

1	2	3	4	5	6	7
Elevation (MSL)	Original 1935 contour areas	1948-49 contour areas	1963-64 contour areas	Column 2 minus Column 3	Column 3 minus Column 4	Column 2 minus Column 4
1050	77.9	75.2	71.2	−2.7	−4.0	−6.7
1060	81.9	79.2	75.1	−2.7	−4.1	−6.8
1070	85.9	83.2	78.6	−2.7	−4.6	−7.3
1080	89.8	86.8	82.2	−3.0	−4.6	−7.6
1090	93.9	90.7	85.6	−3.2	−5.1	−8.3
1100	97.8	94.5	89.5	−3.3	−5.0	−8.3
1110	102.0	98.7	93.4	−3.3	−5.3	−8.6
1120	106.1	102.8	97.3	−3.3	−5.5	−8.8
1130	110.4	106.9	101.8	−3.5	−5.1	−8.6
1140	114.5	110.8	105.9	−3.7	−4.9	−8.6
1150	119.4	115.2	111.6	−4.2	−3.6	−7.8
1160	124.4	120.2	118.7	−4.2	−1.5	−5.7
1170	129.4	125.1	125.6	−4.3	+0.5	−3.8
1180	134.6	132.1	132.3	−2.5	+0.2	−2.3
1190	139.9	138.5	138.9	−1.4	+0.4	−1.0
1200	145.2	144.7	144.9	−0.5	+0.2	−0.3
1210	151.3	151.0	151.2	−0.3	+0.2	−0.1
1220	156.8	156.7	157.1	−0.1	+0.4	+0.3
1230	163.2	163.3	163.3	+0.1	0.0	+0.1
Totals	3,336.3	3,194.3	3,074.0	−142.0	−120.3	−262.3



NOTE
Data shown hereon were obtained from water supply papers published by the Geological Survey for the period prior to October, 1966.

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
REGION 3

RIVER OPERATION DATA HYDROGRAPHS
HOOVER DAM AND LAKE MEAD
COLORADO RIVER

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TRACED W.J.B. RECOMMENDED
CHECKED APPROVED Paul A. Oliver

BOULDER CITY, NEV 10-11-57 SHEET 2 OF 2 | 45-300-90

FIGURE 3-9

PART 4—INVESTIGATIONS OF SEDIMENT PROPERTIES

Methods of Field Investigation

Field investigations during the 1963-64 survey of Lake Mead included the collection of sediment samples at the 17 reservoir locations shown in Figure 4-1. These sampling sites were chosen because they were near th[illegible] of the 1948-49 survey. The sampling was done in two separate phases of collecting samples to determine certain physical and chemical characteristics of the accumulated sediments. Modern instrumentation, field sampling techniques, and laboratory analysis procedures are described. An interpretation of the sediment properties is made.

The first sampling phase was made in the fall of 1963. The objective was to use standard drilling equipment to obtain undisturbed drive samples of the delta formation. A dry delta area in Pierce Basin near River Mile 278 was selected as the test site designated Drill Hole DH-1 (Figure 4-1). The site was located over an old channel just downstream from the mouth of Lower Granite Gorge (Figure 4-2) on a silty sand deposit about 80 feet north of the present channel right bank. A heavy stand of salt cedars averaging about 5 feet high completely covered this delta and had to be cleared before the drilling camp could be established (Figure 4-3).

The sampling operation was rather unique because a helicopter was needed to transport personnel and drilling equipment to the site (Figure 4-4). The equipment was moved to Pierce Ferry by truck and then airlifted about 2 miles to the delta area. It took the helicopter 42 flights and nearly 8 hours to transport personnel and equipment cumulatively weighing about 18,000 pounds. The helicopter was also needed to remove the equipment after the operation.

The ground elevation at the drill hole was 1161 feet or about 12 feet above the river stage. The drill rig setup allowed control of the sampling to a 207-foot depth in the delta formation.

The second sampling phase was carried out a year later in the fall of 1964. The objective was to collect piston-core samples of the inundated reservoir sediment deposits and to use a nuclear gamma probe to get a reading of the density and consolidation effects of the deposits at 16 selected investigation sites (Figure 4-1).

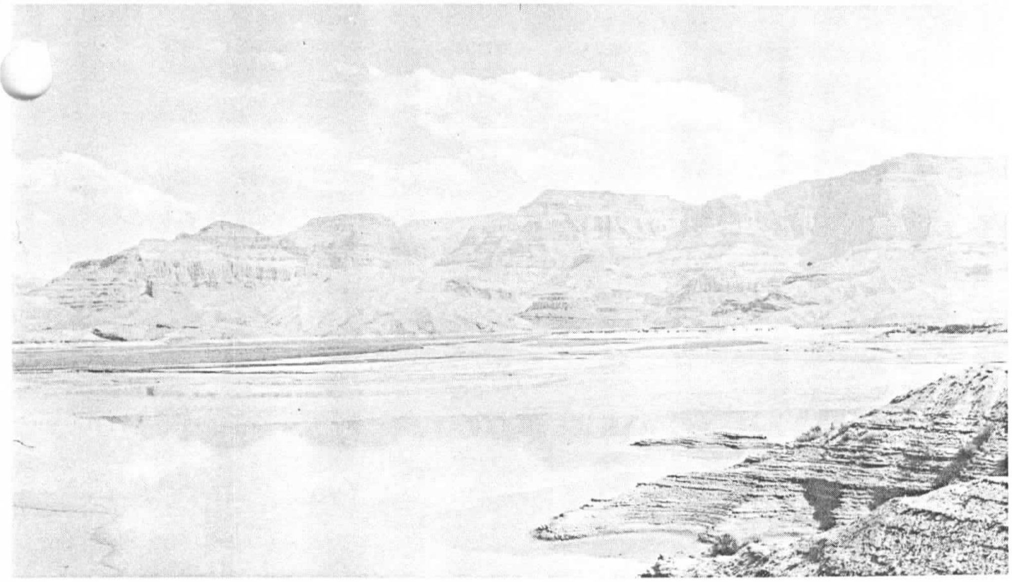
Floating equipment was used to obtain sampling data by both the piston-core and gamma probe. The equipment consisted of a 45-foot working barge, a 105-foot barge used to house personnel and as a base of operations, and a 35-foot cruiser to transport supplies and personnel (Figure 4-5). The barges were self-propelled by on-board gasoline and diesel engines giving the mobility needed to proceed to any desired location (Figure 4-6). Measuring 21 feet by 45 feet, the working barge platform furnished ample space for both personnel and for the derrick, sampler hoist, anchor hoist, and other miscellaneous equipment. A schematic deck layout view in Figure 4-7 shows the relative positions of some equipment.

Samples totaling 215 were collected from the 17 locations in Lake Mead during 1963 and 1964. The samples were analyzed in the laboratories of the Division of Research, Office of Chief Engineer, Denver, Colorado.

Drive Sampling

The drill rig used at Site DH-1 (Figure 4-1) was a skid-mounted unit—hydraulically fed, chain-belt driven, and powered with a four-cylinder gasoline engine (Figure 4-8). A mud pump powered by a four-cylinder air-cooled gasoline engine, trailer mounted, was also used. Undisturbed samples were obtained at 5-foot intervals with a modified thin-wall open-drive sampler (Figure 4-9). The 36-inch-long sampling tube had a 3-inch outside diameter and a No. 14-gage wall thickness and was made of cold-drawn steel tubing. Its cutting edge was sharpened with the bevel on the outside. The inside diameter equal to or slightly less than that of the tube gave internal clearance to allow the sample to enter the tube easier and to assist retaining the sample. The sampling tube fits a modified sampler head having vents for the drilling mud to escape. The modified sampler head was equipped with an "O" ring seal and a rubber-seated ball check valve to prevent the drilling mud from entering during the withdrawal operations and to assist in creating a partial vacuum above the sample needed to retain the sediment core. Attached to a string of "N" drill rods (2-inch inside diameter, 2-3/8-inch outside diameter) the thin-wall sampler was hydraulically forced without rotation into the sediment in one continuous stroke. After penetration, the sampler was rotated to break off the sediment at the bottom and then the drill rod with the sediment bearing sampler was carefully removed from the hole.

The drilling between undisturbed sampling elevations was advanced with a double-tube sampler (Figure 4-10). Principal components of this sampler consisted of a rotating outer barrel with cutting teeth on the bottom, a nonrotating inner barrel with a smooth

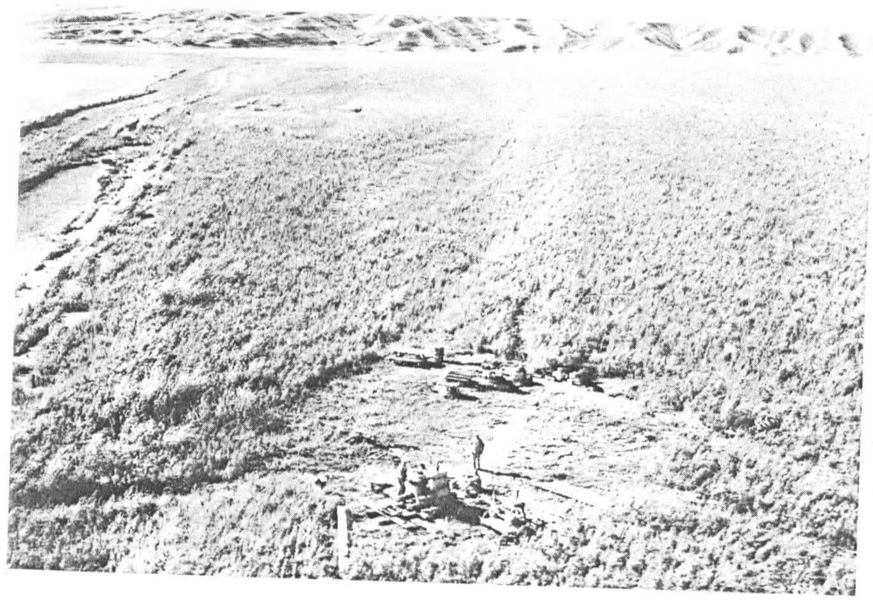


View of Pierce Basin looking northeasterly from a high ridge just north of Pierce Ferry. Photo P45-D-40589 NA

View looking west across Pierce Basin from the mouth of lower Granite Gorge. The drilling site was located approximately 80 feet north from the right bank of the present Colorado River channel at the point where the channel narrows near the center of the photo. Photo P45-D-40600 NA

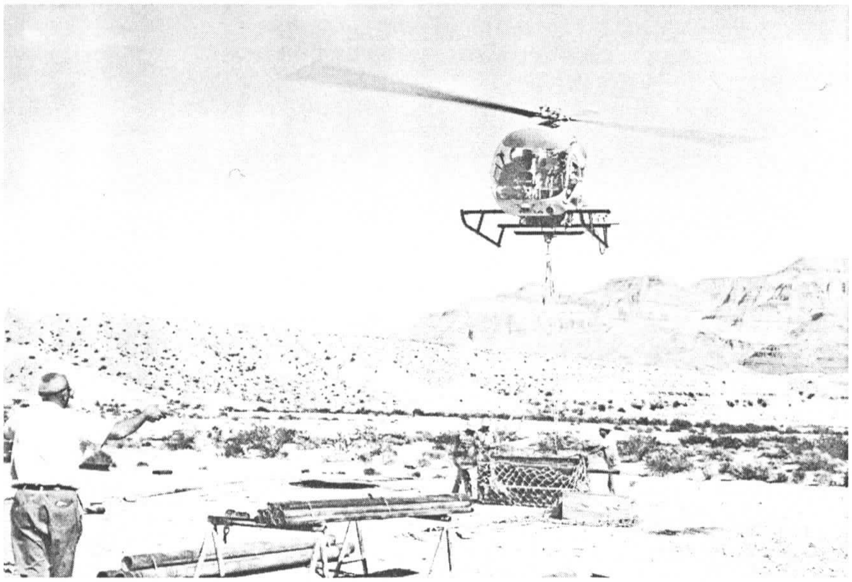
FIGURE 4-2

Surface cracks on dry area of Lake Mead delta topset beds. Picture was taken approximately in the center of Pierce Basin. Salt cedar can be seen growing in the background. Photo P45-D-40597 NA

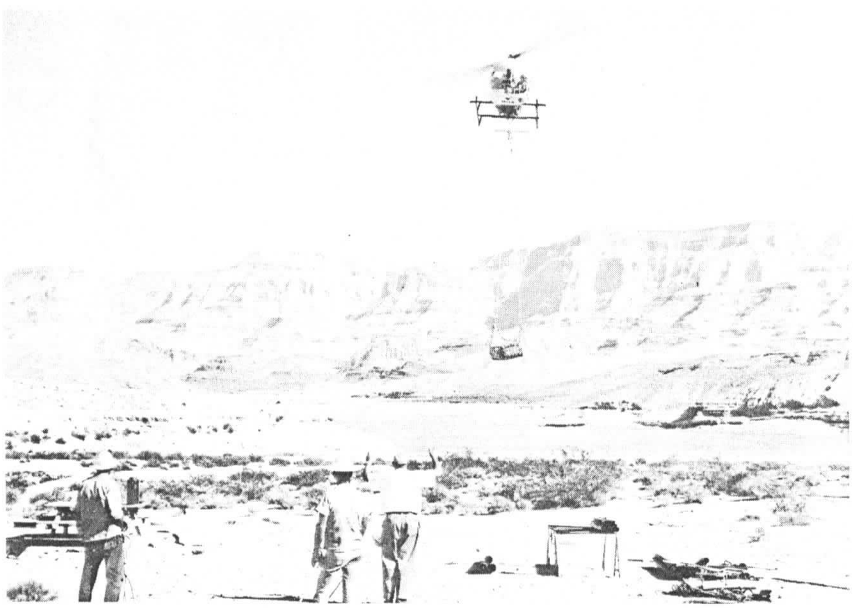


Establishing drilling site on Lake Mead delta. Salt cedars averaging about 5 feet high had to be cut down before equipment could be flown in. Photo P45-D-41749NA

FIGURE 4-3

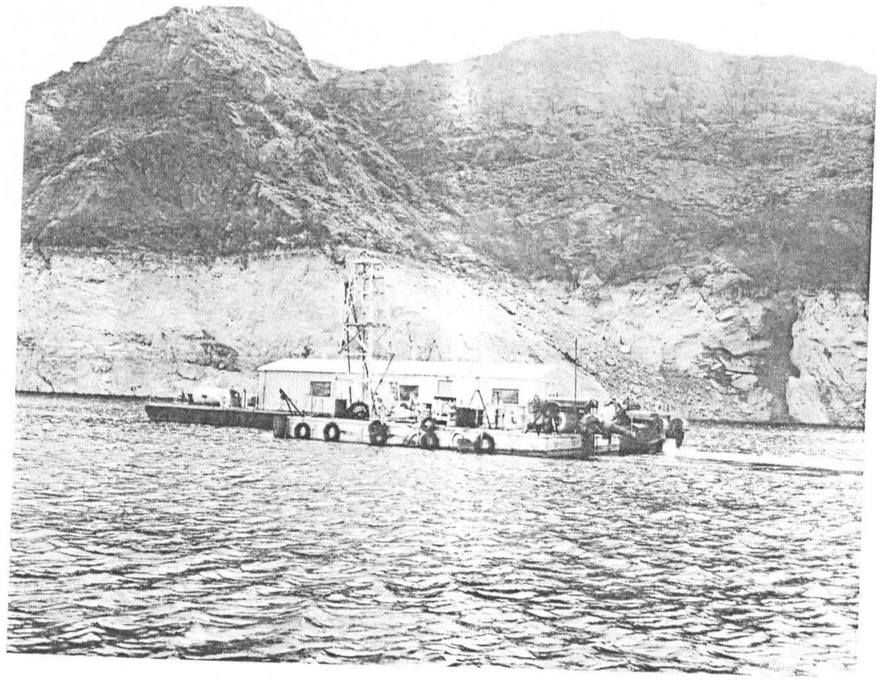


Helicopter picking up equipment at Pierce Ferry. Heavy equipment had to be dismantled in order to make up loads that the helicopter could handle. Bundles of casing and drill rod shown in foreground. Photo P45-D-41750 NA

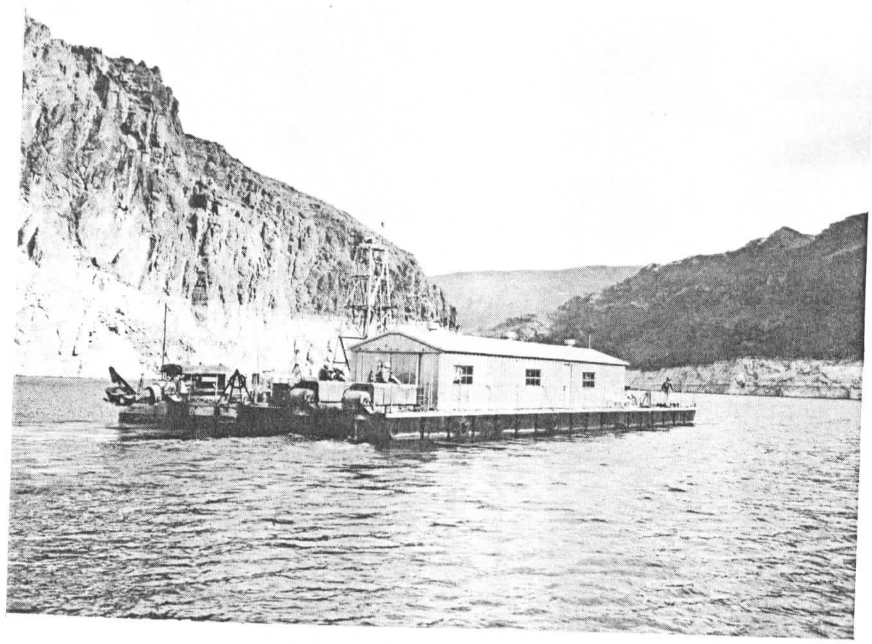


Helicopter carrying equipment with a cargo net. All drilling and camping equipment needed in the delta investigation had to be flown in and out by helicopter. Photo P45-D-41751 NA

FIGURE 4-4

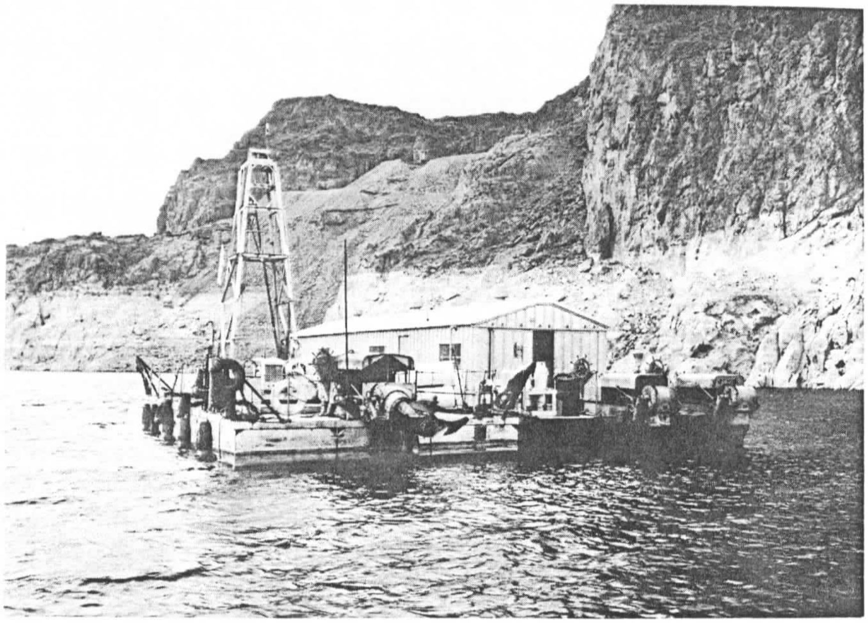


Port and stern view of the barges used in sedimentation investigation.
Photo P45-D-46832 A

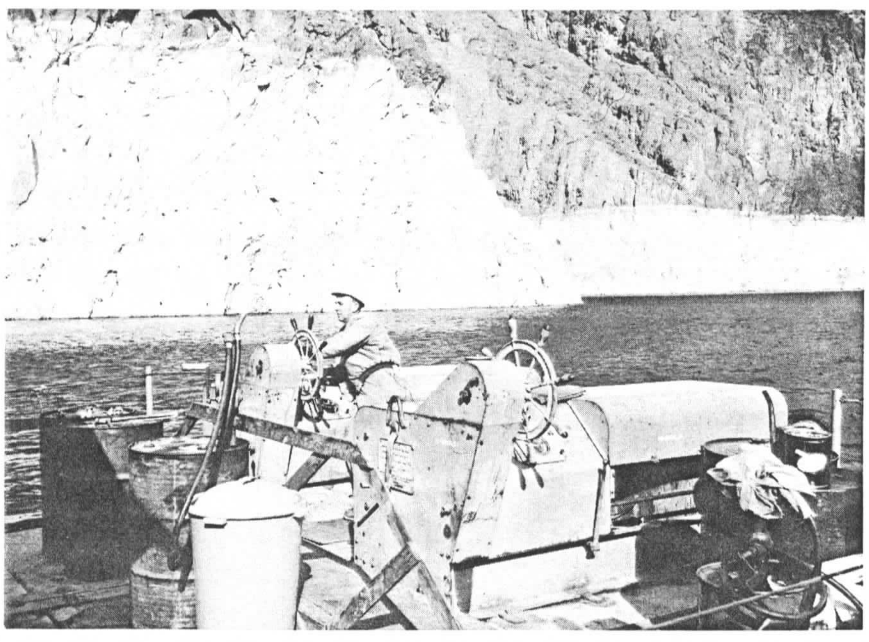


Starboard and stern view of the barges used in sedimentation investigation.
Photo P45-D-46833 A

FIGURE 4-5

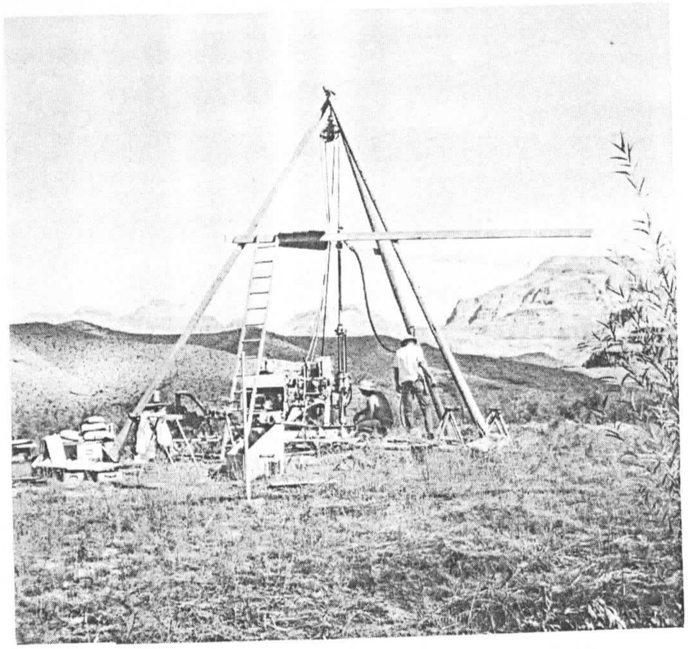


Stern view of barges used in sedimentation investigation. Photo P45-D-46834 A

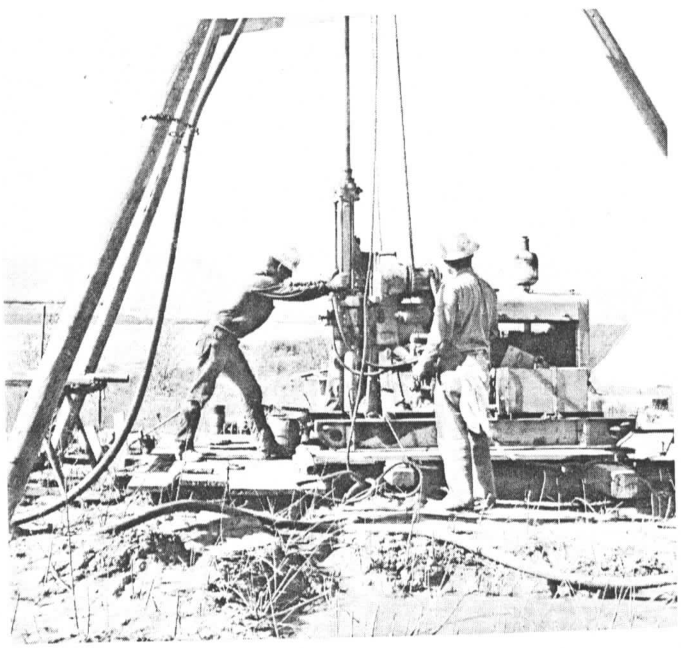


Sea mules used as propulsion units for barges. Photo P45-D-46835 A

FIGURE 4-6



Drill rig setup on Lake Mead delta at Pierce Basin. Photo P45-D-41635 NA



Drill rig with mud pit shown in the lower right corner of photo. Photo P45-D-41636 NA

FIGURE 4-8

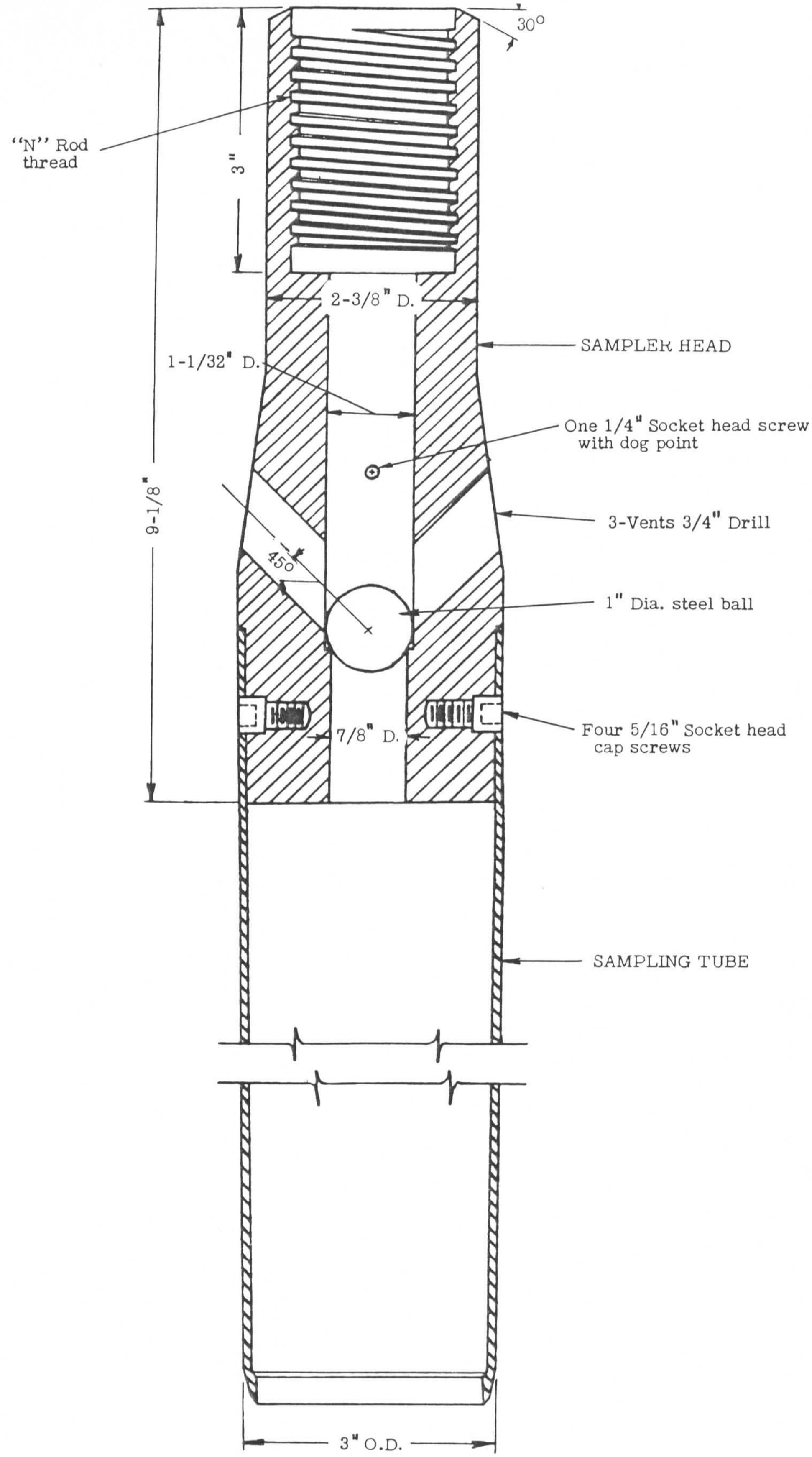


Figure 4-9. Drive sampler.

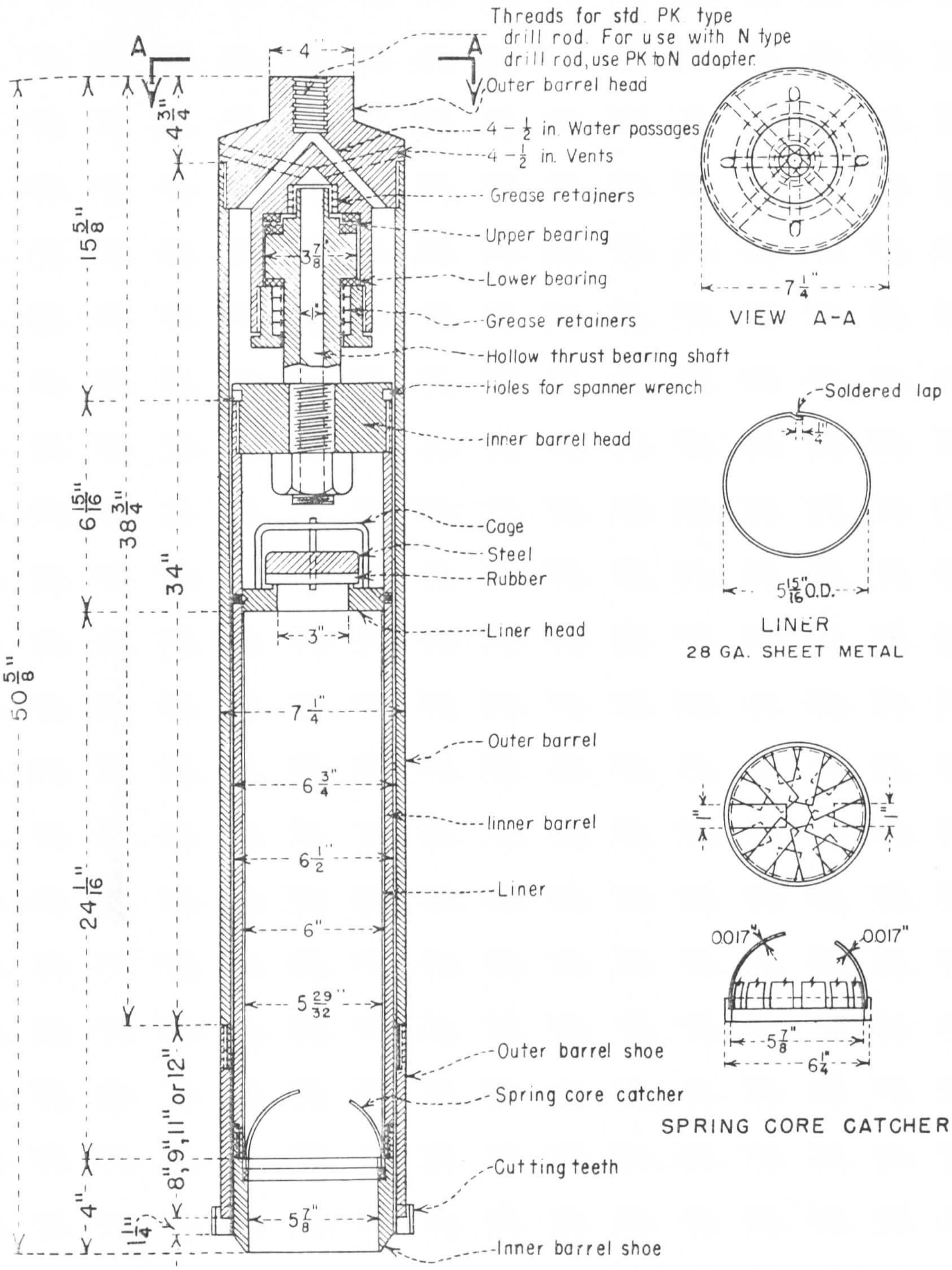


Figure 4-10. Double-tube sampler.

cutting shoe, a spring-core catcher, and a liner to receive the sample. Basically the sampler was operated by sliding the stationary inner barrel over the sample which was sheared off by rotating the outer barrel. The cutting edge of the inner shoe extended beyond the root of the cutting teeth. However, it did not extend beyond the crest or cutting edges of the teeth allowing the drilling fluid to circulate through the teeth. Samples thus obtained were subjected to some degree of washout, penetration, and undercutting by drilling mud. The rotating barrel also had a tendency to tear the sample core before it entered the inner barrel. However, the samples were judged adequate for inspection, classification, and size analysis of material not recovered by undisturbed sampling. It was concluded that this method of drilling provided a relatively continuous log of the drill hole.

Except for the first 20 feet where a casing was set, the drill hole was stabilized with heavy drilling mud composed of water, bentonite, barite, and chemical wall plasticizer. Some of the less stable strata encountered had a tendency to pinch in overnight, and it was necessary to ream the hole each morning before continuing the sampling operation. However, the drilling mud was a satisfactory wall stabilizer to a depth of 212 feet where the walls collapsed.

Of the 46 undisturbed sampling attempts made with an open-drive sampler, 43 samples were successfully obtained. The average recovery of these samples was 93 percent of the drive length. Thirty-seven samples were collected with the double-tube sampler. The double-tube cores were first measured for recovery length and then removed from the barrel for inspection and classification. Representative samples were taken of the material for laboratory testing.

Piston Core Sampling

A schematic drawing of the piston-core sampler used to obtain samples of the inundated sediment deposits is shown in Figure 4-11. A general description of the sampler components follows.

Trigger mechanism.—Consists of a come-a-long with an initial grip and a trigger arm and release. It operates on a principle of an off-centered balance arm. The fulcrum is very close to one end of the arm. The heavy coring weight hangs on the short arm, and a small trigger weight is fastened with a line to the end of the long arm. With both weights in place, the trigger arm will hang almost horizontally. When the trigger weight is removed the system balance is upset and the arm will fly upward because of the excess weight on the short arm. The release is designed to operate after the arm has moved through some preset distance. A safety pin is always kept in place to prevent the apparatus from tripping accidentally. It is only removed just before the sampler is lowered.

Coring head.—Is essentially a weight having guide vanes, hoisting plate, piston stop, and a coupling used to attach the coring tubes. The head is designed so that the trigger mechanism can be attached.

Coring tube.—Is a 12-foot section of 1.5-inch-diameter galvanized pipe. The pipe section is threaded at the lower end to which the cutting shoe can be attached. Four screws are used to couple the coring tube with the head.

Liner.—Is clear plastic tubing with a 1-3/8-inch internal diameter and a 1.5-inch outside diameter. A 12-foot section of this liner is put into the coring tube and is held in place by the cutting shoe.

Piston.—Is attached to the end of the cable with a clamp. It fits into the lower end of the liner forming a seal to keep sediment from entering the sampler until the trigger mechanism is tripped. When the sampler is triggered, the piston creates a vacuum to allow an easier way of retaining the collected sample.

Core catcher.—Is made of spring steel and installed in the end of the liner after the piston has been attached to the cable. It helps retain the core sample in the liner during retrieval of the sampler.

Cutting shoe.—Is made of stainless steel and holds the plastic liner and core catcher in place. Its knife edge and streamline shape make it easier for the sampler to penetrate the sediment deposits.

The sampling operations at each location involved, first, moving the working barge to a chosen site and then dropping the anchors to hold position. The piston-core sampler was then assembled on the barge deck (Figure 4-12), and the safety pin inserted. It was raised from the deck by a hoist until suspended vertically above the deck. The "A" frame was then lowered until the sampler cleared the bow of the barge (Figure 4-13). With the piston sampler in the lowering position, the safety pin was removed from the trigger mechanism.

The sequential steps of operating the sampler are shown schematically in Figure 4-14. Initially (Figure 4-14(a)), the piston is at the bottom edge of the coring tube, just touching the core catcher. The piston

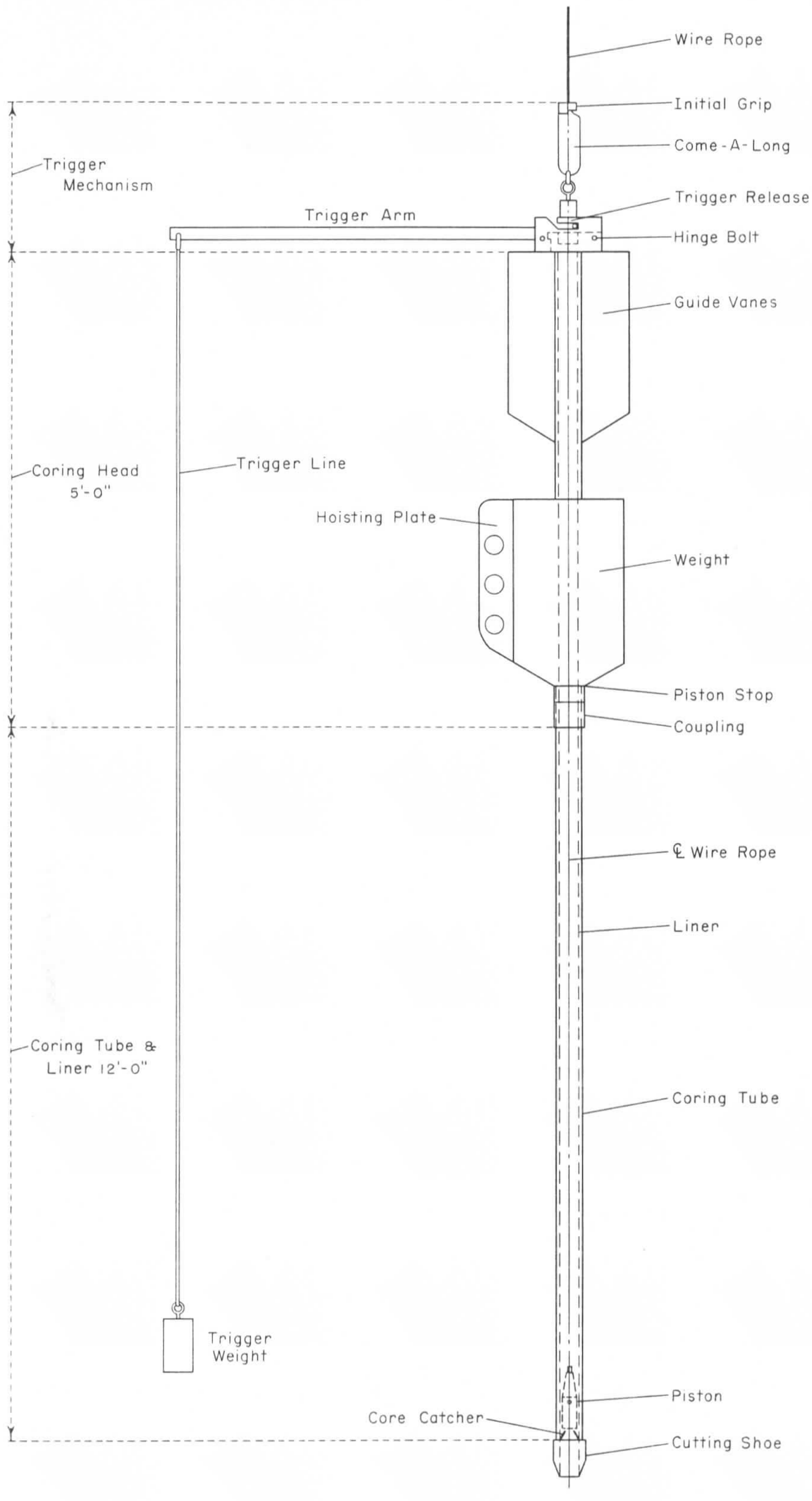
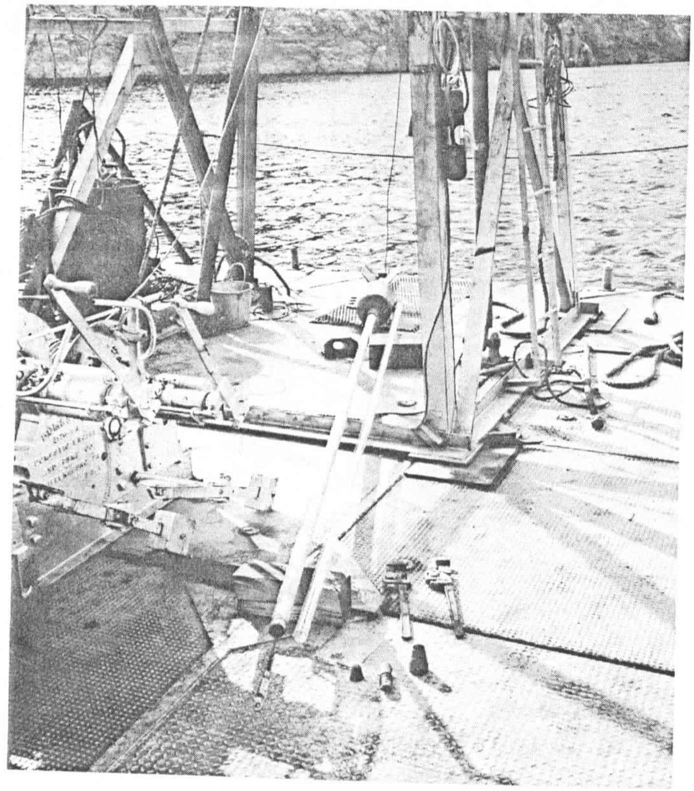


Figure 4-11. Schematic of piston-core sampler.



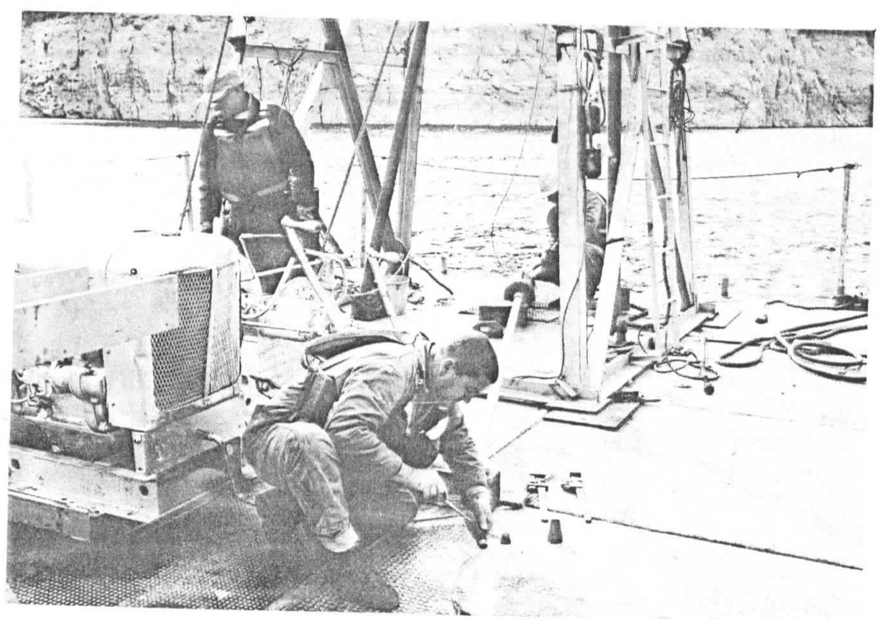


Figure 4-12. The upper photo (P45-D-46838 A) shows the piston-core sampler used to obtain sediment core samples of the inundated deposit. In the lower photo (P45-D-46839 A) the sampler is being prepared for a sampling operation.

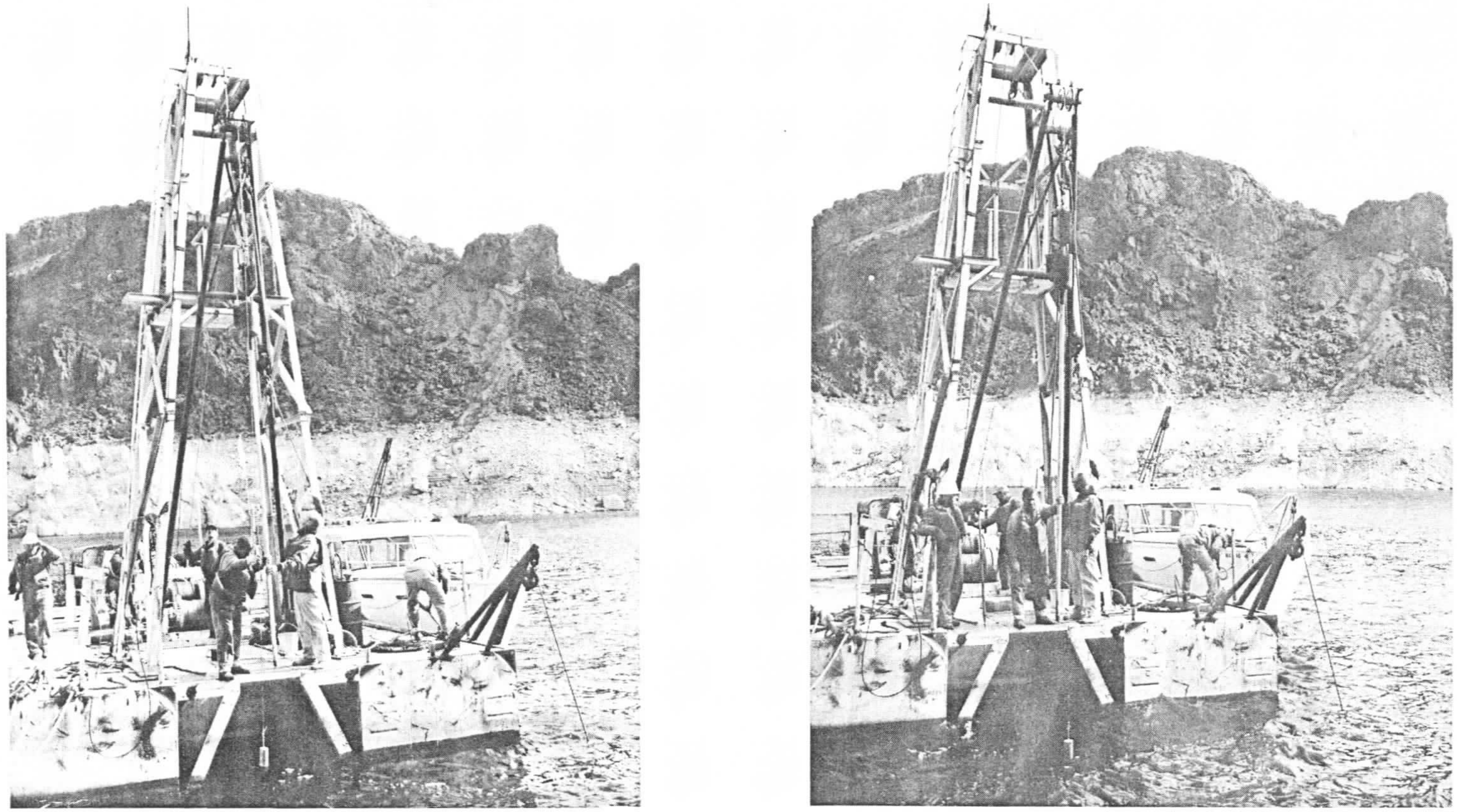


Figure 4-13. The piston-core sampler has been raised off the deck in the left photo (P45-D-46840 A). The "A" frame is being lowered in the right photo (P45-D-46841 A), so that the sampler can be lowered over the bow of the barge.

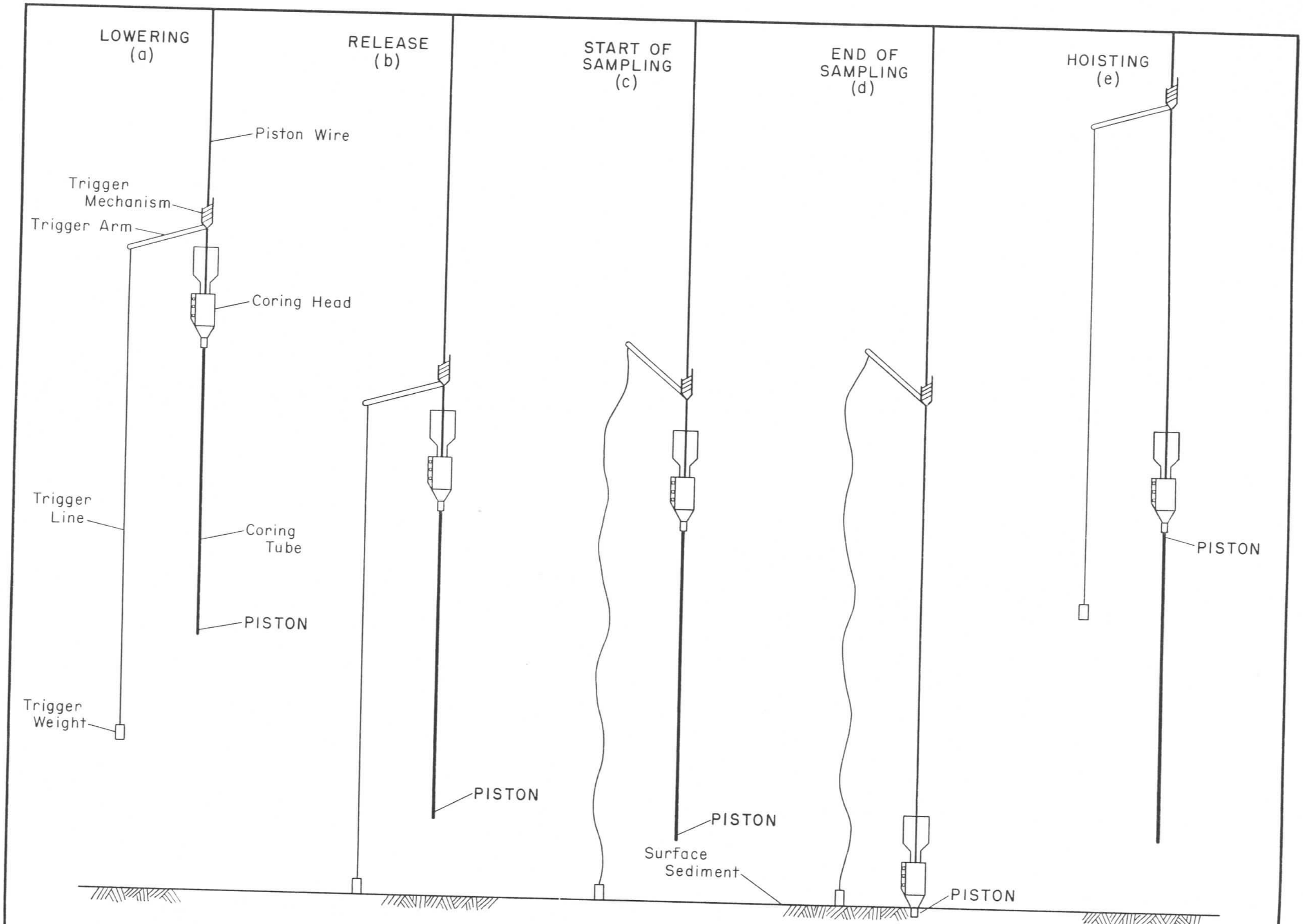


Figure 4-14. Schematic of piston-core sampler operation.

con..cting wire leads through the tube and head and is fastened to the trigger mechanism with a come-a-long having an initial grip. The trigger weight is fastened to the arm with a line.

The piston sampler is lowered until the trigger weight touches the sediment surface. With the trigger weight resting on the bottom, further lowering of the sampler causes the trigger arm to rise and release the coring head (Figure 4-14(b)). As the cutting shoe is just about to penetrate the sediment (Figure 4-14(c)), the sampler is in a state of free fall and the potential energy of its own weight drives the coring tube into the sediment deposit. Collecting longer sediment samples is possible because of the hydrostatic pressure created by the piston to force the sediment into the sampler. This overcomes the frictional resistance of the sediment as it slides up the liner. The falling weight causes the sampler to continue downward, driving the tube farther into the sediment until the coring head ultimately strikes bottom (Figure 4-14(d)). The piston remains fixed and as the outside tube moves past, the desired vacuum state is created to take an undisturbed sample. During this operation the residual water is forced from the coring tube.

The sample has now been taken and the hoisting operation begins. As the wire is reeled in, the piston moves until it hits a stop. Further hoisting lifts the whole tube out of the sediment which is carried to the surface (Figure 4-14(e)). The core catcher prevents the core from dropping out during the hoisting operation.

The sampler is retrieved from the water and lowered to the barge deck (Figure 4-15). The plastic liner containing a sediment core is removed from the sampler, sealed at both ends to retain the moisture, and packed for shipment to the laboratory (Figure 4-16).

Nineteen sediment cores were collected from 16 reservoir locations. The average sample recovery was 90 percent of the penetration depth. The 19 sediment cores produced 121 samples for laboratory testing.

Bottle Sampling

Samples were collected of the most recent sediment deposition using a Modified Foerst sampler. Although this device was initially designed to sample water, it was found suitable for sampling the unconsolidated sediments in the upper or interface zone.

The Modified Foerst sampler shown in Figure 4-17 has a transparent plastic tube cylinder as a principal component. It is open at both ends allowing the water or water/sediment mixture to pass through the tube as it is lowered by cable. When the sampler reaches the sediment-water interface, a small weight attached to the cable is released and slides down the cable as a messenger to operate a tripping device. The tripping mechanism acts to close the rubber stoppers at each end of the cylinder. The sealed sampler is surfaced with the cable system and the sediment sample is emptied in a jar and sealed for subsequent laboratory analysis.

Fourteen samples were collected at 14 different locations in the underwater portions of the reservoir. Bottle samples could not be collected at Locations 7 and 11, situated in the upstream reaches of the Colorado and Virgin River deltas. Here, the sampler was unable to penetrate the coarser sized sediments that had been carried and deposited in these reaches because of the conditions prevailing at low reservoir stage.

Gamma Probing

A sediment density gamma probe system was used in the sedimentation investigations to study the in place consolidation of the sediment deposits. The system consists of three basic components, the probe, ratemeter, and retriever, functioning together as an integrated unit.

The probe (Figure 4-18) is about 10 feet long, weighs about 100 pounds, and comes in three sections. A mechanical cable connection is provided in the upper section which has its cavity filled with lead to give the probe mass. The middle section contains the detectors, preamplifiers, vertical sensor, and shock absorbers. A radioisotope source and lead shielding are housed in the lower section.

The practical function of the ratemeter (topmost unit shown in Figure 4-19) is to record on a meter the radiation of the gamma rays that have penetrated the submerged saturated sediments. It averages random pulses from the detectors over a time period (time constant). The averaging is directly dependent on the time constant used.

The retriever (Figure 4-19) is an electrically powered winch used to raise and lower the probe. It has a built-in variable speed control to permit flexibility in operating the system to handle loads limited to 2,000 pounds.

The gamma probe is connected to 1,000 feet of cable which is stored on and controlled by the ratemeter-retrieval unit.

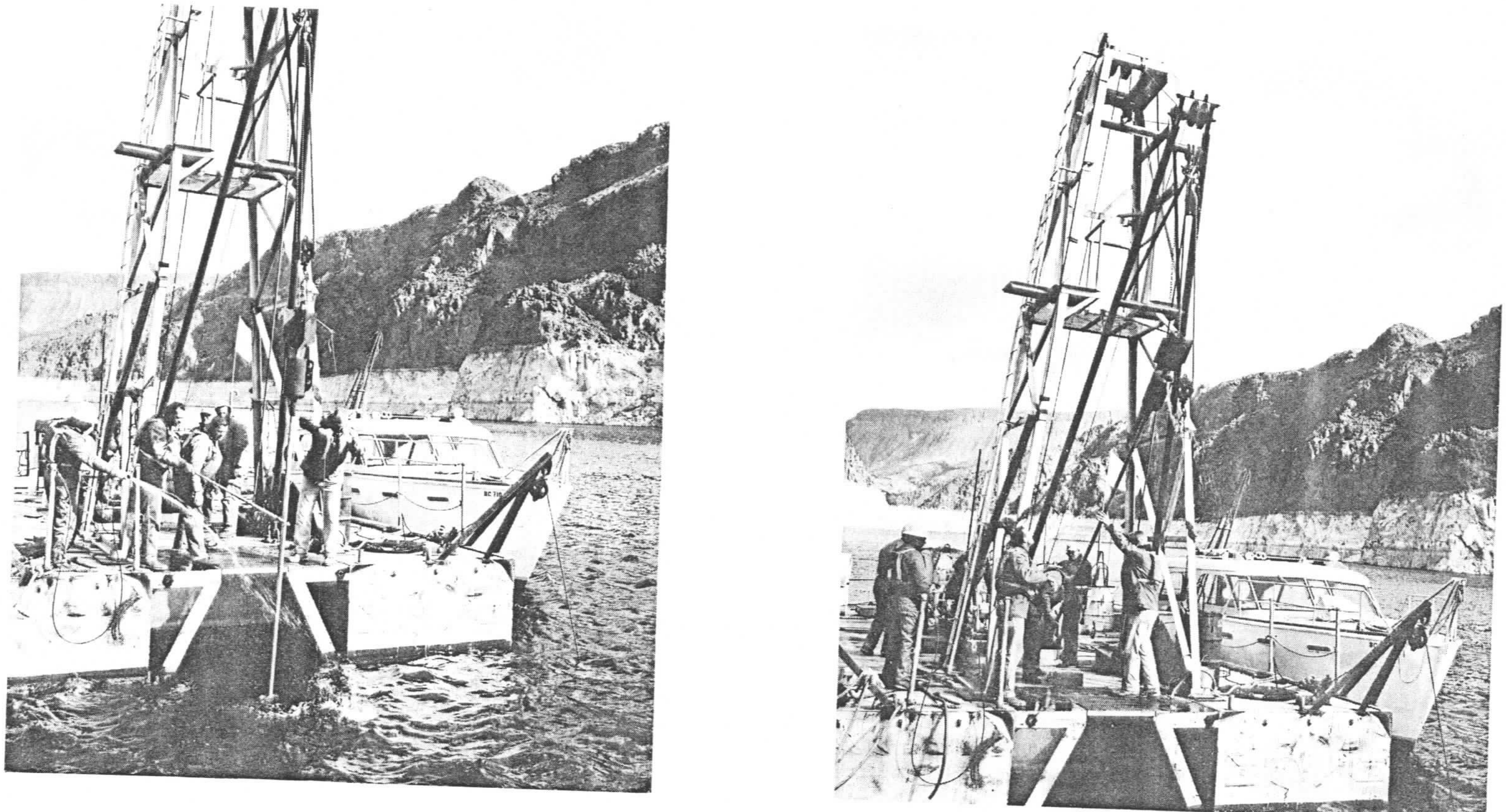
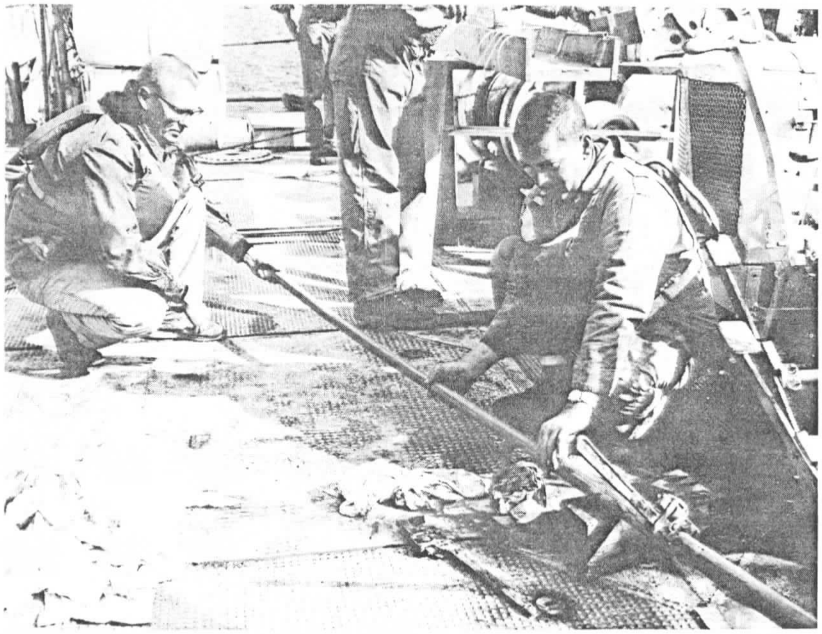
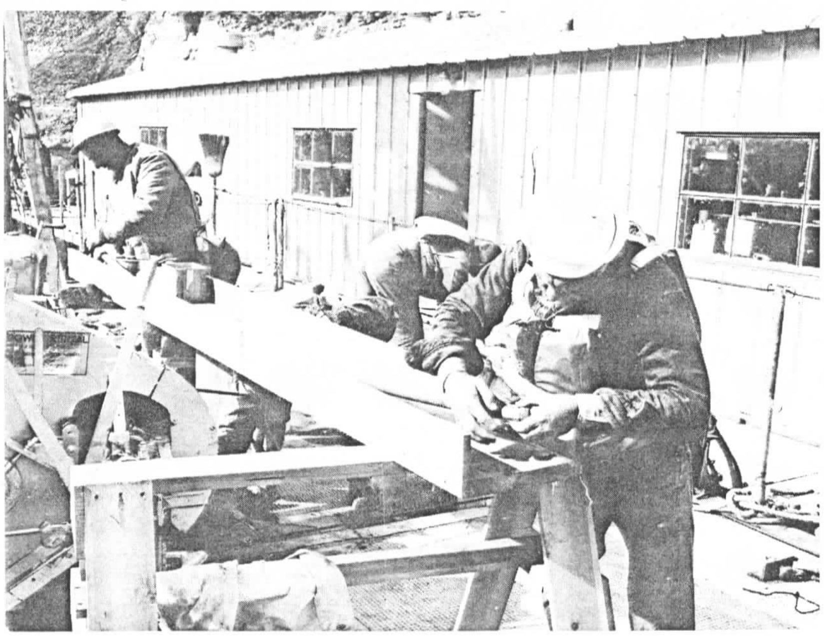


Figure 4-15. The piston-core sampler is being retrieved in the left photo (P45-D-46842 A) after obtaining a sample. The next step in the operation shows the sampler being lowered to the large deck in the right photo (P45-D-46844 A) for removal of the sample.

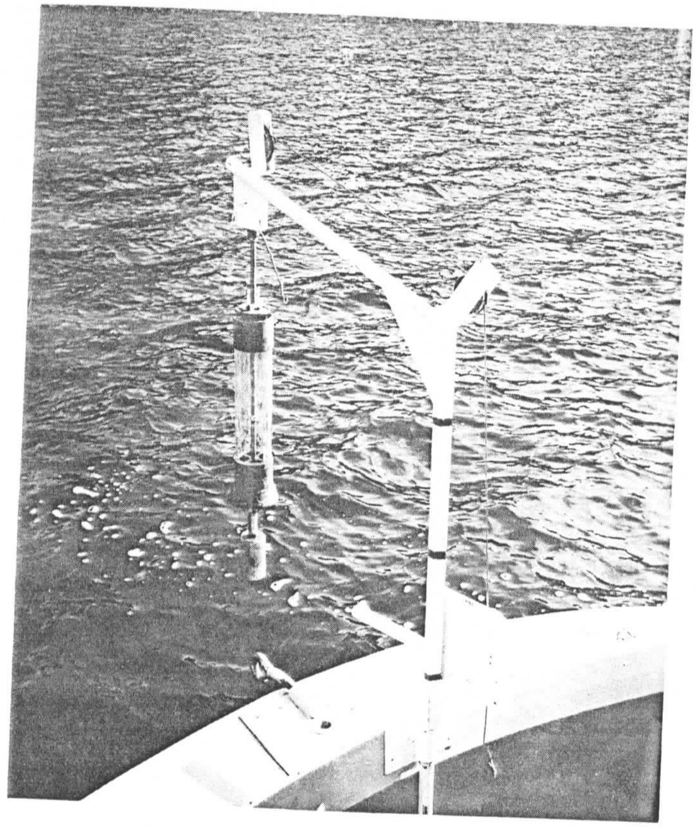


The plastic liner containing the sedimen core is being removed from the piston-core sampler. Photo P45-D-46845 A



The sediment core sample is sealed in the plastic liner for shipment to the laboratory for analyses. Photo P45-D-46846 A

FIGURE 4-16



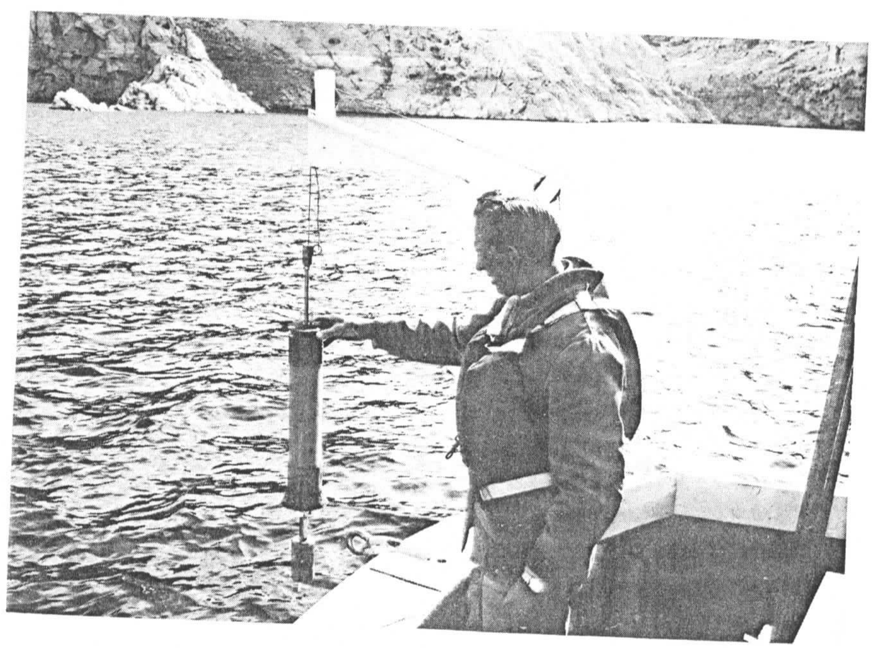


Figure 4-17. The modified Foerst sampler used to collect samples of the most recent sediment deposits which were physically in a very fluid state. Top Photo P45-D-46849 A, bottom Photo P45-D-46850 A

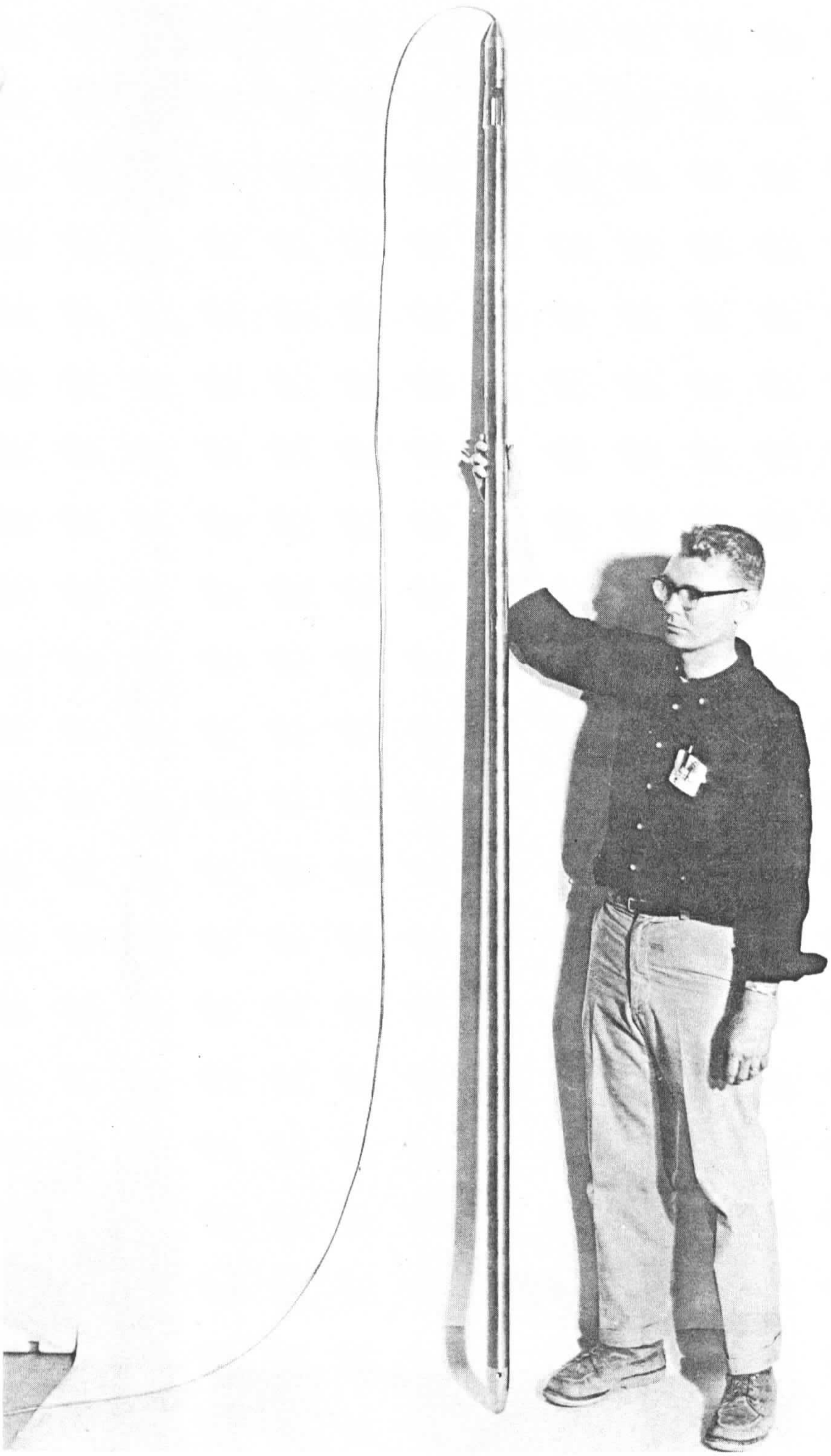


Figure 4-18. Gamma Probe. Photo PX-D-44781 NA

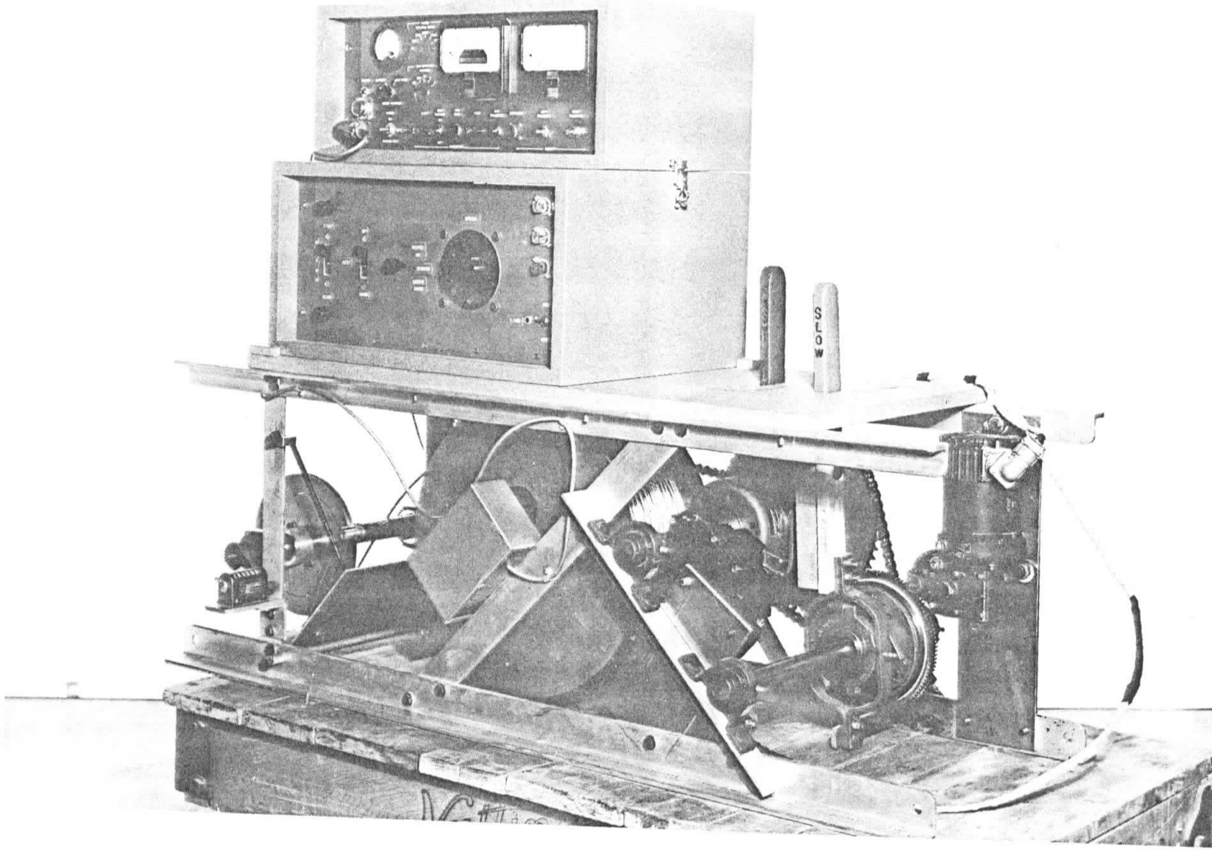


Figure 4-19. Ratemeter and retriever. Photo PX-D-43262 A

In the Lake Mead operations, the ratemeter-retriever was located on the stern deck of a 35-foot cruiser (Figure 4-20). When the boat was anchored above the sampling point, the probe was removed from the protective radiation shield and lowered by cable through the overlying depth of water to the deposit. Penetration of the sediment deposit was achieved by the potential energy of the probe weight causing the instrument to fall free at a rate of about 60 feet per minute.

Densities are measured either as the probe penetrates the sediment deposit or during withdrawal from the deposit after the deepest penetration has been reached. The measurement of the densities using the probe depends upon (1) the homogeneous character of sediments possessing almost the same absorption coefficient; (2) the random emission, penetration, and scattering of gamma rays from a confined source; and (3) the statistical measurement of nonabsorbed or returning rays when the geometry between the source and the detection system remains constant. In brief terms, when a radioactive source, such as Cobalt 60, is placed in a material, such as submerged sediments, the emitted ray or photon collides with an orbiting electron in an atom of the material, gives up some of its energy and changes its direction of travel. Such a collision, known as the Compton effect, causes further random or secondary scattering of the photon until the energy of the photon is either reduced to a level where it is absorbed by the material or it encounters a detector mechanism such as a Geiger tube. The potential for a collision and further scattering increases proportionally with the density of the material; however, as the number of electrons increase, the probability also increases that the photon will be absorbed before it reaches a detector. Thus as the density of a saturated sediment deposit becomes greater, a relatively fewer number of photons will be available for detection; and the quantity of material representing the "sensitive volume" of measurement decreases. Because the density of most soils is proportional to the number of electrons present in a unit volume, this relative number of photons available for detection becomes, through correlation, a means for the direct measurement of the density of the material. It must be recognized at this point that the physics of this phenomenon are much more complicated than described and that in reality the relationship between the counts measured by a detector and the density of the material is an empirical one. The preceding description was presented in a manual prepared by the Corps of Engineers.[4-1]

The gamma probe was used at 15 investigation sites corresponding to the selected sediment sampling locations. The average depth of penetration was 21.7 feet for the 15 test sites. A maximum penetration of 40.5 feet was attained at the upstream mouth of Boulder Canyon (Location No. 12).

Analyses of Sediment Properties

A comprehensive laboratory testing program was established to analyze the physical and chemical properties of the Lake Mead sediment samples collected in 1963 and 1964. All analyses of sediment were made in the Division of Research laboratories, Office of Chief Engineer, Denver, Colorado, except for the 35 control tests of particle size analyses made in the laboratory of the District Chemist, Geological Survey, Albuquerque, New Mexico. The sediment samples collected in 1963 with the drive sampler were analyzed differently from the samples obtained in 1964 with the piston core and bottle sampling methods.

Of the 80 samples collected in 1963, 43 of them were measured for wet unit weight at the sampling site. Representative portions of these samples along with the remaining 37 samples collected with the double-tube sampler were taken to the Bureau laboratory at Hoover Dam to determine the moisture content. Later these samples were sent to the Denver laboratory where further tests were made of the physical and chemical properties of the sediment.

The 19 piston-core samples sealed in plastic liners and the 14 bottle samples sealed in jars were analyzed in the Denver laboratory. A complete testing was made of the physical and chemical properties of these samples.

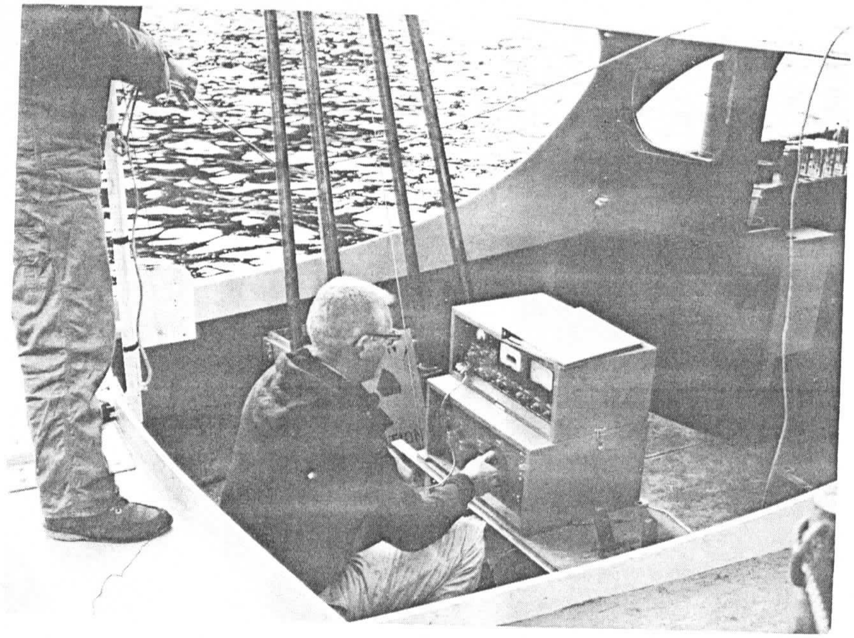
The various laboratory tests made of the Lake Mead sediments are described in the following sections.

Physical Properties

Unit weight.—The Lake Mead sediments were sampled with three devices each differing in type that would directly affect the technique of determining the sample unit weight. Each of unit weight determination techniques will be described.

Drive samples.—The undisturbed samples obtained from the drill hole were measured at the site for determining wet unit weight. The thin-wall sampler tube was removed from the sampler head and the

[4-1] Livesey, Robert H., "Operation Manual for the Radioactive Sediment Density Probe," Department of the Army, Corps of Engineer, p 5, July 1965.



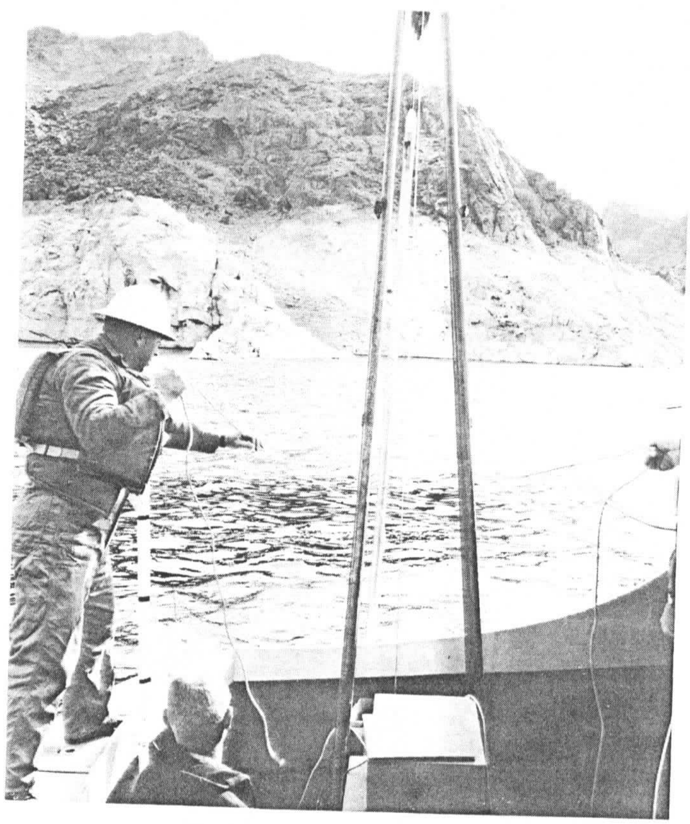


Figure 4-20. The photos show the sediment density gamma probe being raised out of the protective radiation shield and lowered over the side of the boat. The probe is operated by lowering it through the water and into the sediment deposit to measure the inplace density of the sediment medium. Top Photo P45-D-46851 A, bottom Photo P45-D-46852 A

length of the sample measured to determine the percent recovery of the drive length. The sample was then trimmed on one or both ends to measure its length more accurately. Next, the tube containing the sediment sample was weighed with a portable field scale (Figure 4-21) accurate to the nearest hundredth pound. The empty sampler tubes had been weighed previously and the bit area measured. These measurements gave the data needed to compute the wet unit weight of the sample. The samples were extruded from the tube for inspection and classification of material. Representative portions of the sample were then put in a jar and sealed for moisture determination and other specified tests.

Wet unit weights were not determined for samples obtained with the double-tube sampler because they were considered disturbed. However, the samples were inspected, classified, and a representative portion placed in a jar and sealed for moisture determinations.

The dry unit weight of the drive samples was computed by the following equation using the field determined wet unit weights and laboratory determined moisture contents (see subsequent description of moisture content determination).

$$W_d = \frac{W_w}{1 + (m/100)} \qquad (4\text{-}1)$$

W_d = dry unit weight, in pounds per cubic foot
W_w = wet unit weight, in pounds per cubic foot
m = moisture content, in percent

The computed dry unit weights of the drill hole samples are listed in Table 4-1.

Piston-core samples.—The core samples in sealed plastic liners were taken to the laboratory. The liners were marked at points where they would be cut in sections about 2 feet long. The cores were packed in dry ice and frozen at the selected cut points (Figure 4-22). It took about 25 minutes to freeze a 1- to 2-inch section of material in the tube. Freezing was kept to the minimum required to stabilize the sediment and water during cutting and weighing operations. When frozen, the tube and sediment were cut with a carpenter's saw and the sample immediately weighed on a balance accurate to a tenth gram (Figure 4-23). The sediment was pushed out of the liner and thoroughly mixed to pick up any free moisture that had separated out during the shipping and handling processes (Figure 4-24). This mixture was further separated into samples (Figure 4-25) for determining the moisture content and making other tests. The section of plastic liner was cleaned and weighed. Liner volumes were determined by weighing the water required to fill the plastic liner of a measured length (Figure 4-25). Wet unit weight was computed from the weight and volume so determined.

The dry unit weight of each core sample was computed by Equation (4-1) using the data from the laboratory determinations of wet unit weight and moisture content. Dry unit weight values are listed in Table 4-1.

Bottle samples.—The bottle samples of the unconsolidated sediment were taken to the laboratory in sealed jars. The distance measured with a micrometer from the top of the jar to the water surface was used to determine the volume of sediment and water. Two jars identical to the sample containers were filled twice with water to depths equal to the measured sample depth. The sample volume was determined from the average weight of the water of both trials. The tare weight was used as the wet weight of the sample. The sample was thoroughly mixed to a smooth consistency to pick up all free water that had separated from the sediment preparatory to moisture determinations and other specified tests.

The dry unit weight of the bottle sample was computed by Equation (4-1), using the data from the laboratory determinations of wet weight and moisture content. The results of the dry unit weights are shown in Table 4-1.

Moisture Content

The moisture content was determined by placing a representative portion of each sample that had been previously weighed in its natural wet state in a drying oven at a temperature of 110° C until it reached a constant weight. The sample was then placed in a desiccator and cooled to room temperature. The moisture content in percent of ovendry weight of sediment was computed by the following equation:

$$\text{Moisture content, percent} = \frac{\text{weight of water evaporated}}{\text{weight of ovendry sediment}} \times 100 \qquad (4\text{-}2)$$

The moisture content results are listed in Table 4-1.

Specific Gravity

The specific gravity was determined by separating about 100 grams of the sediment sample which was accurately weighed and carefully placed in a

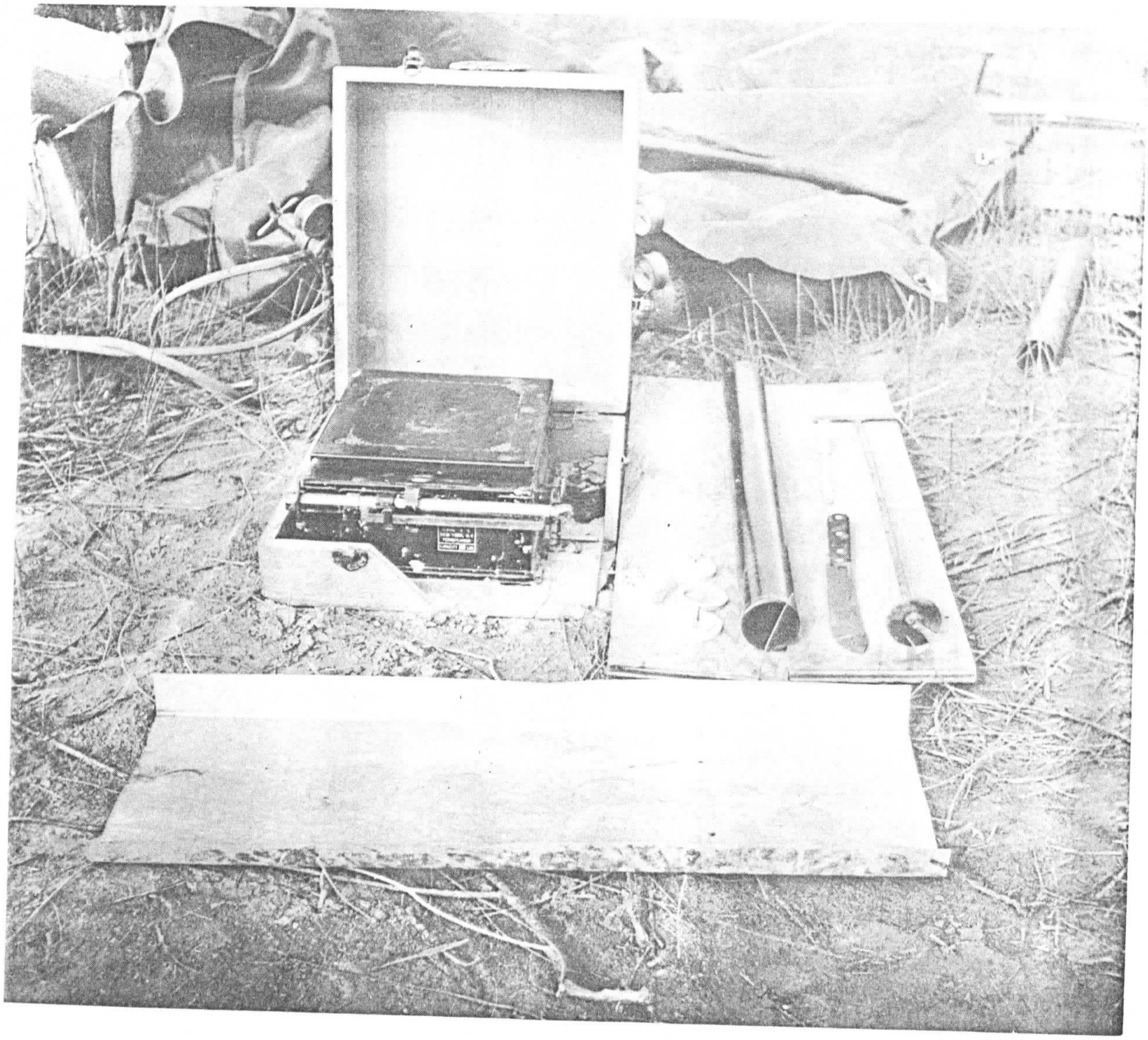


Figure 4-21. Equipment used to determine sediment density. From left to right—weighing scale, packers, thin-wall sampling tube, measuring tape, knife and trimmer. Sample pan is in foreground. Photo P45-D-41637 NA

Table 4-1

SUMMARY OF SEDIMENT TEST DATA

SAMPLE IDENTIFICATION					PHYSICAL PROPERTIES										
LOCATION a/	FIELD SAMPLE NO.	LABORATORY SAMPLE NO. 41Q-	DEPTH BELOW SEDIMENT SURFACE (FEET)	ELEVATION OF MEAN SAMPLE DEPTH (FEET) b/	COLOR (WET) c/	MOISTURE CONTENT (PERCENT)	DRY UNIT WEIGHT (LBS. PER CU. FT.)	POROSITY (PERCENT)	SPECIFIC GRAVITY OF SEDIMENT PARTICLES	PLASTICITY INDEX (PERCENT)	PARTICLE SIZE GRADATION (PERCENT) <0.001 (MILLIMETERS)	0.001-0.004 (MILLIMETERS)	0.004-0.062 (MILLIMETERS)	>0.062 (MILLIMETERS)	MEDIAN DIAMETERS, D_{50} d/ ($X10^{-3}$ MILLIMETERS)
					Drive Samples										
DH-1 (Pierce Basin)	1	1	0.0-2.0	1160.0	L T	5.2	83.1	50.5			6.0	5.0	56.0	33.0	44.0
	2	2	2.0-4.0	1158.0	L T	8.3	85.8	48.9	2.69		16.0	9.0	70.5	4.5	21.0
	3	3	4.0-5.5	1156.2	L T	12.8	80.4	52.1			18.0	13.0	67.1	1.9	11.3
	3	4	5.5-6.0	1155.2	L T	11.5	81.3	51.4			3.0	3.0	40.0	54.0	67.0
	4	5	6.0-7.0	1154.5	T	10.9	99.6	40.4	2.68		7.0	2.8	34.7	55.5	69.0
	4	6	7.0-7.8	1153.6	R B	28.3	86.1	49.8	2.75	36.0	47.0	26.0	27.0	0.0	1.2
	6	7	10.2-10.4	1150.7	R B	40.3	81.3	52.6	2.75	30.0	41.0	24.0	31.4	3.6	1.8
	6	8	10.4-12.3	1149.6	B	33.7	85.3	49.6			6.0	1.5	63.5	29.0	46.0
	7	9	12.3-14.3	1147.7	R B	34.7	87.0	47.8	2.67		9.0	3.0	56.0	32.0	40.0
	8	10	14.3-16.5	1145.6	B G	35.4			2.73	18.0	35.0	24.5	40.5	0.0	2.5
	9	11	17.0-18.4	1143.3	R B G	35.6	85.4	49.3		21.0	29.0	9.0	62.0	0.0	6.8
	9	12	18.4-18.9	1142.3	G B	30.5	88.7	46.8	2.67		5.0	2.5	66.5	26.0	45.0
	10	13	18.9-20.0	1141.5	G R	38.0			2.73	17.0	27.0	18.0	53.3	1.7	5.6
	10	14	20.0-22.0	1140.0	R B	30.3					3.0	1.8	44.2	51.0	63.0
	11	15	22.0-23.3	1138.3	G B	25.2	98.7	42.1			2.0	1.0	11.0	86.0	108.0
	12	16	23.3-23.8	1137.4	D T	41.6			2.73		42.0	27.0	30.9	0.1	1.5
	12	17	23.8-27.0	1135.6	G B	28.4			2.68		4.0	1.8	9.2	85.0	109.0
	13	18	27.0-27.8	1133.6	G B	21.2	101.3	39.4			1.0	1.7	7.3	90.0	133.0
	14	19	27.8-28.3	1132.9	R G	44.3				23.0	30.0	24.5	41.0	4.5	3.4
	14	20	28.3-30.0	1131.8	G B	24.9			2.68		3.0	1.8	8.7	86.5	140.0

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Table 4-1

SUMMARY OF SEDIMENT TEST DATA

SAMPLE IDENTIFICATION					PHYSICAL PROPERTIES										
LOCATION a/	FIELD SAMPLE NO.	LABORATORY SAMPLE NO. 41Q-	DEPTH BELOW SEDIMENT SURFACE (FEET)	ELEVATION OF MEAN SAMPLE DEPTH (FEET) b/	COLOR (WET) c/	MOISTURE CONTENT (PERCENT)	DRY UNIT WEIGHT (LBS. PER CU. FT.)	POROSITY (PERCENT)	SPECIFIC GRAVITY OF SEDIMENT PARTICLES	PLASTICITY INDEX (PERCENT)	PARTICLE SIZE GRADATION (PERCENT) <0.001 (MILLIMETERS)	0.001-0.004 (MILLIMETERS)	0.004-0.062 (MILLIMETERS)	>0.062 (MILLIMETERS)	MEDIAN DIAMETERS, D_{50} d/ ($X10^{-3}$ MILLIMETERS)
DH-1 (Pierce Basin)	15	21	30.0-31.0	1130.5	G	21.6	99.8	40.3			2.0	0.0	4.2	93.8	168.0
	16	22	31.0-35.0	1128.0	G T	20.4			2.68		4.0	0.0	6.2	89.8	175.0
	17	23	35.0-36.3	1125.3	D G	22.6	101.0	39.6			2.0	0.0	2.8	95.2	190.0
	18	24	36.3-39.5	1123.1	D G	25.6			2.67		4.0	1.8	8.7	85.5	170.0
	19	25	39.5-41.1	1120.7	G B	29.43	81.0	50.8			4.0	1.5	35.5	58.0	70.0
	20	26	41.1-45.0	1117.9	G B	29.6			2.60		3.0	2.5	19.0	75.5	93.0
	21	27	45.0-46.8	1115.1	R T	25.8	62.4	61.5			3.0	2.8	34.2	60.0	75.0
	22	28	46.8-50.0	1112.6	R T	28.3			2.60		6.0	3.5	39.5	51.0	63.0
	23	29	50.0-51.2	1110.4	R G	26.6	89.7	44.9			2.0	0.7	20.3	77.0	92.0
	24	30	51.2-55.0	1107.9	R T	28.2			2.62		3.0	0.8	21.2	75.0	92.0
	25	31	55.0-55.9	1105.5	R T	25.9	97.7	40.9			2.0	1.0	16.5	80.5	94.0
	26	32	55.9-57.4	1104.3	R T	28.7			2.67		3.0	0.8	23.2	73.0	88.0
	27	33	57.4-60.0	1102.3	R T	22.6			2.66		3.0	1.9	17.1	78.0	97.0
	28	34	60.0-61.0	1100.5	R T	24.2	98.6	40.6	2.66		3.0	0.0	18.0	79.0	95.0
	30	35	65.0-66.3	1095.3	R T	27.7	95.0	43.2			4.0	0.9	28.1	67.0	80.0
	31	36	66.3-70.0	1092.8	T	24.1			2.70		7.0	3.3	29.7	60.0	78.5
	32	37	70.0-71.3	1090.3	R T	28.8	89.8	46.3			4.0	1.8	32.2	62.0	76.0
	34	38	75.0-76.3	1085.3	R T	28.3	93.5	43.9	2.67		4.0	0.8	29.2	66.0	79.0
	36	39	80.0-82.0	1080.0	G T	30.8	86.1	47.9			3.0	1.5	17.0	78.0	88.0
	37	40	82.0-85.0	1077.5	G T	32.2			2.63		5.0	1.5	19.5	74.0	86.0
	38	41	85.0-87.0	1075.0	G T	31.8	86.5	47.5			4.0	1.8	27.2	67.0	80.0
	39	42	87.0-90.0	1072.0	G T	31.0			2.64		7.0	2.0	34.0	57.0	71.0
	40	43	90.0-91.6	1070.2	D T	30.6	73.1	55.6			6.0	1.5	66.5	26.0	43.5

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Table 4-1

SUMMARY OF SEDIMENT TEST DATA

SAMPLE IDENTIFICATION					PHYSICAL PROPERTIES						PARTICLE SIZE GRADATION (PERCENT)				
LOCATION a/	FIELD SAMPLE NO.	LABORATORY SAMPLE NO. 41Q-	DEPTH BELOW SEDIMENT SURFACE (FEET)	ELEVATION OF MEAN SAMPLE DEPTH (FEET) b/	COLOR (WET) c/	MOISTURE CONTENT (PERCENT)	DRY UNIT WEIGHT (LBS. PER CU. FT.)	POROSITY (PERCENT)	SPECIFIC GRAVITY OF SEDIMENT PARTICLES	PLASTICITY INDEX (PERCENT)	<0.001 (MILLIMETERS)	0.001-0.004 (MILLIMETERS)	0.004-0.062 (MILLIMETERS)	>0.062 (MILLIMETERS)	MEDIAN DIAMETERS, D_{50} d/ ($X10^{-3}$ MILLIMETERS)
DH-1 (Pierce Basin)	41	44	91.6-95.0	1067.7	R T	33.5			2.64		6.0	4.0	62.0	28.0	49.0
	42	45	95.0-96.5	1065.2	R T	32.3	89.2	46.1			6.0	3.6	82.4	8.0	37.5
	42	46	96.5-97.0	1064.2	G	25.7	93.9	43.0			3.0	0.0	3.0	94.0	186.0
	44	47	100.0-101.0	1060.5	G	25.0	97.3	41.2			3.0	0.8	3.0	93.2	160.0
	45	48	101.0-105.0	1058.0	G	29.3					4.0	0.7	6.9	88.4	163.0
	46	49	105.0-106.0	1055.5	G	26.8	95.7	42.6			2.0	1.0	2.8	94.2	170.0
	47	50	106.0-110.0	1053.0	G	27.0			2.67		4.0	2.5	8.3	85.2	162.0
	48	51	110.0-112.0	1050.0	G	26.8	96.3	42.0			3.0	1.8	4.7	90.5	145.0
	49	52	112.0-115.0	1047.5	G	27.8			2.66		5.0	2.5	14.0	78.5	100.0
	50	53	115.0-116.0	1045.5	G	26.8	87.1	47.3			2.0	1.4	10.3	86.3	108.0
	51	54	116.0-120.0	1043.0	G	26.8			2.65		4.0	2.4	14.2	79.4	99.0
	52	55	120.0-121.0	1040.5	G	25.9	92.9	44.2			2.0	1.8	10.2	86.0	108.0
	53	56	121.0-125.0	1038.0	G	27.6			2.68		5.0	0.7	20.3	74.0	92.0
	54	57	125.0-126.2	1035.4	G	26.8	94.2	43.5			4.0	0.0	14.5	81.5	100.0
	55	58	126.2-130.0	1032.9	G	27.4			2.67		4.0	1.8	14.2	80.0	99.0
	56	59	130.0-130.7	1030.6	G T	24.8	98.4	40.9			3.0	1.8	8.0	87.2	117.0
	57	60	130.7-135.0	1028.1	G T	27.6			2.67		4.0	1.4	10.1	84.5	108.0
	58	61	135.0-136.0	1025.5	G T	25.5	99.5	40.5			3.0	0.8	5.9	90.3	119.0
	59	62	136.0-140.0	1023.0	T	26.5			2.68		5.0	1.9	15.3	77.8	101.0
	60	63	140.0-140.7	1020.6	T	24.2	98.6	41.0			2.0	0.7	8.6	88.7	118.0
	61	64	140.7-145.0	1018.1	G T	21.7			2.68		5.0	0.8	7.5	86.7	125.0
	62	65	145.0-145.8	1015.6	T	24.6	98.9	40.8			2.0	0.8	11.5	85.7	114.0
	63	66	145.8-150.0	1013.1	G	25.2			2.69		7.0	3.5	21.0	68.5	90.0

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Table 4-1

SUMMARY OF SEDIMENT TEST DATA

SAMPLE IDENTIFICATION					PHYSICAL PROPERTIES						PARTICLE SIZE GRADATION (PERCENT)				
LOCATION a/	FIELD SAMPLE NO.	LABORATORY SAMPLE NO. 41Q-	DEPTH BELOW SEDIMENT SURFACE (FEET)	ELEVATION OF MEAN SAMPLE DEPTH (FEET) b/	COLOR (WET) c/	MOISTURE CONTENT (PERCENT)	DRY UNIT WEIGHT (LBS. PER CU. FT.)	POROSITY (PERCENT)	SPECIFIC GRAVITY OF SEDIMENT PARTICLES	PLASTICITY INDEX (PERCENT)	<0.001 (MILLIMETERS)	0.001-0.004 (MILLIMETERS)	0.004-0.062 (MILLIMETERS)	>0.062 (MILLIMETERS)	MEDIAN DIAMETERS, D_{50} d/ ($X10^{-3}$ MILLIMETERS)
DH-1 (Pierce Basin)	64	67	150.0-157.0	1010.6	G	30.1	84.4	50.1	2.71	24.0	30.0	18.0	51.8	0.2	4.5
	65	68	157.0-160.0	1002.5	T	36.3			2.70		12.0	3.2	31.8	53.0	68.0
	66	69	160.0-162.0	1000.0	G	29.2	85.2	49.4			23.0	13.0	52.0	12.0	11.5
	68	70	165.0-167.0	995.0	D G	27.4	91.3	45.8	2.70		16.0	12.5	71.1	0.4	16.0
	70	71	170.0-172.0	990.0	D G	26.9	90.9	46.2	2.71		19.0	12.0	66.8	2.2	12.7
	72	72	175.0-177.0	985.0	G T	29.2	89.4	46.3	2.67		6.0	2.5	15.5	76.0	103.0
	74	73	180.0-182.0	980.0	D G	28.5	91.3	45.8	2.70	13.0	22.0	11.5	64.1	2.4	11.0
	76	74	185.0-187.0	975.0	D G	33.7	83.8	50.1			33.0	21.0	45.8	0.2	33.0
	77	75	187.0-189.5	972.7	G T	42.0			2.68		14.0	3.0	26.0	57.0	78.0
	77	76	189.5-190.0	971.2	G	36.8			2.70		22.0	11.5	57.9	8.6	12.3
	78	77	190.0-190.5	970.7	G T	24.2	95.2	43.5			7.0	2.5	17.0	73.5	97.0
	78	78	190.5-192.0	969.7	D G	30.0	90.9	46.2		13.0	23.0	13.0	63.9	0.1	10.1
	82	79	200.0-202.0	960.0	G T	29.9	89.9	46.8	2.71		16.0	7.0	76.8	0.2	12.5
	84	80	205.0-207.0	955.0	G T	33.8	84.4	50.3	2.72	22.0	26.0	22.0	50.8	1.2	4.40

Bottle Samples

1 (Temple Bar)	1A	81	1.0-3.0	828.6	T	224.8	23.73	86.2			65.0	23.7	11.3	0.0	0.36
2 (Virgin Canyon)	2A	82	1.0-3.0	860.6	T	235.5	22.77	86.9			67.0	23.4	9.6	0.0	0.39
3 (Gregg Basin)	3A	83	0.0-2.0	894.9	T	288.5	19.06	88.9			64.0	31.7	4.3	0.0	0.51

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Table 4-1

SUMMARY OF SEDIMENT TEST DATA

Location a/	Field Sample No.	Laboratory Sample No. 41Q-	Depth Below Sediment Surface (Feet)	Elevation of Mean Sample Depth (Feet) b/	Color (Wet) c/	Moisture Content (Percent)	Dry Unit Weight (Lbs. per Cu. Ft.)	Porosity (Percent)	Specific Gravity of Sediment Particles	Plasticity Index (Percent)	Particle Size Gradation (Percent) <0.001 (Millimeters)	0.001-0.004 (Millimeters)	0.004-0.062 (Millimeters)	>0.062 (Millimeters)	Median Diameters, D_{50} d/ ($\times 10^{-3}$ Millimeters)
4 (Gregg Basin)	4A	84	0.0-2.0	917.9	T	295.0	18.87	89.0	2.76		62.0	26.8	11.2	0.0	0.50
5 (Gregg Basin)	5A	85	2.0-4.0	971.9	T	264.1	20.62	87.9			63.0	30.2	6.8	0.0	0.54
6 (Iceberg Canyon)	6A	86	1.0-3.0	1015.4	T G	214.9	24.71	85.5			Jar broken				
8 (Virgin Basin)	8A	88	0.0-2.0	803.3	T	240.0	22.47	87.0			60.0	26.7	19.3	0.0	0.57
9 (Virgin Basin)	9A	89	0.0-2.0	785.3	T	296.0	18.78	89.1			71.0	28.5	0.5	0.0	0.44
10 (Virgin Basin)	10A	90	2.0-4.0	793.0	T	268.0	20.46	88.2			69.0	24.8	6.2	0.0	0.36
12 (Boulder Canyon)	12A	92	6.0-8.0	763.2	T	318.9	17.59	89.9	2.78		72.0	27.5	0.5	0.0	0.38
13 (Boulder Basin)	13A	93	0.0-2.0	745.7	T	359.7	15.83	90.8			74.0	25.5	0.5	0.0	0.39
14 (Boulder Basin)	14A	94	1.0-3.0	734.5	T	316.6	17.52	89.8			73.0	24.7	2.3	0.0	0.38
15 (Black Canyon)	15A	95	1.0-3.0	723.3	T	247.2	22.20	87.2	2.78		70.0	29.5	0.5	0.0	0.40
16 (Boulder Basin)	16A	96	5.0-7.0	727.1	T	332.1	16.95	90.2			73.0	26.5	0.5	0.0	0.36

Sheet 5 of 12

Table 4-1

SUMMARY OF SEDIMENT TEST DATA

Location a/	Field Sample No.	Laboratory Sample No. 41Q-	Depth Below Sediment Surface (Feet)	Elevation of Mean Sample Depth (Feet) b/	Color (Wet) c/	Moisture Content (Percent)	Dry Unit Weight (Lbs. per Cu. Ft.)	Porosity (Percent)	Specific Gravity of Sediment Particles	Plasticity Index (Percent)	Particle Size Gradation (Percent) <0.001 (Millimeters)	0.001-0.004 (Millimeters)	0.004-0.062 (Millimeters)	>0.062 (Millimeters)	Median Diameters, D_{50} d/ ($\times 10^{-3}$ Millimeters)
				Piston-core Samples											
1 (Temple Bar)	1	97	4.0-6.0	825.6	T	119.1	31.70	81.6			55.0	28.2	16.8	0.0	0.80
		98	6.0-8.0	823.6	T	120.0	35.22	79.6			56.0	29.8	14.2	0.0	0.76
		99	8.0-10.0	821.6	G T	120.4	35.32	79.5			58.0	30.5	11.5	0.0	0.68
		100	10.0-12.0	819.6	T	113.8	37.17	78.4			57.0	25.7	17.3	0.0	0.72
		101	12.0-14.0	817.6	G T	122.3	36.42	78.9			55.0	29.0	16.0	0.0	0.81
		102	14.0-16.0	815.6	G T	112.8	35.98	79.1			56.0	28.2	15.8	0.0	0.78
		X103	4.0-16.0	820.6	G T				2.76	56.3	56.0	29.0	15.0	0.0	0.74
2 (Virgin Canyon)	2	109	3.0-5.0	858.6	G	122.6	25.49	85.3			55.0	28.4	16.6	0.0	0.77
		108	5.0-7.0	856.6	G	115.3	31.55	81.8			50.0	30.0	20.0	0.0	1.00
		107	7.0-9.0	854.6	G	149.7	28.29	83.7			55.0	30.5	14.3	0.2	0.81
		106	9.0-11.0	852.6	G	166.7	27.30	84.3			63.0	23.8	13.0	0.2	0.49
		105	11.0-13.0	850.6	G	146.3	31.79	81.7			60.0	27.0	13.0	0.0	0.68
		104	13.0-15.0	848.6	G	124.1	35.35	79.6			53.0	32.2	14.8	0.0	0.90
		X110	3.0-15.0	853.6	G				2.78		56.0	28.4	15.4	0.2	0.77
3 (Gregg Basin)	4	118	6.0-8.0	888.9	T G	125.8	35.09	79.6			51.0	28.9	21.1	0.0	0.93
		119	8.0-10.0	886.9	R G	126.9	36.04	79.0			53.0	27.8	19.0	0.2	0.86
		120	10.0-12.0	884.9	R G	93.0	44.45	74.1			42.0	32.5	25.5	0.0	1.60
		121	12.0-14.0	882.9	R G	127.3	36.11	79.0			61.0	30.9	7.9	0.2	0.62

Sheet 6 of 12

Table 4-1

SUMMARY OF SEDIMENT TEST DATA

SAMPLE IDENTIFICATION					PHYSICAL PROPERTIES										
LOCATION [a]	FIELD SAMPLE NO.	LABORATORY SAMPLE NO. 41Q-	DEPTH BELOW SEDIMENT SURFACE (FEET)	ELEVATION OF MEAN SAMPLE DEPTH [b] (FEET)	COLOR (WET) [c]	MOISTURE CONTENT (PERCENT)	DRY UNIT WEIGHT (LBS. PER CU. FT.)	POROSITY (PERCENT)	SPECIFIC GRAVITY OF SEDIMENT PARTICLES	PLASTICITY INDEX (PERCENT)	PARTICLE SIZE GRADATION (PERCENT) <0.001 (MILLIMETERS)	0.001-0.004 (MILLIMETERS)	0.004-0.062 (MILLIMETERS)	>0.062 (MILLIMETERS)	MEDIAN DIAMETERS, D_{50} [d] ($X10^{-3}$ MILLIMETERS)
		122	14.0-16.0	880.9	R G	138.6	33.20	80.7			62.0	31.3	6.7	0.0	0.60
		123	16.0-18.0	878.9	No Record	119.8	33.87	80.3			59.0	31.8	9.2	0.0	0.6
		X124	6.0-18.0	883.9	T R G				2.75		55.0	30.0	15.0	0.0	0.78
4 (Gregg Basin)	5	129	1.0-3.0	916.9	T G	122.4	27.63	83.9			58.0	29.6	12.4	0.0	0.72
		128	3.0-5.0	914.9	T G	115.2	32.90	80.8			53.0	30.0	16.7	0.3	0.88
		127	5.0-7.0	912.9	T G	108.3	36.84	78.5			46.0	28.0	16.0	0.0	1.23
		126	7.0-9.0	910.9	T G	128.8	33.42	80.5			56.0	31.8	12.2	0.0	0.87
		125	9.0-11.0	908.9	T G	71.4	53.54	68.8			30.0	21.5	48.3	0.2	3.75
		124A	11.0-13.0	906.9	T G	86.6	43.68	74.6			34.0	19.0	46.8	0.2	3.40
		X130	1.0-13.0	911.9	T G				2.75	42.4	46.0	26.0	27.8	0.2	1.23
5 (Gregg Basin)	7	138	7.0-9.0	966.9	T G	118.3	37.05	78.3			47.0	24.5	28.1	0.4	1.17
		139	9.0-11.0	964.9	R G	79.3	47.07	72.5			40.0	22.0	38.0	0.0	2.00
		140	11.0-13.0	962.9	T G	133.9	33.35	80.5			51.0	27.0	22.0	0.0	0.94
		141	13.0-15.0	960.9	R G	130.9	31.22	81.7			45.0	27.8	26.9	0.3	1.30
		142	15.0-17.0	958.9	L G	96.6	37.77	77.9			37.0	27.5	35.3	0.2	2.28
		143	17.0-19.0	956.9	L G	74.8	45.08	73.6			36.0	24.0	40.0	0.0	2.53
		X144	7.0-19.0	961.9	T G				2.74		42.0	25.5	32.3	0.2	1.63
5 (Gregg Basin)	8	145	21.0-23.0	952.9	G	82.6	43.86	74.1			29.0	22.5	48.5	0.0	3.65
		146	23.0-25.0	950.9	G	49.7	58.47	65.4			22.0	13.5	64.5	0.0	7.50
		147	25.0-27.0	948.9	G	53.7	56.02	66.9			17.0	11.5	71.1	0.4	11.00

Table 4-1

SUMMARY OF SEDIMENT TEST DATA

SAMPLE IDENTIFICATION					PHYSICAL PROPERTIES										
LOCATION [a]	FIELD SAMPLE NO.	LABORATORY SAMPLE NO. 41Q-	DEPTH BELOW SEDIMENT SURFACE (FEET)	ELEVATION OF MEAN SAMPLE DEPTH [b] (FEET)	COLOR (WET) [c]	MOISTURE CONTENT (PERCENT)	DRY UNIT WEIGHT (LBS. PER CU. FT.)	POROSITY (PERCENT)	SPECIFIC GRAVITY OF SEDIMENT PARTICLES	PLASTICITY INDEX (PERCENT)	PARTICLE SIZE GRADATION (PERCENT) <0.001 (MILLIMETERS)	0.001-0.004 (MILLIMETERS)	0.004-0.062 (MILLIMETERS)	>0.062 (MILLIMETERS)	MEDIAN DIAMETERS, D_{50} [d] ($X10^{-3}$ MILLIMETERS)
		148	27.0-29.0	946.9	G	46.8	57.52	60.0			23.0	10.3	66.4	0.3	8.40
		X149	21.0-29.0	949.9	G				2.71		23.0	14.8	62.1	0.1	7.40
6 (Iceberg Canyon)	9	150	4.0-6.0	1012.4	T G	73.3	53.42	68.7			31.0	16.5	52.2	0.3	4.70
		151	6.0-8.0	1010.4	T G	57.4	63.53	62.7			26.0	14.2	58.9	0.3	6.25
		152	8.0-10.0	1008.4	T G	72.1	53.27	68.7			35.0	21.5	43.2	0.3	2.70
		153	10.0-12.0	1006.4	G	90.1	44.99	73.6			16.0	22.0	62.0	0.0	7.30
		154	12.0-14.0	1004.4	G	50.9	60.20	64.7			46.0	28.2	25.8	0.0	1.22
		X155	4.0-14.0	1008.4	T G				2.73		31.0	20.5	48.2	0.3	3.60
7 (Iceberg Canyon)	11	161	0.0-2.0	1060.1	G	46.6	73.31	56.7			6.0	1.8	63.7	28.5	4.35
		162	2.0-4.0	1058.1	T	29.02	72.99	56.8			5.0	3.2	64.8	35.2	4.35
		163	4.0-6.0	1056.1	G	34.0	68.93	59.2			7.0	3.5	66.0	23.5	40.00
		164	6.0-8.0	1054.1	G	33.4	78.71	53.5			5.0	3.5	67.0	24.5	40.50
		X165	0.0-8.0	1057.1					2.71		6.0	2.4	65.6	26.0	41.50
8 (Virgin Basin)	12	166	3.0-5.0	800.3	R G	117.9	36.58	78.9			60.0	34.4	5.6	0.0	0.63
		167	5.0-7.0	798.3	R G	110.72	39.80	77.1			57.0	29.5	13.5	0.0	0.71
		168	7.0-9.0	796.3	R G	104.4	41.53	76.1			58.0	33.9	8.1	0.0	0.71
		169	9.0-11.0	794.3	R G	106.9	40.21	76.8			60.0	28.7	11.1	0.2	0.62
		170	11.0-13.0	792.3	R G	98.0	39.42	77.3			55.0	31.2	13.8	0.0	0.80
		X171	3.0-13.0	796.3	R G				2.78		58.0	31.6	10.4	0.0	0.71

Table 4-1

SUMMARY OF SEDIMENT TEST DATA

SAMPLE IDENTIFICATION					PHYSICAL PROPERTIES									
LOCATION a/	FIELD SAMPLE NO.	LABORATORY SAMPLE NO. 41Q-	DEPTH BELOW SEDIMENT SURFACE (FEET)	ELEVATION OF MEAN SAMPLE DEPTH b/ (FEET)	COLOR (WET) c/	MOISTURE CONTENT (PERCENT)	DRY UNIT WEIGHT (LBS. PER CU. FT.)	POROSITY (PERCENT)	SPECIFIC GRAVITY OF SEDIMENT PARTICLES	PLASTICITY INDEX (PERCENT)	PARTICLE SIZE GRADATION (PERCENT) <0.001 (MILLIMETERS)	0.001-0.004 (MILLIMETERS)	0.004-0.062 (MILLIMETERS)	>0.062 (MILLIMETERS)	MEDIAN DIAMETERS, D_{50} d/ ($X10^{-3}$ MILLIMETERS)
8 ([illegible]gin Basin)	13	172	13.0-15.0	790.3	T G	104.7	39.13	77.4			60.0	24.0	16.0	0.0	0.62
		173	15.0-17.0	789.3	T G	112.9	38.36	77.8			58.0	27.0	14.8	0.2	0.70
		174	17.0-19.0	787.3	T G	116.0	37.37	78.4			60.0	29.8	10.2	0.0	0.64
		175	19.0-21.0	785.3	T G	113.9	38.21	77.9			62.0	27.0	10.8	0.2	0.57
		176	21.0-23.0	783.3	T G	114.9	36.49	78.9			59.0	28.8	12.2	0.0	0.65
		X177	13.0-23.0	787.3	T G				2.77		60.0	30.8	9.0	0.2	0.64
9 (Virgin Basin)	14	178	1.0-3.0	784.3	R G	128.2	35.65	79.4			52.0	31.5	16.5	0.0	0.91
		179	3.0-5.0	782.3	R G	120.4	37.09	78.5			62.0	30.2	7.8	0.0	0.60
		180	5.0-7.0	780.3	R G	110.2	40.22	76.7			61.0	26.8	11.9	0.3	0.58
		181	7.0-9.0	778.3	R G	93.5	44.59	74.2			57.0	30.4	12.6	0.0	0.73
		182	9.0-11.0	776.3	T G	92.7	41.04	76.2			59.0	29.9	11.1	0.0	0.79
		X183	1.0-11.0	780.3					2.77	59.6	58.0	29.8	12.0	0.2	0.71
10 (Virgin Basin)	15	184	6.0-8.0	789.0	T G	121.0	35.27	79.7			60.0	27.2	12.8	0.0	0.66
		185	8.0-10.0	787.0	R G	114.6	38.23	78.0			59.0	28.8	11.9	0.3	0.64
		186	10.0-12.0	785.0	R G	106.7	41.78	75.9			60.0	27.8	12.2	0.0	0.63
		187	12.0-14.0	783.0	T G	94.7	45.10	74.0			54.0	28.0	18.0	0.0	0.80
		188	14.0-16.0	781.0	T G	93.8	43.00	75.2			55.0	24.5	20.3	0.2	0.74
		X189	6.0-16.0	785.0	T G				2.78		58.0	26.8	15.0	0.2	0.67
11 (Overton Arm)	16	190	0.0-2.0	1076.2	D G	141.7	29.22	82.9			27.0	21.5	50.1	1.4	4.35
		191	2.0-4.0	1074.2	T D G	83.8	48.12	71.9			44.0	30.0	26.0	0.0	4.40

Table 4-1

SUMMARY OF SEDIMENT TEST DATA

SAMPLE IDENTIFICATION					PHYSICAL PROPERTIES										
LOCATION a/	FIELD SAMPLE NO.	LABORATORY SAMPLE NO. 41Q-	DEPTH BELOW SEDIMENT SURFACE (FEET)	ELEVATION OF MEAN SAMPLE DEPTH b/ (FEET)	COLOR (WET) c/	MOISTURE CONTENT (PERCENT)	DRY UNIT WEIGHT (LBS. PER CU. FT.)	POROSITY (PERCENT)	SPECIFIC GRAVITY OF SEDIMENT PARTICLES	PLASTICITY INDEX (PERCENT)	PARTICLE SIZE GRADATION (PERCENT) <0.001 (MILLIMETERS)	0.001-0.004 (MILLIMETERS)	0.004-0.062 (MILLIMETERS)	>0.062 (MILLIMETERS)	MEDIAN DIAMETERS, D_{50} d/ ($X10^{-3}$ MILLIMETERS)
		192	4.0-6.0	1072.2	T D G	73.0	52.79	69.1			39.0	29.0	32.0	0.0	1.90
		193	6.0-8.0	1070.2	T D G	71.1	50.75	70.3			42.0	30.4	27.6	0.0	1.53
		X194	0.0-8.0	1073.2	T D G				2.74		38.0	28.0	32.8	1.2	2.00
12 (Boulder Canyon)	17	195	14.0-16.0	755.2	T G	132.5	33.20	80.8			60.0	30.8	9.2	0.0	0.65
		196	16.0-18.0	753.2	T G	134.8	33.85	80.4			74.0	27.3	8.7	0.0	0.52
		197	18.0-20.0	751.2	T G	132.75	34.88	79.8			65.0	25.2	9.8	0.0	0.48
		198	20.0-22.0	749.2	T G	119.5	36.87	78.7			62.0	32.6	5.4	0.0	0.59
		199	22.0-24.0	747.2	T G	117.7	36.18	79.1			63.0	34.3	2.7	0.0	0.60
		200	24.0-26.0	745.2	T G	116.2	35.39	75.5			62.0	29.0	8.8	0.2	0.60
		X201	14.0-26.0	750.2	T G				2.77		63.0	29.3	7.7	0.0	0.57
13 (Boulder Basin)	19	209	3.0-5.0	742.7	T G	133.7	31.98	81.5			62.0	28.0	10.0	0.0	0.57
		210	5.0-7.0	740.7	T G	146.8	31.50	81.8			66.0	30.0	4.0	0.0	0.48
		211	7.0-9.0	738.7	T G	129.4	35.11	79.7			63.0	30.3	6.7	0.0	0.55
		212	9.0-11.0	736.7	T G	111.2	37.56	78.3			62.0	28.8	9.2	0.0	0.52
		213	11.0-13.0	734.7	T G	116.4	37.64	78.2			60.0	29.5	10.5	0.0	0.61
		214	13.0-15.0	732.7	G	108.3	36.82	78.7			61.0	29.8	9.2	0.0	0.62
		X215	3.0-15.0	737.7					2.77	57.3	62.0	30.2	7.8	0.0	0.58
14 (Boulder Basin)	21	222	3.0-5.0	732.5	T G	141.2	31.14	81.9			61.0	26.7	12.3	0.0	0.55
		223	5.0-7.0	730.5	T G	131.2	35.33	79.4			58.0	29.7	12.3	0.0	0.54
		224	7.0-9.0	728.5	T G	136.1	34.76	79.7			63.0	30.4	6.6	0.0	0.58

Table 4-1

SUMMARY OF SEDIMENT TEST DATA

SAMPLE IDENTIFICATION					PHYSICAL PROPERTIES										
											PARTICLE SIZE GRADATION (PERCENT)				
LOCATION a/	FIELD SAMPLE NO.	LABORATORY SAMPLE NO. 41Q-	DEPTH BELOW SEDIMENT SURFACE (FEET)	ELEVATION OF MEAN SAMPLE DEPTH b/ (FEET)	COLOR (WET) c/	MOISTURE CONTENT (PERCENT)	DRY UNIT WEIGHT (LBS. PER CU. FT.)	POROSITY (PERCENT)	SPECIFIC GRAVITY OF SEDIMENT PARTICLES	PLASTICITY INDEX (PERCENT)	<0.001 (MILLIMETERS)	0.001-0.004 (MILLIMETERS)	0.004-0.062 (MILLIMETERS)	>0.062 (MILLIMETERS)	MEDIAN DIAMETERS, D50 d/ (X10^-3 MILLIMETERS)
		225	9.0-11.0	726.5	T G	127.6	36.84	78.5			57.0	30.0	13.0	0.0	0.70
		226	11.0-13.0	724.5	T G	123.9	37.47	78.2			55.0	25.0	20.0	0.0	0.7
		227	13.0-15.0	722.5	T G	120.4	34.92	79.7			57.0	29.2	13.8	0.0	0.70
		X228	3.0-15.0	727.5	T G				2.75		58.0	28.3	13.7	0.0	0.67
15 (Black Canyon)	22	229	5.0-7.0	719.3	T G	125.4	34.58	79.9			61.0	25.7	13.3	0.0	0.5
		230	7.0-9.0	717.3	T G	107.3	40.84	76.3			59.0	29.7	11.3	0.0	0.6
		231	9.0-11.0	715.3	T G	97.2	43.93	74.5			61.0	27.4	11.6	0.0	0.4
		232	11.0-13.0	713.3	T G	92.9	45.28	73.7			60.0	29.4	10.6	0.0	0.60
		233	13.0-15.0	711.3	T G	87.1	47.58	72.4			60.0	28.6	11.4	0.0	0.60
		234	15.0-17.0	709.3	T G	87.7	44.47	74.2			59.0	29.2	11.8	0.0	0.60
		X235	5.0-17.0	714.3					2.76	58.2	60.0	28.6	11.4	0.0	0.60
16 (Boulder Basin)	24	243	6.0-8.0	726.1	T G	143.8	30.43	82.3			57.0	31.3	11.7	0.0	0.73
		244	8.0-10.0	724.1	T G	131.1	34.78	79.8			60.0	25.8	14.0	0.2	0.59
		245	10.0-12.0	722.1	T G	124.7	36.24	79.0			58.0	25.4	16.4	0.2	0.65
		246	12.0-14.0	720.1	T G	130.1	35.59	79.3			63.0	30.2	6.8	0.0	0.54
		247	14.0-16.0	718.1	T G	125.2	36.57	78.8			61.0	26.9	12.1	0.0	0.56
		248	16.0-18.0	716.1	T G	122.9	33.41	80.6			70.0	19.4	10.6	0.0	--
		X249	6.0-18.0	721.1	T G				2.76		61.0	27.7	11.3	0.0	0.57
16 (Boulder Basin)	25	250	18.0-20.0	714.1	T G	117.6	37.03	78.6			58.0	28.3	13.7	0.0	0.67
		251	20.0-22.0	712.1	T G	114.5	39.03	77.4			55.0	27.2	17.8	0.0	0.76

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Table 4-1

SUMMARY OF SEDIMENT TEST DATA

SAMPLE IDENTIFICATION					PHYSICAL PROPERTIES										
											PARTICLE SIZE GRADATION (PERCENT)				
LOCATION a/	FIELD SAMPLE NO.	LABORATORY SAMPLE NO. 41Q-	DEPTH BELOW SEDIMENT SURFACE (FEET)	ELEVATION OF MEAN SAMPLE DEPTH b/ (FEET)	COLOR (WET) c/	MOISTURE CONTENT (PERCENT)	DRY UNIT WEIGHT (LBS. PER CU. FT.)	POROSITY (PERCENT)	SPECIFIC GRAVITY OF SEDIMENT PARTICLES	PLASTICITY INDEX (PERCENT)	<0.001 (MILLIMETERS)	0.001-0.004 (MILLIMETERS)	0.004-0.062 (MILLIMETERS)	>0.062 (MILLIMETERS)	MEDIAN DIAMETERS, D50 d/ (X10^-3 MILLIMETERS)
		252	22.0-24.0	710.1	T G	111.8	38.57	77.7			57.0	28.4	14.6	0.0	0.69
		253	24.0-26.0	708.1	T G	112.1	38.58	77.7			55.0	28.8	16.2	0.0	0.78
		254	26.0-28.0	706.1	T G	108.5	37.41	78.4			56.0	26.3	17.7	0.0	0.73
		X255	18.0-28.0	710.1	T G				2.77		56.0	27.8	16.2	0.0	0.72

a/See location map (Figure 4-1).
b/Relative to mean sea level.
c/L-light, D-dark, T-tan, R-red, B-brown, G-gray.
d/Median diameters less than 0.001 millimeter were extrapolated.

Sheet 12 of 12

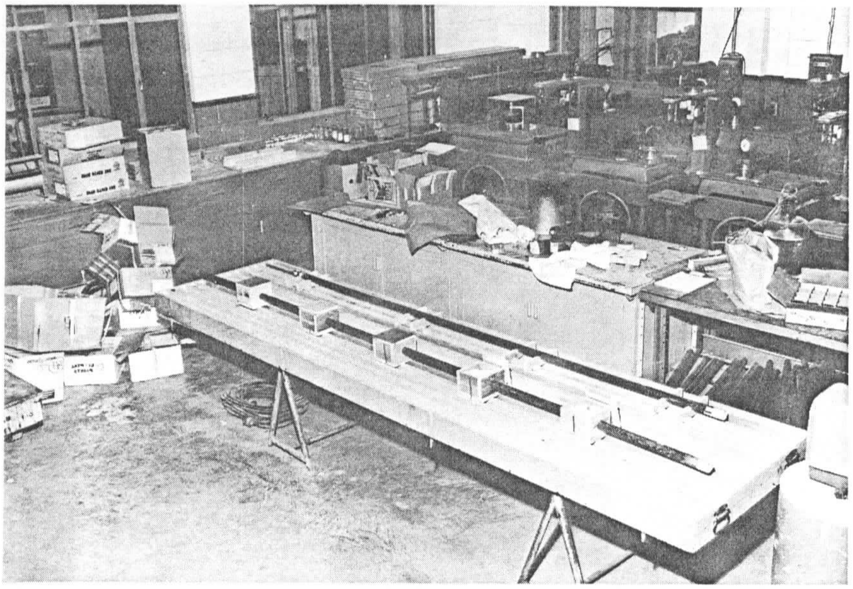
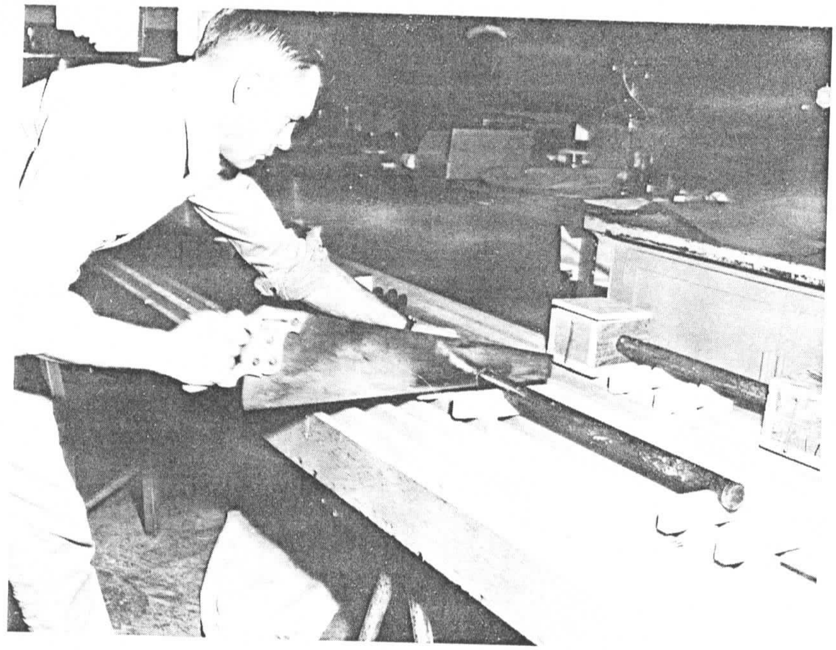


Figure 4-22. The piston-core samples contained in the plastic liners shown above were packed in dry ice and frozen for cutting. Top Photo PX-D-64186, bottom Photo PX-D-64187



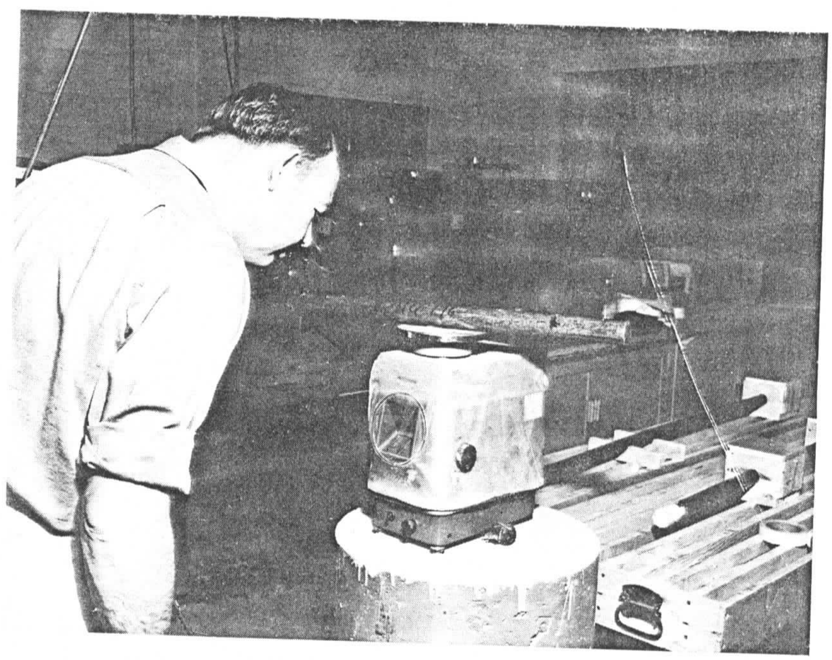
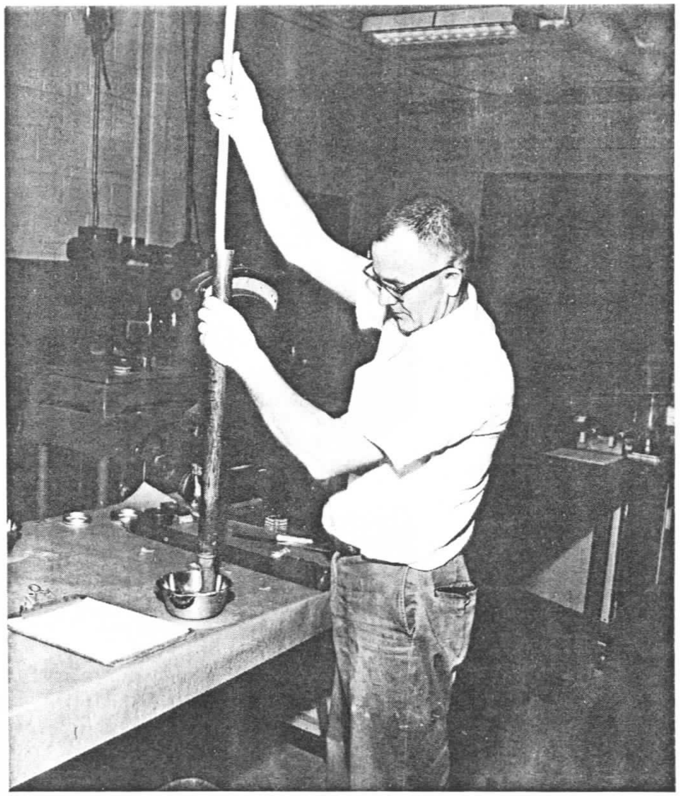


Figure 4-23. The frozen piston-core samples were cut and weighed on a balance. Top Photo PX-D-64188, bottom Photo PX-D-64189



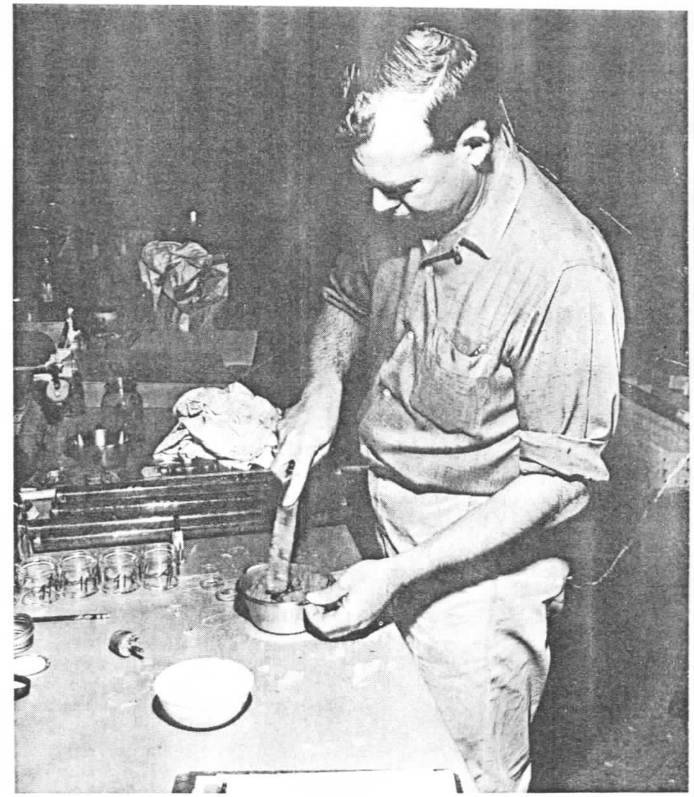
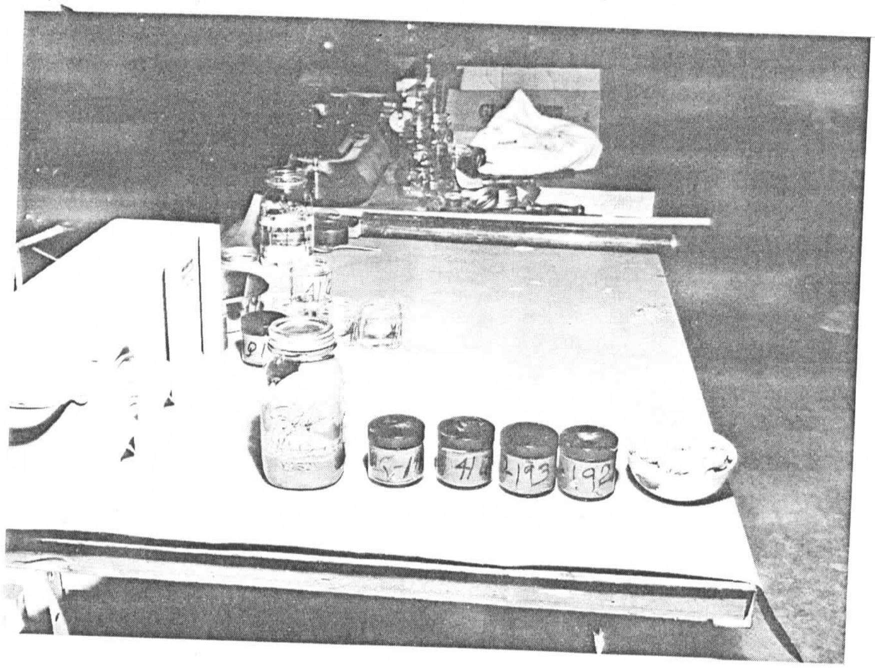
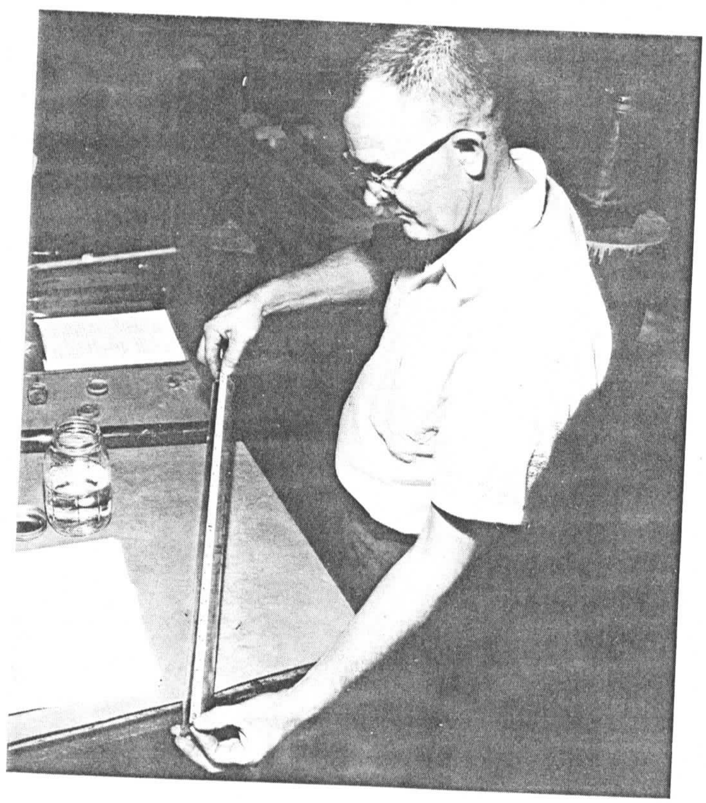


Figure 4-24. The sediment sample was extruded from the plastic liner (left Photo PX-D-64190) and thoroughly mixed to pick up any free moisture (right Photo PX-D-64192).



Each piston-core sample was separated for specified tests. Photo PX-D-64193



The plastic liners were measured for volume determinations. Photo PX-D-64191

FIGURE 4-25

p alibrated flask. Enough distilled water was added cover the sediment. The flask was then connected to vacuum and placed in a cold-water bath where it was mechanically shaken to remove air from the sample (Figure 4-26). When the air was completely evacuated from the sample, the flask was filled with water to a calibration mark on the neck. The flask, sample, and water were weighed as a unit and the temperature of er in the flask was read to the nearest degree from inserted thermometer. The volume of the sediment sample was determined from the flask volume and the computed volume of the water. The specific gravity was computed from these laboratory determinations as the ratio of sediment to the weight in air of an equal volume of distilled water. The specific gravity values are listed in Table 4-1.

Plasticity

ne plasticity index of a selected sediment sample was determined by running Atterberg tests of the liquid and plastic limit. The testing apparatus is shown in Figure 4-27.

The liquid limit is determined by taking a representative 100-gram sample of the air-dried sediment which passes the No. 40 sieve. It is placed in n evaporating dish and thoroughly mixed with a easured quantity of distilled water to a puttylike nsistency. A portion of this sample is placed in a ass cup leveled off to a depth of 1 centimeter and divided using a grooving tool along the diameter of the cup. A mechanical device is used to lift and drop the cup at a rate of two drops per second until the two sides of the sample meet at the bottom of the groove along a distance of about one-half inch. The moisture content of the sediment is determined on a portion taken from around the groove. A record is kept of the number of blows and moisture data. The foregoing procedure is repeated with sufficient water added to bring the soil to a more fluid condition. The objective is to obtain samples of such consistency that the number of blows required to close the groove will be above and below 25.

A flow curve is prepared showing the percent moisture on the linear ordinate scale plotted against the number of blows on the logarithmic abscissa scale. The liquid limit is equal to the percent moisture value where the 25 blow value intersects the flow curve.

To determine plastic limit, a representative 15-gram sample of the air-dried sediment passing the No. 40 sieve is taken and placed in an evaporating dish. It is mixed with distilled water until the mass becomes plastic enough to be easily shaped into a ball. The ball is rolled between the palm of the hand and a ground glass plate with just the right amount of pressure to form the sediment mass into a thread. When the thread measures one-eighth inch in diameter, the sediment is kneaded together and again rolled out. The process is continued until the sediment crumbles when the thread becomes one-eighth inch in diameter and the threads cannot be reformed into a ball. Several threads are made in this manner, and the portions of the crumbled sediment are gathered together and the moisture content determined. The moisture content expressed as a percentage of the weight of the ovendry sediment is the plastic limit.

The plasticity index of a sediment sample is the difference between its liquid and plastic limits, thus:

Plasticity index = liquid limit—plastic limit

The results of the plasticity index are listed in Table 4-1.

Particle-size Gradation

Particle-size gradation tests were run on 215 laboratory samples by sieving and hydrometer methods.

Representative portions of 35 samples were selected as a control group in a special study made of two laboratory methods used to analyze particle sizes. The following descriptions of methods include the two for special study—the hydrometer and pipet methods.

Sieve and hydrometer analyses.—From the ovendried material, a sample weighing 100 grams for sandy sediment or 50 grams for silt or clay sediment was accurately measured, then placed in a porcelain evaporating dish. The required amount of dispersing agent and sufficient distilled water was added to cover the soil and the mixture allowed to stand for at least 18 hours. It was then washed into the dispersion cup with distilled water. Distilled water was poured into the cup until it was within 2 inches of being filled. The sandy contents of the cup were mixed by the stirring apparatus for 5 minutes; clayey soils were mixed up to 15 minutes.

After dispersion, the mixture was transferred to a hydrometer cylinder and distilled water at room temperature was added until a volume of 1,000 milliliters was reached. The contents then were thoroughly mixed for 1 minute.

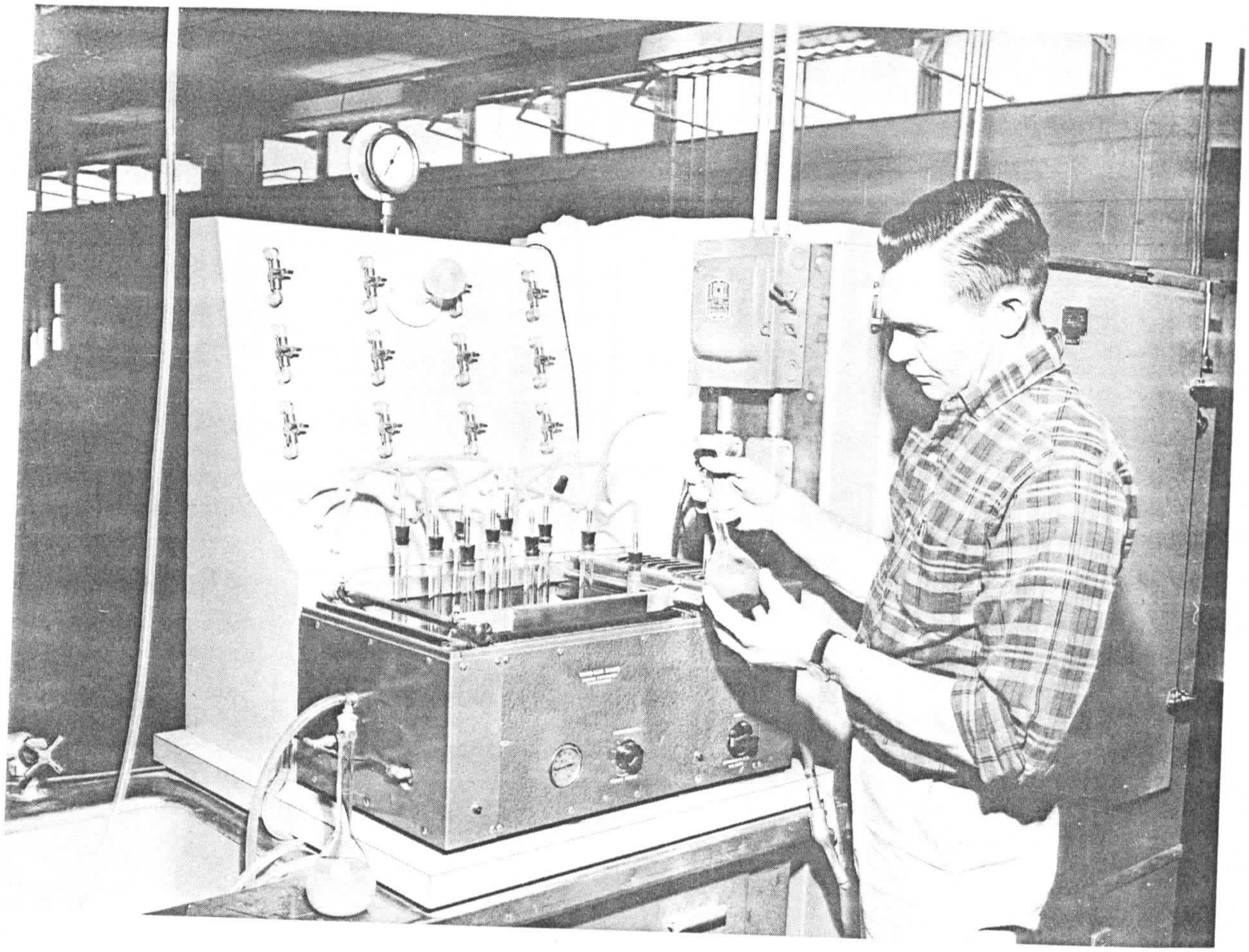


Figure 4-26. Automatic vacuum, shaker and cold water bath used to remove air from samples in specific gravity determinations. Photo PX-D-64194

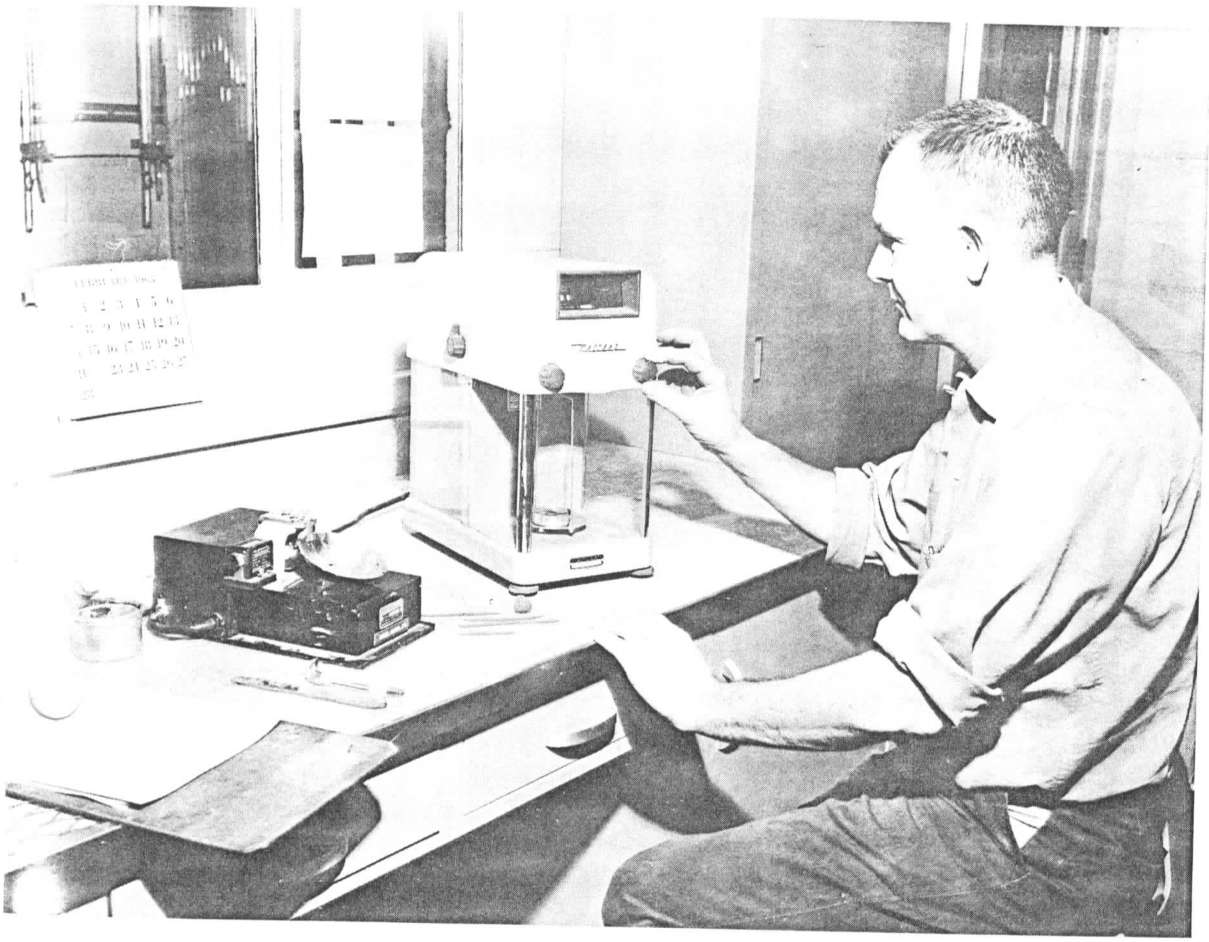


Figure 4-27. Testing apparatus used in the Atterberg Tests of the liquid and plastic limits. Photo PX-D-64195

After the mixing time, the cylinder was immediately placed on a table, timing by a stopwatch started, and a hydrometer inserted carefully into the sediment suspension (Figure 4-28). The hydrometer was read to the nearest half gram per liter at the top point of the meniscus formed around the stem. Readings were observed and recorded at laboratory prescribed time intervals to determine the percents finer than diameters of 37, 19, 9, 5, 2, and 1 microns. Following the 1-minute reading (37 microns), a thermometer was placed in the suspension to measure the temperature which was recorded for the hydrometer readings. After the 4-minute reading (10 microns), the hydrometer was removed and put into distilled water. It was carefully placed in the cylinder again about 30 seconds before the next reading.

When the final hydrometer reading was taken, all material in the graduate was flushed into the No. 200-mesh wash sieve. The material was then carefully washed until all minus No. 200 material passed through the sieve as evidenced by the clear wash water. The fraction of material retained on the No. 200 sieve was dried in an oven and then separated into six sizes on United States Standard Sieves No. 8, 16, 30, 50, 100, and 200. The sieving was done by a powered sieve shaker continuously for the required 15 minutes. After this process the material retained on each sieve was weighed; the accumulative weight of each amount was then recorded. From these data the percent of material passing was computed to the nearest whole percent. Particle size gradations for each sample analyzed were expressed in percentages of clay (less than 0.001 mm plus 0.001–0.004 mm), silt (0.004–0.062 mm), and sand (greater than 0.062 mm) (Table 4-1). The median particle diameter (D_{50}), in millimeters was also listed for each sample analyzed.

Sieve, visual accumulation, and pipet analyses.—The method started by weighing about 25 grams of the wet sample. All organic matter was removed by treating the sample with 100 milliliters of a 6 percent solution of hydrogen peroxide and a half milliliter of glacial acetic acid. It was placed on a steambath for a few hours. The dissolved solids and electrolyte were removed by five complete washings with deionized water. A centrifuge was used to settle the material between washings.

The sand was separated from silt and clay with a 62-micron sieve. Sand fractions of nine samples were analyzed in the visual-accumulation tube apparatus. The remaining samples did not have enough sand for visual analysis and instead were analyzed using wet-sieve techniques. Material finer than 62 microns from the sand fractions was washed into hydrometer cylinders with the silt and clay. This material was stirred for a minute and an aliquot was taken to determine the weight of fine sediment. The aliquot was dried and weighed and a determination was made of the volume of water needed to increase as near as possible the concentration to 10,000 parts per million.

Immediately prior to the pipet analysis, 2 milliliters of 3.75 percent sodium hexametaphosphate solution buffered to pH 8.4 with $NaCO_3$ was added for each 100 milliliters of volume to be analyzed. Each sample was then mixed in an electric mixer for 10 minutes, returned to its hydrometer cylinder, and filled to the predetermined volume. The cylinders were placed in a constant temperature bath (27° C) and stirred 1 minute each. Then using a withdrawal schedule, 20-milliliter pipets were taken from predetermined depths to determine the percents finer than the desired diameters (62, 31, 16, 8, 4, 2, and 1 microns).

All sample portions were dried in an electric-forced draft oven, cooled in a desiccator cabinet, and weighed to the nearest ten thousandth of a gram. The analyses were computed and the percentages, rounded to whole percents, were determined.

Comparing results of the hydrometer and the pipet methods shows that the accuracy and reliability of the two techniques are compatible. The resulting differences in gradation between the two methods are small. These tests indicate that either gradation result could be used in the study of reservoir sediments. The following is a list of factors that may account for some of the differences between the hydrometer and pipet methods:

1. Duplicate samples.—In comparison tests duplicate samples may not be identical.

2. Technique.—Aside from the obvious difference in the methods there is the variation in sample preparation, dispersion, etc.

3. Operators.—It is reasonably assumed that any two persons running the same test on the same material will not necessarily arrive at exactly identical results.

4. Correction factors.—In applying Stokes Law to the hydrometer technique, the following variables were not adjusted:

a. Density of the suspension.

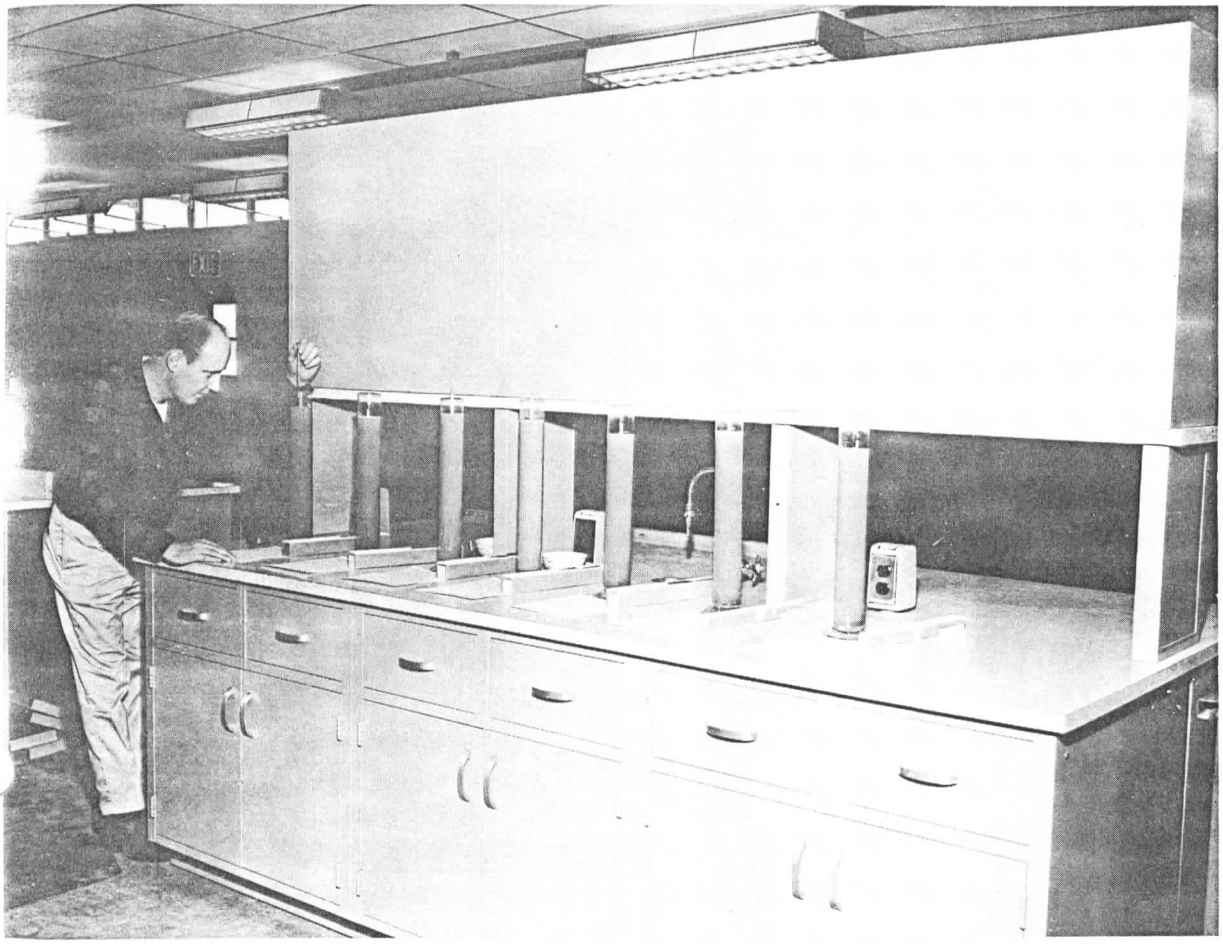


Figure 4-28. Hydrometer tests being performed to determine the sediment particle-size gradation. Photo PX-D-64196

b. Specific gravity of the sediment particles.

c. Viscosity of the suspending medium.

Any one or all of the above factors could affect a given comparative sample test and the variables are certainly not limited to these. Considering the many and varied influences on the two methods, the compatibility of the test results was very good.

Mineralogical Properties

Six selected samples of Lake Mead sediment were examined and analyzed in the Petrographic and Physics Section, Office of Chief Engineer, Denver, Colorado. The sediment samples were examined under the microscope and analyzed by X-ray diffraction and differential thermal analysis.

The sediments were generally similar in appearance and composition. All were fine grained, buff colored when dry, and were composed of silt-sized particles of quartz, calcite, dolomite, feldspar, chlorite, mica, and aggregated clay mineral grains. Other minerals were present in amounts too small for positive identification. No gypsum was seen in these six samples. The clay minerals consisted of montmorillonite-, illite-, and kaolinite-type clays. Actually, in these sediments, the illite- and montmorillonite-type clays were combined in a single mixed-layer clay mineral. As in cases common in alluvial clay deposits, the montmorillonite layers predominated somewhat over the illite. The kaolinite clay was a minor constituent of all the samples.

The chief differences among the six samples were in the grain size of the coarser particles and the relative amount of the minerals. The samples from Locations DH-1 and 4 were more coarse grained and contained more quartz, calcite, and dolomite. The samples from Locations 9, 13, and 15 were finer grained and had a higher content of clay minerals. The mineralogical compositions as estimated by X-ray diffraction and differential thermal analysis are listed in Table 4-2.

Chemical Properties

All 14 samples were reduced to 2 mm, then mixed and quartered to obtain a minimum of 25 grams of sample. The 25-gram sample was ground in a mortar to pass the No. 100 sieve. Samples were then allowed to air dry.

Tests for chemical composition were made to determine the following properties using the procedures outlined in the "Federal Test Method Standard No. 158a," 1960:

a. Loss on ignition.

b. Ferric oxide and aluminum oxide (ammonium hydroxide group).

c. Calcium oxide.

d. Magnesium oxide.

e. Sulfur trioxide.

Tests to determine total phosphorous and total manganese were run as outlined in "Methods of Soil Analysis," American Society of Agronomy, 1965.

The organic matter is determined by procedures outlined in "Soil Chemical Analysis," by M. L.

Table 4-2

ESTIMATED MINERALOGICAL COMPOSITION OF THE SEDIMENTS

Location Lab Sample No.	DH-1 41Q-11	DH-1 41Q-67	DH-4 41Q-X130	DH-9 41Q-X183	DH-13 41Q-X215	DH-15 41Q-X235
Quartz	25	30	25	10	10	13
Feldspar	3	5	3	2	2	2
Calcite	13	13	12	8	7	8
Dolomite	10	6	6	2	3	3
Kaolinite	8	5	8	10	5	10
Mixed-layer clay*	30	30	40	60	60	60
Chlorite	Present	Present	Present	Present	—	Present

*Illite-montmorillonite type.

J... son, 1958, relative to chromic acid determination.

To test for silicon dioxide, a 0.5 gram of moisture-free sample is weighed out. The sample is mixed with 4 to 8 grams of sodium carbonate by grinding in a mortar. The mixture is placed in a 20- to 30-ml crucible between thin layers of sodium carbonate. The crucible is placed on a moderately low flame which is gradually ...reased to about 1,000° C and maintained there until ... mass is quiescent. The burner is removed and the crucible cover transferred to a beaker. Using tongs the crucible is grasped and slowly rotated to spread the molten contents over the sides solidifying as a thin shell over the interior. The crucible is then set aside to cool.

After cooling the crucible is placed upright in a 250-ml ...eaker, and 30 to 40 ml of concentrated hydrochloric ...id are added and the beaker immediately covered ...ith a watchglass. When the action has subsided slightly, the beaker is placed on a steambath and additions of 5 to 10 ml of water are repeated at 3- to 5-minute intervals for as long as each addition causes a noticeable further solution of the fused cake or until a total volume of 75 ml of water has been added. The crucible is then turned on its side with a glass rod and if necessary sufficient water is added to just cover the ...rucible. The sample is digested until disintegration is ...omplete, then both the crucible and the cover from the beaker are lifted thoroughly rinsing each with hot water directly into the beaker.

The liquid is then decanted through a rapid filter paper into a 600-ml beaker. The sides of the 250-ml beaker are washed down with hot hydrochloric acid and the large particles of siliceous material are broken up with the flattened end of a glass rod. The liquid is decanted as before allowing only the finely divided material to pass on to the filter paper. The preceding steps are repeated until all of the siliceous material has been quantitatively transferred to the filter paper. The filter paper and residue are washed several times with small portions of the hot hydrochloric acid and finally with hot water until free of chlorides.

The filtrate is evaporated to dryness on a steambath and the residue baked in an oven for an hour at 105–110° C. The dried residue is cooled and wetted thoroughly with 10 ml of concentrated hydrochloric acid. Ninety ml of hot water are added and the residue heated to incipient boiling and digested with intermittent stirring until all soluble salts are in solution. The mixture is filtered immediately through a medium texture paper and the residue is washed thoroughly with hot hydrochloric acid, then with hot water until free of chlorides. The filtrate and washings are reserved for the determination of the ammonium hydroxide group.

The titanium dioxide is determined by fusing the R_2O_3 from the ammonium hydroxide group with 3 to 5 grams of potassium pyrosulfate and extract the fusion with 75 to 100 ml of 2-normal sulfuric acid using low heat if necessary. The sample is transferred to a volumetric flask and 10 ml of phosphoric acid and 5 ml of hydrogen peroxide are added. It is then mixed thoroughly and diluted to volume with 2-normal sulfuric acid to determine the titanium dioxide colormetrically using the spectrophotometer.

To determine the sodium and potassium oxide, a 0.5000-gram (moisture-free and finely ground) sample is placed in a 30–35-ml crucible. The sample is wetted with a few drops of water, then 0.5 ml of perchloric acid and 10 ml of 48 percent hydrofluoric acid are added. The crucible with the lid almost covering the top is placed on a sandbath and allowed to evaporate at a temperature of 200–225° C. The solution must not boil vigorously or spattering may occur. The perchloric acid should drive off all the fluorine because appreciable amounts of it interfere with the iron determination. The crucible is then removed from the sandbath, cooled, 5 ml of hydrochloric acid added, diluted to two-thirds of volume, and digested for 5 minutes. When the residue is completely dissolved, it is transferred to a volumetric flask and the sodium and potassium determined by flame photometric procedures.

The results of the chemical properties are listed in Table 4-3.

Interpretation of Sediment Properties

The results of the physical, mineral, and chemical analyses of the Lake Mead collected sediment samples characterize the type of sediments accumulated in the reservoir. Some reflect the effect of Glen Canyon Dam on the regimen of the sediment inflow. The data collected in 1963-64 and the resulting analyses should help supplement the data gathered in the 1948-49 survey. A study of the interrelationships among these properties of the deposited sediments should lead to a better understanding of lacustrine sedimentation. Also, they provide useful information in studying the sedimentation process of aggradation which causes the delta formation.

Table 4-3

CHEMICAL PROPERTIES

Laboratory Sample No.	B9552	B9553	B9554	B9555	B9556	B9557	B9558	B9559	B9601	B9602	B9603	B9604	B9605	B9606
SiO_2	72.6	52.8	85.0	86.7	87.2	57.4	83.8	63.2	53.4	73.5	54.1	47.1	52.7	54.0
Fe_2O_3	2.3	3.6	1.2	1.3	1.0	5.2	1.3	3.4	5.7	2.0	5.8	5.2	5.8	5.6
Al_2O_3	6.9	11.8	4.3	4.8	3.9	12.6	5.0	10.0	15.6	7.2	16.7	14.6	18.0	16.2
TiO_2	0.43	0.67	0.22	0.16	0.18	0.69	0.27	0.73	0.79	0.47	0.50	0.49	0.78	0.70
CaO	5.4	10.4	2.6	1.9	2.1	7.2	3.9	7.2	6.5	5.2	5.8	10.2	6.0	5.9
MgO	1.4	3.3	1.0	0.24	0.29	2.7	0.72	2.3	3.0	1.8	3.6	4.9	3.0	4.1
Na_2O	0.84	0.58	0.66	0.68	0.53	0.68	0.63	0.88	0.51	0.80	0.40	0.43	0.40	0.32
K_2O	2.2	2.5	1.7	1.6	1.5	2.1	1.4	1.8	2.2	1.8	2.2	2.3	2.2	2.1
SO_3	0.02	0.04	–	–	–	0.05	0.31	0.03	0.02	–	0.06	0.12	0.04	0.01
Loss	7.1	13.9	3.0	2.3	2.4	11.1	2.9	9.8	11.4	6.5	10.7	14.6	10.8	10.8
Total	99.2	99.6	99.7	99.7	99.1	99.7	100.2	99.3	99.1	99.3	99.9	99.9	99.7	99.7
$CaSO_4 \cdot 2H_2O$[1]	0.04	0.9	–	–	–	0.10	0.66	0.06	0.04	–	0.13	0.26	0.09	0.02
$CaCO_3$	9.6	18.5	4.7	3.4	3.8	12.8	3.7	12.8	11.6	9.3	9.2	16.8	9.2	9.3
Organic[2]	0.82	1.47	0.18	0.00	0.09	1.47	0.18	0.74	1.29	0.37	1.20	1.66	1.38	1.29

[1] Total SO_3 expressed as $CaSO_4 \cdot 2H_2O$.

[2] Organic matter determination by chromic acid reduction.

Of special interest is the results of the drive sampling operation at a point in Pierce Basin where the Colorado River delta was penetrated to a depth of 207 feet to obtain undisturbed samples of the sediment deposits. This pierced depth lacked about 35 feet of reaching the original Colorado River bed profile of 1935. The various physical properties of the delta sediments determined from tests of these samples are plotted in Figure 4-29 in relation to their in-place depth. This investigation gives an interesting picture on how the sediments pile up in the delta area. An extreme stratification pattern is evident from the way the sediment strata vary in thicknesses of a few inches to several feet and the logging record shows a recurrence of clay, silt, and sand. These variations in strata reflect the diverse character of the inflowing sediments and the effects of reservoir stage fluctuations.

A summary can be made of the five physical properties plotted in Figure 4-29. First, the moisture content varies from 3 to 45 percent in the first 30 feet of depth. Between the 30- and 160-foot depths it ranges from 20 to 36 percent and from 23 to 42 percent at depths greater than 160 feet. Secondly, dry densities vary between 80 and 100 pounds per cubic foot throughout the entire depth except they are slightly greater in a depth range of about 27 to 37 feet and drop to about 73 pounds per cubic foot at a 90-foot depth. Thirdly, the specific gravity averages about 2.65 throughout the depth. Except for a few samples, the fourth property, porosity, lies in the 40 to 50 percent range for the full sampling depth. Fifth, the mediam particle diameter, D_{50} size, varies widely (0 to 0.19 mm) in the first 40 feet of depth. From the 40- to 90-foot depth it varies 0.05 to 1 mm. At depths more than 90 feet, the D_{50} again varies widely from 0.001 to 0.18 mm except at depths from 112 to 145 feet where it differs by 0.035 mm or varies from 0.09 to 0.125 mm.

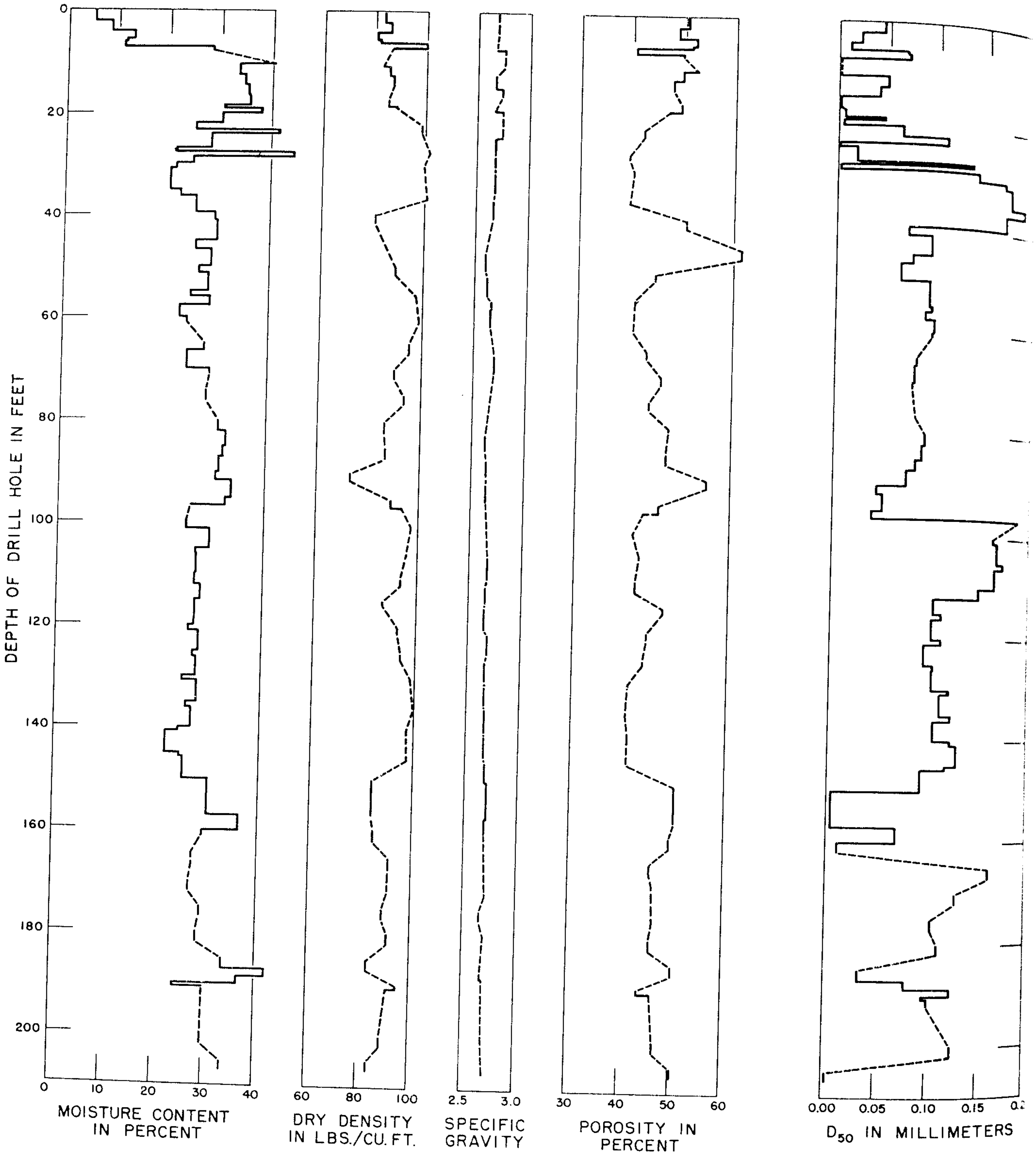
The physical characteristics of the sediments deposited in Figure 4-29 are interrelated for any given stratum, but can be extremely diverse between strata. No significant physical trend was exhibited by the total sediment deposits at Pierce Basin. A specific property in the topmost layer may measure the same in the similar material at lower depths with substantially more overburden. Sediment strata composed of silts and clays have undergone immense consolidation since they were first deposited. These finer materials seem to reach an optimum state of consolidation where the physical properties remain stable regardless of any appreciable change in the overburden.

The characteristics of the fine sediments in the initial unconsolidated state can be studied from the analyses of the bottle and piston-core samples collected in the delta inundated areas. When the samples were collected, a fairly uniform layer of suspended sediment covered the Colorado River delta top area from Iceberg Canyon to Hoover Dam. Turbid underflow often cause these layers to form; however, no physical measurements were made during the survey to detect the existence of these underflows. Results of the four physical property tests run for each sample are plotted with respect to in-place depths in Figure 4-30. These plottings give a picture of the most recent sediment stratum in the unconsolidated state. An abrupt transition in the physical properties occurs immediately below the stratified zone.

Samples taken at Locations 2 through 7 in the reach from lower Virgin Canyon to upper Iceberg Canyon display stratification characteristics similar to those of the drive sampling at Pierce Basin. This pattern of stratification was expected to develop when the Colorado River transported the relatively coarser sediments (silts and fine sands) farther into the lake during the recent cycle of low stage reservoir operation (Figure 3-9). Conditions during the low reservoir stage are also responsible for the river scouring its delta deposit. This is clearly evident in Figure 4-31, a photograph taken of a reach of the river that traverses Pierce Basin.

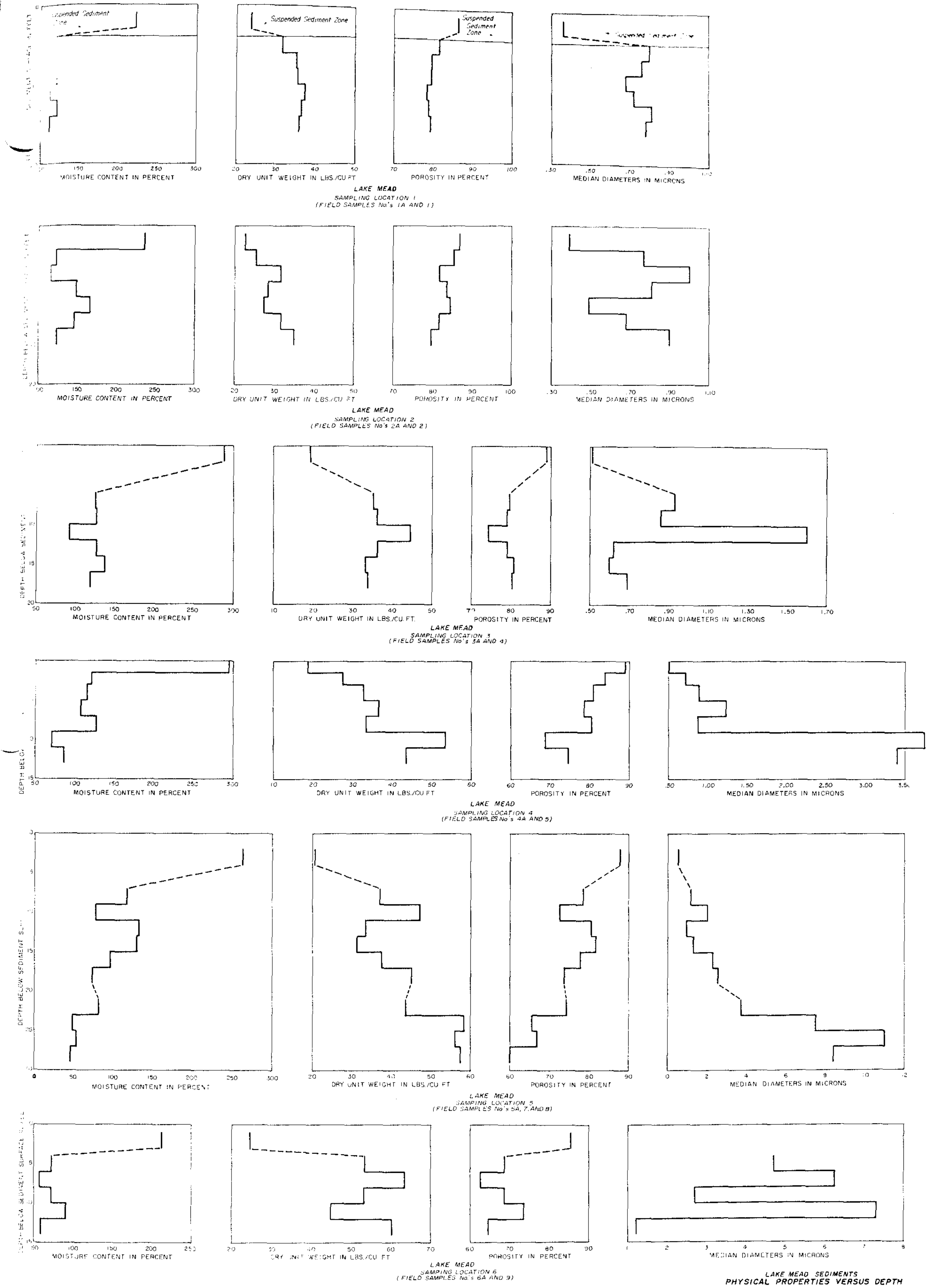
Samples obtained from the reservoir below Gregg Basin show relatively uniform physical characteristics. However, the stratification depositional pattern is still quite evident even in these very fine sediments. The average dry unit weight lies between 35 and 40 pounds per cubic foot for most of these samples at full penetration depth. A trend is indicated of the consolidation increasing with depth which is generally characteristic of these predominately clay sediments.

A comparison of the physical properties of the sediment deposits in the area below Gregg Basin with Pierce Basin (Drill Hole No. 1) disclosed some interesting features. The condition of the strata under heavy overburden at Pierce Basin gives reasonable cause to believe the clay deposits in the area below Gregg Basin could consolidate by as much as 200 percent. However, the properties influencing consolidation of the sediments in the area below Gregg Basin are different from those in Pierce Basin. The Pierce Basin deposits are coarse-grained clays compared to fine-grained clays of the downstream basin deposits.



PHYSICAL PROPERTIES
DRILL HOLE No. 1
LAKE MEAD

FIGURE 4-29



LAKE MEAD SEDIMENTS
PHYSICAL PROPERTIES VERSUS DEPTH

FIGURE 4-30
Sheet 1 of 3

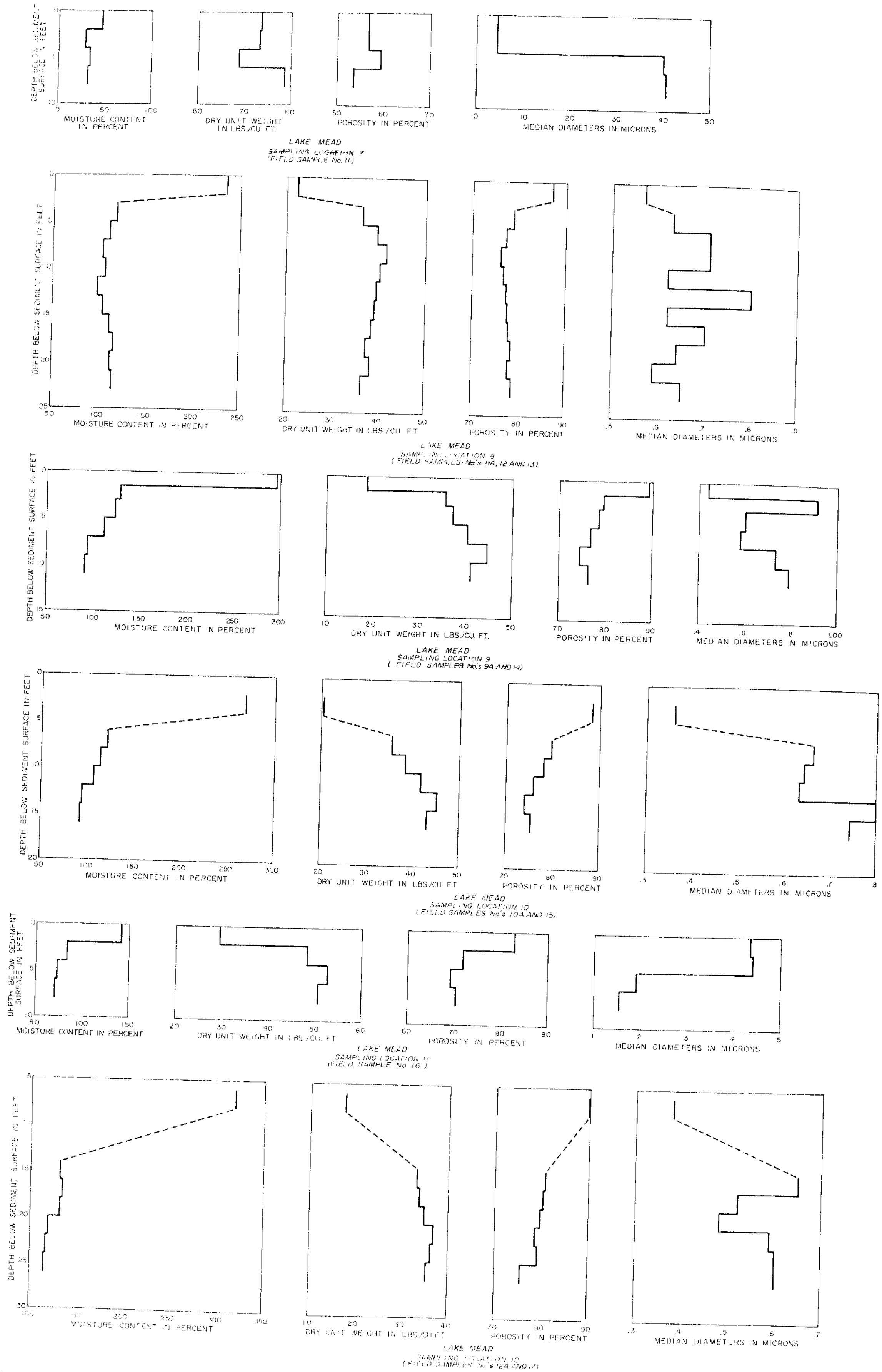
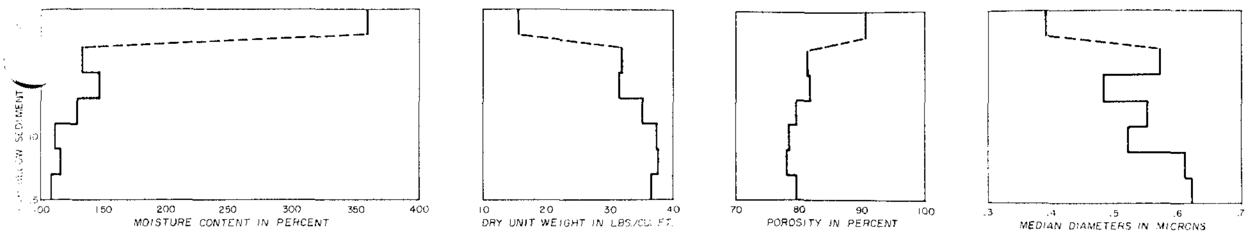
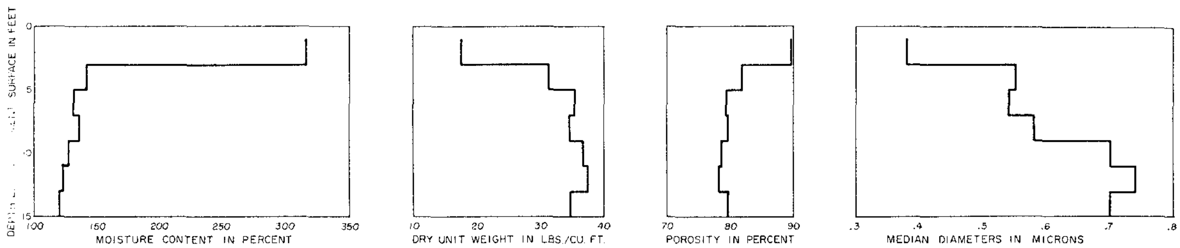


FIGURE 4-30
Sheet 2 of 3

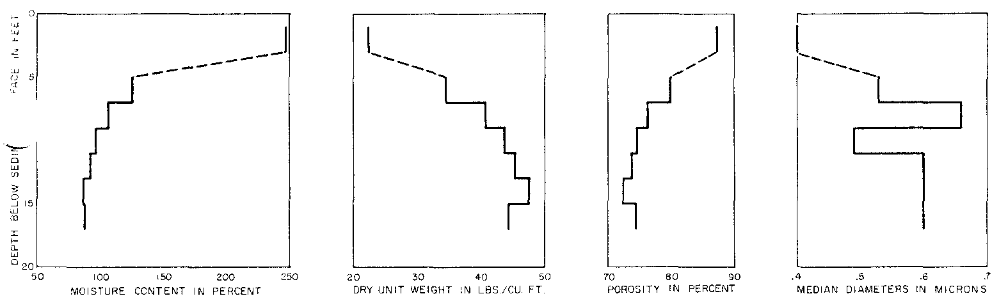
LAKE MEAD SEDIMENTS
PHYSICAL PROPERTIES VERSUS DEPTH



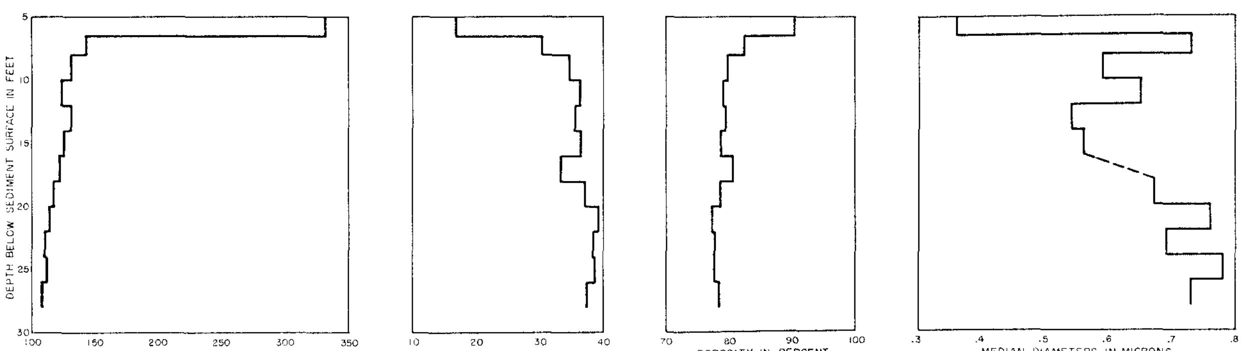
LAKE MEAD
SAMPLING LOCATION 13
(FIELD SAMPLES No's 13A AND 19)



LAKE MEAD
SAMPLING LOCATION 14
(FIELD SAMPLES No's 14A AND 21)



LAKE MEAD
SAMPLING LOCATION 15
(FIELD SAMPLES No's 15A AND 22)



LAKE MEAD
SAMPLING LOCATION 16
(FIELD SAMPLES No's 16A, 24 AND 25)

LAKE MEAD SEDIMENTS
PHYSICAL PROPERTIES VERSUS DEPTH

FIGURE 4-30
Sheet 3 of 3

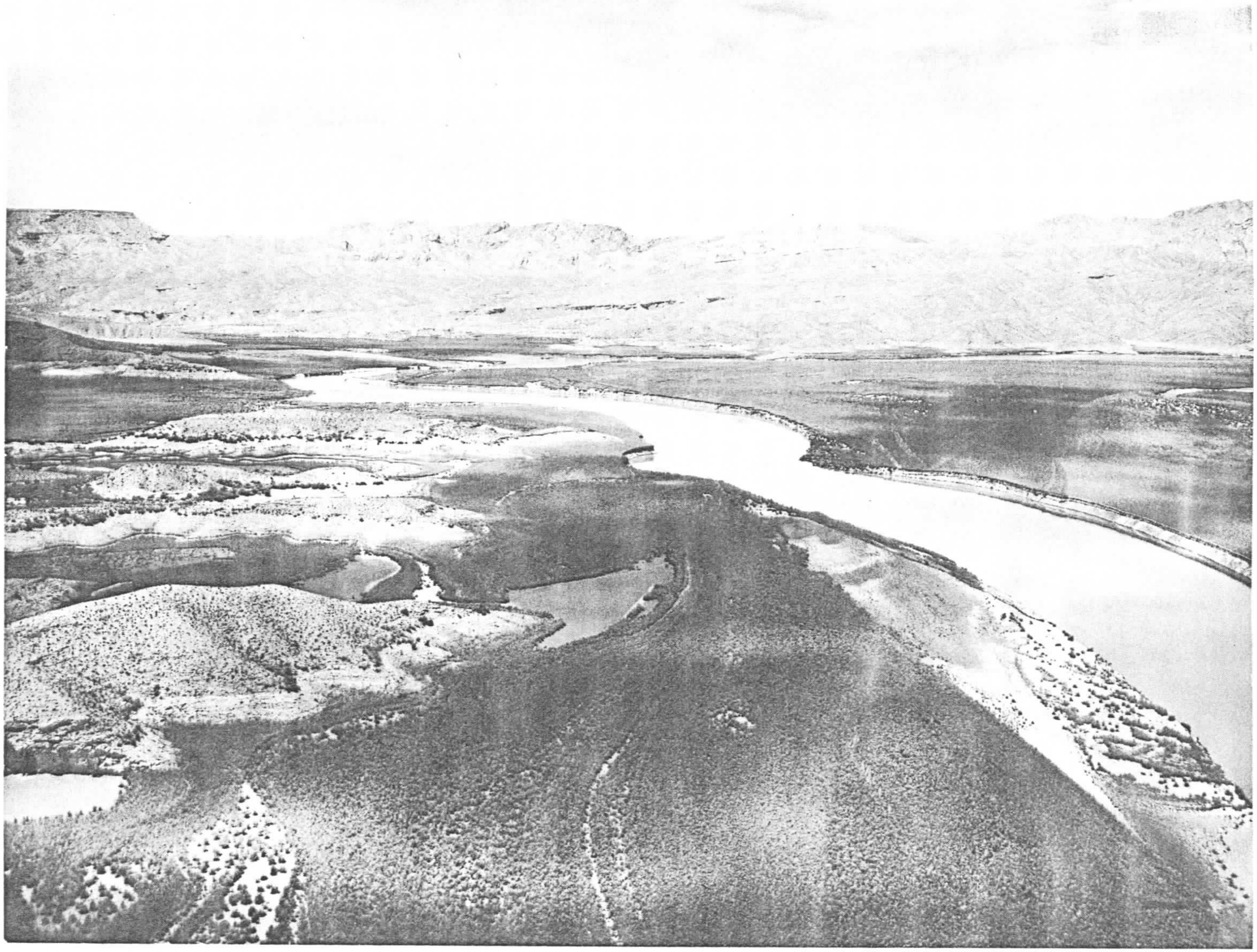


Figure 4-31. Colorado River Delta—June 14, 1966, looking downstream through Pierce Basin. River has incised a channel through old delta deposits which appear to be 30 to 40 feet above river water surface. Photo P45-300-6569 NA

Also, more clay minerals are found in the downstream deposits than in the ones upstream.

The consolidation of sediment deposits is affected mostly by the depth of overburden and the size of the constituent particles. Moisture content determined for each stratum sample is another factor indicative of the consolidation potential. Unfortunately, however, the soil mechanics of lacrustrine sediments based on analytical studies of these soil index properties has not developed to the stage of reliably predicting the consolidation. It is assumed that conditions of optimum consolidation occurs in the finer clay sediments having the physical, mineral, and chemical properties uniquely proportioned to negate the effect of increasing overburden.

Unit weight data from the gamma probe and piston-core sampling tests at 15 of the 16 locations were plotted relative to depth in Figure 4-32. The plottings show that generally a good relationship exists between the two testing procedures. The poorest relationship is at Location 7 where the maximum difference in unit weight is about 26 pounds per cubic foot at the 7-foot depth. A probable reason for the large difference in some of the results between methods is that the piston core sampler recovered, on an average, only 9/10 of the sample at full penetration depth.

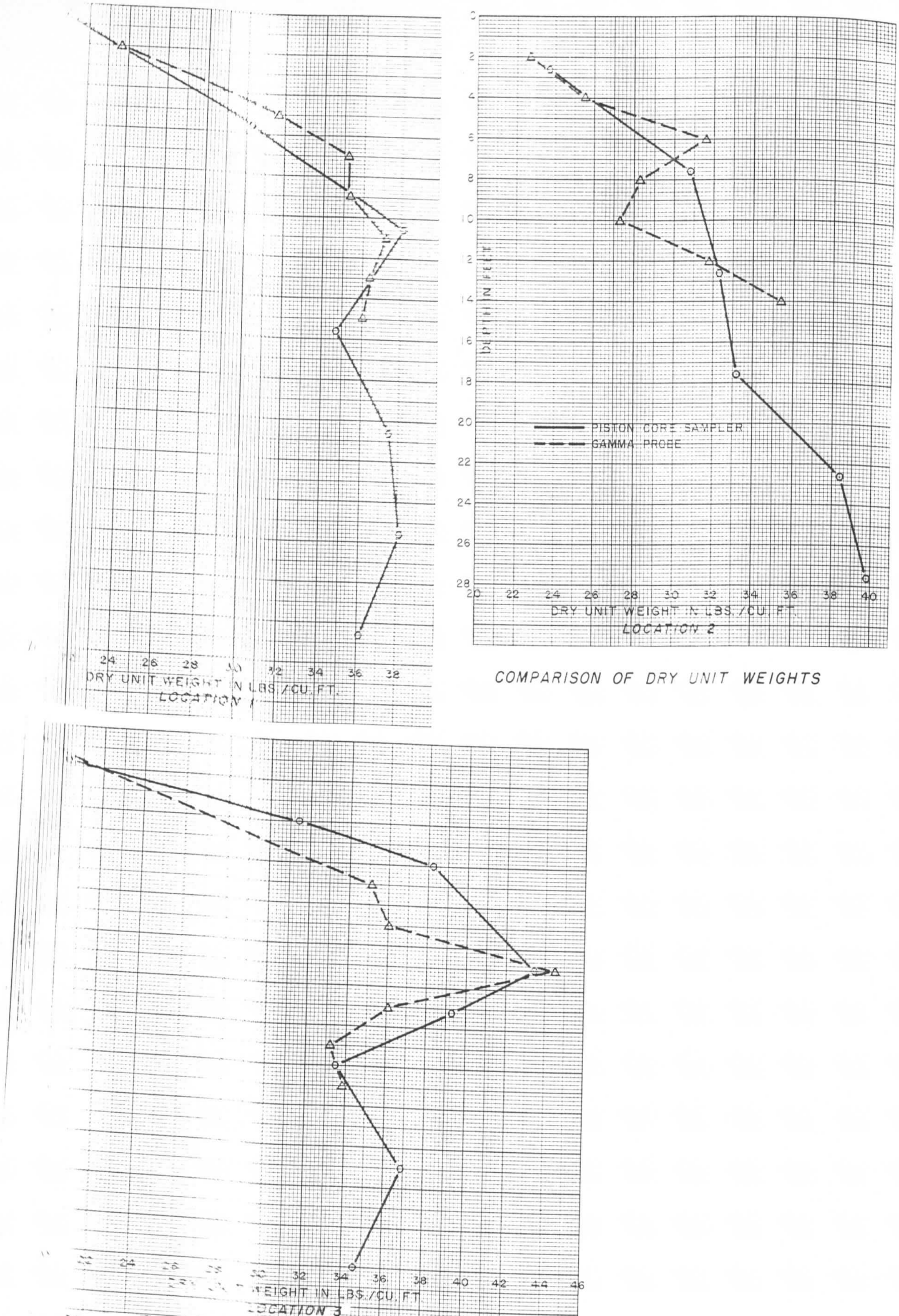
Plottings in Figure 4-32 also reveal the apparent physical stratification pattern of the sediment deposits. The gamma probe reading is the integrated result of the radioactive rays that have penetrated the sediment medium which could include several layers of soil. Because the probe measurements were taken at 5-foot depth increments, the readings would not reflect the detailed stratification pattern.

From the preceding discussion, it is concluded that a favorable comparison resulted in unit weights determined by either the piston-core or gamma probe sampling methods. An advantage of the core sampling method is that it provides the actual samples for other physical property tests. The probe, by penetrating deeper, gives a better picture of the consolidation within the sediment deposits.

A further examination of the physical properties discloses that the sediment particle size appears to be the most significant factor affecting the disposition and consolidation of sediments. Particle size tends to vary inversely with porosity, moisture content, and specific gravity. It varies directly with unit weight and is related to the mineral and chemical properties.

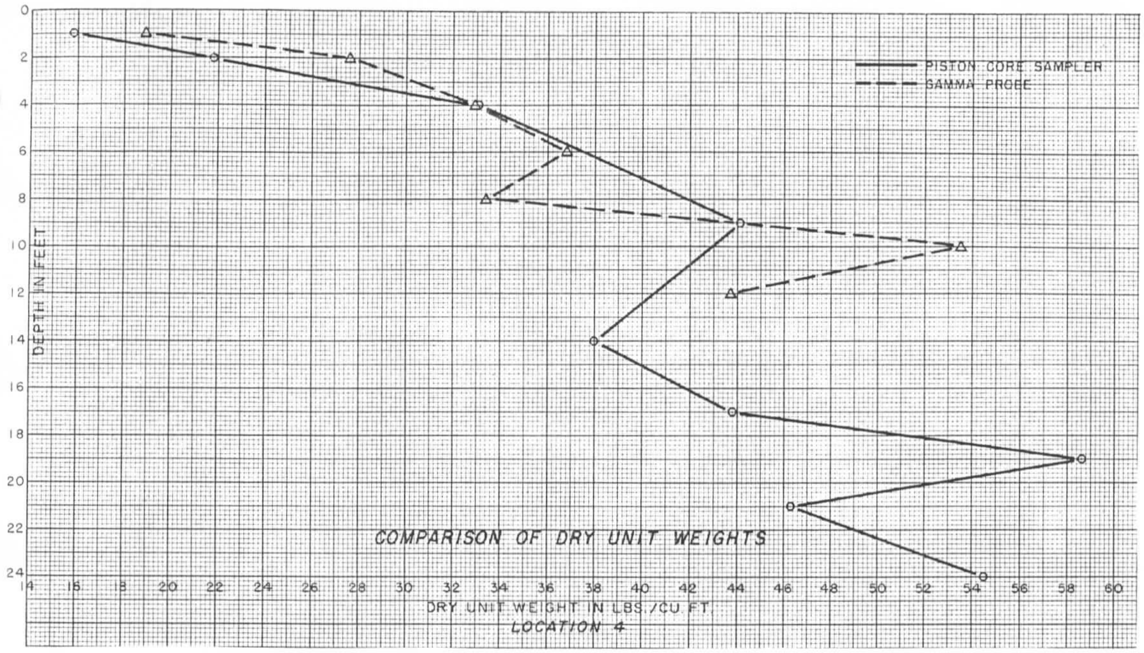
As the delta progressively builds up in the reservoir, the general aggradation process continues. In this process the coarser sediments are conveyed farther downstream creating the stratification pattern found in Pierce Basin. The consolidation of the fine clays found in the bottomset beds would be appreciably affected by the overburden of these coarser sediments.

The mineralogical analysis (Table 4-2) identified the three major groups of clay minerals as kaolinite, montmorillonite, and illites. The predominate mineral was the combined illite-montmorillonite clay. Considering the significance of this mineral aggregate to the total composition, a graphical comparison was made in Figure 4-33 between the percentages of illite-montmorillonite and the plasticity index, particle size gradation, and the median size (see Table 4-4). Although only a few samples were collected for the mineralogical analysis, the graph shows a curvilinear relationship between the clay mineral percentages and the other three factors. The curves show the clay mineral is related exponentially to particle size and plasticity index and hyperbolically to the median diameter.



COMPARISON OF DRY UNIT WEIGHTS

4-32
8



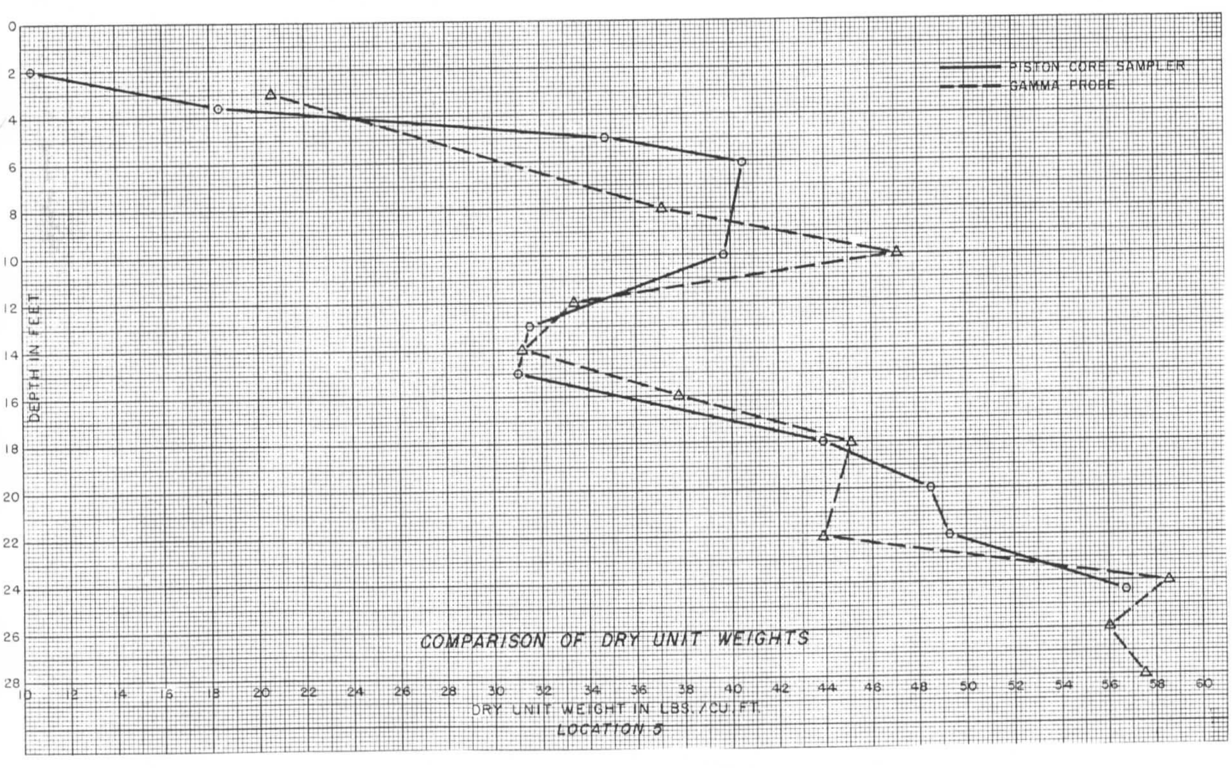
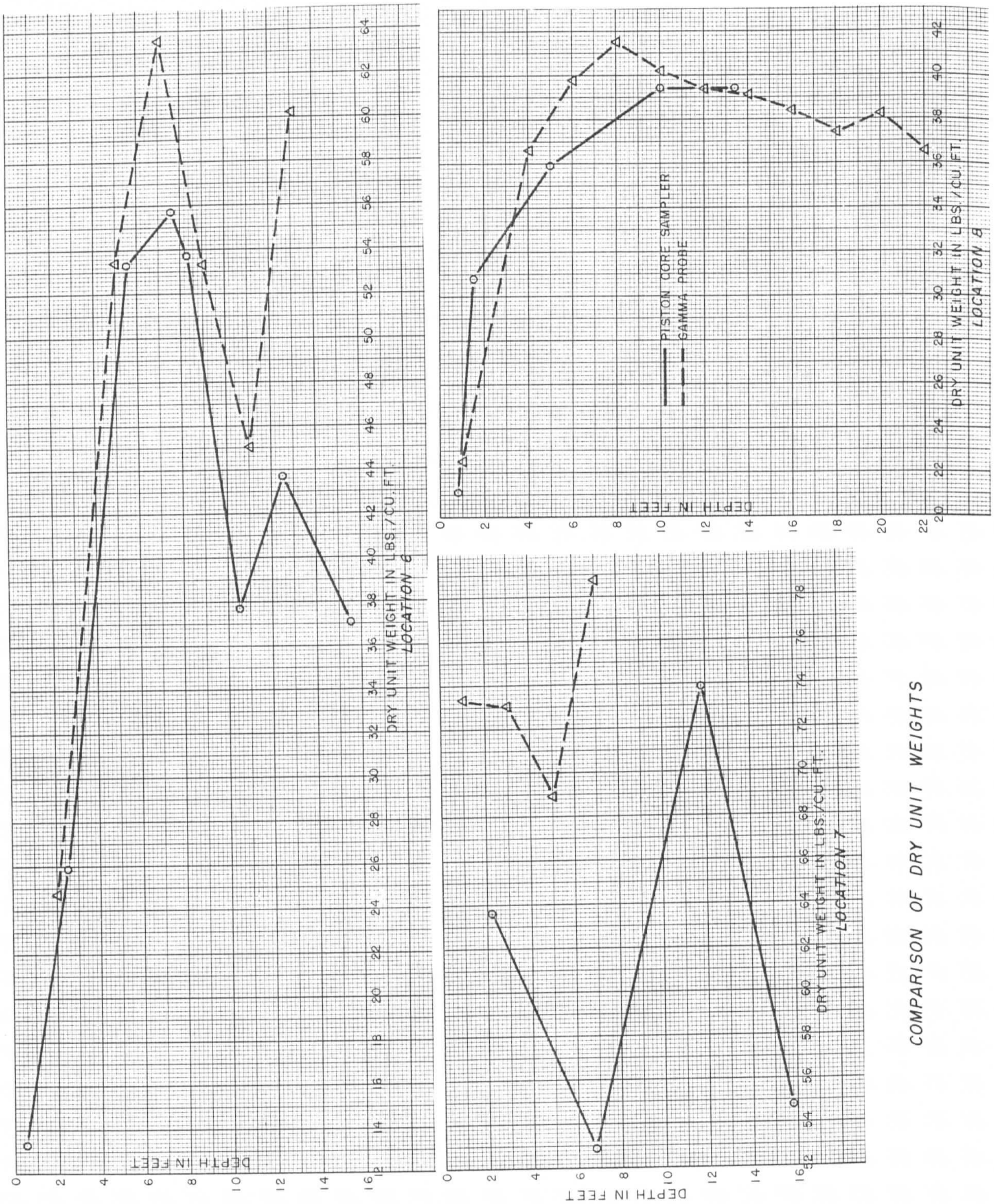
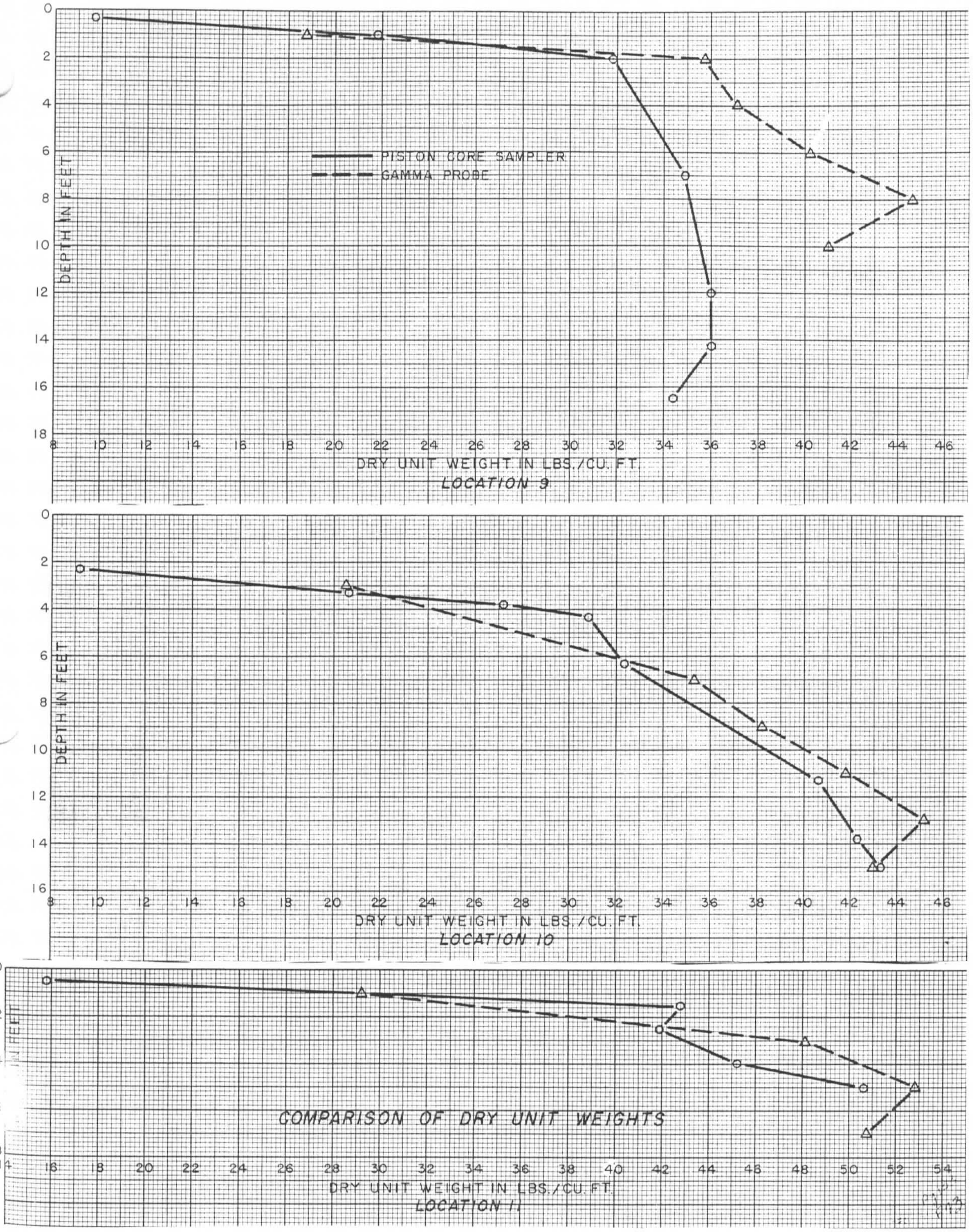


FIGURE 4-32
Sheet 2 of 8



COMPARISON OF DRY UNIT WEIGHTS

FIGURE 4-32
Sheet 3 of 8



COMPARISON OF DRY UNIT WEIGHTS

FIGURE 4-32
Sheet 4 of 8

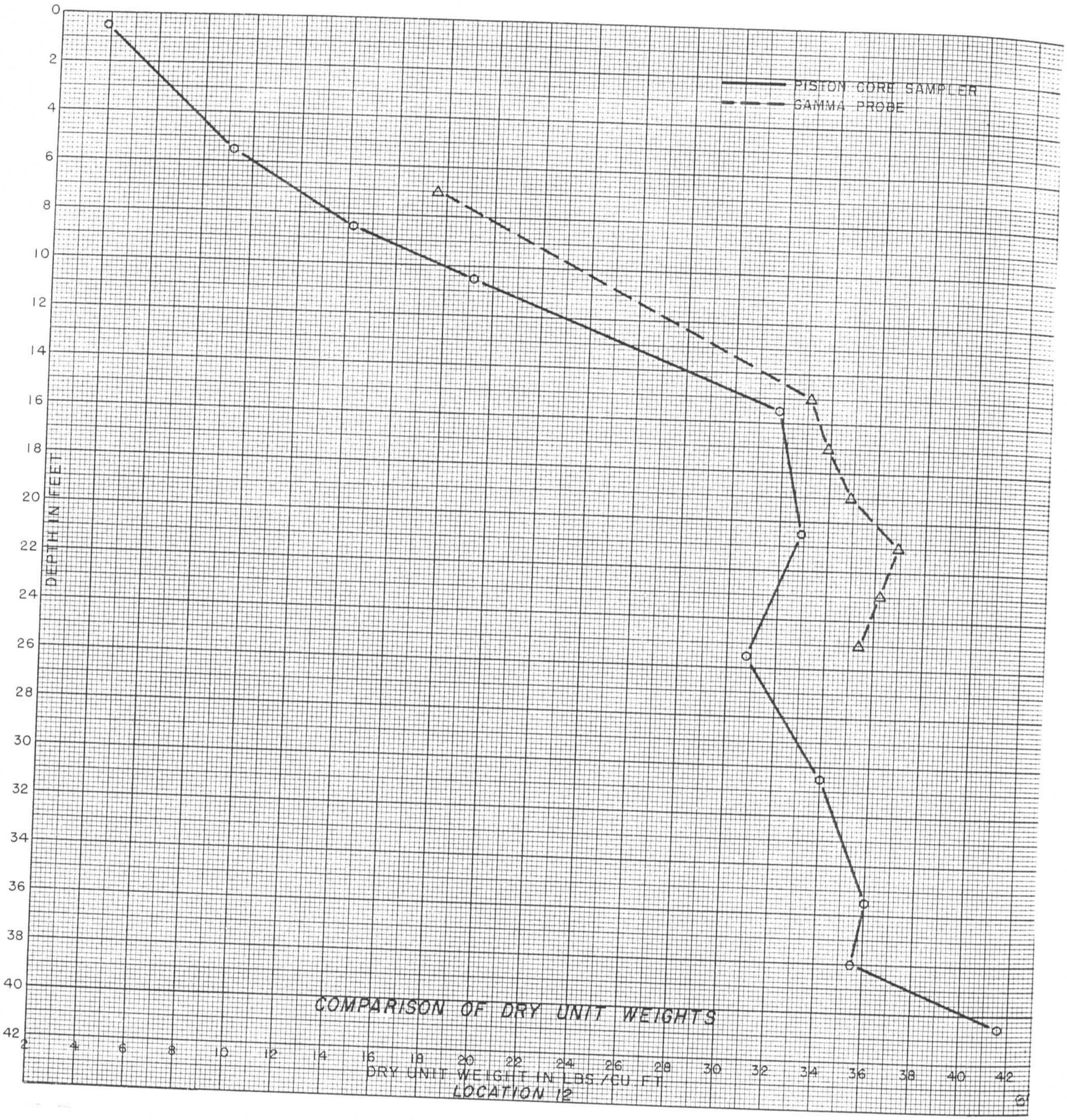
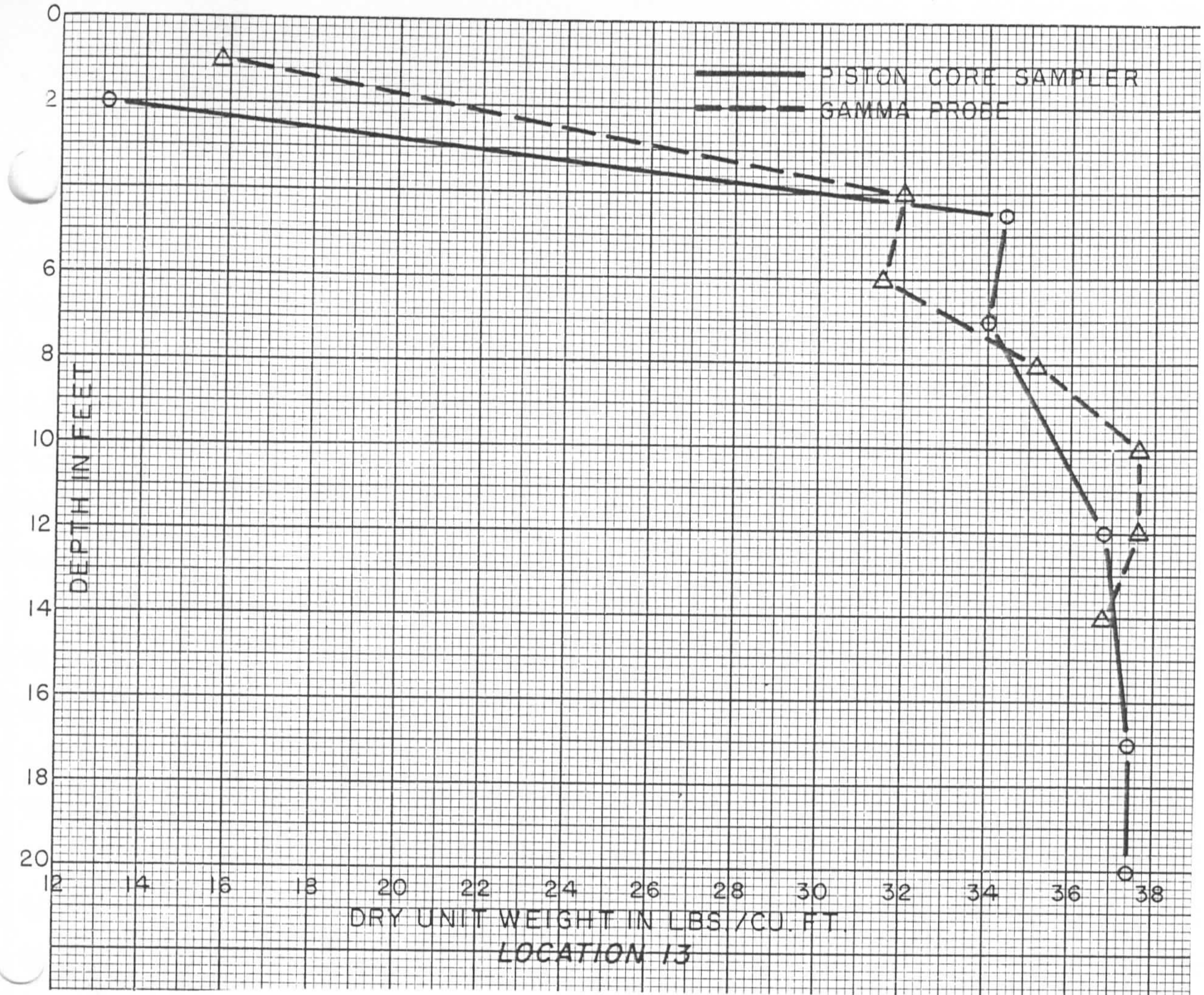


FIGURE 4-32
Sheet 5 of 8



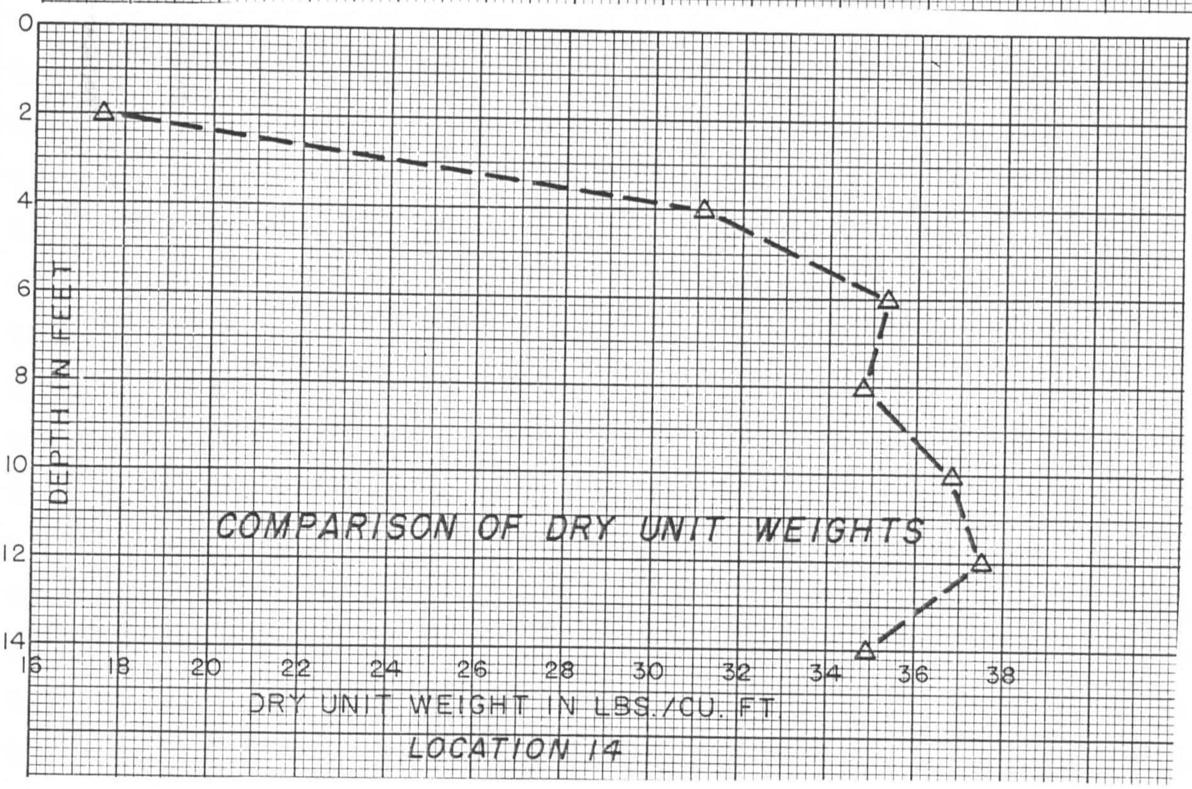


FIGURE 4-32
Sheet 6 of 8

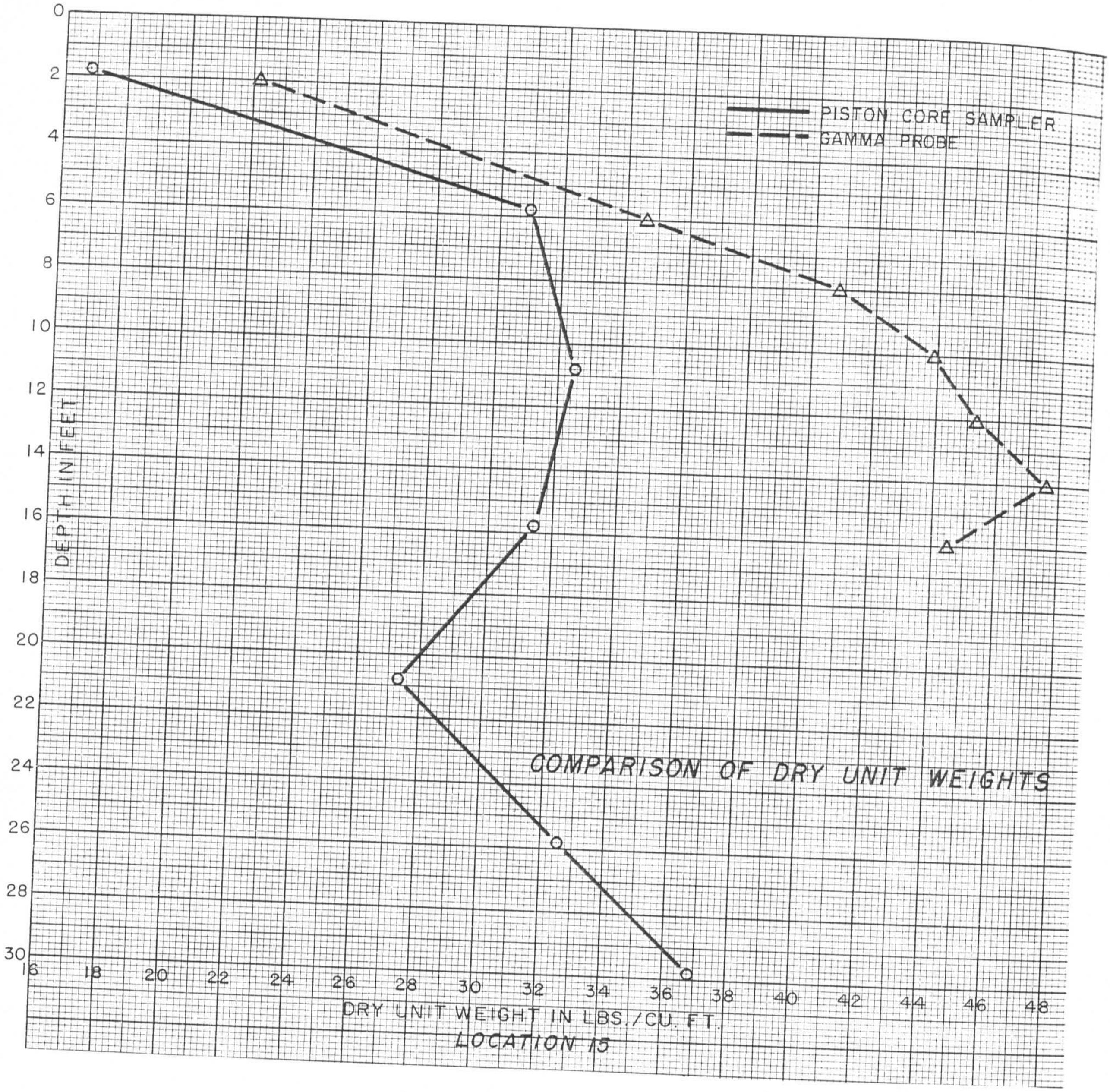


FIGURE 4-32
Sheet 7 of 8

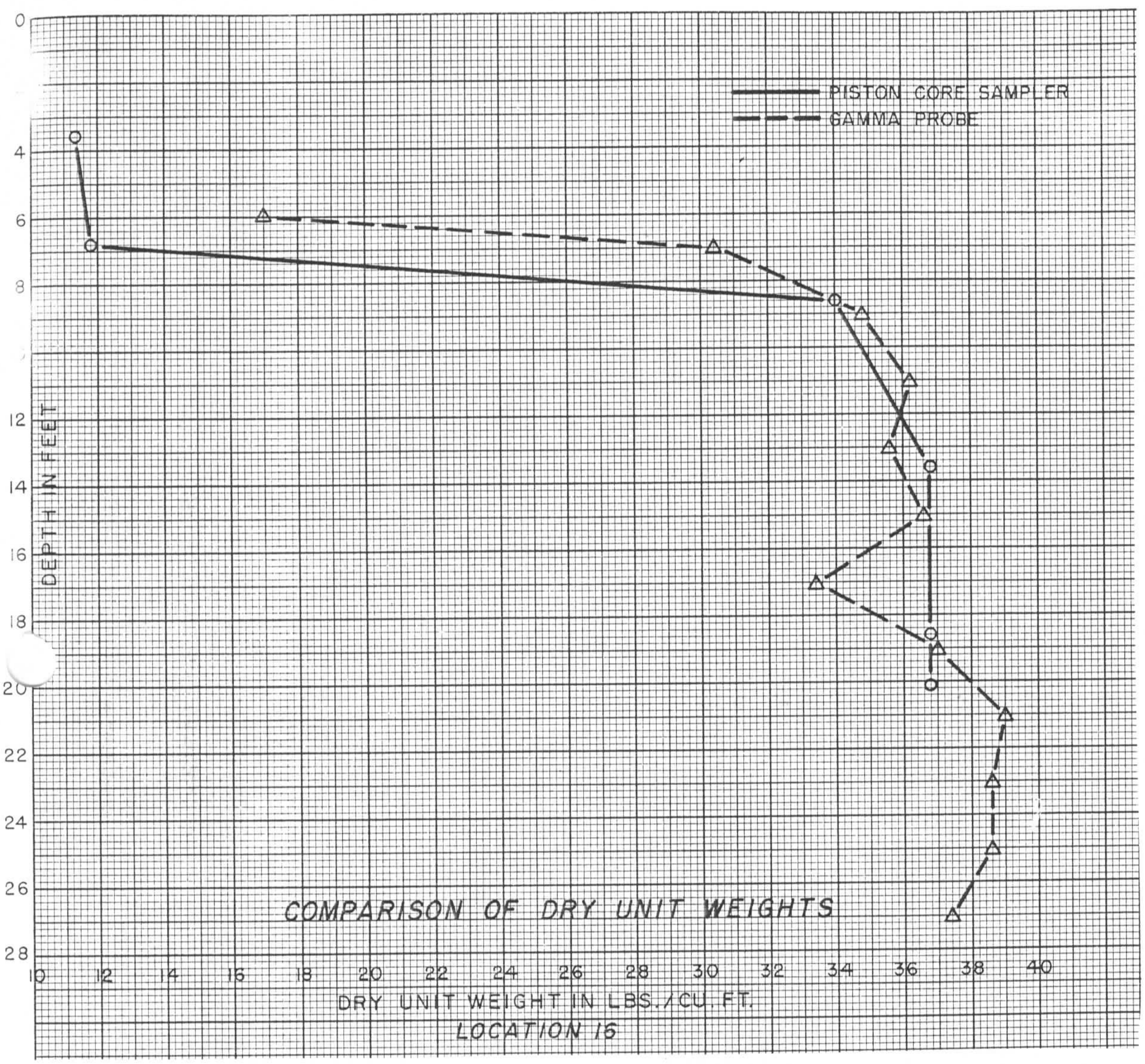
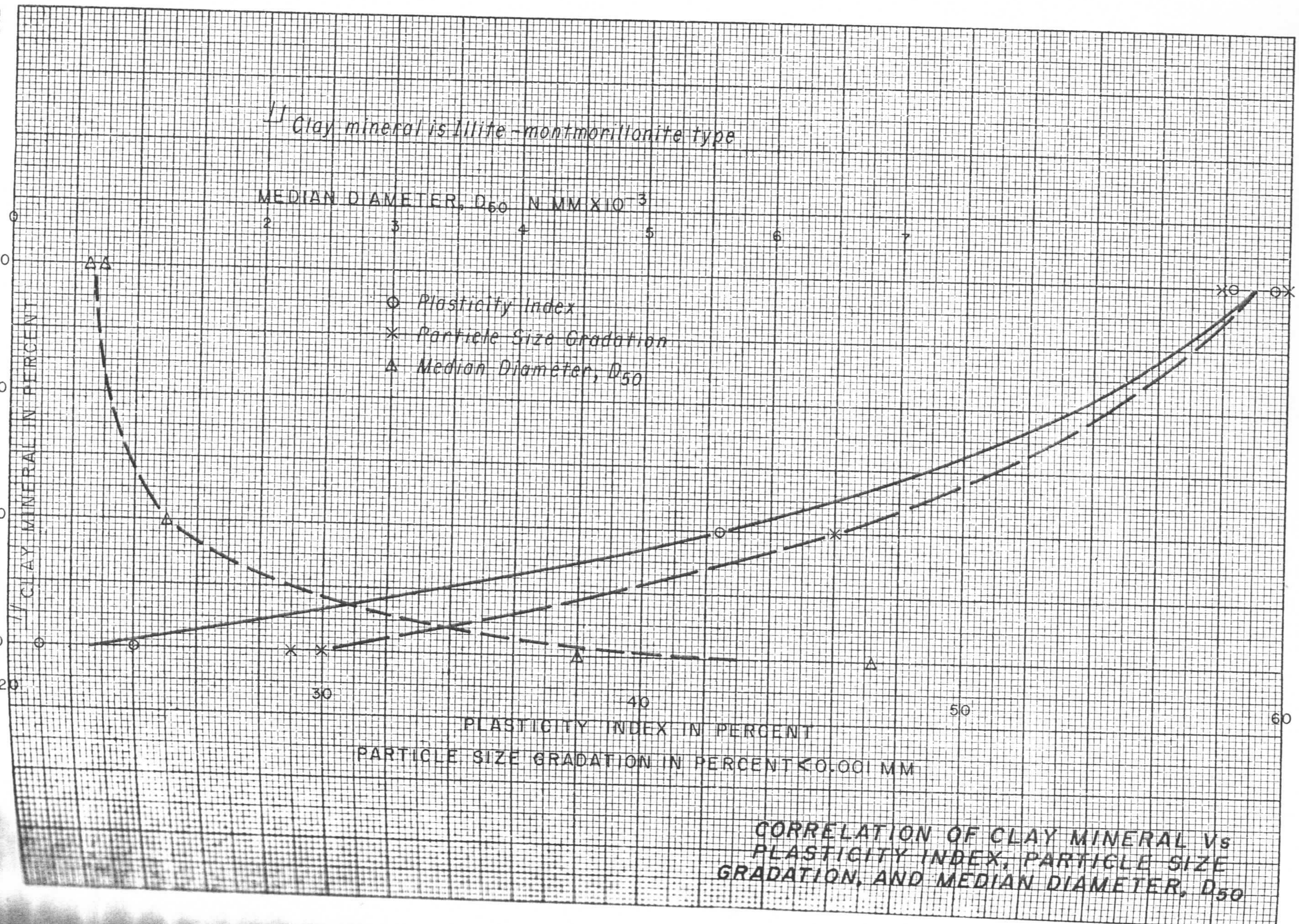


FIGURE 4-32
Sheet 8 of 8

FIGURE 4-33



CORRELATION OF CLAY MINERAL Vs PLASTICITY INDEX, PARTICLE SIZE GRADATION, AND MEDIAN DIAMETER, D_{50}

Table 4-4

COMPARISON OF CLAY MINERAL VERSUS PHYSICAL PROPERTIES

Laboratory Sample No.	Field Sample No.	Clay mineral (percent)	Plasticity index (percent)	Particle size <0.001 mm (percent)	Median diameter (mm)	Specific gravity	Moisture content (percent)
41Q-11	DH-9	30	21.0	29	0.00690	2.67	35.6
41Q-67	DH-64	30	24.0	30	0.00450	2.71	30.1
41Q-X130	DH-5	40	42.4	46	0.00125	2.75	105.0
41Q-X183	DH-14	60	59.6	58	0.00072	2.77	109.0
41Q-X215	DH-19	60	57.3	62	0.00058	2.77	124.0
41Q-X235	DH-22	60	58.2	60	0.00060	2.76	100.0

——— estimated.

PART 5–QUANTITATIVE SEDIMENTATION ANALYSES

Sediment Accumulations

The volume of sediment accumulations in Lake Mead ince the 1948-49 survey amounts to 1,292,000 cre-feet at elevation 1229 feet. This shows that ediments have accumulated at an average rate of 0,750 acre-feet per year. The total loss in lake apacity because of sediment accumulations at evation 1229 feet since 1935 is 2,716,000 acre-feet. he annual sediment accumulation rate since 1935 is ,450 acre-feet.

e pattern of how sediments have accumulated erally in the reservoir can be determined from a dy of the cross-sectional data. The map in Figure shows the location of 21 cross sections that were filed beginning with A-A′ to N-N′ on the Colorado er and from O-O′ to U-U′ on the Virgin River. Plots hese cross sections are shown in Figure 5-2.

s Sections A-A′ to D-D′ represent the headwaters litions proceeding in a downstream direction in er Granite Gorge. The greatest amount of sediment sition to depths of about 230 feet is shown in on D-D′. Inspecting the plot of this section shows 963-64 surface profile dips below the 1948-49 e inc ng the effects of the degradation process he consolidation of some of the sediments that curred along some areas of the section.

ns E-E′ and F-F′ are in the delta area of the oir in Pierce Basin. Section F-F′ is nearly 2 miles the area where the test site for Drill Hole 1 was . Depths of sediment at this section are noted to 270 feet at the greatest point.

nting two points in Gregg Basin are Cross s G-G′ and H-H′. Section G-G′ represents the ns of the area where the reservoir emerges eam from Iceberg Canyon. Sediment depths about 160 feet and at Section H-H′ about 100 he wider area of the basin.

ng downstream to Section I-I′ in Virgin he sediments have accumulated to a depth of 0 feet along a width of 470 feet.

mple Bar Area at Section J-J′ the depths of average about 70 feet. The depths of deposits also reach about 70 feet in the wider rea represented by Section K-K′.

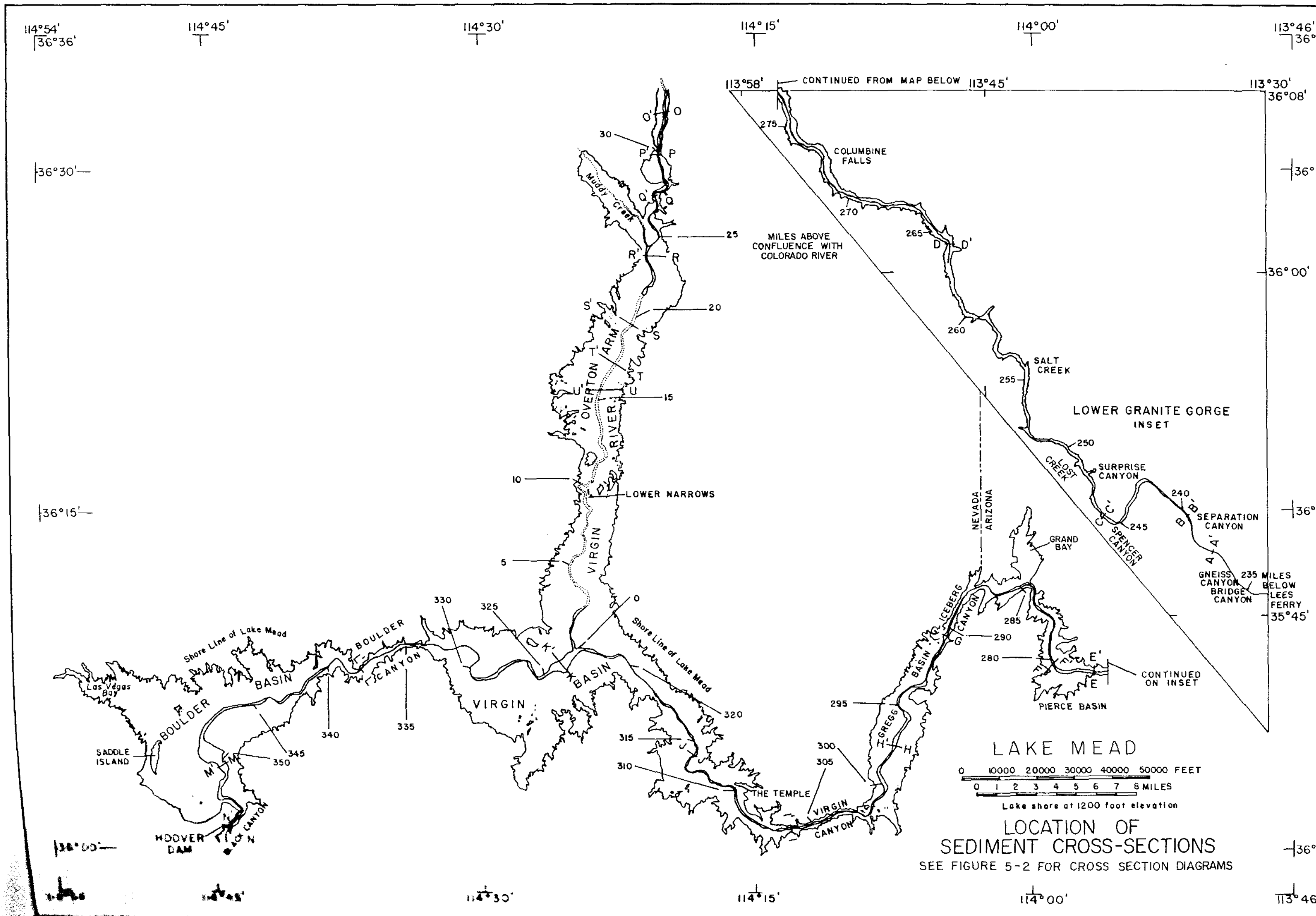
At Section L-L′ in Boulder Canyon sediments have accumulated to about 85 feet and about 14 miles downstream at Section M-M′ sediments have deposited quite uniformly to a depth of 125 feet for a width over 2,500 feet.

The situation near the dam is represented by Section N-N′. Here the sediments accumulated to about 155 feet between the original and 1948-49 survey, then the accumulations drop about 15 feet as shown by the 1963-64 survey.

The Cross Sections O-O′ to U-U′ in the Overton Arm area of the Virgin River show relatively small quantities of sediment have accumulated here. The average depth would lie about 10 to 20 feet for this region of the reservoir.

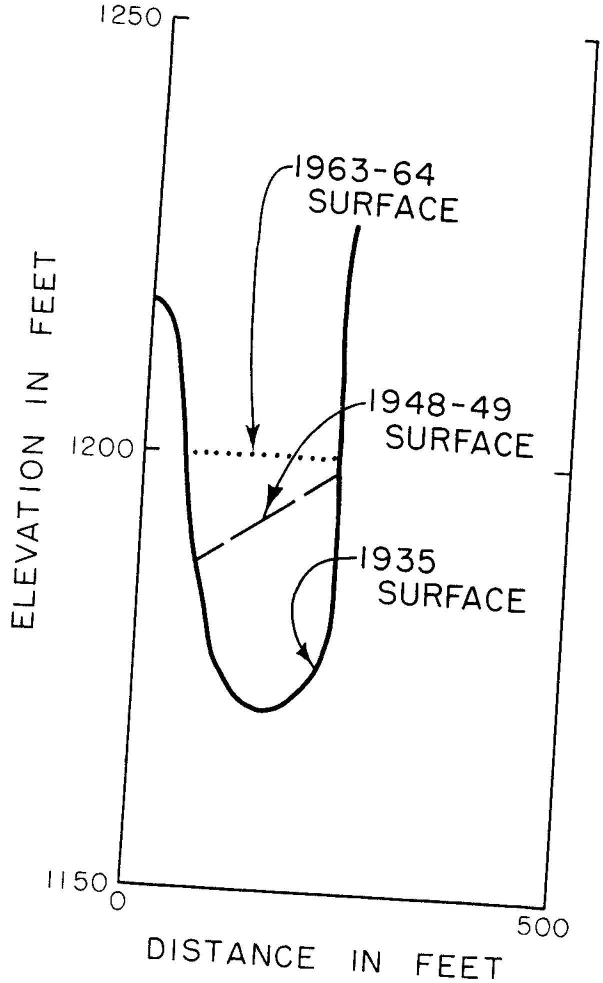
An idea of how and where most of the sediments have accumulated longitudinally in the reservoir can be had by studying the Colorado River profiles in Figure 5-3. The lower profile is a trace of the bottom (thalweg) of the Colorado River before the dam was constructed. The 1948-49 and 1963-64 profiles show the progressive development of the topset, foreset, and bottomset beds. At the upper end of the reservoir the topset bed of the delta area has extended from about River Mile 278 in 1948-49 to Mile 282 in 1963-64. The delta now extends beyond Lower Granite Gorge to the head of Grand Bay Basin. Along most parts in Lower Granite Gorge the 1963-64 profile dips below the 1948-49 profile. It is in this gorge area where the reservoir capacity showed an increase between the 1948-49 and 1963-64 surveys. The drop in the 1963-64 profile is probably due to three factors—first, the effect of the lake levels being lowered; second, the increase in the hydraulic gradient that tends to promote degradation; and third, the effect of consolidation of the delta sediments. Associated with a lowering of the profile is an increase in surface area that would, in turn, affect an increase in the computed capacity for Lower Granite Gorge since the 1948-49 survey. It is also noted in Figure 5-3 that the 1963-64 profile dips below the 1948-49 profile in the lower part of Boulder Basin near the dam where an increase in capacity is also indicated.

Causes of the lower sediment level here are attributed to consolidation of sediments under the weight of the water in Black Canyon although earth tremors under the water also may have been contributing factors to the consolidation of the partially fluid sediments in this canyon area. The approximate location of Drill Hole 1 is shown in this graph. It is noted the 207-foot

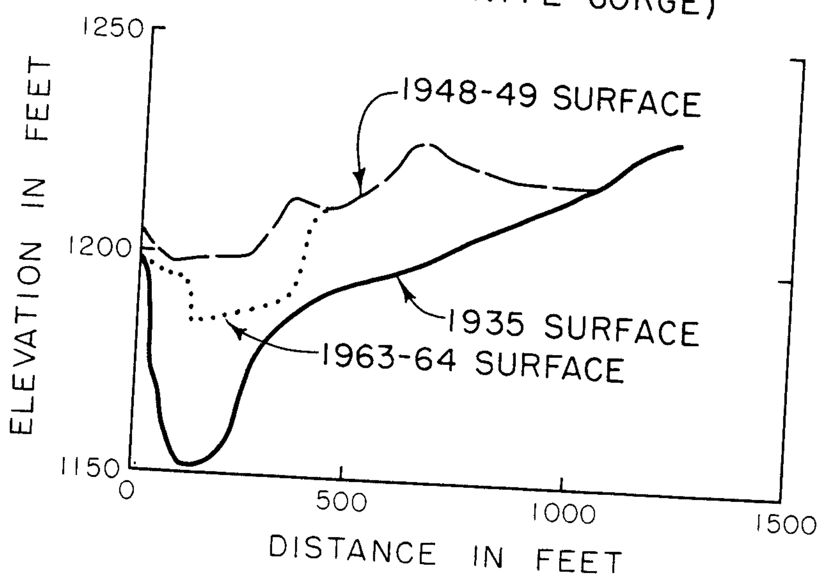


LAKE MEAD
LOCATION OF SEDIMENT CROSS-SECTIONS
SEE FIGURE 5-2 FOR CROSS SECTION DIAGRAMS
0 10000 20000 30000 40000 50000 FEET
0 1 2 3 4 5 6 7 8 MILES
Lake shore at 1200 foot elevation
LOWER GRANITE GORGE INSET
CONTINUED FROM MAP BELOW
CONTINUED ON INSET
MILES ABOVE CONFLUENCE WITH COLORADO RIVER
235 MILES BELOW LEES FERRY
114°54'
114°45'
114°30'
114°15'
114°00'
113°46'
113°58'
113°45'
113°30'
36°36'
36°30'
36°15'
36°08'
36°00'
35°45'
COLUMBINE FALLS
SALT CREEK
SURPRISE CANYON
LOST CREEK
SPENCER CANYON
SEPARATION CANYON
GNEISS CANYON
BRIDGE CANYON
GRAND BAY
PIERCE BASIN
NEVADA
ARIZONA
ICEBERG CANYON
GREGG BASIN
THE TEMPLE
VIRGIN CANYON
VIRGIN BASIN
BOULDER CANYON
BOULDER BASIN
Las Vegas Bay
SADDLE ISLAND
HOOVER DAM
BLACK CANYON
Shore Line of Lake Mead
Muddy Creek
OVERTON ARM
VIRGIN RIVER
LOWER NARROWS

FIGURE 5-1

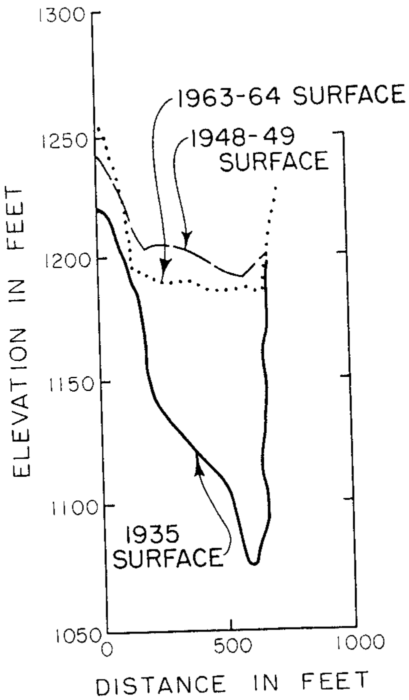


SEDIMENT PROFILES AT SECTION A-A'
(LOWER GRANITE GORGE)

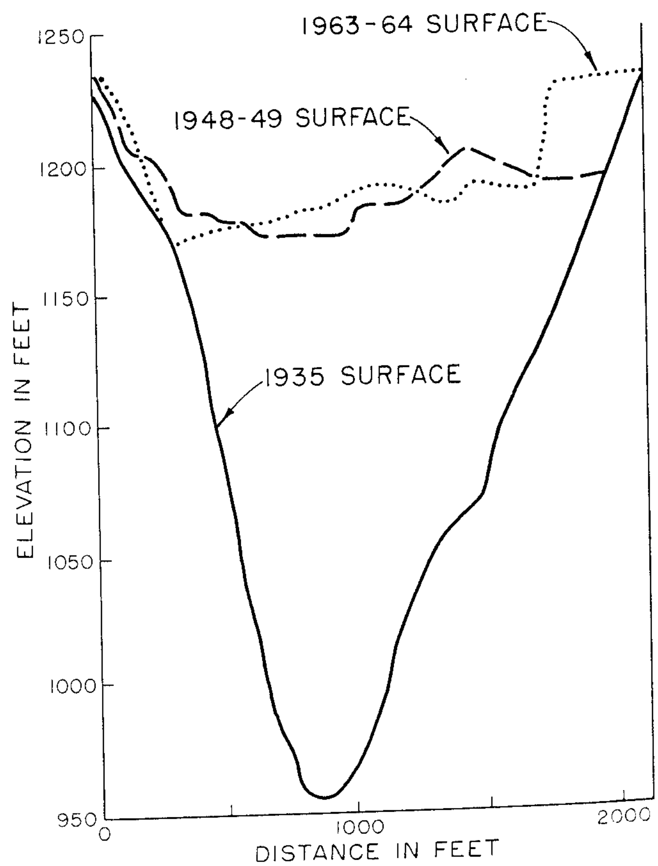


SEDIMENT PROFILES AT SECTION B-B'
(LOWER GRANITE GORGE)

FIGURE 5-2
Sheet 1 of 11

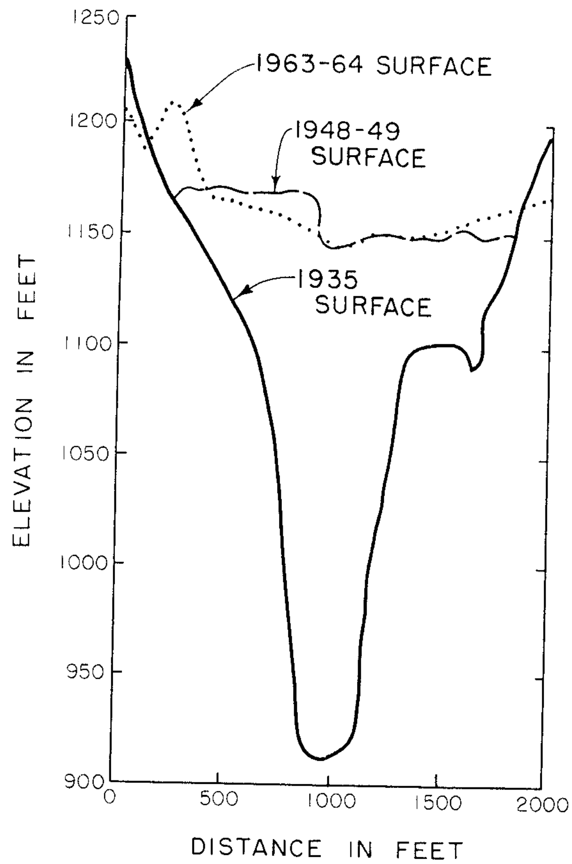


SEDIMENT PROFILES
AT SECTION C-C'
(LOWER GRANITE GORGE)

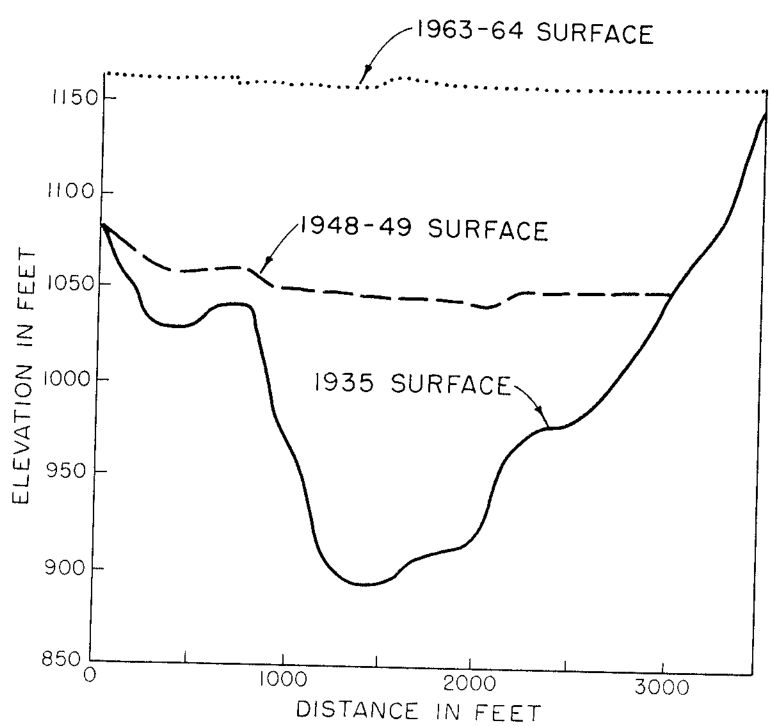


SEDIMENT PROFILES
AT SECTION D-D'
(LOWER GRANITE GORGE)

FIGURE 5-2
Sheet 2 of 11

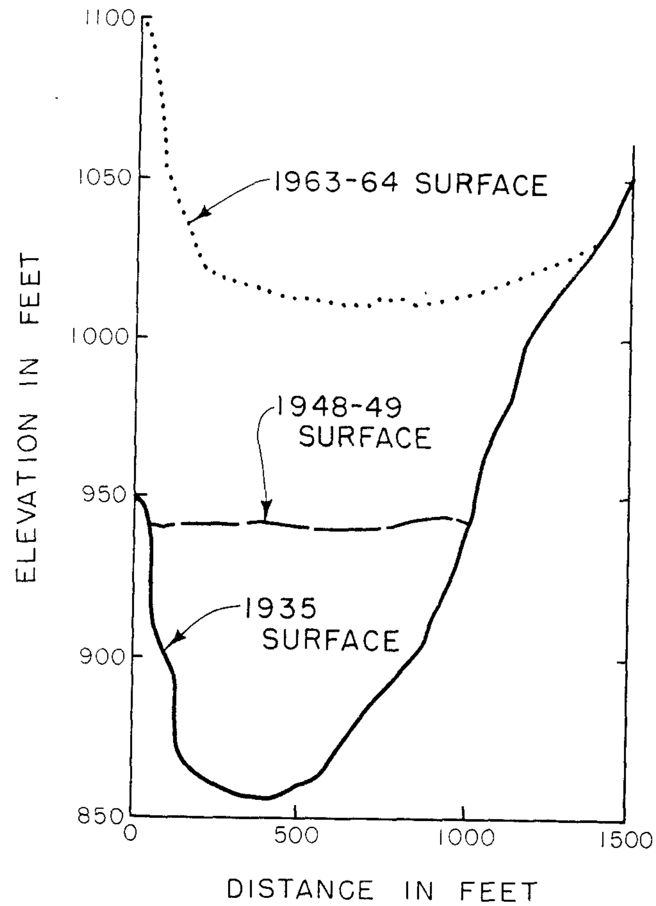


SEDIMENT PROFILES
AT SECTION E-E'
(PIERCE BASIN)

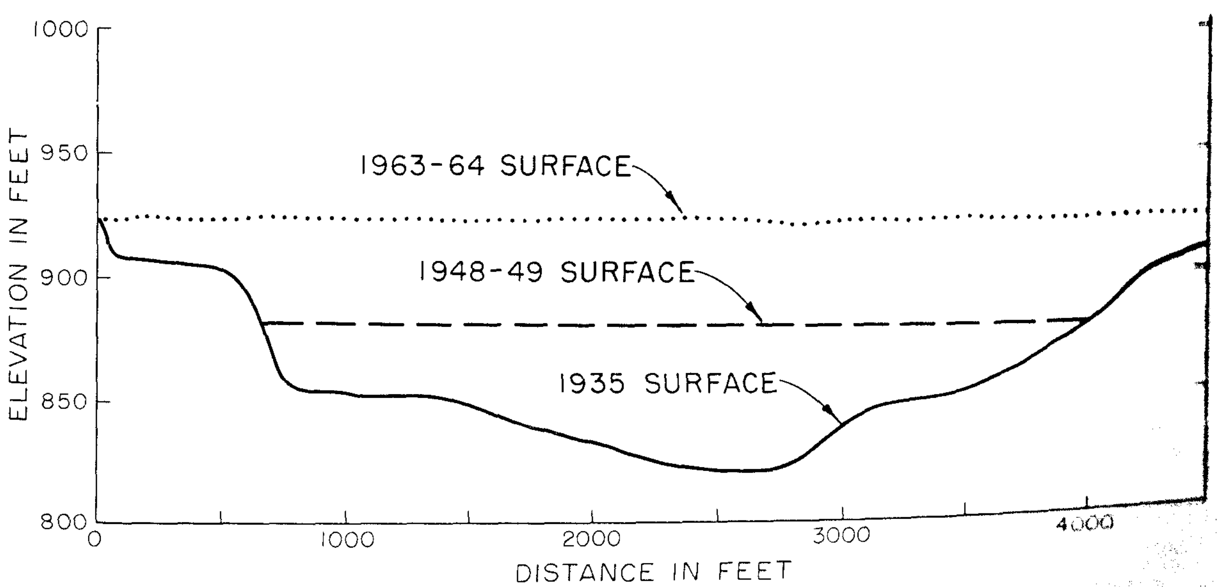


SEDIMENT PROFILES
AT SECTION F-F'
(PIERCE BASIN, DRILL HOLE No. 1)

FIGURE 5-2
Sheet 3 of 11

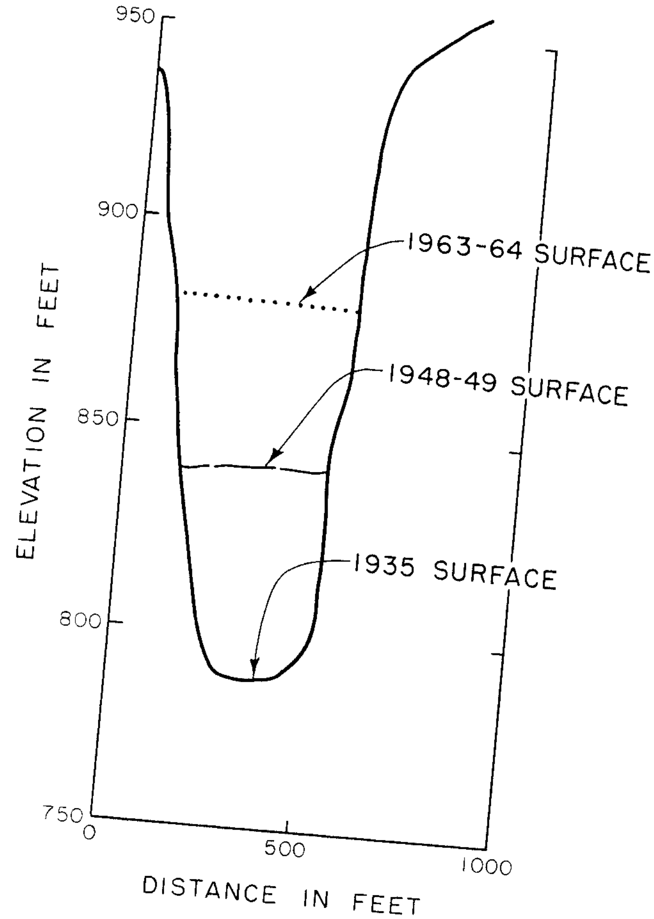


SEDIMENT PROFILES
AT SECTION G-G'
(GREGG BASIN)

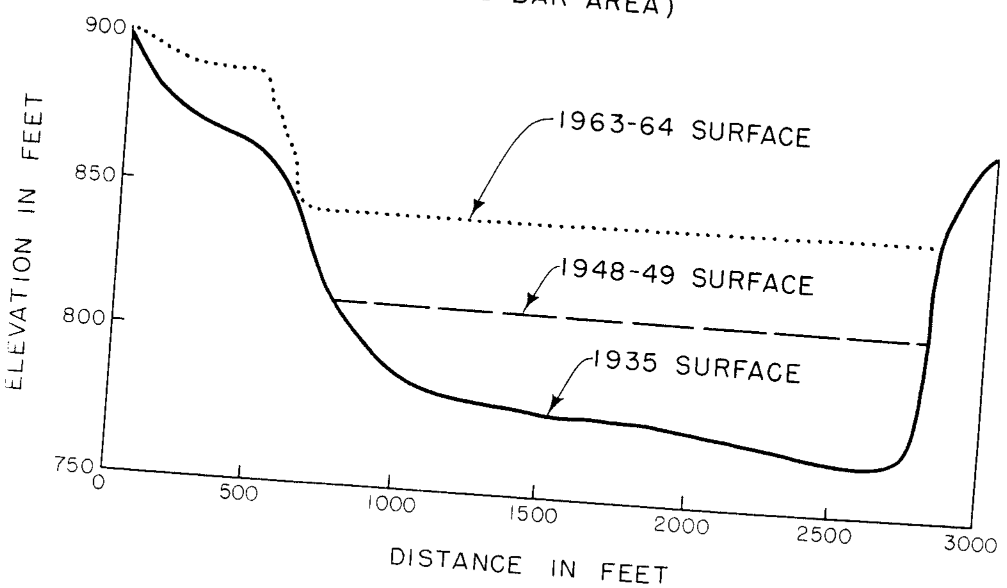


SEDIMENT PROFILES
AT SECTION H-H'
(GREGG BASIN)

FIGURE 5-2
Sheet 4 of 11

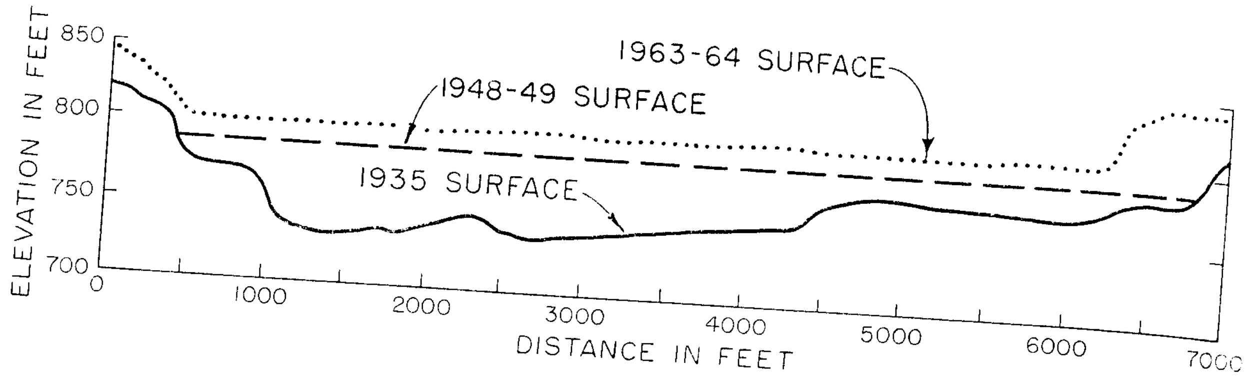


SEDIMENT PROFILES
AT SECTION I-I'
(TEMPLE BAR AREA)

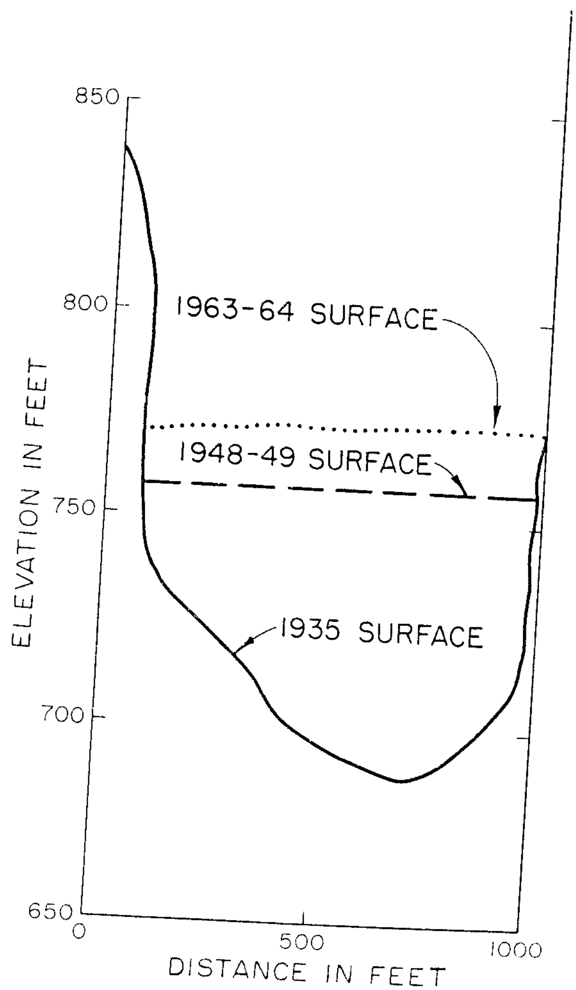


SEDIMENT PROFILES
AT SECTION J-J'
(TEMPLE BAR AREA)

FIGURE 5-2
Sheet 5 of 11

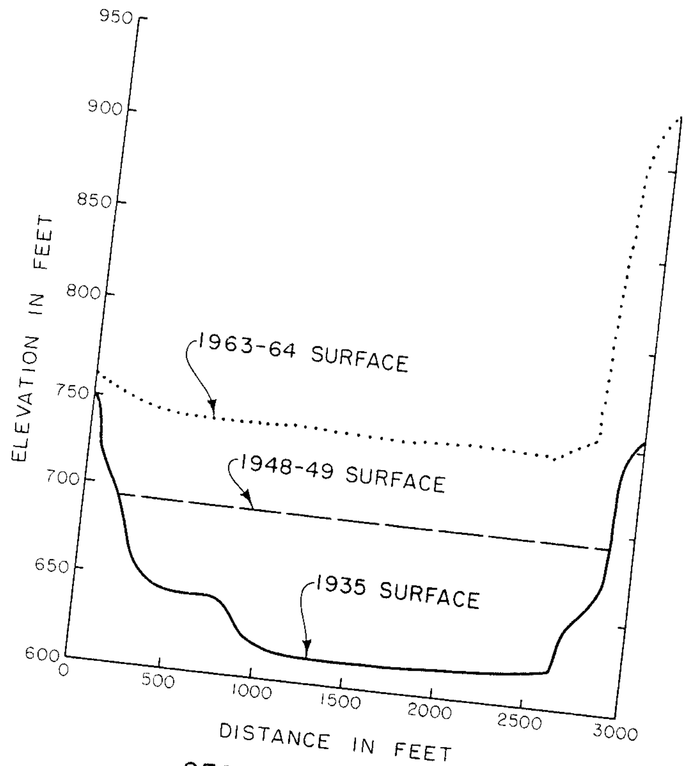


SEDIMENT PROFILES
AT SECTION K-K'
(VIRGIN BASIN)

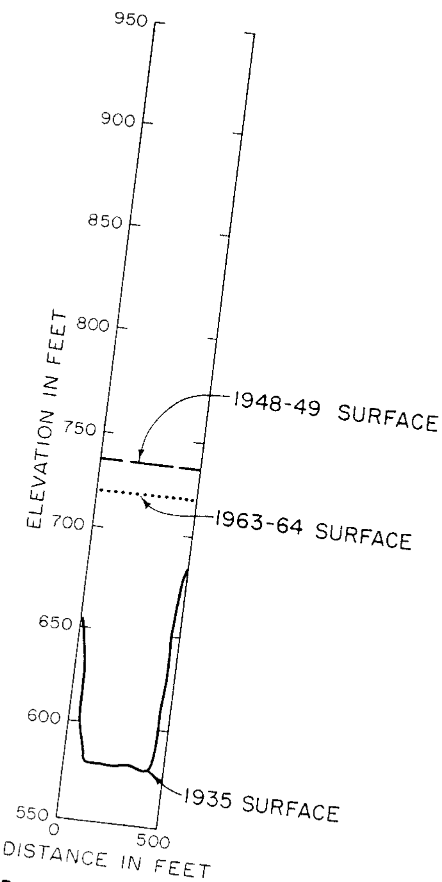


SEDIMENT PROFILES
AT SECTION L-L'
(BOULDER CANYON)

FIGURE 5-2
Sheet 6 of 11

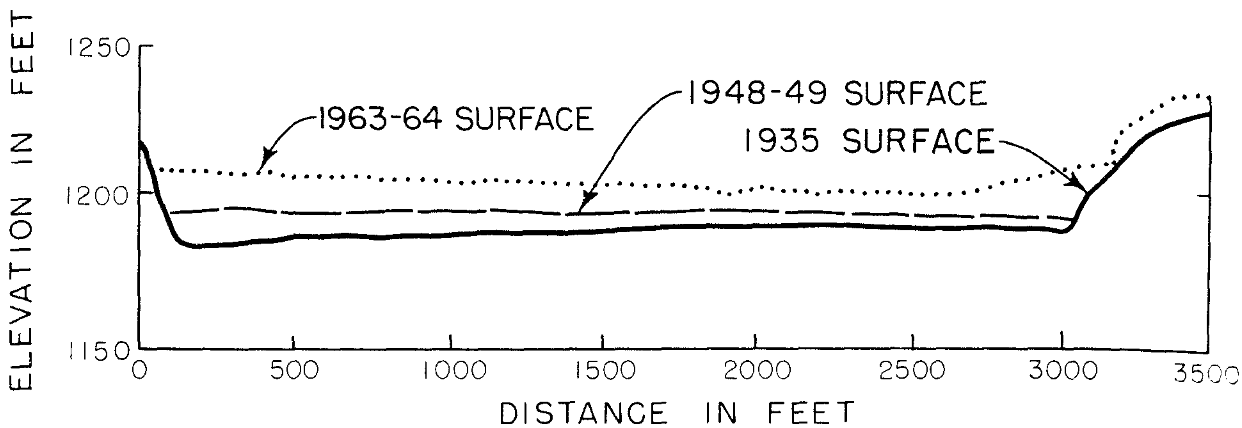


SEDIMENT PROFILES
AT SECTION M-M'
(BOULDER BASIN)

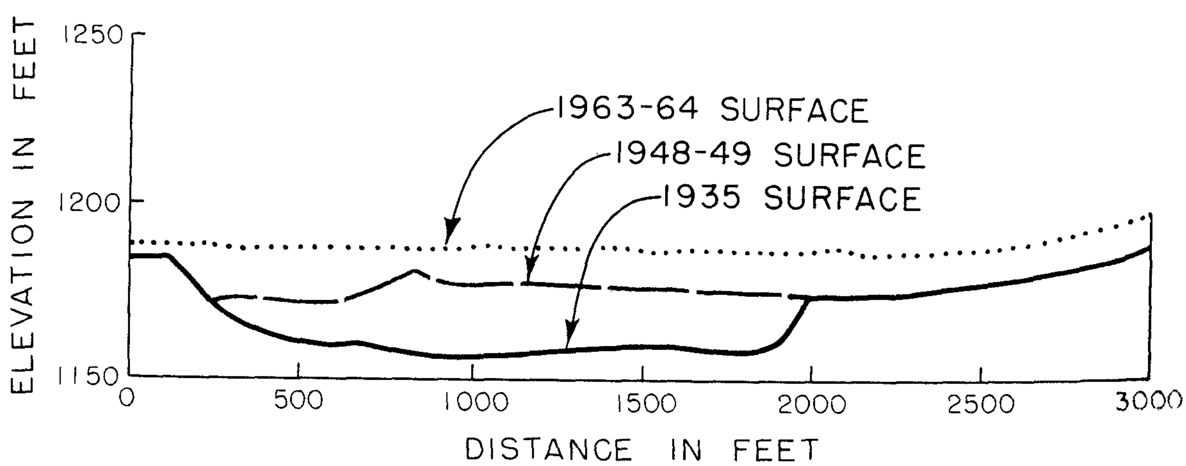


SEDIMENT PROFILES
AT SECTION N-N'
(BOULDER BASIN NEAR DAM)

FIGURE 5-2
Sheet 7 of 11

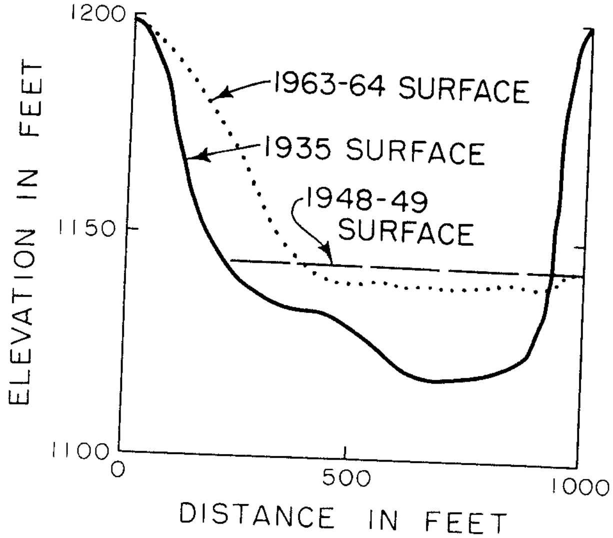


SEDIMENT PROFILES
AT SECTION O-O'
(OVERTON ARM)

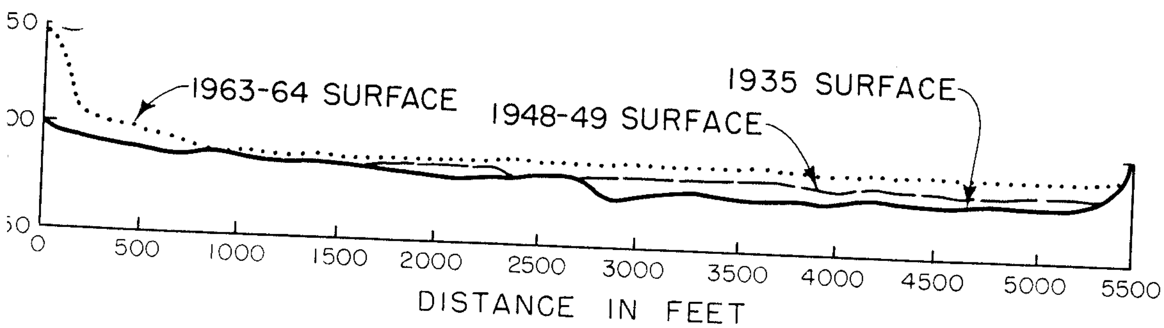


SEDIMENT PROFILES
AT SECTION P-P'
(OVERTON ARM)

FIGURE 5-2
Sheet 8 of 11

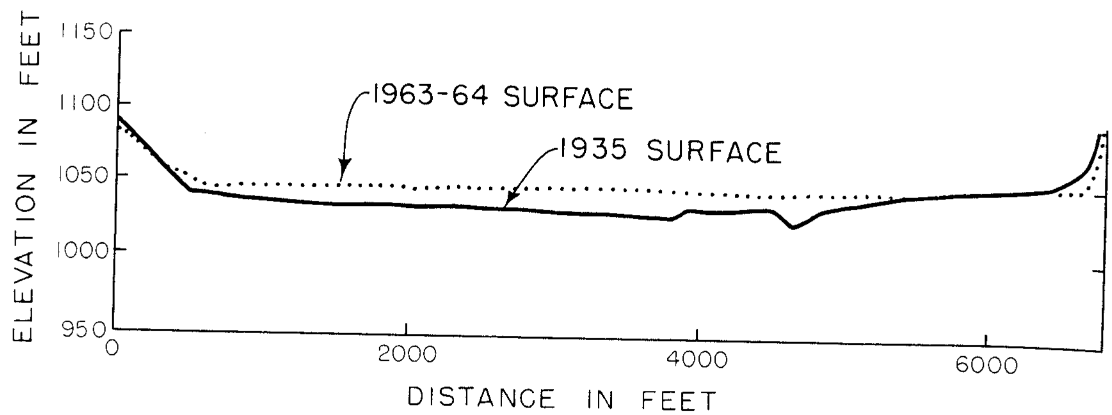


SEDIMENT PROFILES
AT SECTION Q-Q'
(OVERTON ARM)

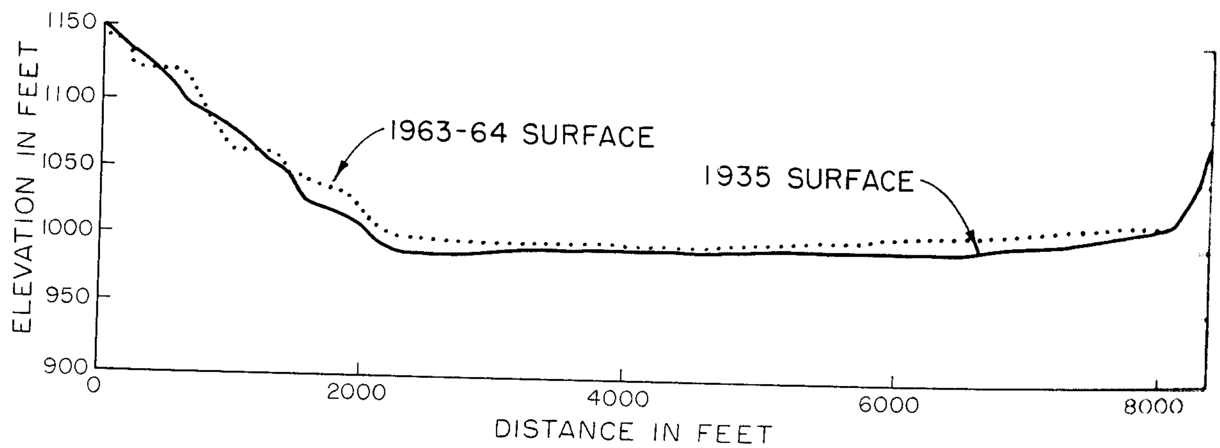


SEDIMENT PROFILES
AT SECTION R-R'
(OVERTON ARM)

FIGURE 5-2
Sheet 9 of 11

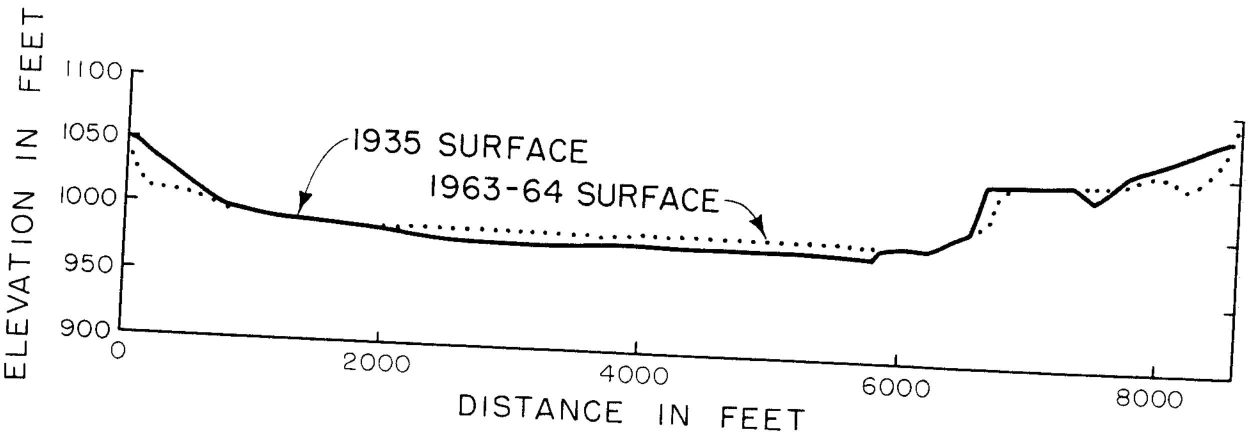


SEDIMENT PROFILES
AT SECTION S-S'
(OVERTON ARM)



SEDIMENT PROFILES
AT SECTION T-T'
(OVERTON ARM)

FIGURE 5-2
Sheet 10 of 11



SEDIMENT PROFILES
AT SECTION U-U'
(OVERTON ARM)

FIGURE 5-2
Sheet 11 of 11

hole was about 35 feet short of reaching the 1935 river bo⁺ . The present foreset beds are seen to extend fro. iver Mile 282 to about River Mile 304 in Virgin Canyon with the bottomset beds running from here on down to the dam.

The longitudinal profiles of the Virgin River are plotted in Figure 5-4. The pattern of sediment deposition is similar to that of the Colorado River except on a smaller scale. Records were not available to trace the 1948-49 profile throughout the reach. The 1963-64 profile is already exhibiting a delta buildup etween River Miles 25 and 36. Below this point the nflowing sediments deposit in a sporadic pattern along e reach. The profiles were plotted along the original 935) thalweg course. Several depressions and saddles ere noted in the topography used to plot the 1963-64 ofile. These resulted in the peaks or depressions own on this profile. These variations in the profile of wide sections of the northern part of Overton Arm y have been caused by flood inflow from the Virgin er and side washes during periods of low Lake Mead er-surface elevations which resulted in formation of ded stream topography. In the narrow canyon ions of the southern portion of Overton Arm, slides the canyon walls caused by dissolving of soluble rials from the Muddy Creek formation probably ed mounds in the profile.

e up region of the reservoir on the Colorado consisting of the Grand Bay, Pierce, and Lower te Gorge Basins is where about 47 percent or 1.24 n acre-feet of the total sediment deposited since The Overton Arm (Virgin River) showed about 4 t or 120,000 acre-feet of the total sediment ulation for the same period.

ed Reservoir nt Volumes

liment volumes in Lake Mead by basins were ed for two periods by subtracting the ces in computed capacities. Listed in Table 5-1 sediment volumes by basins accumulated 1948-49 and 1963-64. The sediment volumes parentheses in this table for Boulder Basin to 830 feet, all of Lower Granite Gorge, and vation 880 to 900 feet for Overton Arm, gain in capacity in these areas between the and 1963-64 surveys. The total sediment hat have accumulated within each basin of l since 1935 are listed in Table 5-2.

Measured and Estimated Sediment Inflow

The gaging station and suspended sampling station of the Colorado River at Grand Canyon, Arizona, about 270 miles upstream from Hoover Dam, provided the data for determining part of the sediment inflow to Lake Mead. The graph in Figure 5-5 gives an idea of the enormous quantities of sediment carried by the Colorado River. Plotted in this graph are the monthly suspended sediment loads in thousands of tons measured in the Colorado River near Grand Canyon, Arizona, from 1935 to 1964. To supplement the sediment picture, the average monthly waterflows measured at the same station are plotted in Figure 5-6 for 1923 to 1964. The measured quantity of suspended sediment passing Grand Canyon was 3,025 million tons from 1935 to 1963 excluding November 1942 through September 1943 when the suspended sediment was not measured. This gives an average of 108 million tons per year. The quantity passing this station was 1,012 million tons from 1949 to 1963.

Additional sediments flowing into Lake Mead are contributed from the numerous Colorado River tributaries below the Grand Canyon station and from the Virgin River system. The frequency and magnitude of runoff from these sediment-producing areas vary extremely. Large quantities of sediments may be moved in the tributaries during any of the isolated torrential downpours characteristic of the arid climate in the Southwestern United States.

Based upon the sediment records available, an estimate of the sediment yield rate for Lake Mead from both the Colorado and Virgin Rivers cannot be made with any significant degree of practical accuracy. A variety of factors also influence this estimate. Taking for example only the records of the Colorado River station near Grand Canyon, an annual total sediment load of 118.8 million tons was estimated assuming 10 percent for the unmeasured load. Applying a unit weight of 60 pounds per cubic foot, this load converts to 90,900 acre-feet per year. This compares to the sediment rate of 91,450 acre-feet per year determined from the 1963-64 survey showing a difference of 550 acre-feet. The difference, however, is not judged to be representative of the annual sediment yield rate for the additional sediment that would be contributed to Lake Mead from both the Colorado River drainage area below the Grand Canyon station and the drainage area of the Virgin River. Regarding the analysis of the

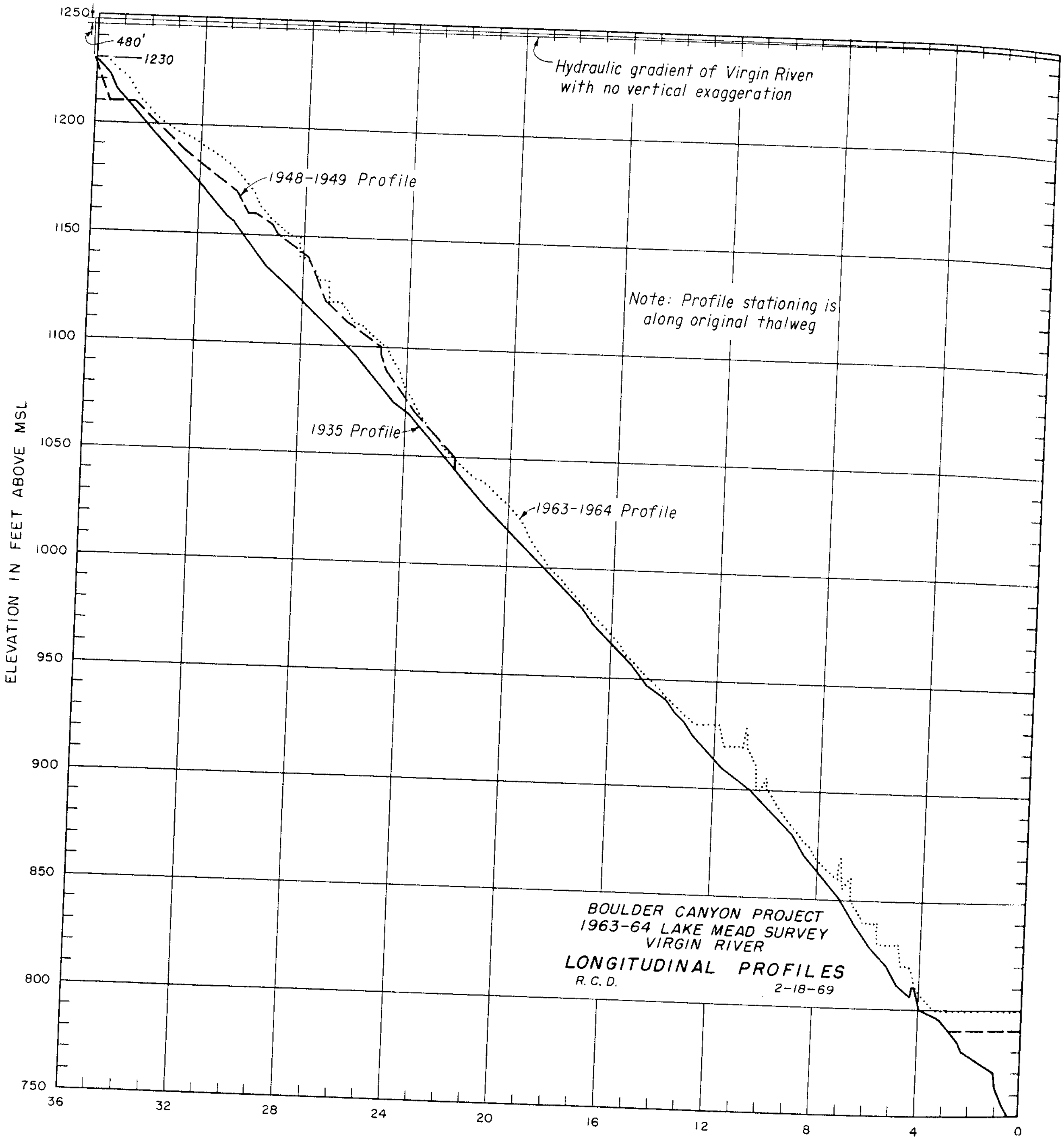


Figure 5-4. River miles above confluence of Virgin and Colorado Rivers.

Table 5-1

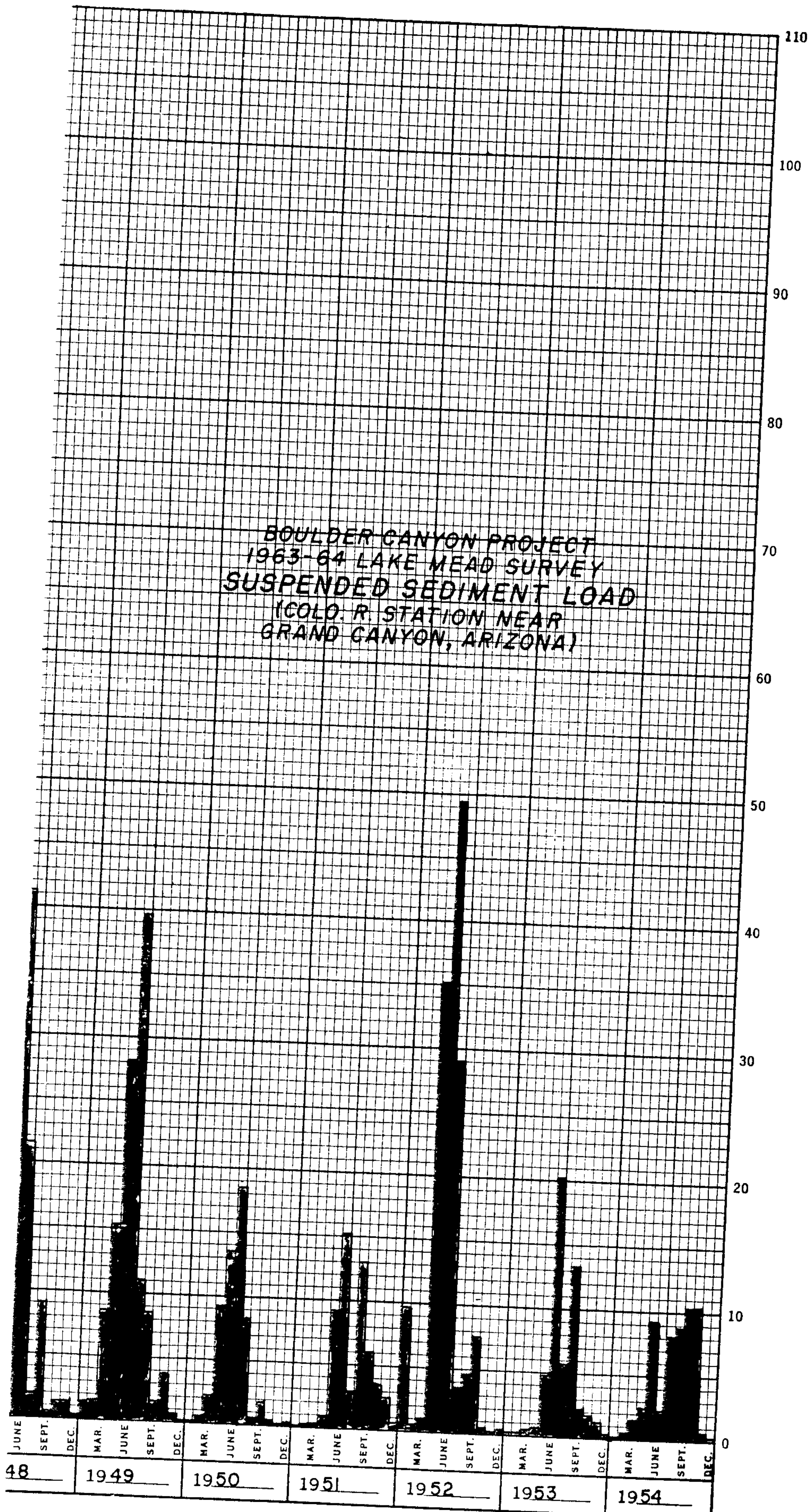
SEDIMENT VOLUMES IN LAKE MEAD BY BASINS 1948-49 to 1963-64
Sediment Volumes in 1,000 Acre-feet

Elevations (feet)	Boulder Basin I-X	Boulder Canyon X+Y	Virgin Basin 2-Y	Temple Bar area 3A	Virgin Canyon 3B	Gregg Basin 4	Grand Bay 5	Pierce Basin 6	Lower Granite Gorge 7	Overton Arm 8	Totals
740	(10.6)										(10.6)
750	(27.1)										(27.1)
760	(22.4)	1.8									(20.6)
770	(17.7)	3.9	1.0								(12.8)
780	(14.6)	6.2	7.5								(0.9)
790	(13.0)	7.2	25.3								19.5
800	(9.2)	8.9	44.2								43.9
810	(6.5)	10.9	52.5								56.9
820	(3.7)	12.6	57.5	6.0							72.4
830	(0.9)	13.9	61.6	17.6							92.2
840	1.8	15.0	65.6	27.6	1.0						111.0
850	4.8	17.7	68.7	33.2	4.0						128.4
860	8.2	19.7	71.7	35.0	8.0	1.0					143.6
870	10.4	21.0	75.4	36.3	10.2	5.0					158.3
880	13.1	22.9	79.4	37.2	11.4	15.0					179.0
890	16.2	25.4	84.1	39.3	11.5	30.4					206.6
900	19.1	27.1	89.4	40.4	11.6	49.1				(0.2)	236.5
910	22.6	28.7	94.4	41.8	11.9	65.7				0.5	265.6
920	26.7	30.5	99.4	44.4	12.0	79.5				1.5	294.0
930	29.8	30.9	104.4	47.1	12.3	93.8				3.4	321.7
940	33.3	33.4	108.0	49.8	12.4	108.2				3.5	348.6
950	36.8	34.1	112.7	52.1	13.2	121.2				5.1	375.2
960	40.1	35.9	117.8	54.1	13.5	133.1	1.0			7.0	402.5
970	43.6	36.9	123.1	56.6	13.6	142.4	3.0			8.2	427.4
980	46.5	37.2	128.6	58.8	13.7	152.2	7.0			8.7	452.7
990	49.8	38.9	134.5	62.9	13.8	159.5	14.0			11.5	484.9
1000	53.0	39.7	141.1	63.9	14.3	165.5	24.0			14.3	515.8
1010	55.4	40.5	147.0	68.7	14.4	170.9	36.0			17.2	550.1
1020	57.4	41.5	152.6	70.8	14.5	175.4	51.0			20.6	583.8
1030	59.5	42.8	158.3	73.7	15.2	177.8	68.6			24.5	620.4
1040	61.4	43.4	165.5	74.3	15.9	180.4	85.4	3.0		30.7	660.0
1050	62.9	44.1	171.3	75.9	16.1	183.0	103.2	9.0		35.8	701.3
1060	64.6	44.7	176.8	77.3	16.5	185.2	119.9	16.0		39.7	720.7
1070	64.7	45.5	182.1	78.3	16.7	187.4	138.8	27.0		43.6	783.1
1080	65.4	45.7	188.8	79.9	16.8	187.8	157.4	40.0		47.6	829.4
1090	65.8	47.0	196.0	81.1	16.9	189.5	175.5	54.0		52.4	878.2
1100	67.6	47.0	202.2	82.6	17.2	191.0	194.8	70.0		57.1	929.5
1110	69.0	47.1	209.2	83.1	17.7	192.1	214.5	88.0		61.3	982.0
1120	70.5	48.1	216.2	83.2		193.2	233.0	107.0		66.3	1,035.2
1130	74.3	48.7	224.8	83.3		194.6	244.8	129.0		72.2	1,089.4
1140	76.9	48.8	234.8	84.2		196.3	251.2	152.0		77.9	1,139.8
1150	78.9	49.6	245.1	85.1		196.6	255.9	177.0		81.0	1,186.9
1160	81.7	50.2	250.7	87.0		197.1	257.6	204.3	(1.1)	82.5	1,227.7
1170		51.6	252.4			199.2	258.6	211.9	(6.0)	82.8	1,236.9
1180		54.0	254.7			203.5	260.1	213.1	(7.0)	83.6	1,248.4
1190			256.8			205.4	263.7	215.7	(11.2)	83.8	1,254.6
1200			259.0			206.1	267.1	217.9	(15.2)	86.1	1,261.4
1210			259.9				269.8	220.1	(15.4)	88.2	1,269.1
1220			262.9					222.7	(15.8)	91.9	1,278.0
1230			278.0						(15.8)		1,293.1

Table 5-2

SEDIMENT VOLUMES IN LAKE MEAD BY BASINS 1935 to 1963-64
Sediment Volumes in 1,000 Acre-feet

Elevations (feet)	Boulder and Virgin Basins	Temple Bar area and Virgin Canyon	Gregg Basin	Grand Bay	Pierce Basin	Lower Granite Gorge	Overton Arm	Totals
650	0							0
660	1							1
670	7							7
680	21							21
690	43							43
700	73							73
710	111							111
720	156							156
730	207							207
740	254							254
750	294	0						294
760	332	1						333
770	371	3						374
780	412	7						419
790	453	15	0					468
800	480	27	1					508
810	494	41	2					537
820	503	57	3					563
830	512	75	7					594
840	520	88	15					623
850	528	96	28	0				652
860	537	102	46	1				686
870	544	106	68	2				720
880	553	108	92	5				758
890	563	110	119	9	0			801
900	573	111	146	15	1	0		846
910	583	113	169	21	3	1	0	890
920	594	115	187	29	6	4	1	936
930	602	118	204	38	11	7	3	983
940	612	121	221	47	16	11	4	1,032
950	620	124	235	57	22	16	5	1,079
960	631	127	247	67	29	22	7	1,130
970	641	129	256	79	36	29	8	1,178
980	649	131	266	91	44	37	9	1,227
990	660	136	273	104	52	48	12	1,285
1000	671	139	279	118	61	59	14	1,341
1010	680	142	284	132	71	73	17	1,399
1020	688	144	289	148	81	87	21	1,458
1030	698	148	292	166	91	103	24	1,522
1040	707	149	294	182	103	120	31	1,586
1050	715	151	297	200	117	138	36	1,654
1060	723	153	299	217	131	159	40	1,722
1070	729	154	301	236	146	181	45	1,792
1080	737	156	302	254	163	204	50	1,866
1090	746	157	303	273	181	228	57	1,945
1100	754	158	305	291	200	255	65	2,028
1110	762		306	311	222	282	71	2,112
1120	772		307	330	244	311	77	2,199
1130	785		309	341	268	342	84	2,287
1140	799		310	348	293	375	91	2,374
1150	809		310	353	319	410	98	2,457
1160	814		310	355	348	446	103	2,534
1170	815		311		356	479	106	2,580
1180	818					505	110	2,613
1190	821					518	114	2,633
1200	823					522	116	2,641
1210	824					523	119	2,646
1220	827					524		2,650
1230	831					525		2,655



nt load—thousands of tons per month, near Grand Canyon, Arizona. (Sheet 1 of 2)

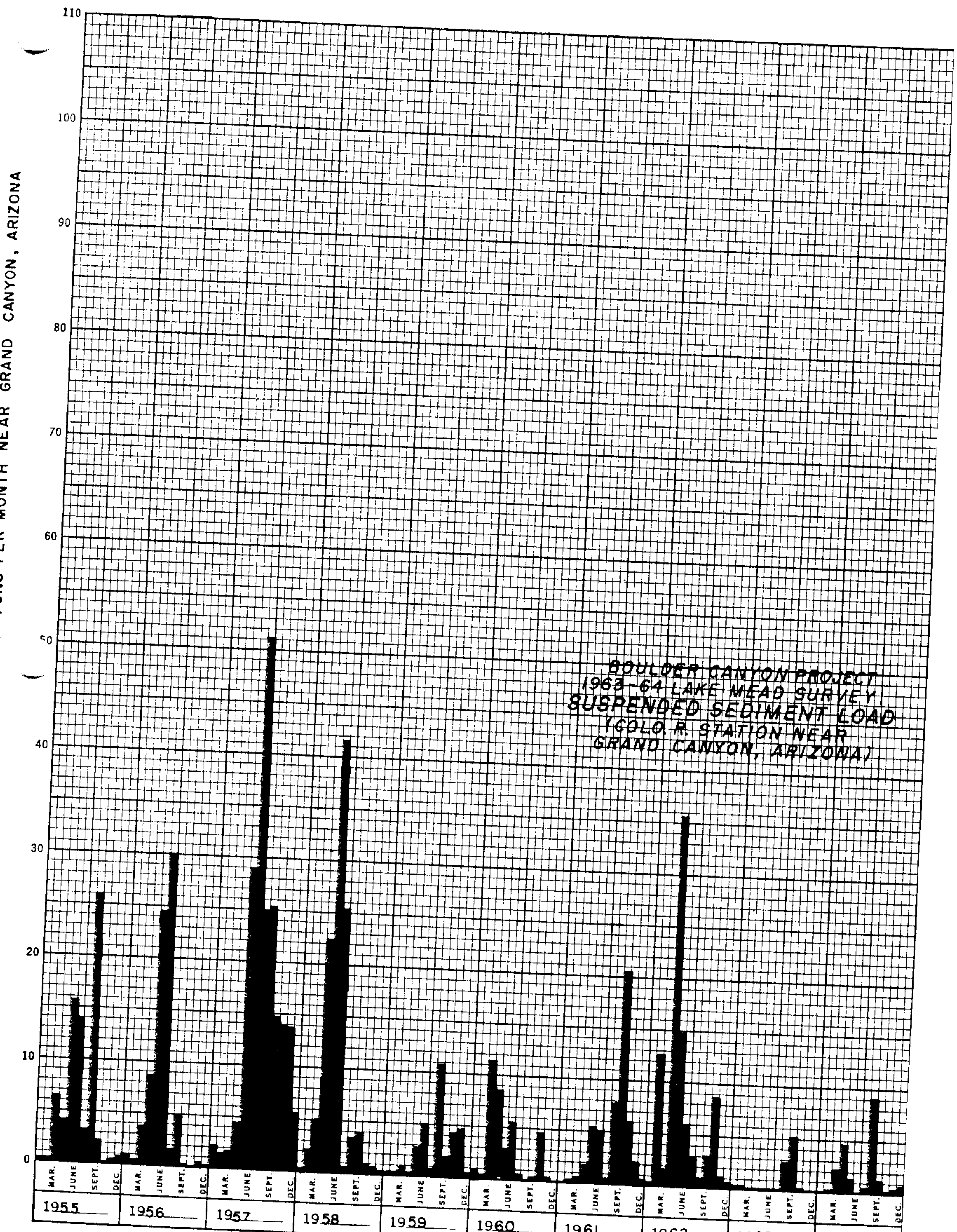
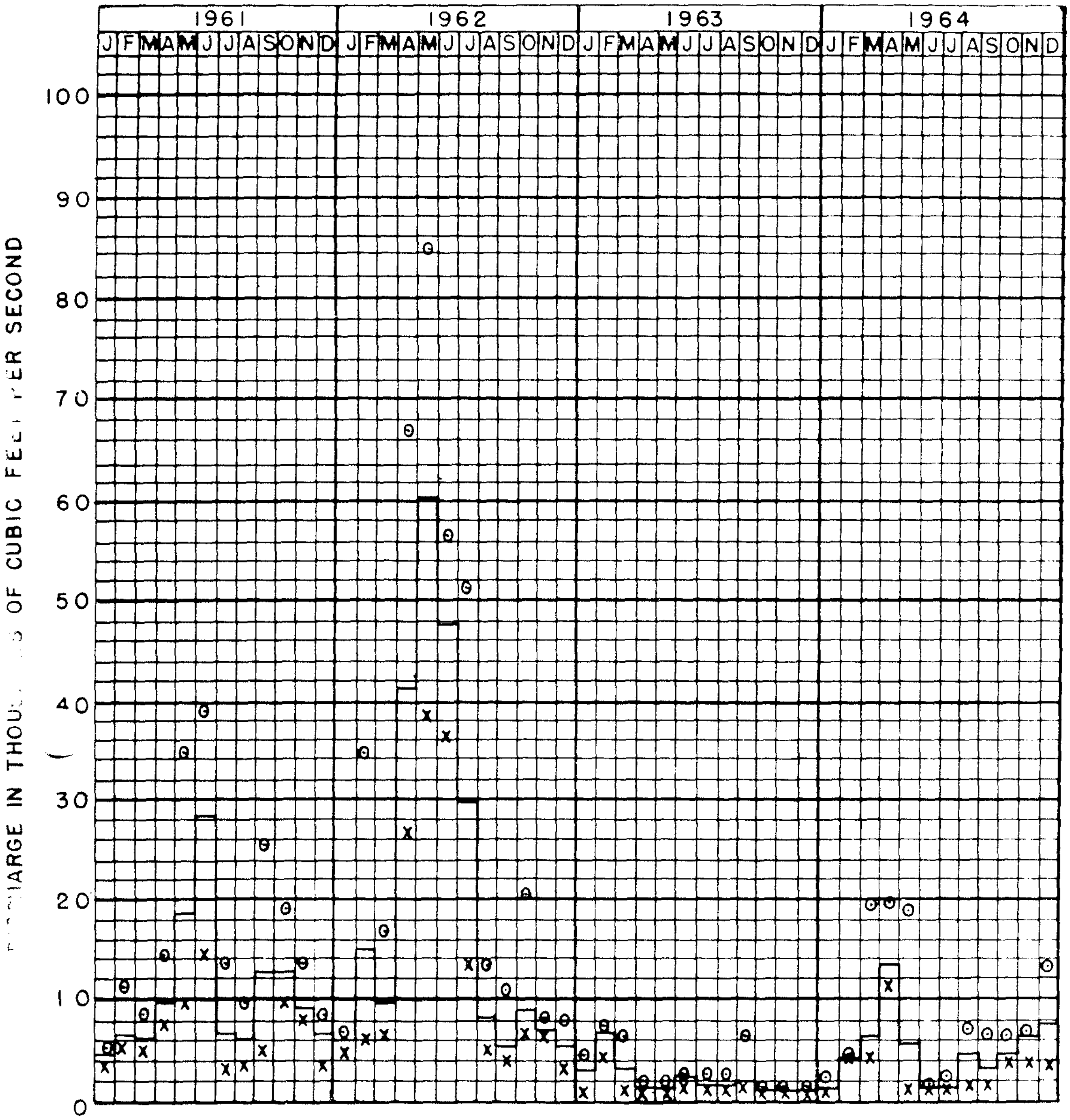


FIGURE 5-5
Sheet 2 of 2



SYMBOLS

⅃⅂ – Average monthly discharge.

o – Maximum mean daily discharge for month.

x – Minimum mean daily discharge for month.

NOTES

DATA SHOWN HEREON WERE OBTAINED FROM WATER SUPPLY PAPERS PUBLISHED BY THE GEOLOGICAL SURVEY FOR THE PERIODS PRIOR TO OCTOBER 1965.

FOR CONVENIENCE, THE MAXIMUM AND MINIMUM MEAN DAILY DISCHARGE FOR EACH MONTH WERE PLOTTED AT THE MIDDLE OF THE MONTH, RATHER THAN ON THE DAY WHEN THE DISCHARGE OCCURRED.

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
LOWER COLORADO RIVER BASIN

RIVER OPERATION DATA

AVERAGE MONTHLY DISCHARGE OF THE COLORADO RIVER NEAR GRAND CANYON, ARIZONA

DRAWN R.C. SUBMITTED C. M. Smith
TRACED W.J.B. RECOMMENDED
CHECKED APPROVED Paul A. Oliver

BOULDER CITY, NEVADA 11-13-57 SHEET 2 OF 2 | 423-300-87

FIGURE 5-6

Colorado River records of the Grand Canyon station, two of the more significant factors influencing the estimated sediment yield rate are:

a. The percentage estimated for the unmeasured load is assumed by judgment and a study of the fluvial conditions therefore is subject to question.

b. The unit weight applied to convert the sediment load to a volume is determined by a weighting analysis (see description in right column) which is subject to an individual interpretation of the collected field sample data.

The sediment yield rate differences would be further affected by the sediment depositional pattern of the Virgin River before it enters the reservoir proper. Some of the sediments transported by this river deposit in the region above the reservoir thus would not be accounted for in the sediment accumulation rate determined by the survey. Other factors affecting the yield rates viewed from opposite ends would be the accuracy to which both the measurements are made of the suspended sediment loads of the Colorado River near Grand Canyon and the actual field measurements made during the 1963-64 survey which serves as the reference base for comparison.

Trap Efficiency

Brune[5-1] in a study related the trap efficiency to the capacity-inflow ratio of several reservoirs and found a reservoir trap efficiency of 99.4 percent for Lake Mead. Based upon the current capacity-inflow ratio of 2.56 (see Item 33, Table 5-3), the trap efficiency for Lake Mead would be 98 percent from the medium curve of Brune's study cited previously. Direct measurements of the sediment outflow have not been made which precludes estimating the trap efficiency. It is judged, however, that the trap efficiency for Lake Mead can be considered equal to 100 percent for all practical purposes.

Representative Particle Gradation

Size analysis data of the collected sediment samples were used to determine the mean particle size gradation representative of the total sediment accumulation. This was done by computing the mean particle size gradations in percentages of clay, silt, and sand for each lake basin. The representative particle size gradation of the total sediments accumulated was computed by weighting the clay, silt, and sand percentages by the ratio of volume of sediment accumulated in a given basin to the total sediment accumulation in all basins. The representative size gradation of the accumulated sediment was computed to be 60 percent clay, 28 percent silt, and 12 percent sand.

Unit Weight Analyses

The dry unit weights of all collected samples listed in Table 4-1 were used in deriving a representative unit weight for the total reservoir sediment accumulation. The graphs in Figure 4-32 relating depth with unit weight were used as guides to estimate the unit weights adjusted for compaction since 1935. A weighting process similar to that applied in determining the representative particle size gradation was used to determine the representative unit weight. This procedure gave a unit weight of about 60 pounds per cubic foot.

The unit weight was also determined by the procedure outlined in the paper of Lara and Pemberton.[5-2] An initial unit weight of 47 pounds per cubic foot was computed with this procedure assuming the sediments are always submerged and using the representative particle size gradations previously determined for clay, silt, and sand. The procedure by Miller[5-3] was used to estimate the unit weight after 30 years of consolidation which also gave a value of 60 pounds per cubic foot.

Additional aspects of the unit weight and other sediment property analyses are discussed in the preceding section, Part 4.

Sedimentation Data Summary

A special summary has been prepared in Table 5-3 listing sediment data that were compiled for Lake Mead. It includes data from both the 1948-49 and 1963-64 surveys.

[5-1] Brune, G. M., "Trap Efficiency of Reservoirs," Am. Geophysical Union Trans., Vol. 34, No. 3, pp 407–418, 1953.
[5-2] Lara, J. M., and Pemberton, E. L., "Initial Unit Weight of Deposited Sediments," Proc. of the Federal Inter-Agency Sedimentation Conf., 1963, U.S. Dept. of Agriculture, Misc. Publ. No. 970, pp 818–845, June 1965.
[5-3] Miller, C. R., "Determination of the Unit Weight of Sediment for Use in Sediment Volume Computations," Bureau of Reclamation Report, 7 p, February 1953.

'ERVOIR SEDIMENT
DATA SUMMARY

LAKE MEAD (HOOVER DAM)
NAME OF RESERVOIR

DATA SHEET NO.

DAM			
DAM	1. OWNER Interior - Bureau of Reclamation	2. STREAM Colorado	3. STATE Nevada - Arizona
DAM	4. SEC. 29 TWP. T22S RANGE R65E	5. NEAREST P.O. Boulder City 6NE	6. COUNTY Clark-Mohave
DAM	7. LAT. 36° 01' " LONG. 114° 44' "	8. TOP OF DAM ELEVATION 1232 1/	9. SPILLWAY CREST ELEV. 1221.4 2/

RESERVOIR: 10. STORAGE ALLOCATION	11. ELEVATION TOP OF POOL	12. ORIGINAL SURFACE AREA, ACRES	13. ORIGINAL CAPACITY, ACRE-FEET	14. GROSS STORAGE, ACRE-FEET	15. DATE STORAGE BEGAN
a. FLOOD CONTROL	1229	162,600	1,587,000	32,471,000	
b. MULTIPLE USE 3/	1219.61	156,600	27,661,000	30,884,000	Feb. 1, 1935
c. POWER					
d. WATER SUPPLY					16. DATE NORMAL OPER. BEGAN
e. IRRIGATION					
f. CONSERVATION					
g. INACTIVE	895	33,400	3,223,000	3,223,000	Mar. 1, 1936

17. LENGTH OF RESERVOIR 152 4/ MILES | AV. WIDTH OF RESERVOIR 1.65 MILES

WATERSHED	
18. TOTAL DRAINAGE AREA 167,800 SQ. MI.	22. MEAN ANNUAL PRECIPITATION 10 6/ INCHES
19. NET SEDIMENT CONTRIBUTING AREA 167,600 5/ SQ. MI.	23. MEAN ANNUAL RUNOFF 1.30 INCHES
20. LENGTH MILES; AV. WIDTH MILES	24. MEAN ANNUAL RUNOFF 11,610,000 7/ AC.-FT.
21. MAX. ELEV. 14,400; MIN. ELEV. 640	25. ANNUAL TEMP.: MEAN RANGE

SURVEY DATA

26. DATE OF SURVEY	27. PERIOD YEARS	28. ACCL. YEARS	29. TYPE OF SURVEY	30. NO. OF RANGES OR CONTOUR INT.	31. SURFACE AREA, ACRES	32. CAPACITY, ACRE-FEET 8/	33. C/I. RATIO, AC.-FT. PER AC.-FT.
2-1-35	–	–	(D)	10 ft.	163,000	32,471,000	2.80
9-30-48	13.7	13.7	(D)	10 ft.	163,000	31,047,000	2.67
10-14-64	16.0	29.7	(D)	10 ft.	163,000	29,755,000	2.56

26. DATE OF SURVEY	34. PERIOD ANNUAL PRECIPITATION	35. PERIOD WATER INFLOW, ACRE-FEET			36. WATER INFL. TO DATE, AC.-FT.	
		a. MEAN ANNUAL	b. MAX. ANNUAL	c. PERIOD TOTAL	a. MEAN ANNUAL	b. TOTAL TO DATE
9-30-48		12,526,000	17,260,000	175,362,000	12,526,000	175,362,000
10-14-64		10,083,000	18,160,000	161,335,000	11,610,000	336,697,000

26. DATE OF SURVEY	37. 8/ PERIOD CAPACITY LOSS, ACRE-FEET			38. TOTAL SED. DEPOSITS TO DATE, ACRE-FEET		
	a. PERIOD TOTAL	b. AV. ANNUAL	c. PER SQ. MI.-YEAR	a. TOTAL TO DATE	b. AV. ANNUAL	c. PER SQ. MI.-YEAR
9-30-48	1,424,000	104,000	0.621	1,424,000	104,000	0.621
10-14-64	1,292,000	80,750	0.482	2,716,000	91,450	0.546

26. DATE OF SURVEY	39. AV. DRY WGT., LBS. PER CU. FT.	40. SED. DEP., TONS PER SQ. MI.-YR.		41. STORAGE LOSS, PCT.		42. SED. INFLOW, PPM	
		a. PERIOD	b. TOTAL TO DATE	a. AV. ANN.	b. TOT. TO DATE	a. PERIOD	b. TOT. TO DATE
9-30-48	65 9/	879	879	0.320	4.39	8,460	8,460
10-14-64	60	572	714	0.282	8.36	7,700	7,760

Data Sheet No.

SUPPLEMENT TO RESERVOIR SEDIMENT DATA SUMMARY–LAKE MEAD

47. REMARKS AND REFERENCES

[1] All elevations refer to powerhouse datum. Add 0.55 foot to convert to datum of 1929, leveling at 1935.

[2] Spillway gates in raised position.

[3] Flood control, municipal and industrial, irrigation, and power use. Originally (1935) the top of the multiple-use pool was at elevation 1213.17 feet above which 2,500,000 acre-feet were provided for flood control storage space. Flood control regulations for Hoover Dam and Lake Mead published in the Federal Register, Vol. 33, No. 147, July 30, 1968, pages 10,801–10,802, revised the flood control space to 1.5 million acre-feet. Elevation 1219.61 feet is the reservoir level established from the 1964 survey to provide the currently required 1.5 million acre-feet of flood control space. This elevation will change with each subsequent survey in order to maintain the fixed flood control storage allocation.

[4] Colorado River about 121 miles; Overton Arm about 31 miles.

[5] Not adjusted for numerous small reservoirs.

[6] Estimated for six states in Colorado River Basin.

[7] Colorado River at Grand Canyon, 1935-64 (30 years).

[8] Capacities at elevation 1229 feet.

[9] Based on measured and estimated sediment inflow of 2 billion tons in 13.7 years.

[10] Based on elevation 1229 feet.

26. DATE OF SURVEY	43. DEPTH DESIGNATION RANGE IN FEET BELOW, AND ABOVE, CREST ELEVAT[illegible]											
	Below 499	499-399	399-299	299-199	199-99	99-Crest						
	PERCENT OF TOTAL SEDIMENT LOCATED WITHIN DEPTH DESIGNATION											
9-30-48	14	21	11	17	21	16						
10-14-64	8	14	14	20	28	16						

26. DATE OF SURVEY	44. REACH DESIGNATION PERCENT OF TOTAL ORIGINAL LENGTH OF RESERVOIR													
	0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100	-105	-110	-115	
	PERCENT OF TOTAL SEDIMENT LOCATED WITHIN REACH DESIGNATION													

45. LAKE MEAD RANGE IN RESERVOIR OPERATION Flow near Grand Canyon, Arizon[illegible]

WATER YEAR	MAX. ELEV.	MIN. ELEV.	INFLOW, AC.-FT.	WATER YEAR	MAX. ELEV.	MIN. ELEV.	INFL[illegible]
1936	1025.85	905.2	12,320,000	1952	1201.10	1133.24	18,160,000
1937	1102.90	1021.90	12,410,000	1953	1168.96	1145.78	8,879,000
1938	1173.90	1094.65	15,630,000	1954	1145.74	1105.40	6,229,000
1939	1183.45	1156.10	9,618,000	1955	1106.70	1089.47	7,580,000
1940	1182.2	1164.2	7,435,000	1956	1116.98	1083.23	8,860,000
1941	1220.45	1166.75	16,940,000	1957	1184.07	1089.63	17,500,000
1942	1213.45	1171.05	17,260,000	1958	1205.89	1161.00	14,550,000
1943	1202.41	1176.70	11,430,000	1959	1185.82	1167.28	6,935,000
1944	1200.35	1157.20	13,530,000	1960	1184.21	1162.99	9,584,000
1945	1182.49	1146.55	11,870,000	1961	1165.12	1152.90	7,050,000
1946	1164.30	1146.50	9,089,000	1962	1204.18	1153.14	15,250,000
1947	1180.24	1133.91	13,740,000	1963	1193.14	1136.88	2,74[illegible]
1948	1192.79	1154.46	13,870,000	1964	1136.84	1088.09	2,72[illegible]
1949	1196.61	1145.50	14,370,000	1965	1129.74	1087.99	10,98[illegible]
1950	1177.54	1149.95	11,080,000	1966	1133.84	1127.20	8,32[illegible]
1951	1168.97	1141.19	9,839,000	1967			8,257,000

46. ELEVATION–AREA–CAPACITY DATA

ELEVATION	AREA	CAPACITY	ELEVATION	AREA	CAPACITY	ELEVATION	AREA	CAPACITY
			920	34,600	3,172,112	1120	97,300	15,737,447
740	2,100	10,599	940	39,100	3,909,899	1140	105,900	17,770,850
760	5,200	88,619	960	44,200	4,741,892	1160	118,700	20,007,[illegible]
780	7,200	212,321	980	49,100	5,675,145	1180	132,300	22,51[illegible]
800	12,300	395,654	1000	54,800	6,710,590	1200	144,900	25,29[illegible]
820	16,200	684,047	1020	61,200	7,871,659	1220	157,100	28,316,[illegible]
840	19,600	1,039,199	1040	67,500	9,157,105	1229	162,700	29,755,37[illegible]
860	23,300	1,469,036	1060	75,100	10,581,403			
880	26,300	1,966,061	1080	82,200	12,154,669			
900	29,900	2,525,433	1100	89,500	13,869,388			

47. REMARKS AND REFERENCES

See supplemental sheet

48. AGENCY MAKING SURVEY U.S. Coast and Geodetic Survey

49. AGENCY SUPPLYING DATA Bureau of Reclamation

50. DATE July 1969

April 1966

PART 6—SUMMARY AND CONCLUSIONS

The 1963-64 survey of Lake Mead was made primarily to determine the capacity of the reservoir. Details of the field surveying procedures and results of the hydrographic and geodetic surveys are described in this report. An explanation is given of the field techniques and equipment used to sample the reservoir sediment deposits and a description is included of each laboratory test made of the samples. The report also presents the results of the analytical methods used to study the nearly 30 years of sediment accumulations in Lake Mead.

A geodetic survey was made in 1963 to determine the amount of vertical movement that occurred in the lands under and surrounding the lake because of the water impounded by the reservoir. With the reservoir full, this water would weigh about 40 billion tons. Comparing the relevel data of the 1963-64 survey showed the reservoir area generally made a rebound since the 1948-49 survey (Figure 2-3, page 35). This means the vertical deformation was generally in a positive direction or there was a rise in the land surface. It varied from no rise at all to 40 mm or slightly greater than 1-1/2 inches in the Boulder and Virgin Basins. During the 1935 and 1963-64 interval, the geodetic survey showed most of the area subsided lowered except for the upper arms on both the orado and Virgin Rivers (Figure 2-2, page 34). The dam subsided an average of 118 mm during this period. The maximum subsidence, over 700 mm or nearly 28 inches, occurred in the vicinity of Las Vegas Valley. This is believed due to the removal of ground water from underlying formations. From the results of the geodetic survey, it was concluded there was no appreciable change in reservoir capacity since 1935 because of any subsidence or rebound in the reservoir basin.

The Region 3 office of the Bureau of Reclamation suggests that the sheet layout for future surveys of Lake Mead be marked with 5-minute quadrangle sheets so that the contours on these quadrangles can be planimetered and checked and closed by a geodetic table of 5-minute quadrangle areas. This would also permit making comparisons to the Soil Conservation Service survey.

A hydrographic survey of Lake Mead was started in July 1963 and completed in October of the next year. The object of this survey was to gather enough data to trace the reservoir contours at 10-foot intervals up to an elevation of 1230 feet. Photogrammetric surveys were made of the Overton Arm, Grand Bay, and Pierce Basins where it was necessary to determine the change in capacity or movement of the sediment deposits above elevation 1150 feet since the 1948-49 survey. For the underwater reservoir areas, sonar soundings were made from a launch to determine lake depths along predetermined range lines in the Colorado River and Overton Arm Basins. In lower Granite Gorge, the uppermost basin on the Colorado River, 174 cross sections were established for the 1948-49 survey. All these cross sections were reprofiled. Important to these surveys was the establishment of vertical and horizontal control. Vertical control was maintained by referencing the levels to reservoir forebay elevation gage at Hoover Dam. Because the lake level decreased continually, it was necessary to install a mobile gage system. These gages facilitated the survey because they could be moved to new locations as necessary. In the Lower Granite Gorge area, levels were tied to existing bench marks in the vicinity. For horizontal control, the same triangulation stations used in the 1948-49 survey were reestablished wherever possible for the 1963-64 survey.

Records of the reservoir gages observed during the 1963-64 survey indicated that seiches, tides, wind, and slope had negligible effect on the horizontality of the lake surface. Based upon these findings which agree with those of the 1948-49 survey, the Coast and Geodetic Survey recommended that future surveys of Lake Mead disregard these actions.

Sediment samples were collected at 17 reservoir locations (Figure 4-1, page 77).The sampling was done in two separate phases to determine certain physical and chemical characteristics of the accumulated sediments. The first sampling work was done in the fall of 1963. The objective was to use standard drilling equipment to obtain extensive undisturbed drive samples of the delta formation. A dry delta area in Pierce Basin was selected as the test site designated Drill Hole No. 1 (Figure 4-1, page 77). The sampling operation was unique in that a helicopter was needed to transport personnel and equipment to the remote site. It took the helicopter 42 flights and nearly 8 hours to move the men and material cumulatively weighing about 18,000 pounds. The drill rig setup (Figure 4-8, page 87) allowed control of the sampling to a 207-foot depth in the delta formation. The second sampling phase was carried out a year later in the fall of 1964. The objective was to collect piston-core samples of the underwater reservoir deposits and to use a nuclear gamma probe to get readings of the density and consolidation effects of the deposits at 16 individual sites. Floating equipment (Figure 4-5, page

82) was used to obtain sampling data by both the piston core and gamma probe.

Upon reducing the collected field data, reservoir area and capacity tables (Table 3-5, page 66 and Table 3-6, page 67) were generated by an electronic computer and the results plotted graphically in Figure 3-7, page 71. The capacity of Lake Mead now is 29,755,000 acre-feet and the reservoir surface 162,700 acres at elevation 1229 feet.

The measured sediment accumulations in Lake Mead amounted to 2,716,000 acre-feet since the dam was closed in 1935. This gives an average inflow rate of 91,450 acre-feet per year. An annual sediment yield rate of 0.546 acre-foot per square mile was indicated from this survey. Representative size gradation of the accumulated sediment was computed to be 60 clay, 28 percent silt, and 12 percent sand. weight of 60 pounds per cubic foot was deterr representative of the deposited sediment analyses of the collected samples. The reserv efficiency is judged to be 100 percent for p purposes. Other sedimentation data are summa Table 5-3, page 167. The longitudinal distribu the sediments is depicted by the profiles in Fig page 155. An idea of how the sediments de laterally can be had by studying the cross s plotted in Figure 5-2, pages 143 to 153.

With the closure of Glen Canyon Dam on the Co River about 370 miles upstream, the life of Lak is estimated to be increased to 500 years.

7-1750 (1-70)
Bureau of Reclamation

CONVERSION FACTORS--BRITISH TO METRIC UNITS OF MEASUREMENT

The following conversion factors adopted by the Bureau of Reclamation are those published by the American Society for Testing and Materials (ASTM Metric Practice Guide, E 380-68) except that additional factors (*) commonly used in the Bureau have been added. Further discussion of definitions of quantities and units is given in the ASTM Metric Practice Guide.

The metric units and conversion factors adopted by the ASTM are based on the "International System of Units" (designated SI for Systeme International d'Unites), fixed by the International Committee for Weights and Measures; this system is also known as the Giorgi or MKSA (meter-kilogram (mass)-second-ampere) system. This system has been adopted by the International Organization for Standardization in ISO Recommendation R-31.

The metric technical unit of force is the kilogram-force; this is the force which, when applied to a body having a mass of 1 kg, gives it an acceleration of 9.80665 m/sec/sec, the standard acceleration of free fall toward the earth's center for sea level at 45 deg latitude. The metric unit of force in SI units is the newton (N), which is defined as that force which, when applied to a body having a mass of 1 kg, gives it an acceleration of 1 m/sec/sec. These units must be distinguished from the (inconstant) local weight of a body having a mass of 1 kg; that is, the weight of a body is that force with which a body is attracted to the earth and is equal to the mass of a body multiplied by the acceleration due to gravity. However, because it is general practice to use "pound" rather than the technically correct term "pound-force," the term "kilogram" (or derived mass unit) has been used in this guide instead of "kilogram-force" in expressing the conversion factors for forces. The newton unit of force will find increasing use, and is essential in SI units.

Where approximate or nominal English units are used to express a value or range of values, the converted metric units in parentheses are also approximate or nominal. Where precise English units are used, the converted metric units are expressed as equally significant values.

Table I

QUANTITIES AND UNITS OF SPACE

Multiply	By	To obtain
LENGTH		
Mil	25.4 (exactly)	Micron
Inches	25.4 (exactly)	Millimeters
	2.54 (exactly)*	Centimeters
Feet	30.48 (exactly)	Centimeters
	0.3048 (exactly)*	Meters
	0.0003048 (exactly)*	Kilometers
Yards	0.9144 (exactly)	Meters
Miles (statute)	1,609.344 (exactly)*	Meters
	1.609344 (exactly)	Kilometers
AREA		
Square inches	6.4516 (exactly)	Square centimeters
Square feet	929.03*	Square centimeters
	0.092903	Square meters
Square yards	0.836127	Square meters
Acres	0.40469*	Hectares
	4,046.9*	Square meters
	0.0040469*	Square kilometers
Square miles	2.58999	Square kilometers
VOLUME		
Cubic inches	16.3871	Cubic centimeters
Cubic feet	0.0283168	Cubic meters
Cubic yards	0.764555	Cubic meters
CAPACITY		
Fluid ounces (U.S.)	29.5737	Cubic centimeters
	29.5729	Milliliters
Liquid pints (U.S.)	0.473179	Cubic decimeters
	0.473166	Liters
Quarts (U.S.)	946.358*	Cubic centimeters
	0.946331*	Liters
Gallons (U.S.)	3,785.43*	Cubic centimeters
	3.78543	Cubic decimeters
	3.78533	Liters
	0.00378543*	Cubic meters
Gallons (U.K.)	4.54609	Cubic decimeters
	4.54596	Liters
Cubic feet	28.3160	Liters
Cubic yards	764.55*	Liters
Acre-feet	1,233.5*	Cubic meters
	1,233,500*	Liters

Table II

QUANTITIES AND UNITS OF MECHANICS

Multiply	By	To obtain
	MASS	
Grains (1/7,000 lb)	64.79891 (exactly)	Milligrams
Troy ounces (480 grains)	31.1035	Grams
Ounces (avdp)	28.3495	Grams
Pounds (avdp)	0.45359237 (exactly)	Kilograms
Short tons (2,000 lb)	907.185	Kilograms
	0.907185	Metric tons
Long tons (2,240 lb)	1,016.05	Kilograms
	FORCE/AREA	
Pounds per square inch	0.070307	Kilograms per square centimeter
	0.689476	Newtons per square centimeter
Pounds per square foot	4.88243	Kilograms per square meter
	47.8803	Newtons per square meter
	MASS/VOLUME (DENSITY)	
Ounces per cubic inch	1.72999	Grams per cubic centimeter
Pounds per cubic foot	16.0185	Kilograms per cubic meter
	0.0160185	Grams per cubic centimeter
Tons (long) per cubic yard	1.32894	Grams per cubic centimeter
	MASS/CAPACITY	
Ounces per gallon (U.S.)	7.4893	Grams per liter
Ounces per gallon (U.K.)	6.2362	Grams per liter
Pounds per gallon (U.S.)	119.829	Grams per liter
Pounds per gallon (U.K.)	99.779	Grams per liter
	BENDING MOMENT OR TORQUE	
Inch-pounds	0.011521	Meter-kilograms
	1.12985×10^{6}	Centimeter-dynes
Foot-pounds	0.138255	Meter-kilograms
	1.35582×10^{7}	Centimeter-dynes
Foot-pounds per inch	5.4431	Centimeter-kilograms per centimeter
Ounce-inches	72.008	Gram-centimeters
	VELOCITY	
Feet per second	30.48 (exactly)	Centimeters per second
	0.3048 (exactly)*	Meters per second
Feet per year	0.965873×10^{-6}*	Centimeters per second
Miles per hour	1.609344 (exactly)	Kilometers per hour
	0.44704 (exactly)	Meters per second
	ACCELERATION*	
Feet per second^2	0.3048*	Meters per second^2
	FLOW	
Cubic feet per second (second-feet)	0.028317*	Cubic meters per second
Cubic feet per minute	0.4719	Liters per second
Gallons (U.S.) per minute	0.06309	Liters per second
	FORCE*	
Pounds	0.453592*	Kilograms
	4.4482*	Newtons
	4.4482×10^{-5}*	Dynes
	WORK AND ENERGY*	
British thermal units (Btu)	0.252*	Kilogram calories
	1,055.06	Joules
Btu per pound	2.326 (exactly)	Joules per gram
Foot-pounds	1.35582*	Joules
	POWER	
Horsepower	745.700	Watts
Btu per hour	0.293071	Watts
Foot-pounds per second	1.35582	Watts
	HEAT TRANSFER	
Btu in./hr ft^2 deg F (k, thermal conductivity)	1.442	Milliwatts/cm deg C
	0.1240	Kg cal/hr m deg C
Btu ft/hr ft^2 deg F	1.4880*	Kg cal m/hr m^2 deg C
Btu/hr ft^2 deg F (C, thermal conductance)	0.568	Milliwatts/cm^2 deg C
	4.882	Kg cal/hr m^2 deg C
Deg F hr ft^2/Btu (R, thermal resistance)	1.761	Deg C cm^2/milliwatt
Btu/lb deg F (c, heat capacity)	4.1868	J/g deg C
Btu/lb deg F	1.000*	Cal/gram deg C
Ft^2/hr (thermal diffusivity)	0.2581	Cm^2/sec
	0.09290*	M^2/hr
	WATER VAPOR TRANSMISSION	
Grains/hr ft^2 (water vapor transmission)	16.7	Grams/24 hr m^2
Perms (permeance)	0.659	Metric perms
Perm-inches (permeability)	1.67	Metric perm-centimeters

Table III

OTHER QUANTITIES AND UNITS

Multiply	By	To obtain
Cubic feet per square foot per day (seepage)	304.8*	Liters per square meter per day
Pound-seconds per square foot (viscosity)	4.8824*	Kilogram second per square meter
Square feet per second (viscosity)	0.092903*	Square meters per second
Fahrenheit degrees (change)*	5/9 exactly	Celsius or Kelvin degrees (change)*
Volts per mil	0.03937	Kilovolts per millimeter
Lumens per square foot (foot-candles)	10.764	Lumens per square meter
Ohm-circular mils per foot	0.001662	Ohm-square millimeters per meter
Millicuries per cubic foot	35.3147*	Millicuries per cubic meter
Milliamps per square foot	10.7639*	Milliamps per square meter
Gallons per square yard	4.527219*	Liters per square meter
Pounds per inch	0.17858*	Kilograms per centimeter

GPO 832-603

	4.4482*	Newtons
	4.4482×10^{-5}*	Dynes
Gallons per square yard	4.527219*	
Pounds per inch		

ABSTRACT

The 1963-64 Lake Mead survey was run to compute the reservoir capacity. Results of the geodetic and hydrographic surveys and sediment sampling equipment are described. The geodetic survey showed Hoover Dam subsided an average of 118 mm since 1935. Sonic sounding, photogrammetry, and cross-sectional profiling methods were used to run the hydrographic survey. Reservoir area and capacity tables were generated using an electronic computer. The present lake capacity is 29,755,000 acre-ft and the reservoir surface area is 162,700 acres at elevation 1229 ft. 2,720,000-acre-ft of sediments accumulated in the lake since 1935. A unit weight of 60 lb/cu ft was determined representative of the deposited sediments. Samples were collected from the major basins with a piston core sampler. A gamma probe was used to measure in situ wet bulk densities. Special sampling with a drill rig was conducted in Pierce Basin representing the sediment accumulation in the delta area. The reservoir trap efficiency is judged to be 100%.

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Lara, J M and Sanders, J I
THE 1963-64 LAKE MEAD SURVEY
Bur Reclam Rep REC-OCE-70-21, Aug 1970. Bureau of Reclamation, Denver and Boulder City, 162 p, 52 fig, 16 tab, 12 ref

DESCRIPTORS--/ *reservoir surveys/ *reservoir silting/ aggradation/ core drilling/ *geodetic surveys/ first order surveys/ land subsidence/ gamma rays/ rebound/ *hydrographic surveys/ sounding/ photogrammetry/ thalweg/ topographic mapping/ sediment sampling/ *sedimentation/ trap efficiency/ fluvial hydraulics/ sediment transport/ *physical properties/ watersheds (basins)/ unit weight
IDENTIFIERS--/ reservoir capacity/ gamma probes/ Arizona-Nevada/ Lake Mead

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