Comprehensive Survey of Sedimentation in Lake Mead, 1948-49

By W. O. SMITH, C. P. VETTER, G. B. CUMMINGS, *and others*

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FOREWORD

Reservoirs are becoming an increasingly prominent feature of the American landscape. Built for flood mitigation and to change a fluctuating river into a dependable source of water for irrigation, power, and other purposes, they are predestined, like natural lakes, to be destroyed sometime following their creation. Sedimentation sooner or later robs most lakes and reservoirs of their capacity to store water. The significance of sedimentation in the life of Lake Mead, the largest artificial reservoir in the world, was realized when the plan for the reservoir was conceived, and an aerial survey of the floor was made in 1935 before the reservoir filled with water. The survey provided a base for the study of future sedimentation.

A casual view of the magnificent expanse of Lake Mead in its desert environment gives no more than a hint of the complex actions and interactions within and near the lake that are critical in relation to the long-term service for which the lake was impounded. The reservoir impounds sediment, dissolved salts, and heat as well as water. Each of these has important effects on the usefulness of the reservoir. Accurate appraisal of the magnitude of the impounded items is the key to longtime successful reservoir management. Such appraisals take the form of budgets, showing the balance between income, outgo, and storage. The sediment budget affects the life of the reservoir, the salt budget affects the chemical quality and usefulness of the impounded water, and the heat budget affects evaporation and the water balance. This report, although centered about the sediment budget, treats the other items to some extent, but each in time will require separate inquiry. The importance of evaporation already has led to a separate report on the heat budget. These problems relate to all reservoirs; but, because of the great size of Lake Mead, the importance and complexity of the problems there reach major proportions. The lake offers an opportunity to test and apply principles that can be derived from study of the sediment, salt, and heat balances. For these reasons the Bureau of Reclamation, the steward of the reservoir on behalf of the people of the country, asked the Geological Survey to lead a joint study by many scientists of the diverse and complicated aspects of Lake Mead. The resulting report is unique in its field because it represents a study by a diversified group of research scientists trained in several different fields of research, including oceanography, hydrology, and geology, working together on a common problem. Such pooling of talents promises to become more common in future hydrologic research because the results of this study have proved the synergistic value of collaboration.

The specific results of the study are food for speculation about future accumulations of sediment and the movement of salt. We have assurances that Lake Mead will not be filled with sediment for at least 350 years and that it will not become a salt lake. The wealth of information in this report undoubtedly will be useful in the operation, not only of Lake Mead, but of many other reservoirs already built or in prospect.

Carl G. Paulsen
Chief Hydraulic Engineer
February 1957

PREFACE

This report on the Lake Mead comprehensive survey of 1948–49 includes a planned collection of papers or chapters that cover fully the intensive field investigations in those years, in which several agencies participated. The technical direction of the comprehensive survey was by the U.S. Geological Survey, with general supervision by C. G. Paulsen, chief of the Water Resources Division, and R. W. Davenport, chief of the Technical Coordination Branch of that Division. W. B. Langbein, hydraulic engineer of the Technical Coordination Branch, contributed importantly to the initial conception of the comprehensive survey and advised in the general supervision. W. O. Smith, physicist of the Water Resources Division, as project chief for the Lake Mead survey was responsible for the overall direction of the program. C. P. Vetter, as Chief of the Office of River Control, Bureau of Reclamation, the contracting agency, approved the general scope of the investigations. He also assisted in the coordination of the field activities and served as principal consultant on reservoir engineering problems. G. B. Cummings, Chief of the Sonar Design Branch of the Bureau of Ships, was in charge of the activities of the Navy Department and served as principal consultant with respect to the echo-sounding and communication problems. Messrs. Smith, Vetter, and Cummings constituted a project staff representing the three agencies principally involved in the Lake Mead survey. These men had primary responsibility for setting the policy of the report, determining what chapters would be included and indicating their general scope; a large proportion of their time was occupied with the project throughout the period of the field investigations.

The project required the services of many consultants who advised in matters pertaining to their respective scientific specialties. Several of these men participated in the development of plans for the survey; most of them visited the area at various times during the survey to consult with members of the field staff. Several of the consultants have contributed technical reports, which appear in succeeding chapters. Consultants within the Geological Survey included: C. S. Howard, staff chemist, Quality of Water Branch, Water Resources Division; C. B. Hunt, chief (during the investigation), General Geology Branch, Geologic Division; H. V. Peterson, staff geologist, Technical Coordination Branch, Water Resources Division; R. M. Wilson, chief, Geodesy and Control Surveys Section, Topographic Division; K. O. Emery, also professor of geology, University of Southern California; and C. R. Longwell, also professor of geology, Yale University.

For the Bureau of Reclamation the following men advised on specific engineering problems: J. W. Stanley, of the Office of River Control; E. A. Moritz, director of Region III; L. R. Douglas, assistant director, and C. P. Christensen, director of power of the Boulder Canyon project.

Consultants for the Navy Department included: Gunnar Leifson, head, and M. R. Ullom, assistant head, of the Survey Branch, Hydrographic Office; Lt. W. R. Brooks, U.S.N.R., and C. E. Nicholson, engineer in the Research and Development Section, Bureau of Ordinance; E. C. LaFond and R. W. Dietz, of the Oceanography Section, and R. D. Russell, consultant on geophysics—all of the Navy Electronics Laboratory in San Diego, Calif.; and C. E. Mongan, Jr., then with the Sonar Design Division of the Bureau of Ships, and now physicist with the Edo Corporation.

Other consultants on the Lake Mead survey included E. J. Parkin, mathematician of the Division of Geodesy, for the Coast and Geodetic Survey; F. D. Sisler, research associate of the Microbiology Division, Scripps Institution of Oceanography, University of California; W. C. Blaisdell, vice president of Bludworth Marine Division of National-Simplex-Bludworth, Inc.; R. P. Geddes, Jr., marine manager of Pacific Division, Bendix Aviation Corporation; and N. B. McLean, president of Edo Corporation.

In field operations of the Geological Survey at Boulder City, F. C. Ames, resident engineer, and his assistant, F. W. Kennon, were responsible for maintenance of vertical control, signaling at horizontal control points, drafting of control maps, layout of lines to be sounded, and plotting of the results of soundings. These men also computed the reservoir-area and capacity tables, using methods developed for the Lake Mead survey by J. L. Speert, geodetic engineer, Topographic Division. The third-order triangulation necessary for horizontal control was done by W. P. McIntosh and J. P. Minta, under the supervision of R. M. Wilson. The survey of the Lower Granite Gorge was made by F. W. O'Bannon, chief of party, under the supervision of L. C. Pampel. Investigations of the geologic changes since Hoover Dam was constructed were made by H. R. Gould, resident geologist, under the supervision of K. O. Emery. Studies of the sediments were made by Gould, partly at the University of Southern California. Irving Sherman assisted in the analyses of sediments in a laboratory set up in Hoover Dam. Chemical analyses to determine dissolved solids in the water were made in the Geological Survey laboratory at Salt Lake City under the direction of C. S. Howard.

Underwater soundings were conducted by Lt. C. C. McCall, Bureau of Ordnance, with a Navy crew of seven petty officers (Chief minemen: J. M. Dickison, J. D. M. Freitas, A. B. Holmes, H. E. Knudsen, G. B. Labagnara, C. D. Malone, and M. L. Perez) under the general supervision of Gunnar Leifson of the Hydrographic Office. Underwater photographic investigations were also made by Lt. McCall. D. W. Pritchard of the Navy Electronics Laboratory directed monthly cruises on the lake for salinity and thermal surveys. E. R. Anderson assumed active charge of these surveys when Mr. Pritchard became associated with the Chesapeake Bay Institute, and he prepared the report on physical limnology in collaboration with Mr. Pritchard.

Biological and biochemical studies of the sediment were made under the direction of F. D. Sisler of the Scripps Institution of Oceanography. The changes in the earth's crust since Hoover Dam was constructed were determined on the basis of precise leveling by the Coast and Geodetic Survey in 1935 and releveling in 1940–41 and 1949–50, under the supervision of E. J. Parkin. Analyses of these leveling data were made by C. R. Longwell.

Some of the papers presented herein rely to an important degree upon data obtained in other parts of the Colorado River basin. Included in this category are discussions of the geologic setting, by C. R. Longwell; the drainage basin tributary to Lake Mead, by H. E. Thomas; the water budget for Lake Mead, by W. B. Langbein; physical and chemical characteristics of the inflowing water, by C. S. Howard; life of the reservoir, by H. E. Thomas, H. R. Gould, and W. B. Langbein; and the sediment problem in reservoirs, by Thomas Maddock, Jr.

This report in advance form (Smith, Vetter, Cummings, and others, 1954), was made available to the public in 1954 by placing it in the open files of the Geological Survey and by reproduction by the Bureau of Reclamation, Boulder City, Nev., for distribution for official use and review by cooperating agencies and others concerned. H.E. Thomas, of the Geological Survey, did the final technical editing of this report both in its advance form and for the present publication. The original draft of the report was assembled by W.O. Smith. Base data obtained as part of this investigation, which will be of use for comparison with future surveys of Lake Mead but is too detailed for inclusion in this report, are contained in the Geological Survey open-file report "Supplemental Base Data for Lake Mead: Comprehensive Survey of 1948–49." This report was also reproduced by the Bureau of Reclamation, Boulder City, Nev., in very limited quantity for reference work. The maps showing the bottom of Lake Mead as determined by the survey were printed only as overlay sheets to the Soil Conservation Service maps of 1935. A summary of the conclusions of this investigation is given in Geological Survey Circular 346, "First Fourteen Years of Lake Mead" (Thomas, 1954).

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COMPREHENSIVE SURVEY OF SEDIMENTATION IN LAKE MEAD, 1948–49

By W. O. Smith, C. P. Vetter, G. B. Cummings, and others

SUMMARY OF RESULTS

By W. O. Smith, C. P. Vetter, and G. B. Cummings

This report presents the results of studies of Lake Mead and its environs made in 1948–49. In the hydrographic survey of the lake, depths were measured by echo sounding. The equipment operating at 50 kilocycles gave a consistent indication of the top of the sediment, with error of less than 2 feet. The instruments operating at 14.25 kilocycles produced an echo from the sediment surface and, where the sediments were dominantly silt and clay of moderate to high water content, produced an echo from the bottom of the old river bed as well. In the Boulder Basin, complete penetration of some 140 feet of soft sediment was obtained.

Area and capacity tables, prepared on the basis of this hydrographic survey, show that the total capacity of the reservoir was reduced 4.9 percent during the first 14 years after Hoover Dam was completed, but that the usable capacity was reduced only 3.2 percent. Practically all this reduction was caused by accumulation of sediment in the reservoir. Studies of inflow and outflow indicate that the reservoir has a total storage capacity about 12 percent greater than that shown by the area-capacity table, because of "bank" storage (ground-water storage) in the bottom and sides of the reservoir. Thus the total capacity in 1949 was greater than the quantity shown by the original 1935 area and capacity table, even though large quantities of sediment had been deposited in the reservoir during the 14 years.

The sediment accumulated in Lake Mead has formed two deltas. One extends from Bridge Canyon to Hoover Dam along the thalweg of the Colorado River; the other, of much smaller size, extends along the inundated Virgin River channel. Most of the sediment brought into Lake Mead is supplied by the Colorado River and accumulates in its delta, which thickens progressively from Bridge Canyon to Pierce Basin, where it attains a maximum thickness of 270 feet. Topset beds make up the surface of this part of the delta. The foreset beds that make up the delta front in Pierce Basin dip sharply beneath the lake surface for a distance of about 1½ miles, measured along the course of the submerged Colorado River channel. From the foot of the delta front to Hoover Dam the slope of the bottomset beds ranges from 9 feet per mile, between the delta front and the mouth of Iceberg Canyon, to less than 1 foot per mile, in the southern part of Boulder Basin. The bottomset beds in 1948 had a minimum thickness of 45 feet in the Temple Bar area, increasing progressively to 106 feet at the dam.

According to computations of the volume and weight of the accumulated sediment, about 2,000 million tons was deposited in the reservoir in 14 years; this is within 2 percent of the amount calculated from measurements of the suspended sediment carried by the inflowing rivers. It is estimated that the sediment capacity of the reservoir, when filled to the permanent spillway crest, is about 75,000 million tons. This quantity is 37 times as great as the amount which occupied 4.9 percent of the reservoir capacity in 1948–49. The prediction is based on estimates that the sediment-storage capacity is about 25 percent greater than the water-storage capacity, and that the mean specific weight of the sediment will ultimately be nearly 50 percent greater than in 1948–49, owing to compaction of the clay and silt. The sediment contributed by the Colorado River averages about 45 percent sand and 55 percent silt and clay. Practically all the clay and much of the silt has been transported by turbidity currents into the lowest parts of the reservoir.

The sediment level at the dam will reach the elevation of the lower outlet gates and the present dead-storage space will be filled when the total accumulation becomes about seven times as great as the amount brought into the lake from 1935 to 1948. The water-storage capacity below the permanent spillway crest will then be about 22 million acre-feet. This prediction is based on certain assumptions, of which an important one concerns reservoir operation. It is assumed that the average operating level will be at spillway level, 35 feet higher than at present, and on that assumption it is predicted that approximately 20 percent of the total sediment load will be deposited above the level of the permanent spillway crest. Lower average operating levels will reduce the proportion of sediment deposited in the upper part of the reservoir, extend the delta front downlake, reduce the area available for deposition of silt and clay, and result in a more rapid rise of the sediment level at the dam.

If the sediment carried by the river in the years 1926–50 represents the long-term average rate of accumulation in Lake Mead, it will be more than 4 centuries before the reservoir is filled with sediment to the level of the permanent spillway crest. The rate of sedimentation since the first year of Lake Mead (1935) has been about 20 percent lower than this 25-year average, and if that rate continues in the future, the life of the reservoir will be correspondingly greater. Construction of upstream reservoirs to capture some of the inflowing sediment, or transportation of sediment in the outflow through Hoover Dam, would also increase the life of the reservoir.

The total bacterial population in the sediment near the dam was found to exceed 1 million bacteria per gram at all depths, which is comparable with the bacterial population in raw sewage. Near the mud surface there is a minimum of 10 million bacteria per gram. By contrast, the water less than a foot above the sediment surface contained only 100 bacteria per gram. By comparison with marine and natural lake muds, the Lake Mead sediments are unique in containing a high bacterial population distributed uniformly throughout a deep and loosely packed layer. Laboratory tests indicate that the abundance

and activity of the microflora have contributed to the heating of the fresh sediment layer in Lake Mead, and also that they affect the hydrogen-ion concentration of the water in the sediment, which in turn influences the rate of sediment compaction.

In the first 12 years of Lake Mead, the dissolved mineral matter in the outflowing water was significantly greater than the average in the inflowing water, owing in part to solution of gypsum and rock salt from the bed of the reservoir. Currently the increased dissolved solids in the outflowing water can be accounted for almost entirely by evaporation from the reservoir, which is about 5 to 7 percent of the annual inflow. The water from Lake Mead is generally of better quality than the water that was diverted from the river for irrigation prior to regulation by Hoover Dam, because it represents an average of the poor water of low stages and the excellent water from melting snow. Since 1935 the concentration of dissolved solids in the inflow has ranged from 225 to 1,720 parts per million, but in the outflow from Lake Mead the concentration has ranged only from 621 to 824 ppm. The "alkali" problem of the areas downstream that are irrigated with the Colorado River water has been decreased to an appreciable extent because of this stabilization.

Oceanographic techniques were utilized to establish the general features of the circulation in Lake Mead. Analysis of the data collected during 12 monthly cruises on Lake Mead indicates a distinct and orderly cyclic progression in the distribution of properties and in the implied circulation, which can be related to the seasonal changes of weather and river inflow.

The changes in elevation measured by precise leveling since 1935 indicate that the weight of water and sediment in the reservoir has caused some subsidence, and that there has also been an extensive tilting subsidence involving the entire lake basin and extending tens of miles farther south. The amount of lowering of bench marks around the reservoir, calculated with respect to a bench mark at Cane Springs, Nev., has been relatively small. Hoover Dam was lowered about 0.4 foot between 1935 and 1950, and bench marks along the shores of the Boulder and Virgin Basins of the lake (which have 60 percent of the reservoir storage capacity) have been lowered as much as 0.6 foot. On the other hand, bench marks near the Overton Arm and east of Virgin Canyon have not dropped as much as those near the dam. It is concluded that the differential subsidence has not changed the reservoir capacity appreciably.

Since 1941 there has been more subsidence at the dam than at any of the six locations—where the level net provides data as to elevations—near the shore of the reservoir. The leveling operation of 1941 was performed while the reservoir was filled nearly to capacity, and the differential rise at these six locations by 1950 may be an indication of elastic rebound with reduced load.

Lake Mead had a noteworthy predecessor in the geologic past. The Colorado River was dammed during the Pleistocene epoch, forming a lake that was deeper and more extensive than Lake Mead, in which there was delta deposition similar to that which has begun since the completion of Hoover Dam. The lower part of the Chemehuevi formation (deposited in that lake) consists chiefly of banded clay, presumably deposited as bottomset beds in a deep lake. This clay is thin in Iceberg Canyon and thicker downstream; extensive remnants occur near Davis Dam, about 60 miles below Hoover Dam. Sand overlies the clay, and composes most of the thickness of the formation in upstream areas. The upper part of the formation consists of river gravel and cobbles, presumably deposited after the lake was filled with fine sediment. Some of these gravels are about 300 feet above the high-water level of Lake Mead. The cobbles in the upper part of the Chemehuevi formation were transported by a larger and more powerful stream than the present Colorado River, which apparently carries nothing coarser than fine gravel into the deltaic fill in the Lower Granite Gorge.