DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY

PREPARED IN COOPERATION WITH THE
CALIFORNIA DEPARTMENT OF WATER RESOURCES

HYDROLOGIC INVESTIGATIONS
ATLAS HA-222

HYDROLOGY AND PHYSIOGRAPHY OF THE SALTON SEA, CALIFORNIA

INTRODUCTION

The increased utilization of the Salton Sea and its shores for recreation, the development of residential complexes on its shores, and the encroachment of the sea into these developments have emphasized the need for a concise summary of hydrologic and physiographic information concerning the area. This report attempts to fill that need.

The report was authorized by a cooperative agreement between the U.S. Geological Survey and the California Department of Water Resources. It was prepared under the general direction of Walter Hofmann, district chief of the Water Resources Division of the Geological Survey, at Menlo Park.

PHYSICAL SETTING

The Salton Sea lies below sea level in the lowest part of an interior valley known as the Salton Trough (See Topographic and Hydrographic Map). The sea, which occupies parts of Imperial and Riverside Counties in California (fig. 1), lies 125 miles northeast of the Gulf of California, and the two bodies of water are separated by the delta of the Colorado River. The Salton Sea receives the drainage from an area of 8,360 square miles that includes the highly developed agricultural areas, Imperial and Coachella Valleys in California and Mexicali Valley in Mexico. All three valleys depend on irrigation water from the Colorado River.

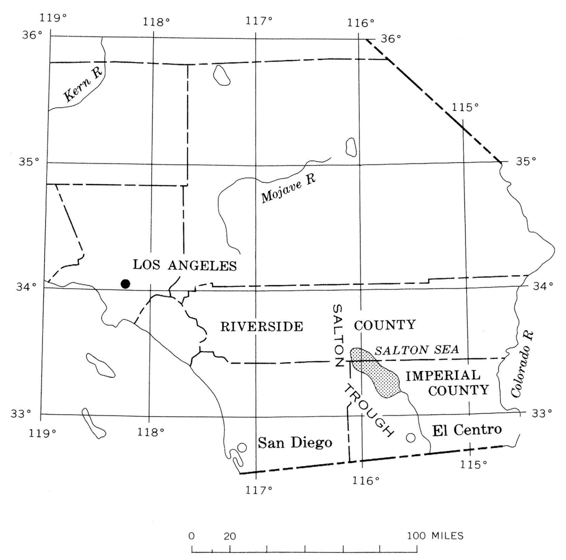


FIGURE 1.—*Index map showing location of the Salton Sea.*

HISTORY

Geologic evidence indicates that, in the geologic past, what is now the Salton Sea was a part of the Gulf of California, which extended about 200 miles farther northwest than at present.

As a result of the Colorado River depositing its silt load at its mouth year after year, the Colorado delta gradually extended southwestward and divided the old gulf into the present gulf and an inland sea. The river must have discharged alternately into the gulf and into the Salton Sea.

Water probably filled the Salton depression and evaporated from it many times, as the meager rainfall and runoff from bordering mountains were greatly exceeded by the evaporation. A clear and definite indication of the last occupancy of the depression by a historically old lake (Lake Cahuilla) may be seen in the remarkably well preserved waterline that rims the desert at an elevation of about 40 feet above mean sea level from Indio, Calif., to the Cerro Prieto, in Mexico. The waterline is especially distinct on Travertine Rock at the northwest end of the sea and along the eastern slopes of the Santa Rosa Mountains just south of Travertine Rock. The thickness of the calcium carbonate deposits forming the waterline indicates that water stood at this elevation for long periods of time. An inner layer of the deposits was dated, by the use of carbon isotopes, at about 13,000 years before the present, and an outer layer at about 1,900 years before the present (Hubbs and others, 1963, p. 260-261).

The date of Lake Cahuilla's disappearance has not been established, but, according to Indian legend, the lake existed until about 300 years ago. This seems to be substantiated by a date obtained by analyzing charcoal, found associated with the remains of fresh-water fish (Fergusson and Libby, 1963). In the years just prior to 1901 the bed of the Salton Sea was a dry lake, or playa, known as Salton Sink. In 1901 irrigation was started in the Imperial Valley with water diverted from the Colorado River, and the present Salton Sea began to form. By November 1904, the water was 0.2 foot deep on the floor of Salton Sink, as a result of irrigation drainage.

Previously, water reaching the sea had resulted from heavier than usual precipitation within the drainage basin and from unusually high flows in the Colorado River which spread over the part of the delta draining into the sea. Floodwaters of noticeable volume had been reported in Salton Sink in 1828, 1840, 1849, 1852, 1859, 1862, 1867, and 1891. In February 1905, during a flood on the Colorado River, irrigators were unable to control the flow entering their diversion canal, and great quantities of floodwater poured into the Salton Sea. Two years elapsed before this diversion could be brought under control, and during that period the sea rapidly increased in depth and volume until March 1907, when the water surface reached its maximum level of recent times, 195.9 feet below sea level. At this level the sea was 45 miles long, its width ranged from 10 to 20 miles, and it covered an area of about 520 square miles. After March 1907, the water level gradually receded as evaporation greatly exceeded inflow (fig. 2).

WATER-LEVEL FLUCTUATIONS

The hydrograph on figure 2 shows the water-surface elevation of the Salton Sea on the last day of each month for 60 years. All elevations are referred to mean sea level, datum of 1929. The vertical scale of figure 2 changes in 1925 to emphasize the seasonal and annual variations in elevation in recent years. These variations are caused by changes in the relative magnitude of inflow and evaporation. When the monthly inflow exceeds the monthly evaporation, the water level rises; when the monthly evaporation exceeds the monthly inflow, the water level falls. Also, when the total annual inflow continues to exceed the total annual evaporation, the water level maintains a general rising trend, as shown for the periods 1925-31 and 1936-64. When the total annual evaporation continues to exceed the total annual inflow, the water level maintains a general falling trend, as shown for the periods 1907-24 and 1931-35. As the elevation of the water surface approaches that level where inflow and evaporation tend to compensate each year, the water level will remain at a fairly constant elevation.

PRECIPITATION

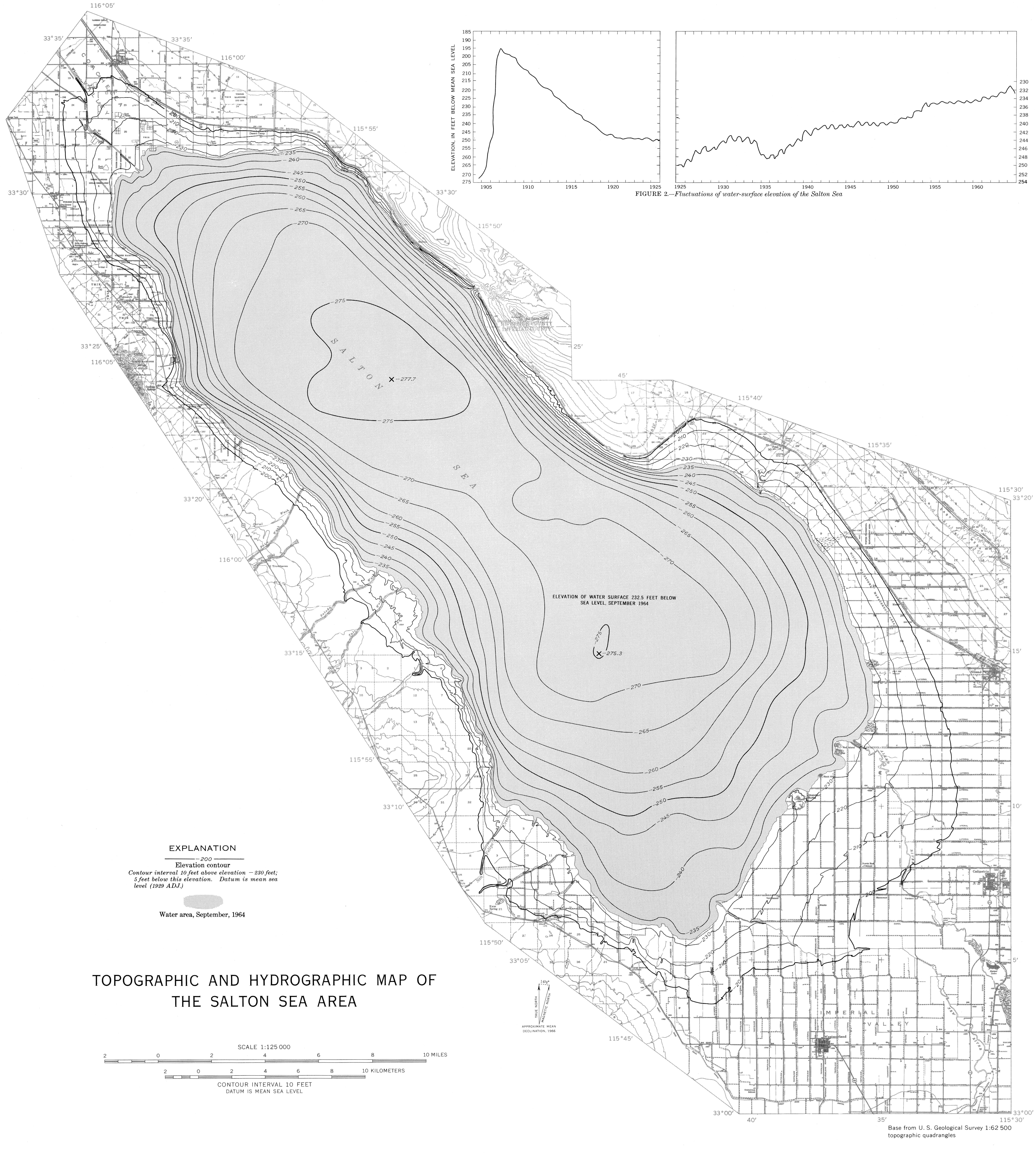
The meager precipitation that occurs in the area results from two types, general winter storms and convective summer storms. Winter precipitation, the predominant type in the southern California coastal region, originates in moisture-laden polar Pacific maritime airmasses. The relatively high coastal Peninsular Ranges that form the western boundary of the Salton Sea Trough act as a barrier to the easterly movement of these airmasses. In passing over the barrier, the airmasses are elevated and cooled, and thereby lose water by condensation. After passing this barrier, the airmasses descend and become warmer, thereby decreasing their potential for causing precipitation and increasing their potential for evaporating water in the area. This tends to cut off the winter precipitation very sharply just east of the mountain divide. For example, the average winter precipitation is about 38 inches in the San Jacinto Mountains, near the divide, and is 5 inches at Palm Springs, 8 miles east of the divide. The average winter precipitation diminishes to about 2.5 inches at Indio and 2.0 inches at El Centro, south of the sea and east of the divide.

Summer precipitation in the basin generally is attributable to the tropical gulf and tropical continental airmasses, which originate over the Gulf of Mexico and over the continental United States and Mexico, respectively. These westerly and northwesterly moving airmasses are largely responsible for occasional intense but widely scattered convectional storms on the desert.

A part of the precipitation that falls on the basin eventually reaches the Salton Sea by surface or subsurface routes, and rain falling directly on the sea contributes a significant quantity of water. During the period 1908-62 this rainfall on the sea averaged 2.5 inches annually, which is an average annual volume of about 42,000 acre-feet of water added directly to the sea. This volume has ranged from 1,000 acre-feet in 1953 to 127,000 acre-feet in 1939.

EVAPORATION

The only way water can leave the Salton Sea is by evaporation. Investigations have shown the average annual evaporation rate, based on data for the period 1948-62, is about 5.8 feet. The volume of water that evaporates in a particular year is dependent not only on the evaporation rate, but also on the water-surface area. This, in turn, causes the volume of annual evaporation to be dependent on the water level of the sea, for when the water level rises, it exposes a greater water-surface area to the elements causing evaporation, and when it falls, the converse is true. For example, in 1951 when the average elevation of the sea was -240 feet (below sea level), 5.8 feet of evaporation would have been equivalent to a loss of about 1,140,000 acre-feet of water; in 1964 when the average elevation of the sea was -232 feet, 5.8 feet of evaporation would have been equivalent to a loss of about 1,340,000 acre-feet of water.



TOPOGRAPHIC AND HYDROGRAPHIC MAP OF THE SALTON SEA AREA

Base from U.S. Geological Survey 1:62 500 topographic quadrangles

FIGURE 2.—*Fluctuations of water-surface elevation of the Salton Sea*

INFLOW TO THE SALTON SEA

Inflow to the Salton Sea, other than rain on the water surface, occurs both as surface-water flow and ground-water flow. A small part of the total inflow is derived from precipitation on the basin surrounding the sea, but in most years nearly all inflow is drainage from irrigation operations.

Geographically, surface-water inflow to the Salton Sea comes from three principal sources: (1) Imperial Valley, (2) Coachella Valley, and (3) the remaining tributary area. Inflow from Imperial Valley includes drainage from Mexicali Valley in Mexico. About 90 percent of the inflow from Imperial Valley reaches the sea through the Alamo and New Rivers, and 10 percent is discharged into the sea from more than 30 minor channels and drains.

The principal surface-water channel in Coachella Valley is the Whitewater River (known locally as Coachella Valley Stormwater Channel). It discharges into the sea about 60 percent of the drainage water from the valley; 40 percent reaches the sea through 18 minor channels and drains.

The principal surface-water channels in the remaining area tributary to the Salton Sea are (1) San Felipe Creek, which enters the southwest end of the sea near Kane Spring, and (2) Salt Creek, which enters the sea near the Durmid railroad station on the northeast shore. These two channels carry about half the surface-water inflow from areas other than Imperial and Coachella Valleys. The remainder is contributed by minor channels discharging directly into the sea.

The table below shows the quantity of surface-water inflow to the Salton Sea, in acre-feet, during the calendar years 1961-63, as measured at U.S. Geological Survey gaging stations on the major streams. The figures in the bottom row do not represent total surface-water inflow; the flow of many minor channels is not measured by the Geological Survey.

River	1961	1962	1963
Alamo River	675,500	681,300	723,700
New River	437,000	455,000	477,500
Whitewater River	53,390	69,600	75,740
Salt Creek	3,500	4,420	5,310
San Felipe Creek	1,130	374	8,700
Total[1]	1,171,000	1,211,000	1,291,000

[1] Rounded to nearest 1 thousand acre-feet

Ground-water inflow to the Salton Sea is about 50,000 acre-feet per year. Of this total, about 30,000 acre-feet is contributed by Coachella Valley and 2,000 acre-feet by Imperial Valley. About 10,000 acre-feet enters through the alluvium bordering San Felipe Creek, and the remaining 8,000 acre-feet enters through the alluvium in other peripheral areas.

Measurement of inflow to the Salton Sea from all sources is not feasible, but total ground- and surface-water inflow can be computed approximately by the water-budget method. Any inaccuracies in the measurement of rainfall on the sea, of evaporation from the sea, and of change in volume of the sea will be reflected in the computed values of inflow, because the inflow is a residual element in the budget equation. The table below shows the calendar-year water budget for the period 1948-63. The data are from Hely and others (written commun., 1964).

Year	Rainfall on the sea		Evaporation		Change in contents	Inflow
	(feet)	(thousands of acre-feet)	(feet)	(thousands of acre-feet)	(thousands of acre-feet)	(thousands of acre-feet)
1948	0.14	27	6.04	1,150	−58	1,060
1949	.15	29	5.76	1,110	+105	1,190
1950	.02	4	5.60	1,090	+117	1,200
1951	.15	30	5.88	1,160	+228	1,360
1952	.22	45	5.58	1,140	+316	1,410
1953	.005	1	5.95	1,260	+197	1,460
1954	.11	24	5.37	1,170	+219	1,360
1955	.08	18	5.87	1,290	+99	1,370
1956	.01	2	6.02	1,330	−18	1,310
1957	.15	33	5.50	1,210	+16	1,190
1958	.18	40	5.57	1,230	−3	1,190
1959	.15	33	5.77	1,280	+53	1,300
1960	.16	36	5.86	1,310	+113	1,390
1961	.15	34	6.08	1,360	+87	1,410
1962	.10	23	5.89	1,330	+162	1,470
1963	.25	57	6.03	1,380	+321	1,640

[1] Inflow computed by equation: Inflow = Evaporation minus rainfall plus change in contents; result rounded to nearest 10 thousand acre-feet

SURFACE AREA AND VOLUME OF THE SALTON SEA

The curves on figure 3 show the water-surface area and volume of the Salton Sea for water-surface elevations between -277.7 feet, the lowest elevation of the bed, and -200.0 feet. The two curves are based on elevation contours drawn on topographic maps similar to the topographic and hydrographic map. The contours for elevations between -200 feet and -235 feet were obtained from the latest 7 1/2-minute quadrangle maps of the Geological Survey; the contours for elevations between -240 feet and -277.7 feet were drawn on the basis of soundings made in August 1962 by a seismological laboratory party from the California Institute of Technology. The shaded area on the map indicates the area covered by the sea in September 1964, when the water surface was at elevation -232.5 feet. The sea was 36 1/2 miles long, its width ranged from 8 1/2 to 15 1/2 miles, and it covered an area of about 360 square miles. The greatest depth, more than 45 feet in 1964, is near the center of the sea, directly opposite the mouth of Salt Creek.

SALINITY OF THE SALTON SEA

The salinity of the water in the Salton Sea has been changing continually since the first significant inflow occurred shortly after the turn of the century. Most of the water in the Salton Sea during the period 1905-07 resulted from large uncontrolled diversions of Colorado River water. Although the river water had an average salinity (total dissolved solids) of less than 800 ppm (parts per million), the salinity of the water in the sea reached 3,550 ppm by June 1907, because of the dissolving of large quantities of salts accumulated on the bed of the Salton Sea during previous centuries. After 1907 the volume of water in the sea decreased rapidly. The loss of water by evaporation, combined with the continued dissolving of salts in the bed of the sea, caused a rapid increase in salinity. By 1920 the salinity had increased to 38,000 ppm, and in 1936 it reached a maximum of about 43,000 ppm. The volume of water in the sea increased greatly during the period 1937-62; by 1962 the salinity had decreased to 34,000 ppm, because water of lower salinity had been draining into the sea and had diluted the sea water. By way of comparison, the salinity of ocean water is about 35,000 ppm.

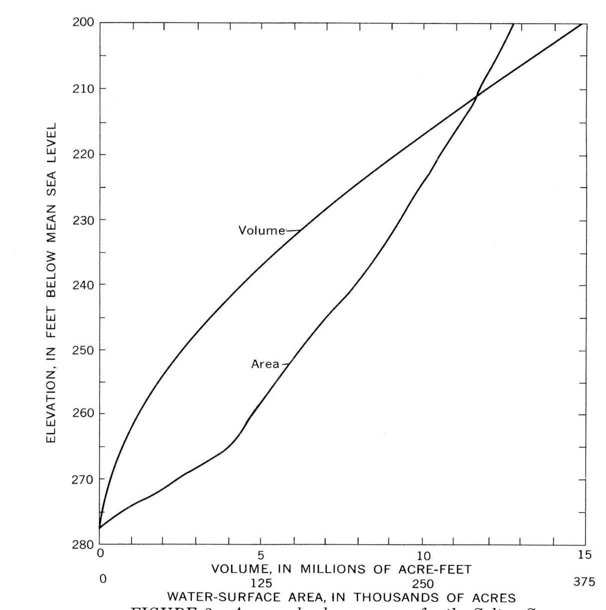


FIGURE 3.—*Area and volume curves for the Salton Sea.*

ADDITIONAL DATA

Additional information pertaining to the Salton Sea may be obtained at the offices of the Geological Survey at Menlo Park and Garden Grove, Calif., and from the following reports:

Brown, J. S., 1923, The Salton Sea region, California, a geographic, geologic, and hydrologic reconnaissance, with a guide to desert watering places: U.S. Geol. Survey Water-Supply Paper 497, 292 p.

California Department of Water Resources, 1964, Coachella Valley investigation: Bull. 108, 145 p.

Dickinson, W. E., 1944, Summary of records of surface waters at base stations in Colorado River Basin, 1891-1938: U.S. Geol. Survey Water-Supply Paper 918, 274 p.

Fergusson, G. J., and Libby, W. F., 1963, UCLA radiocarbon dates II: Radiocarbon, v. 5, p. 6.

Hubbs, C. L., Bien, G. S., and Suess, H. E., 1963, La Jolla natural radiocarbon measurements III: Radiocarbon, v. 5, p. 260-261.

U.S. Geological Survey, 1913, Water resources of California, Part 3, Stream measurements in the Great Basin and Pacific Coast river basins: Water-Supply Paper 300, 956 p.

______1933, Surface water supply of the United States, 1932, Part 10, The Great Basin: Water-Supply Paper 735, 107 p.

______1960, Compilation of records of surface waters of the United States through September 1950, Part 10, The Great Basin: Water-Supply Paper 1314, 485 p.

______1961, Surface water records of California, 1961, Volume 1, Colorado River Basin, Southern Great Basin, and Pacific Slope Basins, excluding Central Valley: Menlo Park, open-file rept., 448 p. Published annually after 1961.

______1963, Compilation of records of surface waters of the United States, October 1950 to September 1960, Part 10, The Great Basin: Water-Supply Paper 1734, 318 p.

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