FLOOD-HAZARD STUDY--100-YEAR FLOOD STAGE FOR BALDWIN LAKE

SAN BERNARDINO COUNTY
CALIFORNIA

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✓U.S. GEOLOGICAL SURVEY

Water Resources Division

Water-Resources Investigations 26-74

Prepared in cooperation with the
San Bernardino County Flood Control District

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Stage-frequency analysis involving 39 years of observed annual maximum stage record of the lake and an additional 40 years of synthetic record of annual maximum stage, based on a precipitation-stage relation, resulted in an estimate of 6,710.7 ft (2,045 m) for lake altitude corresponding to a 100-year flood.

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SAN BERNARDINO COUNTY
CALIFORNIA

By James J. French and Mark W. Busby

U.S. GEOLOGICAL SURVEY [Water Resources Division.]

Water-Resources Investigations 26-74

Prepared in cooperation with the
San Bernardino County Flood Control District

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Factors for converting English units to the International System of Units (SI) are given below to four significant figures. However, in the text the metric equivalents are shown only to the number of significant figures consistent with the values for the English units.

English	*Multiply by*	*Metric (SI)*
acre	4.047×10^3	m^2 (square metre)
acre-ft (acre-foot)	1.233×10^3	m^3 (cubic metre)
ft (foot)	3.048×10^{-1}	m (metre)
ft^3/s (cubic foot per second)	2.832×10^{-2}	m^3/s (cubic metre per second)
in (inch)	2.540	cm (centimetre)
mi (mile)	1.609	km (kilometre)
mi^2 (square mile)	2.590	km^2 (square kilometre)

FLOOD-HAZARD STUDY--100-YEAR FLOOD STAGE FOR BALDWIN LAKE, SAN BERNARDINO COUNTY, CALIFORNIA

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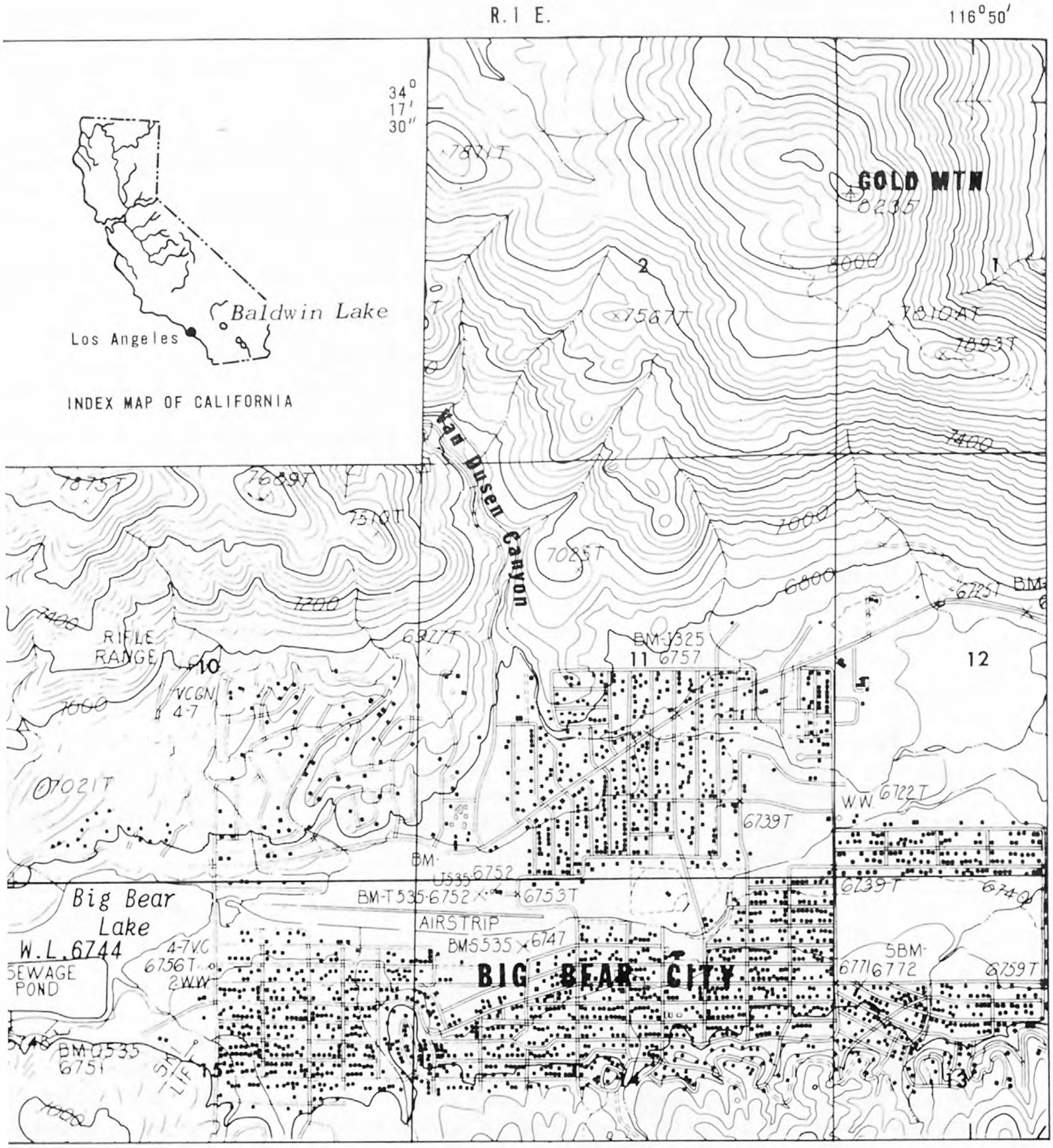
ABSTRACT

Shoreline features that represent former high-water stages on Baldwin Lake are found at 10 different altitudes that range from 6,700 to 6,713 feet (2,042 to 2,046 metres). Stage frequencies were assigned to the stages, but the date of formation of the features could be determined only for the most recent shorelines.

Stage-frequency analysis involving 39 years of observed annual maximum stage record of the lake and an additional 40 years of synthetic record of annual maximum stage, based on a precipitation-stage relation, resulted in an estimate of 6,710.7 feet (2,045 metres) for lake altitude corresponding to a 100-year flood.

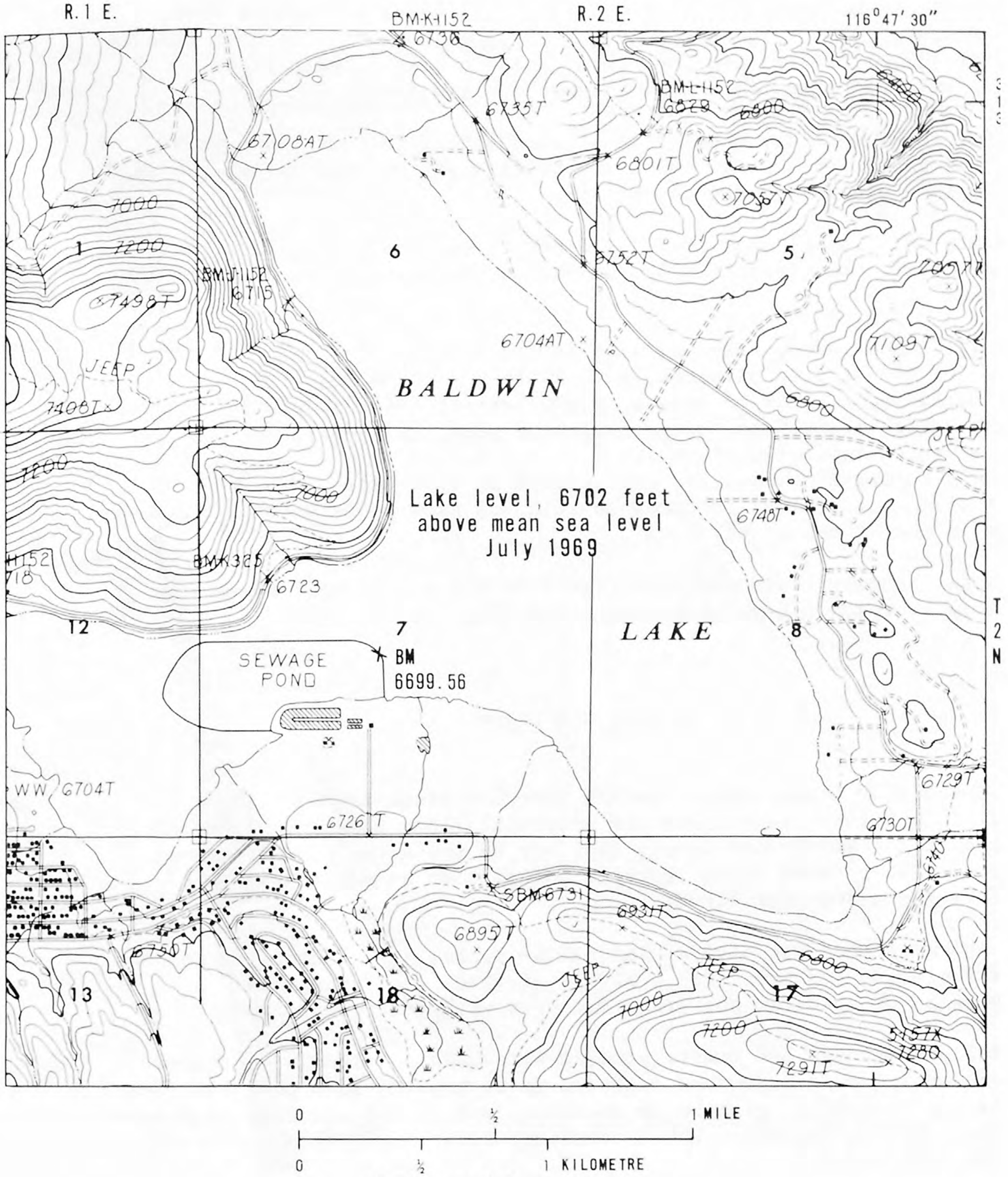
INTRODUCTION

Baldwin Lake (fig. 1) is an intermittent lake in the San Bernardino Mountains of southern California, about 2 mi (3 km) east of Big Bear Lake and about 80 mi (130 km) east of Los Angeles. The altitude of the floor of the valley in which Baldwin Lake lies is about 6,700 ft (2,040 m). Mountain crests that surround the lake are as high as 9,950 ft (3,032 m) above mean sea level. The maximum topographic relief above the valley floor is about 3,250 ft (990 m). The surface area of the lake, when the altitude of the lake surface was 6,702 ft (2,043 m), was 1.75 mi^2 (4.53 km^2). (Data obtained from U.S. Geological Survey topographic quadrangle map, Lucerne Valley, SE, scale 1:24,000, which is based on aerial photography dated July 10, 1969.) The drainage basin tributary to the lake is about 30 mi^2 (78 km^2).



Base from U.S. Geological Survey
Lucerne Valley SE, advance print
1:24,000, 1972

FIGURE 1.--Baldwin Lake and vicinity.



CONTOUR INTERVAL 40 FEET
DATUM IS MEAN SEA LEVEL

(To convert feet to metres, multiply by 3.048×10^{-1})

FIGURE 1.--Continued.

There is no surface-drainage outlet. The altitude of the lowest point in the lakebed when the lake is dry is 6,695.4 ft (2,040.7 m) (Joseph Rowe, written commun., 1973). The normal water surface of nearby Big Bear Lake is about 40 ft (12 m) higher than the bed of Baldwin Lake. There is no historical evidence of surface flow between the two lakes.

Baldwin Lake goes dry about 3 to 4 years out of 10, but can have a carryover of water for several years following a wet period. After the 1938 flood, the lake did not go dry until 1943.

A waste-water management study by Neste, Brudin, & Stone, Inc., and C. M. Engineering Associates (1973) summarized the general hydrology of the Baldwin Lake area:

> Average annual precipitation, 12.8 in (32.5 cm).
> Range of annual precipitation, 6 to 20 in (15 to 50 cm).
> Estimated runoff 1968-69 season, 8,000 acre-ft (9,800,000 m^3).
> Waste-water inflow from sewage-treatment plant (1969-72), 1,480 acre-ft (1,800,000 m^3).
> Annual evaporation from lake surface, 52 in (132 cm).
> Most of the precipitation comes as rain and snow in December and January.
> June is the driest month.

An area-capacity curve was illustrated in the waste-water management study and is reproduced here with permission (fig. 2).

Purpose and Scope

San Bernardino County Flood Control District requested that the U.S. Geological Survey investigate the potential flood hazard of lake and playa areas in San Bernardino County that may be the sites of real-estate development. The present study concerns information on maximum stage of Baldwin Lake for a 100-year flood.

The investigation was divided into three parts: (1) Identification and dating of shoreline features, (2) analysis of stage frequency, and (3) correlation of specific shoreline features with particular floods.

Aerial photographs and onsite studies were used as aids in shoreline identification. Any feature that appeared to be related to a past lake level was studied by trenching, grain-size analysis, and spirit leveling to obtain the altitude of each feature. Local residents were interviewed for eyewitness accounts of high water.

Various methods of dating shoreline features were investigated to derive methods that could be used on other lakes. These included radiocarbon dating, growth-ring studies, and study of human remains such as datable pottery or refuse. However, results were inconclusive.

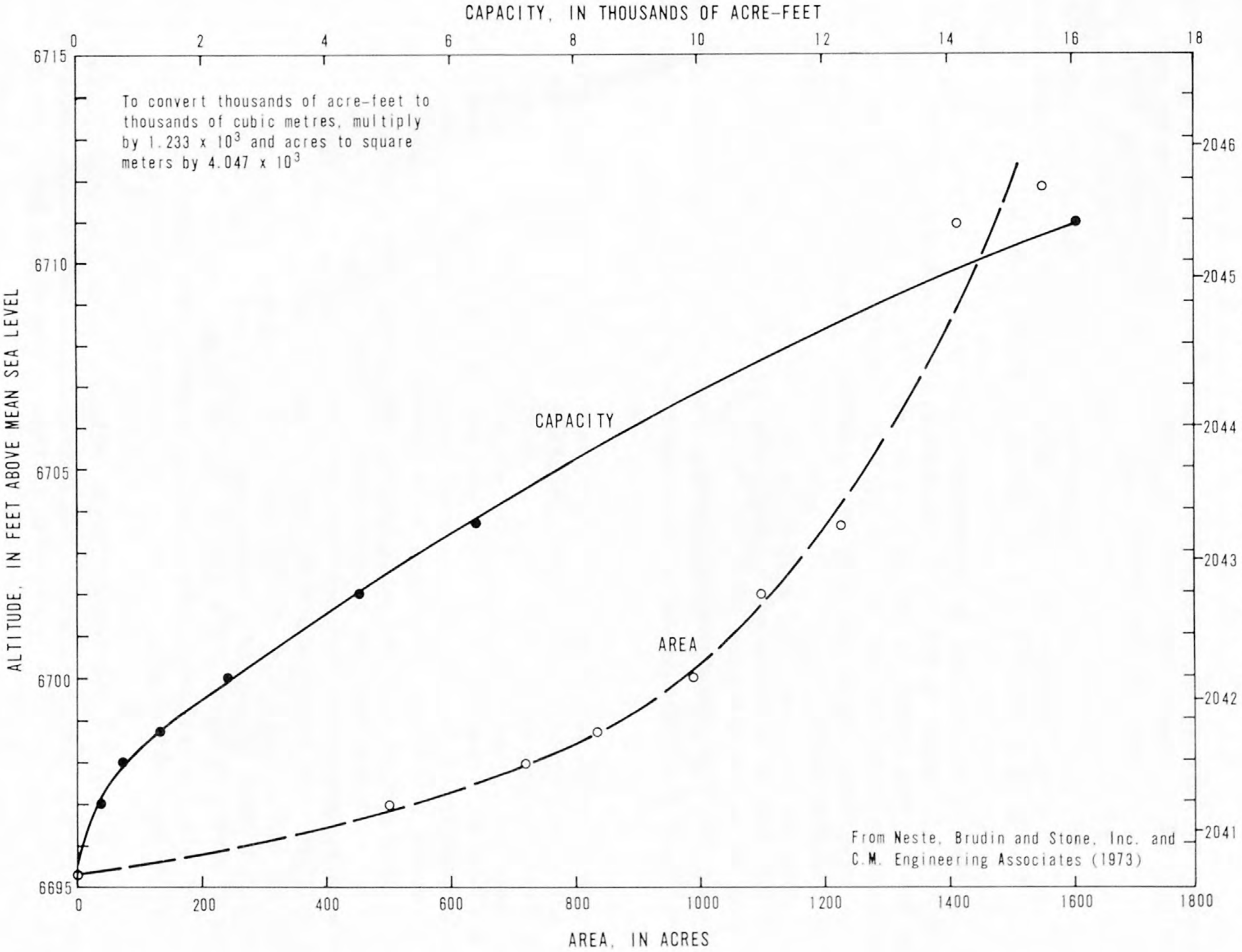


FIGURE 2.--Estimated surface area and capacity of Baldwin Lake.

Lake-Stage Record

The record of lake stage for Baldwin Lake is fragmentary. A record has been kept since 1934 (Joseph Rowe, written commun., 1972) with measurements usually taken twice a year at the normal high and low stages until 1967. In the absence of a stage recorder the measurements may not actually be the maximum and minimum stages for each year. It is assumed, however, that the measurements are approximations of these stages. During 1969-73 measurements usually were taken twice a month (Joseph Rowe, written commun., 1973).

There is little historical documentation of lake levels prior to 1939. Mr. E. J. (Lucky) Baldwin is reported (Murbarger, 1960, p. 48) to have staged Sunday afternoon horse races on the hard floor of the lake in 1865. This would indicate that the lake was dry or at very low stage only 3 years after the unusually wet year, 1862, which is renowned for its disastrous flood on the nearby Santa Ana River.

The maximum reported stage of Baldwin Lake (J. J. Prendergast, written commun., 1930) is at an altitude of 6,711 ft (2,045.5 m), but the record is not clear as to how this stage was obtained. That stage is considered by many to represent the 1916 flood.

Shoreline Features

Most geomorphic features on a lakeshore are related to the stand of the lake at their particular level (Knochenmus, 1967, p. C238). They represent the level at which shoreline processes were active but do not necessarily represent the highest water level attained by the lake. Beach ridges are the principal geomorphic features at Baldwin Lake. These ridges are depositional features caused by reworking of sediments by wave action. They range from 2 to 10 ft (0.6 to 3 m) wide, and most can be traced along the shore for several tens of feet. Most are easily discernible on aerial photographs. The prominent ridge formed by the high water resulting from storms in 1969 can be traced along the entire east shore but is absent along most of the west shore. That is because the prevailing winds from the west create ridge-forming wave action mostly on the east shore.

The average height of the beach ridges attributed to the 1969 storms is about 1.0 ft (0.3 m). The heights of all other ridges surveyed range from 0.26 to 1.01 ft (0.08 to 0.3 m) with the average being about half a foot (0.15 m).

The ridges are made up of reworked alluvial deposits along the strand line. These alluvial deposits are of Pleistocene and Holocene age (Dibblee, 1964) and entirely surround Baldwin Lake.

Most samples taken for grain-size analysis were from the more prominent east-shore ridges and reflect a parent rock origin of quartz diorite gneiss (Dibblee, 1964). Most of the material that makes up the ridges is well sorted and ranges in size from very fine sand (0.125 millimetres) to very fine gravel (4 millimetres). The grains are angular indicating a history of limited transport.

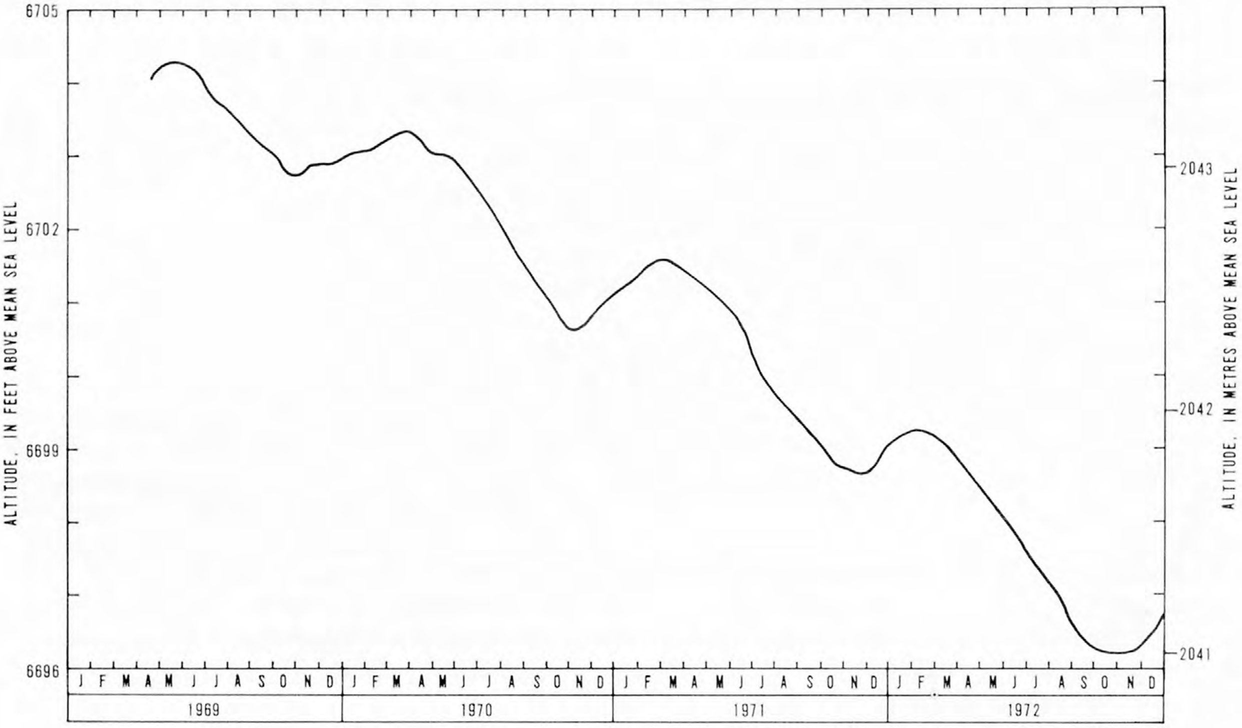
As part of this study, shoreline features that represent 10 different lake levels were identified and surveyed. The altitude of the features ranged from 6,700 to 6,713 ft (2,042 to 2,046 m) (table 1). The beach ridges above and along Baldwin Lake shore could have been formed only when the level of the lake remained constant for a long enough period of time for deposition to have taken place. For example, the peak lake level during the flood season in January and February 1969 was reported as 6,705 ft (2,044 m) altitude (Joseph Rowe, oral commun., 1972). Spirit leveling by the Geological Survey during 1973 indicated that a faint debris line or seed line, which local residents identified as the high waterline of 1969, was at an altitude of 6,705.56 ft (2,043.85 m). However, the altitude of the top of the beach ridge, which resulted from the filling of the lake in 1969, is about 6,703 ft (2,043 m). This is the approximate level at which the lake stabilized from late summer 1969 through May 1970 (fig. 3). This indicates that the difference between the actual high waterline and the associated beach feature can be as much as 2 ft (0.6 m) and perhaps more.

After the floods of January and February 1969 the first lake-level measurement was 6,704.04 ft (2,043.39 m) in mid-April 1969 after the lake had apparently receded from the peak.

It was not possible to determine actual dates for the formation of the shoreline features. The only features that could be dated were the beach ridge formed in the winter of 1969-70 and a less prominent ridge formed in the winter of 1971-72. These were dated by actual observation of their formation.

TABLE 1.--*Altitude of Baldwin Lake shoreline features*

	Feature	Number of sites	Number of altitude readings	Average altitude in feet above mean sea level
1	Dead float grass (1972 high waterline)	5	5	6,700.37
2	"Recent" shore (1971?)	2	2	6,702.09
3	Beach ridge and rampart (1969)	6	12	6,703.31
4	Top of small scarp	2	2	6,704.17
5	Hummocks	3	3	6,704.82
6	Lower barren streak	3	18	6,706.48
7	Upper barren streak	3	17	6,708.66
8	Top of scarp	2	2	6,709.93
9	Lower sandy streak	1	3	6,712.16
10	Upper sandy streak	2	6	6,713.18



From Neste, Brudin and Stone, Inc. and C.M. Engineering Associates (1973)

FIGURE 3.--Baldwin Lake levels 1969-72.

Another geomorphic feature associated with the Baldwin Lake strand line is a beach scarp that is the result of ice push. This beach scarp, or what is technically termed a "lake rampart," is easily identified by its abrupt profile. It has the appearance of having been pushed up by a bulldozer. Sagebrush has been uprooted and pushed landward along the rampart, which is more than a foot (0.3 m) high at its maximum. It is associated with the stand of the lake through the winter of 1969-70.

Lake ramparts are formed when the entire surface of a lake is frozen and then subjected to a wide range of temperature. Acting as a common solid, the ice contracts and cracks during a very cold spell, and water that moves into the cracks quickly freezes. A subsequent warm period will expand the ice, and the volume of ice, now greater than at the initial freezing, exerts pressure against the shore (Wolfe, 1960, p. 290). On large lakes the ice may buckle into ridges, but if the shore is of unconsolidated material and the lake is not large, the ice will push up sharp ridges of sediment and debris on the shore.

Ramparts form most readily on a lake with an area of only a few square miles or less (Zuidema, 1973).

No evidence of older ramparts was found around Baldwin Lake although it is possible that some of the other shoreline features may be, in part, old ramparts. Vegetation cover and rounding of the scarp by erosion could make difficult the definite identification of older ramparts.

Other Features

A prominent dark-colored linear feature appears on all the aerial photographs of the lake area that have been inspected. It is on the east side of the lake about 300 ft (91 m) east of the 1969 beach ridge. The line is nearly parallel to the east shore of the lake, and strikes about N. 40° W. from just east of the center of section 8 to near the southwest part of section 5 (fig. 1). Investigation of the soil along this line yielded no evidence of beach ridge deposits. Spirit leveling of this line indicated that it does not follow the contour of the land, as would a beach ridge. The dark line ranges, where leveled, from 6,717 to 6,727 ft (2,047 to 2,050 m) in altitude.

The dark lineation appears to be a concentration of a more dense growth of sagebrush. This could result from a fracture in shallow bedrock that affords a conduit for moisture to move upward, thereby nourishing the vegetation along it. In addition to the sagebrush, four trees or large bushes grow on this line in an area where few trees occur anywhere else. The strike of the vegetation line parallels the geologic structure in the area. Fractures in the gneissic bedrock nearest the lake and the Helendale fault (Dibblee, 1964), a major structural feature 1 mi (1.6 km) to the east, have about the same strike as the line.

The tree line above the south margin of the lake at an altitude of approximately 6,720 ft (2.048 m) appears to nearly parallel the shoreline. The tree line is probably controlled by the extent of the clay deposited in Baldwin Lake in Pleistocene time when the lake level was presumably much higher than in historical time. Neither tree species (Ponderosa pine and white fir) thrives on clay soils (Collingwood and Brush, 1947, p. 28 and 100).

The shoreward limit of sagebrush appears on aerial photographs to parallel the shore, but careful ground inspection and surveys of the areas show that this is not true. The growth limit is not controlled by flooding but is related to soil type and depth to ground water.

METHODS AND RESULTS OF FIELD STUDY

All features that resembled evidence of shoreline activity, either of deposition or of erosion, were surveyed by spirit leveling at seven sites along the east and south margins of the lake. Datum used is the benchmark on the spillway of a nearby sewage pond, shown near the center of section 7 in figure 1. Features that occurred at equivalent altitudes at different sites were compared by observation, sampling, and measurement. Many readings of altitude were taken along each feature, where possible, to ascertain average altitude of the feature. In that way the irregularities of the surface were averaged.

Trenches were cut across some of the more prominent beach ridges to determine their thickness and shape. Samples for grain-size and mineral analysis were taken from trenches and surface features. The trenches cut across the 1969 beach ridge revealed a surface layer of fine gravel overlying a 2-in (5-cm) mat of dead grass. Immediately under the grass mat was another layer of gravel overlying a thin layer of decayed vegetation that capped an old soil horizon. Because the high water level from the 1938 storm season was very likely at nearly the same level as that occurring in 1969, it seems probable that the lower gravel horizon may represent a beach ridge formed by the high lake stage of 1938.

Drive-core and hand-auger samples were taken at numerous sites along the east and south margins of the lake in an attempt to obtain organic-rich clay samples that could be dated by radiocarbon methods. All samples collected, however, contained only sand, silt, or light-gray clay. The maximum depth cored was 6 ft (1.8 m).

A determination by growth-ring analysis of the relative age of living sage and sage killed by ice push was attempted, but the irregularity of growth-ring patterns did not permit good correlation for age determination. Any reliable growth-ring study of sage would require a sizable collection of specimens for statistical analysis, which would be beyond the scope of this study.

No datable artifacts were found that could be related to a shoreline feature.

STAGE-FREQUENCY ANALYSIS

As part of this study three separate frequency analyses were made using the Baldwin Lake stage records. The first was an analysis of the measured stages of Baldwin Lake. At the time of the analysis 39 years of twice-a-year readings were available (1934-72). These data were plotted and estimated annual maximum stages were selected for each year. The stage-frequency relation based upon a Pearson type III frequency analysis of the 39 annual maximum stages is shown in columns 1 and 2 of table 2 and in figure 4.

Precipitation has been recorded at Big Bear Dam (9 mi or 14 km west of Baldwin Lake) since 1883. By relating the recorded Baldwin Lake stages to this precipitation the lake-stage record can be extended. The appendix describes the techniques used in this extension. The early precipitation records, however, are of questionable accuracy, so the precipitation record used for extending the lake-stage record was restricted to the 79-year period 1894-1972. The results of a Pearson type III frequency analysis of the synthetic 79-year stage record, derived from estimated stages for Baldwin Lake based on the 1894-1972 precipitation record at Big Bear Dam, are given in table 2.

The third frequency analysis was of a composite of the recorded stage record for the period 1934-72 and the synthetic stage record for the period 1894-1933. The results of this stage-frequency analysis are probably the most valid and are given in column 4 of table 2 and in figure 4. The best estimate of the 100-year maximum annual stage for Baldwin Lake from this analysis is a lake level at an altitude of 6,710.7 ft (2,045 m).

TABLE 2.--*Baldwin Lake stage-frequency analysis*

Recurrence interval (years)	Stage (feet above mean sea level)		
	Recorded (39 years)	Synthetic (79 years)	Composite (40 years synthetic plus 39 years recorded)
(1)	(2)	(3)	(4)
5	6,701.2	6,699.7	6,700.4
10	6,703.4	6,701.3	6,702.7
25	6,706.2	6,703.6	6,705.8
50	6,708.4	6,705.4	6,708.2
100	6,710.7	6,707.4	6,710.7
200	6,713.0	6,709.4	6,713.2

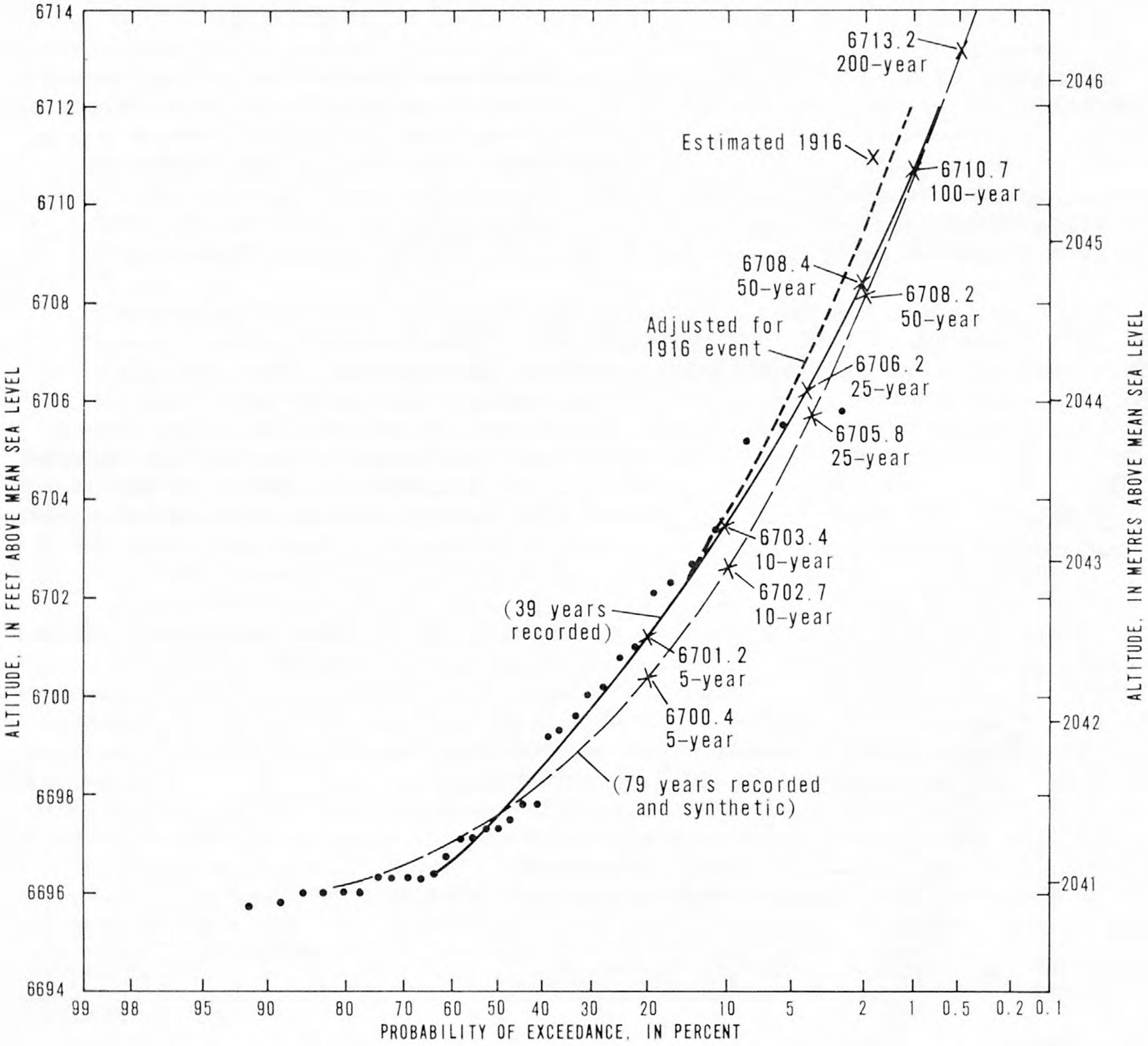


FIGURE 4.--Frequency curves of Baldwin Lake maximum annual stage.

Because regression was used for the last two analyses, it was necessary to consider the regression effect on the resulting frequency curve. When regression is used to estimate values, the regression process can result in the variance of the estimates being biased too small. This could cause the extremes to be in error, and thus the frequency curve to be in error. An adjustment for this effect can be made to give a more accurate frequency curve. Using the techniques described by Gilroy (1970), the adjusted statistics of the frequency distribution were determined. The adjusted statistics indicate that the regression effect is minimal and need not be further investigated.

ESTIMATED 1862 STAGE

The largest flood known to man for the upper Santa Ana River valley occurred in 1862. Because the headwaters of the Santa Ana River and Baldwin Lake are in adjacent basins in the same mountain range, it is likely that Baldwin Lake was very high in 1862, possibly the highest stage reached in well over 100 years.

To assess the possible magnitude of that event, several of the higher stages for the 39 years of record were plotted against the concurrent maximum annual discharge for the Santa Ana River at Riverside Narrows (the only station in the area with a discharge for 1862). As expected, the curve was poorly defined. An envelope curve through the highest points was drawn, and then used with the estimated 1862 Santa Ana River discharge (320,000 ft^3/s or 9,100 m^3/s), to estimate a stage for Baldwin Lake for 1862 of 6,715 ft (2,047 m). From an extension of the curve in figure 4, this stage would have a recurrence interval of about 300 years. Because the envelope curve was so crude, this estimate should be used with caution.

FREQUENCY OF IDENTIFIED SHORELINE FEATURES

The 100-year stage for Baldwin Lake determined by stage-frequency analysis is 6,710.7 ft (2,045 m). Observation of shoreline features formed on the lake during the high-water period in 1969 indicates that maximum levels of the lake when the stage is high can be as much as 2 ft (0.6 m) higher than their associated shoreline features. This would suggest the approximate relation of stage frequency with the shoreline features (table 1) identified on the east side of the lake, as shown in table 3.

TABLE 3.--*Correlation of Baldwin Lake shoreline features with stage frequencies*

Shoreline feature[1]		Stage[2] (altitude in feet)	Recurrence interval[2] (years)
	Average altitude in feet		
1	6,700.37	6,700.4	5
2	6,702.09	6,702.7	10
3	6,703.31	6,705.8	25
4	6,704.17	--	--
5	6,704.82	--	--
6	6,706.48	6,708.2	50
7	6,708.66	6,710.7	100
8	6,709.93	--	--
9	6,712.16	6,713.2	200
10	6,713.18	--	--

[1] Identified in table 1.
[2] Identified in table 2.

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APPENDIX

REGRESSION ANALYSIS

This section describes the analysis used to generate the 79 years of synthetic stages for Baldwin Lake.

Lake levels have been measured about twice a year, once at maximum stage and once at minimum, since 1934 (Joseph Rowe, written commun., 1972). Precipitation has been measured at Big Bear Dam since 1883, but the data are usable only since 1894 for extending Baldwin Lake records. Table A1 presents the stage and precipitation data recorded since 1934 and used in the regression analysis.

Baldwin Lake goes dry about 3 to 4 years in 10, but does have carryover storage in many years. Because of this the form of regression analysis must be more than a simple precipitation-stage relation. The stages from 1938 to 1943 show this carryover effect from the 1938 floods. However, the 1958 and 1959 stages show that the carryover is not always large. Table A2 shows the serial correlation coefficients for various lags. As can be seen from this, the storage effect does not carryover for many years.

Step-forward multiple regression techniques were used in the analysis. The maximum annual stage for the current year was regressed against the stage for the preceding year and up to the 4 previous years, precipitation for the current year, and precipitation for the preceding year. Two transformations of the data were used: (1) The lakebed altitude (6,695.4 ft or 2,040.7 m) was subtracted from the stage; and (2) logarithms of all data were used. Only precipitation for the current year and stages for the 2 prior years were found significant at the 90-percent significance level.

TABLE A1.--*Baldwin Lake maximum annual stage and Big Bear Dam precipitation, 1934-72*

Water year	Historical maximum annual stage (feet)	Precipitation (inches)
1934	6,695.4	25.62
1935	6,697.8	43.46
1936	6,697.8	27.52
1937	6,702.3	58.76
1938	6,705.8	60.25
1939	6,705.2	32.15
1940	6,703.4	23.98
1941	6,702.7	56.46
1942	6,702.1	23.73
1943	6,700.8	39.87
1944	6,701.0	31.24
1945	6,700.2	44.17
1946	6,699.2	41.37
1947	6,697.3	33.64
1948	6,695.7	28.38
1949	6,697.3	32.24
1950	6,696.3	30.53
1951	6,696.0	23.35
1952	6,699.6	59.07
1953	6,697.5	22.62
1954	6,696.4	42.01
1955	6,696.3	32.50
1956	6,696.3	27.02
1957	6,696.0	34.03
1958	6,700.0	60.74
1959	6,696.3	26.04
1960	6,696.0	26.80
1961	6,695.4	16.70
1962	6,697.1	42.28
1963	6,696.0	25.45
1964	6,695.8	26.08
1965	6,696.7	34.95
1966	6,697.1	48.18
1967	6,699.3	60.32
1968	6,697.5 estimated	22.76
1969	6,705.5	56.84
1970	6,703.3	16.31
1971	6,701.6	17.11
1972	6,699.3	18.69

TABLE A2.--*Serial correlation coefficients*

Lag (years)	Correlation coefficients
1	0.45
2	.42
3	.28
4	.17

During the analysis it was apparent that the higher stages were being underestimated (as is common in this type analysis), so the highest six events were duplicated three times to provide more weight for the important high stages. The regression equation thus generated is:

$$\log St_0 = 2.491 + 0.391 \times \log St_1 + 0.206 \times \log St_2 + 1.735 \times \log P$$

where St_0 = maximum stage for current year

St_1 = maximum annual stage with 1-year lag

St_2 = maximum annual stage with 2-year lag

P = precipitation for current year.

Table A3 shows the precipitation data and the generated stages for the 40 years 1894-1933 using the above equation.

TABLE A3.--*Baldwin Lake generated maximum annual stage and Big Bear Dam precipitation, 1894-1933*

Water year	Generated maximum annual stage (feet)	Precipitation (inches)
1894	6,698.1	20.02
1895	6,702.4	48.93
1896	6,696.0	11.13
1897	6,697.1	33.65
1898	6,696.0	20.17
1899	6,695.7	12.94
1900	6,695.8	21.98
1901	6,696.2	33.98
1902	6,696.0	23.59
1903	6,697.0	42.10
1904	6,696.3	24.95
1905	6,697.8	43.05
1906	6,699.2	49.40
1907	6,700.6	46.78
1908	6,698.7	31.72
1909	6,700.6	44.37
1910	6,700.1	39.92
1911	6,703.3	52.19
1912	6,697.6	22.47
1913	6,697.4	26.52
1914	6,700.0	51.14
1915	6,702.2	53.97
1916	6,707.5	62.04
1917	6,700.3	30.85
1918	6,700.7	37.26
1919	6,697.8	25.75
1920	6,699.4	40.67
1921	6,697.5	27.78
1922	6,698.6	38.49
1923	6,696.9	24.30
1924	6,696.3	20.23
1925	6,696.3	25.14
1926	6,697.2	40.07
1927	6,697.5	37.26
1928	6,696.2	18.65
1929	6,696.4	25.87
1930	6,696.7	32.25
1931	6,696.6	28.82
1932	6,699.0	53.03
1933	6,696.5	21.65

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